HYDROGEOLOGY AND WATER RESOURCES OF THE CHICO ARROYO/TORREON WASH AREA, SANDOVAL AND MCKINLEY COUNTIES, NEW MEXICO

by

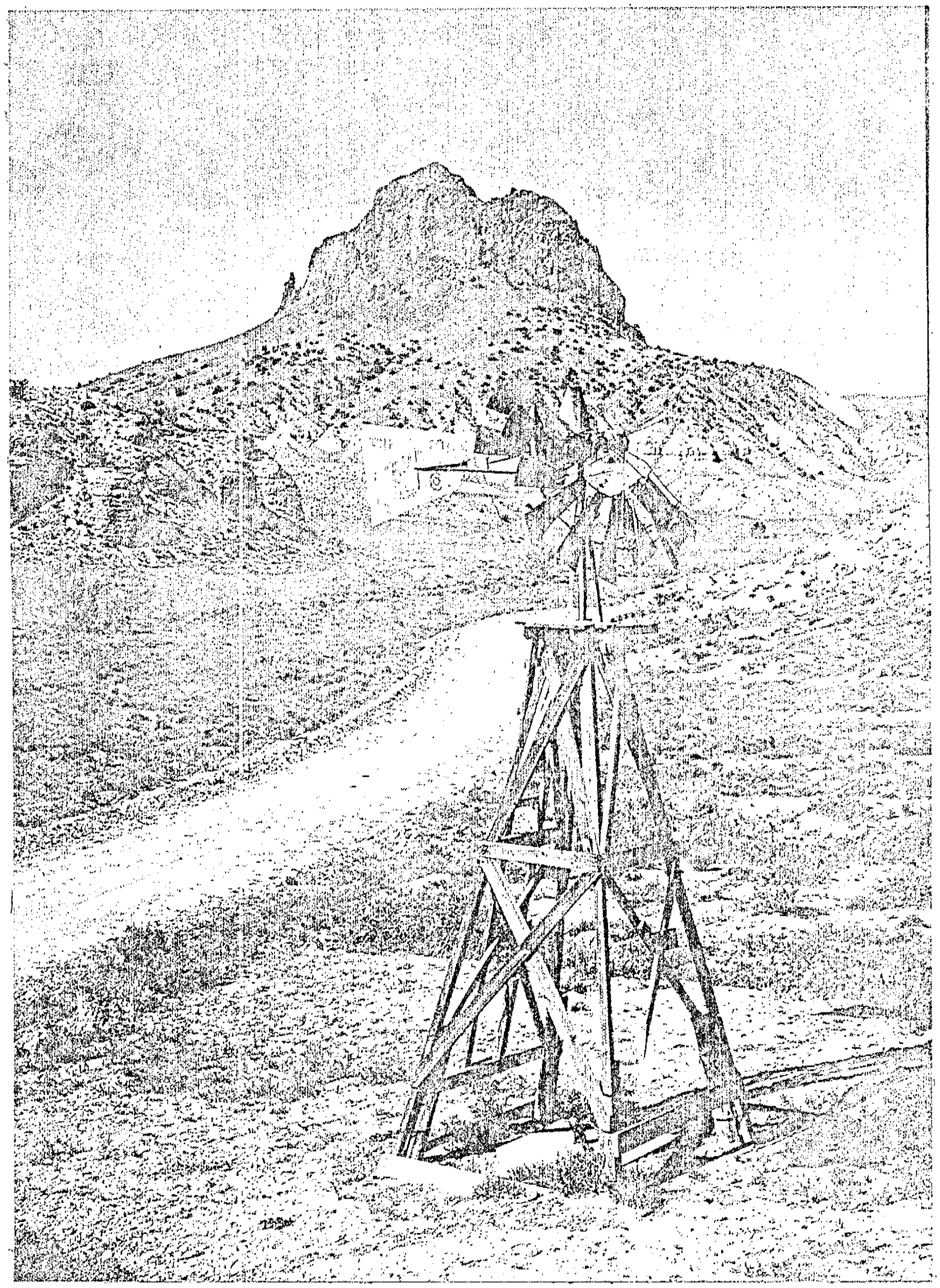
Steven D. Craigg

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

April, 1980



Frontispiece. Abandoned windmill along Abra de Los Cerros. Cerro de Guadalupe volcanic neck (Tertiary) in background intruded Upper Cretaceous strata of Mulatto Tongue of the Mancos Shale (view southwest from NW¼, Sec35, T16N, R3W).

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF PLATES (in pocket)

ABSTRACT

The Chico Arroyo/Torreon Wash area lies in the southeastern part of the San Juan Basin, a Laramide structural depression in northwestern New Mexico. The climate of the area is semiarid. Most of the land is presently used for the grazing of livestock and sufficient water supplies exist for stock needs. Development of water resources for stock use include earthen catchment dams, wells, and developed springs. If future stock-water supplies are needed the Gallup Sandstone, Mulatto Tongue of the Mancos Shale, Point Lookout Sandstone, sandstones in the Menefee Formation, and possibly alluvium could be most economically developed.

The area is one of potential coal development and since no surface-water supplies exist, ground water must be considered as the only possible source of future water supplies for coal mining purposes. The Gallup Sandstone and the Westwater Canyon Member of the Morrison Formation are probably the two major aquifers available to coal mining companies.

Aquifers in the area are recharged directly by transmission losses from streams crossing outcrop areas and by precipitation falling on outcrop areas. The aquifers are recharged indirectly by subsurface leakage between geologic units. Movement of ground water is generally from the north and south toward Chico Arroyo. Yields from wells and springs are commonly very low, 0.064 lps (1.0 gpm), or less. One exception is a flowing well completed in the Gallup Sandstone. This well originally flowed about 26 lps (400 gpm), but flow is now regulated at about one-half this rate.

The best quality water occurs south of Chico Arroyo, especially in the Gallup and Point Lookout Sandstones, and in the Menefee Formation. Water quality within a particular geologic unit tends to deteriorate north of Chico Arroyo. Dissolved-solids contents south of Chico Arroyo range from 328 - 4,270 ppm, whereas north of Chico Arroyo, the range is from 750 - 10,272 ppm. Quality of water in alluvium is generally poor and is probably independent of the locality selected for well drilling.

INTRODUCTION

PROBLEM AND PURPOSE

Water-resource problems for residents of the San Juan Basin are many and varied. Most available surface water has been allocated and, therefore, ground water must be further utilized if communities expect to meet increasing demands on water supplies. In many isolated parts of the Basin domestic and stock-water supplies are at a premium. Yields from existing wells and springs are commonly very low, and water quality is, in many instances, marginal.

The San Juan Basin contains an abundance of energy resources which continue to be developed at an accelerating pace. Ground-water constraints and impacts of development must be considered. Since 1974 the New Mexico Bureau of Mines and Mineral Resources (NMBMMR), the U. S. Geological Survey, Water Resources Division (USGS, WRD), and the New Mexico State Engineer Office (NMSEO) have been cooperating in a regional study to determine the availability of ground-water supplies for energy-resource development. The NMBMMR portion of the study has involved identifying potential aquifers, characterizing the geologic framework of the Basin, and determining how it controls the occurrence, movement, and quality of the Basin's ground water (Stone, 1979). In order to supplement the regional study, the NMBMMR has supported four master's theses, each involving a unique hydrogeologic problem or setting, in selected 15-minute-quadrangle-sized areas in the Basin. The work reported here is one of these.

The general purpose of this study was to examine the hydrogeology and water resources of the Chico Arroyo/Torreon Wash area. This area was selected because of its potential for coal development and because it lies within the southeastern ground-water-discharge area for San Juan Basin aquifers. Specifically, the major objectives of this study were the following:

1) to analyze the stratigraphic framework of the area, identify potential aquifers, examine their petrographic characteristics (texture, composition, porosity), and assess the role these factors play in controlling the occurrence, movement, and quality of ground water in the area;
2) to obtain hydrologic data for the Point Lookout Sandstone and for coal-bearing zones in the Menefee Formation, and assess the aquifer potential of these rocks;
3) to quantify interactions between ground water and surface water this discharge area; and
4) to inventory wells and springs in the area.

APPROACH AND METHODS

The hydrogeology and water-resource potential of the area was examined through field work, laboratory analyses, and review of available literature.

Field work was accomplished mainly during June, 1978 and June, 1979, and consisted of several phases. Five stratigraphic sections were measured, described, and selectively sampled (Appendix A). A geologic map of the area was prepared by field mapping, photogeologic mapping, and compiling geology from existing maps (Plate 1; Fig. 9, p. 30). Area wells and springs were inventoried (Appendix H). This involved the identification of aquifers or sources of water, measurement of well depth and water depth in accessible wells, estimation of discharge from pumping wells and springs, and collection of water samples.

Five coal-test-holes drilled by NMBMMR were completed as water observation wells (Appendix F). Two of these wells were completed in coal-bearing zones of the Menefee Formation and three were completed in the Point Lookout Sandstone. These were developed, aquifer tests were performed, and water samples obtained (Appendix G). The general approach to the construction of these wells was given by Stone and Craigg (1979). Additional details regarding well construction, locations, and testing methods are given in Appendix F; results of aquifer tests are summarized in Appendix G.

Laboratory analyses and compilation of field data were accomplished mainly during the Spring of 1979 and July through September, 1979. This portion of the study included petrographic analyses of rock samples (Appendices B and C) and examination of drill core and cuttings from selected Torreon Wash coal-test holes (Appendices D and E). Two core samples of sandstones from the Menefee Formation and three of the Point Lookout Sandstone were commercially tested for porosity as well as horizontal and vertical permeability (Appendix L). Geophysical logs were used in conjunction with describing cuttings and in constructing the stratigraphic cross-section of the area (Plate 2). Water samples were analyzed by the NMBMMR to evaluate water quality within particular geologic units (Appendix I). The water budget of Chico Arroyo was analyzed in an attempt to quantify relationships between ground water and surface water in the area.

Available literature on the geology, hydrology, climate, soils, vegetation, and land ownership in the area was reviewed to supplement the field and laboratory studies.

PREVIOUS INVESTIGATIONS

Several workers have studied various aspects of the geology and hydrology of the region of interest. Dutton (1885) was among the first to visit the area and conducted reconnaissance work, reporting mainly on the volcanic rocks in the southern portion of the area. Johnson (1907) also studied the volcanic rocks, attempted to interpret their origin, and discussed their relationship to the surrounding Cretaceous strata. In now classic works, Hunt (1936) and Dane (1936) conducted field studies of the stratigraphy and coal beds in rocks of the Mesaverde Group in the Mount Taylor and La Ventana areas. In Hunt's report the volcanic rocks in the southern part of the area were classified as to rock type. In another important paper, Sears and others (1941) discussed the stratigraphy of transgressive and regressive Cretaceous deposits in the southern San Juan Basin. The general stratigraphy of Cretaceous rocks and strippable coal resources of the San Juan Basin were summarized by Shomaker and others (1971). The geology and coal deposits in the Cuba-La Ventana-Torreon areas were summarized by Beaumont and Shomaker (1974), and were discussed in greater detail by Shomaker and Whyte (1977).

In recent stratigraphic and sedimentologic studies conducted in the area, Mannhard (1976) investigated the La Ventana Tongue of the Cliff House Sandstone and its relationship to associated deposits of the Menefee Formation and Lewis Shale. Shetiwy (1978) studied the Point Lookout Sandstone and associated deposits of the Menefee Formation and Mancos Shale. Molenaar (1974) discussed the relationships of the Gallup Sandstone to associated deposits of the Mancos Shale and Crevasse Canyon Formation in the southeastern San Juan Basin.

Few papers deal specifically with the hydrogeology of the region. Renick (1931) conducted reconnaissance investigations in western Sandoval County. Baltz and West (1967) studied the ground-water resources of the southern part of the Jicarilla Apache Indian Reservation and adjacent areas. Shomaker and Stone (1976) discussed major and minor potential aquifers associated with coal trends in the Fruitland, Menefee, and Crevasse Canyon Formations. Brod (1979) investigated the water resources of the Ambrosia Lake area. Anderholm (1979) studied the water resources of the Cuba area.

The most recent geologic work was conducted by Tabet and Frost (1979), who studied coal-bearing zones in the Menefee Formation and mapped much of the bedrock geology of the Torreon Wash area in detail. This study provided a wealth of subsurface data because four holes were drilled per township; one of these was cored and the rest were logged. Stone and Craigg (1979) summarized preliminary results of the water observation well program set up in conjunction with the Torreon Wash coal study.

NUMBERING OF WELLS AND SPRINGS

Wells and springs are numbered according to the NMSEO method. The number describes the geographic location of the well or spring and consists of digits which correspond to township, range, section, and quarter-section(s), respectively (Fig. 1). In unsurveyed areas where projection of section lines is impossible, wells and springs are located by latitude and longitude.

UNITS OF MEASURE

Quantitative information presented in this report is given in metric units followed by the English equivalents in parentheses. Table 1

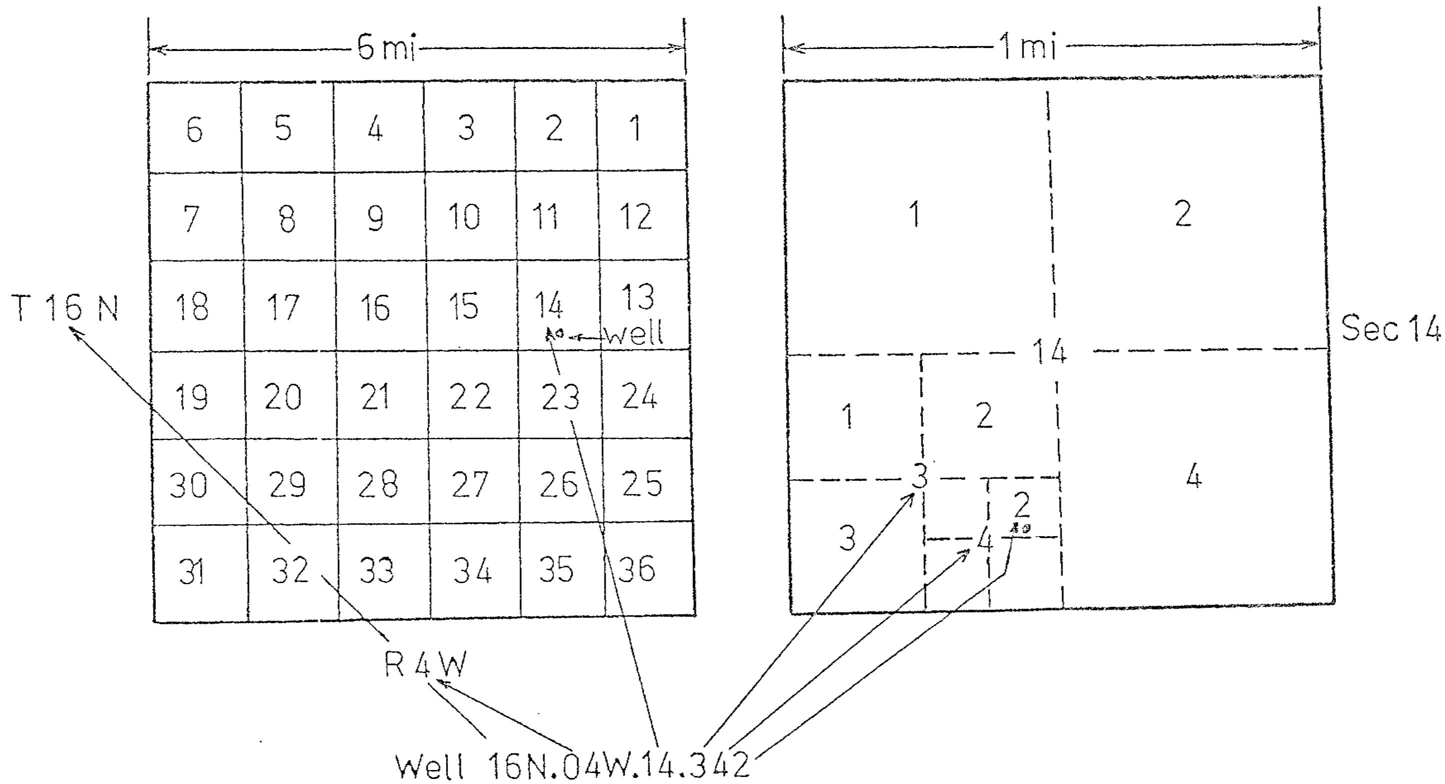


Figure 1. Diagram illustrating system of numbering wells and springs in New Mexico.

Table 1. Factors for converting metric units to English units.

metric unit	÷ conversion factor	= English unit
centimeters (cm)	2.54	inches (not abbreviated)
meters (m)	0.3048	feet (ft)
kilometers (km)	1.6093	miles (mi)
square kilometers (km^2)	2.59	square miles (mi^2)
cubic meters (m^3)	0.00379	gallons (gal)
cubic hectometers (hm^3)	0.0012335	acre-feet (acre-ft)
cubic meters per second (m^3/s)	0.02832	cubic feet per second (ft^3/s)
cubic meters per day (m^3/d)	5.45	gallons per minute (gpm)
liters per second (lps)	0.0639	gallons per minute (gpm)
meters squared per day (m^2/d)	0.0929	feet squared per day (ft^2/d)
kiloNewtons per square meter (kN/m^2)	0.145	pounds per square inch (psi)

gives information necessary for converting metric units to English units. The amount of rounding required varies with the intended precision of the measurements. For example, large values such as distances, elevations, depths, thicknesses, and volumes commonly are approximate and very little precision is lost in rounding. An attempt has been made to retain a similar degree of precision in converting from one system of measurement to the other.

ACKNOWLEDGEMENTS

I wish to thank the members of my thesis committee, Dr. John MacMillan and Dr. Gerardo Gross for their supervision and advice, and especially Dr. William Stone, the chairman of the committe, for his ideas and guidance throughout all aspects of the study. Sincere appreciation is also given to the New Mexico Bureau of Mines and Mineral Resources and especially to the Director, Dr. Frank Kottlowski, for providing financial support, equipment essential to the study, and use of a field vehicle. I would also like to thank the following individuals for their contributions to the study: Mr. David Tabet, NMBMMR Coal Geologist, for his assisstance and cooperation in completing Torreon Wash observation wells, providing core and cuttings, geophysical logs, and for discussing ideas on the field mapping of geologic units; Mrs. Lynn Brandvold, NMBMMR Chemist, for performing chemical analyses of water samples; Mr. Kim Ong, Chemist, USGS, WRD, Albuquerque, for demonstrating and permitting use of Survey well-swabbing equipment, and for his ideas on water-well completion; Mr. Pat Borland, Hydrologist, USGS, WRD, Albuquerque, for allowing access to Survey surface-water files; Mr. Forest Lyford, Hydrologist, USGS, WRD, Albuquerque (now in Little Rock, Arkansas), for freely discussing the hydrology of the area, and for sacrificing his time for personal consultation. I am especially grateful to Scott Anderholm, New Mexico Tech graduate student (now with USGS, WRD, Albuquerque), for his help in measuring four of the stratigraphic sections, cleaning and testing the observation wells, and for his company during the summer months of 1978.

GEOGRAPHIC SETTING

LOCATION AND ACCESS

The study area is located 4.0 km (2.5 mi) south of Torreon Trading Post and 6.4 km (4.0 mi) west of San Luis, in Sandoval and McKinley Counties, New Mexico (Fig. 2). It covers about 635 km^2 (245 mi^2) and is a 15-minute-quadrangle-sized area. It is bounded by 107° 07'30" - 107° 22' 30" West Longitudes and by 35° 30' - 35° 45' North Latitudes. It consists of the four 7.5-minute quadrangles Cañada Calladita, Arroyo Empedrado, Cerro Parido, and Guadalupe.

Access to the area is mainly by traveling south from Torreon Trading Post, south from Torreon Navajo Mission, or west from State Highway 44 opposite the entrance to Holy Ghost Spring recreation area. Roads are only light duty or unimproved dirt and are constructed on shales which makes travel practically impossible during wet periods.

LAND OWNERSHIP AND USE

The areal distribution of land ownership in the study area is shown in Figure 3. Most of the land is federally owned and is controlled by the Bureau of Land Management (BLM). A small portion is owned by the State of New Mexico. The northern part of the area falls in the so-called "checkerboard area", where local tracts of land are owned by the Navajo Tribe. A few parcels of land are privately owned, mainly by absentee landlords. The land ownership is approximately 75 percent Federal, 5 percent State, 10 percent Indian, and 10 percent Private.

The dominant use of the land is for grazing of beef cattle on lands leased from the BLM. In the northern part of the area sheep and goats are tended by Navajo herdsmen. In the southwest, on Mesa Chivato, the

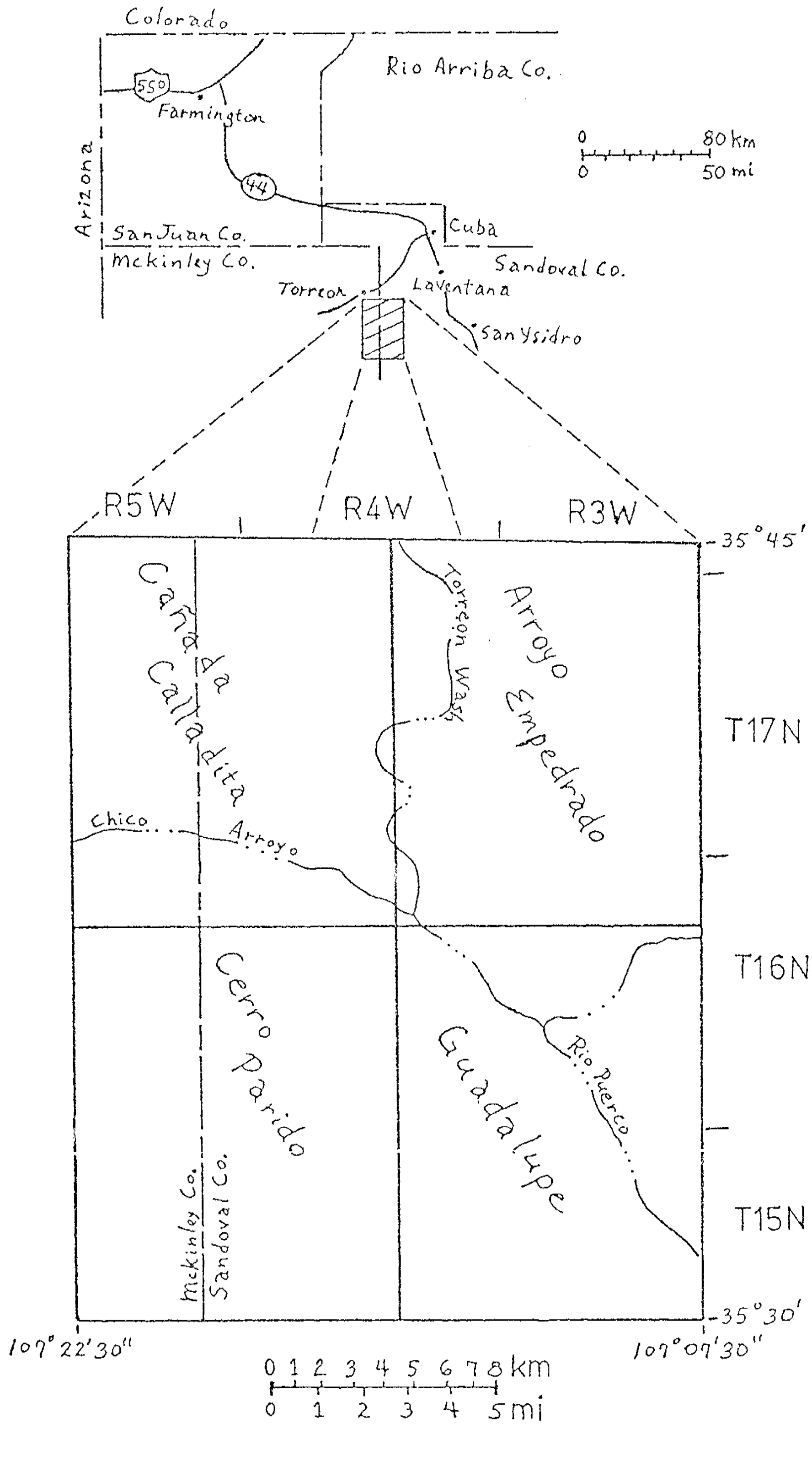


Figure 2. Location of the study area, coverage by 7.5-minute quadrangles, and major streams.

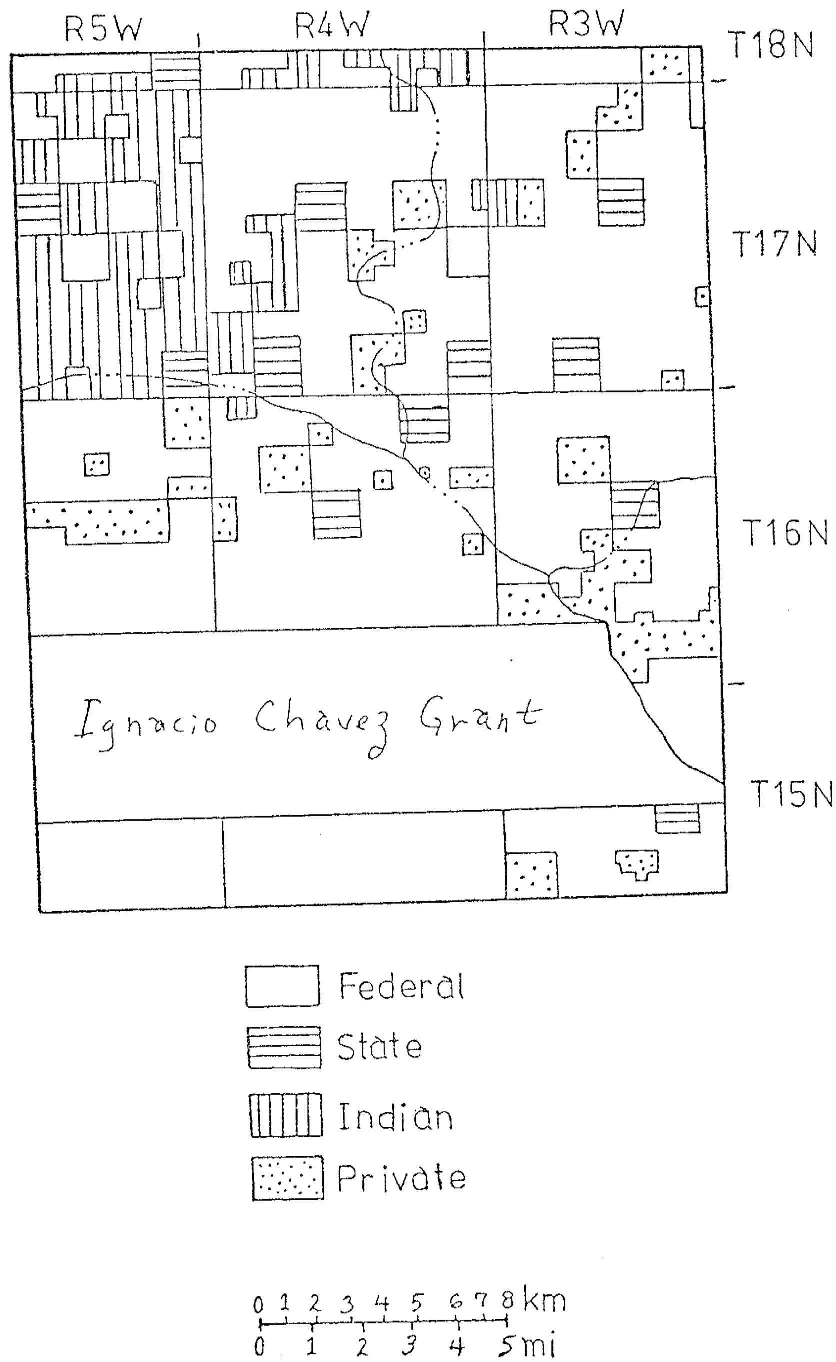


Figure 3. Land ownership in the study area (from Bureau of Land Management, 1972).

BLM supervises a firewood-cutting area and many people from Albuquerque and other areas utilize this resource.

At present the only agriculture is at Guadalupe, where the sole resident maintains a garden irrigated by means of a developed spring (Ojo del Padre). In the north, Navajos also tend small gardens near their hogans. Prior to the 1940's several farming communities along the Rio Puerco used impounded water for irrigation. These settlements, known as Cabezon, Guadalupe, and Casa Salazar, are now abandoned except for three or four families who continue to reside in the hamlets.

CLIMATE

The climate of the region is semiarid with an average annual precipitation of about 25 - 30 cm (10 - 12 inches). The approximate areal distribution of annual precipitation is shown in Figure 4. Greater precipitation is associated with higher altitudes. For example, Mesa Chivato, about 600 m (2,000 ft) above the surrounding area, receives an average of 30 cm (12 inches) of precipitation annually, whereas the lowlands receive only 25 cm (10 inches).

The U. S. Weather Service maintains a station at Torreon Navajo Mission, 6.4 km (4.0 mi) north of the study area. Records from this station for the years 1965 - 1977 indicate an average annual temperature of 9.7°C (49.4°F), and an average annual precipitation of 25.18 cm (9.91 inches). Precipitation at the station varies seasonally, with a distinct rainy season during July through September. During these months as much as 65 percent of the total annual precipitation may occur (Table 2). Annual deviations from the average precipitation can be quite large, however, on the order of plus or minus 10 cm (4 inches).

Potential gross annual lake evaporation in the area is large,

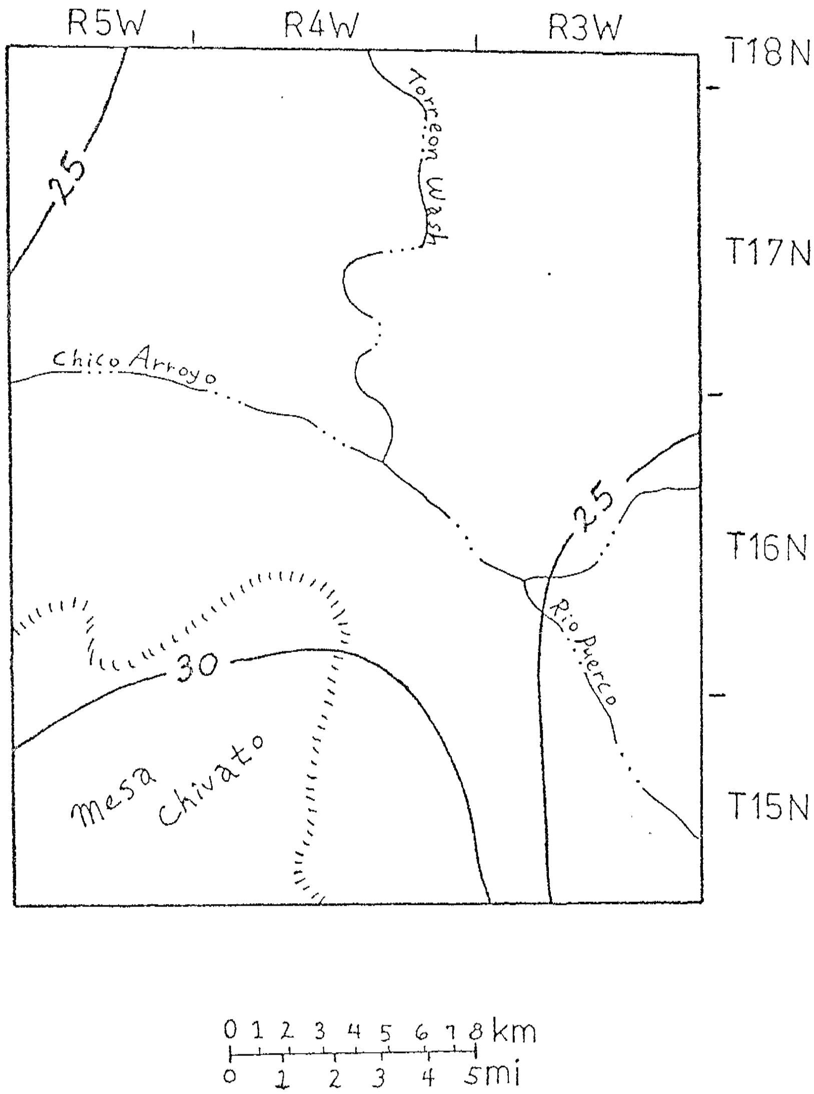


Figure 4. Distribution of average annual precipitation (cm) in the study area (from Bureau of Reclamation, 1974).

Table 2. Distribution of precipitation during the rainy season at Torreon Navajo Mission weather station from 1965 - 1977 (from U. S. Weather Service Annual Climatological Reports).

Year	Annual precipitation cm	(inches)	Precipitation July through September cm	(inches)	Percent of annual precipitation July through September
1965	25.98	(10.23)	8.51	(3.35)	32.7
1966	20.26	(7.98)	11.05	(4.35)	54.5
1967	22.71	(8.94)	14.65	(5.77)	64.5
1968	22.53	(8.87)	9.37	(3.69)	41.6
1969	31.34	(12.34)	12.27	(4.83)	39.1
1970	21.03	(8.28)	11.76	(4.63)	55.9
1971	23.62	(9.30)	12.37	(4.87)	52.4
1972	35.79	(14.09)	19.94	(7.85)	55.7
1973	26.80	(10.55)	10.77	(4.24)	40.2
1974	27.76	(10.93)	9.63	(3.79)	34.6
1975	24.97	(9.83)	14.33	(5.64)	57.4
1976	15.11	(5.95)	6.27	(2.47)	41.5
1977	29.39	(11.57)	18.06	(7.11)	61.5
Mean	25.18	(9.91)	12.23	(4.81)	48.5

amounting to about 127 cm (50 inches), or nearly five times the average annual precipitation (Bureau of Reclamation, 1974).

TOPOGRAPHY AND DRAINAGE

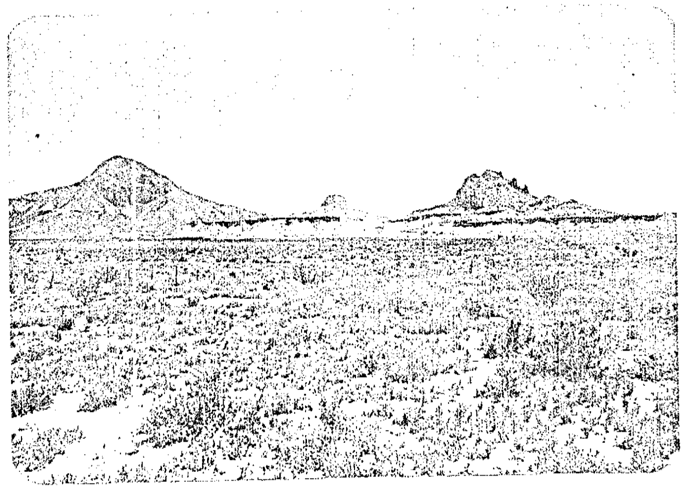
The area lies in the southeastern portion of the Navajo Section and in the northeastern portion of the Datil Section of the Colorado Plateau Physiographic Province of Fenneman (1931).

Topography in the northern and southeastern parts of the area generally consists of mesas and buttes formed of soft shale capped by erosion-resistant sandstone. For example, Chacra Mesa in the north is capped by the Cliff House Sandstone (Fig. 13-A, p. 38), and Mesa San Luis in the south is capped by the Point Lookout Sandstone (Fig. 20, p. 51). Badland topography is commonly formed on soft, easily erodable shales in the Menefee Formation and Mancos Shale.

In the Guadalupe Quadrangle the topography is dominated by volcanic necks which have intruded nearly horizontal sedimentary rocks of Cretaceous age. The tops of these necks commonly stand 180 - 300 m (600 - 1,000 ft) above the surrounding, dissected lowlands. Some of the more impressive necks are Cerro del Guadalupe (Frontispiece), Cerro Salado, Cerro Cuate, Cerro del Ojo Frio, Cerro de Santa Clara, and Cerro Parido. Cabezon Peak, just east of the study area, is the most prominant neck and rises to a height of about 550 m (1,800 ft; Fig. 5-A).

Most of the southwestern part of the area is an extensive upland known as Mesa Chivato (Fig. 5-B). This feature is capped by a sequence of lava flows and contains several, scatterred, local volcanic centers. Mesa Chivato stands about 550 - 600 m (1,800 - 2,000 ft) above the surrounding countryside.

Chico Arroyo is the major drainageway in the area (Fig. 2, p. 13).



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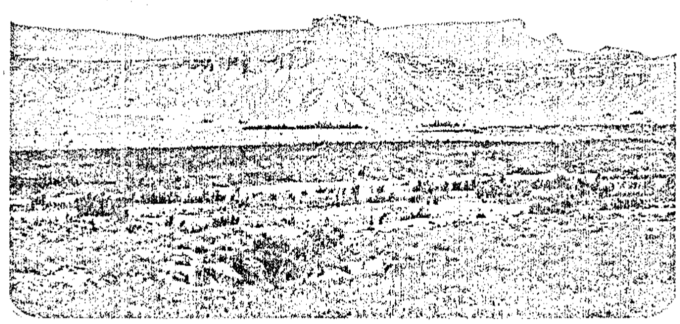


B

Figure 5. Topography in the southern part of the Chico Arroyo/Torreon Wash area. A) Three prominent volcanic necks along the Rio Puerco: from left to right, Cerro de Santa Clara, Cabezon Peak, and Cerro de Guadalupe. These Tertiary-aged features have intruded nearly horizontal Cretaceous strata, in this instance a limy, silty zone above the Gallup Sandstone (view northeast from SW¼, Sec6, T15N, R3W). B) An unamed mesa formed on the Hosta Tongue of the Point Lookout Sandstone (in foreground); Mesa Chivato and Bear Mouth volcanic neck (in background). The incised stream in foreground is Chico Arroyo (view west from NW¼, Sec30, T16N, R3W).

Drainage is toward the southeast into the Rio Puerco, the master stream for this area. A recording stream gage and cable car have been in operation for several years at the mouth of Chico Arroyo, just above the confluence with the Rio Puerco (Fig. 27, p. 82). Streams in the area are ephemeral, except locally, where spring discharge results in intermittent flow.

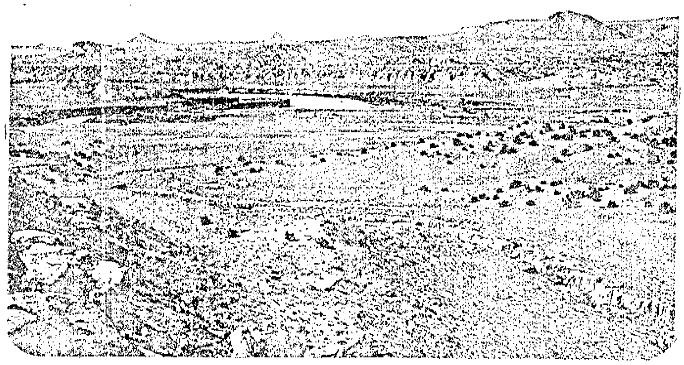
Arroyos are commonly deeply entrenched into alluvium and shale (Fig. 6). Cross sections are box-like with steep, vertical walls. Most impressive is the Rio Puerco near Guadalupe. In this vicinity the stream width is about 120 - 150 m (400 - 500 ft), and depth of entrenchment is about 15 m (50 ft). According to Renick (1931), local residents reported that in the 1890's the Rio Puerco was only 1.5 m (5 ft) wide and 1.8 m (6 ft) deep. If this is true, then most of the downcutting has occurred during the last 80 or 90 years. Erosion is accomplished mainly by bank caving. For example, several bridges and culverts have either washed out or have gradually fallen because of lateral bank extension (Fig 6-B).

SOILS AND VEGETATION

Five general soil associations have been recognized in the study area by Maker and others (1971, 1974). These include the Christianburg-Navajo, Basalt Rockland-Cabezon-Torreon, Persayo-Billings-Badland, Las Lucas-Litle-Persayo, and Travesilla-Persayo-Rockland associations (Fig. 7). The pertinent characteristics of the soils are discussed below and summarized in Table 3.

Christianburg-Navajo Association

This association occurs principally in valley bottoms along major drainageways. Maker and others (1971) mapped it only in the southeastern



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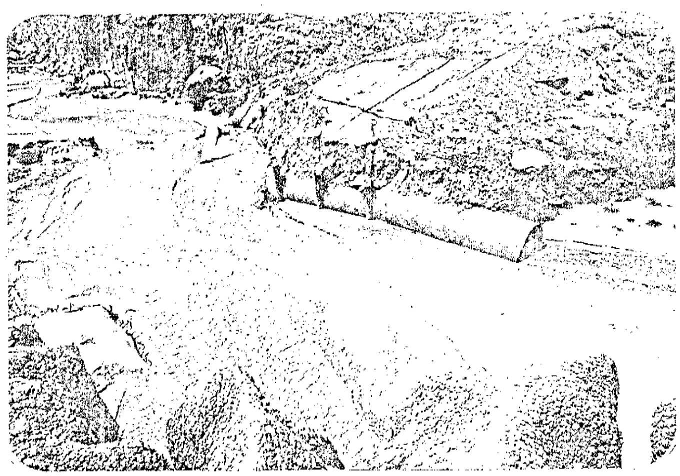


B

Figure 6. Erosion and bank caving in the Chico Arroyo/Torreon Wash area. A) Confluence of Chico Arroyo and Rio Puerco (in center of picture) showing box-like cross sections. These streams have downcut into the Mulatto Tongue of the Mancos Shale. Small tributary incised into alluvium in lower right (view south from NW¼, Sec20, T16N, R3W). B) Recently washed-out culvert and stream crossing on Chico Arroyo. Wash out probably occurred during Spring, 1979 runoff. The stream has downcut through alluvium and is incised into the Cleary Coal Member of the Menefee Formation at this locality (view north from NW¼, Sec2, T16N, R5W).

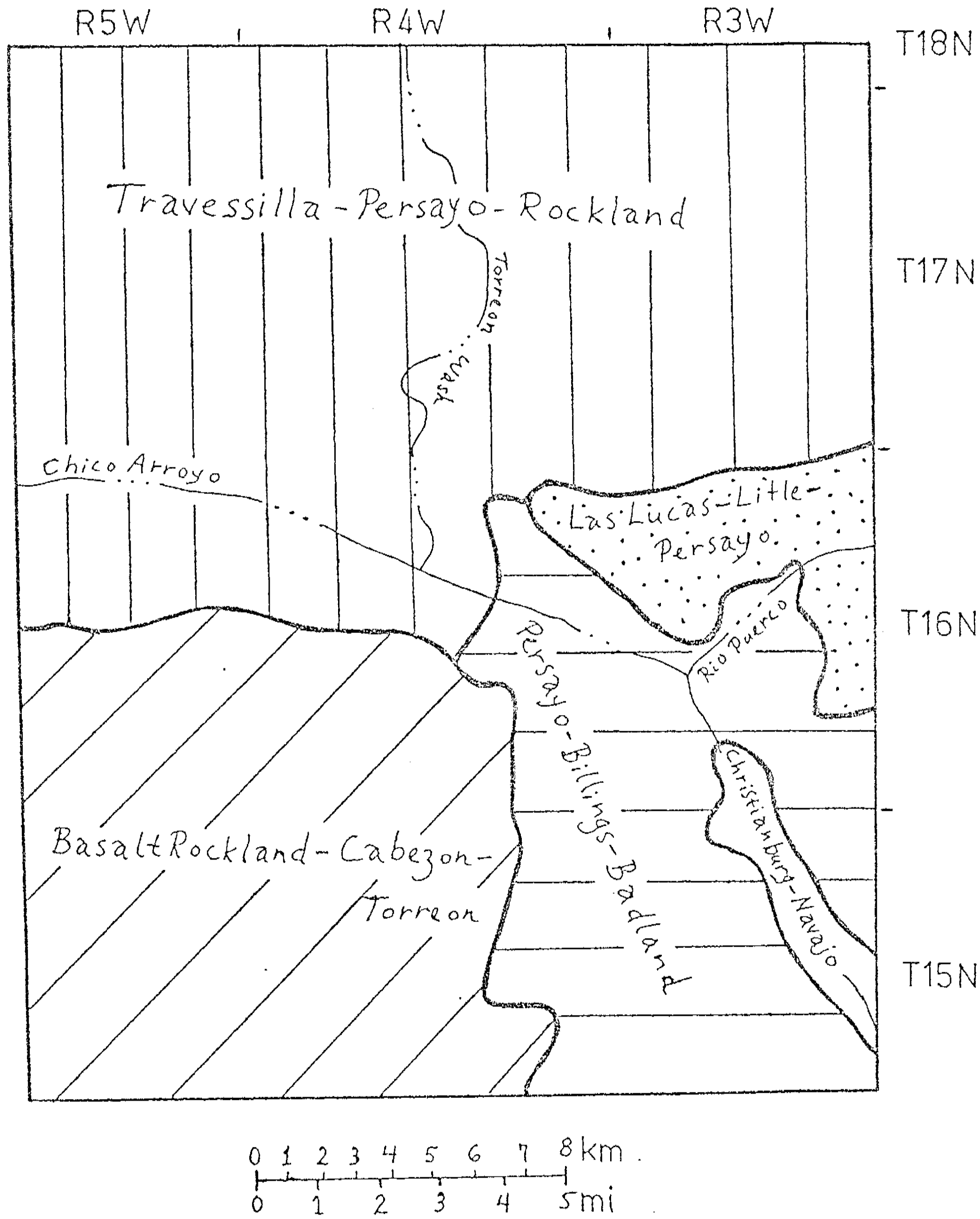


Figure 7. Areal distribution of major soil associations in the Chico Arroyo/Torreon Wash area (modified from Maker and others, 1971, 1974).

Table 3. Summary of pertinent characteristics of major soil associations in the Chico Arroyo/Torreon Wash area (modified from Maker and others, 1971, 1974).

Major Association Subsoil	Classification	Permeability[1]	Soil Depth cm	(inches)	Substratum
Christianburg-Navajo					
Christianburg	Typic Torrifluvent	Very slow	152	(60)	Clayey alluvium
Navajo	Typic Torrifluvent	Very slow	152	(60)	Clayey alluvium
Basalt Rockland-Cabezon-Torreon					
Basalt Rockland	Outcrop area				
Cabezon	Aridic Lithic Arguistoll	Slow	25 - 61	(10 - 24)	Eolian/alluvial deposits
Torreon	Aridic Arguistoll	Slow	152	(60)	Basalt
Persayo-Billings-Badland					
Persayo	Typic Torriorthent	Slow	15 - 46	(6 - 18)	Shale
Billings	Typic Torrifluvent	Slow	152	(60)	Loamy alluvium
Badland	Outcrop area				
Las Lucas-Litle-Persayo					
Las Lucas	Ustollic Cambric	Slow	102 - 152	(40 - 60)	Shale
Litle	Ustollic Cambric	Very slow	51 - 102	(20 - 40)	Shale
Persayo	Typic Torriorthent	Slow	15 - 46	(6 - 18)	Shale
Travesilla-Persayo-Rockland					
Travesilla	Lithic Ustic Torriorthent	Rapid	20 - 51	(8 - 20)	Sandstone
Persayo	Typic Torriorthent	Slow	15 - 46	(6 - 18)	Shale
Rockland	Outcrop area				

[1]Permeability classes and rates
- Very slow 0.5 cm/hr (0.2 inches/hr)
- Slow 0.5 - 1.6 cm/hr (0.2 - 0.6 inches/hr)
- Rapid 6.3 - 16 cm/hr (2.5 - 6.3 inches/hr)

part of the area along the Rio Puerco, but it probably occurs along other drainageways as well. The soils occur on nearly level to gently-sloping surfaces and are associated with fine-grained alluvium. They are slightly to moderately saline, and some are alkaline.

The association supports a fair cover of natural vegetation including western wheatgrass, mat muhly, red muhly, alkali sacaton, saltgrass, greasewood, chamiza, shadscale, and some big sagebrush and rabbitbrush.

Under ideal conditions the soils would be suitable for irrigation. However, problems with severe gullying, bank slumping along streams, flooding, salt accumulation, very slow permeability, along with the small size, irregular shape, and isolated nature of many of the areas tend to restrict their suitability for irrigation.

Basalt Rockland-Cabezon-Torreon Association

This association occurs on Mesa Chivato in the southwestern part of the area. The soils are formed on Tertiary basaltic rocks, and to a limited extent, on Quaternary eolian deposits. Many of the soils are stony as they are associated with outcrops on the escarpments and mesa fronts.

Vegetation on this association is variable. Grasses occur in open, meadowlike areas and include mountain muhly, mountain brome, Arizona fesque, western wheatgrass, and blue grama. Woody species occur in dense stands consisting of ponderosa pine, pinyon, juniper, and various shrubs.

Basalt rockland and Cabezon soils are nonirrigable because of high stone content, shallow soil depth, and low water-holding capacity. Torreon soils are considered to be irrigable, but their location on top of Mesa Chivato, together with the small size and irregular shape of the areas, tend to limit their irrigation potential.

Persayo-Billings-Badland Association

This association occurs in the southeastern quarter of the area along broad, gently sloping, incised valleys, and strongly sloping to rolling and steep uplands. The valleys contain deep soils, whereas upland areas contain shallow soils associated with sandstone and shale outcrops. The soils are developed residually on sandstone or shale or on alluvium derived from these materials.

The association supports a fair cover of grasses and shrubs including galleta, alkali sacaton, western wheatgrass, Indian ricegrass, blue grama, sand dropseed, winterfat, shadscale, rabbitbrush, and chamiza. Scatterred, sparse stands of pinyon and juniper also occur.

The soils are fairly suitable for irrigation. Limiting factors include local, severe gullying, shallow soil depths in upland areas, salinity problems, and low water-holding capacity.

Las Lucas-Litle-Persayo Association

This association occurs in the east-central part of the area, mainly on gently to strongly sloping and rolling uplands. The soils are calcareous and highly erodable. They are formed on shales.

Vegetation consists mainly of alkali sacaton, western wheatgrass, Indian ricegrass, galleta, ring muhly, three-awn grass, winterfat, chamiza, rabbitbrush, and broom snakeweed. Scatterred, thin stands of pinyon and juniper trees occur locally.

The soils have several limitations for irrigation and may not be suitable as croplands. When underlain by shales, the free movement of water is restricted, and local salinity problems may develop. This is especially true of the Las Lucas and Litle soils. Persayo soils are not suitable for irrigation because of shallow soil depths, low water-holding capacity, and salinity.

Travesilla-Persayo-Rockland Association

This association occurs in the northern half of the area on nearly level to strongly sloping and rolling uplands, and on steep escarpments and breaks. It is rough and broken, and is formed mainly on sandstone and shale.

Vegetation is generally sparse, consisting of blue grama, galleta, western wheatgrass, alkali sacaton, Indian ricegrass, sand dropseed, three-awn grass, chamiza, winterfat, and rabbitbrush. Scatterred, thin stands of pinyon, juniper, and big sagebrush occur locally, especially where the soils are formed on sandstones.

Use as irrigated cropland is severely restricted because of salinity, drainage, flooding, and erosion problems. When underlain by shales, the movement of water through the soil is restricted, and waterlogging problems may develop. Shallow soil depths further reduce the irrigation potential.

GEOLOGIC SETTING

The study area lies in the southeastern portion of the San Juan Basin, a Laramide, northwest-trending, asymmetric structural depression. Structural relief in the Basin is about 1,800 m (6,000 ft). The Basin covers an area of about 77,000 km^2 (30,000 mi^2) at the eastern edge of the Colorado Plateau, in northwest New Mexico and southwest Colorado. The central Basin is bounded by steep uplifts (Fig. 8).

The Basin contains a thick sequence of marine and nonmarine sedimentary deposits ranging in age mainly from Pennsylvanian through Quaternary. These deposits attain a maximum total thickness of about 4,270 m (14,000 ft) in the central part of the Basin near Gobernador.

STRUCTURAL FRAMEWORK

The general structural framework of the Torreon Wash area has been described as a gentle, northwestward-dipping block (Tabet and Frost, 1979). Regional strike of the rocks is northeast; dips vary from 0 - 10 toward the northwest. The study area lies along the western edge of the Rio Puerco fault zone and the strata are offset by a series of northeast-trending, high-angle, normal faults (Fig. 9; Plate 1). These faults are usually downdropped on the west, and maximum displacements are only about 15 m (50 ft). Tabet and Frost (1979) reported displacements of up to 45 m (150 ft) along some of the more major faults. Commonly however, major sandstone units, such as the Point Lookout Sandstone, are not completely offset. The faulting is most apparent along continuous, resistant outcrops of major sandstone units, such as the Cliff House, Point Lookout, and Gallup Sandstones. Dips of the strata become gradually steeper and the fault blocks rise in a step-like fashion toward the steep uplift along the western flank of the Sierra Nacimiento. Also

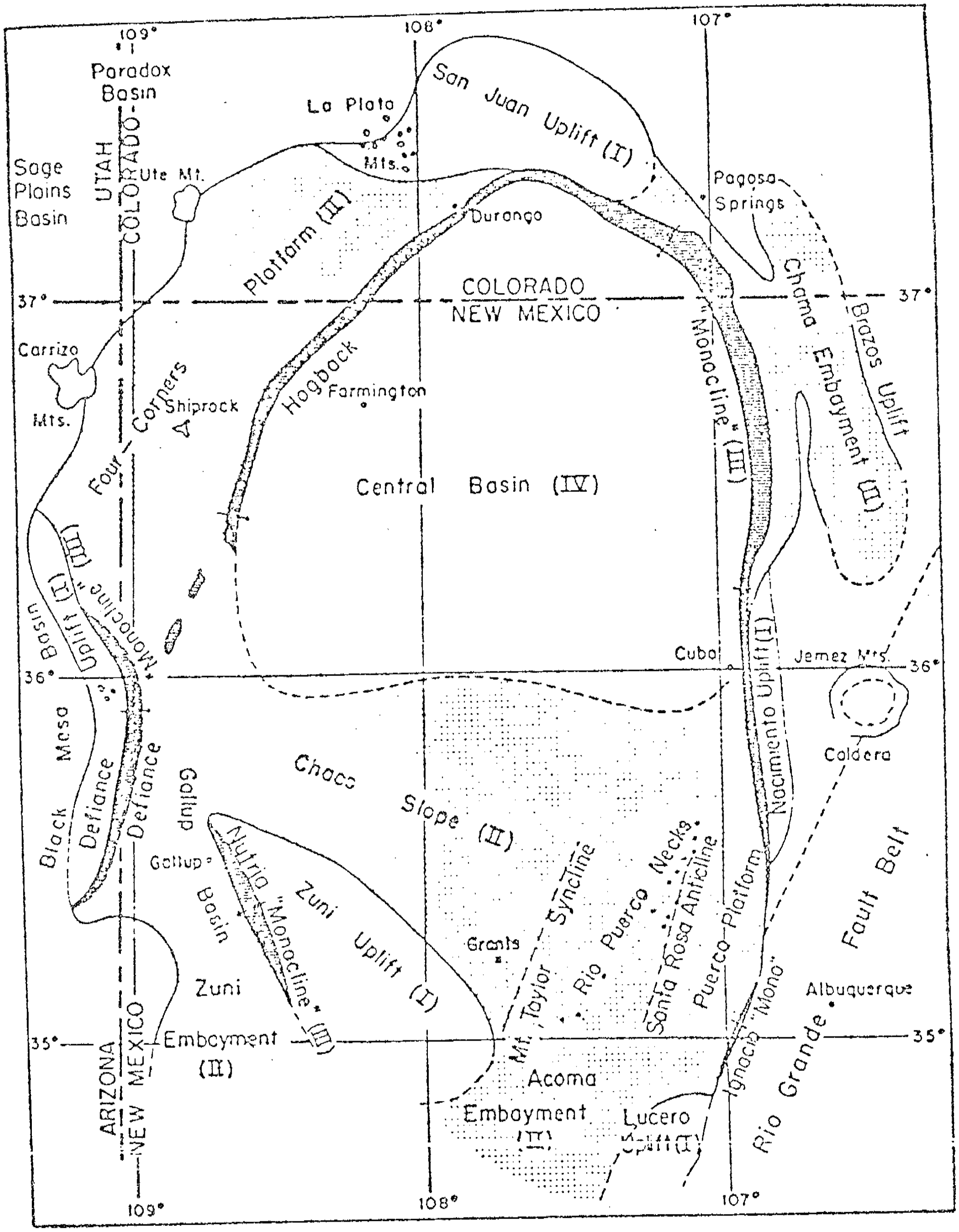


Figure 8. Structural elements of the San Juan Basin (from Kelley, 1951).

EXPLANATION FOR FIGURE 9

Tb / Ti	Tertiary igneous rocks: Tb, basalt flows; Ti, intrusions
Kch	Cliff House Sandstone
Kmfu, Kmfa, Kmfc	Menefee Formation: Kmfu, "Upper Member"; Kmfa, Allison Member; Kmfc, Cleary Coal Member
Kpl	Point Lookout Sandstone
Kph	Hosta Tongue of Point Lookout Sandstone
Kg	Gallup Sandstone
Kms, Kmm, Kml	Mancos Shale: Kms, Satan Tongue; Kmm, Mulatto Tongue; Kml, "Lower" Mancos
	Fault, ball on down-thrown block
	Geologic contact, dashed where approximate
	Gradational geologic contact
*	Volcanic centers

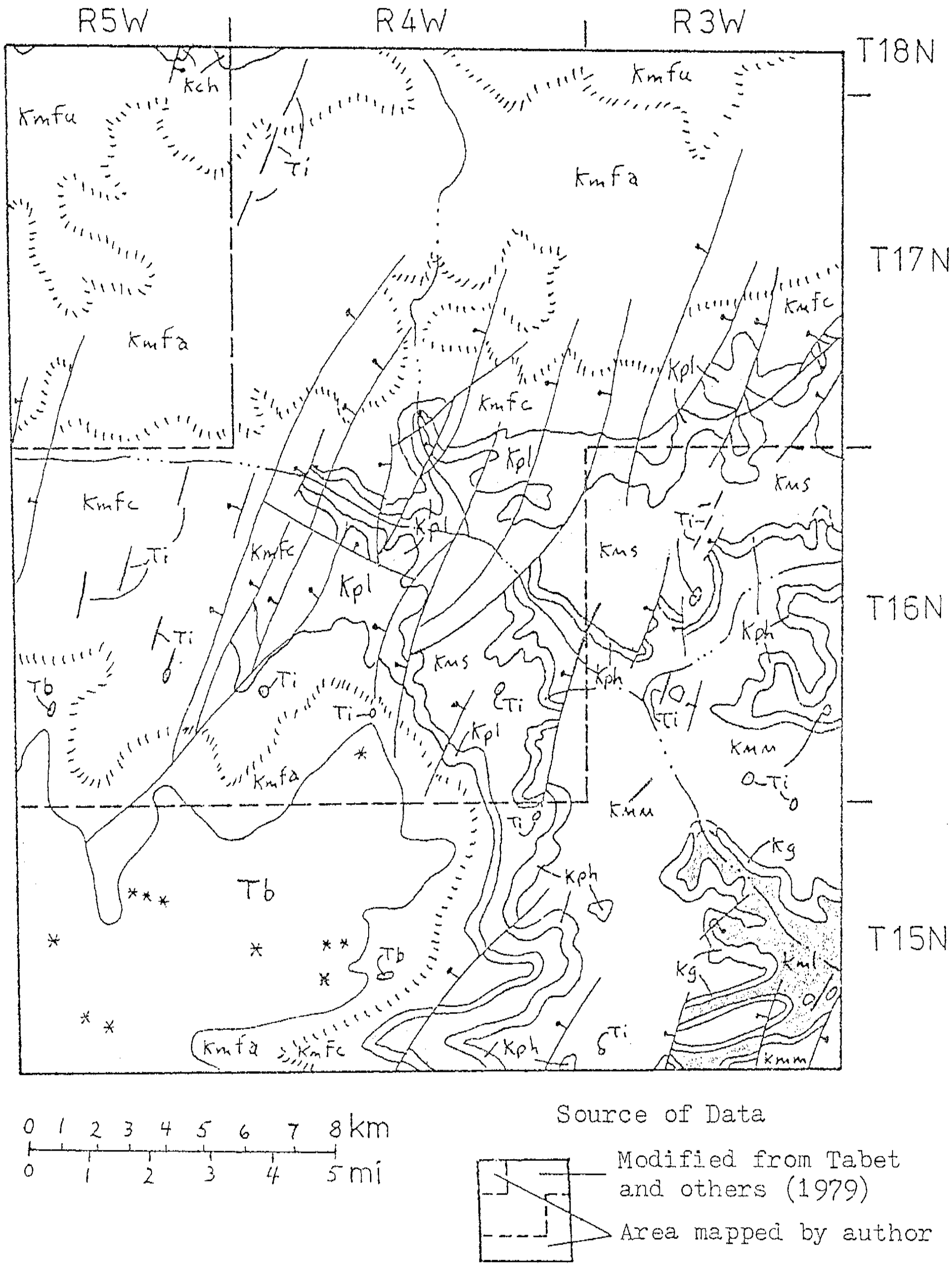


Figure 9. Generalized geologic map of the Chico Arroyo/Torreon Wash area (see Plate 1).

associated with the dominant northeast-trending fractures are several basaltic dikes.

No obvious folding can be observed in outcrops in the area. On a structure contour map, drawn on top of the Point Lookout Sandstone, Tabet and Frost (1979, Fig. 13, p. 30) show a small dome and two gentle, northward-plunging anticlinal features.

STRATIGRAPHIC FRAMEWORK

Strata in the Chico Arroyo/Torreon Wash area consist mainly of Upper Cretaceous marine and nonmarine sedimentary deposits (Fig. 10). Molenaar (1977) summarized the depositional history of many of these deposits throughout the San Juan Basin area. In ascending order these strata include the "Lower" Mancos Shale, consisting of offshore marine deposits; the Gallup Sandstone, a regressive beach deposit; the Mulatto Tongue of the Mancos Shale, offshore marine; the Hosta Tongue of the Point Lookout Sandstone, a transgressive beach deposit; the Satan Tongue of the Mancos Shale, offshore marine; the main body of the Point Lookout Sandstone, a regressive beach deposit; the Menefee Formation, consisting of continental deposits of sandstone, shale, claystone, and coal; and the Cliff House Sandstone, a transgressive beach deposit.

In the southern part of the area the Upper Cretaceous strata are intruded and overlain by volcanic rocks of Tertiary age. Lava flows occur on Mesa Chivato which have several local sources, but are ultimately related to the Mount Taylor complex to the southwest. Locally, especially in the Guadalupe Quadrangle, the Cretaceous rocks are intruded by volcanic necks and dikes (Frontispiece; Fig. 5-A, p. 19; Plate 1).

Quaternary-aged deposits include alluvium, eolian sand, terrace deposits, and, locally, landslide debris.

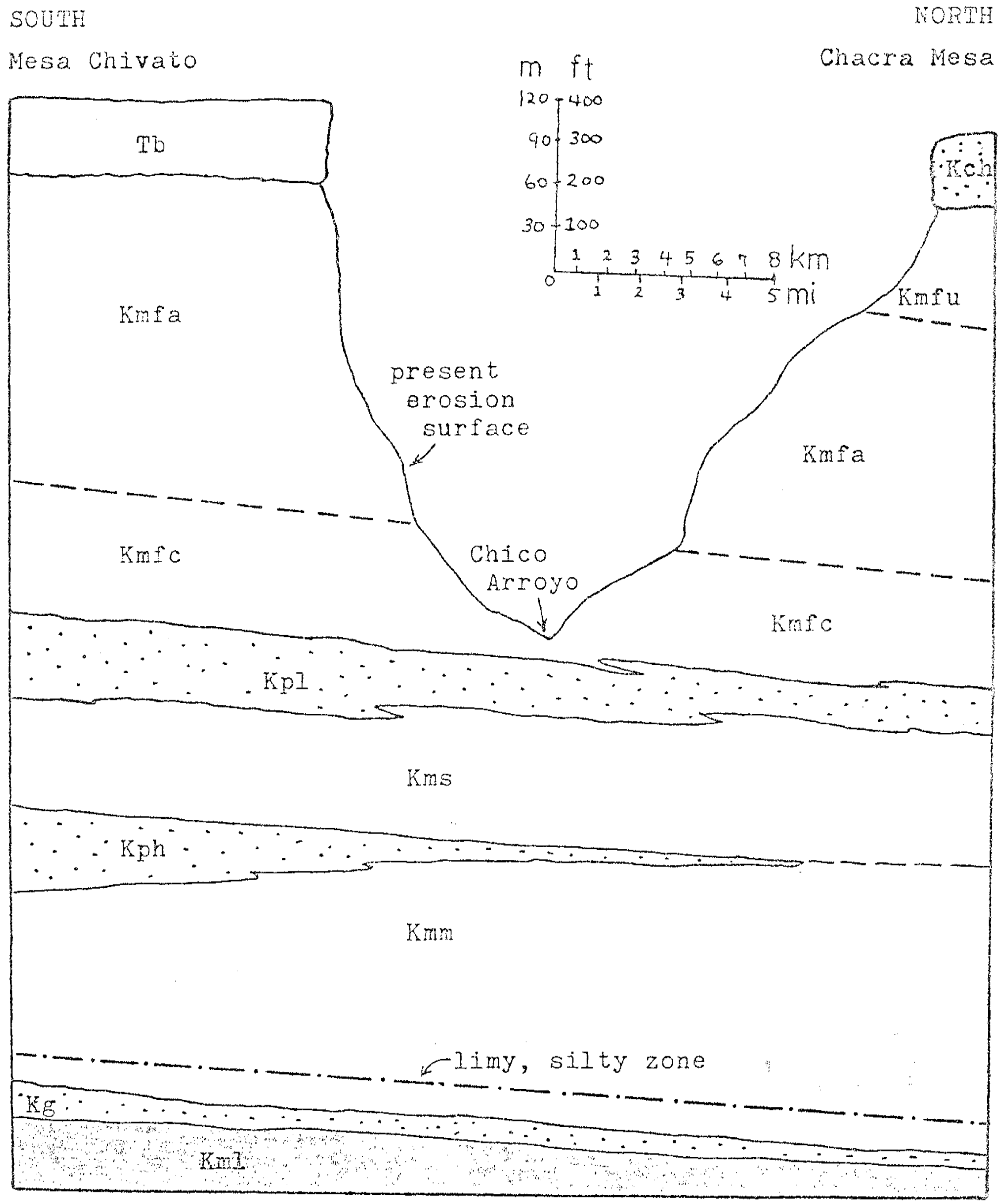


Figure 10. Diagrammatic cross-section through Chico Arroyo/Torreon Wash area showing major stratigraphic relationships. Abbreviations for rock units same as Figure 9 (modified from Tabet and Frost, 1979).

MAJOR POTENTIAL AQUIFERS

Major potential aquifers are those geologic units which are known water producers in the area and for which sufficient hydrologic data exist to evaluate their aquifer potential. In descending order these include the Menefee Formation, Point Lookout Sandstone, Mulatto Tongue of the Mancos Shale, Gallup Sandstone, and Westwater Canyon Sandstone Member of the Morrison Formation.

MENEFEE FORMATION (CRETACEOUS)

Geologic Characteristics

The Menefee Formation crops out mainly in the northern half of the area and along the slopes around Mesa Chivato (Plate 1). Topography formed the unit is commonly rolling to rough, broken, and steep. The Menefee conformably overlies the Point Lookout Sandstone and is conformably overlain by the Cliff House Sandstone. Intertonguing occurs locally at both contacts.

In general the Menefee Formation consists of interbedded, light brown to gray, thick- to very thick-bedded sandstones; yellowish gray to olive gray, medium- to thick-bedded siltstones; light brownish-gray, thick- to very thick-bedded shales and claystones; medium- to very thick-bedded carbonaceous shales; and coal beds of variable thickness. Most of the coal beds range from 0.2 - 1.0 m (0.5 - 3.0 ft) in thickness, but may attain a thickness of up to 4 m (14 ft).

Three members have been recognized in the Chico Arroyo/Torreon Wash area. In descending order these are the unnamed "Upper Member", Allison Member, and Cleary Coal Member. The "Upper Member" is present only in the northern part of the area. Contacts between the members are gradational, and therefore somewhat arbitrary, but they are recognizable. The contacts are economic in that, as mapped by Tabet and others (1979), they were based essentially on the presence or absence of coal.

The "Upper Member" is approximately 200 m (650 ft) thick in this area (Tabet and Frost, 1979, p. 17). It consists mainly of local sandstone lenses up to 12 m (40 ft) thick, siltstones, barren (noncarbonaceous) shales and claystones, and an abundance of carbonaceous shales and coals (section SDC-1, Appendix A; Appendix E; Fig. 11). The unit is more sandy in the lower part, near the contact with the Allison Member, and more carbonaceous in the upper part.

Textural (mechanical) analysis of one sandstone outcrop sample (sample SDC-1-4b, Appendix C) showed it to be fine grained and poorly sorted. Silt-plus-clay content was 22 percent, very fine-plus-fine-sand content was 71 percent, and medium-plus-coarse-sand content was 7 percent. Mineralogic analysis of the same sample yielded 73 percent framework components. The rock plotted in the lithic arkose field on Folk's (1974) triangular diagram (Appendix B).

Thickness of the Allison Member ranges from about 120 - 170 m (400 - 550 ft; Tabet and Frost, 1979, p. 15). It consists of sandstones up to about 15 m (50 ft) thick, siltstones, and barren gray shales and claystones (Appendix E). Thin carbonaceous shales and coals do occur locally, but Tabet and Frost (1979) reported that these make up no more than 5 percent of the member. Just above the contact with the Cleary Coal Member, the Allison forms steep cliffs about 60 m (200 ft) high. These cliffs consist of vertically-stacked sequences of sandstone bodies. Individual sandstone bodies are lenticular in cross section and commonly have scour bases. Tabular siltstone beds up to 1 m (3 ft) thick are

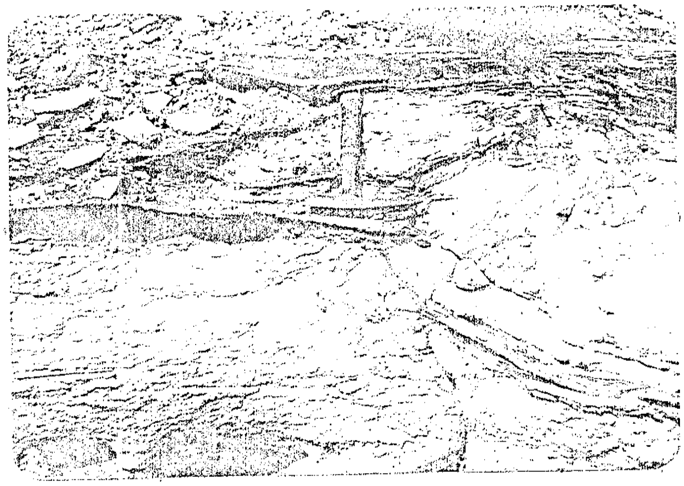


Figure 11. Soft-sediment deformation in a sandstone of the "Upper Member" of the Menefee Formation. Hammer is positioned between two deformed, thin-bedded, carbonaceous sandstone beds (photo taken at Black Mountain, SE¼, Sec15, T18N, R4W).

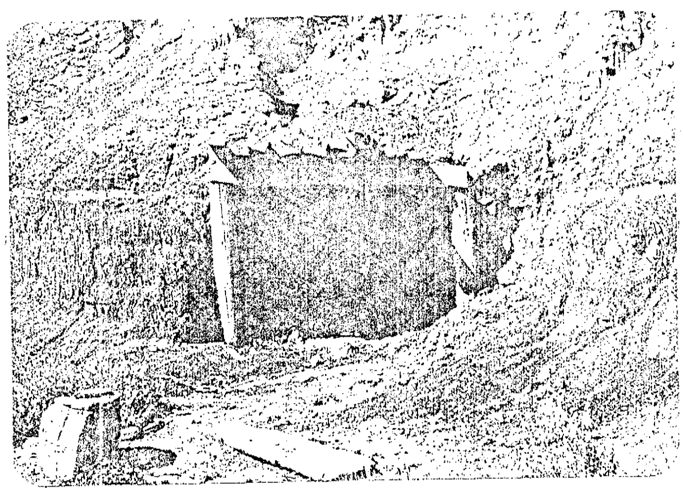


Figure 12. Abandoned coal shaft in Cleary Coal Member of the Menefee Formation. The coal bed is about 1 m (3 ft) thick. Tabet and Frost (1979) gave further details about this prospect (photo taken near south bank of Torreon Wash, NW¼, Sec34, T17N, R4W).

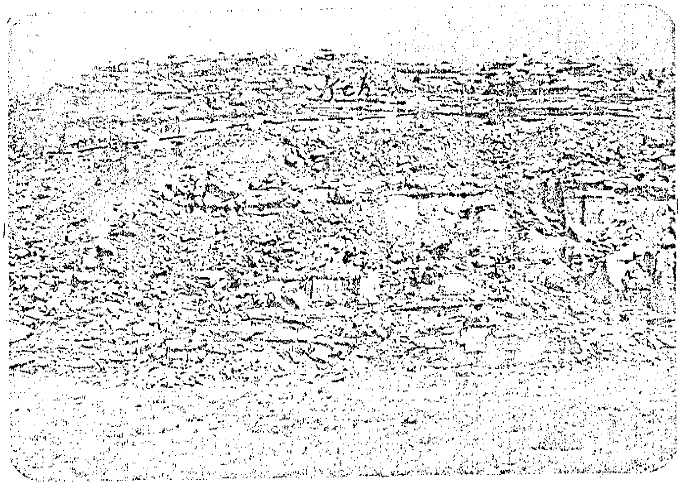
associated with these sandstone bodies.

The thickness of the Cleary Coal Member ranges from about 60 - 90 m (200 - 300 ft; Tabet and Frost, 1979, p. 12). It consists of scatterred sandstones, siltstones, barren gray shales and claystones, and abundant carbonaceous shales and coals (Appendices D and E; Fig. 12, p. 35). The unit is more carbonaceous in the lower part and more sandy in the upper part, near the contact with the Allison Member. Iron-stained concretions are commonly associated with carbonaceous zones.

Textural analyses of two core samples from sandstones showed sorting to be poor and modal grain size to be fine sand. Silt-plus-clay content was 16 and 18 percent, very fine-plus-fine-sand content was 53 and 72 percent, and medium-plus-coarse-sand content was 11 and 29 percent (samples C5-2-87 and C6-5-37.2, Appendix C). Mineralogic analyses of the same samples yielded framework percentages of 76 and 82 percent, respectively. Both rocks plotted in the lithic arkose field (Appendix B).

The members of the Menefee Formation in this area represent the gradational succession of continental depositional environments ranging from a coastal swamp (and lower floodplain) associated with the regressing Point Lookout shoreline, to an upper floodplain, and back to a similar coastal swamp associated with the transgressing Cliff House shoreline (Tabet and Frost, 1979). The lower and upper coal-bearing members were formed landward from these shorelines, respectively (Molenaar, 1977). Figure 13 shows typical exposures of the Menefee Formation in the area and the rock types commonly associated. The lenticular sandstone bodies represent fluvial environments; tabular siltstones represent crevasse splay or levee deposits; the gray barren shales and claystones were deposited in a well-drained floodplain environment; and the carbonaceous

Figure 13. Typical exposures of the Menefee Formation in the Chico Arroyo/Torreon Wash area. A) "Upper Member" at Chacra Mesa (section SDC-1, Appendix A) consists of channel sandstones, barren shales and claystones, siltstones, and carbonaceous shales and coals. The thick sequence of flat-bedded sandstones capping the mesa is the Cliff House Sandstone (Kch), about 55 m (180 ft) thick at this locality (view north from SE¼, Sec31, T18N, R4W). B) Allison Member, consisting of channel sandstones, barren shales and claystones, and siltstones (photo by Dave Tabet, NMBMMR Coal Geologist; view north from NE¼, Sec21, T17N, R4W). C) Cleary Coal Member, consisting of channel sandstones, barren shales and claystones, siltstones, and carbonaceous shales and coals (photo by Dave Tabet; view south from NW¼, Sec34, T17N, R4W).



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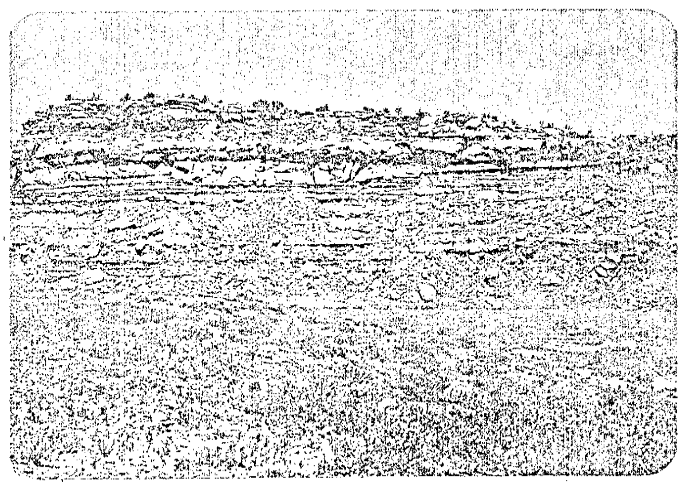

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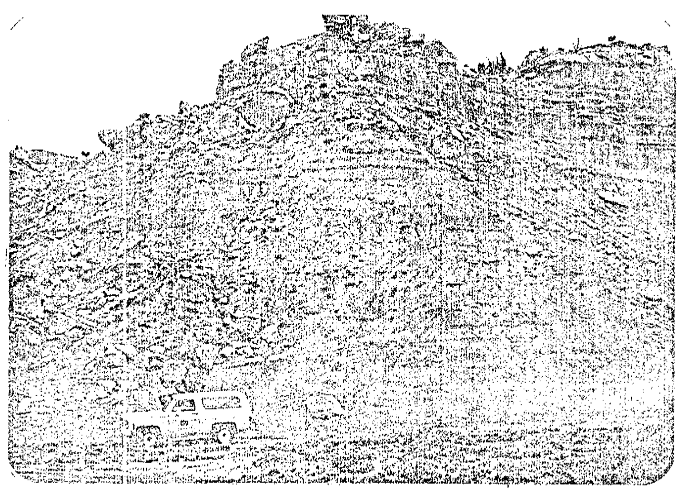


C

shales and coals were deposited in a poorly-drained swamp environment (Mannhard, 1976; Shetiwy, 1978; Tabet and Frost, 1979).

Hydrologic Characteristics

Two observation wells were completed in coal beds of the Menefee Formation. Well R32 (17N.04W.23.243, Appendix H) is completed in a 1.5-m (5.0-ft)-thick coal bed in the Cleary Coal Member. This well was tested by the swabbing method (Appendix F) for only 15 minutes, at which time it was pumped dry. Transmissivity was calculated by the slug method of data analysis (Lohman, 1972, p. 28) to be 9.3×10^{-6} m^2/d (1.0×10^{-4} ft^2/d). Well C1 (18N.03W.20.311, Appendix H) is completed in a 4.2-m (13.7-ft)-thick coal bed in the "Upper Member". An attempt was made to test this well by the swabbing method at an average rate of 0.08 lps (1.3 gpm) for 50 minutes, but the water level could not be lowered by this method. The well was later tested by the instantaneous recharge or "slug" method described by Loman (1972, p. 27). The calculated value for transmissivity using this method was 1.9 m^2/d (20.0 ft^2/d; Appendix G).

Two core samples from sandstones in the Cleary Coal Member (core holes C5 and C6) were analyzed commercially for porosity as well as horizontal and vertical permeability (Appendix L). Values for porosity were 26.4 and 26.3 percent. Values for horizontal permeability were 210 and 163 millidarcys, whereas those for vertical permeability were 98 and 314 millidarcys.

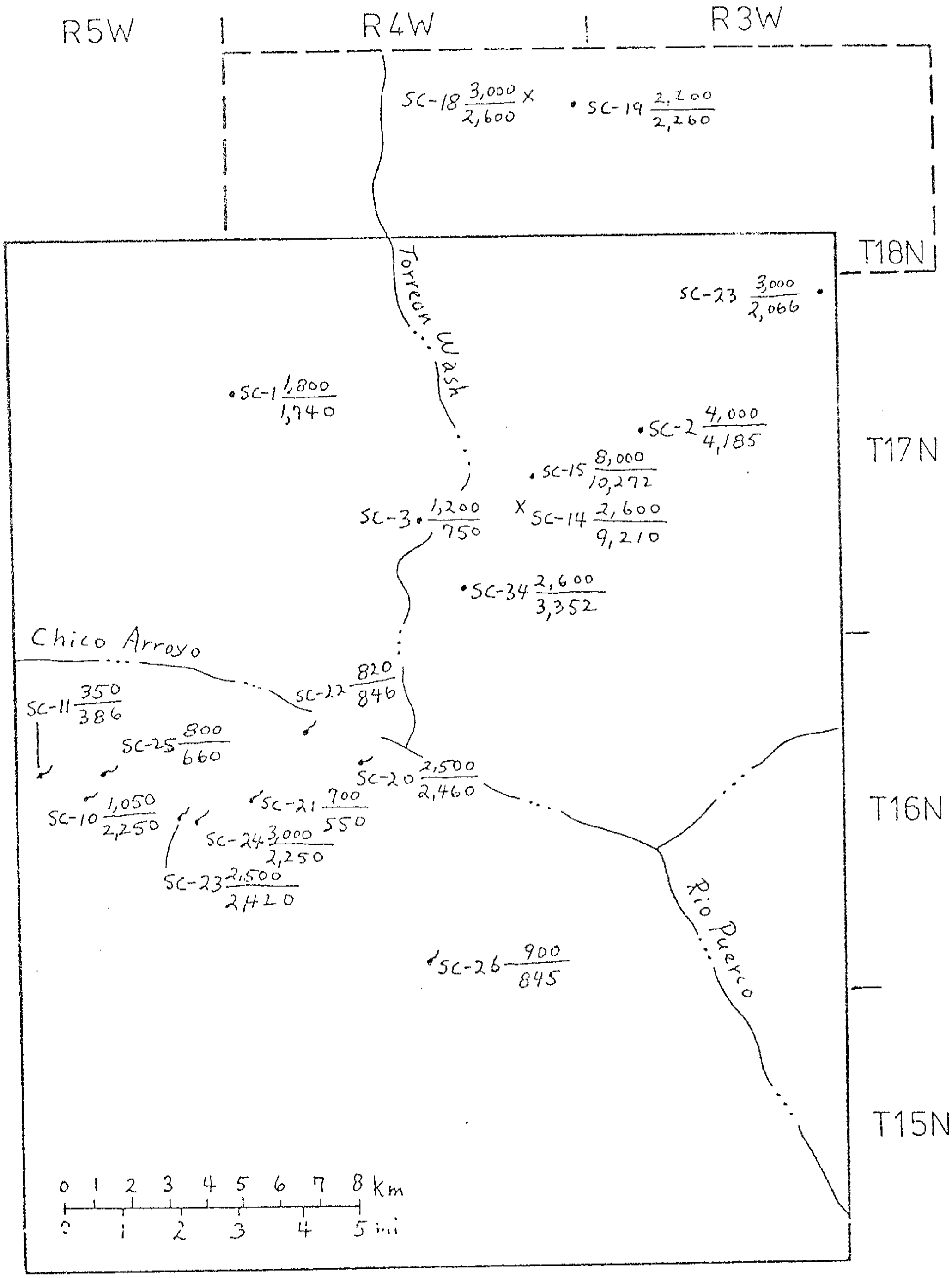
Seven other wells completed in the Menefee Formation were inventoried. At least two of these wells (17N.05W.12.423 and 18N.03W.20.433, Appendix H) are completed in sandstones of the Allison and "Upper Member, respectively USGS, WRD, Albuquerque). The other wells are also probably completed in sandstones. Three wells (17N.03W.18.242, 17N.04W.22.331, and 17N.04W.23.224, Appendix H) may be partially completed in alluvium. Yields from pumping wells are low, 0.064 lps (1.0 gpm), or less.

Water in wells tapping the Menefee Formation in this area will probably be under artesian pressure, but flow would not be expected.

Nine springs were inventoried which issue from the Menefee Formation. All these springs are south of Chico Arroyo, and issue from either the Cleary Coal or Allison Member (Plates 1 and 3). Two springs, Ojo Azabache and Coal Spring (16N.05W.15.233 and 16N.05W.15.412, Appendix H), are associated with a major northeast-trending dike which cuts sandstones in the Cleary Member. Most other springs occur along northeast-trending normal faults (Plate 1). Sandoval Spring (16N.05W.16.124, Appendix H) issues from a coal-shale contact in the Cleary Member. Barrel Spring (16N.04W.34.334, Appendix H; Fig. 34-A, p,107) occurs on a northeast slope of Mesa Chivato and issues from the Allison Member. Yields from all springs are low, estimated at 0.032 - 0.064 lps (0.5 - 1.0 gpm).

Water Quality

Quality of water from the Menefee Formation ranges from fresh to moderately saline (classification from Swenson and Baldwin, 1965). Specific conductance ranges from 350 - 8,000 micromhos per centimeter at 25°C (µmhos/cm), and total-dissolved-solids contents from 386 - 10,272 parts per million (ppm). Available data indicate that the quality of water in the Menefee Formation occurring south of Chico Arroyo is generally better than that of water north of the Chico (Fig. 14). Both well and spring waters plot in the sodium-bicarbonate to sodium-sulfate fields on the Piper diagrams (Figs. 15 and 16). Water from observation well R32, completed in a coal bed of the Cleary Member, plots in the sodium-bicarbonate-sulfate-chloride field (Fig. 15). Examination of Figures 15 and 16 reveals that no separation of water types by member of the Menefee Formation is possible in this area.



Explanation

- • Water Well
- × Observation Well
- ✓ Spring

sample number • SC-1 1,800 specific conductance (μmhos/cm)
1,740 total dissolved solids (ppm)

Figure 14. Distribution of water quality in the Menefee Formation (see Appendix I; Plate 3).

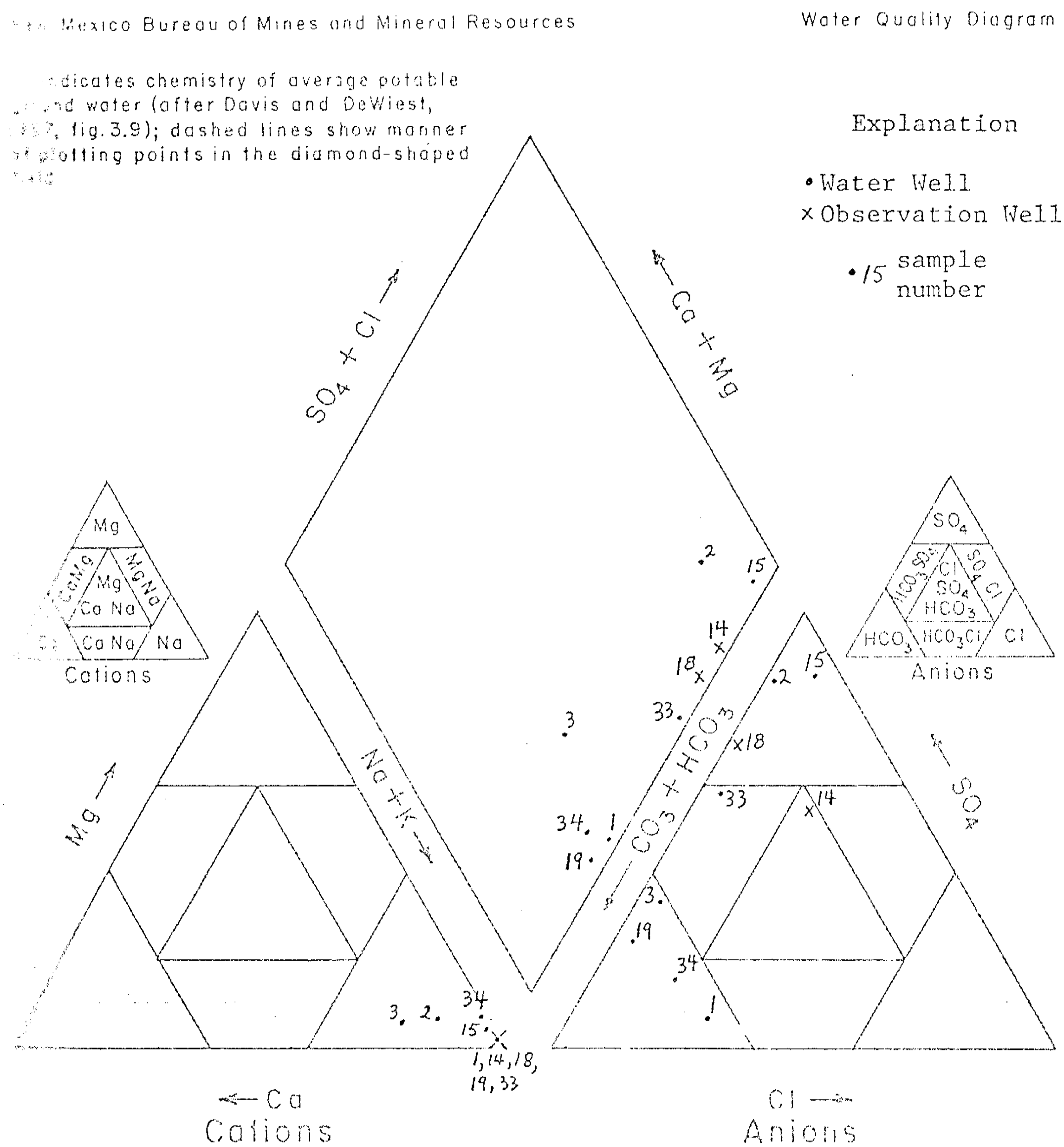


Figure 15. Trilinear plot of concentrations of major dissolved solids in well waters from the Menefee Formation. Samples 2, 3, 14, 15 = Cleary Coal Member; 33, 34 = Allison Member; 1, 18, 19 = "Upper Member"; Samples 2, 3, 15 may also contain water from alluvium. Small triangles at sides give key to classification of waters (see Appendix J; Plate 3).

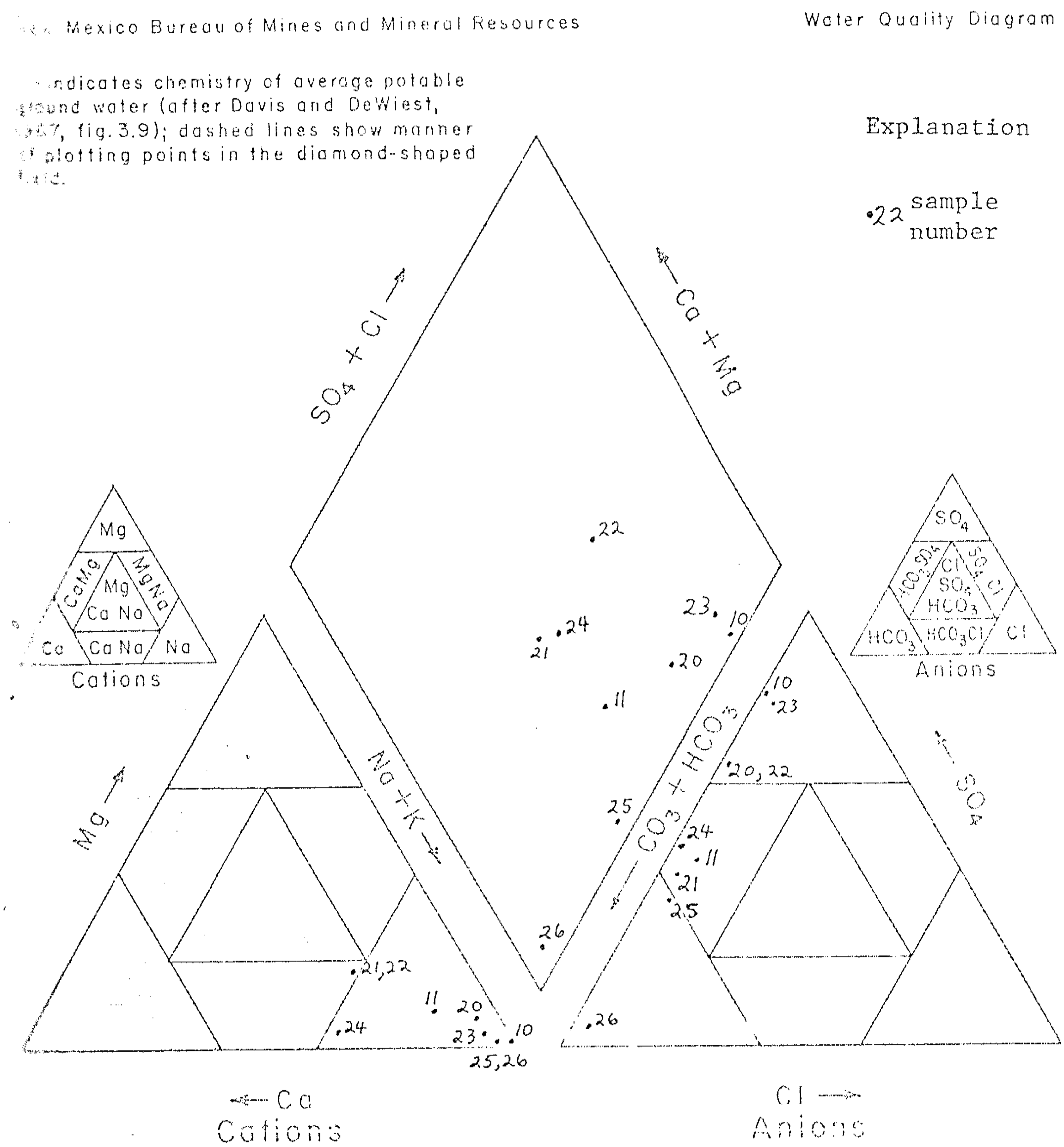


Figure 16. Trilinear plot of concentrations of major dissolved solids in spring waters from the Menefee Formation. Sample 26 = Allison Member; all others = Cleary Coal Member (see Appendix J; Plate 3).

POINT LOOKOUT SANDSTONE (CRETACEOUS)

Geologic Characteristics

The main body of the Point Lookout Sandstone crops out along an east-west trend in the east-central portion of the area on Mesa San Luis, and along a north-south trend on the eastern slopes of Mesa Chivato (Plate 1). The outcrops on Mesa San Luis have been eroded and stripped back in a northerly direction on their upper surfaces. The outcrops along Mesa Chivato are obscured in many places by basaltic colluvium. Surface exposures of the Point Lookout commonly form steep, vertical cliffs and escarpments throughout the area.

The Point Lookout Sandstone conformably overlies the Satan Tongue of the Mancos Shale; the contact is characterized by a distinct, alternating sandstone/shale transition zone (see sections SDC-3 and SDC-4, Appendix A). The Point Lookout is conformably overlain by the Cleary Coal Member of the Menefee Formation, with which it intertongues locally.

The Point Lookout Sandstone is generally characterized by upward-coarsening sequences of light olive-gray to pale brown to yellowish gray, thick- to very thick-bedded, very fine- to medium-grained, locally cross-bedded, bioturbated sandstones; these sandstones locally contain Ophiomorpha. Dark greenish-yellow to moderate brown, thin- to thick-bedded shales are commonly interbedded with the sandstones, especially in the lower parts of the unit. The upper few meters of the Point Lookout commonly consist of light gray, distinctly laminated sandstone.

Core samples and cuttings of sandstones from the Point Lookout differ in color from surface samples, core and cuttings being usually light gray to very light gray. Also in core samples, clay clasts of various sizes can be observed, whereas in outcrop samples, clay clasts are usually weathered away, leaving a pitted surface (Appendices A, D, and E).

Textural analyses of two outcrop and five core samples of sandstones showed that sorting is poor to moderate, and modal grain size varies from very fine to medium sand. Clay-plus-silt content ranges from 5 - 24 percent, very fine-plus-fine-sand content from 48 - 85 percent, and medium-plus-coarse-sand content from 0 - 46 percent (Appendix C). Figure 17 is a plot of mean grain size (from textural analyses) for samples taken every 5 ft in the upper 50 ft of a Point Lookout core. The overall coarsening-upward trend is well illustrated. Figure 17 also shows three coarsening-upward and three fining-upward sequnces. Mineralogic analyses of two outcrop and four core samples of sandstones yielded a range of 73 to 87 percent framework components. Of the individual framework components quartz accounted for 34 - 50 percent, feldspar plus granitic rock fragments for 31 - 44 percent, and chert plus other rock fragments for 10 - 27 percent. Cement accounted for 3 - 12 percent, matrix (clay-sized material filling interstices between grains) for 4 - 8 percent, and porosity for 5 - 8 percent of the rocks. Two samples plotted in the arkose field and four plotted in the lithic arkose field (Appendix B).

Thickness of the main body of the Point Lookout Sandstone (not including the transition zone at the base) ranges from about 23 - 79 m (75 - 260 ft) in the area (Fig. 18). Examination of the thickness map (Fig. 18) reveals that thickness varies systematically forming a series of northwest-trending, relatively thicker "ridges" and thinner "troughs". Tabet and Frost (1979) concluded that these thicker areas document temporary stillstands of the Point Lookout shoreline as it regressed in a step-like fashion toward the northeast. The northwest-trending "ridges" indicate the orientation of the paleoshoreline. The northeastward step-

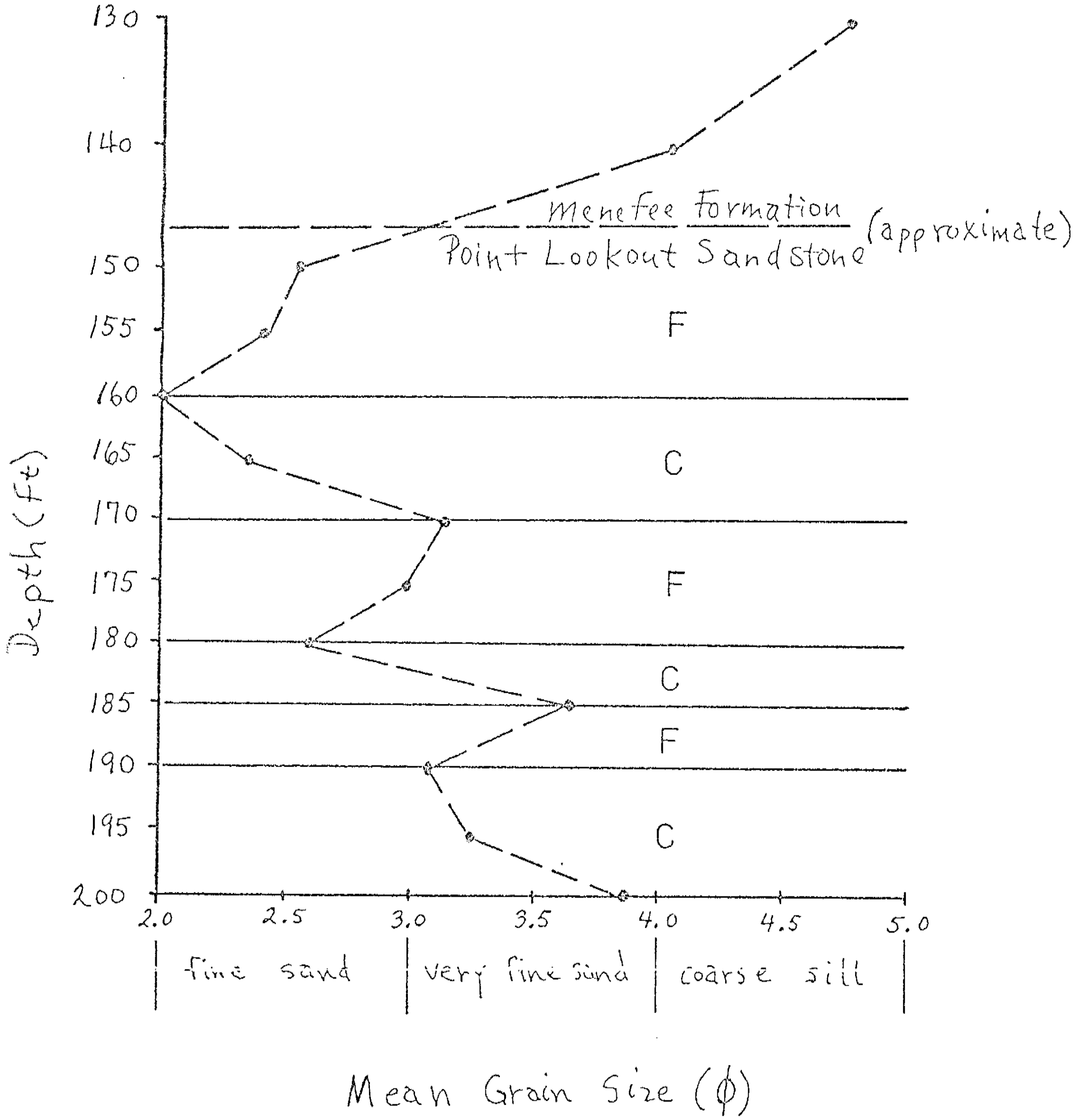
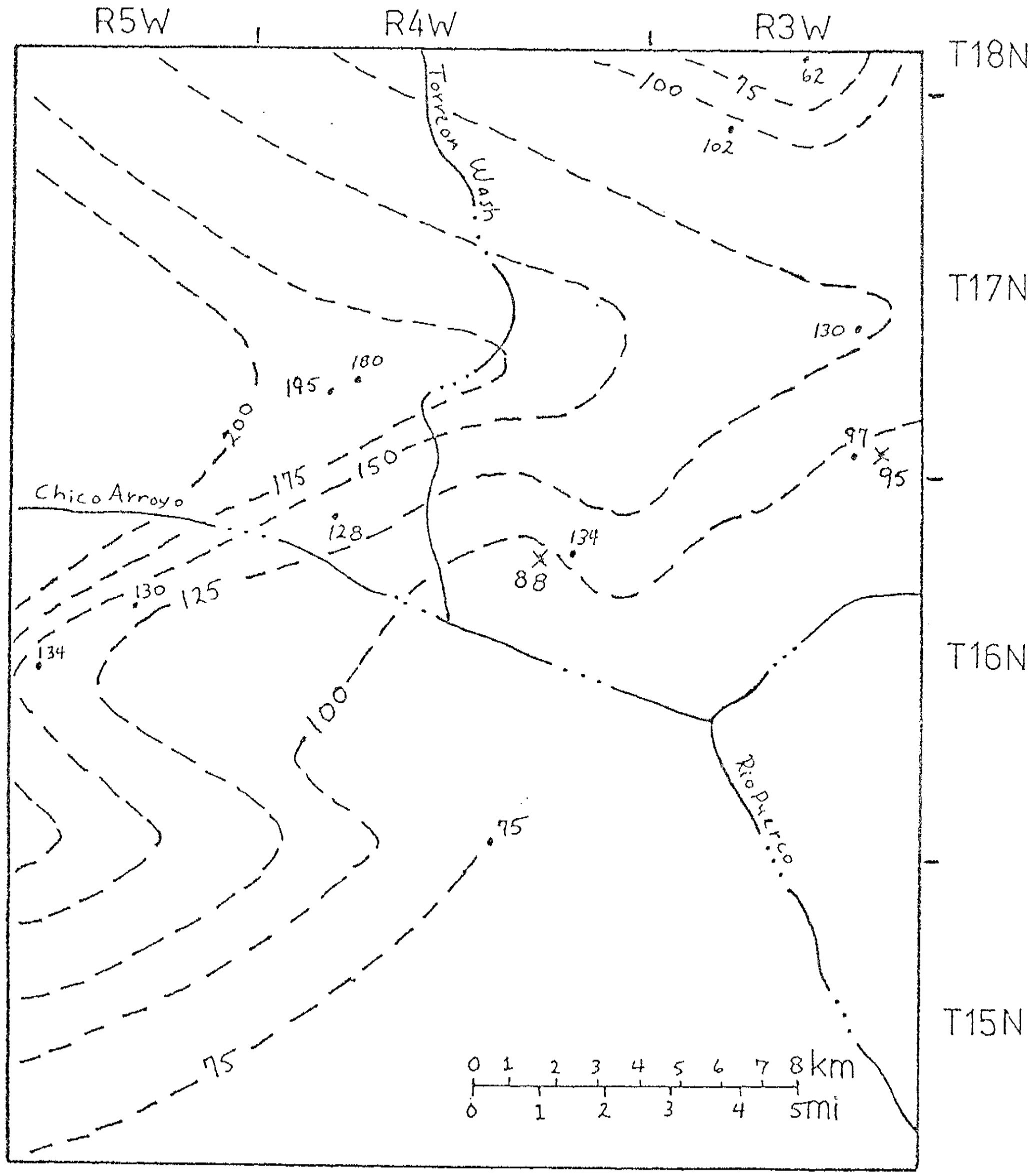


Figure 17. Plot of mean grain size for core C5; C = coarsening upward, F = fining upward (textural analyses performed by Dave Tabet, NMBMMR Coal Geologist, and Scott Anderholm, USGS, WRD, Albuquerque; results for samples C5-150 and C5-160 reported in Appendix C).



Explanation

ж measured section
• drill hole

Contour Interval = 25 ft

Figure 18. Thickness of the Point Lookout Sandstone. Based on drill-hole and outcrop data (see Appendices A, K; modified from Tabet and Frost, 1979).

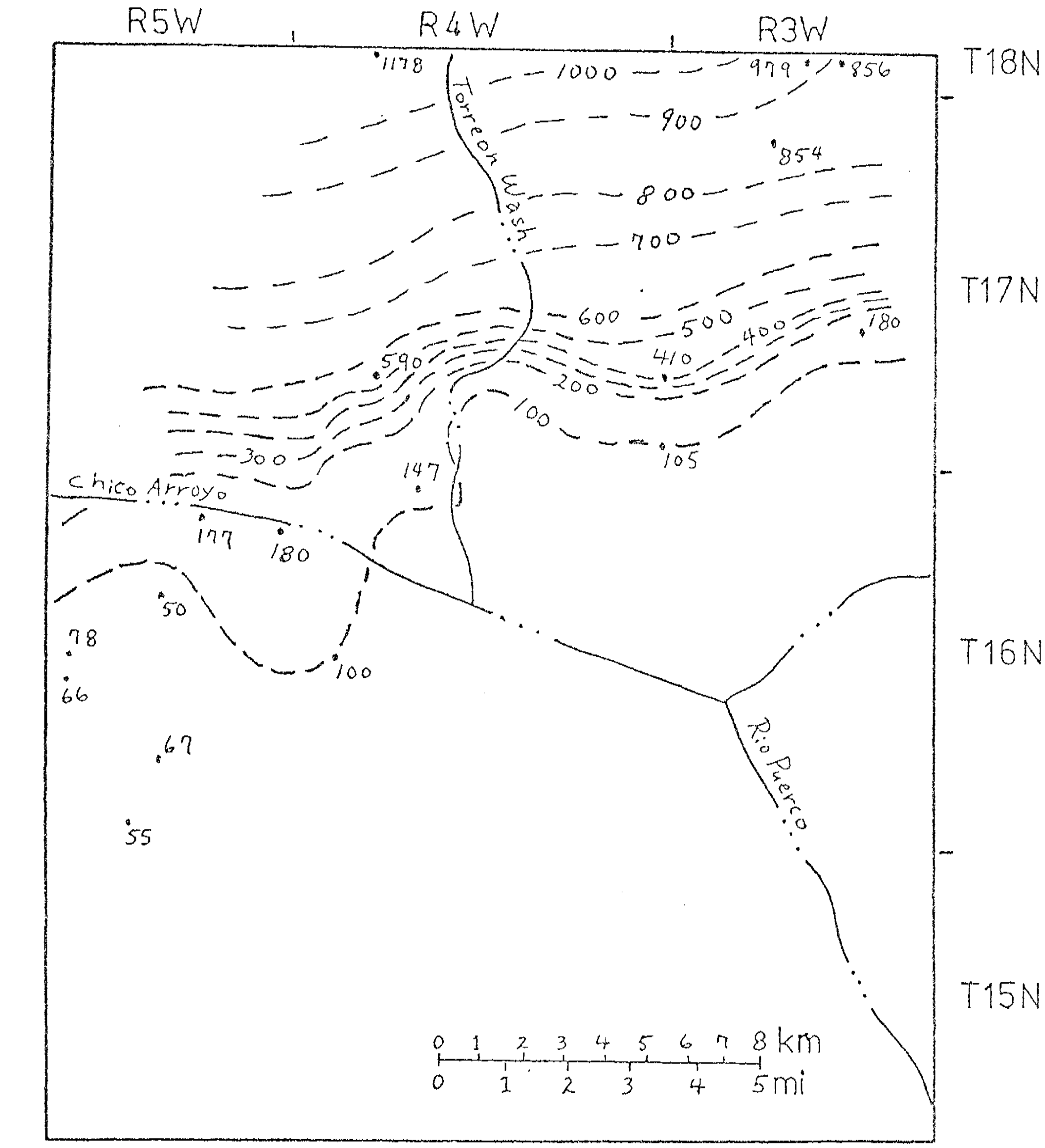
like rise of the Point Lookout can also be seen on the regional cross-section of the area (Plate 2).

Depths to the top of the Point Lookout in this area range from 0 - 370 m (0 - 1,200 ft; Fig. 19). Depths increase toward the north and northwest, mainly because of dip of the unit, but also because of higher surface elevations in the north. Depths to the top of the unit beneath Mesa Chivato probably range from about 275 - 370 m (900 - 1,200 ft), reflecting the higher surface elevations of the mesa.

The Point Lookout Sandstone is a regressive, marine shoreline deposit. Shetiwy (1978) recognized three major sedimentary facies in the main body of the Point Lookout: a shoreface environment, consisting of thick-bedded, tabular sandstones and thin-bedded shales; a foreshore/backshore environment, consisting of very thin- to thick-bedded sandstones; and an estuarine/beach environment, consisting of very thick-bedded sandstones containing clay clasts (in ascending order). Shetiwy (1978) also identified transition zones at the Point Lookout/Mancos Shale contact and the overlying Menefee Formation. All the facies identified by Shetiwy (1978) can be observed in surface exposures of the Point Lookout Sandstone in the area (Fig. 20).

Hydrologic Characteristics

Analyses of aquifer tests performed on three observation wells completed in the Point Lookout Sandstone indicate that transmissivity is very low (Appendices F and G). Calculated values range from 0.0009 - 0.009 m^2/d (0.01 - 0.1 ft^2/d). None of these wells is perforated throughout the entire thickness of the unit however, and, since transmissivity is a function of thickness, the values calculated are not maximum values. Observation well R21 was tested by both the bailer mathod and the instan-

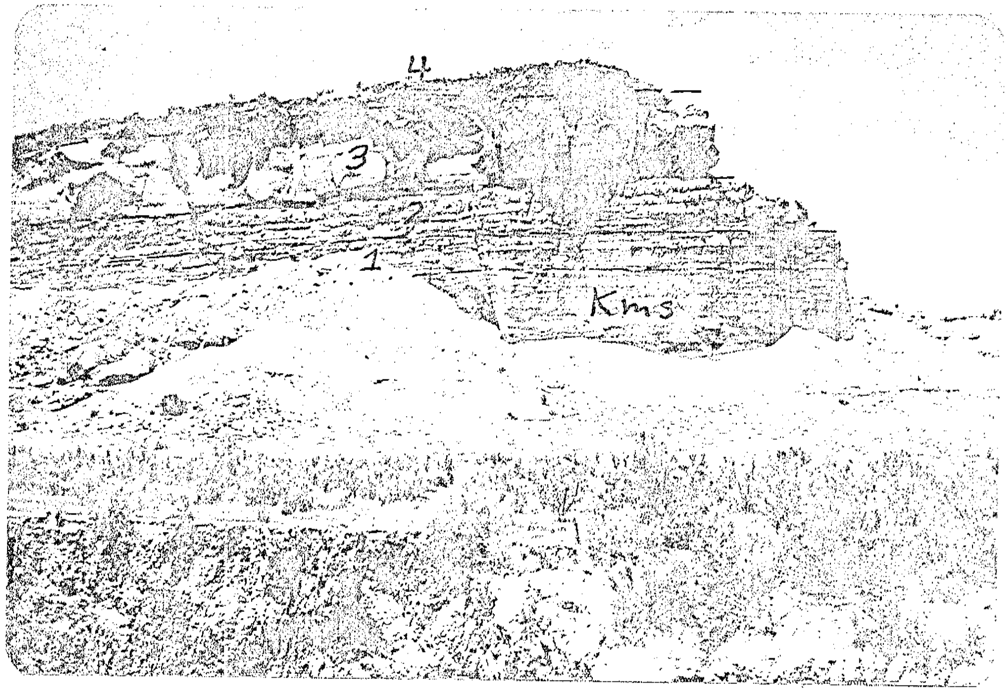


Contour Interval = 100 ft

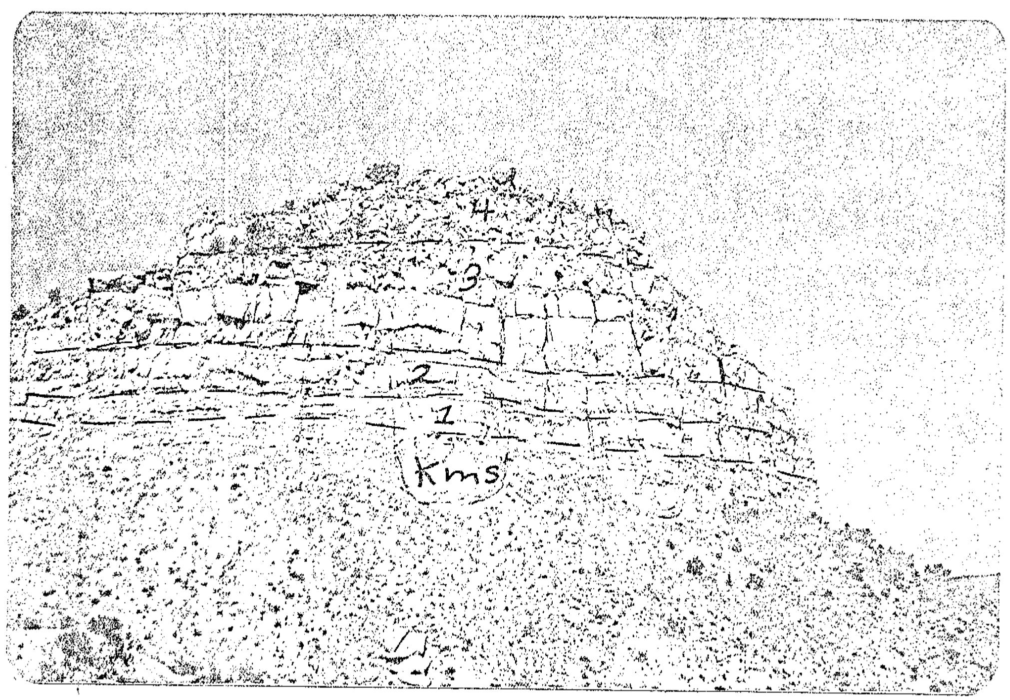
Figure 19. Depth to top of the Point Lookout Sandstone. Based on drill-hole data (Appendix K).

Figure 20. Typical exposures of the Point Lookout Sandstone in the Chico Arroyo/Torreon Wash area, on Mesa San Luis. Four of the sedimentray facies described by Shetiwy (1978) for the Point Lookout sequence are present throughout the area. These facies are labeled on the photos as follows: 1) offshore-beach transition zone, consisting of thin, discontinuous sandstones and a predominance of shales; 2) thick-bedded sandstones, locally interbedded with shales, deposited in a shoreface environment; 3) cliff-forming, major sandstone unit of the Point Lookout, consisting of very thick-bedded, massive to cross-bedded sandstones, deposited in the upper beach environment; 4) thick-bedded, laminated sandstones, deposited in the backshore environment. The Satan Tongue of the Mancos Shale (Kms) grades up into the transition zone.

A) Measured section SDC-3 (Appendix A). Thickness is about 30 m (100 ft; view east from SW¼, Sec34, T17N, R3W). B) Measured section SDC-4 (Appendix A). Thickness is about 27 m (90 ft; view northwest from NW¼, Sec11, T16N, R4W).



A



B

taneous recharge method; Wells R23 and R24 were tested by the swabbing method (Appendix F). Average discharge values during the tests were 0.02 lps (0.27 gpm) for R21, 0.07 lps (1.1 gpm) for R23, and 0.09 lps (1.4 gpm) for R24.

Three core samples from sandstones in the Point Lookout (core holes C5 and C6) were analyzed commercially for porosity as well as horizontal and vertical permeability. Values for porosity ranged from 18.2 - 21.3 percent. Values for horizontal permeability ranged from 0.81 - 8.9 millidarcys, whereas those for vertical permeability ranged from 0.72 - 5.4 millidarcys (Appendix L). Porosities determined from these analyses were greater than those determined microscopically (Appendix B) for the same samples. This difference probably results from the difficulty in recognizing true porosity in thin sections.

A windmill and a spring located on the south bank of Torreon Wash were also inventoried. The well (17N.04W.34.213, Appendix H) has a pumping yield of 0.03 lps (0.5 gpm) and a completed depth of 34 m (111 ft). Yield from the spring (17N.04W.34.213, Appendix H) could not be determined because the source is near the base of a deep pool in the arroyo bottom.

Water in wells tapping the Point Lookout Sandstone in this area will probably be under artesian pressure, except near outcrop areas, where depths to the unit are shallow. Confining pressures are probably not great enough to cause flow, however. Leakage from the underlying Mancos Shale and into the overlying Menefee Formation probably occurs.

Water Quality

Quality of water from the Point Lookout Sandstone in this area ranges from fresh to moderately saline. Specific conductance ranges from 380 - 5,000 μmhos/cm. Total-dissolved-solids content for waters analyzed ranges from 415 - 6,290 ppm. Available data indicate that water quality is good south of Chico Arroyo, but deteriorates near and north of that stream (Fig. 21). Waters from the Point Lookout plot in the sodium-bicarbonate, sodium-bicarbonate-sulfate, and sodium-sulfate fields on the Piper diagram (Fig. 22).

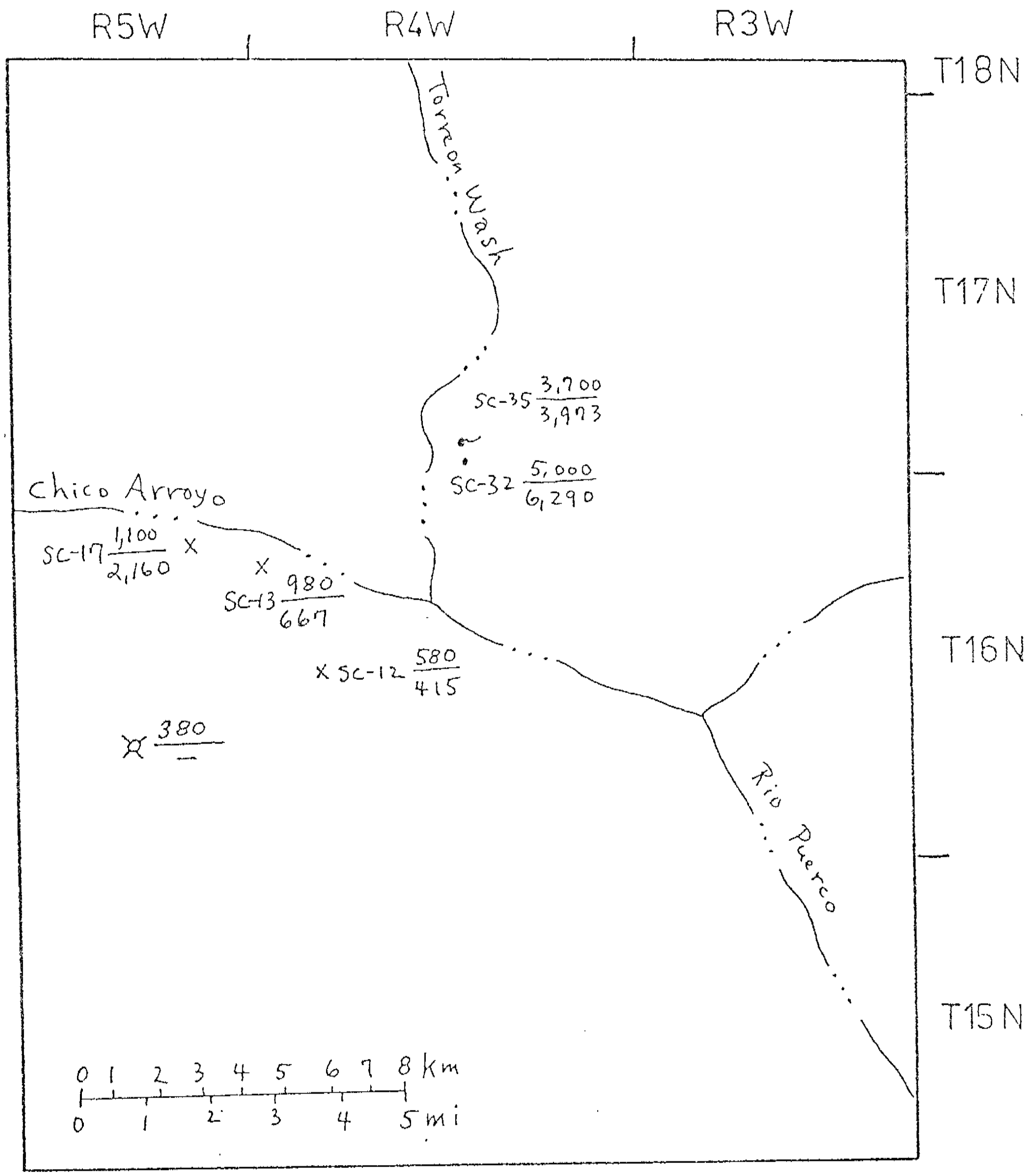
MANCOS SHALE (CRETACEOUS)

Geologic Characteristics

The Mancos Shale is exposed mainly in the Guadalupe Quadrangle where it is the dominant Cretaceous deposit (Plate 1). Topography formed on the Mancos is commonly rollong to steep, rough, and broken. Badland topography is common in the southwestern part of the area.

In general the Mancos Shale consists of thin- to very thick-bedded shales and thin- to thick-bedded, very fine- to medium-grained, silty sandstones. Total thickness of the Mancos in this area is about 550 - 610 m (1,800 - 2,000 ft; Plate 2). The Mancos thins toward the north. Three divisions of the Mancos Shale are exposed in the study area; the Satan Tongue, Mulatto Tongue, and "Lower" Mancos (in descending order). Of these three divisions, the Mulatto Tongue is best known hydrologically and the following discussion will center mainly on it. The other two divisions will be briefly mentioned since a water sample was taken from each of them.

The Satan Tongue occurs stratigraphically between and separates the Hosta Tongue and main body of the Point Lookout Sandstone. Thickness of the unit ranges from about 90 - 120 m (300 - 400 ft; Plate 2), increasing from south to north. The Satan Tongue merges with the Mulatto Tongue about midway through the area (Plate 2). The combined thickness of the



Explanation

• Water Well
X Observation Well
Abandoned Observation Well
Spring

sample number SC-17 1,100 specific conductance (µmhos/cm) / 2,160 total dissolved solids (ppm)

Figure 21. Distribution of water quality in the Point Lookout Sandstone (see Appendix I; Plate 3).

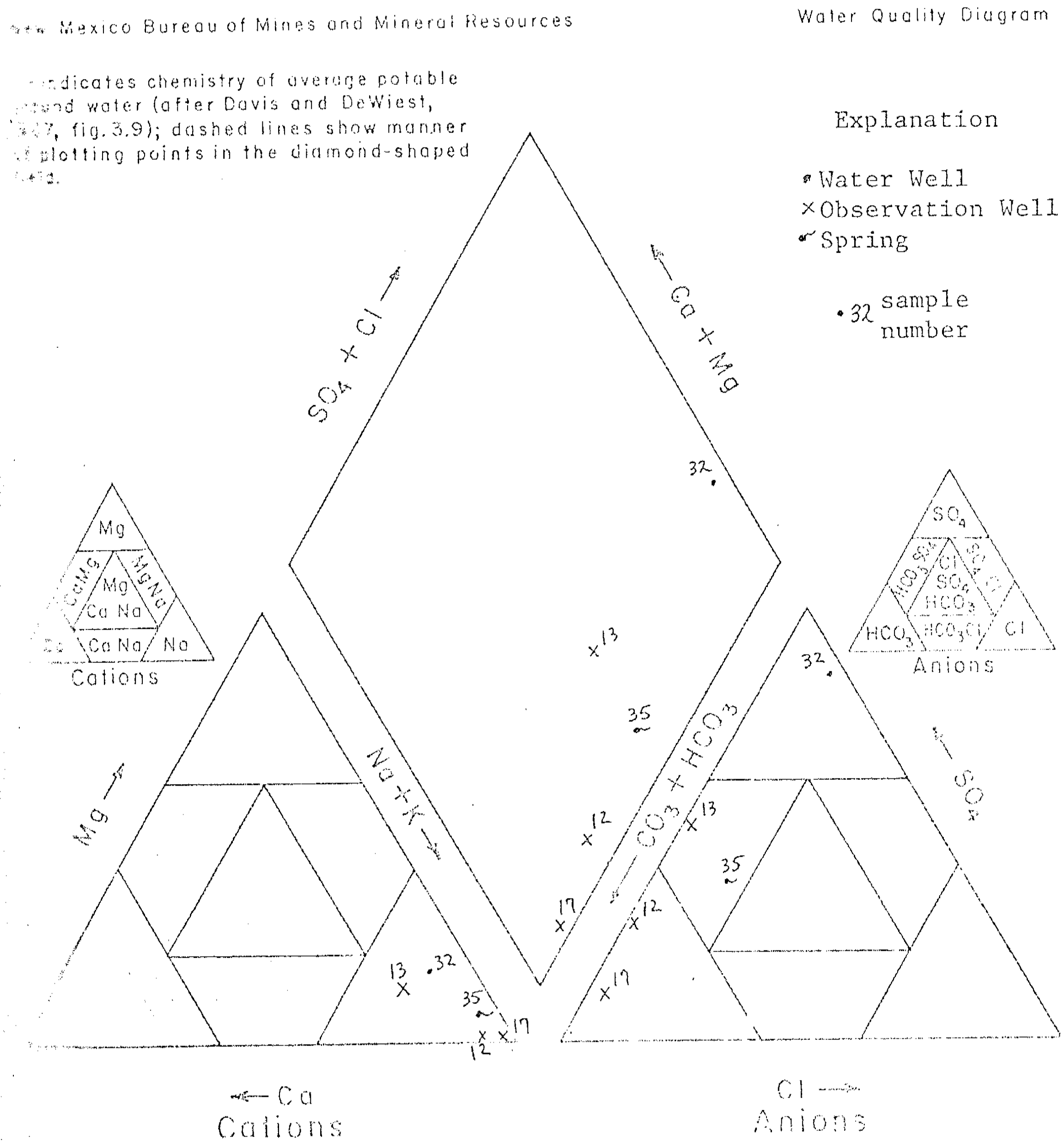


Figure 22. Trilinear plot of concentrations of major dissolved solids in waters from the Point Lookout Sandstone (see Appendix J; Plate 3).

Satan and Mulatto Tongues increases toward the north from about 245 - 300 m (800 - 1,000 ft). In outcrop the Satan Tongue consists mainly of olive brown to grayish olive, medium- to very thick-bedded shales interbedded with pale olive, thin- to thick-bedded, very fine- to fine-grained, silty sandstones. Near the gradational contacts with the Hosta and main body of the Point Lookout Sandstone the Satan Tongue becomes more sandy as sandstone gradually predominates over shale (sections SDC-3 and SDC-4, Appendix A).

The Mulatto Tongue is the most areally extensive Cretaceous deposit is the Guadalupe Quadrangle. It occurs stratigraphically below the Hosta Tongue and above the Gallup Sandstone. Before merging with the Satan Tongue, its thickness is about 140 - 150 m (450 - 500 ft). The Mulatto generally consists of interbedded, pale brown, thin- to very thick-bedded shales and yellowish gray, thin- to thick-bedded, very fine- to fine-grained, silty sandstones. Locally, especially in the lower part of the unit, medium- to coarse-grained sandstone bodies and limy, silty zones occur. These zones are discussed with the Gallup Sandstone (section SDC-5, Appendix A; Frontispiece; Fig. 5-A, p. 19). The Mulatto Tongue appears to be more sandy overall than the Satan Tongue.

The only "Lower" Mancos Shale exposed in the study area is in the vicinity of Guadalupe and southward. It is conformably overlain by the Gallup Sandstone and separates the Gallup from the Dakota Sandstone below (Plate 2). Thickness of the "Lower" Mancos is about 300 m (1,000 ft) in the subsurface. Surface exposures consist of interbedded, dusky yellow to pale green, thin- to very thick-bedded shales and light brown to yellowish green, thin- to thick-bedded, fine- to medium-grained sandstones (section SDC-5, Appendix A).

Hydrologic Characteristics

The Mulatto Tongue is considered to have fair aquifer potential in this area, at least for stock-water supplies. Two wells completed in the unit were inventoried. A well located in SW¼, Sec11, T16N, R4W was pumping at a rate of 0.13 lps (2.0 gpm) when inventoried (16N.04W.11.312, Appendix H). This well is inaccessible so the depth of water and depth of well could not be measured, and no records could be located which gave this information. It is possible that the well is completed in the sandstone/shale interval which is the northward extension of the Hosta Tongue (Plate 2), but, because of lack of completion data, it is discussed here. An abandoned well (16N.03W.35.131, Appendix H; Frontispiece) has a completion depth of 14.4 m (47.2 ft) and a water level of 11.1 m (36.4 ft). This well was probably abandoned because the water level is quickly lowered to near the bottom of the well when pumped.

Four springs were inventoried which have their sources in the Mulatto Tongue. Ojo Atascoso (16N.04W.25.433, Appendix H) has been developed by the BLM, who constructed an enclosed catchment/storage structure which feeds a stock tank below the source. Yield to the stock tank is 0.064 lps (1.0 gpm). This spring occurs along a major northeast-trending fault (Plate 1). Ojo de Los Jaramillos (16N.03W.33.342, Appendix H), another developed spring, associated with a volcanic neck (Cerro de Santa Clara), issues from the Mulatto Tongue. The source of this spring is in a dug, wood-lined enclosure where the water is collected and directed to three stock tanks in the vicinity. Yield to the stock tanks was measured at 0.032 lps (0.5 gpm). An undeveloped spring (16N.04W.36.332, Appendix H) in an arroyo bottom at the base of a volcanic neck (Cerro del Ojo de las Yeguas) also issues from the Mulatto. The source is actually four small seeps which have a combined yield of 0.13 lps (2.0 gpm). Interestingly, a developed spring located only about 245 m (800 ft) east, was dry each time it was visited during 1978 and 1979. The fourth spring is also undeveloped and occurs in an arroyo bottom in Cañon Salado (15N. 03W.20.133, Appendix H). Yield from this spring could not be measured because the source is several small seeps which flow into a deep pool. The arroyo is intermittent for a short distance below the spring, but surface flow is quickly lost by seepage and evapotranspiration.

The Satan Tongue and "Lower" Mancos Shale in this area are considered to have low water-resource potential. Only one spring in each of these units was located and inventoried; no wells are known to be completed in either unit. Ojo Frio (16N.04W.26.213, Appendix H; Fig. 34-C, p.107) is known to have its source in the Satan Tongue. It occurs at the base of a volcanic neck (Cérro del Ojo Frio). The BLM has developed the spring by constructing an enclosed catchment/storage structure which feeds a small stock tank below by gravity. Yield to the tank is 0.064 lps (1.0 gpm). This spring seemed to be a reliable source of stock water. Guadalupe Springs, located west of Guadalupe (Appendix H; Plate 1), has its apparent source in the "Lower" Mancos Shale. This spring is not developed and occurs in an arroyo bottom (Guadalupe Cañon), which is intermittent for a short distance below the spring. Estimated yield from the spring is 0.064 lps (1.0 gpm) or less, but the discharge seems to be constant.

Water Quality

Quality of water from the Mulatto Tongue is variable, ranging from fresh to moderately saline. Specific conductances of water from wells are 2,000 μmhos/cm for the pumping well and 3,500 μmhos/cm for the abandoned well. Dissolved-solids contents are 1,770 and 4,195, respectively.

Specific conductances of waters from springs range from 800 - 3,000 µmhos/cm; dissolved-solids contents range from 740 - 3,105 ppm (Appendix I). Five of the waters from the Mulatto Tongue plot in the sodium-sulfate field and one plots in the sodium-bicarbonate field (Fig. 23).

Water from Ojo Frio, the developed spring in the Satan Tongue, has a specific conductance of 560 µmhos/cm and a dissolved-solids content of 328 ppm. The water plots in the sodium-bicarbonate field (Fig. 23). The water from Guadalupe Springs, in the "Lower" Mancos, has a specific conductance of 4,000 µmhos/cm, a dissolved-solids content of 4,270 ppm, and plots in the sodium-sulfate field (Fig. 23).

GALLUP SANDSTONE (CRETACEOUS)

Geologic Characteristics

The main body of the Gallup Sandstone crops out in the southern half of the area along the Rio Puerco and its tributaries (Plate 1). The Gallup forms resistant escarpments and commonly weathers with a rounded, "beehive" appearance. Maximum thickness of the unit in this area is about 20 m (60 ft); surface exposures may vary locally in thickness. The Gallup Sandstone conformably overlies the "Lower" Mancos Shale and is conformably overlain by the Mulatto Tongue of the Mancos Shale.

Molenaar (1974) has shown that the main body of the Gallup in this area consists of the Gallego Sandstone Member. This unit extends northward from the outcrop area for only a few kilometers to a line which roughly connects Star Lake, Chaco Canyon, and Shiprock, beyond which it is removed by pre-Niobrara erosion (Molenaar, 1973).

The Gallup Sandstone generally consists of very light gray to pinkish gray, medium- to thick-bedded, very fine- to fine-grained, locally cross-bedded, bioturbated sandstones (section SDC-5, Appendix A).

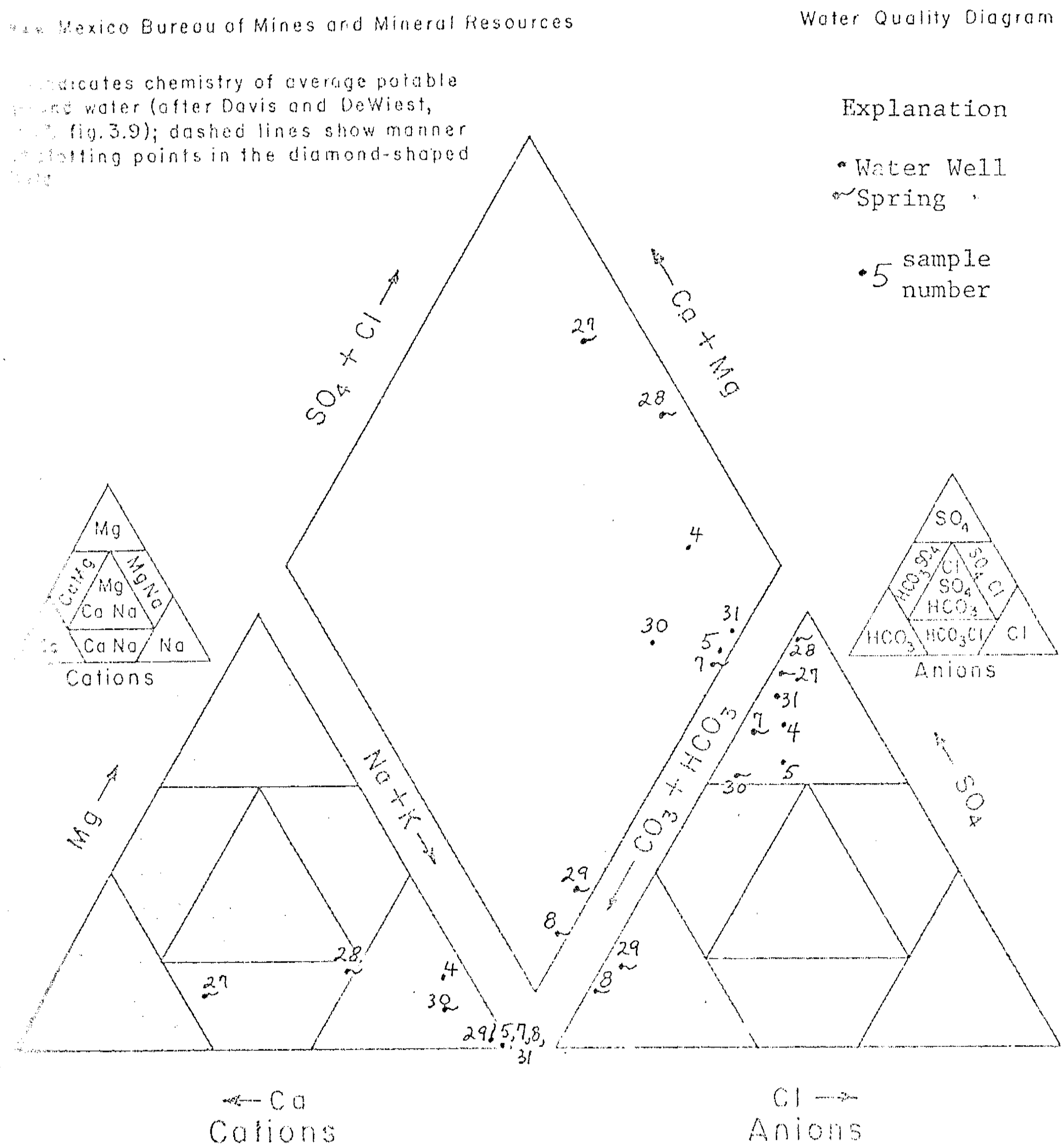


Figure 23. Trilinear plot of concentrations of major dissolved solids in well and springs waters from the Mancos Shale. Sample 8 = Satan Tongue; 28 = "Lower" Mancos; 5 = Dakota Sandstone; all others = Mulatto Tongue (see Appendix J; Plate 3).

Textural analyses of three samples from the Gallup showed that sorting is poor to moderate, and modal grain size ranges from very fine to fine sand. Clay-plus-silt content ranges from 3 - 30 percent, very fine-plus-fine-sand content from 75 - 94 percent, and medium-plus-coarse-sand content from 0 - 17 percent (samples SDC-5-1A, SDC-5-1B, and SDC-5-1C, Appendix C). Mineralogic analyses of these same samples showed that framework varies from 64 - 87 percent (58 - 69 percent quartz, 25 - 38 percent feldspar plus granitic rock fragments, and 4 - 6 percent chert plus other rock fragments). Cement ranges from 2 - 34 percent (usually calcite), matrix from 2 - 6 percent, and porosity from 0 - 8 percent. All three samples plotted in the arkose field (Appendix B).

The Gallup Sandstone in this area is a regressive shoreline deposit (Molenaar, 1974). Associated with the Gallup here is a zone of locally discontinuous sandstone bodies or limy, silty intervals up to about 6 m (20 ft) thick. These zones occur about 20 m (60 ft) or more stratigraphically above the top of the Gallup (section SDC-5, Appendix A; Fig. 5-A, p. 19). The sandstone bodies are commonly medium to coarse grained and bioturbated. The limy, silty intervals consist of thin-bedded siltstones and shales, and discontinuous, wedge-shaped, fine-grained silty sandstones up to about 3 m (10 ft) thick. Molenaar (1974) suggested that these zones may be associated with offshore bars. Stone and Mizell (1978) recognized a resistive zone on electric logs at the same horizon which extends at least to the Colorado border in the northeastern part of the San Juan Basin. They interpretted this zone to be a limy or a silty interval. Field observation of these intervals confirms their interpretations.

Hydrologic Characteristics

One flowing well (16N.04W.36.232, Appendix H; Fig. 34-D, p. 107) is known to produce water from the Gallup Sandstone. This well was drilled in 1971 by Homestake Partners and was converted to a water well by the BLM. Total depth is reportedly 184 m (602 ft). The initial flow was 25 lps (400 gpm) at a pressure of 655 kN/m^2 (95 psi). Flow is now regulated by valves at about 13 lps (200 gpm) at a pressure of 448 kN/m^2 (65 psi). A private company determined, by flow meter, that 75 percent of the flow comes from an interval lying between the depths of 142.7 and 143 m (468 and 469 ft). The remaining 25 percent of the flow comes from an interval lying between the depths of 125 and 128 m (410 and 420 ft).

Another flowing well located west of the study area, in SW¼, Sec19, T16N, R5W, reportedly taps the Gallup Sandstone. This well is a converted oil well drilled in 1962 to a total depth of 381 m (1,251 ft). Flow is reportedly 7.7 lps (120 gpm; USGS, WRD, Albuquerque). No other data are available and the well was not visited.

Water in the Gallup Sandstone in this area is under artesian pressure, often great enough to cause flow. Leakage of water from the Gallup into the overlying Mulatto Tongue of the Mancos Shale probably occurs; leakage of water from the "Lower" Mancos into the Gallup also probably occurs.

Ojo del Padre (15N.03W.09.444, Appendix H), a spring located in Guadalupe, has its source in the Gallup Sandstone. This spring is developed for both stock and domestic uses. Although yield from the spring is small, measured at 0.064 lps (1.0 gpm), it is constant and reliable according to the sole resident of Guadalupe (Luciano Sanchez, personal communication, 1979).

Water Quality

Water analyzed from the Gallup Sandstone is fresh. Water from the

BLM flowing well has a specific conductance of 580 µmhos/cm and a total-dissolved-solids content of 390 ppm. Water from Ojo del Padre has a specific conductance of 600 µmhos/cm and a dissolved-solids content of 626 ppm. Both of these waters plot in the sodium-bicarbonate field on the Piper diagram (Fig. 24). The concentrations of major dissolved ions are given in Appendix I.

Water from the flowing well west of the study area reportedly had a specific conductance of 3,130 µmhos/cm in 1962. No chemical analysis was available, but a strong hydrogen sulfide odor was reported (USGS, WRD, Albuquerque).

WESTWATER CANYON SANDSTONE MEMBER, MORRISON FORMATION (JURASSIC)

Geologic Characteristics

The Morrison Formation is not exposed in the study area, but is exposed several kilometers to the east along the western flank of the Sierra Nacimiento, and to the southeast near San Ysidro. The Morrison is unconformably overlain by the Dakota Sandstone of Cretaceous age. The Morrison is generally divided into three members in the southern part of the San Juan Basin. In descending order these are the Brushy Basin Shale, Westwater Canyon, and Recapture Shale Members. The Westwater Canyon is hydrologically the most important unit and is the only one discussed.

Shomaker and Stone (1976) summarized the lithologic characteristics of the Westwater Canyon as light gray to pale yellowish-brown, fine- to coarse-grained sandstone. Analyses of five thin sections show that the Westwater Canyon plots in the arkose or lithic arkose fields (Stone, 1979b, samples SJR-18, SJR-19, SJR-20, SJR-30, and IA-12(6), Table 2, p. 15). Shomaker and Stone (1976) reported that thickness ranges from about 9 - 92 m (30 - 300 ft), with an average of 50 m (165 ft). Thickness of the

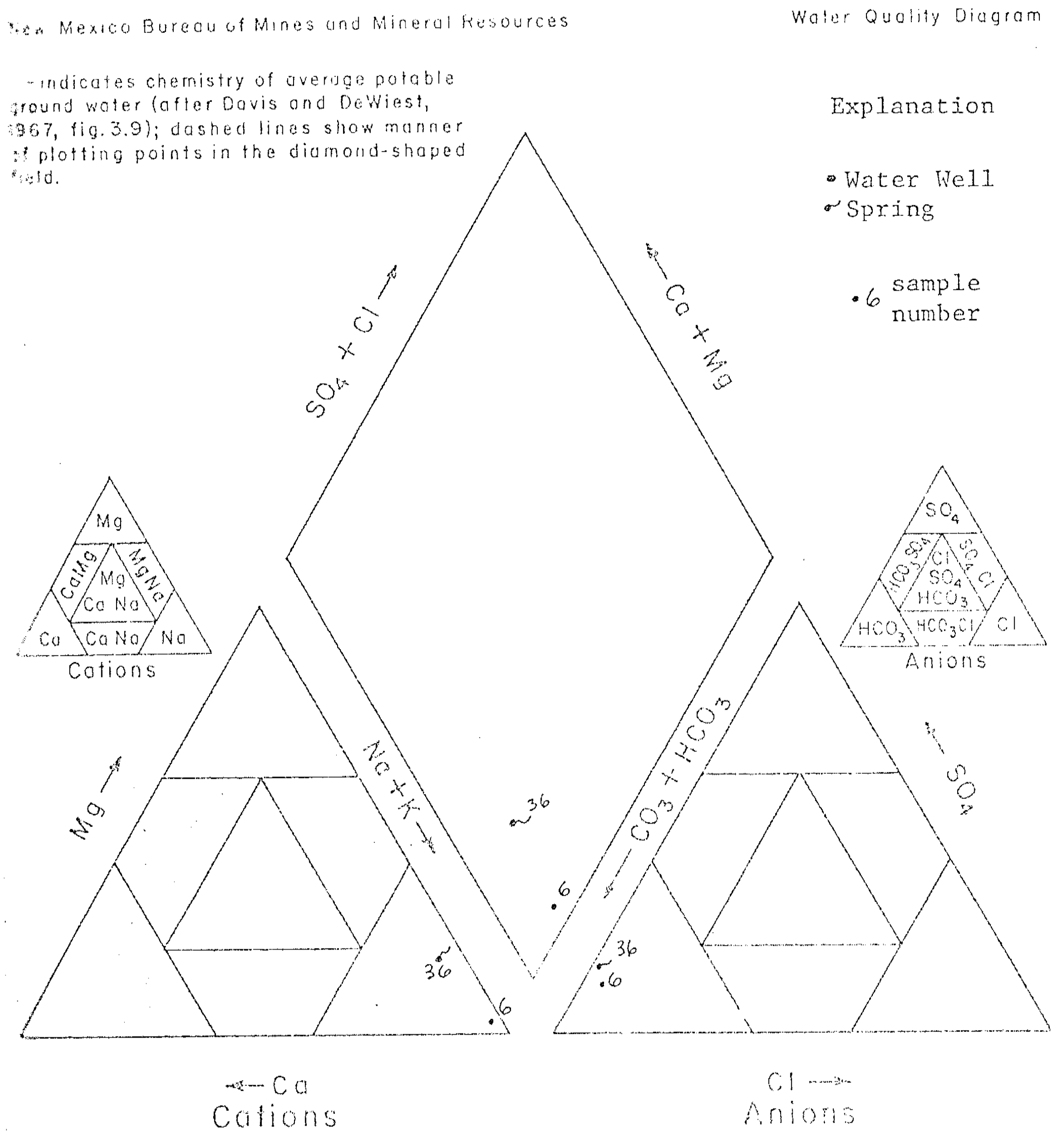


Figure 24. Trilinear plot of concentrations of major dissolved solids in waters from the Gallup Sandstone (see Appendix J; Plate 3).

Westwater Canyon in the study area is probably no more than 46 m (150 ft). Maximum depth to the unit is about 1,100 m (3,600 ft; Plate 2).

Hydrologic Characteristics

No wells in the study area are known to produce water from the Westwater Canyon Member. Shomaker and Stone (1976) summarized results of two aquifer tests performed on the unit in the vicinity of Crownpoint, New Mexico. They reported yields of 14.2 and 20.7 lps (221 and 323 gpm) with drawdowns of 59.9 and 61.3 m (195 and 201 ft) from static water levels of 106.8 and 117.4 m (350 and 385 ft). Specific capacities were 0.23 and 0.34 lps/m (1.1 and 1.6 gpm/ft). Transmissivities computed from the tests were 25 and 28 m^2/d (270 and 310 ft^2/d), respectively.

Water in wells tapping the Morrison Formation in this area will not only be under artesian pressure, but may flow. Subsurface leakage into the overlying Brushy Basin Shale Member probably occurs from the Westwater Canyon, and leakage from the underlying Recapture Shale Member probably occurs into the Westwater Canyon Member.

Water Quality

Water-quality data from the Morrison Formation in this part of the San Juan Basin are sparse, but Shomaker and Stone (1976) reported that water from the Westwater Canyon is generally fresh in the vicinity of Crownpoint. The total-dissolved-solids content for water from a well in Sec20, T17N, R12W was reportedly 447 ppm, and included 250 ppm bicarbonate, 48 ppm sulfate, and 119 ppm sodium. Water from this aquifer may be more saline in the study area, however, because of increased distance from outcrop and because of leakage from adjacent units containing poorer quality water.

MINOR POTENTIAL AQUIFERS

Minor potential aquifers are those geologic units for data are too sparse to evaluate their aquifer potential, and which, for various reasons, have limited water-resource potential in the area. In descending order these include alluvial deposits, basaltic rocks (especially lava flows), the Cliff House Sandstone, Hosta Tongue of the Point Lookout Sandstone, and the Dakota Sandstone.

ALLUVIUM (QUATERNARY)

Geologic Characteristics

Alluvium in the Chico Arroyo/Torreon Wash area occurs mainly in the banks adjacent to and in the channels of streams (Fig. 6, p. 21; Plate 1). At least two ages of alluvium are present; older deposits that are now incised, and modern deposits of the floors of the incised channels. Many of the major streams also are incised into bedrock, commonly shale.

No textural analyses were performed on alluvial samples, but, based on visual examination, the deposits consist of light brown, clayey, silty, very fine- to medium-grained sand. Much of this material is probably locally derived from sandstone and shale outcrops in the area.

No reliable thickness data could be obtained, but drillers' logs were examined for reported thicknesses (USGS, WRD, Albuquerque). A drillers' log from a hole drilled in Torreon Wash in NE¼, Sec22, T18N, R4W, gave an approximate thickness of 24 m (80 ft) for alluvium. Another record from a well dug north of the study area in Sec20, T18N, R4W (Vincente Arroyo?) reported about 12 m (40 ft) of alluvium. Maximum thickness of the bank alluvium at the Chico Arroyo gaging station is 6 m (20 ft; Fig. 27, p. 82).

Hydrologic Characteristics

Water-level depths in wells completed in alluvium or suspected to be at least partially completed in alluvium range from 0.2 - 10.0 m (0.7 - 33.0 ft). Yields from these wells are low, with a maximum of 0.064 lps (1.0 gpm). The well in Torreon Wash was reportedly tested at a rate of 1.5 - 2.4 lps (23.0 - 38.0 gpm) for 6.75 hours, with 8.0 m (26.0 ft) of drawdown. No recovery data are available, but assuming an average discharge of 2.0 lps (30.5 gpm) during the test, specific capacity of the well would be 0.25 lps/m (1.2 gpm/ft).

No springs were located which are known to issue from alluvium.

Water Quality

Water from alluvium in the area is generally slightly to moderately saline. Three wells in the study area may be partially completed in alluvium, although the Cleary Coal Member of the Menefee Formation is probably the principal aquifer (17N.03W.18.242, 17N.04W.22.331, and 17N.04W.23.224, Appendix H). Specific conductances of water from these wells are 4,000, 1,200, and 8,000 μmhos/cm, respectively. Dissolved-solids contents are 4,185, 750, and 10,272 ppm (Appendix I). The waters plot in the sodium-sulfate, sodium-bicarbonate, and sodium-sulfate fields, respectively (Fig. 15, p. 42).

USGS, WRD files in Albuquerque were examined for other wells completed in alluvium in this area. Two wells north of the study area are reportedly completed in alluvium and the Menefee Formation. These wells are located along Torreon Wash in NW¼, Sec22, T18N, R4W, and SE¼, Sec23, T18N, R4W. Specific conductances of water from these wells are 3,680 and 8,280 μmhos/cm, respectively. The Cabezon well, located east of the study area along the Rio Puerco (SW¼, Sec6, T16N, R2W), is reportedly completed in alluvium and the "Lower" Mancos Shale. Specific conductance of water from this well is reportedly 7,050 μmhos/cm.

IGNEOUS ROCKS (TERTIARY)

Geologic Characteristics

Igneous rocks of basaltic composition (Hunt, 1936) occur mainly in the southern half of the area, where they overlie and intrude Upper Cretaceous strata. A thick sequence of sheet-like, columnar-jointed, locally scoriaceous volcanic flows caps Mesa Chivato (Fig. 5-B, p. 19; Plate 1). Several scatterred, dome-shaped volcanic centers dot the top of the mesa. These flows are ultimately related to the Mount Taylor volcanic complex southwest of the area. Maximum aggregate thickness of the flows is about 60 m (200 ft), but outcrops on top of the mesa are sparse because of burial by Recent eolian deposits.

Dikes intruding the Cretaceous strata usually follow the dominant northeast-trending fracture pattern in the area (Plate 1). The dikes are vertical, and are usually less than 0.3 m (1.0 ft) thick. They are commonly traceable in outcrop for distances of up to 0.8 km (0.5 mi).

Volcanic necks are especially common in the Rio Puerco valley, in the Guadalupe Quadrangle, where they reach heights of up to 300 m (1,000 ft; Fig. 5-A, p. 19; Frontispiece). The Cretaceous strata intruded by the necks remain essentially horizontal, with little or no obvious structural deformation or metamorphism. Small normal faults are associated with a few of these necks (Plate 1). The necks represent the conduits which fed former volcanoes. Johnson (1907) suggested that the volcanoes stood at about the same elevation as Mesa Chivato. He further suggested, as had Dutton (1885), that the flows capping Mesa Chivato were once connected with those capping Mesa Prieta, just east of the study area.

In hand specimen the basaltic rocks are usually very dense and hard, brownish black in color, and aphanitic in texture. Locally, scoriaceous materials are associated with the flows on Mesa Chivato.

Hydrologic Characteristics

Hydrologic characteristics of volcanic rocks could not be evaluated as no wells are known to produce water from these rocks in the area.

A few springs, however, are associated with volcanic features. For example, Barrel Spring (16N.04W.34.334, Appendix H) issues from the Allison Member of the Menefee Formation a short distance below the basalt flows on Mesa Chivato (Plate 1). Both Coal Spring and Ojo Azabache (16N.05W.15.412 and 16N.05W15.233, Appendix H) are associated with a single northeast-trending dike (Plate 1). These springs issue from the Cleary Coal Member of the Menefee at the contact with the dike. Ojo Frio and Ojo de Las Jaramillos (16N.04W.26.213 and 16N.03W.33.342, Appendix H) occur at the base of volcanic necks and issue from the Mancos Shale (Plate 1).

Water Quality

Quality of water from the flows on Mesa Chivato could not be evaluated, but would be expected to be good because the Mesa is a recharge area.

CLIFF HOUSE SANDSTONE (CRETACEOUS)

Geologic Characteristics

The Cliff House Sandstone crops out only in the extreme northwestern part of the study area on Chacra Mesa (Fig. 13-A, p. 38). In this area the Cliff House consists of light brown to dusky yellow, thick- to very thick-bedded, very fine- to fine-grained, locally cross-bedded, bioturbated sandstones. These sandstones commonly contain scatterred _Ophiomorpha_. Thickness of the Cliff House at Chacra Mesa is about 54 m (180 ft). Zones of light olive-gray shales and silty shales about 3 - 10 m (9 - 30 ft) thick are interbedded with the sandstones (section SDC-1, Appendix A). The contact between the Cliff House and the underlying Menefee Formation is conformable, but variable. At most localities the contact is sharp, but locally, it is transitional or intertonguing.

The Cliff House thins rapidly toward the north and northeast. In the vicinity of Torreon School it consists of two sandstone tongues separated by about 50 m (165 ft) of Lewis Shale. Tabet and Frost (1979) reported that the upper tongue at this locality is about 14 m (45 ft) thick, and that the lower tongue is about 8 m (25 ft) thick. A short distance northeast, where Highway 197 crosses the outcrop at Black Mountain (Sec11, T18N, R4W), these two tongues grade laterally into the Lewis Shale and can be observed to pinch out.

No samples from the Cliff House were analyzed, however, Hollenshead and Pritchard (1961) analyzed 19 core samples of this unit from scatterred wells in the San Juan Basin. They found that the average mineralogic composition of framework components was 80 percent quartz, 13 percent feldspar, and 7 percent rock fragments. This average composition would plot in the subarkose field. An outcrop sample analyzed by the author from SE¼, Sec13, T22N, R13W, also plotted in the subarkose field (Stone, 1979b, sample SJR-68, Table 2, p. 15).

Hydrologic Characteristics

Hydrologic characteristics of the Cliff House Sandstone could not be evaluated. Transmissivities, however, would probably be low, perhaps similar to those of the Point Lookout Sandstone (Appendix G). A well drilled north of the study area (SW¼, Sec23, T19N, R5W), was reportedly completed in the Cliff House (USGS, WRD, Albuquerque). Total depth of this well is 144 m (471 ft). In 1976, the water level was 53 m (175 ft), and the yield was 0.64 lps (10 gpm).

Shomaker and Stone (1976) reported that in the general area, specific capacities of wells completed in the Cliff House Sandstone are low, commonly less than 0.2 lps/m (1.0 gpm/ft). They also reported that well performance is variable because of varying thickness and character of the aquifer at different localities.

Water in the Cliff House would be expected to be confined. Leakage of water into the overlying Lewis Shale probably occurs; leakage of water from the underlying Menefee Formation into the Cliff House also probably occurs.

Water Quality

Quality of water from the Cliff House Sandstone could not be evaluated in the study area. Water from the well north of the study area had a specific conductance of 3,400 μmhos/cm in 1976. Shomaker and Stone (1976) reported that quality of water from the Cliff House is usually marginal. Reported specific conductances range from 1,500 - 5,000 μmhos/cm, and total-dissolved-solids contents range from 1,200 - 3,500 ppm. They further stated the waters contain high concentrations of sodium, potassium, bicarbonate, sulfate, and chloride.

Subsurface leakage of water from units containing poorer quality water would tend to decrease the quality of water from the Cliff House Sandstone.

HOSTA TONGUE OF THE POINT LOOKOUT SANDSTONE (CRETACEOUS)

Geologic Characteristics

The Hosta Tongue crops out in the southwestern part of the area at the base of the slope around Mesa Chivato, and above the Rio Puerco and Chico Arroyo (Plate 1; Fig. 5-B, p. 19; Fig. 25). One stratigraphic

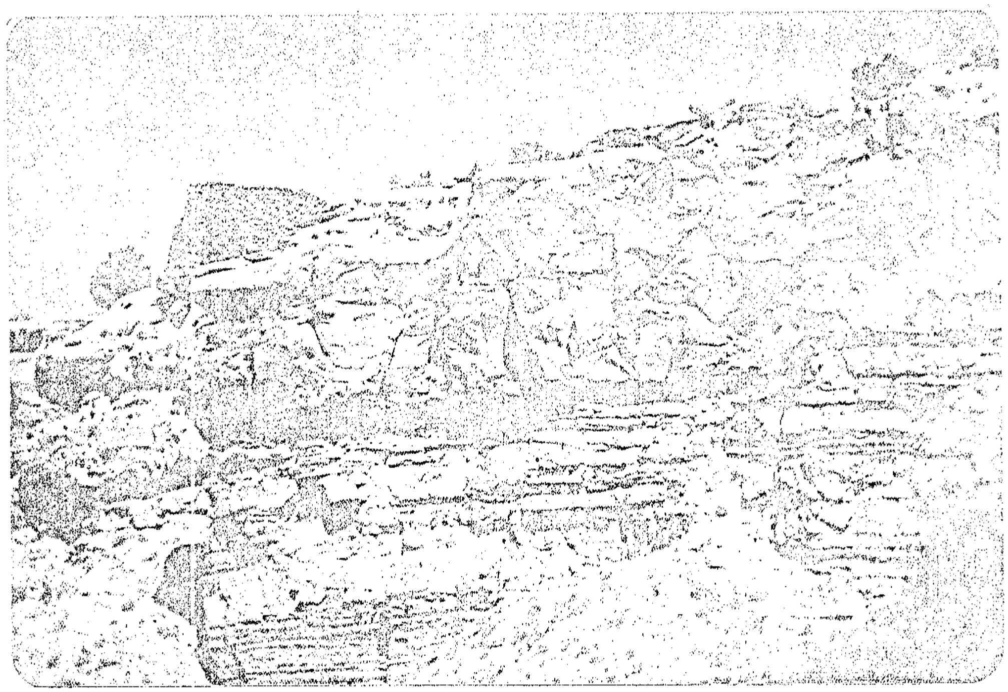


Figure 25. Typical exposure of the Hosta Tongue of the Point Lookout Sandstone in the southwestern part of the Guadalupe Quadrangle, on Banco de la Casa. The Hosta is roughly 60 m (200 ft) thick at this locality. Note the two-story ruin on top of the butte at left (view west from NW¼, Sec25, T15N, R4W).

section was measured through the Hosta Tongue (section SDC-2, Appendix A). At this locality it consists of yellowish gray, thick- to very thick-bedded, very fine- to fine-grained, locally cross-bedded, bioturbated sandstones. Locally, these sandstones contain Ophiomorpha and the clam Mactra. Thickness of the unit is about 29 m (95 ft) at this locality.

Textural analysis of a sample from this locality showed the rock to be poorly to moderately sorted, with a modal grain size of very fine sand. Clay-plus-silt content was 20 percent, very fine-plus-fine sand content was 79 percent, and medium-sand content was 1 percent (sample SDC-2-2, Appendix C). Mineralogic analysis of the same sample yielded 91 percent framework components (47 percent quartz, 35 percent feldspar plus granitic rock fragments, and 18 percent chert plus other rock fragments), 14 percent cement, 8 percent matrix, and 6 percent porosity. The rock plotted in the lithic arkose field (Appendix B).

The Hosta Tongue is an interesting stratigraphic unit in that it is separated from the main body of the Point Lookout Sandstone by the Satan Tongue of the Mancos Shale (Plate 2). The Hosta undergoes rapid changes in thickness from south to north in the Guadalupe Quadrangle. In the extreme southwestern part of the quadrangle, it is roughly 60 m (200 ft) thick at Bancos de la Casa (Fig. 25; Plate 1). Hunt (1936) mapped the Crevasse Canyon Formation directly underlying the Hosta at this locality and for about 5 km (3 mi) farther north. Wyant and Olson (1978) mapped the Gallup Sandstone at this locality, in exactly the same position as that where Hunt (1936) had mapped the Crevasse Canyon Formation. Lateral tracing of surface exposures revealed that the Hosta Tongue thickens southward, and no evidence of either the Crevasse Canyon Formation or Gallup Sandstone could be found. From Banco de la Casa, the Hosta thins rapidly northward for about 13 km (8 mi), until, in the vicinity of Cerro Cuate (Plate 1), it consists of only a zone of interbedded sandstone and shale. The total combined thickness of this sandstone/shale interval is only about 15 m (50 ft). As noted by Hunt (1936), this zone can be traced northeastward in outcrop for several kilometers. Electric logs show that this zone continues northward to the vicinity of Chacra Mesa, where it grades laterally into the Mancos Shale (Plate 2).

Maximum depth to the Hosta Tongue, beneath Mesa Chivato, is roughly between 400 and 460 m (1,300 and 1,500 ft).

Hydrologic Characteristics

No wells in the general area are known to produce water from the Hosta Tongue, and no springs were observed issuing from the unit. Hydrologically, however, the Hosta would probably be a leaky, confined unit. Low values of transmissivity and specific capacity, along with small yields, would be expected.

Water Quality

Quality of water from the Hosta Tongue could not be evaluated, but would probably be similar to that of the main body of the Point Lookout Sandstone (Appendix I).

DAKOTA SANDSTONE (CRETACEOUS)

Geologic Characteristics

The Dakota Sandstone is not exposed in the study area, but its geologic characteristics in the region have been well documented (Owen, 1973; Landis and others, 1973; Molenaar, 1977). East of the area, along the western flanks of the Sierra Nacimiento, and southeast of the area, near San Ysidro, the Dakota Sandstone consists of three distinct members on the basis of lithology: a yellow brown, fine-grained, ledge-forming sandstone at the top; a shale and carbonaceous shale unit in the middle; and a light gray, conglomeratic, ledge-forming sandstone at the base. Examination of electric logs from oil wells in the study area reveals that this three-member subdivision is also valid in the subsurface (Plate 2; Appendix K). Thickness of the upper sandstone unit ranges from about 9 - 12 m (30 - 40 ft), that of the middle shale unit from about 9 - 18 m (30 - 60 ft), and that of the lower sandstone unit from about 9 - 15 m (30 - 50 ft). The approximate total thickness of the Dakota Sandstone in the study area is 43 - 46 m (140 - 150 ft). Depth to the unit should reach a maximum of about 900 m (3,000 ft) in the northeast part of the area.

Mineralogic analysis of an outcrop sample from SE¼, Sec36, T21N, R1W by the author revealed 89 percent framework components (78 percent quartz, 19 percent feldspar plus granitic rock fragments, and 3 percent chert plus other rock fragments), 6 percent cement, 3 percent matrix, and 2 percent porosity. It plotted in the subarkose field (Stone, 1979b, sample SJR-2, Table 2, p. 15). Grain size ranged from very fine to medium sand, and the modal grain size was fine sand. Another outcrop sample, from SE¼, Sec14, T13N, R10W, consisted of 84 percent framework (57 percent quartz, 42 percent feldspar plus granitic rock fragments, and 1 percent chert plus other rock fragments), 4 percent cement, 6 percent matrix, and 6 percent porosity. The rock was fine to medium grained, well sorted, and the modal grain size was fine sand. It plotted in the arkose field (Stone, 1979b, sample 1A-16, Table 2, p. 15). Textural analysis of a different sample from the same locality as that of the above, consisted of 14 percent clay and silt, 80 percent very fine and fine sand, and 6 percent medium and coarse sand. Modal grain size was fine sand (Stone, 1979b, sample BB-6, Table 1, p. 10).

Hydrologic Characteristics

One flowing well (16N.03W.17.333, Appendix H) in the study area, a converted oil well drilled in 1959, is known to produce water from the Dakota Sandstone. Total reported depth of this well is 561 m (1,840 ft). The top of the Dakota was penetrated at about 544 m (1,785 ft). Flow from the well is regulated by valves on the casing, and is directed into an earthen stock tank (Fig. 34-E, p.107). Flow was estimated at 0.3 - 0.6 lps (5 - 10 gpm). Interestingly, Renick (1931) predicted the Dakota would occur at a depth of about 458 - 519 m (1,500 - 1,700 ft) at this same locality, and that the water would be under sufficient artesian pressure to flow. Another converted oil well, located north of the study area in Sec14, T19N, R3W, is reportedly completed in the Dakota at a depth of more than 1,220 m (4,000 ft). No other completion data exist, and the well was not visited.

Water in the Dakota Sandstone in this area will not only be under artesian pressure, but will probably flow. Leakage of water into the overlying Mancos Shale probably occurs, and leakage of water from the underlying Morrison Formation into the Dakota also probably occurs. Shomaker and Stone (1976) reported that transmissivities are very low for the Dakota in this area. Specific capacities are also low, estimated at 0.01 - 0.04 lps/m (0.05 - 0.20 gpm/ft).

Water Quality

Water from the Dakota Sandstone in this area is slightly to moderately saline. Water from the flowing well in the study area has a specific conductance of 2,500 μmhos/cm, and a dissolved-solids content of 1,885 ppm (Appendix I). Water from this well plots in the sodium-sulfate field on the Piper diagram (Fig. 23, p. 60). A strong hydrogen sulfide odor was noted when the water was sampled. Water from the flowing well north of the study area has a specific conductance of 10,100 μmhos/cm (USGS, WRD, Albuquerque). Shomaker and Stone (1976) reported that east of R10W, the total-dissolved-solids content ranges from 2,611 to 59,259 ppm, and that the waters are high in sodium and bicarbonate.

ANALYSIS OF WATER BALANCE IN CHICO ARROYO

Chico Arroyo drains an area of about 3,550 km^2 (1,370 mi^2) in the southern and southeastern San Juan Basin. The drainage basin is roughly elliptical and elongated in a northeasterly direction (Fig. 26). Inasmuch as the study area lies within the southeastern ground-water discharge area for San Juan Basin aquifers, an attempt was made to quantify relationships between ground-water and surface-water discharge. Although this attempt met with only limited success, several useful things were investigated:

1) the relationship between average annual basin precipitation and annual runoff was quantified;
2) sources of sustained flows were identified; and
3) possible sources of water loss in the basin were examined.

PRECIPITATION

Rainfall data for the drainage basin of Chico Arroyo were obtained from two major sources; the US Weather Service in Albuquerque, and the US Bureau of Reclamation Precipitation Map for New Mexico, 1972.

Records from two weather stations in the basin were used to examine the seasonal distribution of precipitation. Rainfall totals from the Torreon Navajo Mission and Star Lake weather stations show that most of the annual rainfall occurs during the summer rainy season, usually from July through September (less commonly from June through October). During this period, as much as 75 percent of the annual precipitation may occur. Most of this rainfall is probably in the form of intense, convective afternoon thunderstorms (Table 2, p. 17).

Average annual precipitation for the drainage basin was determined by the isohyetal method (Gray, 1970; Linsley and others, 1975) to be 29.2 cm (11.5 inches). Isohyets were transferred from the US Bureau of Reclamation

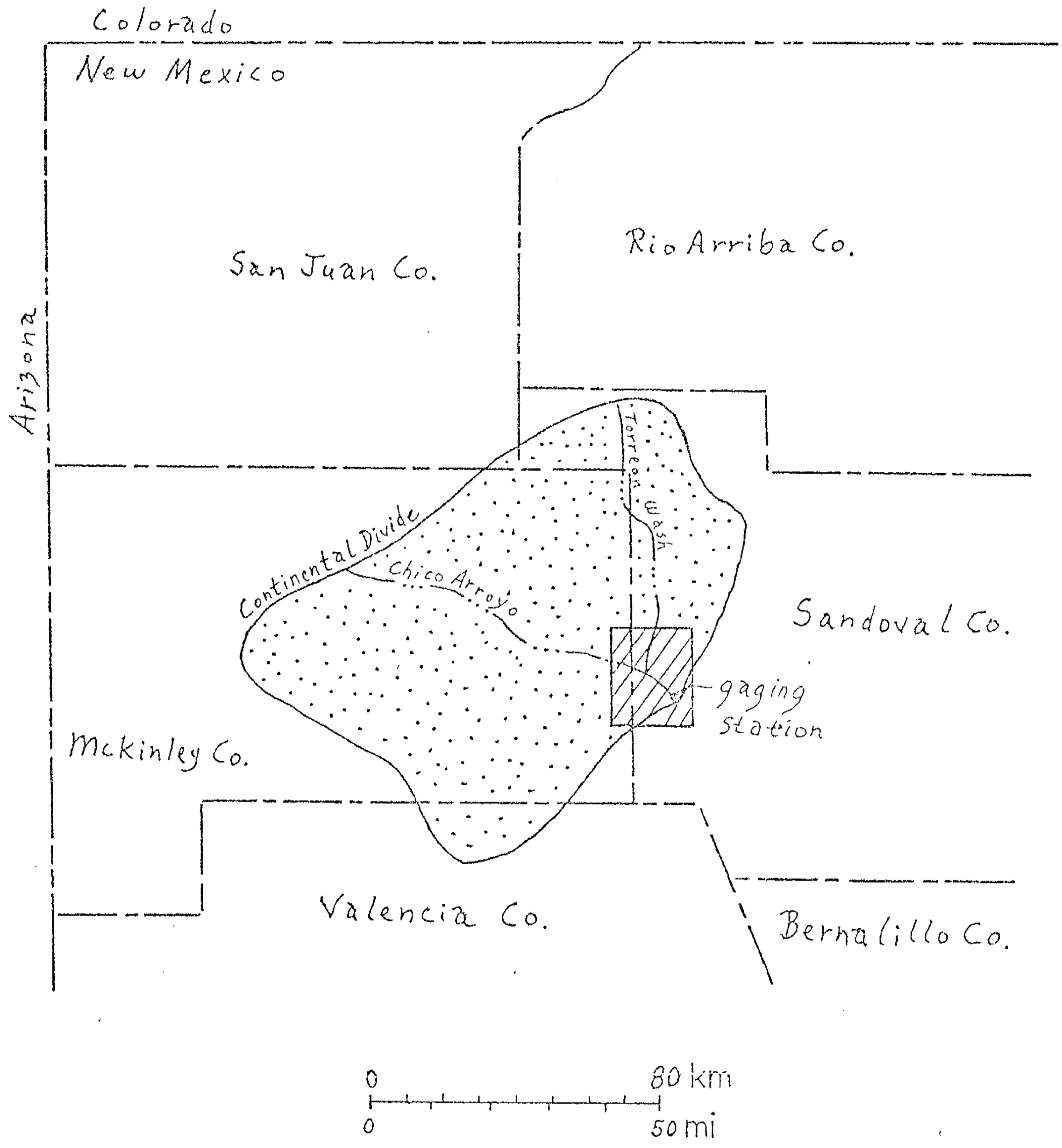


Figure 26. Drainage basin of Chico Arroyo (stippled) and relationship to thesis area (cross-hatched).

Precipitation Map for New Mexico (1972).

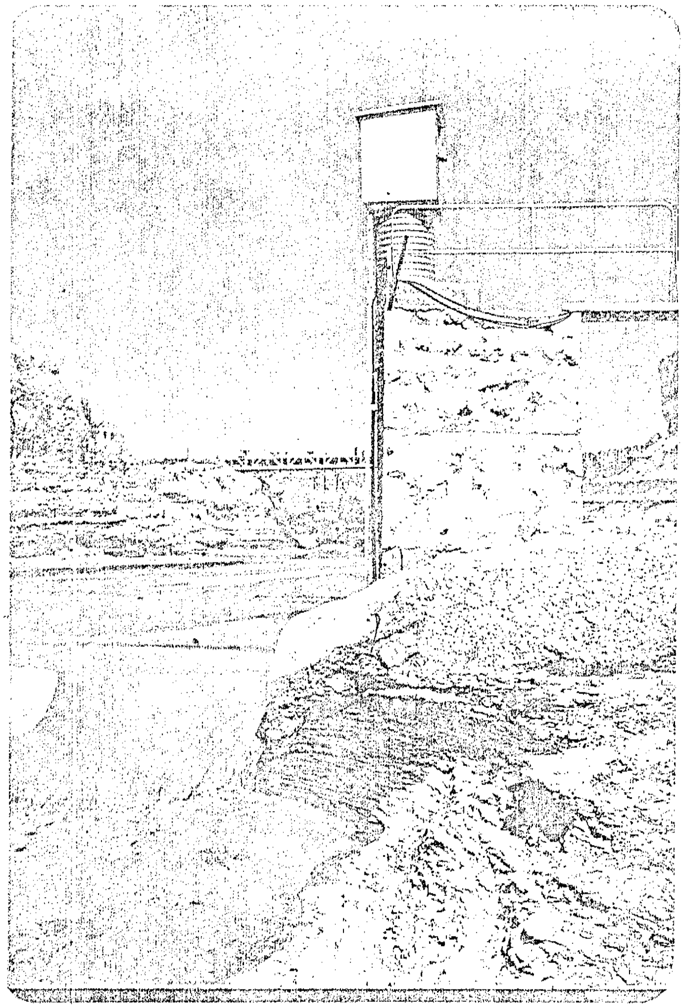
RUNOFF

All discharge records were obtained from the USGS, WRD, Albuquerque, surface-water files.

Discharge has been measured at the mouth of Chico Arroyo for 35 years, with an average annual discharge for this period of 220 m^3/s (7,770 ft^3/s). Several years ago, a continuous-recording stream gage was installed at the mouth of the stream, 0.3 km (0.2 mi) upstream from the junction with the Rio Puerco (Fig. 26, p. 79; Fig. 27).

Runoff occurs in the Chico Arroyo drainage basin at many times throughout a given year, but volumes vary enormously, depending mainly on season. This strong seasonal control on runoff is shown graphically on the monthly discharge hydrograph (Plate 4). Peaks commonly occur during the summer and early autumn months, which coincide with the summer rainy season from July through September. During this period, afternoon thunderstorms may generate tremendous volumes of runoff. Comparison of rainfall data with discharge data for the summer rainy season shows that up to 99 percent of the annual discharge recorded at the gage may occur during this period (Table 4).

Other seasonal variations in discharge are also apparent from examination of Plate 4. For example, the period from October through November is generally one of decreasing monthly flow, recording the drier autumn season. December through March is commonly a period of increasing flow; most likely the result of seasonal change in rainfall patterns from the drier autumn season to the frontal storm systems of winter. Toward the end of this period, snowmelt from the Mount Taylor area also probably contributes to flow. The period from April through June is usually one of decreasing runoff. This decrease is probably related to the combination



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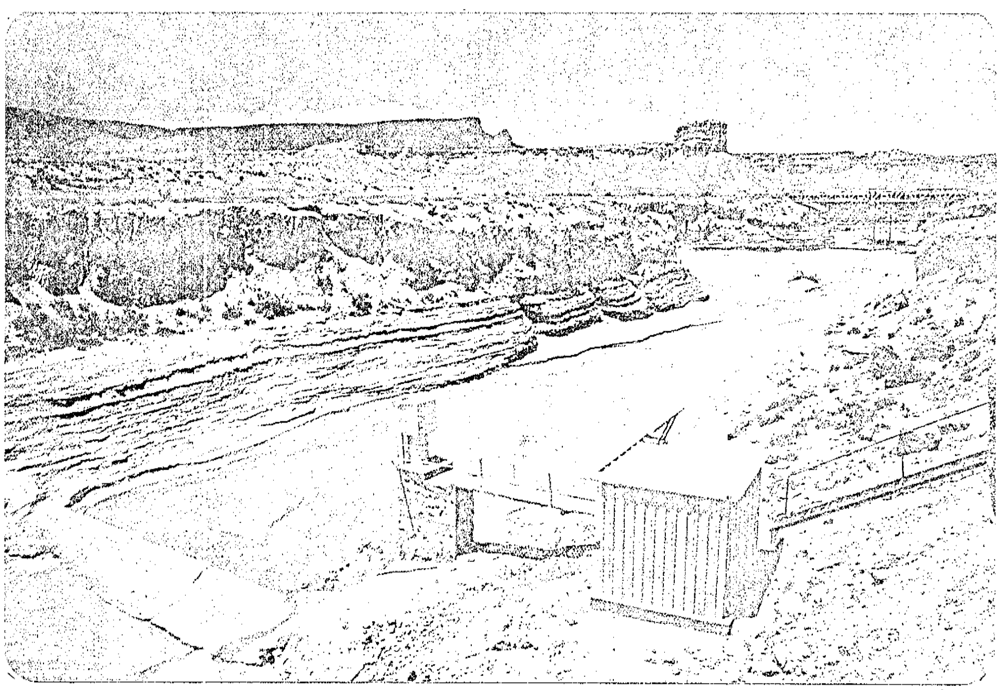


B

Table 4. Comparison of seasonal distribution of precipitation at Torreon Mission station and observed runoff at Chico Arroyo gage for the water years 1966 - 1978 (from U. S. Weather Service annual reports and USGS, WRD Albuquerque surface-water files).

Water Year	Precipitation at Torreon Mission Annual cm	(inches)	July - Sept cm	(inches)	Percentages of Annual[1] July - Sept	June	Oct	Discharge at Chico Gage Annual m^3/s	(ft^3/s)	July - Sept m^3/s	(ft^3/s)	Percentages of Annual[2] July - Sept	June	Oct
1966	23.67	(9.32)	11.05	(4.35)	46.7	23.5	4.3	213	(7,517)	151	(5,355)	71.2	15.8	0.0
1967	19.51	(7.68)	14.66	(5.77)	75.1	7.9	0.3	496	(17,522)	488	(17,263)	98.5	1.0	0.3
1968	23.57	(9.28)	9.37	(3.69)	39.8	2.5	3.2	164	(5,805)	162	(5,723)	98.6	0.0	0.3
1969	26.85	(10.57)	12.27	(4.83)	45.7	7.7	4.2	116	(4,115)	98	(3,470)	84.3	1.8	5.3
1970	28.22	(11.11)	11.76	(4.63)	41.7	5.4	27.3	200	(7,052)	76	(2,691)	38.3	0.1	57.6
1971	20.60	(8.11)	12.37	(4.87)	60.0	0.0	5.9	108	(3,825)	105	(3,722)	97.2	0.0	1.0
1972	27.38	(10.78)	19.94	(7.85)	72.8	3.7	8.4	235	(8,317)	215	(7,616)	91.6	0.0	5.2
1973	38.18	(15.03)	10.77	(4.24)	28.2	2.3	20.6	260	(9,177)	69	(2,425)	26.4	0.2	0.0
1974	18.87	(7.43)	9.23	(3.79)	51.0	1.3	3.1	43	(1,525)	40	(1,403)	92.0	0.0	0.1
1975	33.96	(13.37)	14.33	(5.64)	42.2	1.0	26.9	188	(6,641)	118	(4,157)	62.0	0.0	22.6
1976	14.71	(5.79)	6.27	(2.47)	42.7	0.0	0.0	92	(3,261)	91	(3,223)	98.9	0.0	0.0
1977	29.39	(11.57)	18.06	(7.11)	61.4	0.0	2.5	109	(3,845)	103	(3,624)	94.2	0.1	0.0
1978	29.35	(11.56)	5.54	(2.18)	18.9	8.3	7.9	39	(1,370)	3	(99)	7.2	2.2	5.3
Mean	25.71	(10.12)	11.97	(4.72)	45.0	4.9	8.8	175	(6,151)	114	(4,675)	73.9	1.6	7.5

[1] Water Year 1978: 17.5 percent of precipitation occurred in May; 23.7 percent in November.

[2] Water Year 1973: 5.5 percent of annual discharge occurred in February; 21.6 percent in March; 24.5 percent in April.
Water Year 1978: 34.5 percent of annual discharge occurred in March; 26.6 percent in May; 18.4 percent in November.

of depletion of flow from snowmelt and a seasonal change in rainfall patterns, reflecting a drier spring period.

The effects of individual storms or storm systems on hydrograph shape can be seen on hydrographs constructed for various time intervals. For example, Figure 28 shows the daily discharge at the gage from September 29 through October 16, 1966. Two storm recessions are well shown on the graph: the first storm probably occurred late September 30, with a peak runoff of 0.004 m^3/s (36 ft^3/s) on October 1; the second storm probably occurred late on October 7, with a peak runoff of 0.0006 m^3/s (5.2 ft^3/s) on October 8. Figure 29 shows the mean weekly discharge from July 16 through October 5, 1976. Effects of the summer rainy season on hydrograph shape are well shown on this graph. Three peaks and recessions are apparent. The steeply rising and falling limbs are conspicuous and represent the input from various storms in the drainage basin. The falling limbs rapidly approach zero discharge before the rise resulting from the next storm occurs.

In order to determine a quantitative relationship between average annual basin precipitation and annual runoff, theoretical volumes of runoff were computed (based on various percentages of the average basin precipitation). These values were then compared to actual recorded volumes at the gaging station. Using the value of 29.2 cm (11.5 inches) for average basin precipitation, runoff volumes were computed for 0.5, 1.0, 1.5, 2.0, 3.0, and 4.0 percent (Table 5). The 35-year average discharge of 220 m^3/s (7,770 ft^3/s) represents 1.86 percent of the average annual precipitation recieved in the basin. Runoff for the water years 1966 - 1978 (a water year is defined as the period from October 1 of a given year through September 30 of the following year) ranges from 0.32 - 4.1 percent of the average annual precipitation. The average runoff for this 13-year period

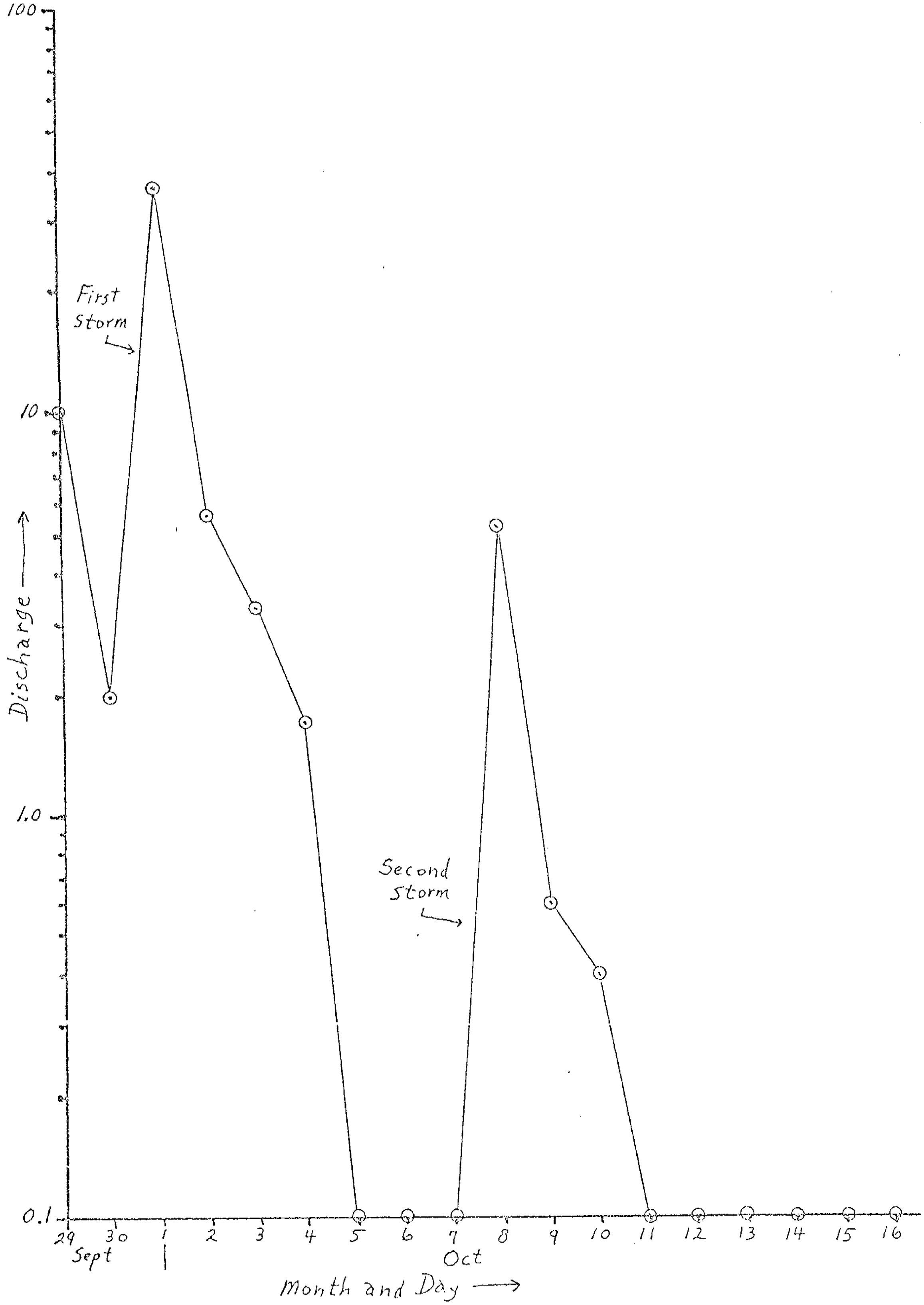


Figure 28. Daily discharge (ft^3/s) at Chico Arroyo gage from September 29 through October 16, 1966.

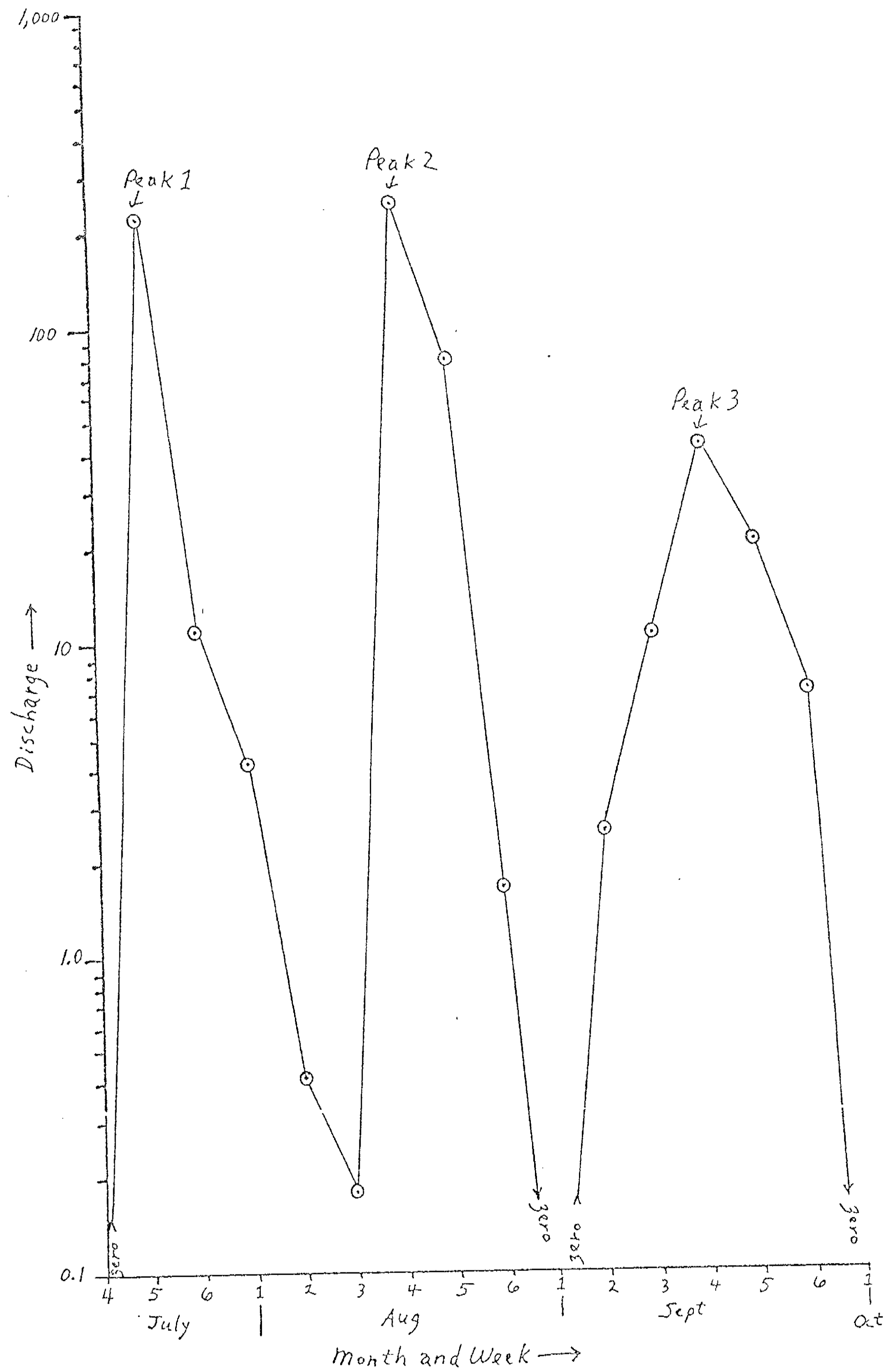


Figure 29. Mean weekly discharge (ft^3/s) at Chico gage from July 16 through October 5, 1976.

Table 5. Annual precipitation at Star Lake and Torreon Mission stations, observed runoff at Chico Arroyo gage, and corresponding runoff percentage (based on average annual drainage basin precipitation) for the water years 1966 - 1978 (from U. S. Weather Service annual reports and USGS, WRD Albuquerque, surface-water files).

Water Year	Annual Precipitation Star Lake cm	(inches)	Torreon Mission cm	(inches)	Annual Runoff Chico Gage m^3/s	(ft^3/s)	Corresponding Runoff Percentage (based on average annual drainage basin precipitation of 29.2 cm (11.5 inches))[1]
1966	22.45	(8.84)	23.67	(9.32)	213	(7,517)	1.80
1967	19.61	(7.72)	19.51	(7.68)	496	(17,522)	4.10
1968	24.87	(9.79)	23.57	(9.28)	164	(5,805)	1.40
1969	25.63	(10.09)	26.85	(10.57)	116	(4,115)	1.00
1970	25.25	(9.94)	28.22	(11.11)	200	(7,052)	1.65
1971	19.05	(7.50)	20.60	(8.11)	108	(3,825)	0.90
1972	16.43	(6.47)	27.38	(10.78)	235	(8,317)	2.00
1973	28.73	(11.31)	38.18	(15.03)	260	(9,177)	2.15
1974	11.71	(4.61)	18.87	(7.43)	43	(1,525)	0.35
1975	29.57	(11.64)	33.96	(13.37)	188	(6,641)	1.55
1976	12.14	(4.78)	14.71	(5.79)	92	(3,261)	0.75
1977	17.35	(6.83)	29.39	(11.57)	109	(3,845)	0.90
1978	24.59	(9.68)	29.36	(11.56)	39	(1,370)	0.32
Mean[2]	21.34	(8.40)	25.71	(10.12)	175	(6,151)	1.45

[1] Percentages

Percentages	m^3/s	(ft^3/s)
0.5	60	(2,114)
1.0	120	(4,229)
1.5	180	(6,325)
2.0	240	(8,460)
3.0	360	(12,680)
4.0	480	(16,910)

[2] 35-year average annual discharge = 220 m^3/s (7,780 ft^3/s), or 1.86 percent of average annual basin precipitation

is 175 m^3/s (6,151 ft^3/s) and represents 1.45 percent of the average annual basin precipitation. Figure 30 is a hydrograph showing the annual recorded discharge at the gaging station for the water years 1966 - 1978. Also shown on the graph are the 35-year average discharge and the average discharge for 1966 - 1978. By examination of the graph, years of relatively low or high discharge can be seen. Table 5 (p. 87) gives the basic annual discharge datafrom 1966 - 1978, along with corresponding percentages of the average basin precipitation the values represent. Also given in the table are annual precipitation totals for the Torreon Mission and Star Lake weather stations. Examination of the table reveals that years of relatively high runoff do not necessarily coincide with years of high rainfall. The major reason for this discrepancy is the time of year when most of the rainfall occurs, usually from July through September.

The low values of runoff are probably characteristics of semiarid drainage basins. In a previous study, Stone and Brown (1975) obtained runoff values of 2.3 - 7.7 percent of precipitation for individual storm/runoff events in a small, semiarid drainage basin covering 13 km^2 (5 mi^2). They concluded that the range of values reflected the influence of various parameters such as direction of storm movement, storm intensity/duration, and time since last storm (antecedent moisture conditions).

Chico Arroyo is an intermittent stream throughout a short reach from around Sec36, T17N, R5W to Sec9, T16N, R4W, a distance of about 6 km (4 mi). The source of intermittent flow is a combination of discharge from a spring located in the channel bottom (SE¼, SW¼, SW¼, Sec36, T17N, R5W; Plate 3), and input from various other springs in smaller, tributary arroyos (Plate 3). The intermittent flow in Chico Arroyo commonly does not reach the gaging station at the mouth of the stream. This was observed during the field seasons of 1978 and 1979, and is also apparent from examination

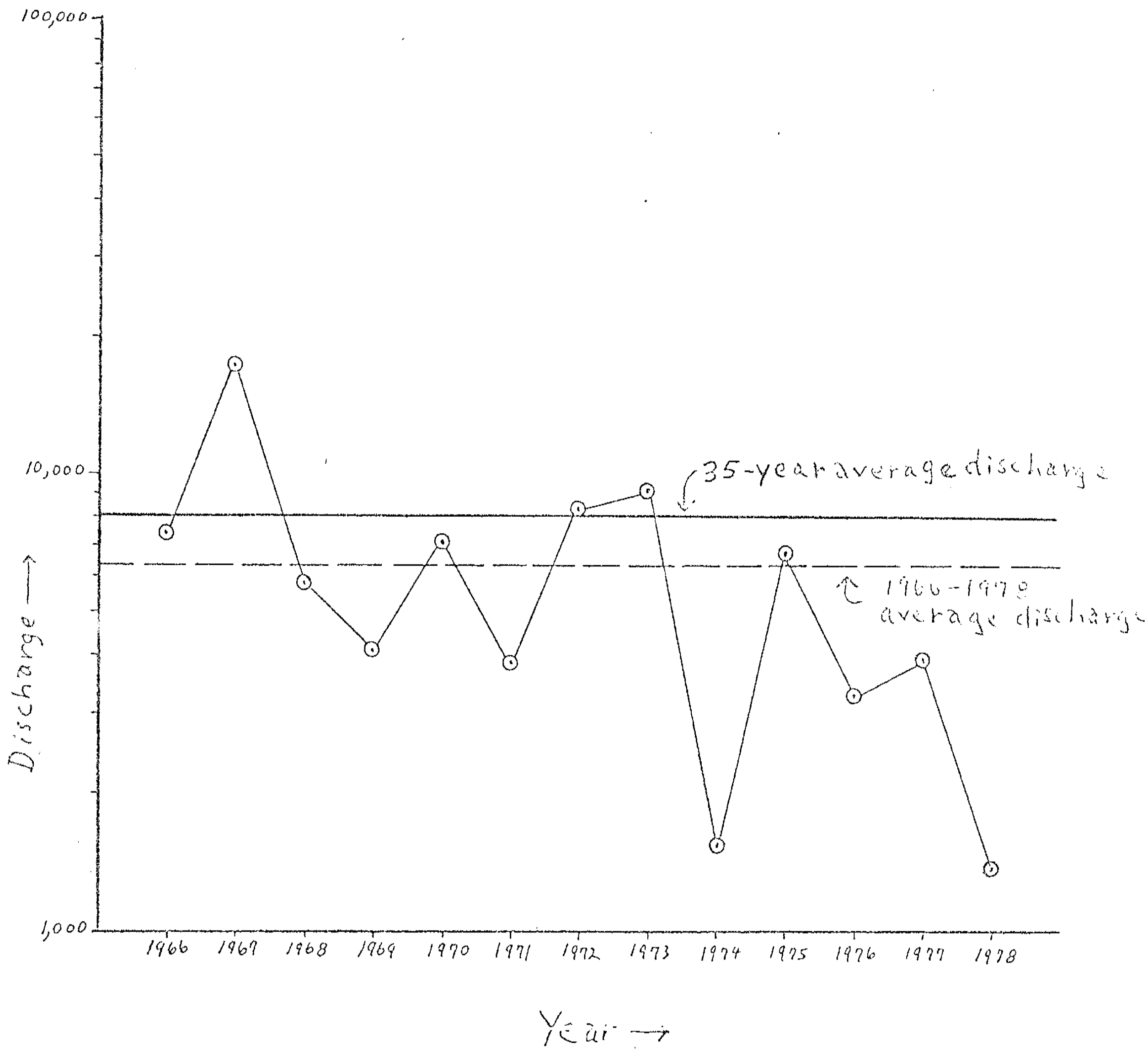


Figure 30. Annual discharge (ft^3/s) at Chico gage for water years 1966 through 1978.

of discharge records. Records of discharge for the periods October through November, February through March or April sometimes indicate a sustained flow in the channel, however. This is probably because during these periods, evapotranspiration losses are at a minimum, freezing of water in the channel does not occur frequently, and masking of the sustained discharge by larger volume flows is not common. Figure 31 is a daily discharge hydrograph from November 13, 1970 through January 3, 1971. The rising and falling limbs on this hydrograph show what is probably the result of fluctuating discharge due to intermittent flow generated by the input of springs near Chico Arroyo.

The springs which discharge into Chico Arroyo occur south of the stream, at the base of the slope around Mesa Chivato (Plate 3). The immediate source of the water from these springs is the Menefee Formation. Upward leakage of water from the Point Lookout Sandstone, and also possibly deeper geologic units, could also contribute to spring flow in this area. This is especially true for the spring located in the channel of Chico Arroyo, mentioned above. In this vicinity, the top of the Point Lookout probably lies at a shallow depth below the alluvium. Water levels in two of the observation wells (R23 and R24, Appendices H, F, and G), both completed in the Point Lookout, just south of Chico Arroyo, are practically at the same elevation as the channel bottom. This would tend to suggest the Point Lookout does contribute to spring flow in this area. Other, deeper units also may contribute to spring flow by upward leakage through permeable or semipermeable geologic units.

Ideally, water-quality data can be used to help define ground-water systems contributing to stream flow in an area (Van Voast and Novitzki, 1968). This is difficult in the Chico Arroyo area because waters from springs contributing to intermittent flows probably have at least two major

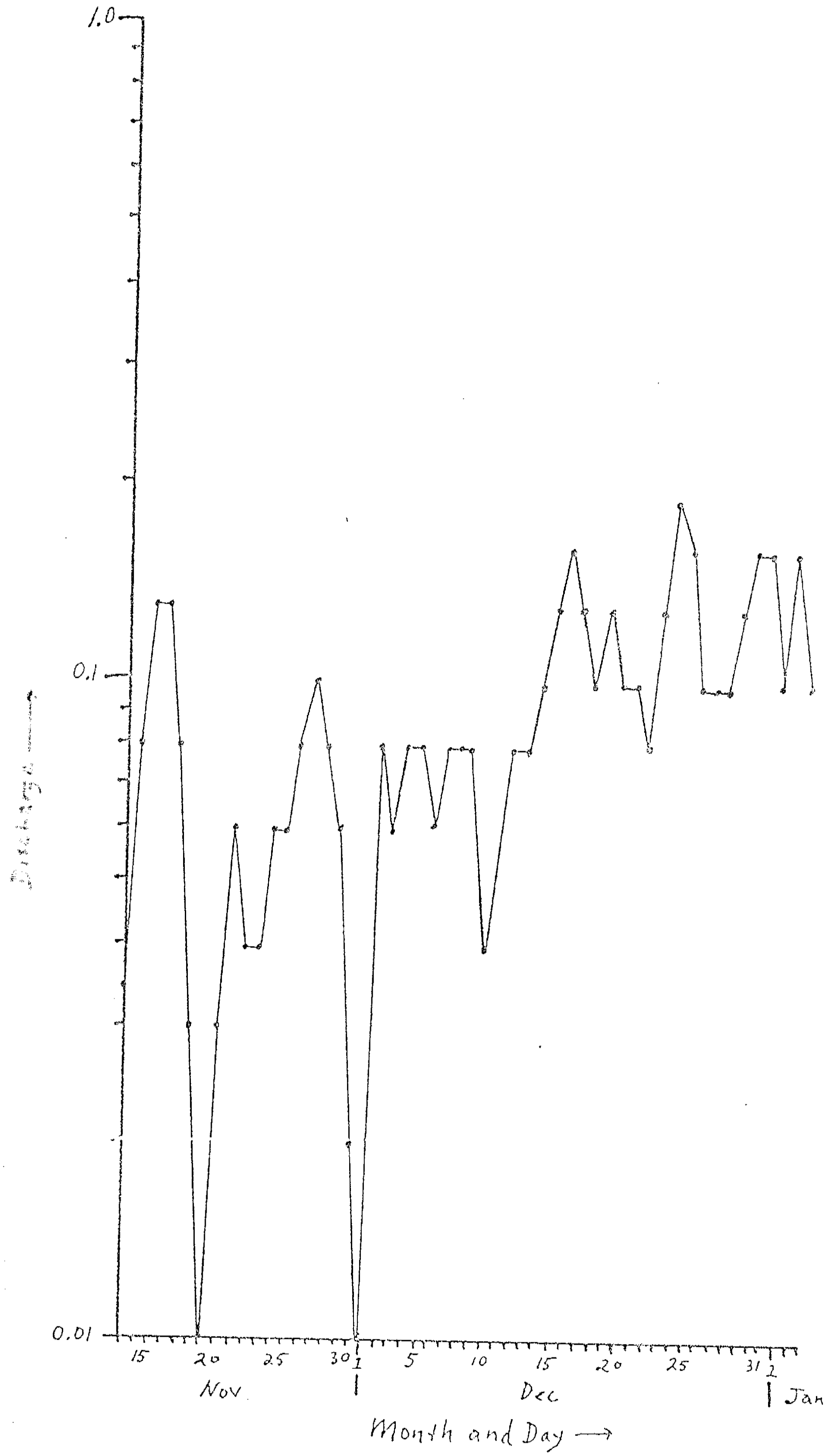


Figure 31. Daily discharge (ft^3/s) at Chico gage from November 13, 1970 through January 3, 1971.

sources. The main source is probably the Mount Taylor region to the southwest. Water from that area moves northward and discharges around the base of Mesa Chivato (Figs. 32 and 33, p. 101 and 102). The second source is probably a combination of of waters moving west and southwest from the Sierra Nacimiento area, and deeper waters moving southeast from the central part of the San Juan Basin area. Separation based on water quality types into shallow and deep ground-water flow systems is difficult in this area because of the effects of upward leakage of water, and subsequent mixing of waters from the different sources. The distribution of water quality in the Chico Arroyo area is shown on Plate 3. Water quality is generally better south of Chico Arroyo; this may reflect the shallower ground-water flow system with a source in the Mount Taylor region. A surface-water sample taken during low-flow conditions in April, 1978, is probably representative of intermittent flow in the channel of Chico Arroyo. Chemical analysis of the water showed 2,380 ppm dissolved solids, with high concentrations of sodium, sulfate, and bicarbonate (USGS, 1978, Water-Data Report NM-78-1, p. 215). Chemistry of this water, however, is the result of various processes including dissolution of ions along the stream bed, evaporation of water during flow above the sampling point, and mixing of waters from the various sources contributing to the intermittent flow.

WATER LOSSES

Of the average annual precipitation recieved in the drainage basin of Chico Arroyo, only a small amount, probably less than 4 percent, reaches the gaging station as runoff. If 4 percent or less runs off, then 96 percent or more must be lost. This loss occurs in various ways including seepage into alluvium, seepage into bedrock units, and evapotranspiration. Much of the initial loss of water probably occurs during runoff due to transmission loss in alluvial channels. Eventually, much of the water which infiltrated into the alluvium and was retained as interstitial pore moisture, becomes subject to evapotranspiration. The major effect of evapotranspiration, then, is probably the reduction of recharge volumes, especially to the alluvial aquifers.

Gregory and Walling (1973) gave a generalized water-balance equation for any drainage basin as:

$$P = Q + E \pm \Delta s;$$

where P = available precipitation,
Q = runoff,
E = evapotranspiration, and
Δs = changes in storage.

For the purposes of this study, the value for P is the average annual basin precipitation, and that for Q is the 35-year average annual discharge. Potential evapotranspiration for the drainage basin was computed by the Thornwaite method (1948). This method uses mean monthly temperatures, an annual heat index, and relative day lengths as constants for a particular drainage basin. As no temperature maps were available, a nonweighted arithmetic mean was obtained for the basin by using temperature records from four weather stations in the area which are probably representative of various regions in the basin. Thirteen-year records were used from the Torreon Mission, Star Lake, Chaco Canyon, and Cuba stations (US Weather Service, Annual Reports, 1965 - 1977). A monthly average temperature for each station was computed, and then monthly averages for the drainage basin were determined. The results are summarized in Table 6.

Annual potential evapotranspiration was computed by the Thornwaite formula (Thornwaite, 1948), given below:

$$e = ct^a = 1.6\left(\frac{10t}{I}\right)^a$$

where t = mean basin monthly temperature (^{o}C),
I = annual heat index (the sum of monthly

Table 6. Values of mean monthly temperature (°C), monthly heat index (i), and adjusted monthly potential evapotranspiration (cm) for drainage basin of Chico Arroyo.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Sum
Mean Monthly Temperature[1]	-3.60	-0.34	3.35	7.34	12.73	17.88	21.46	19.98	15.54	9.54	2.92	-2.76	
Monthly Heat Index	0.00	0.00	0.54	1.79	4.12	6.90	9.08	8.15	5.57	2.66	0.44	0.00	39.26
Potential Evapotranspiration	0.00	0.00	1.33	4.11	9.59	15.31	19.92	16.93	10.65	5.17	0.91	0.00	83.92

[1] Averages based on 13 years of record from 1965 - 1977, U. S. Weather Service Annual Reports.

indices; the value for I in this study is 39.26; Table 6, p. 94),

a = an exponent related to I by the expression,

$$a = 0.000000675(I^3) - 0.0000771(I^2) + 0.01792(I) + 0.49239$$ (the value for a in this study is 1.356), and

c = a constant.

Thornthwaite (1948, p. 92) gave precalculated values of the monthly heat indices, i, for given mean monthly temperatures (Table 6, p. 94).

According to Thornwaite (1948) the values computed for evapotranspiration are "unadjusted" values. To obtain adjusted values, correction factors which account for unequal day lengths between months at particular latitudes were given by Thornwaite (1948, p. 93). The adjusted values are given in Table 6, p. 94). Summation of the monthly potential evapotranspiration values gives an annual total of about 84 cm (33 inches). This value is practically three times the average annual basin precipitation of 29.2 cm (11.5 inches), not surprising for a semiarid environment. Multiplying the annual potential evapotranspiration by the drainage basin area gives an annual potential evapotranspiration of 2.8 X 10^3 hm^3/year (2.3 X 10^6 acre-ft/year).

The water-balance equation can now be evaluated for the storage term, Δs. By substitution, $\Delta s = P - Q - E = -1.8 \times 10^3$ hm^3/year (-1.5 X 10^6 acre-ft/year). This value represents a storage deficit of almost twice the average annual basin precipitation. Expected annual losses may amount to 96 percent or more of the average annual precipitation, or 9.8 X 10^2 hm^3 (7.9 X 10^5 acre-ft). This is only about one-half the calculated storage deficit, and about one-third the calculated potential evapotranspiration.

The values obtained for the storage deficit and potential evapotranspiration by the Thornwaite formula may not be very realistic because of any combination of the following factors:

1) there is no knowledge regarding the status of soil moisture (antecedent moisture conditions);

2) the effect of moisture deficiency on the relationship between actual and potential evapotranspiration is not certain, but Linsley and others (1975) reported that the rate of evaporation from an initially saturated soil plot tends to decrease with time;
3) there is no regarding vegetation density (water-table plants are confined to stream channels, whereas nonwater-table plants grow sparsely above the channels);
4) there is no knowledge concerning parameters such as intermittent cloud cover, fluctuating solar radiation, or wind speed near the ground; and
5) the value computed for evapotranspiration is only a potential value, therefore the additional complication of water availability, both on the land surface and in soil pores, is important. In other words, if water is not available, it cannot be lost to the atmosphere.

Obviously, further investigation is needed concerning water losses before any major conclusions can be made. Conclusions based on the values computed from the Thornthwaite formula should be regarded with skepticism. The major conclusion which may be drawn from this study is that overall, Chico Arroyo and other intermittent streams in this area are losing streams throughout most of their courses.

HYDROGEOLOGY

Hydrogeology is the study of geologic controls of the occurrence, movement, and quality of ground water in an area. Once the geologic and hydrologic characteristics of an area have been delimited, their relationship may be assessed. Although many geologic controls can be generalized for most hydrologic systems, each area has its own set of peculiarities.

GEOLOGIC CONTROLS OF GROUND-WATER OCCURRENCE

Ground water in the Chico Arroyo/Torreon Wash area occurs mainly in the intergranular pore spaces of sandstone and alluvium, in fractures in coal beds, and, to a lesser extent, in fractures in basalt flows.

The occurrence of ground water in sandstones is primarily controlled by their porosity, permeability, and geometry. These factors are in turn controlled by depositional and postdepositional history of the sandstone. For example, the Point Lookout Sandstone, Hosta Tongue of the Point Lookout, and Gallup Sandstones are all of marine shorezone origin (Molenaar, 1977), and would be expected to have similar values of porosity and permeability. However, the geometries of these units control their aquifer potential at a given locality. The Hosta Tongue and Gallup Sandstone both thin northward, and eventually grade into the Mancos Shale (Plate 2). The aquifer potential of these two units therefore is greatly reduced in a northerly direction. The Point Lookout Sandstone, though varying in thickness locally (Fig. 18, p. 47; Plate 2), has more or less a sheet-like geometry. This geometry results in a more uniform distribution of hydrologic characteristics throughout the area. Ground-water occurrence in units deposited in a continental environment, in addition to being controlled by geometry of individual sandstone bodies, is also controlled by the location and distribution of these bodies. For example, the Menefee Formation contains lenticular-shaped channel sandstone bodies which are commonly elongate in a northeasterly direction, and are probably essentially randomly distributed. Exploration for ground water in this unit is therefore largely a "hit-or-miss" proposition. Given ideal circumstances, units such as these should yield small amounts of water to wells. During recent test drilling by NMBMMR into coal-bearing zones of the Menefee, several channel sandstones were penetrated. Some of these were dry, a few contained oil, and others contained poor-quality water (Dave Tabet, NMBMMR Coal Geologist, personal communication, 1979). Coal beds in the area are also lenticular shaped, discontinuous, elongate bodies.

An additional control on ground-water occurrence in this area may be subsurface fracturing, resulting in increased secondary permeability. For example, coal beds in the Menefee Formation are commonly fractured and do yield water to wells (observation wells R32 and C1, Appendices H, G, and F). Fracture permeability may be partly responsible for the high flow reported from the BLM flowing well (16N.04W.36.232, Appendix H), completed in the Gallup Sandstone. This well is located very near a major fault (Plates 1 and 3).

Transmissivity of an aquifer is controlled by its thickness and permeability. Assuming constant permeability, transmissivity will vary with thickness and vice versa.

The occurrence of several springs south of Chico Arroyo is apparently controlled by northeast-trending, normal faults. Many of these springs occur directly on the faults (Plates 1 and 3). Other springs are associated with dikes which follow the same northeasterly fracture pattern as do the faults. Springs in the southeastern part of the area are commonly associated with volcanic necks and their existence may be controlled by local fracturing near the necks.

GEOLOGIC CONTROLS OF GROUND-WATER MOVEMENT

Ground-water movement consists of three major parts: Recharge, or the process by which ground water is replenished; Flow, the process by which ground water moves from areas of recharge to areas of discharge; and Discharge, the process by which ground water is depleted.

Recharge

Recharge of an aquifer is enhanced when the aquifer lies at or near the surface where it may intersect runoff. Uplift, along with folding and faulting, have placed aquifers in the Chico Arroyo/Torreon Wash area at the surface both inside and outside the study area. Recharge in this area is both direct (from the surface itself) and indirect (from the surface by means of other geologic units). A certain amount of subsurface recharge probably also occurs between leaky, confined units and their confining layers. Major means of recharge to units in this area are by transmission loss of runoff crossing outcrops, and by the infiltration of precipitation falling directly on outcrops. Outcrop belts in the area are quite extensive laterally and much recharge probably occurs outside the study area. Two principal areas of recharge are believed to exist outside the study area. The first is the flanks of the Mount Taylor complex to the south and southwest. The second is the western flanks of the Sierra Nacimiento to the northeast, east, and southeast. Geologic units such as the Dakota Sandstone and the Morrison Formation are not exposed in the study area, and aside from subsurface leakage, recharge to these units occurs totally outside the area. Alluvium is recharged mainly by transmission loss of runoff in stream channels, and to a lesser extent, by discharge of water from bedrock units.

Flow

Movement of ground water occurs in flow systems. In these systems, flow is commonly through interconnected pore spaces. Ground water in confined bedrock aquifers flows from areas of higher potentiometric surface to areas of lower potentiometric surface. In unconfined (or water table) aquifers, water moves from areas of higher water table to areas of lower water table, in response to gravity. The direction of ground-water flow may be controlled by the orientation of permeable zones, structural dip, or regional topography.

Flow of ground water in bedrock units in this area is down-dip away from recharge areas. Direction of flow is roughly toward Chico Arroyo, from the north and south. Figures 32 and 33 show general directions of ground-water flow in the Menefee Formation and Point Lookout Sandstone, respectively. Lack of data does not permit contouring of the potentiometric surface for the Point Lookout north of Chico Arroyo, but ground-water flow from the south is well shown. A component of flow toward the southeast from deep aquifers in the San Juan Basin is also thought to exist in this region (Forest Lyford, Hydrologist, USGS, WRD, personal communication, 1979). Movement of water in alluvium in this area would be expected to be downslope in response to gravity, in basically the same directions as stream flow.

Discharge

Geologic controls of discharge are much like those of recharge. Ground water in unconfined aquifers, such as alluvium, discharges wherever the water table intersects the land surface. Ground water in confined aquifers, such as bedrock units in this area, discharges wherever the potentiometric surface is at or above the land surface and the aquifer has access

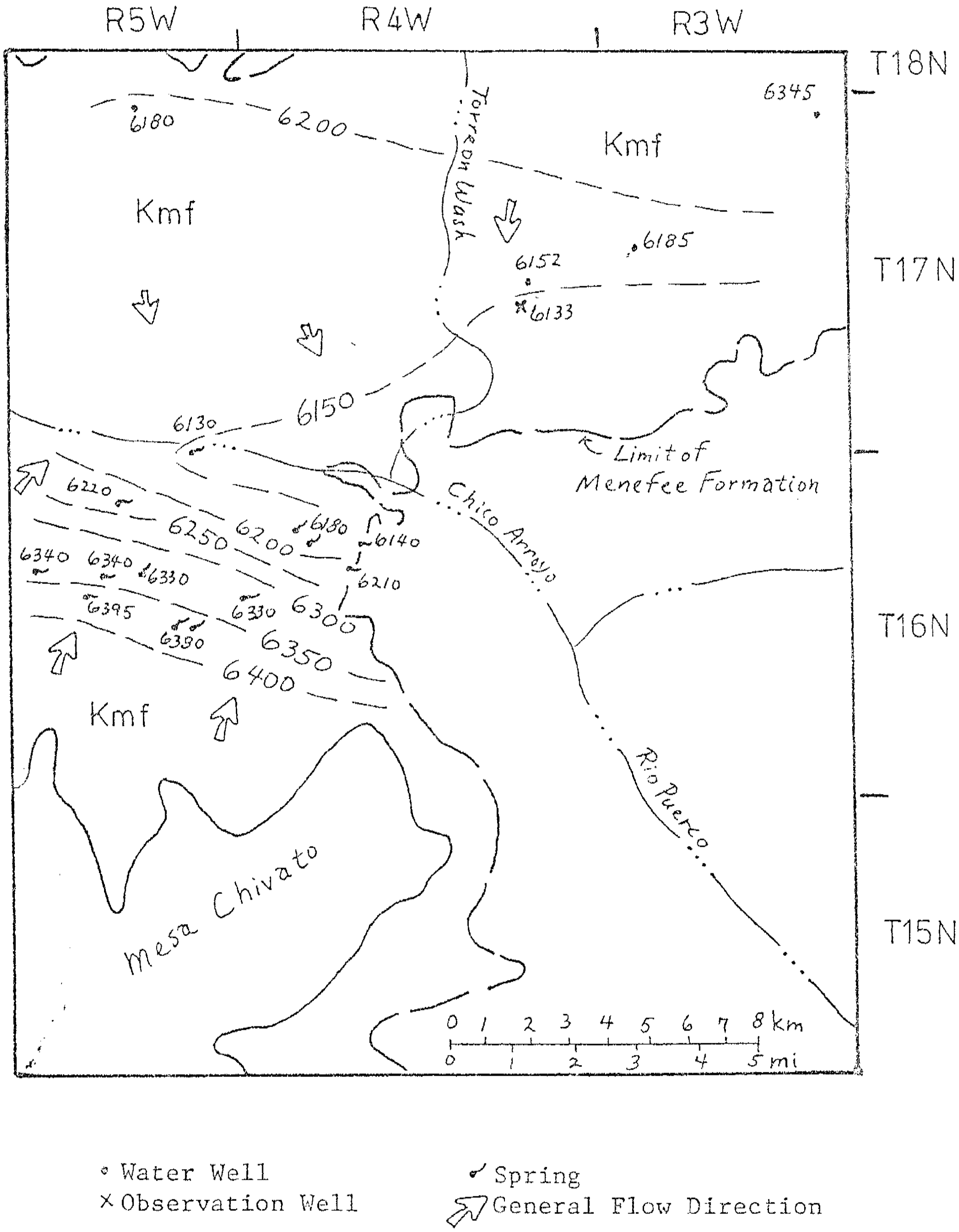
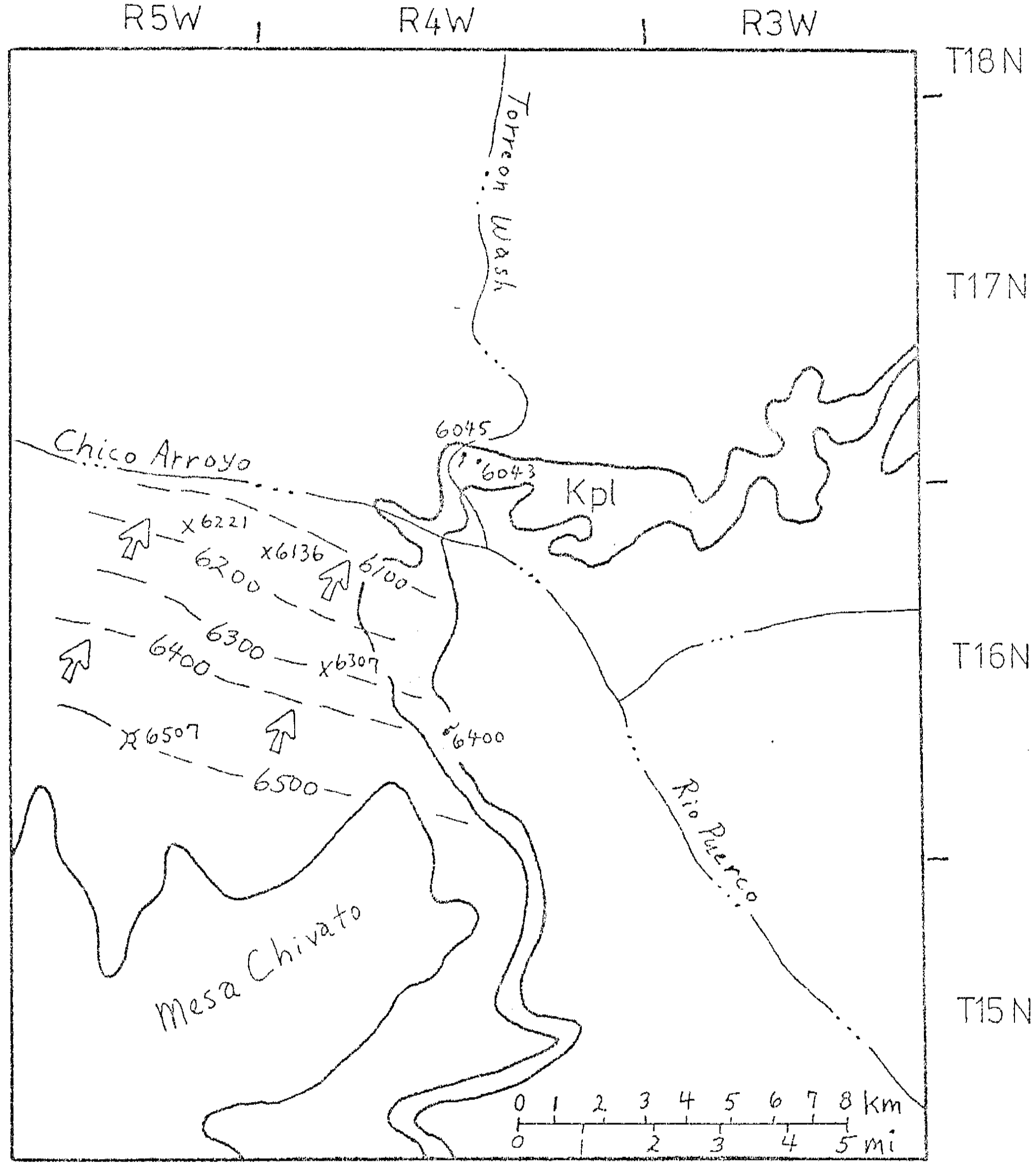


Figure 32. Water-level elevations, potentiometric surface, and elevations of springs (ft) in the Menefee Formation. Contour Interval = 50 ft.



• Water Well
× Observation Well
¤ Abandoned Obseravtion Well
Spring
General Flow Direction

Figure 33. Water-level elevations, potentiometric surface, and elevations of springs (ft) in the Point Lookout Sandstone. Contour Interval = 100 ft.

to the land surface by means of outcrop or fractures.

Ground-water discharge in the Chico Arroyo/Torreon Wash area is both natural and induced. Natural discharge consists of spring flow, especially in the southern part of the area around the base of Mesa Chivato, and evapotranspiration, especially along channels. Induced discharge occurs at pumping and flowing wells.

GEOLOGIC CONTROLS OF GROUND-WATER QUALITY

A commonly used measure of ground-water quality is dissolved-solids content. Dissolved materials in ground water in this area come from dissolution of minerals in rocks through which the water flows, subsurface leakage, and mixing with waters from adjacent units. For example, the Point Lookout Sandstone is a leaky, confined aquifer. In areas of recharge, leakage from the overlying Menefee Formation would probably occur, resulting possibly in reduction of water quality in the Point Lookout Sandstone. As ground water flows down-dip, away from recharge areas, leakage of water from the Point Lookout into the Menefee Formation would occur. Leakage water from the underlying Mancos Shale into the Point Lookout would also occur, probably reducing water quality in the Point Lookout. In alluvial aquifers, water quality may be reduced in downstream areas because of the contribution of poorer quality water discharging from bedrock sources.

Locally, lithology exerts a strong control on the quality of ground water. For example, the high sulfate content of waters from coal beds in the Menefee Formation is probably the result of dissolution of iron-sulfide minerals, and the oxidation of organic materials. Calcium and carbonate in ground waters in the area probably result from dissolution of calcite cement. Ground water in the area is commonly of the sodium-sulfate or sodium-bicarbonate types. The source of much of the sodium in the waters may be clay minerals in the matrix of sandstones, and subsurface leakage and mixing with waters from semipermeable shales.

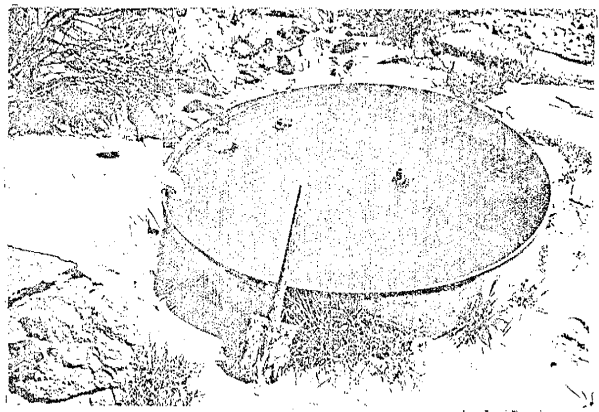
Quality of water from the Menefee Formation and Point Lookout Sandstone in the area is generally better south of Chico Arroyo (Fig. 14, p. 41 and Fig. 21, p. 54). This water-quality separation is most obvious in the Point Lookout. The water from this unit gradually becomes worse toward Chico Arroyo from the south, and totally deteriorates north of the stream. This quality difference probably results from mixing of waters moving toward Chico Arroyo from the north and south. Also waters moving north from the recharge area on Mount Taylor, may have a shorter residence time in the rocks, therefore resulting in better water quality south of Chico Arroyo.

WATER USE AND SUPPLY

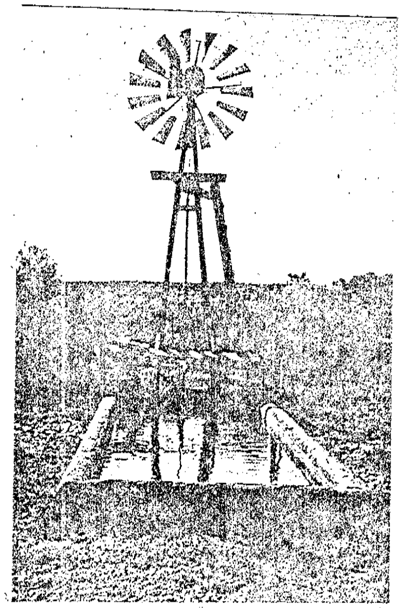
RURAL DWELLINGS

Few permanent dwellings are located in the study area, and the inhabitants of the scatterred homes obtain water for domestic uses mainly from local sources. For example, the sole permanent resident of Guadalupe obtains water from a developed spring, Ojo del Padre, which issues from the Gallup Sanstone (Appendices H, I; Plate 3). Water from this spring is of good quality and is used for domestic needs, irrigation of a small garden, and for watering stock. A well completed in the Cleary Coal Member of the Menefee Formation (17N.04W.27.444, Appendix H), is located along Torreon Wash, at the seasonal residence of Max Tachias. This well is equipped with a windmill and the water, although of marginal quality, is used for both domestic and stock needs. The seasonal residents of the Joe Montoya and Ernest Montoya shacks use water from developed springs (16N.05W.13.333 and 16N.05W.13.422, Appendix H) in the Menefee Formation to meet their needs. These springs are also used for watering stock. Many of the absentee ranchers who graze beef cattle in the southern part of the area obtain their drinking water from the BLM flowing well (16N.04W. 36.232, Appendix H; Fig. 34-D), completed in the Gallup Sandstone. Local residents in the vicinity of Torreon Trading Post, north of the study area, obtain water from a developed spring, Ojo Encino. This spring is located to the northwest (SW¼, Sec23, T20N, R5W; Javin Tanner, owner Torreon Trading Post, personal communication, 1978). The water is supplied by means of a pipeline.

Should future water supplies be required for local domestic needs, the Point Lookout Sandstone and Gallup Sandstone offer the best aquifer potential in the southern part of the area. In the north, channel sandstones and possibly coal beds in the Menefee Formation are the best targets for



A



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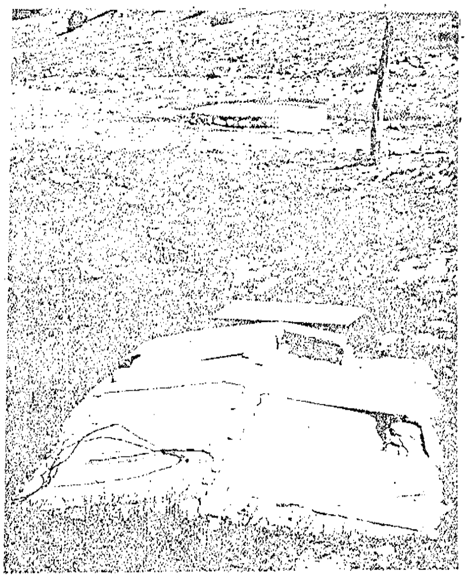

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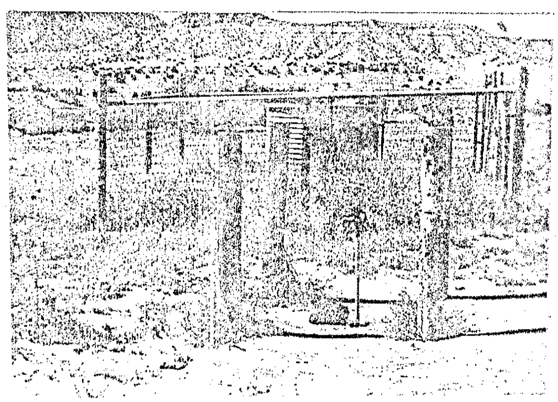

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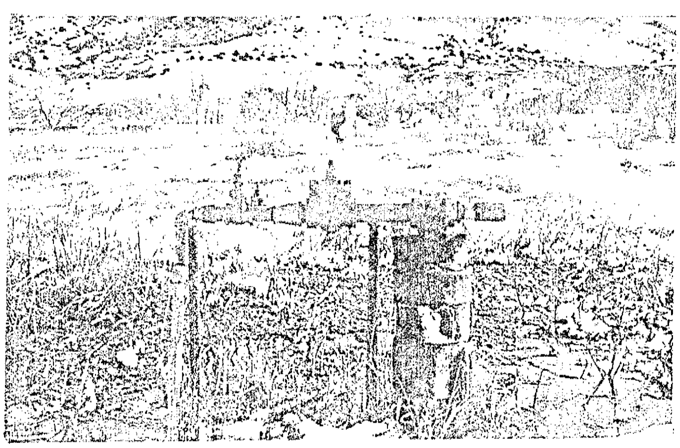

E

Figure 34. Development of water resources in the Chico Arroyo/Torreon Wash area. A) Barrel Spring (16N.04W.34.334, Appendix H), on the northern edge of Mesa Chivato, issues from the Allison Member of the Menefee Formation. The spring was developed by the BLM. Yield is 0.03 lps (0.5 gpm). B) Windmill on south bank of Arroyo Piedra Lumbre (17N.03W.18,242, Appendix H). Well is completed in Cleary Coal Member of Menefee Formation and also possibly in alluvium. Note thick vegetative growth resulting from local wet conditions around stock tank (view west from NE¼, Sec 18, T17N, R3W). C) Ojo Frio (16N.04W.26.213, Appendix H), a spring developed by the BLM, issues from the Satan Tongue of the Mancos Shale. This spring is associated with a volcanic neck known as Cerro del Ojo Frio (view northeast from NE¼, Sec26, T16N, R4W). D) Flowing well (16N.04W.36.232, Appendix H) completed in the Gallup Sandstone. The BLM has constructed a pipeline which feeds several stock tanks in the area (Plate 3). Note normal fault in Hosta Tongue of Point Lookout Sandstone in background (view south from NE¼, Sec36, T16N, R4W). E) Flowing well (16N.03W.17.333, Appendix H) converted from oil well tapping Dakota Sandstone (view east from SW¼, Sec17, T16N, R3W).

water wells, although water quality may be marginal. Alluvium would also yield small quantities of water to wells, but because of insufficient data no reliable predictions concerning the aquifer-potential of alluvium can be made. Springs in the area also offer potential for water resources, especially when developed.

LIVESTOCK

Water for stock use is obtained mainly from wells and springs (Fig. 34, p. 107). A major source of stock water in the southern portion of the area is the BLM flowing well (16N.04W.36.232, Appendix H; Fig. 34-D, p. 107). The BLM has constructed a pipeline from this well which feeds several small stock tanks along its route (Plate 3). The BLM has also constructed reservoirs by damming small arroyos to collect runoff. Cabezon Reservoir, Ned Tank, Seco Tank, and Laguna Cuarenta are some of the larger reservoirs (Plate 3).

Sufficient quantities of stock water probably already exist in the area. If future supplies are needed, the Menefee Formation in the northern part of the area, and the Point Lookout Sandstone, Gallup Sandstone, and Mulatto Tongue of the Mancos Shale elsewhere would yield sufficient amounts of water to wells. Several undeveloped springs could also be developed for stock-water supplies.

ENERGY-RESOURCE EXPLORATION AND DEVELOPMENT

Teton Exploration is presently conducting deep test-drilling into the Morrison Formation for uranium in the area, and the NMBMMR recently completed a test-drilling program to evaluate coal resources in the Menefee Formation (Tabet and Frost, 1979). Water used for these drilling operations was taken mainly from the BLM flowing well (16N.04W.36.232, Appendix H), completed in the Gallup Sandstone.

Water will be required for development of the Menefee Formation coal reserves in this area. Since streams are ephemeral, ground water is the only source of suitable water supplies for future coal development. Water uses related to coal mining were summarized by Shomaker and Stone (1976, p. 43). Water is required mainly for the washing of coal, boiler feed, cooling, and reclamation of strip-mined lands. If gasification becomes feasible, water will also be required as a processing fluid.

Only two geologic units could be expected to yield water in large enough quantities and of good enough quality for future mining operations in the area. These units are the Gallup Sandstone and Westwater Canyon Member of the Morrison Formation. Obtaining water rights for water in the Gallup Sandstone could be difficult, since the BLM has developed a pipeline from the flowing well (16N.04W.36.232, Appendix H), and has future plans for additional development of this unit. The Dakota Sandstone has little potential as a source of water for mining operations because of small yields and poor water quality. The Point Lookout Sandstone is also a poor candidate mainly because of small yields, but also because water quality deteriorates north of Chico Arroyo.

SUMMARY AND CONCLUSIONS

1. The major aquifers in the Chico Arroyo/Torreon Wash area are the Gallup Sandstone, Point Lookout Sandstone, and sandstones in the Menefee Formation.
2. The Mulatto Tongue of the Mancos Shale, Hosta Tongue of the Point Lookout Sandstone, and alluvium also offer some potential for development of water supplies.
3. The Gallup and Point Lookout Sandstones can be most economically developed in the southern part of the area. In the northern part, the Menefee Formation and possibly alluvium are the major candidates for water supplies.
4. Ground water in bedrock units is under artesian pressure. Wells in the Gallup and Dakota Sandstones could be expected to flow.
5. Yields from most units in the area are very low, because of low permeability and transmissivity. Therefore, it is important in this area that the entire thickness of a particular unit be penetrated and perforated or screened to obtain maximum yields.
6. Springs are most common in the southern part of the area, at the base of the slope around Mesa Chivato. Many springs are associated with northeast-trending faults and dikes, or with volcanic necks. Yields from springs are very low.
7. Quality of ground water in the area ranges from fresh to moderately saline, but is commonly marginal for domestic uses. The Gallup and Point Lookout Sandstones will yield fair quality water, but the quality can be expected to deteriorate toward the north in response to increasing depth of the unit and distance from outcrop.
8. Proper well construction should be a major consideration for wells

completed in any geologic unit in this area. Care should be taken to avoid setting perforations adjacent to shaley zones, because water quality will be adversely affected.

9. A wide range of flow conditions are recorded at the Chico Arroyo gagging station. These conditions are mainly the result of seasonal variations in precipitation in the drainage basin. Several consecutive weeks of zero flow occur, usually during May, June, October, and midwinter. Short-lived, high-discharge flow events occur during the summer rainy season during July through September in response to afternoon, convective thunderstorms. As much as 75 percent of the annual precipitation may occur during this period and as much as 99 percent of the annual runoff at the gage may occur.

10. Intermittent flows in Chico Arroyo and other streams in the area are the result of discharge from springs. Intermittent flows are most obvious during periods of low evapotranspiration, and when they are not masked by higher discharge flows from storm events. This usually occurs from February through March or April.

11. Between 0.3 and 4.0 percent of the average annual precipitation received in the drainage basin of Chico Arroyo flows past the gaging station at the mouth of the stream. The remainder of the precipitation is lost by evapotranspiration and by seepage into alluvial channels, other surficial deposits, and bedrock units.

12. Most ground water moving toward Chico Arroyo is probably underflow, and is thus not discharged at the surface. Most ground water which is discharged is probably from the Mount Taylor area to the southwest, and has a relatively shallow source. Some upward leakage and surface discharge of water from deeper geologic units probably occurs, but it is masked by the shallower ground-water discharge.

13. Ground water in this area occurs mainly in the intergranular pore spaces of sandstones and alluvium, in fractures in coal beds, and, to a lesser extent, in fractures in basalt flows.

14. Occurrence of ground water in the area is controlled primarily by depositional environment. Many springs in the area are controlled by a northeast-trending fracture system, and by fractures associated with volcanic necks.

15. Major methods of recharge to units in the area are by transmission loss of runoff from streams crossing outcrop areas, by precipitation falling on outcrop areas, and, to a lesser extent, by subsurface leakage of water between units.

16. Two major areas of recharge exist outside the study area for bedrock aquifers. One is the northern flanks of Mount Taylor to the south and southwest. The other is the western flanks of the Sierra Nacimiento, to the northeast, east, and southeast.

17. Flow of ground water in the area is roughly from the north and south toward Chico Arroyo.

18. Ground water discharges by means of springs and evapotranspiration. Spring discharge is apparently controlled by northeast-trending faults.

19. Water quality appears to be somewhat better south of Chico Arroyo, probably because of faster ground-water flow from the Mount Taylor recharge area in the southwest. Poorer quality water north of Chico Arroyo is probably the result of slower ground-water flow from the Sierra Nacimiento area, and upward leakage from deeper units discharging toward the southeast.

20. Geologic controls of water quality are composition of the aquifer, depth of the aquifer, and distance from outcrop or recharge area. Subsurface leakage between units will adversely affect water quality.

21. At the present time, the major use of land in the area is grazing of livestock. Sufficient and reliable water supplies exist for stock needs. If additional supplies are needed, several undeveloped springs in the southern part of the area could be developed.

22. The Gallup Sandstone and Westwater Canyon Member of the Morrison Formation are the two major aquifers available for water supplies should coal mining be initiated in this area. Water from wells tapping either unit will not only be under artesian pressure, but may flow. The Gallup Sandstone thins northward and its aquifer potential would be greatly reduced in a northerly direction.

23. During coal-stripping operations in the Menefee Formation, mine seepage will occur from rocks associated with coal beds, and from the coal beds themselves. Mining in the Cleary Member will probably be hindered by upward seepage from the Point Lookout Sandstone.

24. It was fortunate that the study area overlapped in part with the NMBMMR Torreon Wash coal project because valuable hydrologic information was obtained from the observation wells completed in the Menefee Formation and Point Lookout Sandstone. These will also provide valuable data in the future, especially should coal mining be intitiated in the area. Therefore, they should be monitored at least annually. Water levels should be measured, water samples taken and analyzed, and the general condition of each well checked. This monitoring could be performed by NMBMMR personnel or by USGS, WRD Albuquerque personnel during routine maintenance checks to the gaging stations on the Rio Puerco and Chico Arroyo.

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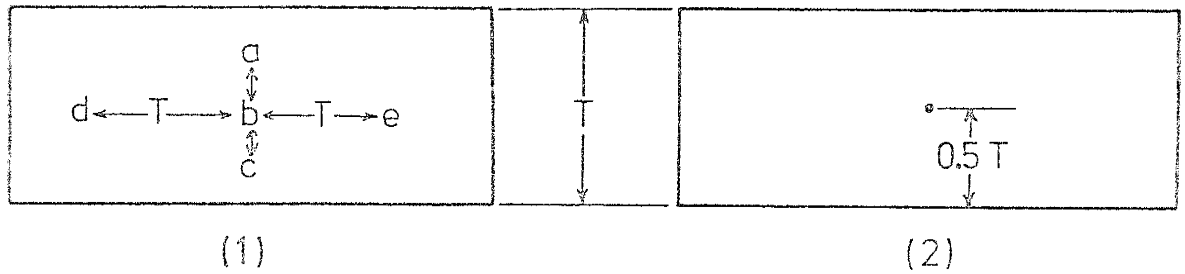
APPENDIX A

DESCRIPTIONS OF MEASURED SECTIONS

Five stratigraphic sections were measured to provide information on the thicknesses and lithology of potential aquifers and associated rocks. Table A-1 summarizes the location and units covered by the measured sections.

All sections were measured by the Jacob's staff method for exposures on slopes, and by using a steel tape for steep cliffs. Bedding thicknesses were measured with the Jacob's staff or ruler. Grain sizes were estimated by comparison with a sand card; sorting was estimated by comparison with Figure 12-1 in Compton (1962, p. 214); roundness was estimated by comparison with samples on a sand card. Composition of rock units was determined with a hand lens and acid bottle containing hydrochloric acid.

In the field, selected beds of major sandstones were sampled by one of the following two methods:



T = thickness of bed

a = sample taken at 0.25 thickness above midpoint
b = sample taken at 0.50 thickness (at midpoint)
c = sample taken at 0.75 thickness below midpoint
d = sample taken at 1.0 thickness to left of line of measured section, at midthickness
e = sample taken at 1.0 thickness to right of line of measured section, at midthickness

When the thickness of a particular sandstone unit was greater than the length of one Jacob's staff, or 1.6 m (5.2 ft), the unit was sampled by method 1; when the thickness was less than one Jacob's staff length, the unit was sampled by method 2. For laboratory analyses, samples were selected from point b, or from midthickness. Samples from measured section SDC-5 were selected from points a, b, and c. In interbedded sandstone and shale sequences, units which were representative of the major rock types in the sequence were sampled.

Precision of Jacob's staff measurements was determined by measuring up a control section (SDC-1) three times. The thicknesses determined were 20.3 m (66.6 ft), 20.1 m (65.9 ft), and 20.4 m (66.9 ft). The mean was 20.3 m (66.6 ft), variance was 0.015, and standard deviation was 0.12. Accuracy was not determined.

Table A-1. Location and units covered by measured stratigraphic sections in Chico Arroyo/Torreon Wash area (abbreviations for units same as Plate 1).

Section number	Location	Units covered
SDC-1	SE¼, sec31, T18N, R4W	Kmf, Kch
SDC-2	SE¼, sec36, T16N, R4W	Kmm, Kph, Kms
SDC-3	SW¼, sec34, T17N, R3W	Kms, Kpl
SDC-4	NW¼, sec11, T16N, R4W	Kms, Kpl
SDC-5	35° 31' 52"N. lat. 107° 08' 57"W. long.	Kml, Kg, Kmm

All descriptions start at the top with a heading giving the section number, geographic location, 7.5-minute quadrangle, location with respect to roads or landmarks, legal description, county, date measured, and the names of the analyst(s). The descriptions begin with the uppermost unit and proceed down section down the page to the lowermost unit measured. Units were numbered in the field starting at the bottom. The general format for describing individual rock units is as follows:

> GENERAL ROCK TYPE(S)--color; bedding/internal structures; other primary structures; texture; major composition of grains, matrix, cement; induration; nodules/concretions; fossils; miscellaneous characteristics; contact with unit above.

When a unit is identical to one previously described, the reader is referred to the first description of that rock type, rather than repeating the description.

The source and definition of descriptive field terms used are listed below (from a reference sheet compiled by W. J. Stone).

BEDDING SIZE (McKee and Weir, 1953, as modified by Ingram, 1954; Campbell, 1967):

Very thick beds	$>$ 100.0 cm (1 m)
Thick beds	30.0 - 100.0 cm
Medium beds	10.0 - 30.0 cm
Thin beds	1.0 - 10.0 cm
Very thin beds	$<$ 1.0 cm

BEDDING UNIFORMITY (Dunbar and Rodgers, 1963):

Regular	- beds do not vary in thickness laterally
Irregular	- beds do vary in thickness laterally
Even	- all beds in vertical succession similar in size
Uneven	- vertically adjacent beds not similar in size

INTERNAL STRUCTURE OF BEDS (McKee and Weir, 1953; Campbell, 1967):

Very thick laminae	> 30.0 mm
Thick laminae	10.0 - 30.0 mm
Medium laminae	3.0 - 10.0 mm
Thin laminae	1.0 - 3.0 mm
Very thin laminae	< 1.0 mm
Massive	no laminae distinguishable

BEDDING/LAMINAR SURFACE SHAPES (modified from Campbell, 1967):

Planar
Wavy
Curved

Surfaces are further described as to continuous/discontinuous and parallel/nonparallel.

RIPPLE MARKS (Pettijohn, Potter, and Siever, 1973; Allen, 1969):

1. Plan view
   - Continous pattern
     - Straight - (rectilinear) parallel crests, normal to current.
     - Catenary - parallel crests but not straight, nor everywhere normal to current, may grade into sinuous or lunate forms.
     - Sinuous - nonparallel crests, not everywhere normal to current.
   - Discontinuous pattern
     - Lunate - cresentic, extremeties point up-current.
     - Lingoid - cresentic, extremeties point down-current.

2. Cross-section view
   - Symetrical/Assymetrical
   - Climbing/"Normal"

CROSS STRATIFICATION (Allen, 1963; Jacob, 1973; McKee and Weir, 1953):

1. Magnitude (Jacob, 1973);

Small scale	< 0.05 m
Large scale	0.05 - 5.0 m
Very large scale	> 5.0 m

2. Relation with lower bounding surface (Jacob, 1973);
   - Concordant
   - Tangential
   - Discordant

3. Dip (Jacob, 1973);

Low angle	2.0° - 15.0°
High angle	> 15.0°

4. Grouping (Allen, 1963);
   - Solitary
   - Grouped

5. General Shape (modified from McKee and Weir, 1953);
   Planar
     Tabular - sets bounded by parallel planar surfaces.
     Wedge - sets bounded by converging planar surfaces.
   Nonplanar
     Trough - sets bounded by curved surfaces.

GRAIN SIZE (Wentworth, 1922):

Gravel	Boulders	> 256.0 mm			
	Cobbles	64.0	-	256.0	mm
	Pebbles	4.0	-	64.0	mm
	Granules	2.0	-	4.0	mm
Sand	Very coarse sand	1.0	-	2.0	mm
	Coarse sand	0.5	-	1.0	mm
	Medium sand	0.25	-	0.5	mm
	Fine sand	0.125	-	0.25	mm
	Very fine sand	0.0625	-	0.125	mm
Fines	Silt	0.0039	-	0.0625	mm
	Clay	< 0.0039 mm			

MEASURED SECTION SDC-1, LA SALADITA (Cañada Calladita 7.5' Quadrangle). South-facing slopes about 8 km (5 mi) southwest of Torreon Trading Post, and 0.2 km (0.13 mi) north of east-west dirt road, on northeast side of La Saladita arroyo; NW¼, NW¼, SE¼, Sec.31, T18N, R4W, Sandoval County; section through Menefee Formation measured by S. D. Craigg, June 1978; section through Cliff House Sandstone measured by Steven Craigg and Scott Anderholm, June 1978 (see Fig. 13-A, p. 38; Plate 1).

UNIT	LITHOLOGY	THICKNESS: M	(FT)
	CLIFF HOUSE SANDSTONE		
20	SANDSTONE--dusky yellow (5Y6/4) weathered and fresh; beds thick, irregular, uneven, with medium curved (continuous/parallel) laminae; large scale, discordant to tangential, low-angle, grouped, trough cross bedding present throughout unit; grains fine, well sorted, subrounded; composed mainly of clear quartz and feldspar with clay matrix and calcite cement; well indurated; locally bioturbated; top of unit eroded.	4.2	(13.8)
19	SILTY SHALE--like silty shale in unit 15 below.	1.4	(5.0)
18	SANDSTONE--light olive (10Y5/4) weathered, dusky yellow (5Y6/4) fresh; beds thick, irregular, uneven, with thin to medium planar (continuous/parallel) laminae; large scale, concordant, low-angle, grouped, wedge-planar cross bedding present throughout unit; grains fine to medium, moderately well sorted, subrounded; composed mainly of clear quartz and feldspar with clay matrix and calcite cement; well indurated; locally bioturbated; contact with above sharp, conformable.	2.7	(8.9)

17	SILTY SHALE--like silty shale in unit 15 below.	9.6	(31.5)
16	SANDSTONE--light brown (5YR6/4) weathered and beds very thick, regular, uneven, massive; grains fine to medium, moderately well sorted, subrounded; composed mainly of clear quartz and feldspar with clay matrix and calcite cement; bioturbated and contains scattered Ophiomorpha; contact with above sharp, conformable.	9.5	(31.2)
15	SILTY SHALE--dusky yellow (5Y6/4) weathered, light olive-gray (5Y5/2) fresh; beds thin to medium, regular, uneven, with thin to medium planar (continuous/parallel) laminae; calcite cement; moderately indurated; contact with above sharp conformable.	3.4	(11.1)
14	SANDSTONE--light brown (5YR6/4) weathered and fresh; beds medium to very thick, irregular to regular, uneven, either massive or with thin to medium planar (continuous/parallel) laminae; large scale, discordant to concordant, low to high-angle, solitary, wedge-planar, cross bedding scattered throughout unit; grains fine to medium, moderately well sorted, subangular to subrounded; composed mainly of clear quartz and feldspar with clay matrix and calcite cement; moderately to well indurated; locally bioturbated and contains abundant Ophiomorpha; contact with above sharp, conformable.	13.5	(44.3)
13	INTERBEDDED SANDSTONE AND SHALES	10.0	(32.8)
b	SANDSTONE--light brown (5YR6/4) weathered and fresh; beds medium to very thick, irregular to regular, uneven, with medium planar (continuous/parallel) laminae; grains fine to medium, well sorted, subrounded; composed mainly of clear quartz and feldspar with clay matrix and calcite cement; well indurated; locally bioturbated and contains scattered Ophiomorpha; contact with Shales sharp, conformable.		

a SHALE--pale yellowish-brown (10YR6/2) to dark yellowish-orange (10YR6/6) weathered and fresh; beds medium, regular, uneven, with thin planar (continuous/parallel) laminae; noncalcareous cement; moderately indurated; contact with Sandstone sharp, conformable.

Contact of unit 13 with unit 14 is sharp, conformable.

Measured thickness of CliffHouse Sandstone = 54.3 (178.6)

"UPPER MEMBER" OF MENEFEE FORMATION

12 INTERBEDDED SANDSTONE, SHALE, and COALY SHALE 19.7 (64.6)

c SANDSTONE--like sandstone in unit 10 below.

b SHALE--like shale in unit 10 below.

a COALY SHALES--grayish black (N2); beds very thick, regular, uneven, with thin to medium planar (continuous/parallel) laminae; noncalcareous cement; moderately indurated; coal occurs in thin layers along laminae planes; contact with Sandstones sharp, erosional.

Contact of unit 12 with unit 13 in line of this measured section is gradational, conformable, but at other localities on the same outcrop, the contact is sharp, conformable or erosional, or is intertonguing.

11 SANDSTONE--light olive-gray (5Y5/2) weathered, grayish yellow-green (5GY7/2) to dark greenish-yellow (10Y6/6) fresh; beds very thick, irregular, uneven, with medium planar (continuous/parallel) to medium curved (continuous/nonparallel) laminae; large scale, low to high-angle, grouped and opposed, trough cross bedding present throughout unit, especially near top in iron-stained, calcite-cemented concretionary bodies; grains medium to coarse, moderately sorted, subrounded to rounded; composed mainly of clear quartz and feldspar with clay matrix and calcite cement; moderately indurated; contact with above sharp, conformable. 12.5 (41.0)

10	INTERBEDDED SANDSTONE AND SHALE	19.7	(64.6)
b	SANDSTONES--light brown (5YR6/4 weathered, grayish-pink (5R8/2) fresh; beds thick to very thick, irregular, uneven, with medium wavy (continuous/parallel) laminae; grains fine to medium, moderately well sorted, subangular to subrounded; composed mainly of clear quartz and feldspar with clay matrix and noncalcareous cement; moderately indurated; contact with Shales sharp, conformable.		
a	SHALES--light brownish-gray (5YR6/1) weathered, pale brown (5YR5/2) to dark yellowish-orange (10YR6/6) fresh; beds very thick, regular, uneven, with medium planar (continuous/parallel) laminae; noncalcareous cement; poorly indurated; contact with Sandstones sharp and either erosional or conformable.		

Contact of unit 10 with unit 11 is sharp, erosional.

9	SANDSTONE--light olive-gray (5Y5/2) weathered, grayish yellow-green (5GY7/2) fresh; beds very thick, irregular, uneven, with medium planar (continuous/parallel) to medium curved (continuous/nonparallel) laminae; large scale, tangential, low to high-angle, grouped and opposed, trough cross bedding present throughout unit, especially near top in iron-stained, calcite-cemented concretionary bodies about 1 by 2 m (3 by 6 ft) in size; grains medium to coarse, moderately sorted, subrounded to rounded; composed mainly of clear quartz and feldspar with clay matrix and calcite cement; moderately to well indurated; contains scattered dense iron (siderite?) nodules about 5 cm (2 in) wide and 40 cm (16 in) long which follow bedding planes; contact with above sharp, conformable.	11.0	(36.0)
8	INTERBEDDED SANDSTONE, SHALE, and CARBONACEOUS SHALE	6.8	(22.3)
c	SANDSTONES--light brown (5YR6/4) weathered, grayish-pink (5R8/2) fresh; beds medium to thick, irregular, uneven, with medium wavy (continuous/parallel) laminae, some beds contain interference ripple marks and root borings(?) on upper surfaces; grains fine to medium, moderately well sorted, subangular to subrounded; composed mainly of clear quartz and feldspar with clay matrix and noncalcareous		

cement; moderately indurated; contact with Shales sharp, conformable.

b SHALES--light brownish-gray (5YR6/1) weathered, pale brown (5YR5/2) fresh; beds very thick, regular, uneven, with medium planar (continuous/parallel) laminae; noncalcareous cement; poorly indurated; contact with Sandstones sharp, and either erosional or conformable.

a CARBONACEOUS SHALES--grayish-black (N2) weathered and fresh; beds very thick, regular, uneven, with medium planar (continuous/parallel) laminae; noncalcareous cement; poorly indurated; contains remains of plant stems and leaves; contact with Sandstones sharp, and either erosional or conformable.

Contact with shales gradational, conformable.
Contact of unit 8 with unit 9 is sharp, erosional.

7 SANDSTONE--light brown (5YR6/4) weathered, grayish-pink (5R8/2) fresh; beds medium to thick, irregular, uneven, with medium wavy (continuous/parallel) laminae; contains sinuous, assymetricl ripple marksin upper part of unit, crest height = 0.2 cm (0.08 in), wave length = 1.2 cm (0.2 in), striking northwest/southeast, current towards northeast; grains fine to medium, moderately well sorted, subrounded; composed mainly of clear quartz and feldspar with clay matrix and noncalcareous cement; moderately indurated; contains scattered discontinuous iron nodules about 4 cm (1.6 in) wide which follow bedding planes; contact with above sharp, conformable. 4.7 (15.4)

6 INTERBEDDED SHALE and CARBONACEOUS SHALE 4.6 (15.1)

b SHALES--grayish orange-pink (5YR7/2) weathered, pale reddish-brown (10R5/4) fresh; beds very thick, regular, even, with thin planar (continuous/parallel) laminae; noncalcareous cement; poorly inudrated; contact with Carbonaceous Shales gradational, conformable.

a CARBONACEOUS SHALES--dusky brown (5YR2/2) weathered and fresh; beds very thick, regular, even, with thin planar (continuous/parallel) laminae; noncalcareous cement; poorly indurated; contains remains of plant stems and leaves; contact with Shales gradational, conformable.

Contact of unit 6 with unit 7 is sharp, erosional.

5	SANDSTONE--pale yellowish-green (10GY7/2) weathered and fresh; beds thick to very thick, irregular, uneven, with medium curved (continuous/parallel) laminae; large scale, tangential, low to high-angle, grouped, trough cross bedding present throughout unit; grains medium to coarse, moderately sorted, subangular to rounded; composed mainly of clear quartz and feldspar with clay matrix and noncalcareous cement; moderately indurated; unit becomes slightly carbonaceous in upper part; contact with above gradational, conformable.	6.1	(20.0)
4	SHALE--pale yellowish-green (10GY7/2) weathered, pale reddish-brown (10R5/4) fresh; beds very thick, regular, even, with medium wavy (continuous/parallel) laminae; noncalcareous cement; moderately indurated; locally contains plant stem molds; contact with above sharp, erosional.	2.0	(6.6)
3	SANDSTONE--light brown (5YR6/4) weathered, pale yellowish-green (10GY7/2) fresh; single very thick bed, irregular, with medium wavy (continuous/parallel) laminae; grains fine to medium, moderately well sorted, subrounded; composed mainly of clear quartz and feldspar with clay matrix and noncalcareous cement; moderately indurated; contact with above sharp, conformable.	1.8	(5.9)
2	CLAYSTONE--pale brown (5YR5/2) to grayish-orange pink (5YR7/2) weathered and fresh; single very thick bed, regular, even, massive; noncalcareous cement; moderately indurated; contact with above sharp, erosional.	1.3	(4.3)
1	GRANULAR SANDSTONE--pale brown (5YR5/2) weathered and fresh; single thick bed, irregular, massive; grains fine-sand to granules, poorly sorted, subangular to rounded; composed mainly of clear quartz, feldspar, and lithic fragments with clay matrix and noncalcareous cement; well indurated; contains dense iron nodules about 5 cm (2 in) thick and 40 cm (8 in) long; locally contains plant stem remains; contact with above sharp, conformable.	0.4	(1.3)

TOTAL SECTION THICKNESS = 144.9 (475.7)

Measurement was begun at base of lowest portion of Menefee Formation exposed at this locality, just above the contact with alluvium.

MEASURED SECTION SDC-2, CERRO DEL OJO DE LAS YEGUS (Guadalupe 7.5' Quadrangle). Northeast-facing slopes 6.4 km (4.0 mi) north of Guadalupe, and 0.8 km (0.5 mi) west of north-south dirt road, below small volcanic neck (Cerro del Ojo de las Yegus); SW¼, SW¼, SE¼, Sec.36, T16N, R4W (projected), Sandoval County; section measured by Steven Craigg and Scott Anderholm, June 1978 (also see Plate 1).

UNIT	LITHOLOGY	THICKNESS: M	(FT)
	SATAN TONGUE OF MANCOS SHALE		
14	INTERBEDDED SILTY SANDSTONES and SHALES	11.1+	(36.4)
b	SILTY SANDSTONES--yellowish-gray (5Y7/2) weathered and fresh; beds medium to thick, regular, uneven, with thin planar (continuous/parallel) laminae; grains very fine to fine, well sorted, subangular; composed mainly of clear quartz and feldspar(?) with clay matrix and noncalcareous cement; moderately indurated; contact with Shales sharp, conformable.		
a	SHALES--dark yellowish-green (10GY4/4) weathered and fresh; beds medium to thick, regular, uneven, with thin planar (continuous/parallel) laminae; noncalcareous cement; poorly indurated; contact with Silty Sandstones sharp, conformable.		
	Partially covered by sandy gravel deposits.		
	HOSTA TONGUE OF POINT LOOKOUT SANDSTONE		
13	SANDSTONE--yellowish-gray (5Y7/2) weathered and fresh; beds thick to very thick, regular, uneven, with thin to thick planar (continuous/	29.0	(95.2)

parallel to discontinuous/parallel) laminae; large scale, concordant, low-angle, solitary, wedge-planar cross bedding present throughout unit; grains fine, well sorted, subangular to subrounded; composed mainly of clear quartz and feldspar with clay matrix and calcite cement; well indurated; locally bioturbated and contains Ophiomorpha throughout unit; contact with above sharp, conformable.

Thickness of Hosta Tongue = 29.0 (95.2)

MULATTO TONGUE OF MANCOS SHALE/HOSTA TONGUE OF POINT LOOKOUT SANDSTONE TRANSITION ZONE

12 INTERBEDDED SANDSTONES and SHALES 12.0 (39.3)

b SANDSTONES--yellowish-gray (5Y7/2) weathered and fresh; beds thin to very thick, regular, uneven, with thin to thick planar (continuous/parallel) laminae; grains very fine to fine, well sorted, subangular to subrounded; composed mainly of clear quartz and feldspar(?) with clay matrix and calcite cement; moderately indurated; generally bioturbated and contains scattered Ophiomorpha and bivalves; contact with Shales sharp, conformable.

a SHALES--pale yellowish-brown (10YR6/2) weathered and fresh; beds medium, regular, uneven, with thin to medium planar (continuous/parallel) laminae; noncalcareous cement; moderately indurated; contact with Sandstones sharp, conformable.

Contact of unit 12 with unit 13 is sharp, conformable.

MULATTO TONGUE OF MANCOS SHALE

11 INTERBEDDED SANDSTONES and SHALES 8.0 (26.2)

b SANDSTONES--grayish-yellow green (5GY7/2) weathered and fresh; beds thin to thick, regular, uneven, with thin planar (continuous/parallel) laminae; grains very fine to fine, subangular to subrounded; composed mainly of clear quartz and feldspar(?) with clay matrix and calcite cement; moderately indurated; locally bioturbated; contact with Shales sharp, conformable.

a SHALES--pale brown (5YR5/2) weathered, dark reddish-brown (10R3/4) fresh; beds thick to very thick, regular, uneven, with thin planar (continuous/parallel) laminae; noncalcareous cement; poorly indurated; contact with Sandstones sharp, conformable.

Contact of unit 11 with unit 12 is gradational, conformable.

10	SANDSTONE--like sandstone in unit 4 below.	2.3	(7.5)
9	SHALE--like shale in unit 7 below.	1.4	(4.6)
8	SANDSTONE--like sandstone in unit 6 below.	0.9	(2.9)
7	SHALE--pale brown (5YR5/2) weathered, dark reddish-brown (10R3/4) fresh; beds thick, regular, uneven, with thin planar (continuous/parallel) laminae; noncalcareous cement; poorly indurated; contact with above sharp, erosional.	0.6	(2.0)
6	SANDSTONE--yellowish-gray (5Y7/2) weathered, grayish yellow-green (5GY7/2) fresh; beds medium to thick, regular, uneven, with thin planar (continuous/parallel) laminae; grains fine, well sorted, subrounded; composed mainly of clear quartz and feldspar with clay matrix and calcite cement; well indurated; generally bioturbated; contact with above sharp, conformable.	1.3	(4.3)
5	INTERBEDDED SANDSTONES and SHALES--same as unit 2 below.	12.0	(39.3)

Contact of unit 5 with unit 6 is sharp, conformable.

4	SANDSTONE--yellowish-gray (5Y7/2) weathered and fresh; single thick bed, regular, with thin to medium curved to wavy (continuous/parallel) laminae; large scale, tangential,	0.9	(2.9)

low-angle, grouped, trough cross bedding present throughout unit; grains fine, well sorted, subrounded; composed mainly of clear quartz and feldspar with clay matrix and calcite cement; well indurated; contact with above sharp, conformable.

3 INTERBEDDED SANDSTONES and SHALES--same as unit 1 below. 14.8 (48.5)

Contact of unit 3 with unit 4 is sharp, erosional.

2 LIMY SANDSTONE OR SANDY LIMESTONE--yellowish-gray (5Y7/2) weathered and fresh; single thick bed, regular, with medium planar (continuous/parallel) laminae; grains very fine to fine, well sorted, subangular to subrounded; composed mainly of clear quartz and feldspar(?) with calcite cement; well indurated; locally bioturbated and contains cephalopod fragments; contact with above sharp, conformable. 0.8 (2.6)

1 INTERBEDDED SANDSTONES and SHALES 19.5+ (63.9)

b SANDSTONES--yellowish-gray (5Y7/2) weathered, grayish yellow-green (5GY7/2) fresh; beds thin to thick, regular, uneven, with medium planar (continuous/parallel) laminae; grains fine, well sorted, subrounded; composed mainly of clear quartz and feldspar with clay matrix and calcite cement; well indurated; locally bioturbated; contact with Shales sharp, conformable.

a SHALES--pale brown (5YR5/2) weathered, dark reddish-brown (10R3/4) fresh; beds thick to very thick, regular, uneven, with thin planar (continuous/parallel) laminae; noncalcareous cement; poorly indurated; contact with Sandstones sharp, conformable.

Contact of unit 1 with unit 2 is sharp, conformable.

TOTAL SECTION THICKNESS = 114.6 (375.6)

Measurement was begun at the base of a tongue-shaped slope formed on the Mancos Shale, just above the contact with alluvium.

MEASURED SECTION SDC-3, LA CAÑADA SANTIAGO (Arroyo Empedrado 7.5' quadrangle). Southwest-facing slopes on Mesa San Luis, 9.6 km (6 mi) west of San Luis, and 2.8 km (1.75 mi) north of Cabezon Community Reservoir, on east side of road across La Cañada Santiago arroyo;' NE¼, NE¼, SW¼, Sec.34, T17N, R3W, Sandoval County; section measured by Steven Craigg and Scott Anderholm, June 1978 (see Fig. 20-A, p. 50; Plate 1).

UNIT	LITHOLOGY	THICKNESS: M	(FT)
	POINT LOOKOUT SANDSTONE		
11	SANDSTONE--light olive-gray (5Y5/2) weathered and fresh; beds thin to thick, irregular to regular, uneven, with thick planar (continuous/parallel) laminae; grains fine to medium, moderately well sorted, subangular to subrounded; composed mainly of clear quartz and feldspar with clay matrix and calcite cement; moderately indurated; unit is slope-forming and weathers with a pitted appearance; top of unit eroded.	3.0	(9.8)
10	SANDSTONE--light olive-gray (5Y5/2) weathered and fresh; beds thick to very thick, regular, uneven, either massive or with medium planar (continuous/parallel to discontinuous/parallel) laminae; large scale, tangential to concordant, low-angle, solitary, wedge-planar cross bedding occurs locally in calcite-cemented, well inurated concretionary zones; grains fine to medium, moderately well sorted, subangular to subrounded; composed mainly of clear quartz and feldspar with clay matrix and calcite cement; well indurated; unit contains abundant *Ophiomorpha*; contact with above sharp, conformable.	17.3	(56.8)

9	SHALE--dark greenish-yellow (10Y6/6) weathered, light olive-gray (5Y5/2) fresh; beds medium, regular, uneven, with thin planar (continuous/parallel) laminae; noncalcareous cement; moderately indurated; contact with above sharp, conformable.	0.4	(1.3)
8	SANDSTONE--dusky yellow (5Y6/4) weathered, pale olive (10Y6/2) fresh; beds thick, regular, even, with medium planar (continuous/paralle) laminae; grains fine, well sorted, subangular to subrounded; composed mainly of clear quartz and feldspar with clay matrix and calcite cement; moderately indurated; contact with above sharp, conformable.	2.4	(7.9)
7	SANDSTONE--light olive-brown (5Y5/6) weathered, pale olive (10Y6/2) fresh; single very thick bed, regular, massive; grains fine to medium, moderately well sorted, subangular to subrounded; composed mainly of clear quartz and feldspar with clay matrix and calcite cement; well indurated; contains scattered iron-stained concretions about 2 by 4 cm (1 by 2 in) in size; contact with above sharp, conformable.	1.5	(4.9)
6	SANDSTONE--light olive-gray (5Y6/1) weathered, pale olive (10Y6/2) fresh; beds thick, regular, uneven, with medium planar (continuous/parallel) laminae; grains fine to medium, moderately well sorted, subangular to subrounded; composed mainly of clear quartz and feldspar with clay matrix and calcite cement; moderately indurated; contact with above sharp, conformable.	1.6	(5.3)
5	SANDSTONE--light olive-brown (5Y5/6) weathered, pale olive (10Y6/2) fresh; single very thick bed; regular, massive; grains fine, well sorted, subangular; composed mainly of clear quartz and feldspar with clay matrix and calcite cement; well indurated; contains scattered iron-nodules about 2 by 2 cm (1 by 1 in) in size; contact with above sharp, conformable.	2.8	(9.2)
	Measured thickness of Point Lookout Sandstone =	29.0	(95.2)

SATAN TONGUE OF MANCOS SHALE/POINT LOOKOUT SANDSTONE TRANSITION ZONE

4	INTERBEDDED SILTY SANDSTONES and SILTY SHALES	17.4	(57.0)
b	SILTY SANDSTONES--pale olive (10Y6/2) weathered and fresh; beds thin to thick, irregular to regular, uneven, either massive or with thin to medium planar (continuous/parallel) laminae, some beds are lenticular and scour-like bases; grains very fine to fine, well sorted, subangular; composed mainly of clear quartz and feldspar(?) with clay matrix and calcite and silica(?) cement; moderately to well indurated; generally bioturbated; contact with Silty Shales sharp, conformable.		
a	SILTY SHALES--dark greenish-gray (10Y6/6) weathered, light olive gray (5Y5/2) fresh; beds medium to thick, regular, uneven, with thin planar (continuous/parallel) laminae; noncalcareous cement; moderately indurated; contact with Silty Sandstones sharp, and either erosional or conformable.		

Contact of unit 4 with unit 5 is sharp, conformable.

3	Interval covered by thick talus and colluvial deposits; unit is slope-forming and most likely consists of thin-bedded silty sandstones and thick-bedded silty shales.	11.4	(37.4)

SATAN TONGUE OF MANCOS SHALE

2	SILTY SANDSTONE--light olive-gray (5Y5/2) weathered, grayish yellow green (5GY7/2) fresh; one medium bed, regular, with thin planar (continuous/parallel) laminae; grains very fine to fine, well sorted, subangular; composed mainly of clear quartz and feldspar(?) with clay matrix and calcite cement; well indurated; unit is locally bioturbated; contact with above sharp, conformable.	0.3	(1.0)

1	SILTY SHALE--light olive-brown (5Y5/6) to grayish olive (10Y4/2) weathered and fresh; beds thin, regular, even, with thin wavy to planar (continuous/parallel) laminae; calcite cement, moderately indurated; contact with above sharp, conformable.	2.7	(8.9)
	TOTAL SECTION THICKNESS =	60.8	(199.5)

Measurement was begun at the base of a tongue-shaped slope formed on the Mancos Shale, just above the contact with alluvium. Selenite crystals were abundant at this locality.

MEASURED SECTION SDC-4, RINCON LARGO (Arroyo Empedrado 7.5' Quadrangle). Northwest-facing slopes on Mesa San Luis, 16.6 km (11.4 mi) west of San Luis, and 1.2 km (0.75 mi) north of Chico Arroyo/Torreon Wash stream junction, on southeast side of Rincon Largo arroyo; NE¼, NE¼, NW¼, Sec.11, T16N, R4W, Sandoval County; section measured by Steven Craigg, September 1978 (see Fig.20-B, p. 50; Plate 1).

UNIT	LITHOLOGY	THICKNESS: M	(FT)
	POINT LOOKOUT SANDSTONE		
13	SANDSTONE--pale olive (10Y6/2) weathered, light olive-gray (5Y5/2) fresh; beds thick to very thick, irregular to regular, uneven, either massive or with thick planar (continuous/parallel) laminae; grains fine to medium, moderately well sorted, subangular to subrounded; composed mainly of clear quartz and feldspar with clay matrix and noncalcareous cement; poorly to moderately indurated; unit is slope-forming and partially covered by eolian(?) sand; top of unit eroded.	3.6	(11.8)
12	SANDSTONE--yellowish gray (5Y7/2) weathered, pale olive (10Y6/2) fresh; beds thick to very thick, regular, uneven, either massive or with thin to medium planar (continuous/parallel) or curved (discontinuous/parallel) laminae; large scale, tangential, low-angle, solitary, trough cross bedding occurs locally in calcite-cemented, well indurated concretionary zones; grains fine to medium, moderately well sorted, subangular to subrounded; composed mainly of clear quartz and feldspar with clay matrix and calcite	12.2	(40.0)

cement in cross-bedded zones, noncalcareous cement in planar-bedded and massive zones; well indurated; unit contains abundant Ophiomorpha; contact with above sharp, conformable.

11	LIMY SILTY SANDSTONE--light olive (10Y5/4) weathered, yellowish gray (5Y7/2) fresh; single thick bed, irregular, massive; grains fine, well sorted, subrounded; composed mainly of clear quartz and feldspar with calcite cement; well indurated; contact with above sharp, conformable.	0.6	(2.0)
10	SANDSTONE--yellowish gray (5Y7/2) weathered, pale olive (10Y6/2) fresh; beds thick to very thick, irregular, uneven, either massive or with thin to medium planar (continuous/parallel) or curved (discontinuous/parallel) laminae; large scale, tangential, low-angle, solitary, trough cross bedding occurs locally in calcite-cemented, well indurated, iron-stained concretionary bodies about 0.5 m (1.6 ft) thick and 4 to 5 m (13 to 16 ft) long; grains fine to medium, well sorted, subangular to subrounded; composed mainly of clear quartz and feldspar with clay matrix and calcite cement in cross-bedded zones, noncalcareous cement in planar-bedded and massive zones; contains scattered Ophiomorpha; contact with above sharp, conformable.	3.2	(10.5)
9	INTERBEDDED SILTY SANDSTONES and SILTY SHALES--like unit 1 below.	1.7	(5.6)

Contact of unit 9 with unit 10 is sharp, conformable.

8	LIMY SANDSTONE--yellowish gray (5Y7/2) weathered, pale olive (10Y6/2) fresh; single thick bed, irregular, with medium curved (discontinuous/parallel) laminae; large scale, tangential, low-angle, solitary, trough cross bedding present throughout unit; grains fine to medium, moderately well sorted, subangular to subrounded; composed mainly of clear quartz and feldspar with clay matrix and calcite cement; well indurated; contact with above sharp, conformable.	0.8	(2.6)

7 SHALE--moderate brown (5YR3/4) weathered and fresh; single very thick bed, regular, with thin planar (continuous/parallel) laminae; noncalcareous cement; moderately indurated; contact with above sharp, conformable. 1.5 (4.9)

6 LIMY SANDSTONE--pale brown (5YR5/2) weathered yellowish gray (5Y7/2) fresh; single thick bed, regular, with medium to thick planar (continuous/parallel) laminae; grains fine to medium, moderately well sorted, subangular to subrounded; composed mainly of clear quartz and feldspar with clay matrix and calcite cement; well indurated; contact with above sharp, conformable. 0.5 (1.6)

5 SANDSTONE--like sandstone in unit 3 below. 2.7 (8.9)

4 INTERBEDDED SILTY SANDSTONES and SILTY SHALES--same as unit 1 below. 1.1 (3.6)

Contact of unit 4 with unit 5 is sharp, conformable.

3 SANDSTONE--yellowish gray (5Y7/2) weathered pale olive (10Y6/2) fresh; single very thick bed, irregular, massive; grains fine, well sorted, subangular; composed mainly of clear quartz and feldspar with clay matrix and calcite cement; well indurated; bioturbated; contact with above sharp, conformable. 1.6 (5.2)

Measured thickness Point Lookout Sandstone = 26.8 (87.9)

SATAN TONGUE OF MANCOS SHALE/POINT LOOKOUT SANDSTONE TRANSITION ZONE

2 INTERBEDDED SILTY SANDSTONES and SILTY SHALES 12.5 (41.0)

b SILTY SANDSTONES--pale olive (10Y6/2) weathered, yellowish gray (5Y7/2) fresh; beds thin to thick, irregular to regular, either massive or with thin to medium planar (continuous/parallel) laminae, some beds are lenticular and have scour-like bases; grains very fine to fine, well sorted, subangular; composed mainly of clear quartz and feldspar(?) with clay matrix and calcite and silica(?) cement; moderately to well indurated; generally bioturbated; contact with Silty Shales sharp, conformable.

a SILTY SHALES--light olive-gray (5Y5/2) weathered and fresh; beds medium, regular, uneven, with thin planar (continuous/parallel) laminae; noncalcareous cement; moderately indurated; contact with Silty Sandstones sharp, and either erosional or conformable.

Contact of unit 2 with unit 3 is sharp, conformable.

SATAN TONGUE OF MANCOS SHALE

1 INTERBEDDED SILTY SANDSTONES and SHALES 14.4+ (47.2+)

b SILTY SANDSTONES--grayish-yellow green (5GY7/2) weathered and fresh; beds thin to thick, irregular to regular, uneven, with thin planar to curved (continuous/parallel) laminae; small scale, concordant to tangential, low-angle, solitary, wedge-planar and trough cross bedding present throughout Sandstones; grains fine to medium, well sorted, subangular; composed mainly of clear quartz and feldspar(?) with clay matrix and calcite cement; moderately indurated; contains scattered bivalve fragments; contact with Shales sharp, conformable.

a SHALES--dusky yellow (5Y4/6) to grayish olive (10Y4/2) weathered and fresh; beds thin to thick, regular, uneven, with thin planar (continuous/parallel) laminae; calcite and silica(?) cement; moderately indurated; contact with Silty Sandstones sharp, and either erosional or conformable.

Contact of unit 1 with unit 2 is gradational, conformable.

TOTAL SECTION THICKNESS = 56.4 (185.0)

Measurement was begun about halfway up a tongue-shaped slope formed on the Mancos Shale.

MEASURED SECTION SDC-5, GUADALUPE CAÑON (Guadalupe 7.5' quadrangle). South-facing slopes 1.2 km (0.75 mi) south of Quadalupe where north-south dirt road makes abrupt turn to west, on north side of road; 35°31'52" north latitude, 107°08'57" west longitude (Ignacio Chavez Grant), Sandoval County; section measured by Steven Craigg and Scott Anderholm, June 1978 (see Plate 1).

UNIT	LITHOLOGY	THICKNESS: M	(FT)
	MULATTO TONGUE OF MANCOS SHALE		
5	SANDSTONE--moderate yellowish-green (10GY6/4) to light brown (5YR6/4) to pale brown (5YR5/2) weathered, moderate yellowish-green (10GY6/4) to light brown (5YR6/4) fresh; beds medium to thick, regular, uneven, with medium planar (continuous/parallel) laminae; grains medium to coarse, moderately sorted, subrounded to rounded; composed mainly of clear quartz and feldspar with clay matrix and calcite cement; well indurated; contains scattered spheroidal concretions up to 0.5 m (1.6 ft) in diameter with crystalline calcite centers; unit is generally bioturbated, contains Ophiomorpha, bivalves, and locally contains finely-disseminated plant fragments.	6.4	(21.0)
4	INTERBEDDED SANDSTONES AND SILTY SHALES	19.1	(62.6)
b	SANDSTONES--yellowish gray (5Y7/2) weathered and fresh; beds thin, regular, even, with medium planar (continuous/parallel) laminae; grains fine, well sorted, subrounded; composed mainly of clear quartz and feldspar with clay matrix and calcite cement; well indurated; contact with Silty Shales sharp conformable.		
a	SILTY SHALES--moderate brown (5YR4/4) to pale brown (5YR5/2) weathered and fresh; beds thin, regular, uneven, with thin		

planar to wavy (continuous/parallel) laminae; noncalcareous cement; poorly indurated; contact with Sandstones sharp, conformable.

Contact of unit 4 with unit 5 is sharp, conformable.

GALLUP SANDSTONE

3	SANDSTONE--very light gray (N8) to pinkish gray (5YR8/1) weathered and fresh; beds medium to thick, regular, uneven, with medium curved (noncontinuous/parallel) laminae; large scale, tangential, low-angle, grouped, trough cross bedding present throughout unit; grains fine to coarse, moderately sorted, angular to subrounded; composed mainly of clear quartz and feldspar with clay matrix and calcite cement; well indurated; contact with above sharp, conformable.	1.5	(4.9)

Line of measured section offset 0.5 km (0.3 mi) to southwest into valley (see Plate 1).

2	SANDSTONE--moderate yellow-green (5GY7/4) to moderate greenish-yellow (10Y7/4) weathered, yellowish gray (5Y7/2) to grayish yellow-green (5GY7/2) fresh; beds thick, regular, uneven, with medium planar (continuous/parallel) laminae; grains fine to medium, moderately well sorted, subrounded; composed mainly of clear quartz and feldspar with clay matrix and calcite cement; well indurated; contains scattered spheroidal iron-stained concretions up to 0.5 m (1.6 ft) in diameter with crystalline calcite centers; unit is generally bioturbated and contains <u>Ophiomorpha</u>; weathers with a "beehive-like" surface; contact with above sharp, conformable.	18.7	(61.4)
	Measured thickness of Gallup Sandstone =	20.2	(66.2)

"LOWER" MANCOS SHALE

1	INTERBEDDED SANDSTONES and SHALES	9.0+	(29.5+)
b	SANDSTONES--pale brown (5YR5/2) to light		

brown (5YR6/4) to moderate yellowish-green (10GY6/4) weathered, light brown (5YR6/4) to moderate yellowish-green (10GY6/4) fresh; beds thin to thick, regular, uneven, with thin to medium planar (continuous/parallel) laminae; grains fine to medium, moderately well sorted, subrounded; composed mainly of clear quartz and feldspar with clay matrix and calcite cement; well indurated; generally bioturbated; contact with shales sharp, conformable.

a SHALES--dusky yellow (10GY3/2) to very pale green (10G8/2) weathered and fresh; beds thin, regular, even, with thin wavy (continuous/parallel) laminae; contact with Sandstones sharp, conformable.

Contact of unit 1 with unit 2 is sharp, conformable.

TOTAL SECTION THICKNESS = 54.7 (179.3)

Measurement was begun at the lowest portion of the Mancos Shale exposed at this locality, at the contact with alluvium in Guadalupe Cañon.

APPENDIX B

RESULTS OF MINERALOGIC (THIN-SECTION) ANALYSES

Thirteen thin sections of rock samples from potential aquifers were examined to determine the amounts of framework components, matrix (clay filling interstices between grains), cement, and porosity. Three samples were from channel sandstones in the Menefee Formation, six were from the Point Lookout Sandstone, one was from the Hosta Tongue of the Point Lookout, and three were from the Gallup Sandstone. Two Menefee and four Point Lookout samples were from drill core. Samples closely correspond to those used for the textural analyses (Appendix C).

Thin sections were either prepared in the NMBMMR laboratory or were commercially prepared (Western Petrographic). All slides were stained for potassium feldspar by the cobalto-nitrate method.

The analyses were performed with a binocular polarizing microscope and mechanical stage; point counts were recorded with manual laboratory counters. Prior to each point count, a hand speciman corresponding to each thin section was examined. General procedure was to first scan each thin section to become familar with constituents present, noting useful parameters such as grain-size range, model grain-size, general sorting, range of elongation indices (Folk, 1974), and accessory minerals. The technique used for point counting consisted of two phases. The first involved counting 100 points to determine percentages of cement, matrix, porosity, and framework. Counting was then resumed, recording only framework points, until a total of 300 framework points had been counted. Table B-1 and Figure B-1 summarize results of the mineralogic analyses.

Operator precision was checked by performing three point counts on the same sample, at the same point spacing, but scanning the slide in different ways (table B-2). Accuracy was not determined, but operator bias was checked by comparing results of three point counts by the author with results of a point count by Brown (1976, sample AR-B, p. 140; table B-3).

Point count data were analyzed with the aid of a computer program originally written by Williams and Randazzo (1076). This program was modified by the author for use with the point counting technique employed in this study and the computer at New Mexico Tech. The program is on file at the NMBMMR. The printouts which follow contain the following information:

1) Sample number, total points counted, and framework points counted (always 300).

2) Numbers of points counted for individual constituents (QTZ = quartz, KSPAR = potassium fledspar, PLAG = plagioclase feldspar, UNDFS = undifferentiated feldspar, GR-RF = granitic rock fragments, VRF = other igneous rock fragments, MRF = metamorphic rock fragments, CHERT = chert rock fragments, CARF = carbonate rock fragments, SSRF = sandstone rock fragments, SHRF = shale and siltstone rock fragments; FECM = iron-oxide cement, CACM = calcite cement, SICM = silica cement, CLAY = matrix, any clay material filling interstices between grains, POROSITY = thin-section porosity). The last five constituents are noted only in the first 100 points counted and thus directly re-

Table B-1. Location, stratigraphic unit, and miscellaneous characteristics and constituents of samples used in the minerologic analyses.[1]

Analysis number	Sample number	Unit	Location	Percent Framework	Rdns	E.I.	Accessory minerals
1	SDC-1-4b	Kmfu	SE¼, Sec31, T18N, R4W	73	A-R	VEL-SE	Op,M,B
2	SDC-2-2	Kph	SE¼, Sec36, T16N, R4W	76	A-SR	VEL-VE	Op
3	SDC-3-3b	Kpl	SW¼, Sec34, T17N, R3W	73	A-R	VEL-E	Op,M
4	SDC-4-4	Kpl	NW¼, Sec11, T16N, R4W	87	A-R	VEL-VE	Op,M
5	SDC-5-1a	Kg	35° 31′ 52″ N. lat.	86	A-SR	VEL-VE	Op,M
6	SDC-5-1b	Kg		87	A-R	VEL-VE	Op,M
7	SDC-5-1c	Kg	107° 08′ 57″ W. long.	64	A-WR	VEL-VE	M
8	C5-91.9	Kmfc	NW¼, Sec5, T16N, R4W	82	A-R	VEL-E	Op,M,B
9	C5-162.3	Kpl	NW¼, Sec5, T16N, R4W	81	A-R	VEL-VE	M,B,Z,Or
10	C5-190	Kpl	NW¼, Sec5, T16N, R4W	77	A-SR	VEL-VE	Op,M,B,Or
11	C6-5-37	Kmfc	NW¼, Sec17, T16N, R5W	76	A-WR	VEL-VE	Op,M,B
12	C6-3-150	Kpl	NW¼, Sec17, T16N, R5W	82	SA-R	VEL-VE	Op,M,B
13	C6-4-218	Kpl	NW¼, Sec17, T16N, R5W	74	A-SR	VEL-VE	Op,M,B

[1] Unit abbreviations same as Plate 1.
Rdns = roundness (Krumbein and Sloss, 1963, Figure 4-10): A=angular, SA=subangular, SR=subrounded; R=rounded, WR=well rounded. E.I.=elongation index (Folk, 1974): VEL=very elongate, SE=subequant, E=equant, VE=very equant. Accessory minerals: Op=opaques, M=muscovite, B=biotite, Z=zircon, Or=organic material. (See Table B-1 for plots of framework composition and classification).

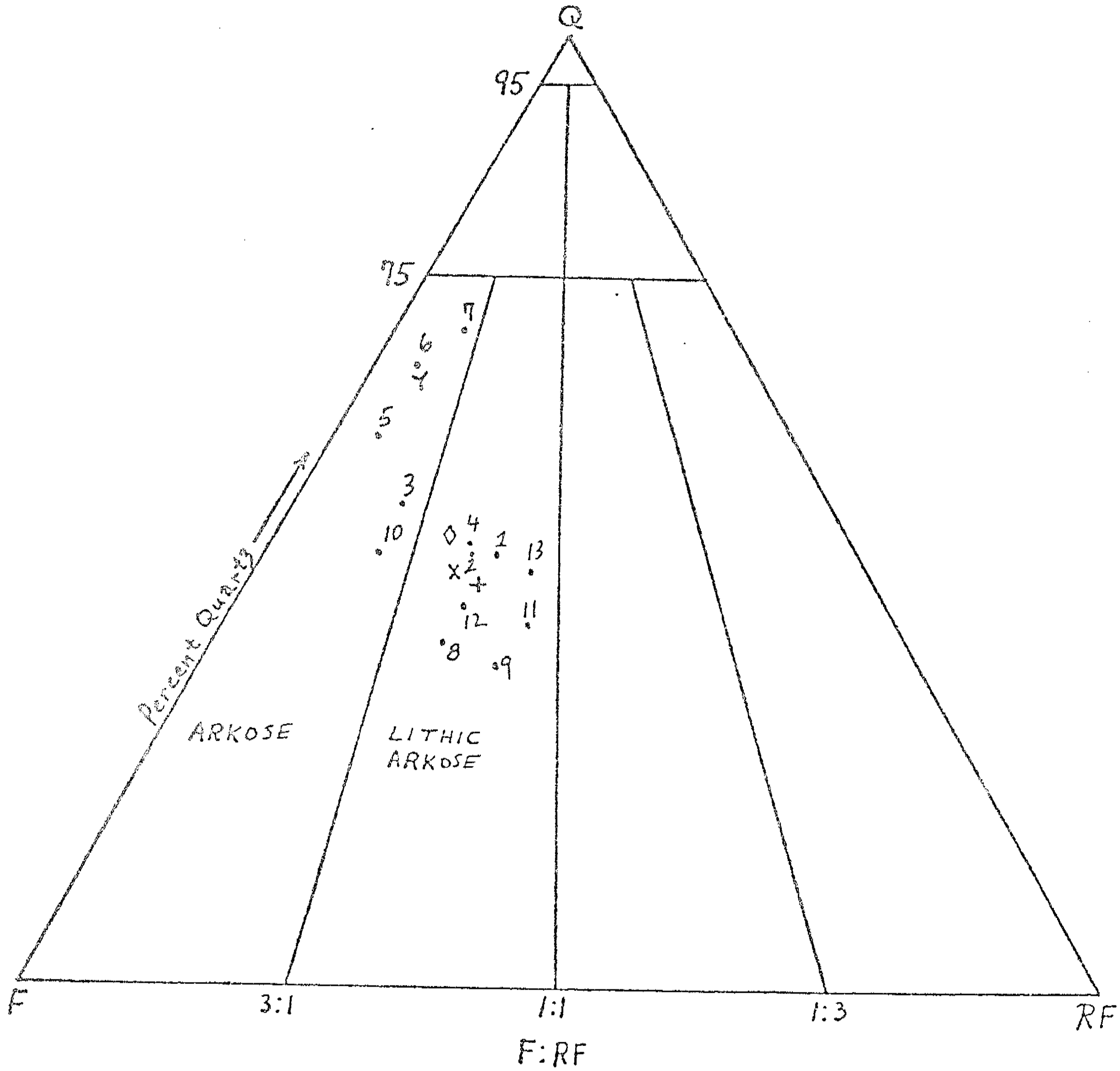
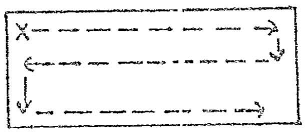
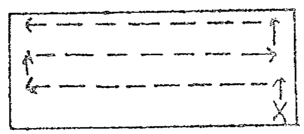
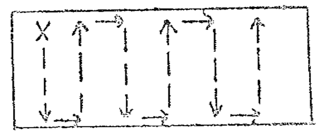


Figure B-1. Framework composition and classification for potential aquifers in the Chico Arroyo/Torreon Wash area. Samples identified by analysis number (table B-1). Q = quartz, F = feldspar plus granitic rock fragments, RF = chert plus other rock fragments (Folk, 1974) + = average for Menefee Formation, X = average for Point Lookout Sandstone, Y = average for Gallup Sandstone, ◊ = average for all samples.

Table B-2. Results of multiple point counts on sample C6-5-37[1].

Starting positions and sequence of points counted	RUN 1	RUN 2	RUN 3			
						
Component				Mean	Variance	Standard Deviation
QTZ	114	120	117	177.0	6.0	2.4
KSPAR	75	78	73	75.3	4.2	2.0
PLAG	12	8	10	10.0	2.6	1.6
UNDFS	6	3	8	5.6	4.2	2.0
GR-RF	9	7	11	9.0	2.6	1.6
VRF	9	11	8	9.3	1.5	1.2
MRF	18	15	20	17.6	4.2	2.0
CHERT	36	37	33	35.3	2.9	1.7
CARF	not observed	not observed	not observed	not applicable		
SSRF	6	4	7	5.6	1.5	1.2
SHRF	15	17	13	15.0	2.6	1.6
FECM	2	not observed	not observed	0.6	0.9	0.9
CACM	7	9	10	8.6	1.5	1.2
SICM	not observed	not observed	not observed	not applicable		
CLAY	8	10	6	8.0	2.6	1.6
POROSITY	7	6	8	7.0	0.6	0.8
Group Name	Lithic Arkose	Lithic Arkose	Lithic Arkose			

[1] Horizontal spacing = 0.2 mm, vertical spacing = 0.3 mm
Abbreviations explained on p. 149.
Point-counting technique explained on p. 148.

Table B-3. Results of operator bias check[1]

		Percentages			
		Quartz	Feldspar	Rock fragments	Framework
Brown (1976)		57	37	9	71
Craigg	Run 1	61	34	5	73
	Run 2	58	34	8	80
	Run 3	53	34	13	78

[1]sample AR-B (Brown, 1976, p. 140)

present whole rock percentages.

3) Framework percentages (based on 300 points); used to classify the rock (Folk, 1974).

4) Group name (based on the field in which a rock plots on a triangular diagram like Figure B-1).

5) Specific name (based on the most commonly occurring feldspar).

A zero in a particular column on the printouts indicates that the constituent was not observed.

SAMPLE NUMBER = SJC-1-4B   TOTAL POINTS COUNTED = 327   FRAMEWORK POINTS = 300

RAW DATA (INDIVIDUAL POINTS)

*QTZ	*KSPAR	*PLAG	*UNDFS	*GR-RF	*VRF	*MRF	*CHERT	*CARF	*SSRF	*SHRF	*(FECM	*CACM	*SICM	*CLAY	*POROSITY)
137	85	12	0	2	8	5	34	0	10	7	3	10	0	6	8

FRAMEWORK PERCENTAGES

Q-POLE**** 45.7

F-POLE**** 33.0
  KSPAR 87.6
  FLAG 12.4
  UNDFS 0.0
  GR-RF 0.0
R-POLE**** 21.7
  VRF 12.5
  MRF 7.8
  SRF 79.7
    SED-RF POLE
      CHERT 66.7
      CARF 0.0
      SSRF 19.6
      SHRF 13.7

GROUP NAME IS **** LITHIC ARKOSE

SPECIFIC NAME IS **** K-FELDSPAR-BEARING LITHIC ARKOSE

SAMPLE NUMBER = SDC-2-2 TOTAL POINTS COUNTED = 328 FRAMEWORK POINTS = 300

RAW DATA (INDIVIDUAL POINTS)

*QTZ	*KSPAR	*PLAG	*UNDFS	*GR-RF	*VRF	*MRF	*CHERT	*CARF	*SSRF	*SHRF	*(FECM	*CACM	*SICM	*CLAY	*POROSITY)
139	89	13	4	0	8	5	42	0	0	0	4	2	8	8	6

FRAMEWORK PERCENTAGES

Q-POLE**** 46.3

F-POLE**** 35.3
  KSPAR 84.0
  PLAG 12.3
  UNDFS 3.8
  GR-RF 0.0
R-POLE**** 18.3
  VRF 14.5
  MRF 9.1
  SRF 76.4
    SED-RF POLE
      CHERT 100.0
      CARF 0.0
      SSRF 0.0
      SHRF 0.0

GROUP NAME IS **** LITHIC ARKOSE

SPECIFIC NAME IS **** K-FELDSPAR-BEARING LITHIC ARKOSE

```
SAMPLE NUMBER = SDC-3-3B      TOTAL POINTS COUNTED = 327     FRAMEWORK POINTS = 300

RAW DATA (INDIVIDUAL POINTS)
-----------------------------

*QTZ*KSPAR*FLAG*UNDFS*GR--RF*VRF*MRF*CHERT*CARF*SSRF*SHRF*(FECM*CACM*SICM*CLAY*POROSITY)
 151   92   17     0      9    5    0     26     0     0     0     6     4     2     8      7

FRAMEWORK PERCENTAGES
---------------------

Q-POLE**** 50.3

F-POLE**** 39.3
  KSPAR    78.0
  PLAG     14.4
  UNDFS     0.0
   GR-RF    7.6
R-POLE**** 10.3
  VRF     16.1
  MRF      0.0
  SRF     83.9
    SED-RF POLE
     CHERT 100.0
     CARF    0.0
     SSRF    0.0
     SHRF    0.0

GROUP NAME IS **** ARKOSE

SPECIFIC NAME IS **** K-FELDSPAR-BEARING ARKOSE
```

SAMPLE NUMBER = SDC-4-4 TOTAL POINTS COUNTED = 313 FRAMEWORK POINTS = 300

RAW DATA (INDIVIDUAL POINTS)

QTZ	KSPAR	PLAG	UNDFS	GR-RF	VRF	MRF	CHERT	CARF	SSRF	SHRF	(FECM	CACM	SICM	CLAY	POROSITY)
143	77	15	7	5	12	8	29	0	2	2	3	0	0	4	6

FRAMEWORK PERCENTAGES

Q-POLE**** 47.7

F-POLE**** 34.7
  KSPAR 74.0
  PLAG 14.4
  UNDFS 6.7
  GR-RF 4.8
R-POLE**** 17.7
  VRF 22.6
  MRF 15.1
  SRF 62.3
    SED-RF POLE
     CHERT 87.9
     CARF 0.0
     SSRF 6.1
     SHRF 6.1

GROUP NAME IS **** LITHIC ARKOSE

SPECIFIC NAME IS **** K-FELDSPAR-BEARING LITHIC ARKOSE

```
SAMPLE NUMBER = SDC-5-1A     TOTAL POINTS COUNTED = 314     FRAMEWORK POINTS = 300

RAW DATA (INDIVIDUAL POINTS)
--------------------------------

*QTZ*KSPAR*FLAG*UNDFS*GR-RF*VRF*MRF*CHERT*CARF*SSRF*SHRF*(FECM*CACM*SICM*CLAY*POROSITY)
 174  100   14     0     0    0   0    12     0     0    0     4    0    0    6      4

FRAMEWORK PERCENTAGES
---------------------

Q-POLE**** 58.0

F-POLE**** 38.0
  KSPAR  87.7
  FLAG   12.3
  UNDFS   0.0
  GR-RF   0.0
R-POLE****  4.0
  VRF     0.0
  MRF     0.0
  SRF   100.0
    SED-RF POLE
     CHERT 100.0
     CARF    0.0
     SSRF    0.0
     SHRF    0.0

GROUP NAME IS **** ARKOSE

SPECIFIC NAME IS **** K-FELDSPAR-BEARING ARKOSE
```

```
SAMPLE NUMBER = SDC-5-1B     TOTAL POINTS COUNTED = 313     FRAMEWORK POINTS = 300

RAW DATA (INDIVIDUAL POINTS)
----------------------------

*QTZ*KSPAR*FLAG*UNDFS*GR-RF*VRF*MRF*CHERT*CARF*SSRF*SHRF*(FECM*CACM*SICM*CLAY*POROSITY)
 196   86    7     0     0   0   0    11    0    0    0     2    0    0    3     8

FRAMEWORK PERCENTAGES
---------------------

Q-POLE**** 65.3

F-POLE**** 31.0
  KSPAR  92.5
  PLAG    7.5
  UNDFS   0.0
  GR-RF    0.0
R-POLE****  3.7
  VRF     0.0
  MRF     0.0
  SRF   100.0
    SED-RF POLE
     CHERT 100.0
     CARF    0.0
     SSRF    0.0
     SHRF    0.0

GROUP NAME IS **** ARKOSE

SPECIFIC NAME IS **** K-FELDSPAR-BEARING ARKOSE
```

SAMPLE NUMBER = SDC-5-1C   TOTAL POINTS COUNTED = 336   FRAMEWORK POINTS = 300

RAW DATA (INDIVIDUAL POINTS)

QTZ	KSPAR	PLAG	UNDFS	GR-RF	VRF	MRF	CHERT	CARF	SSRF	SHRF	(FECM	CACM	SICM	CLAY	POROSITY)
206	68	7	0	0	0	0	19	0	0	0	0	34	0	2	0

FRAMEWORK PERCENTAGES

```
Q-POLE**** 68.7

F-POLE**** 25.0
  KSPAR  90.7
  PLAG    9.3
  UNDFS   0.0
  GR-RF   0.0
R-POLE****  6.3
  VRF     0.0
  MRF     0.0
  SRF   100.0
    SED-RF POLE
     CHERT 100.0
     CARF    0.0
     SSRF    0.0
     SHRF    0.0
```

GROUP NAME IS **** ARKOSE

SPECIFIC NAME IS **** K-FELDSPAR-BEARING ARKOSE

SAMPLE NUMBER = C5-91.9   TOTAL POINTS COUNTED = 318   FRAMEWORK POINTS = 300

RAW DATA (INDIVIDUAL POINTS)

*QTZ	*KSPAR	*FLAG	*UNDFS	*GR-RF	*VRF	*MRF	*CHERT	*CARF	*SSRF	*SHRF	*(FECM	*CACM	*SICM	*CLAY	*POROSITY)
111	96	6	9	14	13	12	27	0	9	3	4	0	0	6	8

FRAMEWORK PERCENTAGES

```
Q-POLE**** 37.0

F-POLE**** 41.7
  KSPAR     76.8
  FLAG       4.8
  UNDFS      7.2
  GR-RF     11.2
R-POLE**** 21.3
  VRF     20.3
  MRF     18.8
  SRF     60.9
    SED-RF POLE
     CHERT   69.2
     CARF     0.0
     SSRF    23.1
     SHRF     7.7
```

GROUP NAME IS **** LITHIC ARKOSE

SPECIFIC NAME IS **** K-FELDSPAR-BEARING LITHIC ARKOSE

SAMPLE NUMBER = C5-162.3   TOTAL POINTS COUNTED = 318   FRAMEWORK POINTS = 300

RAW DATA (INDIVIDUAL POINTS)

*QTZ	*KSPAR	*PLAG	*UNDFS	*GR-RF	*VRF	*MRF	*CHERT	*CARF	*SSRF	*SHRF	*(FECM	*CACM	*SICM	*CLAY	*POROSITY)
102	102	3	3	9	4	15	45	1	7	9	0	4	1	6	7

FRAMEWORK PERCENTAGES

```
Q-POLE**** 34.0

F-POLE**** 39.0
  KSPAR    87.3
  PLAG      2.5
  UNDFS     2.5
  GR-RF     7.7
R-POLE**** 27.0
  VRF      4.9
  MRF     18.5
  SRF     76.5
    SED-RF POLE
     CHERT  72.6
     CARF    1.6
     SSRF   11.3
     SHRF   14.5
```

GROUP NAME IS **** LITHIC ARKOSE

SPECIFIC NAME IS **** K-FELDSPAR-BEARING LITHIC ARKOSE

SAMPLE NUMBER = CS-190 TOTAL POINTS COUNTED 323 FRAMEWORK POINTS 300

RAW DATA (INDIVIDUAL POINTS)

*QTZ	*KSPAR	*FLAG	*UNDFS	*GR-RF	*VRF	*MRF	*CHERT	*CARF	*SSRF	*SHRF	*(FECM	*CACM	*SICM	*CLAY	*POROSITY)
138	111	2	8	10	5	1	14	4	5	2	1	5	3	6	8

FRAMEWORK PERCENTAGES

Q-POLE**** 46.0

F-POLE**** 43.7
- KSPAR 84.7
- FLAG 1.5
- UNDFS 6.1
- GR-RF 7.6

R-POLE**** 10.3
- VRF 16.1
- MRF 3.2
- SRF 80.6
  - SED-RF POLE
    - CHERT 56.0
    - CARF 16.0
    - SSRF 20.0
    - SHRF 8.0

GROUP NAME IS **** ARKOSE

SPECIFIC NAME IS **** K-FELDSPAR-BEARING ARKOSE

SAMPLE NUMBER = C6-5-37 TOTAL POINTS COUNTED = 324 FRAMEWORK POINTS = 300

RAW DATA (INDIVIDUAL POINTS)

```
*QTZ*KSPAR*FLAG*UNDFS*GR-RF*VRF*MRF*CHERT*CARF*SSRF*SHRF*(FECM*CACM*SICM*CLAY*POROSITY)
 114   75   12    6     9    9  18    36     0     6   15     2    7     0    8       7
```

FRAMEWORK PERCENTAGES

```
Q-POLE**** 38.0

F-POLE**** 34.0
  KSPAR    73.5
  PLAG     11.8
  UNDFS     5.9
  GR-RF     8.8
R-POLE**** 28.0
  VRF     10.7
  MRF     21.4
  SRF     67.9
    SED-RF POLE
     CHERT  63.2
     CARF    0.0
     SSRF   10.5
     SHRF   26.3
```

GROUP NAME IS **** LITHIC ARKOSE

SPECIFIC NAME IS **** K-FELDSPAR-BEARING LITHIC ARKOSE

```
SAMPLE NUMBER = C6-3-150      TOTAL POINTS COUNTED = 318      FRAMEWORK POINTS = 300

RAW DATA (INDIVIDUAL POINTS)
--------------------------------

*QTZ*KSPAR*FLAG*UNDFS*GR-RF*VRF*MRF*CHERT*CARF*SSRF*SHRF*(FECM*CACM*SICM*CLAY*POROSITY)
 121    83    14     12      7  10  18     35     0     0     0     2    4    0    7      5

FRAMEWORK PERCENTAGES
----------------------

Q-POLE**** 40.3

F-POLE**** 38.7
  KSPAR    71.5
  PLAG     12.1
  UNDFS    10.3
   GR-RF    6.0
R-POLE**** 21.0
  VRF     15.9
  MRF     28.6
  SRF     55.6
    SED-RF POLE
     CHERT 100.0
     CARF     0.0
     SSRF     0.0
     SHRF     0.0

GROUP NAME IS **** LITHIC ARKOSE

SPECIFIC NAME IS **** K-FELDSPAR-BEARING LITHIC ARKOSE
```

```
SAMPLE NUMBER = C6-4-218     TOTAL POINTS COUNTED = 326     FRAMEWORK POINTS = 300

RAW DATA (INDIVIDUAL POINTS)
--------------------------------

*QTZ*KSPAR*PLAG*UNDFS*GR-RF*VRF*MRF*CHERT*CARF*SSRF*SHRF*(FECM*CACM*SICM*CLAY*POROSITY)
 133   68   15 ,   5     4   6  17    34    0    0   18     2    9    0    7      8

FRAMEWORK PERCENTAGES
---------------------

Q-POLE**** 44.3

F-POLE**** 30.7
  KSPAR    74.0
  FLAG     16.3
  UNDFS     5.4
   GR-RF    4.3
R-POLE**** 25.0
  VRF      8.0
  MRF     22.7
  SRF     69.3
    SED-RF POLE
     CHERT  65.4
     CARF    0.0
     SSRF    0.0
     SHRF   34.6

GROUP NAME IS **** LITHIC ARKOSE

SPECIFIC NAME IS **** K-FELDSPAR-BEARING LITHIC ARKOSE
```

APPENDIX C

RESULTS OF TEXTURAL (MECHANICAL) ANALYSES

Fourteen mechanical analyses of selected samples from potential aquifers in the study area were performed to determine their general textural characteristics (sand, silt, clay content). Of the samples analyzed, three were from channel sandstones in the Menefee Formation, seven were from the Point Lookout Sandstone, one was from the Hosta Tongue of the Point Lookout, and three were from the Gallup Sandstone. Two of the Menefee and five of the Point Lookout samples were selected from core. All samples closely correspond to those used in the mineralogic analyses (Appendix B). Table C-1 gives the source of samples used in the textural analyses.

All analyses were performed in the NMBMMR by the author, except where notes. Disaggregation and sieving procedures were those of Folk (1974). The pan fraction (4Ø) from each sieve run was further analyzed by hydrometer according to the method given by Royse (1970). Statistics used to describe results are those of Folk (1974). For the sieving phase of the analyses, a quarter-phi-interval sieve set was used and samples were weighed to the nearest one-hundredth of a gram with a triple-beam balance.

Results of the textural analyses are plotted on a trilinear diagram (fig. C-1). End-members are silt plus clay, very fine plus fine sand, and medium plus coarse sand. All samples plot in the very fine plus fine sand field except for one Point Lookout sample, which

Table C-1. Location, stratigraphic unit, sorting, and sand/mud ratio for samples used in the textural analyses[1].

Analysis number	Sample number	Stratigraphic unit	Location	Sorting	Sand/mud ratio
1	SDC-1-4b	Kmfu	SE¼, Sec31, T18N, R4W	P	3.6
2	SDC-2-2	Kph	SE¼, Sec36, T16N, R4W	P - M	4.1
3	SDC-3-3b	Kpl	SW¼, Sec34, T17N, R3W	P	3.4
4	SDC-4-4	Kpl	NW¼, Sec11, T16N, R4W	M	12.2
5	SDC-5-1a	Kg	35° 31' 52" lat.	P	3.0
6	SDC-5-1b	Kg		MW	15.8
7	SDC-5-1c	Kg	107° 08' 57" W. long.	W	34.6
8	C5-2-87	Kmfc	NW¼, Sec5, T16N, R4W	P	5.1
9	C5-160	Kpl	NW¼, Sec5, T16N, R4W	M	14.9
10	C5-190	Kpl	NW¼, Sec5, T16N, R4W	M	6.1
11	C6-5-37.2	Kmfc	NW¼, Sec17, T16N, R5W	P	4.6
12	C6-3-150.2	Kpl	NW¼, Sec17, T16N, R5W	P	3.8
13	C6-4-218.2	Kpl	NW¼, Sec17, T16N, R5W	P	3.2
14	C5-150	Kpl	NW¼, Sec5, T16N, R4W	M	10.5

[1]Unit abbreviations same as Plate 1. Sorting; P = poor, M = moderate, MW = moderately well, W = well (based on Folk, 1974, inclusive graphic standard deviation). Analysis numbers 9, 10, 14 were analyzed by D. Tabet and S. Anderholm; all other analyses performed by author (also see fig. C-1, plots of textural data).

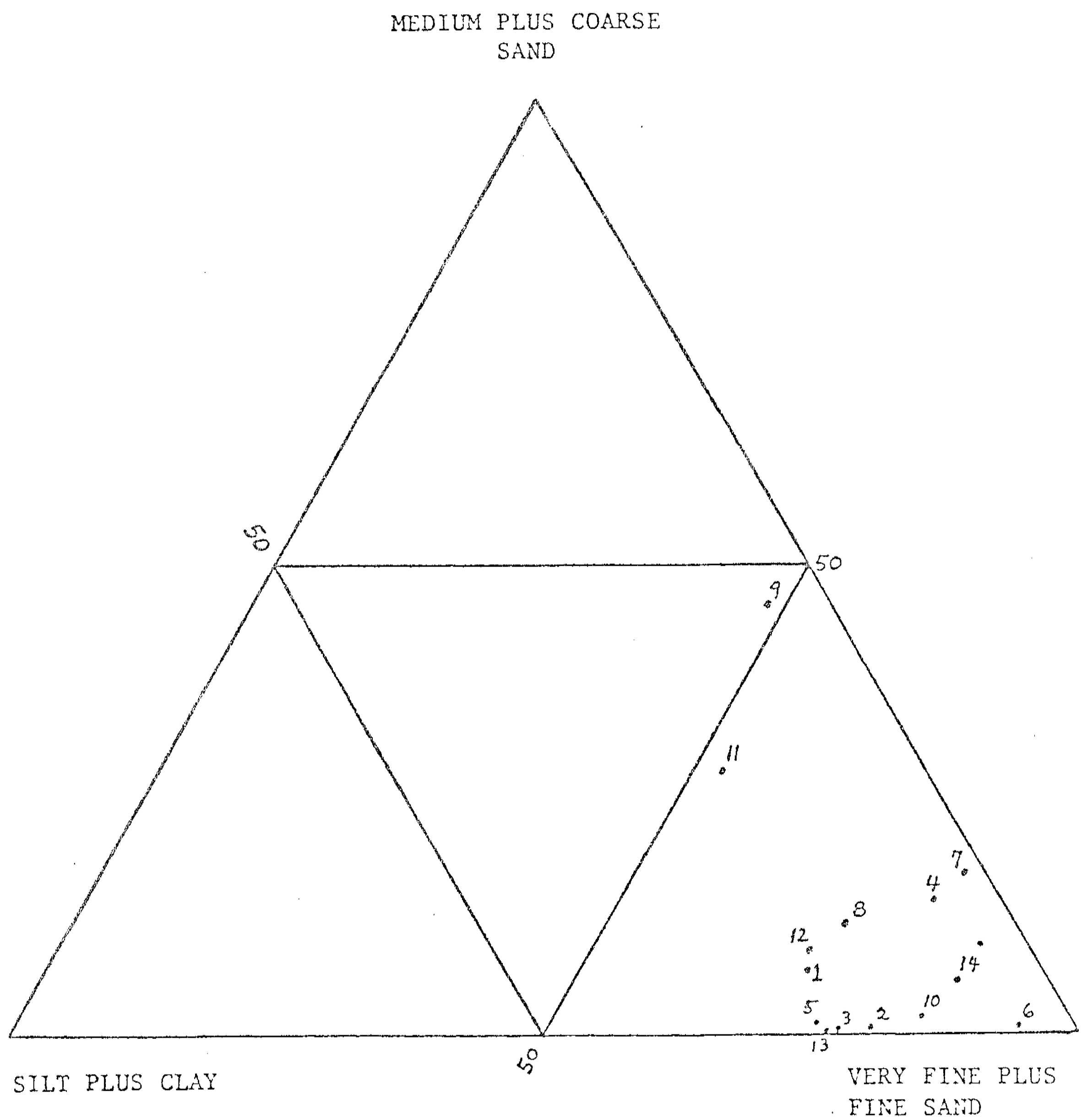


Figure C-1. Texture of selected samples from potential aquifers in the Chico Arroyo/Torreon Wash area. Samples identified by analysis number (table C-1). 50 percent lines marked for reference.

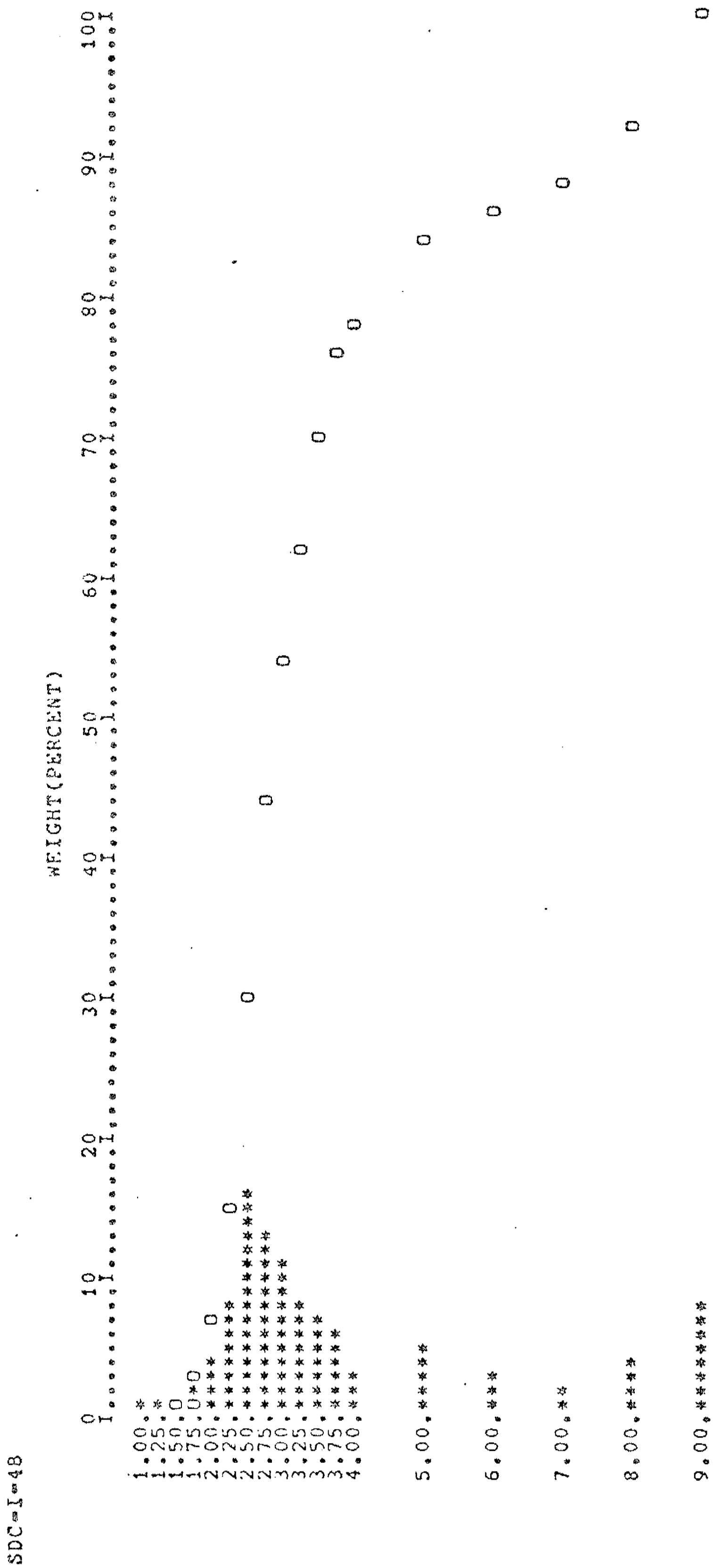
plots in the central part of the diagram. On a similar diagram prepared by Stone (1979b, Fig. 3, p. 12), Upper Cretaceous rocks also plotted in the very fine plus fine sand field.

As reported by Stone (1979b, p. 13), much of the fine fraction may be secondary, a result of diagenesis and weathering. For example, if mudclasts and weathered feldspars are present in a sample, the percentages of clay reported in the textural analysis would be too great, and the median grain-size would be too fine.

Textural data were analyzed with a computer program (on file at NMBMMR) which calculates various statistics from the basic data. Output for each sample consists of two pages which give the following information:

Page 1 - Sample number, initial sample weight, sum of size fraction weights, experimental sample loss weight, a table giving the size-class weights, percentages, and cumulative percentages, and a table giving the statistics computed for the sample (Folk, 1974);

Page 2 - Sample number, and a cumulative curve and histogram plotted on the same set of axes.


SDC-I-48
WEIGHT(PERCENT)
0
10
20
30
40
50
60
70
80
90
100
1.00
1.25
1.50
1.75
2.00
2.25
2.50
2.75
3.00
3.25
3.50
3.75
4.00
5.00
6.00
7.00
8.00
9.00

SDC-11 -2

INITIAL SAMPLE WEIGHT= 55.60 GRMS

SUM OF SIZE FRACTION WEIGHTS= 45.81 GRMS

EXPERIMENTAL SAMPLE LOSS= 9.79 GRMS

CUMULATIVE PERCENTAGES CALCULATED USING SUM OF SIZE FRACTION WEIGHTS

PHI	DIAMETER (MM)	WEIGHT (GRMS)	WEIGHT PERC	CUM PERC
1.50	0.350	0.02	0.04	0.04
1.75	0.300	0.08	0.17	0.22
2.00	0.250	0.16	0.35	0.57
2.25	0.210	0.33	0.72	1.29
2.50	0.177	1.00	2.18	3.47
2.75	0.149	1.34	2.93	6.40
3.00	0.125	2.11	4.61	11.00
3.25	0.105	3.50	7.64	18.64
3.50	0.088	9.31	20.32	38.97
3.75	0.074	13.21	28.84	67.80
4.00	0.063	5.75	12.55	80.35
5.00	0.031	3.40	7.42	87.78
6.00	0.016	1.70	3.71	91.49
7.00	0.008	1.10	2.40	93.89
8.00	0.004	0.80	1.75	95.63
9.00	0.002	2.00	4.37	100.00

STATISTICS

PERCENTILES

CUMULATIVE PERCENT	PHI VALUE
5.	2.631
16.	3.164
25.	3.328
50.	3.596
75.	3.893
84.	4.491
95.	7.637

STATISTICAL PARAMETERS

MEDIAN = 3.596

GRAPHIC MEAN = 3.750

QUARTILE DEVIATION = 0.283

GRAPHIC STANDARD DEVIATION = 0.664

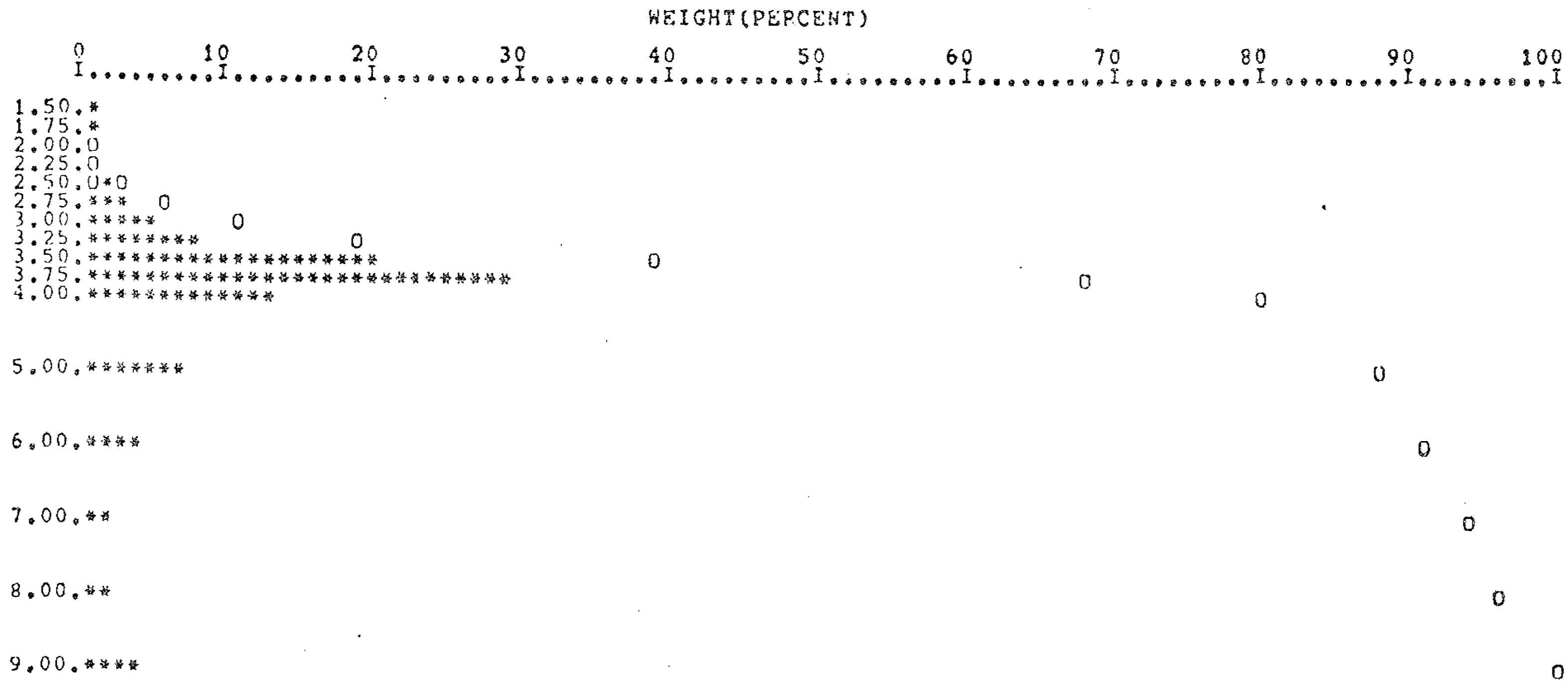
INCLUSIVE STANDARD DEVIATION = 1.090

GRAPHIC SKEWNESS = 0.349

INCLUSIVE GRAPHIC SKEWNESS = 0.482

GRAPHIC KURTOSIS = 3.630

SDC-II -2


WEIGHT(PERCENT)
0
10
20
30
40
50
60
70
80
90
100
1.50
1.75
2.00
2.25
2.50
2.75
3.00
3.25
3.50
3.75
4.00
5.00
6.00
7.00
8.00
9.00

SDC-III-3B

INITIAL SAMPLE WEIGHT= 59.70 GRMS

SUM OF SIZE FRACTION WEIGHTS= 55.82 GRMS

EXPERIMENTAL SAMPLE LOSS= 3.88 GRMS

CUMULATIVE PERCENTAGES CALCULATED USING SUM OF SIZE FRACTION WEIGHTS

PHI	DIAMETER (MM)	WEIGHT (GRMS)	WEIGHT PERC	CUM PERC
2.00	0.250	0.04	0.07	0.07
2.25	0.210	0.52	0.93	1.00
2.50	0.177	1.30	2.33	3.33
2.75	0.149	1.66	2.97	6.31
3.00	0.125	1.45	7.97	14.28
3.25	0.105	10.34	18.52	32.80
3.50	0.088	15.61	27.96	60.77
3.75	0.074	6.92	12.40	73.16
4.00	0.063	2.18	3.91	77.07
5.00	0.031	3.90	6.99	84.06
6.00	0.016	1.90	3.40	87.46
7.00	0.008	1.50	2.69	90.15
8.00	0.004	2.40	4.30	94.45
9.00	0.002	3.10	5.55	100.00

STATISTICS

PERCENTILES

CUMULATIVE PERCENT	PHI VALUE
5.	2.640
16.	3.023
25.	3.145
50.	3.408
75.	3.868
84.	4.992
95.	8.160

STATISTICAL PARAMETERS

MEDIAN = 3.408

GRAPHIC MEAN = 3.808

QUARTILE DEVIATION = 0.361

GRAPHIC STANDARD DEVIATION = 0.984

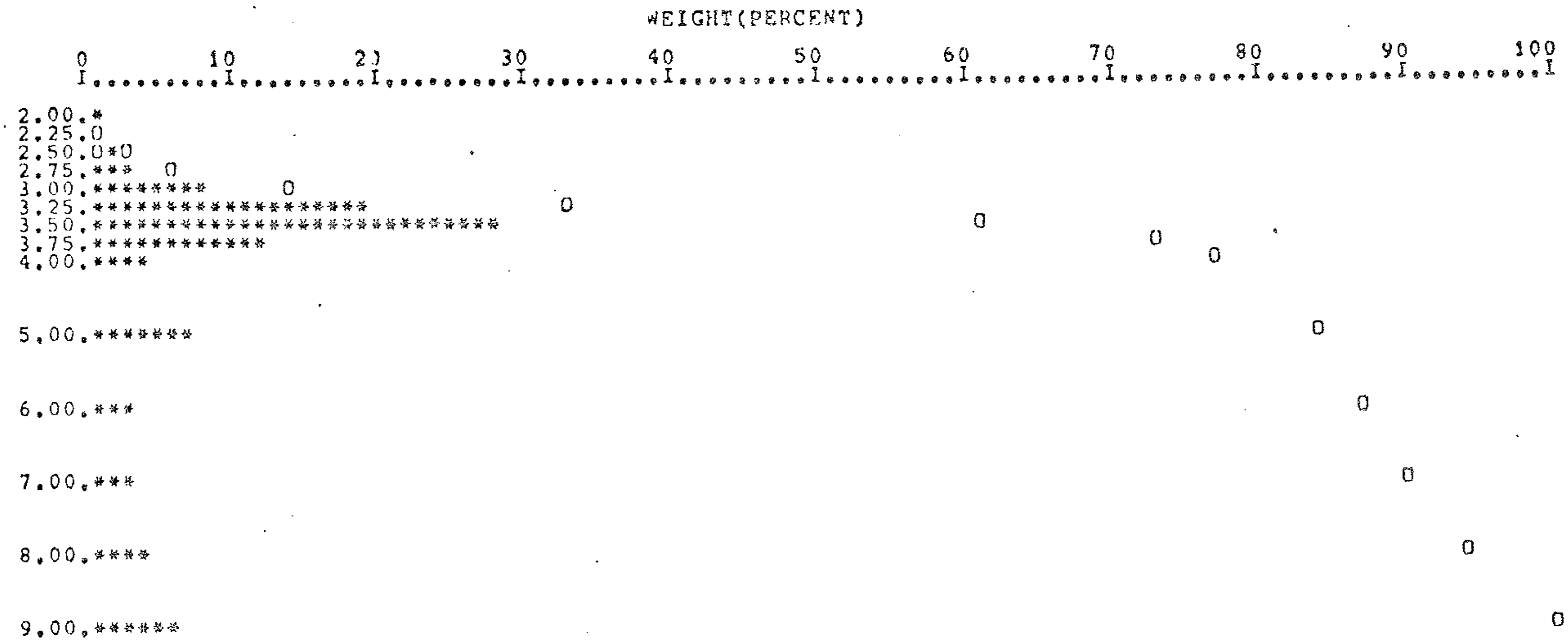
INCLUSIVE STANDARD DEVIATION = 1.319

GRAPHIC SKEWNESS = 0.613

INCLUSIVE GRAPHIC SKEWNESS = 0.667

GRAPHIC KURTOSIS = 3.095

SDC-III-3B


WEIGHT(PERCENT)
0 10 20 30 40 50 60 70 80 90 100
2.00
2.25
2.50
2.75
3.00
3.25
3.50
3.75
4.00
5.00
6.00
7.00
8.00
9.00

SDC-IV-4

INITIAL SAMPLE WEIGHT= 53.85 GRMS

SUM OF SIZE FRACTION WEIGHTS= 52.59 GRMS

EXPERIMENTAL SAMPLE LOSS= 1.26 GRMS

CUMULATIVE PERCENTAGES CALCULATED USING SUM OF SIZE FRACTION WEIGHTS

PHI	DIAMETER (MM)	WEIGHT (GRMS)	WEIGHT PERC	CUM PERC
1.25	0.420	0.08	0.15	0.15
1.50	0.350	0.26	0.49	0.65
1.75	0.300	2.26	4.30	4.94
2.00	0.250	4.16	7.91	12.85
2.25	0.210	6.50	12.36	25.21
2.50	0.177	14.35	27.29	52.50
2.75	0.149	11.27	21.43	73.93
3.00	0.125	6.68	12.70	86.63
3.25	0.105	1.71	3.25	89.88
3.50	0.088	0.63	1.20	91.08
3.75	0.074	0.47	0.89	91.90
4.00	0.063	0.22	0.42	92.39
5.00	0.031	1.20	2.28	94.68
6.00	0.016	0.80	1.52	96.20
7.00	0.008	0.50	0.95	97.15
8.00	0.004	0.50	0.95	98.10
9.00	0.002	1.00	1.90	100.00

STATISTICS

PERCENTILES

CUMULATIVE PERCENT	PHI VALUE
5.	1.752
16.	2.064
25.	2.246
50.	2.477
75.	2.771
84.	2.948
95.	5.213

STATISTICAL PARAMETERS

MEDIAN = 2.477

GRAPHIC MEAN = 2.496

QUARTILE DEVIATION = 0.263

GRAPHIC STANDARD DEVIATION = 0.442

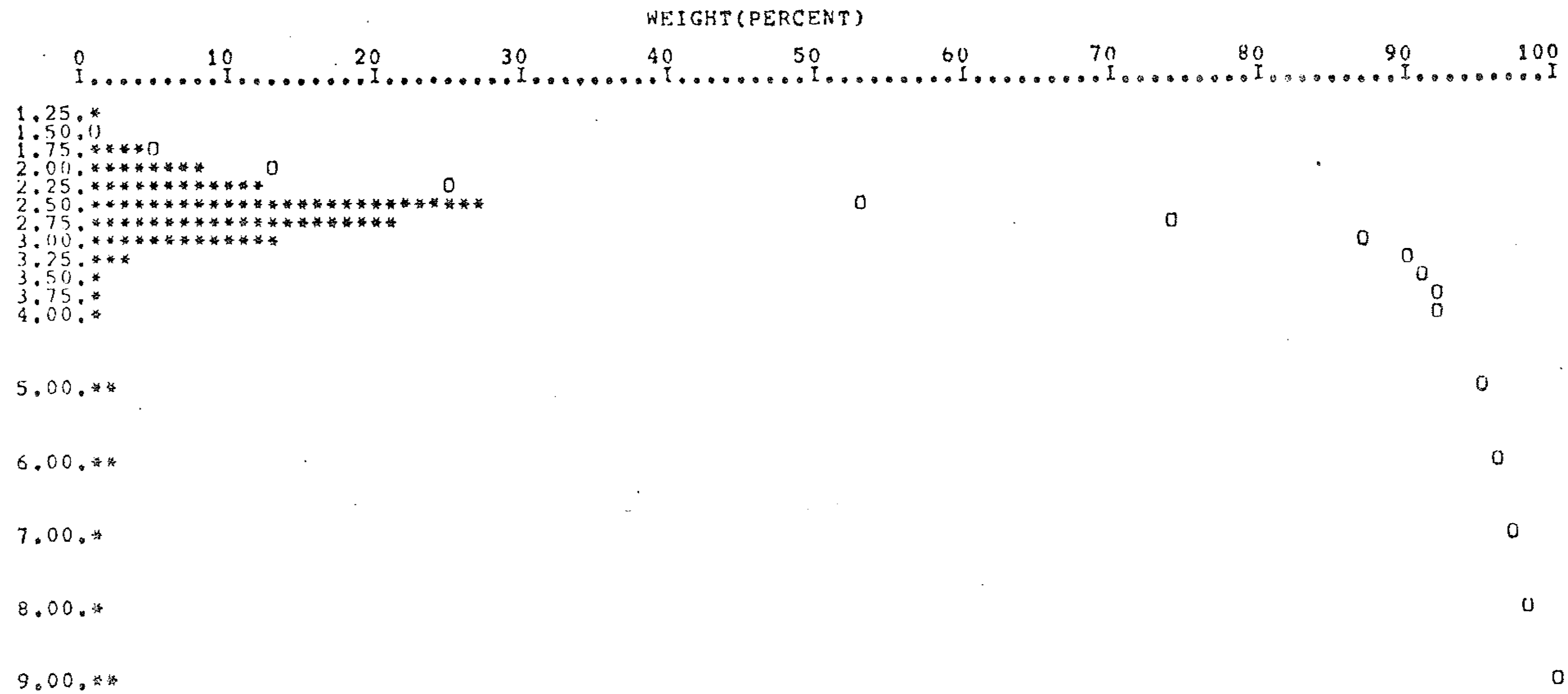
INCLUSIVE STANDARD DEVIATION = 0.746

GRAPHIC SKEWNESS = 0.065

INCLUSIVE GRAPHIC SKEWNESS = 0.323

GRAPHIC KURTOSIS = 2.700

SDC-IV-4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40
50
60
70
80
90
100
1.25
1.50
1.75
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2.50
2.75
3.00
3.25
3.50
3.75
4.00
5.00
6.00
7.00
8.00
9.00

SDC-Y-1A

INITIAL SAMPLE WEIGHT= 58.20 GRMS
SUM OF SIZE FRACTION WEIGHTS= 52.03 GRMS
EXPERIMENTAL SAMPLE LOSS= 6.17 GRMS
CUMULATIVE PERCENTAGES CALCULATED USING SUM OF SIZE FRACTION WEIGHTS

PHI	DIAMETER (MM)	WEIGHT (GRMS)	WEIGHT PERC	CUM PERC
2.00	0.250	0.04	0.08	0.08
2.25	0.210	0.56	1.08	1.15
2.50	0.177	1.67	3.11	4.27
2.75	0.149	3.22	6.19	10.46
3.00	0.125	6.71	12.90	23.35
3.25	0.105	9.35	17.97	41.32
3.50	0.088	8.85	17.01	58.33
3.75	0.074	5.84	11.22	69.56
4.00	0.063	2.84	5.46	75.01
5.00	0.031	4.60	8.84	83.86
6.00	0.016	2.40	4.61	88.47
7.00	0.008	1.00	1.92	90.39
8.00	0.004	0.90	1.73	92.12
9.00	0.002	4.10	7.88	100.00

STATISTICS

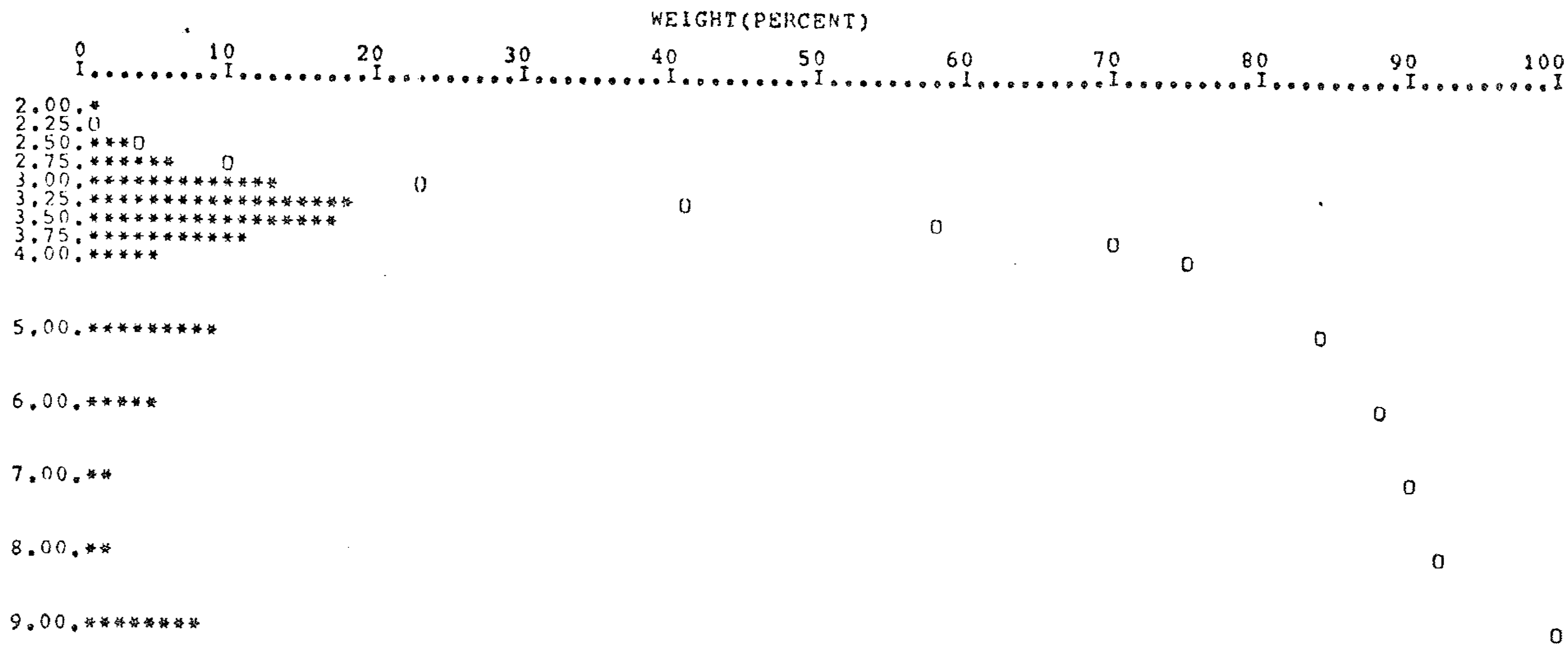
PERCENTILES

CUMULATIVE PERCENT	PHI VALUE
5.	2.530
16.	2.857
25.	3.073
50.	3.378
75.	3.999
84.	5.031
95.	8.365

STATISTICAL PARAMETERS

MEDIAN = 3.378
GRAPHIC MEAN = 3.755
QUARTILE DEVIATION = 0.488
GRAPHIC STANDARD DEVIATION = 1.087
INCLUSIVE STANDARD DEVIATION = 1.428
GRAPHIC SKEWNESS = 0.522
INCLUSIVE GRAPHIC SKEWNESS = 0.615
GRAPHIC KURTOSIS = 2.450

SDC-V-1A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90
100
2.00
2.25
2.50
2.75
3.00
3.25
3.50
3.75
4.00
5.00
6.00
7.00
8.00
9.00

SOC-V-1B

INITIAL SAMPLE WEIGHT= 56.95 GRMS
SUM OF SIZE FRACTION WEIGHTS= 51.58 GRMS
EXPERIMENTAL SAMPLE LOSS= 5.37 GRMS
CUMULATIVE PERCENTAGES CALCULATED USING SUM OF SIZE FRACTION WEIGHTS

PHI	DIAMETER (MM)	WEIGHT (GRMS)	WEIGHT PERC	CUM PERC
2.00	0.250	0.05	0.10	0.10
2.25	0.210	0.11	0.21	0.31
2.50	0.177	0.33	0.64	0.95
2.75	0.149	3.00	5.82	6.77
3.00	0.125	7.33	14.21	20.98
3.25	0.105	15.14	29.35	50.33
3.50	0.088	13.67	26.50	76.83
3.75	0.074	6.70	12.99	89.82
4.00	0.063	2.18	4.23	94.05
5.00	0.031	0.77	1.49	95.54
6.00	0.016	0.90	1.74	97.29
7.00	0.008	0.70	1.36	98.64
8.00	0.004	0.60	1.16	99.81
9.00	0.002	0.10	0.19	100.00

STATISTICS

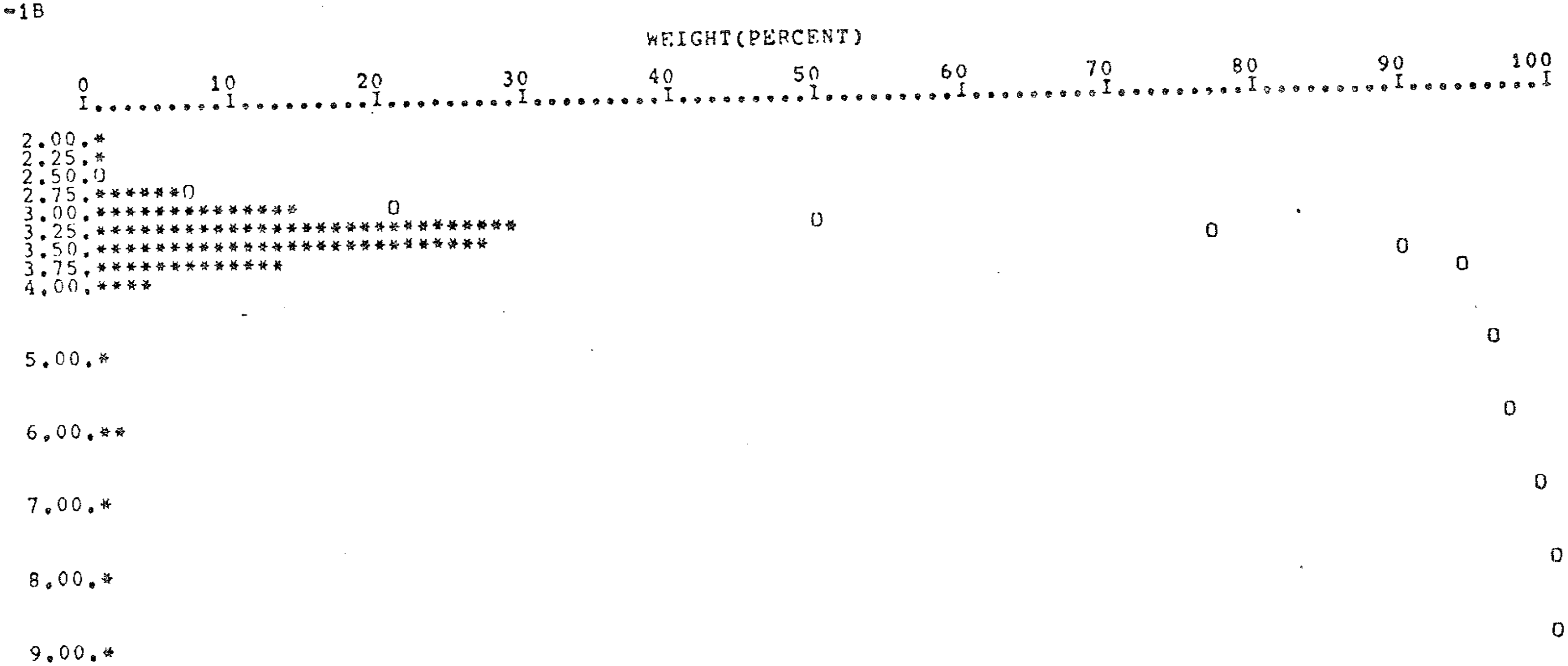
PERCENTILES

CUMULATIVE PERCENT	PHI VALUE
5.	1.514
16.	1.543
25.	1.568
50.	1.636
75.	1.704
84.	1.728
95.	4.638

STATISTICAL PARAMETERS

MEDIAN = 1.636
GRAPHIC MEAN = 1.636
QUARTILE DEVIATION = 0.068
GRAPHIC STANDARD DEVIATION = 0.092
INCLUSIVE STANDARD DEVIATION = 0.520
GRAPHIC SKEWNESS = 0.000
INCLUSIVE GRAPHIC SKEWNESS = 0.461
GRAPHIC KURTOSIS = 9.429

SDC-V-1B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2.50
2.75
3.00
3.25
3.50
3.75
4.00
5.00
6.00
7.00
8.00
9.00

SDC-V-1C

INITIAL SAMPLE WEIGHT= 52.92 GRMS

SUM OF SIZE FRACTION WEIGHTS= 32.67 GRMS

EXPERIMENTAL SAMPLE LOSS= 20.25 GRMS

CUMULATIVE PERCENTAGES CALCULATED USING SUM OF SIZE FRACTION WEIGHTS

PHI	DIAMETER (MM)	WEIGHT (GRMS)	WEIGHT PERC	CUM PERC
0.25	0.840	0.04	0.12	0.12
0.50	0.710	0.01	0.03	0.15
0.75	0.590	0.08	0.24	0.40
1.00	0.500	0.06	0.18	0.58
1.25	0.420	0.14	0.43	1.01
1.50	0.350	0.31	0.95	1.96
1.75	0.300	1.64	5.02	6.98
2.00	0.250	3.26	9.98	16.96
2.25	0.210	7.08	21.67	38.63
2.50	0.177	9.95	30.46	69.08
2.75	0.149	4.93	15.09	84.18
3.00	0.125	2.27	6.80	90.97
3.25	0.105	1.08	3.31	94.28
3.50	0.088	0.41	1.25	95.53
3.75	0.074	0.32	0.98	96.51
4.00	0.063	0.22	0.67	97.18
5.00	0.031	0.20	0.61	97.80
6.00	0.016	0.17	0.52	98.32
7.00	0.008	0.05	0.15	98.47
8.00	0.004	0.40	1.22	99.69
9.00	0.002	0.10	0.31	100.00

STATISTICS

PERCENTILES

CUMULATIVE PERCENT	PHI VALUE
5.	1.651
16.	1.976
25.	2.093
50.	2.343
75.	2.598
84.	2.747
95.	3.393

STATISTICAL PARAMETERS

MEDIAN = 2.343

GRAPHIC MEAN = 2.355

QUARTILE DEVIATION = 0.253

GRAPHIC STANDARD DEVIATION = 0.386

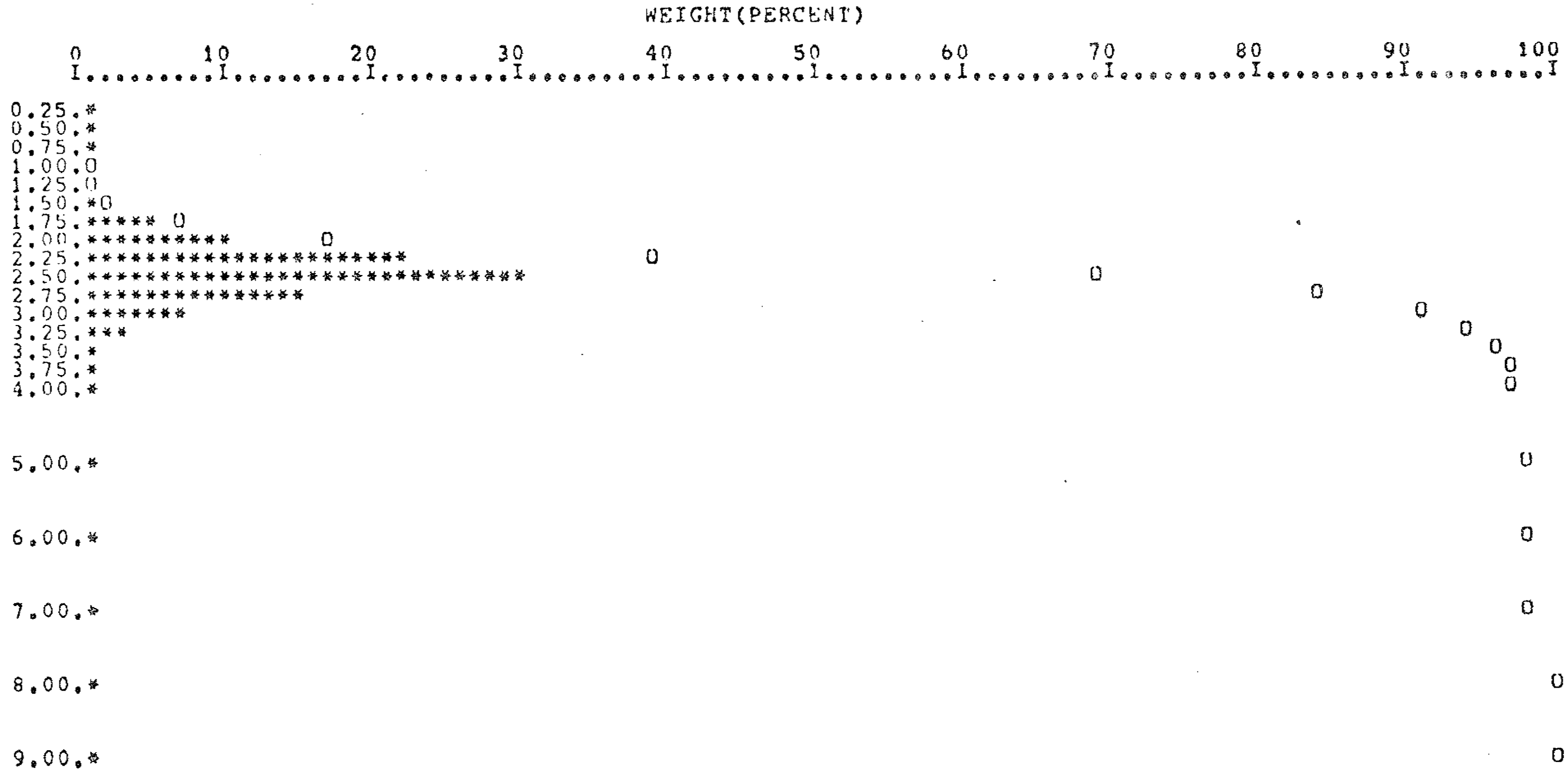
INCLUSIVE STANDARD DEVIATION = 0.457

GRAPHIC SKEWNESS = 0.047

INCLUSIVE GRAPHIC SKEWNESS = 0.127

GRAPHIC KURTOSIS = 1.414

SDC-V-1C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1.50
1.75
2.00
2.25
2.50
2.75
3.00
3.25
3.50
3.75
4.00
5.00
6.00
7.00
8.00
9.00

C5-2-87

INITIAL SAMPLE WEIGHT= 54.64 GRMS
SUM OF SIZE FRACTION WEIGHTS= 52.55 GRMS
EXPERIMENTAL SAMPLE LOSS= 2.09 GRMS
CUMULATIVE PERCENTAGES CALCULATED USING SUM OF SIZE FRACTION WEIGHTS

PHI ,	DIAMETER (MM)	WEIGHT (GRMS)	WEIGHT PERC	CUM PERC
1.50	0.350	0.15	0.29	0.29
1.75	0.300	1.37	2.61	2.89
2.00	0.250	4.56	8.68	11.57
2.25	0.210	7.60	14.46	26.03
2.50	0.177	13.16	25.04	51.08
2.75	0.149	8.70	16.56	67.63
3.00	0.125	4.23	8.05	75.68
3.25	0.105	1.57	2.99	78.67
3.50	0.088	1.15	2.19	80.86
3.75	0.074	1.00	1.90	82.76
4.00	0.063	0.46	0.88	83.63
5.00	0.031	1.80	3.43	87.06
6.00	0.016	0.70	1.33	88.39
7.00	0.008	0.30	0.57	88.96
8.00	0.004	2.30	4.38	93.34
9.00	0.002	3.50	6.66	100.00

STATISTICS

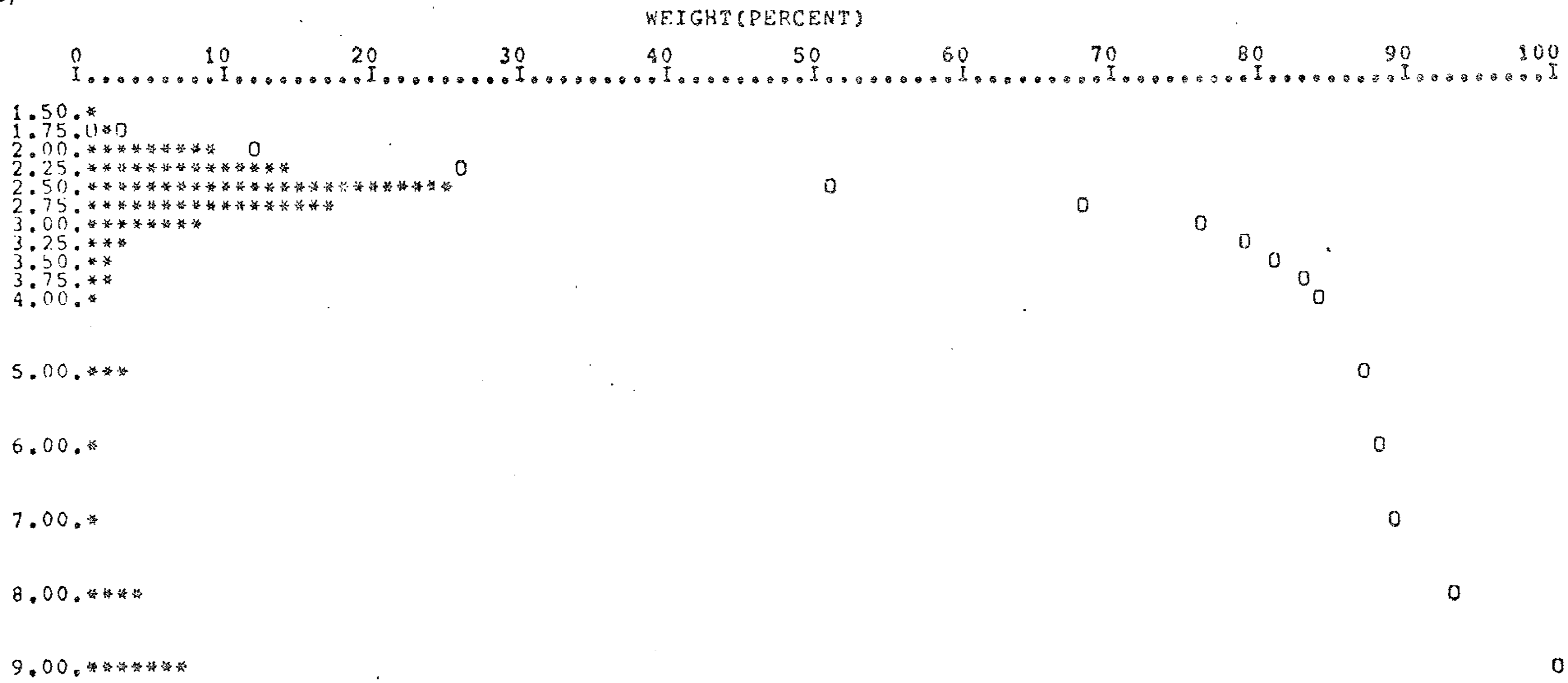
PERCENTILES

CUMULATIVE PERCENT	PHI VALUE
5.	1.812
16.	2.077
25.	2.232
50.	2.489
75.	2.979
84.	4.107
95.	8.249

STATISTICAL PARAMETERS

MEDIAN = 2.489
GRAPHIC MEAN = 2.891
QUARTILE DEVIATION = 0.374
GRAPHIC STANDARD DEVIATION = 1.015
INCLUSIVE STANDARD DEVIATION = 1.483
GRAPHIC SKEWNESS = 0.593
INCLUSIVE GRAPHIC SKEWNESS = 0.691
GRAPHIC KURTOSIS = 3.534

C5-2-87



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2.75
3.00
3.25
3.50
3.75
4.00
5.00
6.00
7.00
8.00
9.00

C-5-160

INITIAL SAMPLE WEIGHT= 60.87 GRMS

SUM OF SIZE FRACTION WEIGHTS= 57.30 GRMS

EXPERIMENTAL SAMPLE LOSS= 3.57 GRMS

CUMULATIVE PERCENTAGES CALCULATED USING SUM OF SIZE FRACTION WEIGHTS

PHI	DIAMETER (MM)	WEIGHT (GRMS)	WEIGHT PERC	CUM PERC
1.00	0.500	0.12	0.21	0.21
1.25	0.420	0.25	0.44	0.65
1.50	0.350	2.58	4.50	5.15
1.75	0.300	7.36	12.84	17.99
2.00	0.250	15.81	27.59	45.58
2.25	0.210	12.64	22.06	67.64
2.50	0.177	7.10	12.39	80.03
2.75	0.149	2.83	4.94	84.97
3.00	0.125	1.98	3.46	88.43
3.25	0.105	1.13	1.97	90.40
3.50	0.088	0.82	1.43	91.83
3.75	0.074	0.75	1.31	93.14
4.00	0.063	0.33	0.58	93.72
5.00	0.031	1.30	2.27	95.99
6.00	0.016	0.30	0.52	96.51
7.00	0.008	1.00	1.75	98.25
8.00	0.004	0.80	1.40	99.65
9.00	0.002	0.20	0.35	100.00

STATISTICS

PERCENTILES

CUMULATIVE PERCENT	PHI VALUE
5.	1.492
16.	1.711
25.	1.813
50.	2.050
75.	2.398
84.	2.761
95.	4.565

STATISTICAL PARAMETERS

MEDIAN = 2.050

GRAPHIC MEAN = 2.154

QUARTILE DEVIATION = 0.292

GRAPHIC STANDARD DEVIATION = 0.495

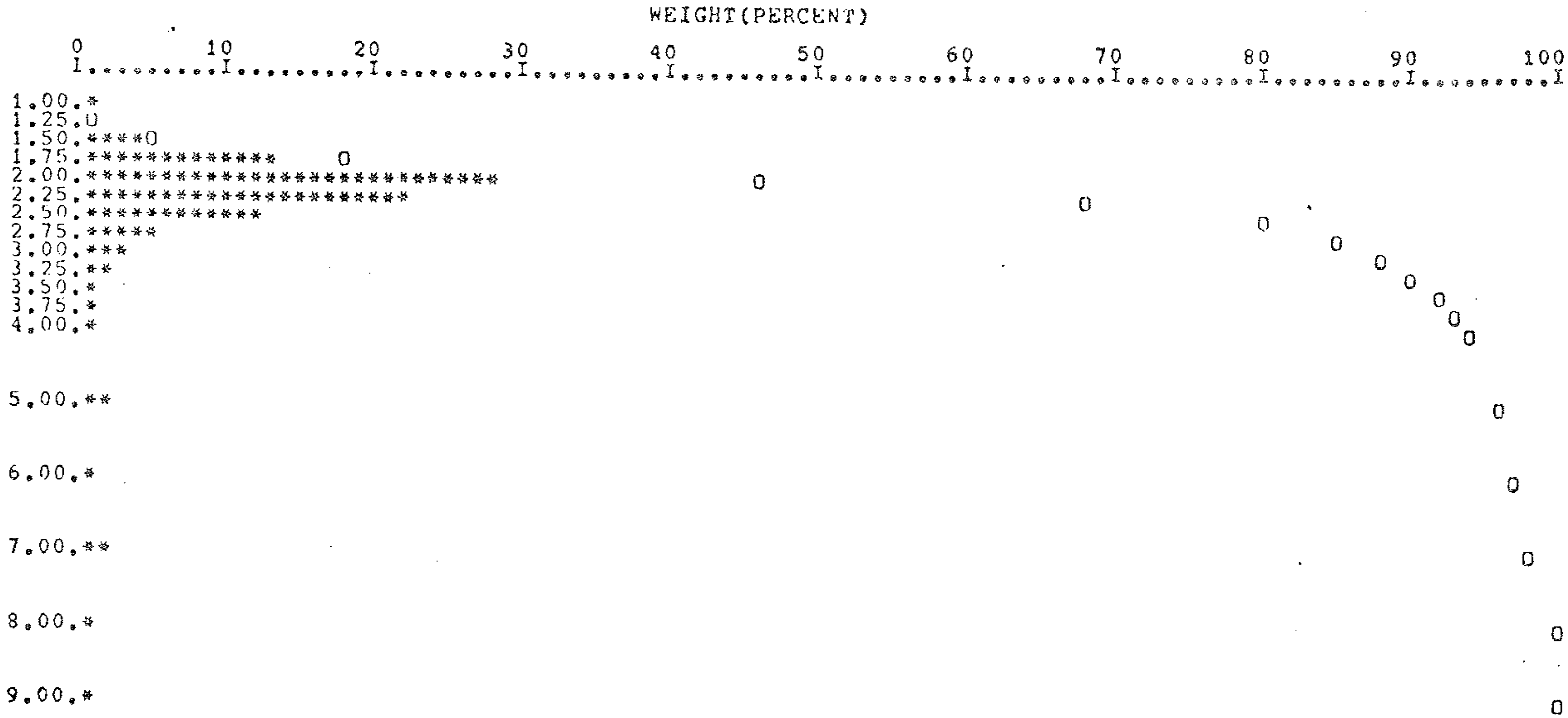
INCLUSIVE STANDARD DEVIATION = 0.713

GRAPHIC SKEWNESS = 0.315

INCLUSIVE GRAPHIC SKEWNESS = 0.476

GRAPHIC KURTOSIS = 2.154

C-5-160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2.25
2.50
2.75
3.00
3.25
3.50
3.75
4.00
5.00
6.00
7.00
8.00
9.00

C-5-190

INITIAL SAMPLE WEIGHT= 87.51 GRMS

SUM OF SIZE FRACTION WEIGHTS= 86.83 GRMS

EXPERIMENTAL SAMPLE LOSS= 0.68 GRMS

CUMULATIVE PERCENTAGES CALCULATED USING SUM OF SIZE FRACTION WEIGHTS

PHI	DIAMETER (MM)	WEIGHT (GRMS)	WEIGHT PERC	CUM PERC
1.75	0.300	0.03	0.03	0.03
2.00	0.250	1.94	2.23	2.27
2.25	0.210	2.69	3.09	5.36
2.50	0.177	4.52	5.21	10.56
2.75	0.149	7.01	8.07	18.63
3.00	0.125	18.07	20.81	39.44
3.25	0.105	12.58	14.49	53.93
3.50	0.088	15.60	17.97	71.90
3.75	0.074	8.92	10.27	82.17
4.00	0.063	3.26	3.78	85.95
5.00	0.031	6.70	7.72	93.67
6.00	0.016	2.50	2.88	96.54
7.00	0.008	1.40	1.61	98.16
8.00	0.004	1.20	1.38	99.54
9.00	0.002	0.40	0.46	100.00

STATISTICS

PERCENTILES

CUMULATIVE PERCENT	PHI VALUE
5.	2.221
16.	2.668
25.	2.826
50.	3.182
75.	3.575
84.	3.871
95.	5.413

STATISTICAL PARAMETERS

MEDIAN = 3.182

GRAPHIC MEAN = 3.241

QUARTILE DEVIATION = 0.374

GRAPHIC STANDARD DEVIATION = 0.601

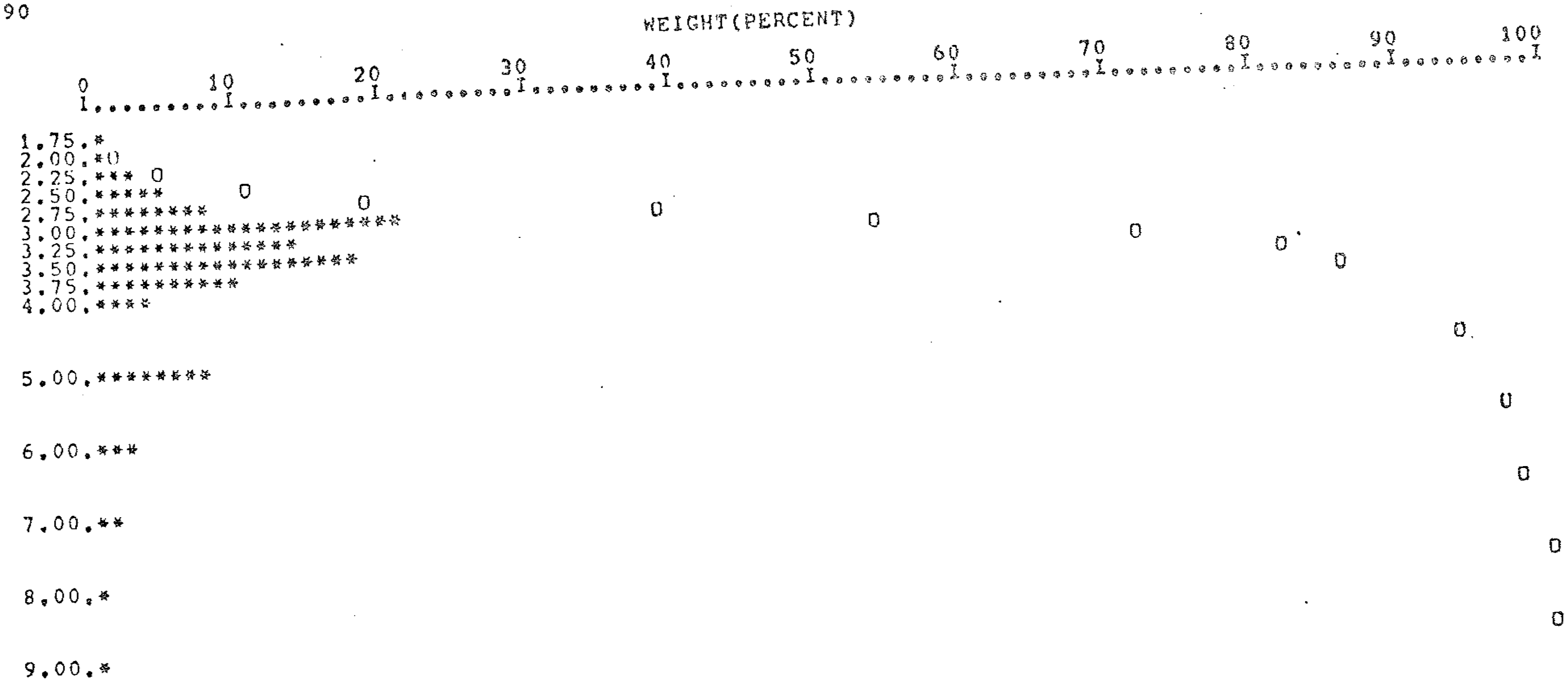
INCLUSIVE STANDARD DEVIATION = 0.792

GRAPHIC SKEWNESS = 0.146

INCLUSIVE GRAPHIC SKEWNESS = 0.276

GRAPHIC KURTOSIS = 1.774

C-5-190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2.75
3.00
3.25
3.50
3.75
4.00
5.00
6.00
7.00
8.00
9.00

C6-5-37.2

INITIAL SAMPLE WEIGHT= 55.16 GRMS
SUM OF SIZE FRACTION WEIGHTS= 53.57 GRMS
EXPERIMENTAL SAMPLE LOSS= 1.59 GRMS
CUMULATIVE PERCENTAGES CALCULATED USING SUM OF SIZE FRACTION WEIGHTS

PHI	DIAMETER (MM)	WEIGHT (GRMS)	WEIGHT PERC	CUM PERC
1.00	0.500	0.01	0.02	0.02
1.25	0.420	0.51	0.95	0.97
1.50	0.350	2.48	4.63	5.60
1.75	0.300	5.96	11.13	16.73
2.00	0.250	6.73	12.56	29.29
2.25	0.210	6.96	12.99	42.28
2.50	0.177	8.40	15.68	57.96
2.75	0.149	5.67	10.58	68.55
3.00	0.125	3.16	5.90	74.44
3.25	0.105	1.42	2.65	77.10
3.50	0.088	1.20	2.24	79.34
3.75	0.074	0.90	1.68	81.02
4.00	0.063	0.57	1.06	82.08
5.00	0.031	1.30	2.43	84.51
6.00	0.016	1.40	2.61	87.12
7.00	0.008	0.90	1.68	88.80
8.00	0.004	2.10	3.92	92.72
9.00	0.002	3.90	7.28	100.00

STATISTICS

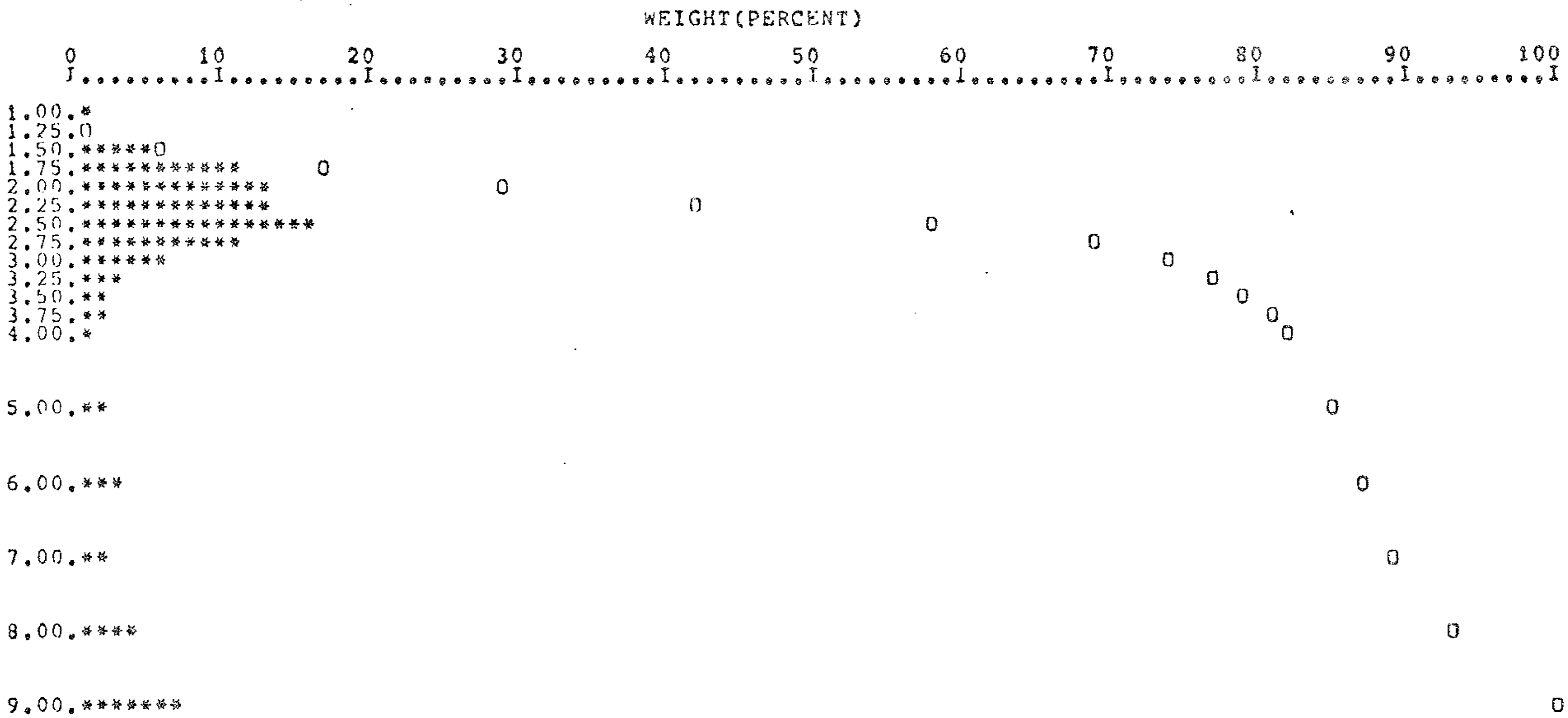
PERCENTILES

CUMULATIVE PERCENT	PHI VALUE
5.	1.468
16.	1.734
25.	1.915
50.	2.373
75.	3.052
84.	4.791
95.	8.313

STATISTICAL PARAMETERS

MEDIAN = 2.373
GRAPHIC MEAN = 2.966
QUARTILE DEVIATION = 0.569
GRAPHIC STANDARD DEVIATION = 1.529
INCLUSIVE STANDARD DEVIATION = 1.802
GRAPHIC SKEWNESS = 0.582
INCLUSIVE GRAPHIC SKEWNESS = 0.659
GRAPHIC KURTOSIS = 2.466

C6-5-37.2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2.25
2.50
2.75
3.00
3.25
3.50
3.75
4.00
5.00
6.00
7.00
8.00
9.00

C6-3-150.2

INITIAL SAMPLE WEIGHT= 53.76 GRMS

SUM OF SIZE FRACTION WEIGHTS= 48.34 GRMS

EXPERIMENTAL SAMPLE LOSS= 5.42 GRMS

CUMULATIVE PERCENTAGES CALCULATED USING SUM OF SIZE FRACTION WEIGHTS

PHI	DIAMETER (MM)	WEIGHT (GRMS)	WEIGHT PERC	CUM PERC
1.25	0.420	0.15	0.31	0.31
1.50	0.350	0.60	1.24	1.55
1.75	0.300	1.41	2.92	4.47
2.00	0.250	2.34	4.84	9.31
2.25	0.210	3.56	7.36	16.67
2.50	0.177	7.25	15.00	31.67
2.75	0.149	8.56	17.71	49.38
3.00	0.125	7.28	15.07	64.40
3.25	0.105	3.00	6.21	70.60
3.50	0.088	1.93	3.99	74.60
3.75	0.074	1.42	2.94	77.53
4.00	0.063	0.76	1.57	79.11
5.00	0.031	0.70	1.45	80.55
6.00	0.016	1.50	3.10	83.66
7.00	0.008	1.40	2.90	86.55
8.00	0.004	1.40	2.90	89.45
9.00	0.002	5.10	10.55	100.00

STATISTICS

PERCENTILES

CUMULATIVE PERCENT	PHI VALUE
5.	1.777
16.	2.277
25.	2.389
50.	2.760
75.	3.534
84.	6.118
95.	8.576

STATISTICAL PARAMETERS

MEDIAN = 2.760

GRAPHIC MEAN = 3.702

QUARTILE DEVIATION = 0.573

GRAPHIC STANDARD DEVIATION = 1.946

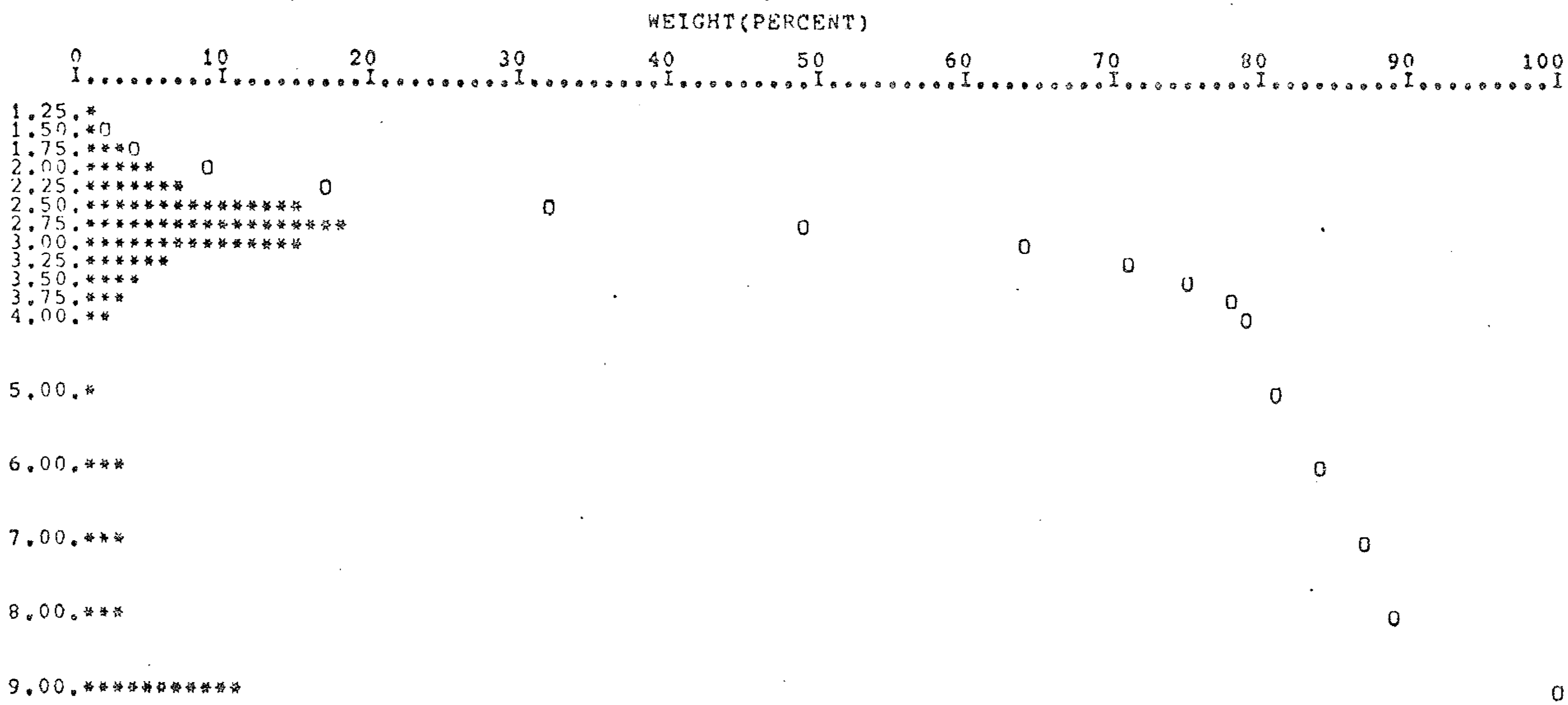
INCLUSIVE STANDARD DEVIATION = 1.995

GRAPHIC SKEWNESS = 0.726

INCLUSIVE GRAPHIC SKEWNESS = 0.717

GRAPHIC KURTOSIS = 2.414

C6-3-150.2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2.50
2.75
3.00
3.25
3.50
3.75
4.00
5.00
6.00
7.00
8.00
9.00

C6-4-218.2

INITIAL SAMPLE WEIGHT= 53.30 GRMS
SUM OF SIZE FRACTION WEIGHTS= 47.07 GRMS
EXPERIMENTAL SAMPLE LOSS= 6.28 GRMS
CUMULATIVE PERCENTAGES CALCULATED USING SUM OF SIZE FRACTION WEIGHTS

PHI	DIAMETER (MM)	WEIGHT (GRMS)	WEIGHT PERC	CUM PERC
2.25	0.210	0.15	0.32	0.32
2.50	0.177	0.35	0.74	1.06
2.75	0.149	3.65	7.76	8.83
3.00	0.125	3.31	7.04	15.87
3.25	0.105	9.48	20.16	36.03
3.50	0.088	10.47	22.27	58.29
3.75	0.074	6.10	12.97	71.27
4.00	0.063	2.41	5.13	76.39
5.00	0.031	4.00	8.51	84.90
6.00	0.016	1.60	3.40	88.30
7.00	0.008	1.00	2.13	90.43
8.00	0.004	2.30	4.89	95.32
9.00	0.002	2.20	4.68	100.00

STATISTICS

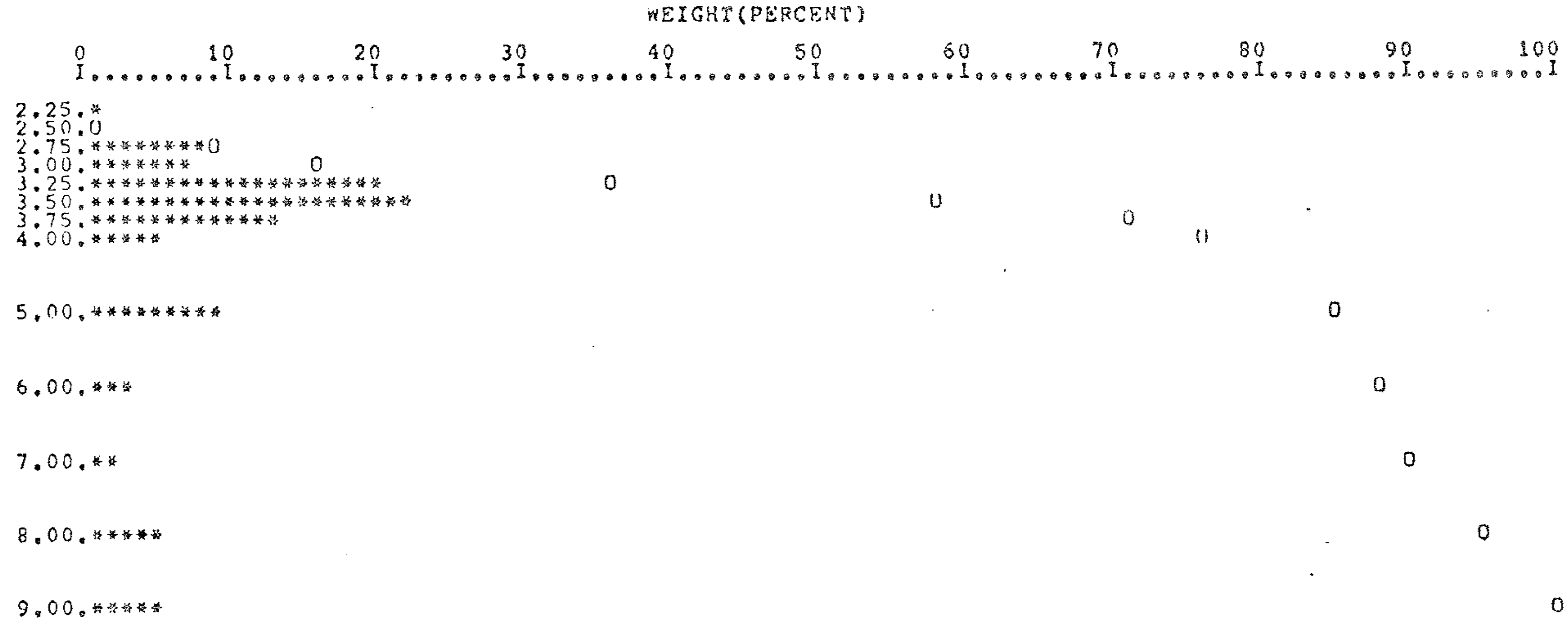
PERCENTILES

CUMULATIVE PERCENT	PHI VALUE
5.	2.677
16.	3.082
25.	3.113
50.	3.407
75.	3.932
84.	4.894
95.	7.934

STATISTICAL PARAMETERS

MEDIAN = 3.407
GRAPHIC MEAN = 3.768
QUARTILE DEVIATION = 0.409
GRAPHIC STANDARD DEVIATION = 0.946
INCLUSIVE STANDARD DEVIATION = 1.277
GRAPHIC SKEWNESS = 0.572
INCLUSIVE GRAPHIC SKEWNESS = 0.639
GRAPHIC KURTOSIS = 2.657

C6-4-218.2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3.50
3.75
4.00
5.00
6.00
7.00
8.00
9.00

C-5-150

INITIAL SAMPLE WEIGHT=100.60 GRMS

SUM OF SIZE FRACTION WEIGHTS= 98.09 GRMS

EXPERIMENTAL SAMPLE LOSS= 2.51 GRMS

CUMULATIVE PERCENTAGES CALCULATED USING SUM OF SIZE FRACTION WEIGHTS

PHI	DIAMETER (MM)	WEIGHT (GRMS)	WEIGHT PERC	CUM PERC
1.50	0.350	0.01	0.01	0.01
1.75	0.300	0.60	0.61	0.62
2.00	0.250	5.27	5.37	5.99
2.25	0.210	9.05	9.23	15.22
2.50	0.177	23.16	23.61	38.83
2.75	0.149	25.83	26.33	65.16
3.00	0.125	14.37	14.65	79.81
3.25	0.105	5.21	5.31	85.13
3.50	0.088	2.96	3.02	88.14
3.75	0.074	2.12	2.16	90.30
4.00	0.063	1.01	1.03	91.33
5.00	0.031	1.70	1.73	93.07
6.00	0.016	1.20	1.22	94.29
7.00	0.008	0.90	0.92	95.21
8.00	0.004	1.00	1.02	96.23
9.00	0.002	3.76	3.77	100.00

STATISTICS

PERCENTILES

CUMULATIVE PERCENT	PHI VALUE
5.	1.954
16.	2.258
25.	2.354
50.	2.606
75.	2.918
84.	3.197
95.	6.773

STATISTICAL PARAMETERS

MEDIAN = 7.606

GRAPHIC MEAN = 2.687

QUARTILE DEVIATION = 0.282

GRAPHIC STANDARD DEVIATION = 0.469

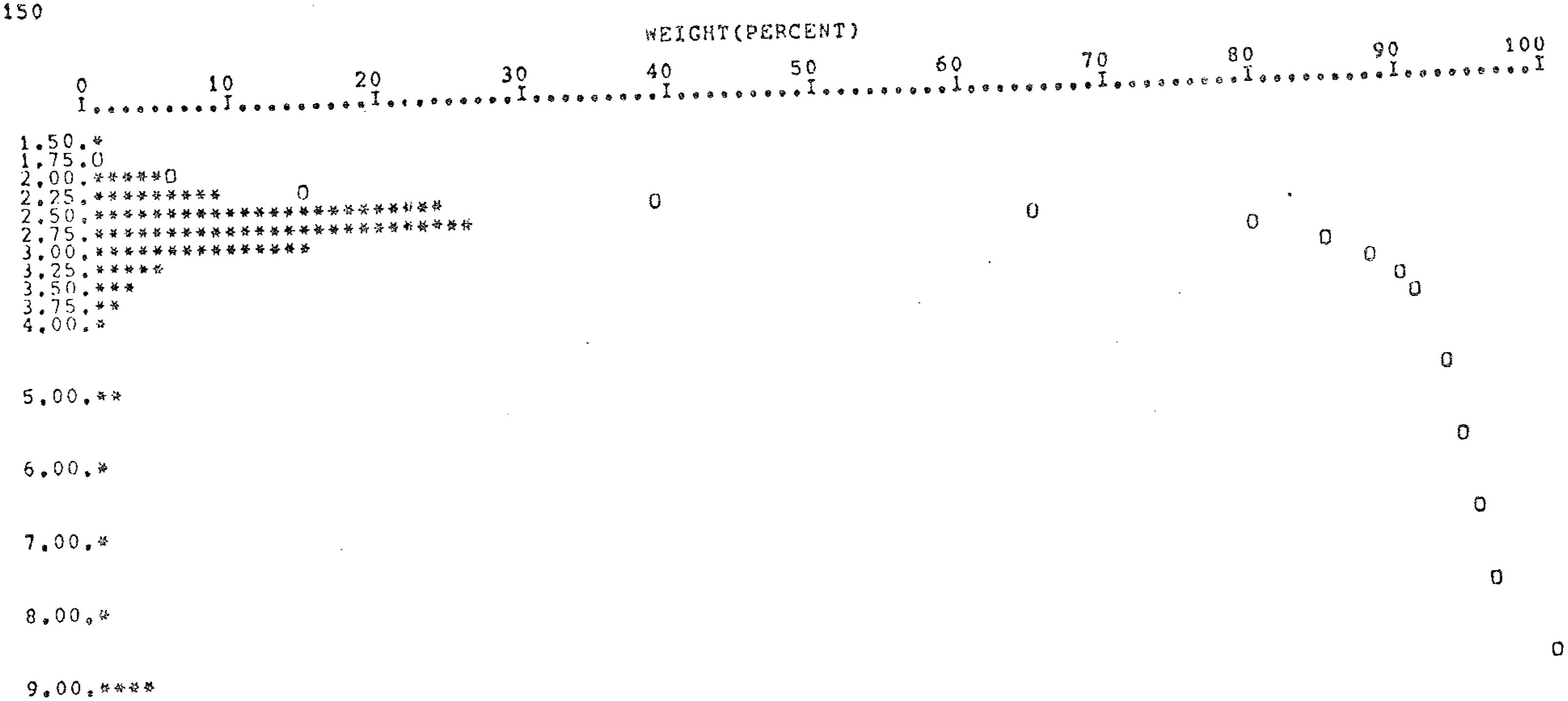
INCLUSIVE STANDARD DEVIATION = 0.955

GRAPHIC SKEWNESS = 0.259

INCLUSIVE GRAPHIC SKEWNESS = 0.494

GRAPHIC KURTOSIS = 3.500

C-5-150


WEIGHT(PERCENT)
0
10
20
30
40
50
60
70
80
90
100
1.50
1.75
2.00
2.25
2.50
2.75
3.00
3.25
3.50
3.75
4.00
5.00
6.00
7.00
8.00
9.00

APPENDIX D

DESCRIPTIONS OF CORES

Two cores from 2.5-inch-diameter test holes drilled during the NMBMMR Torreon coal study were described in order to supplement information obtained from measured sections of the Menefee Formation and Point Lookout Sandstone. Both core holes were spudded in the Cleary Coal Member of the Menefee and partially penetrated the Point Lookout.

General lithologic characteristics of the core were described by basically the same methods as those used for describing units in measured sections (Appendix A). Some details readily observed in outcrop are lost in core samples. For example, bedding size/regularity, scale of cross beds, unit geometry, continuity and intertonguing of units, and macrofossils may not be as apparent in cores. Core samples, nonetheless, do provide valuable information concerning aquifer characteristics in the subsurface because effects of weathering are minimal.

The general format used in descrbing the cores is basically that used for measured sections, with some modifications:

> GENERAL ROCK TYPE--color; bedding/internal structure (if apparent); other primary structures; texture; grain composition, matrix, cement; induration; miscellaneous constituents and characteristics; concretions/nodules; fossils; contact with above unit.

Much of the terminology used is identical to that used for measured sections (Appendix A).

Several intervals in the cores, especially poorly-indurated coals, coaly shales, and shales, were locally fragmented, resulting in partial or total loss of the core. In these instances, only the major rock types present are reported for the interval, or in the case of no core, a missing interval is reported.

When a lithologic unit is identical to a previously described unit, the reader is referred to the first description of that rock type, rather than repeating it several times.

Depths are reported only in feet since they were recorded in this manner during drilling.

Each description begins with a heading giving the core number, location, total depth drilled, stratigraphic units penetrated, date drilled, name(s) of the analysts(s), and date described. Numbering is down the page in order the rock types were encountered during drilling, so that depths increase downward. A comments section is included at the end of each description in which information such as formation tops, thicknesses of particular intervals, and other miscellaneous information is reported. Stratigraphic units penetrated are given at the lefthand margin of a page, under the depth column.

NMBMMR CORE HOLE C5 (Cañada Calladita 7.5' Quadrangle); SE¼, NW¼, NW¼, Sec5, T16N, R4W, Sandoval County. Total depth, 200 ft (61 m). Units penetrated--Menefee Formation (Cleary Coal Member), Point Lookout Sandstone. Drilled, May 1978. Core described by Steve Craigg and Barbara Spence, August 1979.

UNIT	DESCRIPTION	DEPTH: FT
Not cored.		0.0 - 10.0
CLEARY COAL MEMBER OF MENEFEE FORMATION		
1	SILTY SANDSTONE--yellowish gray (5Y7/2) to light olive-gray (5Y6/1); single thick bed with thin to medium horizontal laminae; grains very fine to fine, well sorted, subangular to subrounded; composed mainly of clear quartz and feldspar with clay matrix and noncalcareous cement; moderately indurated; locally iron stained; finely-disseminated carbonaceous material scattered throughout unit and concentrated along laminae planes; trace of muscovite.	10.0 - 11.0
2	CLAYEY SILTSTONE--medium gray (N5) to light gray (N7); single thick bed with thin to medium horizontal laminae; noncalcareous cement; moderately indurated; muscovite common along laminae planes; trace of carbonaceous material; contact with above sharp, probably erosional.	11.0 - 12.2
3	SILTY SANDSTONE--yellowish gray (5Y7/2) to greenish gray (5GY6/1); single very thick bed with very thin to thin curved laminae; grains very fine to fine, well sorted, subangular to subrounded; composed mainly of clear quartz and feldspar with clay matrix and silica(?) cement; well indurated; trace of carbonaceous material; contact with above sharp, conformable.	12.2 - 13.8
4	COAL--black (N1); moderately indurated; vitreous; blocky; trace of amber; contact with above sharp, probably erosional.	13.8 - 16.3
Interval missing.		16.3 - 18.3

5	CLAYEY, CARBONACEOUS SILTSTONE--brownish black (5YR2/1) to brownish gray (5YR4/1); single thin bed with very thin horizontal laminae; noncalcareous cement; moderately indurated; carbonaceous material occurs along laminae planes.	18.3 - 18.5
6	SILTY SANDSTONE--light gray (N7); single medium bed with thin to medium horizontal and inclined laminae; grains very fine to fine, well sorted, subangular; composed mainly of clear quartz and feldspar with clay matrix and noncalcareous cement; moderately indurated; trace of carbonaceous material and mud clasts; contact with above sharp, conformable.	18.5 - 18.9
7	CLAYEY, CARBONACEOUS SILTSTONE--like unit 5 above; contact with above sharp, probably erosional.	18.9 - 20.3
8	SHALE--medium dark gray (N4); single thin bed with very thin horizontal laminae; noncalcareous cement; poorly indurated; trace of carbonaceous material; contact with above sharp, conformable.	20.3 - 20.6
9	COALY, CARBONACEOUS SILTSTONE--medium dark gray (N4) to dark gray (N3); single thick bed with very thin to thin horizontal laminae; noncalcareous cement; moderately indurated; coal occurs along laminae planes and throughout unit as fragments or clasts 3 - 4 cm in size; contact with above sharp, conformable.	20.6 - 23.1
10	COAL--like unit 4 above; contact with above sharp, erosional.	23.1 - 24.2
11	SHALE--like unit 8 above; contact with above sharp, conformable.	24.2 - 25.1
12	CLAYEY SILTSTONE--light gray (N7) to light olive-gray (5Y6/1); single thick bed with medium horizontal laminae; noncalcareous cement; moderately indurated; contains scattered fragments of coal; contact with above sharp, conformable.	25.1 - 26.5
Interval missing.		26.5 - 28.3
13	CLAYEY SILTSTONE--like unit 12 above.	28.3 - 30.0
14	SILTY SANDSTONE--light gray (N7) to medium gray (N5); single thick bed with thin horizontal laminae; grains very fine to fine, well sorted, subangular; composed mainly of clear quartz and feldspar with clay matrix and silica(?) cement; well indurated; trace of carbonaceous material along laminae planes; noncarbonized leaf fragments common; contact with above sharp, conformable.	30.0 - 31.0

15	SILTY SHALE--greenish gray (5GY6/1); single thick bed with thin to medium wavy laminae; noncalcareous cement; poorly indurated; trace of muscovite and finely-disseminated carbonaceous material; contact with above sharp, probably erosional.	31.0 - 32.1
16	CLAYEY SILTSTONE--light gray (N7) to greenish gray (5GY6/1); single thick bed with medium horizontal laminae; noncalcareous cement; moderately indurated; trace of muscovite and finely-disseminated carbonaceous material; contact with above sharp, conformable.	32.1 - 33.2
17	SILTY SANDSTONE--greenish gray (5GY6/1); single thick bed with thin to medium wavy laminae; grains very fine to fine, well sorted, subangular; noncalcareous cement; moderately indurated; trace of finely-disseminated carbonaceous material; contains lenses of clay 2 - 3 cm long and clay-filled root tubes; contact with above sharp, conformable.	33.2 - 34.3
18	CLAYEY SILTSTONE--like unit 16 above; contact with above sharp, probably erosional.	34.3 - 36.5
19	SHALE--medium dark gray (N4); single thick bed with thin to medium horizontal laminae; noncalcareous cement; moderately indurated; trace of carbonaceous material which increases downward; contact with above sharp, conformable.	36.5 - 37.6
20	SHALEY COAL--light brownish-gray (5YR6/1); single medium bed with wavy discontinuous laminae; noncalcareous cement; poorly to moderately indurated; contact with above gradational, conformable.	37.6 - 38.2
21	SHALE--like unit 20 above; contact with above gradational, conformable.	38.2 - 39.3
22	SHALEY COAL--like unit 20 above; contact with above gradational, conformable.	39.3 - 40.0
23	SILTY SHALE--medium light gray (N6); single thick bed with medium horizontal laminae; noncalcareous cement; poorly to moderately indurated; locally contains fragments of coal 1 - 2 cm wide and 4 - 5 cm long; contact with above sharp, conformable.	40.0 - 41.6
24	CONGLOMERATIC MUDSTONE--medium gray (N5) to yellowish gray (5Y7/2); single medium bed, massive; contains siltstone and claystone clasts in a mud matrix with calcite cement; moderately to well indurated; contact with above sharp, conformable(?).	41.6 - 42.1
Interval missing.		42.1 - 45.2

25	SILTY SANDSTONE--light gray (N7); single medium bed with thin horizontal laminae; grains very fine to fine, well sorted, subangular; composed mainly of clear quartz and feldspar with clay matrix and calcite cement; moderately indurated; trace of finely-disseminated carbonaceous material; iron nodules (siderite?) 1 - 2 cm wide and 3 - 4 cm long scattered throughout unit.	45.2 - 45.6
Interval missing.		45.6 - 66.0
26	SANDSTONE--very pale orange (10YR8/2); single thick bed with medium horizontal laminae; grains fine, well sorted, subangular; composed mainly of clear quartz and feldspar with clay matrix and calcite cement; moderately to well indurated; trace of muscovite.	66.0 - 68.0
27	SANDSTONE--very pale orange (10YR8/2); beds thick with medium inclined laminae (cross beds); cross bed sets about 9 cm thick, low angle, opposed, trough(?); grains fine to medium, moderately well sorted, subangular to subrounded; composed mainly of clear quartz and feldspar with clay matrix and calcite cement; moderately to well indurated; trace of muscovite and finely-disseminated carbonaceous material concentrated along laminae planes; contact with above gradational, conformable.	68.0 - 74.0
28	SANDSTONE--very pale orange (10YR8/2); beds thick and either massive or with medium wavy laminae; grains medium, well sorted, subrounded; composed mainly of clear quartz and feldspar with clay matrix and calcite cement; well indurated; trace of finely-disseminated carbonaceous material concentrated along laminae planes; unit becomes iron stained toward base; contact with above gradational, conformable.	74.0 - 83.5
29	CLAYEY SILTSTONE--medium light gray (N6); single medium bed with thin horizontal laminae; noncalcareous cement; moderately indurated; trace of carbonaceous material along laminae planes; contact with above sharp, erosional.	83.5 - 84.0
30	SANDSTONE--light gray (N7); single thick bed with thin to medium horizontal laminae; grains fine, well sorted, subangular; composed mainly of clear quartz and feldspar with clay matrix and calcite cement; trace of muscovite and carbonaceous material along laminae planes; contact with above sharp, conformable.	84.0 - 85.5

31	CLAYEY SILTSTONE--like unit 29 above; contact with above sharp, erosional.	85.5 - 86.3
32	SANDSTONE--very light gray (N8) to light gray (N7); thick beds, generally massive, but with medium inclined laminae (high-angle cross beds) near top; grains fine to medium, moderately well sorted, subrounded; composed mainly of clear quartz and feldspar with clay matrix and silica(?) cement; well indurated; trace of muscovite and carbonaceous material along laminae planes; locally iron stained; contact with above sharp, conformable.	86.3 - 90.5
33	SILTY SANDSTONE--like unit 25 above; contact with above sharp, erosional.	90.5 - 91.0
34	SANDSTONE--medium light gray (N6) to light brownish-gray (5YR6/1); single thick bed with medium horizontal laminae; grains medium to coarse, moderately well sorted, subrounded; composed mainly of clear quartz and feldspar with clay matrix and calcite cement; moderately to well indurated; contains mud clasts in upper part of unit; contains scattered pyrite crystals and siderite(?) nodules; trace of muscovite and carbonaceous material along laminae planes; contact with above gradational, conformable.	91.0 - 92.0
35	SILTY SANDSTONE--brownish black (5YR2/1) to light brownish-gray (5YR6/1); single thick bed with thin to medium wavy laminae; grains very fine to fine, well sorted, subangular; composed mainly of clear quartz and feldspar with clay matrix and noncalcareous cement; moderately indurated; trace of carbonaceous material along laminae planes; contact with above sharp, erosional.	92.0 - 93.7
36	SILTY SANDSTONE--medium light gray (N6) to light brownish-gray (5YR6/1); single thick bed with thin to medium horizontal laminae; grains very fine to fine, well sorted, subangular; composed mainly of clear quartz and feldspar with clay matrix and silica(?) cement; well indurated; trace of carbonaceous material along laminae planes; locally iron stained; contact with above gradational, conformable.	93.7 - 96.0
37	COAL--like unit 4 above; contact with above sharp, erosional.	96.0 - 96.9
38	SHALE--like unit 19 above; contact with above gradational, conformable.	96.9 - 97.1

39	COAL--like unit 4 above; contact with above gradational, conformable.	97.1 - 98.8
40	CARBONACEOUS SHALE--medium dark gray (N4); single thick bed with thin horizontal laminae; noncalcareous cement; poorly indurated; contact with above gradational, conformable.	98.8 - 101.3
41	COAL--like unit 4 above; contact with above gradational, conformable.	101.3 - 102.1
42	SILTY, CARBONACEOUS SHALE--grayish black (N2) to medium dark gray (N4); beds thick with thin to medium horizontal laminae; noncalcareous cement; poorly to moderately indurated; trace of finely-disseminated carbonaceous material along laminae planes, coal fragments, and carbonized plant stems; contact with above gradational, conformable.	102.1 - 107.8
43	SANDSTONE--light brownish-gray (5YR6/1); beds thick to very thick, either massive or with medium inclined laminae (cross beds 2 - 3 cm thick); grains very fine to fine, well sorted, subangular to subrounded; composed mainly of clear quartz and feldspar with clay matrix and calcite cement; moderately to well indurated; contains (siderite?) nodules up to about 5 cm in diameter; locally burrowed; contact with above sharp, conformable.	107.8 - 113.9
44	SHALE--like unit 19 above; contact with above sharp, erosional.	113.9 - 116.8
45	SILTY SHALE--medium dark gray (N4) to greenish black (5G2/1); single very thick bed with thin horizontal laminae; noncalcareous cement; poorly to moderately indurated; locally contains fragments of coal; contact with above gradational, conformable.	116.8 - 120.0
46	SANDSTONE--like unit 30 above; contact with above sharp, conformable.	120.0 - 120.9
47	SILTY SHALE--like unit 45 above; contact with above sharp, probably erosional.	120.9 - 121.5
48	SANDSTONE--like unit 30 above; contact with above sharp, conformable.	121.5 - 122.5
49	CLAYEY SILTSTONE--like unit 29 above; contact with above sharp, probably erosional.	122.5 - 123.7
50	SANDSTONE--like unit 30 above; contact with above sharp, conformable.	123.7 - 124.2

51	CLAYEY SILTSTONE--like unit 29 above; contact with above sharp, probably erosional.	124.2 - 124.8
52	SANDSTONE--like unit 30 above; contact with above sharp, conformable.	124.8 - 125.0
53	CLAYEY SILTSTONE--like unit 29 above; contact with above sharp, probably erosional.	125.0 - 125.5
54	SHALEY COAL--like unit 20 above; contact with above sharp, conformable.	125.5 - 126.7
55	SILTY SHALE--like unit 45 above; contact with above gradational, conformable.	126.7 - 128.0
56	Fragmented interval--fragments include Silty Shale (unit 55), Shaley Coal (unit 54), and Sandstone (unit 52).	128.0 - 130.0
57	SILTY SANDSTONE--light olive gray (5Y6/1); single thick bed with thin to medium inclined laminae (cross beds 3 - 5 cm thick); grains very fine to fine, well sorted, subangular; composed mainly of clear quartz and feldspar with clay matrix and noncalcareous cement; moderately indurated; trace of noncarbonized plant stems.	130.0 - 132.4
58	CARBONACEOUS SHALE--olive black (5Y2/1); beds thick to very thick with thin horizontal laminae; silica(?) cement; well indurated; carbonaceous material concentrated along laminae planes; contact with above sharp, probably erosional.	132.4 - 137.4
59	SANDSTONE--light brownish-gray (5YR6/1); single very thick bed with medium wavy laminae; grains fine to medium, moderately well sorted, subangular to subrounded; composed mainly of clear quartz and feldspar with clay matrix and silica(?) cement; well indurated; trace of muscovite and iron-oxide heavy minerals; contains clay lenses about 1 - 2 mm thick and 2 - 4 cm long; contact with above sharp, conformable.	137.4 - 142.3
60	SHALE--olive gray (5Y4/1); single very thick bed with medium horizontal laminae; noncalcareous cement; moderately indurated; contact with above sharp, erosional.	142.3 - 145.1
61	SANDSTONE--like unit 59 above; contact with above sharp, conformable.	145.1 - 146.9
62	SHALE--like unit 60 above; contact with above sharp, erosional.	146.9 - 147.2

63	SANDSTONE--like unit 59 above; contact with above sharp, conformable.	147.2 - 148.5
64	SHALE--like unit 60 above; contact with above sharp, erosional.	148.5 - 148.7

POINT LOOKOUT SANDSTONE

65	SANDSTONE--light brownish-gray (5YR6/1) in upper part, very light gray (N8) in lower part; beds medium to thick, either massive or with medium horizontal laminae; grains fine to medium, moderately well sorted, subangular to subrounded; composed mainly of clear quartz and feldspar with clay matrix and silica(?) cement; well indurated; trace of iron-oxide heavy minerals; contact with above sharp, conformable.	148.7 - 155.1
66	SILTY SHALE--brownish gray (5YR4/1); single medium bed with thin horizontal laminae; silica(?) cement; well indurated; contact with above sharp, probably erosional.	155.1 - 155.7
67	SANDSTONE--like unit 65 above; contact with above sharp, conformable.	155.7 - 158.0
68	SANDSTONE--light brownish-gray (5YR6/1); single very thick bed, massive; grains fine to coarse, moderately sorted, subangular to subrounded; composed mainly of clear quartz and feldspar with clay matrix and calcite cement; well indurated; trace of iron-oxide heavy minerals; contains carbonaceous lenses about 1 - 3 mm thick; gradually coarsens downward in grain size; contact with above gradational, conformable.	158.0 - 161.0
69	SILTY SHALE--like unit 66 above; contact with above sharp, erosional.	161.0 - 161.6
70	SANDSTONE--like unit 68 above; contact with above sharp, conformable.	161.6 - 162.5
71	SILTY SHALE--like unit 66 above; contact with above sharp, erosional.	162.5 - 162.9
72	SANDSTONE--very light gray (N8); beds thick to very thick, either massive or with medium horizontal laminae; grains fine to medium, moderately well sorted, subangular to subrounded; composed mainly of clear quartz and feldspar with clay matrix and calcite cement; poorly to well indurated;	162.9 - 180.0

trace of iron-oxide heavy minerals; unit gradually fines downward; contact with above sharp, conformable.

73	SHALE--olive gray (5Y4/1); single thin bed with thin horizontal laminae; noncalcareous cement; moderately indurated; contact with above sharp, probably erosional.	180.0 - 180.2
74	SANDSTONE--very light gray (N8); single thick bed, massive; grains fine to medium, moderately well sorted, subangular to subrounded; composed mainly of clear quartz and feldspar with clay matrix and silica(?) cement; well indurated; trace of iron-oxide heavy minerals; contains clay clasts up 4 cm in diameter, but most are 1 cm or smaller; contact with above sharp, conformable.	180.2 - 181.3
75	SHALE--like unit 73 above; contact with above sharp, probably erosional.	181.3 - 181.6
76	SANDSTONE--light gray (N7); beds thick to very thick, massive in upper half, medium horizontal and inclined laminae in lower half; grains fine, well sorted, subangular to subrounded; composed mainly of clear quartz and feldspar with clay matrix and calcite cement; poorly indurated in lower half, well indurated in upper half; trace of iron-oxide heavy minerals; contact with above sharp, conformable.	181.6 - 200.0

COMMENTS

Top Point Lookout Sandstone placed at base of interbedded carbonaceous sandstone and shale sequence, where major sandstone interval begins.

Depth of penetration into Point Lookout Sandstone is about 51 ft (16 m).

NMBMMR CORE HOLE C6 (Mesa Cortada 7.5' Quadrangle); NE¼, NE¼, NW¼, Sec17, T16N, R5W, McKinley County. Total depth, 251 ft (76.5 m). Units penetrated--Menefee Formation (Cleary Coal Member), Point Lookout Sandstone. Drilled, July 1978. Core described by Steve Craigg, October 1978 and August 1979.

UNIT	DESCRIPTION	DEPTH: FT
Not cored.		0.0 - 12.0
CLEARY COAL MEMBER OF MENEFEE FORMATION		
1	SANDSTONE--dusky yellow (5Y6/4) to light gray (N7); beds thick with medium horizontal laminae in upper part and inclined laminae in lower part (cross beds); grains fine to medium, moderately well sorted, subangular to subrounded; composed mainly of clear quartz and feldspar with clay matrix and calcite cement; moderately indurated; trace of muscovite and biotite.	12.0 - 31.0
2	SANDSTONE--yellowish gray (5Y7/2); beds medium to thick with medium inclined laminae (cross beds) in upper part and massive in lower part; grains fine to coarse, moderately sorted, subangular to subrounded; composed mainly of clear quartz and feldspar with clay matrix and calcite cement; moderately to well indurated; trace of muscovite, biotite, and carbonaceous material along laminae planes; contact with above gradational, conformable.	31.0 - 39.6
3	CLAYSTONE--moderate yellowish-green (10Y7/4); single thick bed, massive; silica(?) cement; well indurated; brittle; trace of noncarbonized plant stems; contact with above sharp, probably erosional.	39.6 - 42.0
4	SILTY SANDSTONE--light olive gray (5Y6/1); single thick bed with medium horizontal laminae; grains very fine to fine, well sorted, subangular to subrounded; composed mainly of clear quartz and feldspar with clay matrix and noncalcareous cement; poorly indurated; trace of noncarbonized plant stems and carbonaceous material along laminae planes; contact with above sharp, conformable.	42.0 - 44.0

5	INTERBEDDED CARBONACEOUS SHALE, CLAYSTONE, and COALY SHALE---CARBONACEOUS SHALE and CLAYSTONE--light brownish-gray (5YR6/1); Shale has thin horizontal laminae, Claystone is massive, silica(?) cement, well indurated; Shale is gradational into Claystone; carbonaceous material occurs along laminae planes. COALY SHALE--dark gray (N3); thin to medium laminae; silica(?) cement; well indurated; coal occurs in 1 - 2 mm layers along laminae planes; contact with above sharp, probably erosional.	44.0 - 46.0
6	COAL--black (N1); moderately to well indurated; vitreous; blocky; trace of amber; contact with above sharp, conformable.	46.0 - 46.5
7	INTERBEDDED SHALE and CLAYSTONE--light brownish-gray (5YR6/1); Shale has thin horizontal to wavy laminae; Claystone is massive, silica(?) cement; well indurated; Shale is gradational into Claystone; trace of carbonaceous material along laminae planes; contact with above sharp, conformable.	46.5 - 53.0
8	SHALEY COAL--brownish black (5YR2/1); single thick bed with medium horizontal laminae; noncalcareous cement; poorly laminated; contact with above sharp, conformable.	53.0 - 54.5
9	INTERBEDDED SHALE and CLAYSTONE--like unit 7 above; contact with above sharp, conformable.	54.5 - 57.5
10	COAL--like unit 6 above; contact with above sharp, conformable.	57.5 - 58.1
11	INTERBEDDED SHALE and CLAYSTONE--like unit 7 above; contact with above sharp, conformable.	58.1 - 59.2
12	COAL--like unit 6 above; contact with above sharp, conformable.	59.2 - 60.5
13	COALY SHALE--light brownish-gray (5YR6/1); single medium bed with medium curved laminae; calcareous cement; poorly indurated; coal occurs in 1 - 2 mm layers along laminae planes; contact with above sharp, conformable.	60.5 - 61.0
14	COAL--like unit 6 above; contact with above sharp, conformable.	61.0 - 61.5
15	INTERBEDDED SHALE and CLAYSTONE--like unit 7 above; contact with above sharp, conformable.	61.5 - 68.7
16	COAL--like unit 6 above; contact with above sharp, conformable.	68.7 - 69.1

17	INTERBEDDED SHALE and CLAYSTONE--like unit 7 above; contact above sharp, conformable.	69.1 - 71.2
18	SILTY SANDSTONE--medium gray (N5); medium beds either massive or with thin to medium horizontal laminae; grains very fine to fine, well sorted, subangular to subrounded; composed mainly of clear quartz and feldspar with clay matrix and silica(?) cement; well indurated; trace of muscovite, biotite, and finely-disseminated carbonaceous material; contact with above sharp, conformable.	71.2 - 76.4
19	SANDSTONE--like unit 2 above; contact with above gradational, conformable.	76.4 - 78.0
20	SILTY CLAYSTONE--medium dark gray (N4); single medium bed, massive; silica(?) cement; well indurated; contact with above sharp, probably erosional.	78.0 - 78.3
21	SANDSTONE--like unit 2 above; contact with above sharp, conformable.	78.3 - 79.0
22	COALY SHALE--brownish black (5YR2/1); single thick bed with medium horizontal laminae; noncalcareous cement; poorly indurated; coal occurs in 1 - 2 mm layers along laminae planes; a 5-cm-thick coal bed occurs at the top of the unit; contact with above sharp, probably erosional.	79.0 - 80.5
23	CLAYEY SILTSTONE--light brownish-gray (5YR6/1); beds thick to very thick, massive; silica(?) cement; well indurated; contains carbonized plant stems locally; contact with above sharp, conformable.	80.5 - 103.8
24	SANDSTONE--very light gray (N8); beds medium to thick and either massive or with thin to medium horizontal to inclined laminae; contains low-angle cross beds locally; grains fine to medium; moderately well sorted, subangular to subrounded; composed mainly of clear quartz and feldspar with clay matrix and calcite cement; well indurated; trace of muscovite and carbonaceous material; contact with above sharp, conformable.	103.8 - 107.4
25	CLAYEY SILTSTONE--like unit 23 above; contact with above sharp, probably erosional.	107.4 - 113.0
26	SANDSTONE--like unit 24 above; contact with above sharp, conformable.	113.0 - 117.4
27	CLAYEY SILTSTONE--like unit 23 above; contact with above sharp, probably erosional.	117.4 - 119.1

28	COAL--like unit 6 above; contact with above sharp, conformable.	119.1 - 122.3
29	CLAYEY SILTSTONE--like unit 23 above; contact with above sharp, conformable.	122.3 - 125.8
30	SILTY SANDSTONE--like unit 18 above; contact with above sharp, conformable.	125.8 - 128.6
31	SHALE--brownish gray (5YR4/1); single medium bed with medium horizontal laminae; noncalcareous cement; poorly to moderately indurated; contact with above sharp, probably erosional.	128.6 - 129.1
32	COAL--like unit 6 above; contact with above sharp, conformable.	129.1 - 132.1
33	INTERBEDDED CARBONACEOUS SHALE and CLAYSTONE--grayish black (N2); Shale has thin horizontal laminae, Claystone is massive, silica(?) cement; well indurated; carbonaceous material occurs throughout unit; contact with above sharp, conformable.	132.1 - 135.1
34	SILTY SANDSTONE--like unit 18 above; contact with above sharp, conformable.	135.1 - 137.2
35	COAL--like unit 6 above; contact with above sharp, conformable.	137.2 - 139.3

POINT LOOKOUT SANDSTONE

36	SANDSTONE--dark gray (N3); single thick bed with medium wavy laminae; grains fine, well sorted, subangular; composed mainly of clear quartz and feldspar with clay matrix and silica(?) cement; well indurated; carbonaceous material scattered throughout unit; contact with above sharp, conformable.	139.3 - 140.9
37	SANDSTONE--very light gray (N8); massive(?); grains fine to coarse, poorly to moderately sorted, subangular to rounded; composed mainly of clear quartz and feldspar with clay matrix and silica(?) cement; well indurated; trace of muscovite and iron-oxide heavy minerals; contact with above sharp, conformable.	140.9 - 155.2

38	SANDSTONE--medium light gray (N6); either massive or with medium to thick inclined laminae; low-angle cross bedding occurs locally in sets about 8 cm thick; grains fine to coarse in upper part and fine in lower part of unit, moderately to well sorted, subangular to subrounded; composed mainly of clear quartz and feldspar with clay matrix and calcite cement; moderately to well indurated; iron-oxide heavy minerals common in the cross-bedded zones; unit gradually fines downward; contact with above gradational, conformable.	155.2 - 188.7
39	SILTY SANDSTONE--very light gray (N8); single medium bed with thin to medium horizontal laminae; grains very fine to fine, well sorted, subangular; composed mainly of clear quartz and feldspar with clay matrix and silica(?) cement; well indurated; trace of carbonaceous material; contact with above gradational, conformable.	188.7 - 190.0
40	SANDSTONE--very light gray (N8); single medium bed with thin to medium horizontal laminae; grains fine to medium, moderately sorted, subangular to subrounded; composed mainly of clear quartz and feldspar with clay matrix and silica(?) cement; well indurated; locally contains scattered mudclasts; contact with above gradational, conformable.	190.0 - 190.4
41	SILTY SANDSTONE--like unit 39 above; contact with above gradational, conformable.	190.4 - 191.0
42	SANDSTONE--like unit 40 above; contact with above gradational, conformable.	191.0 - 198.7
43	SHALE--medium gray (N5); single medium bed with thin to medium horizontal laminae; noncalcareous cement; poorly to moderately indurated; contact with above sharp, probably erosional.	198.7 - 199.7
44	SILTY SANDSTONE--medium gray (N5) to very light gray (N8); single thick bed with thin to medium horizontal to curved laminae; unit contains one set of discordant, high-angle, 9-cm-thick cross beds; grains very fine to medium, moderately sorted, subangular to subrounded; composed mainly of clear quartz and feldspar with clay matrix and calcite cement; well indurated; contact with above sharp, conformable.	199.7 - 201.0
45	SILTY CLAYSTONE--dark gray (N3); single medium bed, massive; silica(?) cement; well indurated; contact with above sharp, probably erosional.	201.0 - 201.5

46	SANDSTONE--light gray (N7) to light brownish-gray (5YR6/1); massive; grains fine to medium, moderately well sorted, subangular to subrounded; composed mainly of clear quartz and feldspar with clay matrix and calcite cement; well indurated; trace of muscovite and iron-oxide heavy minerals; locally contains scattered mudclasts; contact with above sharp, conformable.	201.5 - 239.5
47	SILTY, LIMY SHALE--brownish gray (5YR4/1); single thick bed with thin to medium horizontal laminae; calcite cement; poorly to moderately indurated; contact with above sharp, probably erosional.	239.5 - 240.5
48	SANDSTONE--like unit 46 above; contact with above sharp, conformable.	240.5 - 251.0

COMMENTS

Top of Point Lookout Sandstone placed at bottom of first coal bed where major sandstone interval begins, at about 139 ft (42 m).

Depth of penetration into Point Lookout Sandstone is about 112 ft (32 m).

APPENDIX E

DESCRIPTIONS OF CUTTINGS

Seven sets of drill cuttings from 4-inch-diameter test holes drilled during the NMBMMR Torreon Wash coal study were described in order to provide additional information concerning the lithology and of the Menefee Formation and Point Lookout Sandstone. Five of the holes begin in the Cleary Coal Member of the Menefee Formation and partially penetrate the Point Lookout Sandstone; one hole begins in the Allison Member of the Menefee and enters the Cleary Coal Member; another hole is entirely in the "Upper Member" of the Menefee. The locations of drill holes, total depths, and units penetrated are given in Table E-1.

In selecting cuttings for analysis emphasis was placed on the five drill holes which were converted to observation wells in order to provide information on lithologies of perforated intervals and general rock types encountered during drilling.

General lithologic characteristics were described with a binocular microscope by basically the same techniques used for describing core (Appendix D). Most detail concerning bedding/internal structures, concretions/nodules, and fossils is lost in cuttings. However, the major rock types described are still a useful tool in evaluating subsurface characteristics of aquifers. The general outline used for describing cuttings is given below:

> GENERAL ROCK TYPE--color; texture; grain composition; matrix; cement; induration; miscellaneous constituents or characteristics.

Much of the terminology used is identical to that used for measured sections (Appendix A) and for core descriptions (Appendix D).

Table E-1. Location, depths, and stratigraphic units penetrated by NMBMMR test holes. Abbreviations same as Plate 1.

Drill hole number	Location	Total depth ft	Units penetrated
R13	NW¼, Sec26, T16N, R5W	230	Kmfc, Kpl
R21	SE¼, Sec18, T16N, R4W	250	Kmfc, Kpl
R23	SW¼, Sec6, T16N, R5W	250	Kmfc, Kpl
R24	NE¼, Sec2, T16N, R5W	250	Kmfc, Kpl
R32	SE¼, Sec23, T17N, R4W	240	Kmfc
R42	NW¼, Sec17, T17N, R3W	250	Kmfa, Kmfc
C1	SW¼, Sec20, T18N, R3W	170	Kmfu

When cuttings were not available for a particular footage, a missing interval was reported. When a rock type was identical to one previously described, the reader is referred to the first description rather than repeating the entire description. Depths are reported in only feet since they were recorded in this manner during drilling.

Each description begins with a heading giving the drill hole number, location, total depth, sampled interval, sample spacing, stratigraphic units penetrated, principle aquifer and perforated interval (if applicable), date drilled, and date described. Descriptions are given in the order materials were encountered during drilling, so that depths increase down the page. Stratigraphic units penetrated are given at the left-hand margin of a page, under the depth column. When a different formation is penetrated the dashed line above that unit indicates the approximate top of the unit. A comments section is included at the end of each description to report formation tops (from electric logs) and depths to particular units.

Relative abundances of rock types present in a particular interval are indicated in the following manner: two rock types joined by "and" with both rock types capitalized indicates that each makes up about 50 percent of the sample; two rock types joined by "and" with only the first capitalized indicates that the first rock type makes up greater than 50 percent and that the second makes up less than 50 percent of the sample; a single capitalized rock type indicates that the entire sample consists of that rock type.

NMBMMR OBSERVATION WELL R21 (Cerro Parido 7.5' Quadrangle); SE¼, SE¼, SE¼, Sec18, T16N, R4W, Sandoval County. Total depth, 250 ft (76 m); sampled interval, to total depth; sample spacing, 5 ft (1.5 m). Units penetrated--Colluvium(?), Menefee Formation (Cleary Coal Member), Point Lookout Sandstone. Principle aquifer, Point Lookout Sandstone, from 100 - 241 ft (30 - 73 m). Drilled June, 1978; cuttings described by Steve Craigg, July, 1979 (see Plate 1).

DEPTH: FT	DESCRIPTION
COLLUVIUM(?)	
0.0 - 10.0	SAND--moderate yellowish-green (5GY7/4); grains fine to medium, moderately well sorted, subangular to subrounded; clear quartz and feldspar; trace of chert, muscovite.
CLEARY COAL MEMBER OF MENEFEE FORMATION	
10.0 - 30.0	SANDSTONE--moderate yellowish-green (5GY7/4); grains fine to medium, moderately well sorted, subangular to subrounded; clear quartz and feldspar; clay matrix; noncalcareous cement; moderately indurated; trace of chert, muscovite.
30.0 - 40.0	SANDSTONE and SANDY SHALE--SANDSTONE, same as Sandstone from 10.0 - 30.0. SANDY SHALE, grayish yellow green (5GY7/2); trace of fine, subrounded, clear quartz grains; calcite cement; well indurated; trace of carbonaceous material.
40.0 - 50.0	SHALE--grayish green (5G5/2); noncalcareous cement; moderately indurated;
50.0 - 55.0	SHALE and COAL--SHALE, like Shale from 40.0 - 50.0. COAL, black (N1); moderately indurated; vitreous; blocky.
55.0 - 60.0	CARBONACEOUS SHALE--brownish gray (5YR4/1); noncalcareous cement; moderately indurated; trace of carbonized plant remains.

60.0 - 70.0	CARBONACEOUS SHALE and SHALE--CARBONACEOUS SHALE, like carbonaceous shale from 55.0 - 60.0. SHALE, like Shale from 40.0 - 50.0.
70.0 - 90.0	SHALE--light brownish-gray (5YR6/1); noncalcareous cement; moderately indurated; trace of carbonaceous material.
90.0 - 95.0	SHALE and Sandstone--SHALE, like Shale from 70.0 - 90.0. Sandstone, medium light gray (N6); grains fine to medium, well sorted, subangular to subrounded; clear quartz and feldspar; clay matrix; calcite cement; moderately indurated.
95.0 - 100.0	SHALE--like Shale from 70.0 - 90.0.
100.0 - 105.0	SHALE and Sandstone--SHALE, like Shale from 70.0 - 90.0. Sandstone, like Sandstone from 90.0 -95.0.

POINT LOOKOUT SANDSTONE

105.0 - 140.0	SANDSTONE--very light gray (N8); grains fine to coarse, moderately sorted, subangular to subrounded; clear quartz and feldspar; clay matrix; calcite cement; well indurated; trace of chert, muscovite.
140.0 - 145.0	SANDSTONE and Shale--SANDSTONE, like Sandstone from 105.0 - 140.0. Shale, brownish gray (5YR4/1); noncalcareous cement; moderately indurated.
145.0 - 165.0	SANDSTONE-very light gray (N8); grains fine, well sorted, subangular; clear quartz and feldspar; clay matrix; clacite cement; well indurated; trace of muscovite.
165.0 - 170.0	SANDSTONE ans Shale--SANDSTONE, like Sandstone from 145.0 - 165.0. Shale, like Shale from 140.0 - 145.0.
170.0 - 250.0	SANDSTONE--very light gray (N8); grains fine, well sorted, subangular; clear quartz and feldspar; clay matrix; clacite cement; well indurated; trace of muscovite; local iron staining on sandstone fragments.

COMMENTS

Electric log shows top of Point Lookout Sandstone at approximately 100 ft (30.5 m), where major sandstone interval begins.

Approximate depth of penetration into Point Lookout Sandstone is 145 ft (44 m).

NMBMMR OBSERVATION WELL R23 (Cañada Calladita 7.5' Quadrangle); NW¼, SW¼, SW¼, Sec6, T16N, R4W, Sandoval County. Total depth, 250 ft (76 m); sampled interval, to total depth; sample spacing, 5 ft (1.5 m). Units penetrated--Colluvium(?), Menefee Formation (Cleary Coal Member), Point Lookout Sandstone. Principle aquifer, Point Lookout Sandstone, from 180 - 245 ft (55 - 75 m). Drilled June, 1978; cuttings described by Steve Craigg, July 1979 (see Plate 1).

DEPTH: FT	DESCRIPTION
	COLLUVIUM(?) and CLEARY COAL MEMBER OF MENEFEE FORMATION
0.0 - 10.0	SAND and SILTSTONE--SAND, yellowish gray (5Y8/1); grains fine to medium, moderately well sorted, subangular to subrounded; clear quartz and feldspar. SILTSTONE, light olive gray (5Y6/1); calcite cement; well indurated.
10.0 - 15.0	SANDSTONE and SILTSTONE--SANDSTONE, pale olive (10Y6/2); grains fine to medium, moderately well sorted, subangular to subrounded; clear quartz and feldspar; clay matrix; calcite cement; moderately indurated; trace of chert, iron-oxide heavy minerals. SILTSTONE, like Siltstone from 0.0 - 10.0.
15.0 - 20.0	SANDSTONE--like Sandstone from 10.0 - 15.0.
20.0 - 25.0	SHALE--light brownish-gray (5YR6/1); silica(?) cement; well indurated; brittle; trace of muscovite, carbonaceous material.
25.0 - 30.0	COALY SHALE and Shale--COALY SHALE, dark gray (N3); noncalcaroues cement; moderately indurated; coal occurs in thin layers along laminae; Shale, like Shale from 20.0 -25.0.
30.0 - 40.0	COAL and SILTY CLAYSTONE--COAL, black (N1); moderately indurated; vitreous; blocky. SILTY CLAYSTONE, light olive gray (5Y6/1); noncalcareous cement; poorly indurated.
40.0 - 45.0	CARBONACEOUS SHALE and Coal--CARBONACEOUS SHALE, dark gray (N3); noncalcareous cement; moderately indurated; trace of carbonaized plant remains. Coal, like Coal from 30.0 - 40.0.

45.0 - 50.0	SHALE and Carbonaceous Shale--SHALE, olive gray (5Y4/1); noncalcareous cement; moderately indurated. Carbonaceous Shale, like Carbonaceous Shale from 40.0 - 45.0.
50.0 - 65.0	SHALE--light olive gray (5Y6/1); silica(?) cement; well indurated.
65.0 - 70.0	SHALE and Coal--SHALE, like Shale from 50.0 - 65.0. Coal, like Coal from 30.0 - 40.0.
70.0 - 75.0	COAL--black (N1); moderately indurated; vitreous; blocky; trace of amber.
75.0 - 95.0	SILTY SANDSTONE--light brownish-gray (5YR6/1); grains very fine to medium, moderately well sorted, subangular to subrounded; clear quartz and feldspar; clay matrix; calcite cement; poorly indurated; trace of muscovite.
95.0 - 105.0	SANDSTONE--light olive gray (5Y6/1); grains fine to medium, moderately well sorted, subangular to subrounded; clear quartz and feldspar; clay matrix; calcite cement; poorly indurated; trace of muscovite.
105.0 - 115.0	SANDSTONE and SHALE--SANDSTONE, like Sandstone from 95.0 - 105.0. SHALE, light brownish-gray (5YR6/1); noncalcareous cement; moderately indurated; trace of carbonaceous material.
115.0 - 145.0	SANDSTONE--light olive gray (5Y6/1) to grayish yellow green (5GY7/2) to pinkish gray (5YR8/1); grains fine to medium, moderately well sorted, subangular to subrounded; clear quartz and feldspar; clay matrix; calcite cement; moderately indurated; trace of muscovite.
145.0 - 150.0	COAL and Sandstone--COAL, like Coal from 30.0 - 40.0. Sandstone, pinkish gray (5YR8/1); grains fine to medium, moderately well sorted, subangular to subrounded; clear quartz and feldspar; clay matrix; calcite cement; moderately indurated; trace of muscovite.
150.0 - 155.0	SANDY SILTSTONE and Coal--SANDY SILTSTONE, light brownish-gray (5YR6/1); trace of fine, subangular, clear quartz and feldspar grains; calcite cement; well indurated. Coal, like coal from 30.0 - 40.0.
155.0 - 165.0	SANDY SILTSTONE--like Sandy Siltstone from 150.0 - 155.0.
165.0 - 170.0	COAL--like Coal from 30.0 - 40.0.
170.0 - 180.0	CARBONACEOUS SHALE and Coal--CARBONACEOUS SHALE, like Carbonaceous Shale from 40.0 - 45.0. Coal, like Coal from 30.0 - 40.0.

POINT LOOKOUT SANDSTONE

180.0 -195.0	SANDSTONE--light olive gray (5Y6/1); grains fine to medium, moderately well sorted, subangular to subrounded; clear quartz and feldspar; clay matrix; calcite cement; poorly indurated; trace of muscovite.
195.0 - 215.0	SANDSTONE--very light gray (N8) to light brownish-gray (5YR6/1); grains fine to medium, moderately well sorted, subangular to subrounded; clear quartz and feldspar; clay matrix; calcite cement; moderately indurated; trace of muscovite.
215.0 - 250.0	SANDSTONE--light gray (N7) to light brownish-gray (5YR6/1); grains fine to medium, moderately well sorted, subangular to subrounded; clear quartz and feldspar; clay matrix; calcite cement; moderately indurated; trace of muscovite.

COMMENTS

Electric log shows top of Point Lookout Sandstone at approximately 180 ft (55 m), where major sandstone interval begins.

Approximate depth of penetration into Point Lookout Sandstone is 70 ft (21 m).

NMBMMR OBSERVATION WELL R24 (Canada Calladita 7.5' Quadrangle); SW¼, SE¼, NE¼, Sec2, T16N, R5W, McKinley County. Total depth, 250 ft (76 m); sampled interval, to total depth; sample spacing, 5 ft (1.5 m). Units penetrated--Colluvium(?), Menefee Formation (Cleary Coal Member), Point Lookout Sandstone. Principle aquifer, Point Lookout Sandstone, from 200 - 240 ft (61 - 73 m). Drilled June, 1978; cuttings described by Steve Craigg, July, 1979 (see Plate 1).

DEPTH: FT	DESCRIPTION
COLLUVIUM(?)	
0.0 - 5.0	SAND--yellowish gray (5Y7/2); grains fine to coarse, moderately sorted, subangular to rounded; clear quartz and feldspar; trace of chert, muscovite.
CLEARY COAL MEMBER OF MENEFEE FORMATION	
5.0 - 10.0	SANDSTONE--pinkish gray (5YR8/1); grains fine to medium, moderately well sorted, subangular to subrounded; clear quartz and feldspar; clay matrix; calcite cement; moderately indurated; trace of chert, muscovite, biotite.
10.0 - 20.0	SANDSTONE and Shale--SANDSTONE, like Sandstone from 5.0 - 10.0. Shale, medium dark gray (N4); silica(?) cement; well indurated; brittle.
20.0 - 30.0	SANDSTONE--like Sandstone from 5.0 - 10.0.
30.0 - 40.0	SANDSTONE and SHALE--SANDSTONE, pinkish gray (5YR8/1); grains fine to coarse, moderately sorted, subangular to rounded; clear quartz and feldspar; clay matrix; calcite cement; moderately indurated; trace of chert, muscovite, biotite. SHALE, grayish green (10GY5/2); noncalcareous cement; moderately indurated.
40.0 - 45.0	SHALE--like Shale from 30.0 - 40.0.
45.0 - 60.0	SHALE--brownish gray (5YR4/1); silica(?) cement; well indurated; brittle.

60.0 - 70.0	SANDSTONE and SHALE--SANDSTONE, grayish yellow (5Y8/4); grains fine to medium, moderately well sorted, subangular to subrounded; clear quartz and feldspar; clay matrix; silica(?) cement; well indurated; trace of muscovite. SHALE, like Shale from 45.0 - 60.0.
70.0 - 75.0	SANDSTONE--like Sandstone from 60.0 - 70.0.
75.0 - 80.0	COAL and Sandstone--COAL, black (N1); moderately indurated; vitreous; blocky. Sandstone, like Sandstone from 60.0 - 70.0.
80.0 - 95.0	SHALE--light brownish-gray (5YR6/1); noncalcareous cement; moderately indurated.
95.0 - 100.0	SHALE and Sandstone--SHALE, like Shale from 80.0 - 95.0. Sandstone, light gray (N7); grains fine, well sorted, subangular; clear quartz and feldspar; clay matrix; calcite cement; poorly indurated; trace of muscovite.
100.0 - 105.0	CARBONACEOUS SHALE and SHALE--CARBONACEOUS SHALE, brownish black (5YR2/1); noncalcareous cement; poorly indurated; trace of carbonized plant remains. SHALE, like Shale from 80.0 - 95.0.
105.0 - 120.0	SHALE--like Shale from 80.0 -95.0.
120.0 - 150.0	SANDSTONE and SHALE--SANDSTONE, like Sandstone from 95.0 - 100.0. SHALE, like Shale from 80.0 - 95.0.
150.0 - 155.0	SANDSTONE and Carbonaceous Shale--SANDSTONE, light brownish-gray (5YR6/1); grains fine, well sorted, subangular; clear quartz and feldspar; clay matrix; calcite cement; poorly indurated; trace of muscovite. Carbonaceous Shale, like Carbonaceous Shale from 100.0 - 105.0.
155.0 - 160.0	SANDY SHALE--light gray (N7); trace of fine, subangular, clear quartz grains; noncalcareous cement; moderately indurated.
160.0 - 165.0	SANDSTONE--light gray (N7); grains fine to medium, moderately sorted, subangular to rounded; clear quartz and feldspar; clay matrix; calcite cement; poorly indurated; trace of chert, muscovite, pyrite crystals.
165.0 - 170.0	COAL--black (N1); moderately indurated; vitreous; blocky; trace of amber.
170.0 - 175.0	COAL and CARBONACEOUS SHALE--COAL, like Coal from 165.0 - 170.0. CARBONACEOUS SHALE, like Carbonaceous Shale from 150.0 - 155.0.

175.0 - 180.0	CARBONACEOUS SHALE and Sandstone--CARBONACEOUS SHALE, like Carbonaceous Shale from 150.0 - 155.0. Sandstone, very light gray (N8); grains very fine to medium, moderately sorted, subangular to subrounded; clear quartz and feldspar; clay matrix; noncalcareous cement; moderately indurated; trace of chert, muscovite.

POINT LOOKOUT SANDSTONE

180.0 - 190.0	SANDSTONE--like Sandstone from 175.0 - 180.0.
190.0 - 220.0	SANDSTONE--very light gray (N8); grains very fine to fine, well sorted, subangular; clear quartz and feldspar; clay matrix; noncalcareous cement; moderately indurated; trace of muscovite.
220.0 - 230.0	SANDSTONE and Shale--SANDSTONE, like Sandstone from 190.0 - 220.0. Shale, medium dark gray (N4); noncalcareous cement; moderately indurated.
230.0 - 250.0	SANDSTONE--like Sandstone from 190.0 - 220.0.

COMMENTS

Electric log shows top of Point Lookout Sandstone at approximately 177 ft (54 m), where major sandstone interval begins.

Approximate depth of penetration into Point Lookout Sandstone is 73 ft (22 m).

NMBMMR OBSERVATION WELL R32 (Arroyo Empedrado 7.5' Quadrangle); NE¼, NW¼, SE¼, Sec23, T17N, R4W, Sandoval County. Total depth, 240 ft (73 m); sampled interval, to toal depth; sample spacing, 5 ft (1.5 m). Units penetrated--Menefee Formation (Cleary Coal Member). Principle aquifer, Coal Bed, from 224 - 229 ft (68 - 70 m). Drilled April, 1978; cuttings described by Steve Craigg, July, 1979 (see Plate 1).

DEPTH: FT	DESCRIPTION
0.0 - 15.0	Interval missing.
CLEARY COAL MEMBER OF MENEFEE FORMATION	
15.0 - 20.0	SHALE--moderate yellowish-green (10GY6/4); noncalcareous cement; moderately indurated; trace of plant molds.
20.0 - 35.0	SHALE--dusky yellow green (5GY5/2); noncalcareous cement; moderately indurated.
35.0 - 50.0	SANDY SHALE--light gray (N7); trace of fine, subangular, clear quartz grains; noncalcareous cement; moderately indurated; trace of plant remains.
50.0 - 55.0	SILTY SHALE--light brownish-gray (5YR6/1); noncalcareous cement; moderately indurated.
55.0 - 60.0	SILTY SHALE and Coal--SILTY SHALE, like Silty Shale from 50.0 -55.0. Coal, black (N1); moderately indurated; vitreous; blocky.
60.0 - 70.0	Interval missing.
70.0 - 90.0	SANDSTONE and Silty Shale--SANDSTONE, very light gray (N8); grains fine, well sorted, subangular to subrounded; clear quartz and feldspar; clay matrix; calcite cement; moderately indurated; trace of muscovite, biotite. Silty Shale, like Silty Shale from 50.0 - 55.0.
90.0 - 100.0	SANDSTONE and Coal--SANDSTONE, like Sandstone from 70.0 - 90.0. Coal, like Coal from 55.0 - 60.0.

100.0 - 105.0	CARBONACEOUS SHALE and SANDSTONE--CARBONACEOUS SHALE, dark gray (N3); noncalcareous cement; moderately indurated; trace of carbonized plant remains. SANDSTONE, like Sandstone from 70.0 - 90.0.
105.0 - 110.0	SHALE--brownish gray (5YR4/1); noncalcareous cement; moderately indurated.
110.0 - 115.0	COALY SHALE--dark gray (N3); noncalcareous cement; moderately indurated; coal occurs in thin layers along laminae planes.
115.0 - 120.0	SANDSTONE--very light gray (N8); grains very fine to fine, well sorted, subangular to subrounded; clear quartz and feldspar; clay matrix; noncalcareous cement; moderately indurated; trace of muscovite, biotite, iron-oxide heavy minerals.
120.0 - 125.0	SHALE and Sandstone--SHALE, like Shale from 105.0 - 110.0. Sandstone, like Sandstone from 115.0 - 120.0.
125.0 - 135.0	CARBONACEOUS SHALE and Sandstone--CARBONACEOUS SHALE, like Carbonaceous Shale from 100.0 - 105.0. Sandstone, like Sandstone from 115.0 - 120.0.
135.0 - 140.0	SANDSTONE--like Sandstone from 115.0 - 120.0.
140.0 - 145.0	COAL and Sandstone--COAL, like Coal from 55.0 - 60.0. Sandstone, like Sandstone from 115.0 - 120.0.
145.0 - 165.0	SHALE--brownish gray (5YR4/1); noncalcareous cement; moderately indurated; trace of carbonaceous material.
165.0 - 175.0	Interval missing.
175.0 - 190.0	SANDSTONE--very light gray (N8); grains fine to medium, moderately well sorted, subangular to subrounded; clear quartz and feldspar; clay matrix; noncalcareous cement; moderately well indurated; trace of chert, muscovite.
190.0 - 195.0	COAL and Sandstone--COAL, black (N1); moderately indurated; vitreous; blocky; trace of amber. Sandstone, like Sandstone from 175.0 - 190.0.
195.0 - 200.0	SANDSTONE--very light gray (N8); grains fine to medium, moderately well sorted, subangular to subrounded; clear quartz and feldspar; clay matrix; noncalcareous cement; moderately indurated; trace of chert, muscovite, carbonaceous material.
200.0 - 205.0	SANDSTONE and SHALE--SANDSTONE, like Sandstone from 195.0 - 200.0. SHALE, like Shale from 145.0 - 165.0.

205.0 - 210.0	SHALE--like Shale from 145.0 - 165.0.
210.0 - 215.0	COAL and Carbonaceous Shale--COAL, like Coal from 55.0 - 60.0. Carbonaceous Shale, like Carbonaceous Shale from 100.0 - 105.0.
215.0 - 220.0	CARBONACEOUS SHALE--like Carbonaceous Shale from 100.0 - 105.0.
220.0 - 225.0	SANDSTONE--light gray (N7); grains fine to coarse, poorly sorted, subangular to well rounded; clear quartz and feldspar; clay matrix; calcite cement; moderately indurated; trace of chert, muscovite, carbonaceous material.
225.0 - 230.0	COAL--like coal from 55.0 - 60.0.
230.0 - 240.0	SHALE--brownish gray (5YR4/1); silica(?) cement; well indurated; brittle.

NMBMMR OBSERVATION WELL C1 (Wolf Stand 7.5' Quadrangle); NW¼, NW¼, SW¼, Sec20, T18N, R3W, Sandoval County. Total depth, 170 ft (52 m); sampled interval, to total depth; sample spacing, 5 ft (1.5 m); coal-bearing intervals cored. Units penetrated--Menefee Formation ("Upper Member"). Principle aquifer, Coal Bed, from 155 - 169 ft (47 - 51 m). Drilled September, 1978; cuttings described by Steve Craigg, July, 1979.

DEPTH: FT	DESCRIPTION
0.0 - 10.0	Interval missing.

"UPPER MEMBER OF MENEFEE FORMATION"

10.0 - 15.0	SHALE--olive gray (5Y4/1); silica(?) cement; well indurated; trace of carbonaceous material.
15.0 - 25.0	SILTY SHALE--light brownish gray (5YR6/1); noncalcareous cement; moderately indurated.
25.0 - 30.0	SILTY SHALE and Silty Sandstone--SILTY SHALE, like Silty Shale from 15.0 - 25.0. Silty Sandstone, very light gray (N8); grains very fine to fine, well sorted, subangular to subrounded; clear quartz and feldspar; clay matrix; calcite cement; moderately indurated; trace of muscovite, biotite.
30.0 - 40.0	SILTY SANDSTONE--like Silty Sandstone from 25.0 - 30.0.
40.0 - 45.0	SILTY SANDSTONE and Carbonaceous Shale--SILTY SANDSTONE, like Silty Sandstone from 25.0 - 30.0. Carbonaceous Shale, dark gray (N3); noncalcareous cement; moderately indurated; trace of carbonized plant remains.
45.0 - 60.0	CARBONACEOUS SHALE and COAL--CARBONACEOUS SHALE, like Carbonaceous Shale from 40.0 - 45.0. COAL, black (N1); moderately indurated; vitreous; blocky.
60.0 - 70.0	CARBONACEOUS SHALE and COALY SHALE--CARBONACEOUS SHALE, like Carbonaceous Shale from 40.0 - 45.0. COALY SHALE, olive black (5Y2/1); noncalcareous cement; moderately indurated; coal occurs in thin layers along laminae planes.

70.0 - 80.0	SILTY SANDSTONE and SILTY SHALE--SILTY SANDSTONE, like Silty Sandstone from 25.0 - 30.0. SILTY SHALE, like Silty Shale from 15.0 - 25.0.
80.0 - 85.0	SILTY SHALE--like Silty Shale from 15.0 - 25.0.
85.0 - 90.0	SILTY SHALE and Shale--SILTY SHALE, like Silty Shale from 15.0 - 25.0. Shale, medium gray (N5); noncalcareous cement; moderately indurated.
90.0 - 95.0	SHALE and COALY SHALE--SHALE, like Shale from 85.0 - 90.0. COALY SHALE, like Coaly Shale from 60.0 - 70.0.
95.0 - 100.0	CARBONACEOUS SHALE and Silty Sandstone--CARBONACEOUS SHALE, medium dark gray (N4); noncalcareous cement; moderately indurated; trace of carbonized plant remains. Silty Sandstone, like Silty Sandstone from 25.0 - 30.0.
100.0 - 105.0	CARBONACEOUS SHALE--olive black (5Y2/1); noncalcareous cement; poorly indurated; trace of carbonized plant remians.
105.0 - 110.0	SHALE--brownish gray (5YR4/1); noncalcareous cement; moderately indurated.
110.0 - 115.0	SILTY SANDSTONE and SILTY SHALE--SILTY SANDSTONE, light gray (N7); grains very fine to fine, well sorted, subangular to subrounded; clear quartz and feldspar; clay matrix; calcite cement; moderately indurated; trace of carbonaceous material. SILTY SHALE, grayish green (10GY5/2); silica(?) cement; well indurated.
115.0 - 120.0	CARBONACEOUS SHALE and COALY SHALE--CARBONACEOUS SHALE, like Carbonaceous Shale from 95.0 - 100.0. COALY SHALE, like Coaly Shale from 90.0 - 95.0.
120.0 - 125.0	COALY SHALE and COAL--COALY SHALE, like Coaly Shale from 90.0 - 95.0. COAL, like Coal from 45.0 - 60.0.
125.0 - 130.0	SILTY SANDSTONE and SILTY SHALE--SILTY SANDSTONE, like Silty Sandstone from 110.0 - 115.0. SILTY SHALE, like Silty Shale from 15.0 - 25.0.
130.0 - 135.0	CARBONACEOUS SHALE and COALY SHALE--CARBONACEOUS SHALE, like Carbonaceous Shale from 95.0 - 100.0. COALY SHALE, like Coaly Shale from 90.0 - 95.0.
135.0 - 150.0	SILTY SANDSTONE and SILTY SHALE--SILTY SANDSTONE, like Silty Sandstone from 25.0 - 30.0. SILTY SHALE, like Silty Shale from 15.0 - 25.0.

150.0 - 155.0	SHALE and Silty Sandstone--SHALE, medium dark gray (N4); silica(?) cement; well indurated; trace of plant molds. Silty Sandstone, like Silty Sandstone from 25.0 - 30.0.
155.0 - 160.0	COAL and Coaly Shale--COAL, like Coal from 45.0 - 60.0. Coaly Shale, like Coaly Shale from 90.0 - 95.0.
160.0 - 165.0	COAL--like Coal from 45.0 - 60.0.
165.0 - 170.0	COAL and Carbonaceous Shale--COAL, like Coal from 45.0 - 60.0. Carbonaceous Shale, like Carbonaceous Shale from 95.0 - 100.0

COMMENTS

Although labeled as a core hole, only the coal-bearing intervals were cored; these descriptions are included with the cuttings descriptions.

NMBMMR DRILL HOLE R13 (Cerro Parido 7.5' Quadrangle); SW¼, NW¼, NW¼, Sec 26, T16N, R5W, McKinley County. Total depth, 230 ft (70 m); sampled interval, to total depth; sample spacing, 10 ft (3 m). Units penetrated--Menefee Formation (Cleary Coal Member), Point Lookout Sandstone. Drilled May, 1978; cuttings described by Steve Craigg, July, 1979.

DEPTH: FT	DESCRIPTION
CLEARY COAL MEMBER OF MENEFEE FORMATION	
0.0 - 10.0	SILTY SANDSTONE and Shale--SILTY SANDSTONE, grayish yellow green (5GY7/2); grains very fine to medium, moderately well sorted, subangular to rounded; clear quartz and feldspar; clay matrix; silica(?) cement; well indurated; trace of muscovite. Shale, grayish green (5G5/2); noncalcareous cement; poorly indurated; crumbly; trace of carbonaceous material.
10.0 - 40.0	SHALE--like Shale from 0.0 - 10.0.
40.0 - 50.0	COAL and Shale--COAL, black (N1); moderately indurated; vitreous; blocky; trace of amber. Shale, like Shale from 0.0 - 10.0.
50.0 - 60.0	COAL--like Coal from 40.0 - 50.0.
60.0 - 70.0	SHALE--grayish green (10G4/2); silica(?) cement; well indurated; brittle.
POINT LOOKOUT SANDSTONE	
70.0 - 90.0	SANDSTONE--yellowish gray (5Y8/1); grains fine to medium, moderately well sorted, subangular to subrounded; clear quartz and feldspar; clay matrix; calcite cement; poorly indurated; trace of chert, muscovite.
90.0 - 100.0	SANDSTONE--pinkish gray (5YR8/1); grains fine to coarse, poorly sorted, subangular to rounded; clear quartz and feldspar; clay matrix; calcite cement; moderately indurated; trace of chert, muscovite.

100.0 - 140.0	SANDSTONE--pinksih gray (5YR8/1); grains very fine to medium, moderately weel sorted, subangular to subrounded; clear quartz and feldspar; clay matrix; noncalcareous cement; poorly indurated; trace of chert, muscovite, biotite, iron-oxide heavy minerals.
140.0 - 150.0	SANDSTONE--grayish pink (5R8/2); grains very fine to fine, well sorted, subangular to subrounded; clear quartz and feldspar; clay matrix; nocalcareous cement; moderately indurated; trace of muscovite, biotite.
150.0 - 170.0	Interval missing.
170.0 - 180.0	SANDSTONE and Shale--SANDSTONE, light olive gray (5Y6/1); grains very fine to fine, well sorted, subangular to subrounded; clear quartz and feldspar; clay matrix; calcite cement; moderately indurated; trace of muscovite. Shale, brownish gray (5YR4/1); silica(?) cement; well indurated; brittle.
180.0 - 230.0	Interval missing.

COMMENTS

Electric log shows top of Point Lookout Sandstone at approximately 67 ft (20 m), where major sandstone interval begins.

Approximate depth of penetration into the Point Lookout Sandstone is 160 ft (49 m).

NMBMMR DRILL HOLE R42 (Arroyo Empedrado 7.5' Quadrangle); SW¼, SE¼, NW¼, Sec17, T17N, R3W, Sandoval County. Total depth, 250 ft (76 m); sampled interval, to total depth; sample spacing, 5 ft (1.5 m). Units penetrated--Alluvium(?), Menefee Formation (Allison and Cleary Coal Members). Drilled July, 1978; cuttings described by Steve Craigg, July, 1979 (see Plate 1).

DEPTH: FT	DESCRIPTION
ALLUVIUM(?)	
0.0 - 10.0	SAND--yellowish gray (5Y7/2); grains fine to coarse, poorly sorted, subangular to rounded; clear quartz and feldspar; trace of chert, muscovite.
ALLISON MEMBER OF MENEFEE FORMATION	
10.0 - 20.0	SANDSTONE and Shale--SANDSTONE, light brownish-gray (5YR6/1); grains fine to medium, moderately well sorted, subangular to subrounded; clear quartz and feldspar; clay matrix; calcite cement; well indurated; trace of chert, muscovite. Shale, light olive gray (5Y5/2); silica(?) cement; well indurated, brittle.
20.0 - 30.0	SHALE--like Shale from 10.0 - 20.0.
30.0 - 40.0	SANDSTONE and SHALE--SANDSTONE, like Sandstone from 10.0 - 20.0. SHALE, like Shale from 10.0 - 20.0.
40.0 - 45.0	SANDSTONE--like Sandstone from 10.0 - 20.0.
45.0 - 60.0	SHALE--medium light gray (N6); silica(?) cement; moderately indurated.
60.0 - 75.0	SANDSTONE--like Sandstone from 10.0 - 20.0.
75.0 - 80.0	SHALE and Sandstone--SHALE, like Shale from 45.0 - 60.0. Sandstone, like Sandstone from 10.0 - 20.0.
80.0 - 100.0	SILTY SANDSTONE--light gray (N7); grains fine to medium, moderately well sorted, subangular to subrounded; clear quartz and feldspar; clay matrix; calcite cement; moderately indurated.

CLEARY COAL MEMBER OF MENEFEE FORMATION

100.0 - 105.0	CARBONACEOUS SHALE--brownish black (5YR2/1); noncalcareous cement; moderately indurated; trace of carbonized plant remains.
105.0 - 115.0	CARBONACEOUS SHALE and COAL--CARBONACEOUS SHALE, like Carbonaceous Shale from 100.0 - 105.0. COAL, black (N1); moderately indurated; vitreous; blocky.
105.0 - 135.0	CARBONACEOUS SHALE--like Carbonaceous Shale from 100.0 - 105.0.
135.0 - 145.0	SANDSTONE--light gray (N7); grains fine to medium, moderately well sorted, subangular to subrounded; clear quartz and feldspar; clay matrix; noncalcareous cement; poorly indurated.
145.0 - 155.0	SHALE and Sandstone--SHALE, light brownish-gray (5YR6/1); silica(?) cement; well indurated. Sandstone, like Sandstone from 135.0 - 145.0.
155.0 - 170.0	SANDSTONE--like Sandstone from 135.0 - 145.0.
170.0 - 185.0	SHALE and Sandstone--SHALE, greenish gray (5GY6/1); silica(?) cement; well indurated. Sandstone, like Sandstone from 135.0 - 145.0.
185.0 - 205.0	SANDSTONE and CARBONACEOUS SHALE--very light gray (N8); grains fine to coarse, moderately sorted, subrounded to rounded; clear quartz and feldspar; clay matrix; calcite cement; well indurated; trace of chert, muscovite. CARBONACEOUS SHALE, like Carbonaceous Shale from 100.0 - 105.0.
205.0 - 210.0	SANDSTONE--like Sandstone from 185.0 - 205.0.
210.0 - 220.0	SANDSTONE and CARBONACEOUS SHALE--SANDSTONE, like Sandstone from 185.0 - 205.0. CARBONACEOUS SHALE, like Carbonaceous Shale from 100.0 - 105.0.
220.0 - 250.0	SANDSTONE--like Sandstone from 185.0 - 205.0.

COMMENTS

Contact between Allison and Cleary Coal Members is placed at the first appearance of carbonaceous shales and coals.

APPENDIX F

METHODS OF CONSTRUCTING, DEVELOPING, AND TESTING WELLS

The study area overlapped in part with the recent NMBMMR Torreon Wash coal project area (Fig. F-1; Tabet and Frost, 1979). During test drilling int(coal-bearing zones it was possible to arrange for the completion of five water observation wells. Three of these wells were completed in the Point Lookout Sandstone and two were completed in coal beds of the Menefee Formation. Original plans had called for the completion of seven wells, with two additional wells to be completed in a shale/claystone, and a channel sandstone of the Menefee. Geologic and hydrologic conditions encountered during drilling, however, did not permit these two additional wells to be completed. The general approach to construction of the wells is shown in Figure F-2, whereas, details concerning location and construction of specific wells is given Table F-1.

Before aquifer tests could be performed, it was necessary to clean out the drilling mud and develop the wells. This was accomplished by blowing air into the casing with a Smith 150-cubic-feet-per-minute air compressor and a one-inch-diameter plastic air hose. During the cleaning and developing phase, air was blown into the holes for several minutes. Surging was accomplished by alternating periods of air blowing with periods of shut-down. During shut-down, the water levels were allowed to recover for several minutes, then air was again blown into the holes. Each well was cleaned and developed in this manner for at least three hours. Developing was stopped when the water cleared and when a constant specific conductance was attained. Figure F-3 illustrates the drilling, cleaning, and developing phases of the program.

Aquifers tests were conducted by one or more of the following methods:

1) Bailer method (Fig. F-4A); A 0.65-gallon plastic bailer

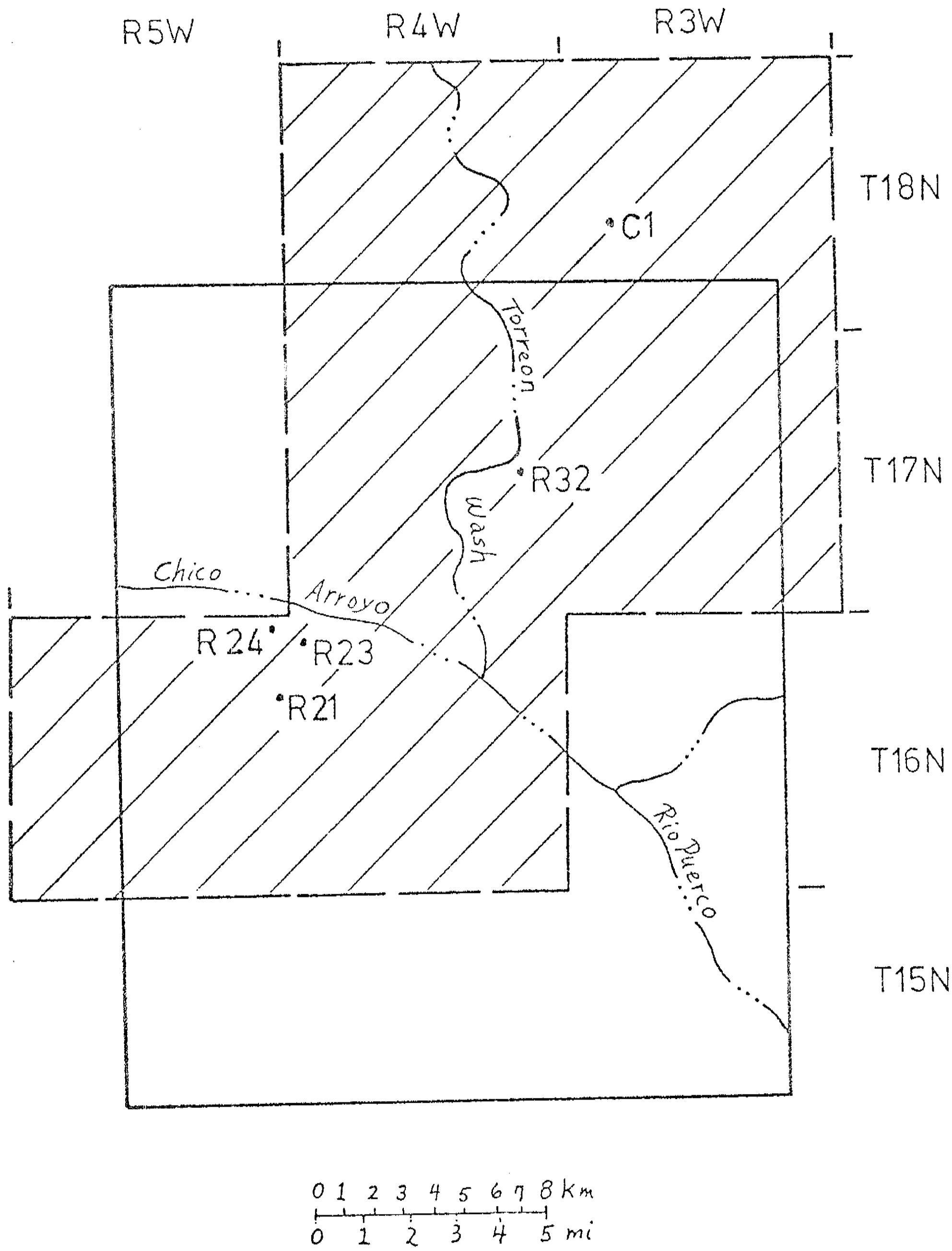


Figure F-1. Relationship of study area to NMBMMR Torreon Wash coal project area (cross-hatched), and locations of observation wells.

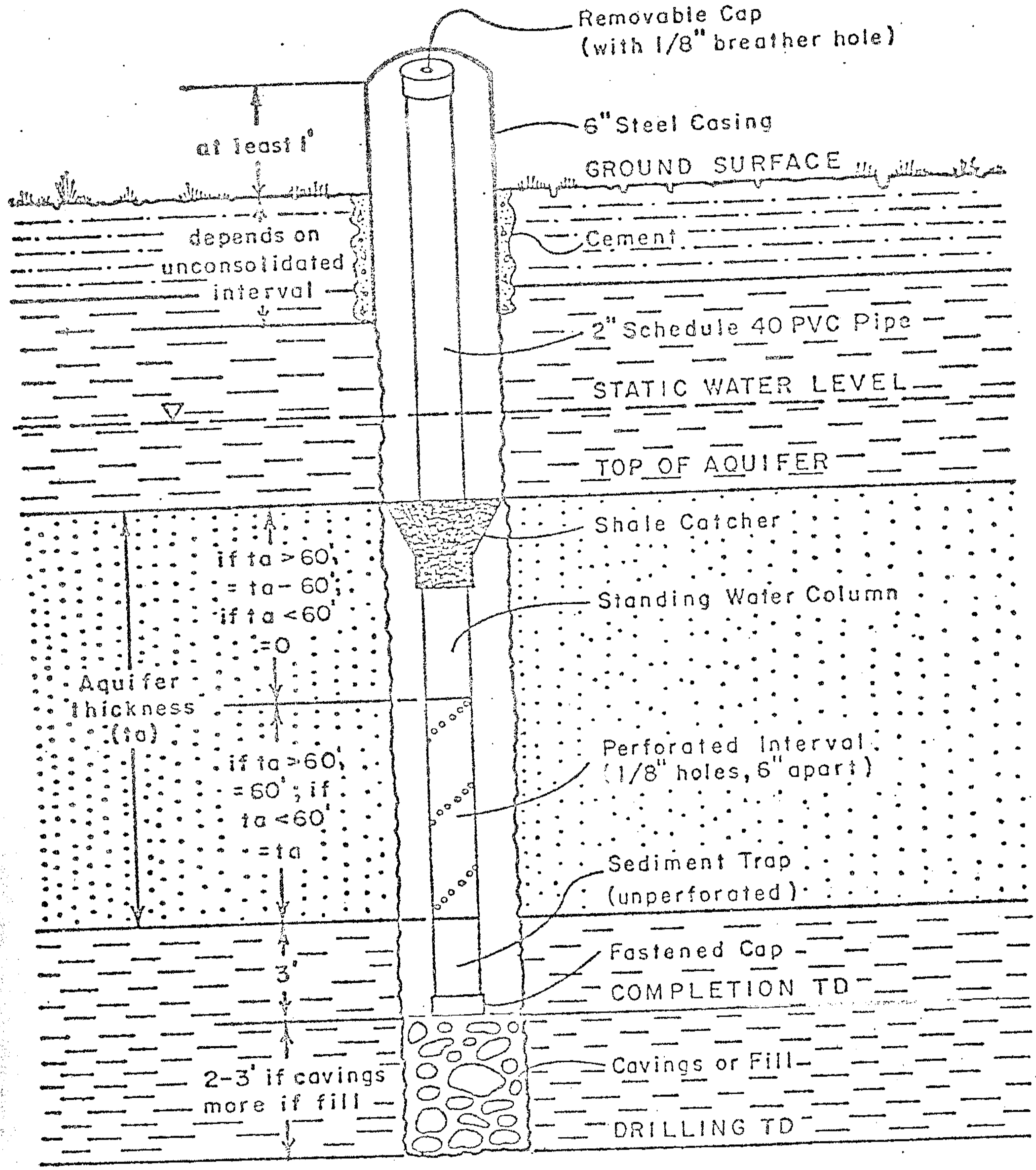
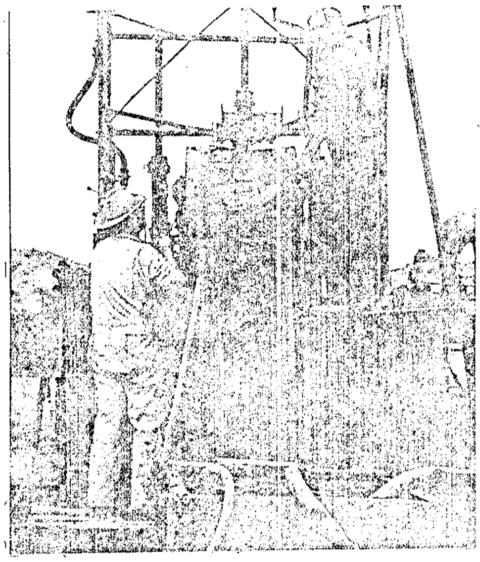


Figure F-2. Idealized construction of NMBMMR observation wells (not to scale). Aquifer extends to bottom of hole in wells R21, R23, and R24 (from Stone and Craigg, 1979, Appendix B).

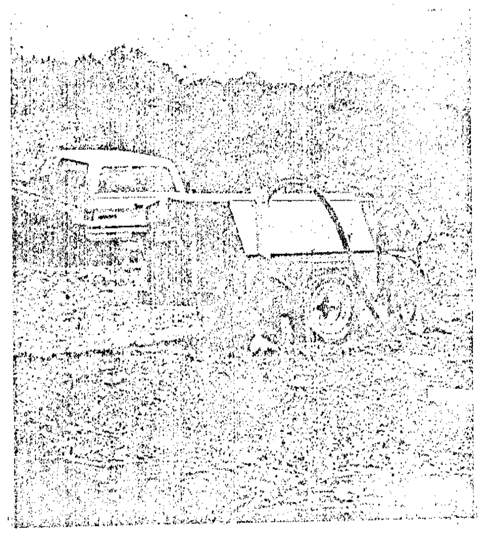
Table F-1. Summary of location and construction details for coal test-holes converted to water observation wells, NMBMMR Torreon project; Abbreviations for rock units same as Plate 1; D, drillers' log, F, field measurement, L, log value (modified from Stone and Craigg, 1979, p. 130).

Well Number		R21	R23	R24	R32	C1
Location		SE¼, SE¼, SE¼ Sec18, T16N, R4W	NW¼, SW¼, SW¼ Sec6, T16N, R4W	SW¼, SE¼, NE¼ Sec2, T16N, R5W	NE¼, NW¼, SE¼ Sec23, T17N, R4W	NW¼, NW¼, SW¼ Sec20, T18N, R3W
Ground Elevation	m (ft)	1,950 (6,395)	1,902 (6,235)	1,923 (6,305)	1,883 (6,175)	1,995 (6,540)
Depth[1]	m (ft)	74 (244 D)	76 (248 D)	73 (240 F)	72 (235 D)	52 (172 D)
Water[1] Level	m (ft) (date)	31.15 (102.2F) (7/27/78)	28.42 (93.25F) (8/31/78)	36.7 (120.3F) (6/4/79)	12.65 (41.50F) (9/29/78)	32.37 (106.2F) (6/27/79)
Aquifer		Kpl	Kpl	Kpl	Kmfc (coal)	Kmfc (coal)
Top of Aquifer[1]	m (ft)	30.5 (100L)	55 (180L)	54 (177L)	69.5 (288L)	47.3 (155D)
Aquifer Thickness[1]	m (ft)	43.9 (144L)	20.7 (68L)	14.9 (49L)	1.5 (5L)	4.2 (13.7F)
Perforated Interval[1]	m (ft)	27.5 - 75.3 (90 - 247)	39 - 74.7 (128 - 245)	61 - 73.2 ([illegible]00 - 240)	69.5 - 71.1 (228 - 233)	47.3 - 51.5 (155 - 169)
Perforated Length[1]	m (ft)	47.9 (157)	35.7 (117)	12.2 (40)	1.5 (5)	4.3 (14)

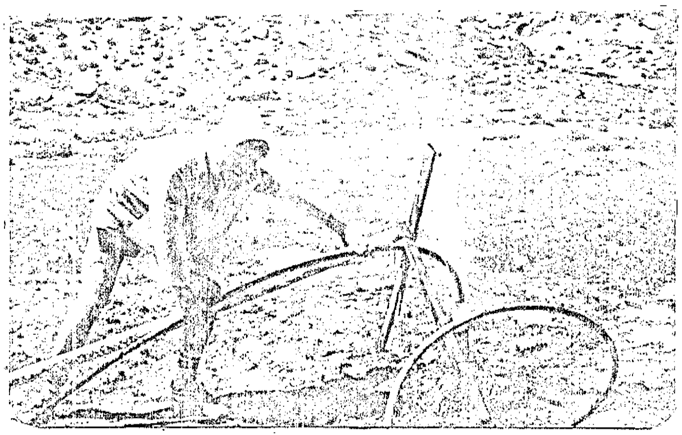
[1] Values given are depths below ground surface.



A



B



C

Figure F-3. Drilling, cleaning, and development phases of the observation well program. A) NMBMMR drill rig and crew at observation well C1; well is completed in 4.2-m (13.7-ft)-thick coal bed in "Upper Member" of the Menefee Formation (photo taken from NW¼, SW¼, Sec20, T18N, R3W). B) Scott Anderholm (New Mexico Tech graduate student, now with USGS, WRD, Albuquerque) assisting in cleaning and developing observation well R13 (now abandoned). Note 150-cubic-feet-per-minute air compressor, hose, and water blowing from top of 2.5-inch-diameter plastic casing (photo taken from NW¼, NW¼, Sec26, T16N, R5W). C) Author demonstrating method of keeping air hose in hole after compressor is first turned on. Black fluid on ground is oil; water has strong hydrogen sulfide odor (photo by Scott Anderholm at observation well C1).

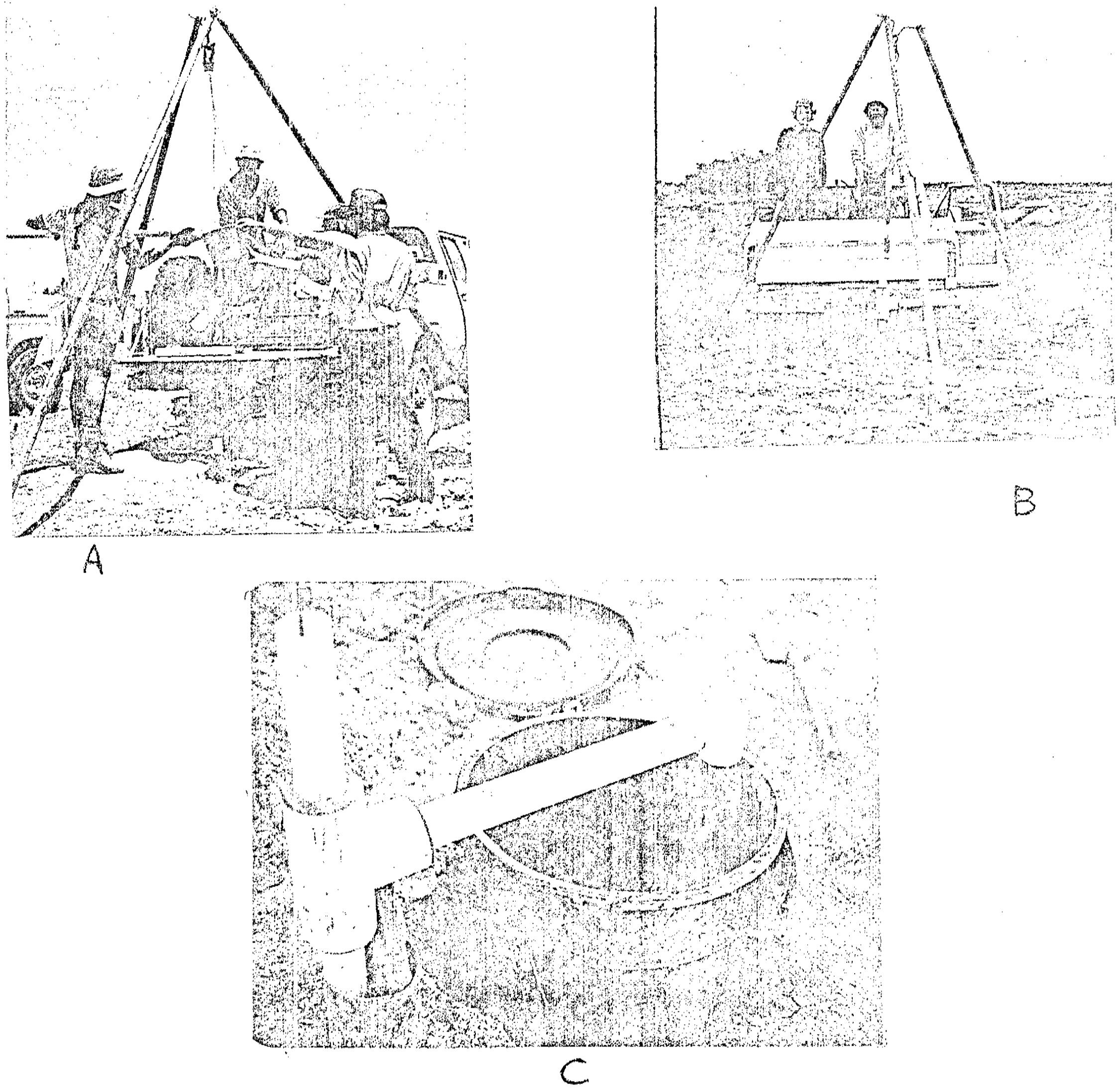


Figure F-4. Aquifer-test phase of the observation well program. A) USGS, WRD personnel demonstrating bailer method at observation well R21; well is completed in the Point Lookout Sandstone. Note tripod assembly and gasoline-powered winch in truck bed (photo taken from SE¼, SE¼, Sec18, T17N, R4W). B) Scott Anderholm and author demonstrating swabbing method at observation well C1. Note swabbing mandrel with rubber discs hanging from tripod assembly, T-bar faucet assembly and can for measuring discharge, and gasoline-powered winch in truck bed (photo taken from NW¼, SW¼, Sec20, T18N, R3W). C) Method of measuring discharge during swabbing test. Column of water raised from well by swabs is diverted into T-bar faucet assembly and out into graduated can.

was lowered into the well below the water level and raised back up with a gasoline-powered winch. Average discharge was measured by counting the number of bailers and dividing the total volume of water withdrawn by the elapsed time. Bailing was discontinued when a reasonable drawdown was attained. Residual drawdown was then measured by conventional techniques.

2) Swabbing method (Fig. F-4B, F-4C); This method utilized a specially constructed steel mandrel with sliding, 2-inch-diameter rubber discs mounted on it. The swabbing tool was lowered into the well below water level and raised back up with the winch. The rubber discs raised a column of water from the well, about 5 - 10 gallons. The average discharge was measured by dividing the the volume of water discharged into a graduated can by the elapsed time. After a reasonable drawdown was attained, recovery was measured by conventional techniques.

3) Instananeous Recharge or "Slug Method" described by Lohman (1972, p. 27); In this method a known volume of water (5 gallons) was poured into the well. The rate at which the water level returned to static level was then measured.

The results of the aquifer tests are given in Appendix G.

APPENDIX G

RESULTS OF AQUIFER TESTS

Aquifer tests were conducted on each of the five NMBMMR observation wells by one or more of the field methods described in Appendix F. The results of these tests are summarized in Table G-1. Data from the tests were analyzed by the Instantaneous Discharge or Recharge "Slug Method" of data analysis, a type-curve matching given by Lohman (1972, p. 27-29). Variables used in the data analysis are the following:

t = time (minutes) since injection or removal of "slug";

r_c = radius of casing (0.083 ft for all wells);

H_o = head inside well above or below initial head at instant of injection or removal of "slug" (i.e. at $t = 0$, or the positive difference between static water level and water level at instant "slug" is injected into well);

H = head inside well at time t after injection or removal of "slug" above or below initial head (i.e. the positive difference between static water level and consecutive water level measurements, at a time t).

Data points are plotted on semilogarithmic graph paper. The quotient H/H_o is plotted on the arithmetic scale of the graph, and time t is plotted on the logarithmic scale (note that H/H_o is always 1.0 or less, and that it is a dimensionless ratio, and therefore is independent of units of measurements used in the field). The data curve is superposed on a best-fit type curve by the usual curve-matching procedure (Lohman, 1972, Plate 2). A match point is chosen for the value of t on the data curve, and for the value of Tt/r_c^2 on

Table G-1. Summary of aquifer tests conducted on observation wells (modified from Stone and Craigg, 1979, p. 131, Appendix III).

Well Number	R21	R23	R24	R32	C1
Aquifer	Kpl	Kpl	Kpl	Kmfc (coal)	Kmfu (coal)
Water Level: m	31.15	28.42	36.7	12.65	32.4
(ft)	(102.21)	(93.25)	(120.3)	(41.50)	(106.2)
Date	7/27/78	8/31/78	6/4/79	9/29/78	6/27/79
Swabbing/Bailer Test Data					
Type of test	Bailer	Swabbing	Swabbing	Swabbing	Attempted Swabbing Test on 6/5/79; could not lower water level over 0.3 m (1.0 ft) after 30 min swabbing at rate of 0.8 lps (1.3 gpm).
Date	7/27/78	8/31/78	6/4/79	9/29/78	
Rate: lps	0.02	0.07	0.09	0.09	
gpm	(0.27)	(1.1)	(1.4)	(1.4)	
Drawdown: m	5.4	1.3	11.4	23.2	
(ft)	(17.6)	(4.1)	(37.4)	(76.0)	
Elapsed time: min	85	74	34	15	
Recovery: m	3.3	0.34	9.7	1.2	
(ft)	(10.9)	(4.1)	(31.9)	(4.0)	
Elapsed time: min	87	180	806	381	
Transmissivity[2]: m^2/d	0.009	0.00093 - 0.0033	0.0084	0.00025 - 0.0003	
(ft^2/d)	(0.10)	(0.01 - 0.035)	(0.09)	(0.0027 - 0.0036)	
Slug Test Data					
Water level: m	31.24				32.4
(ft)	(102.42)				(106.2)
Date	6/23/79				6/27/79
Volume of water poured into well: m^3	0.02	Slug Test not performed	Slug Test not performed	Slug Test not performed	0.02
gal	(5.0)				(5.0)
Theoretical H_o	7.54				7.54
Return of water level to static: Elapsed time in min;	330				35
Transmissivity[3]: m^2/d	0.0014				1.9
(ft^2/d)	(0.015)				(20)

[1]Locations of wells given in Appendix H. [2]Determined by "slug method" of data analysis with swabbing/bailer test data (Lohman, 1972, p. 28, Plate 2).
[3]Determined by "slug method" of data analysis with slug test data (Lohman, 1972).

the type curve (a match point for H/H_o is not needed). The transmissivity is then approximated by the equation, $T = Tt/r_c^2/t$, where Tt/r_c^2 is the match point on the type curve a t is the match point on the data curve. Transmissivities were computed in units of ft^2/d, and then were converted to m^2/d.

In the following sections, the procedure will be to give both a summary table and data curve for aquifer tests conducted on each observation well.

Table G-2. Summary of field data from Bailing Test conducted on observation well R21[1]. Aquifer = Point Lookout Sandstone, rate = 0.02 l/s (0.27 gpm), drawdown = 5.37 m (17.6 ft). Theoretical H_o = 20.3 ft, by projection of recovery curve.

t (minutes)	H (ft)	H/H_o
2	17.40	0.86
3	16.80	0.83
4	16.70	0.82
5	16.54	0.81
6	15.90	0.78
7	15.70	0.77
12	14.85	0.73
17	13.03	0.64
29	12.06	0.59
38	10.84	0.53
47	9.80	0.48
62	8.60	0.42
87	6.60	0.32

[1]Aquifer test performed by USGS, WRD personnel, 7-27-78 (see Fig. F-4A, p. 242).

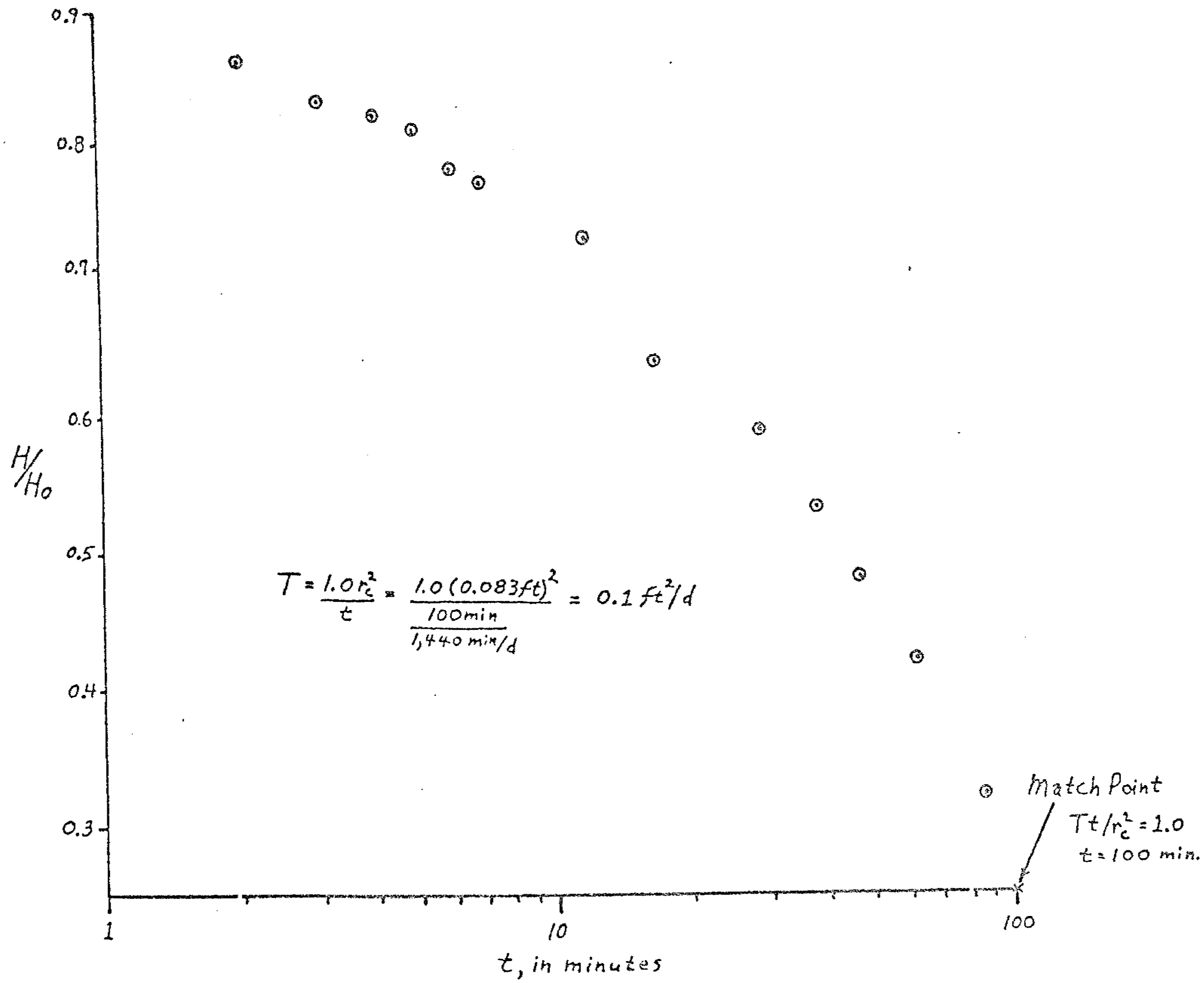


Figure G-1. Data curve of Bailing Test, match point, and transmissivity calculation for observation well F21.

Table G-3. Summary of field data from Instantaneous Recharge "Slug" Test conducted on observation well R21[1]. Theoretical H_o = 7.54 ft, by pouring 5 gal water into well.

t (minutes)	H (ft)	H/H_o
1	5.92	0.79
2	6.00	0.80
3	5.96	0.79
4	5.88	0.78
5	5.88	0.78
6	5.69	0.76
7	5.67	0.76
8	5.65	0.75
9	5.69	0.76
10	5.67	0.76
12	5.57	0.74
14	5.52	0.74
16	5.44	0.73
18	5.36	0.71
20	5.27	0.70
22	5.17	0.69
24	5.13	0.68
26	5.00	0.67
28	4.92	0.66
30	4.86	0.65
35	4.67	0.62
40	4.48	0.60
45	4.26	0.57
50	4.09	0.54
55	3.96	0.53
60	3.77	0.50
70	3.50	0.47
80	3.26	0.43
90	2.94	0.39
100	2.79	0.37
110	2.60	0.35
120	2.36	0.31
135	2.17	0.29
150	1.96	0.26
165	1.77	0.24
180	1.59	0.21
210	1.27	0.17
240	0.96	0.13
270	0.68	0.09
300	0.45	0.06
330	0.08	0.01

[1]Aquifer test performed by S. D. Craigg, 6-23-79.

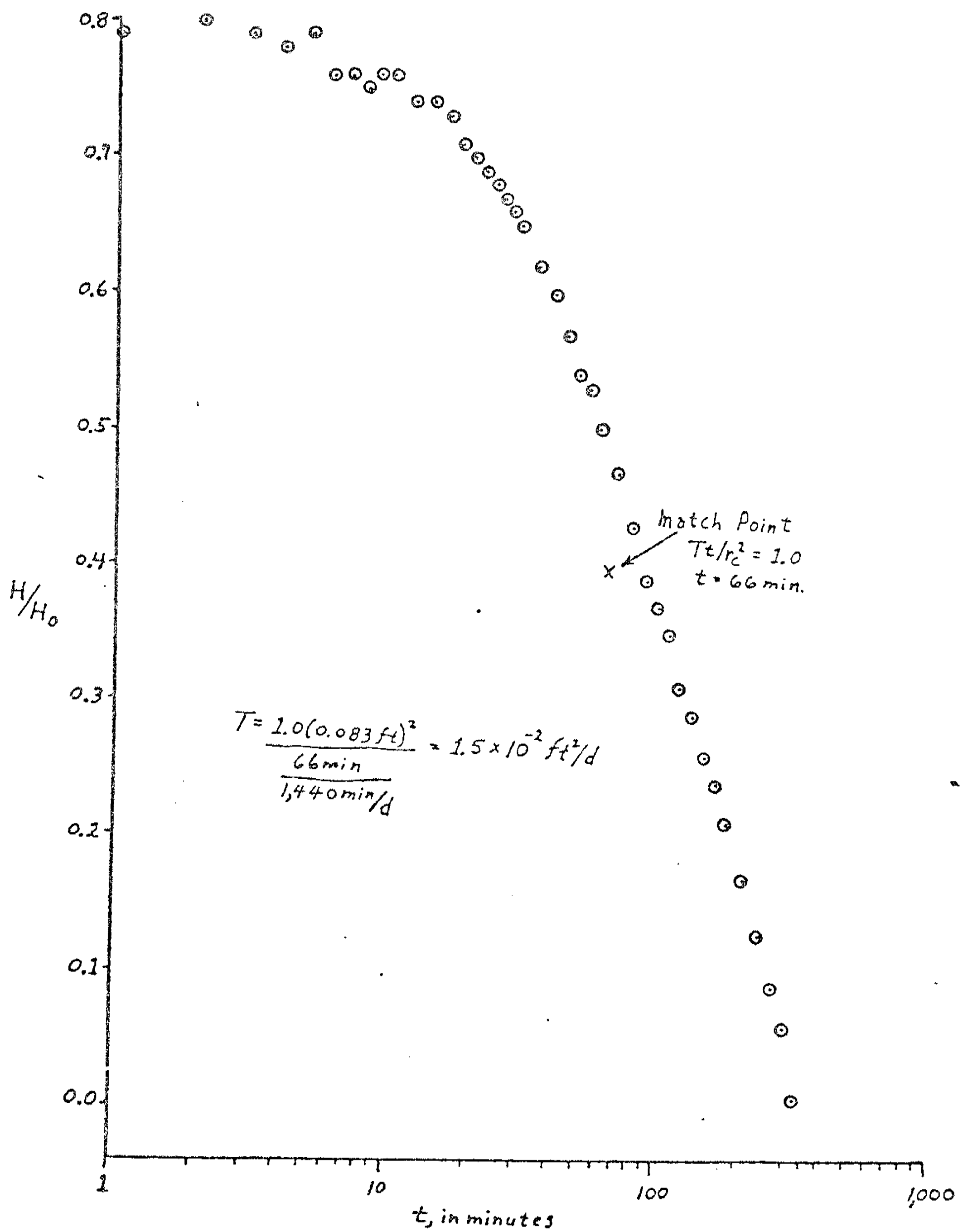


Figure G-2. Data curve of Instantaneous Recharge "Slug" Test, match point, and transmissivity calculation for observation well R21.

Table G-4. Summary of field data from Swabbing Test conducted on observation well R23[1]. Aquifer = Point Lookout Sandstone, rate = 0.07 l/s (1.1 gpm), drawdown = 1.25 m (4.1 ft). Theoretical H_o = 4.45 ft, by projection of recovery curve.

t (minutes)	H (ft)	H/H_o
10	4.05	0.91
15	3.83	0.86
17	3.79	0.85
19	3.75	0.84
20	3.75	0.84
21	3.71	0.83
23	3.67	0.82
25	3.67	0.82
27	3.67	0.82
29	3.62	0.81
30	3.58	0.80
35	3.55	0.80
40	3.57	0.80
45	3.55	0.80
50	3.51	0.79
55	3.48	0.78
60	3.45	0.77
70	3.43	0.77
80	3.38	0.76
90	3.33	0.75
100	3.32	0.75
120	3.30	0.74
150	3.25	0.73
180	3.19	0.72
210	3.28	0.74
240	3.00	0.67

[1]Aquifer test performed by S. D. Craigg and Scott Anderholm, 8-31-78.

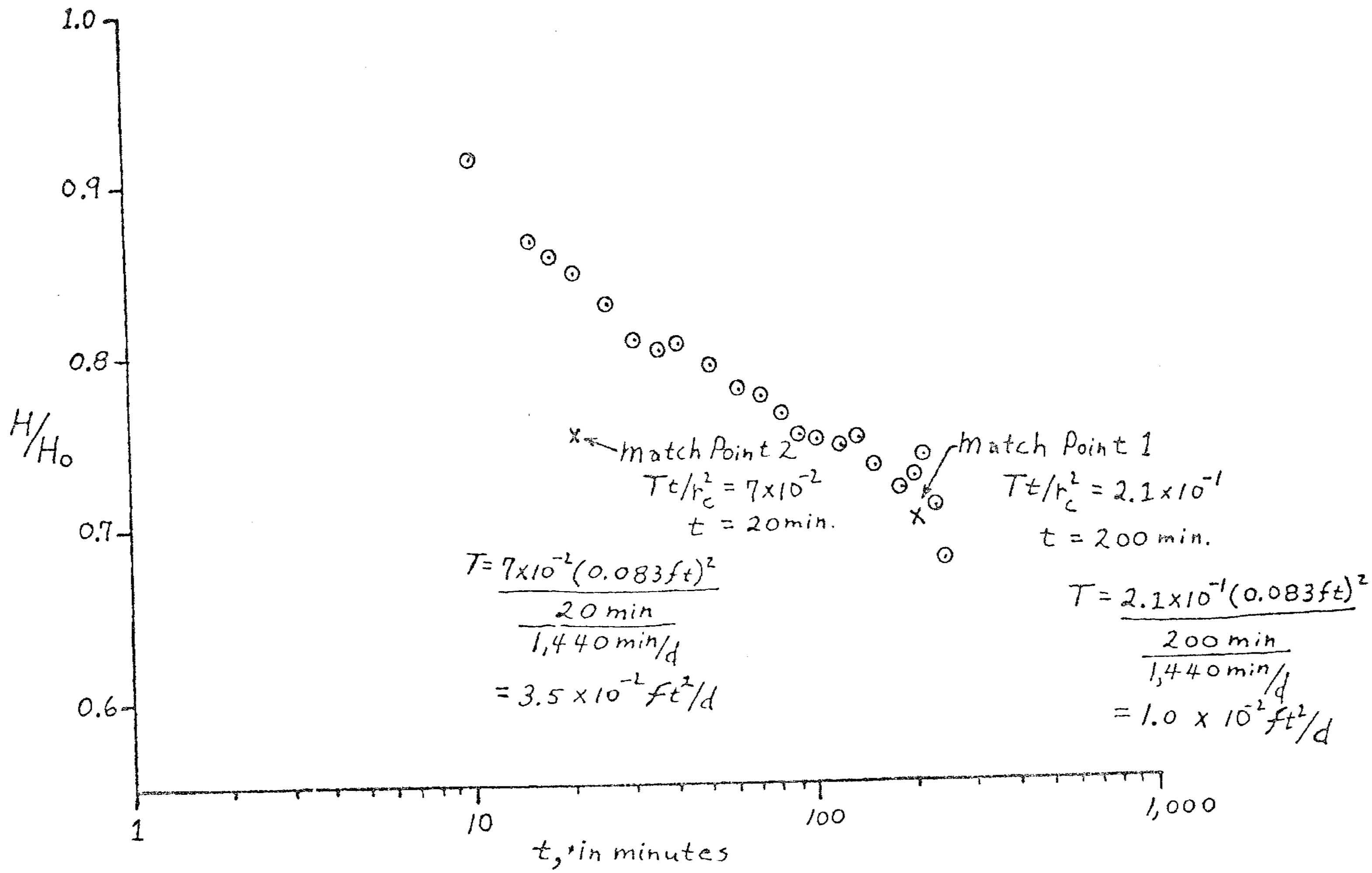


Figure G-3. Data curve of Swabbing Test, match points, and transmissivity calculations for observation well R23.

Table G-5. Summary of field data from Swabbing Test conducted on observation well R24[1]. Aquifer = Point Lookout Sandstone, rate = 0.09 l/s (1.4 gpm), drawdown = 11.4 m (37.4 ft). Theoretical H_o = 37.7 ft, by projection of recovery curve.

t (minutes)	H (ft)	H/H_o
1	37.40	0.99
2	37.00	0.98
3	36.91	0.98
4	36.69	0.97
5	36.52	0.97
6	36.24	0.96
7	36.03	0.95
8	35.72	0.94
9	35.55	0.94
10	35.32	0.93
16	33.89	0.90
21	32.80	0.87
26	31.92	0.84
31	31.04	0.82
46	28.71	0.76
61	26.69	0.70
76	24.70	0.65
91	23.03	0.61
106	21.42	0.57
121	20.11	0.53
151	17.88	0.47
181	16.10	0.43
211	14.31	0.38
241	12.89	0.34
446	7.30	0.19
806	5.5	0.15

[1]Aquifer test performed by S. D. Craigg and Scott Anderholm, 6-4, 5-79.

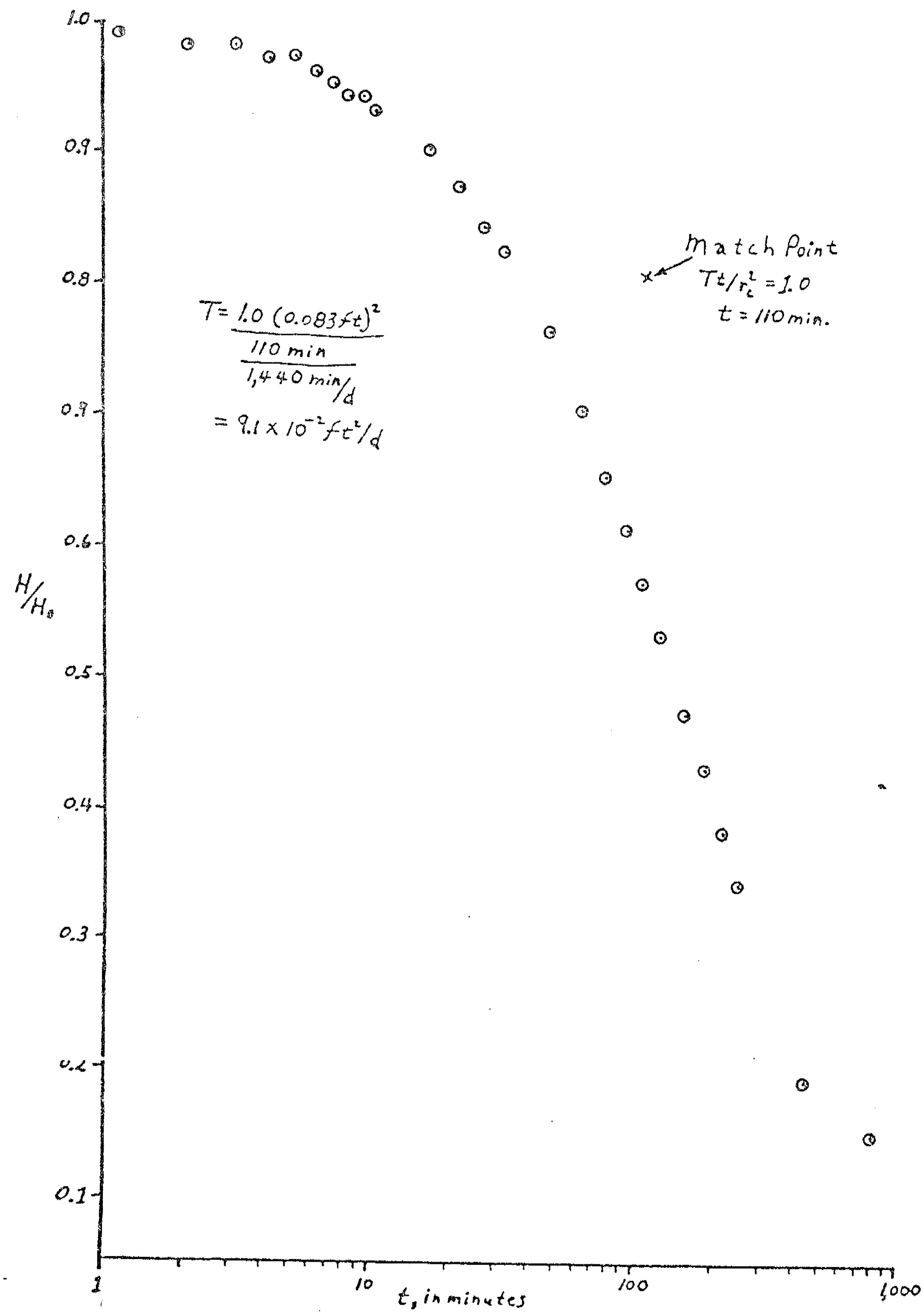


Figure G-4. Data curve of Swabbing Test, match point, and transmissivity calculation for observation well R24.

Table G-6. Summary of field data from Swabbing Test conducted on observation well R32[1]. Aquifer = Cleary Coal Member of Menefee Formation (coal bed), drawdown = 23.2 m (76 ft), rate = 0.09 l/s (1.4 gpm). Theoretical H_o = 75.8 ft, by projection of recovery curve.

t (minutes)	H (ft)	H/H_o
6	75.67	0.998
7	75.55	0.997
8	75.34	0.994
9	75.50	0.996
10	75.50	0.996
11	75.42	0.995
12	75.46	0.996
13	75.46	0.996
14	75.44	0.995
15	75.38	0.994
16	75.42	0.995
21	75.38	0.994
26	75.25	0.993
31	75.17	0.992
36	75.17	0.992
41	75.13	0.991
51	75.09	0.991
81	74.50	0.983
111	75.21	0.979
141	73.36	0.968
171	73.67	0.972
201	73.42	0.969
231	73.13	0.965
291	72.52	0.957
321	72.42	0.955
351	72.17	0.952
381	71.88	0.948

[1]Aquifer test performed by S. D. Craigg and Scott Anderholm, 9-29-78.

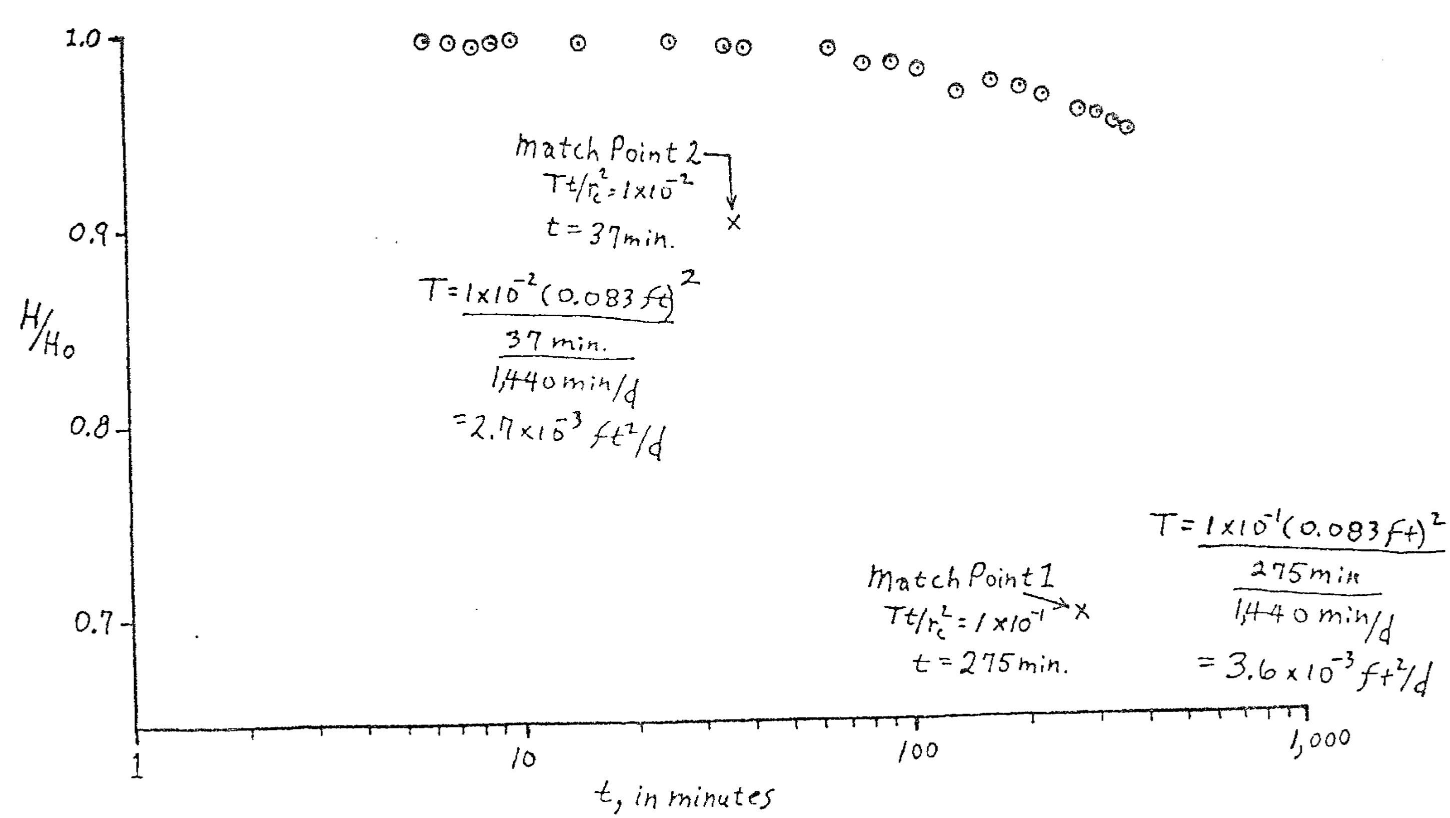


Figure G-5. Data curve of Swabbing Test, match points, and transmissivity calculations for observation well R32.

Table G-7. Summary of field data from Instantaneous Recharge "Slug" Test conducted on observation well C1[1]. Aquifer = "Upper Member" of Menefee Formation (coal bed). Theoretical H_o = 7.54 ft, by pouring 5 gal water into well.

t (minutes)	H (ft)	H/H_o
1	3.01	0.40
2	2.33	0.31
3	1.42	0.19
4	0.95	0.13
5	0.57	0.08
6	0.40	0.05
7	0.31	0.04
8	0.28	0.04
9	0.24	0.03
10	0.24	0.03
12	0.20	0.03
14	0.12	0.02
16	0.10	0.02
18	0.12	0.02
20	0.07	0.01
22	0.07	0.01
24	0.04	0.00
26	0.04	0.00
28	0.03	0.00
30	0.02	0.00
35	0.00	0.00

[1]Aquifer test performed by S. D. Craigg, 6-27-79.

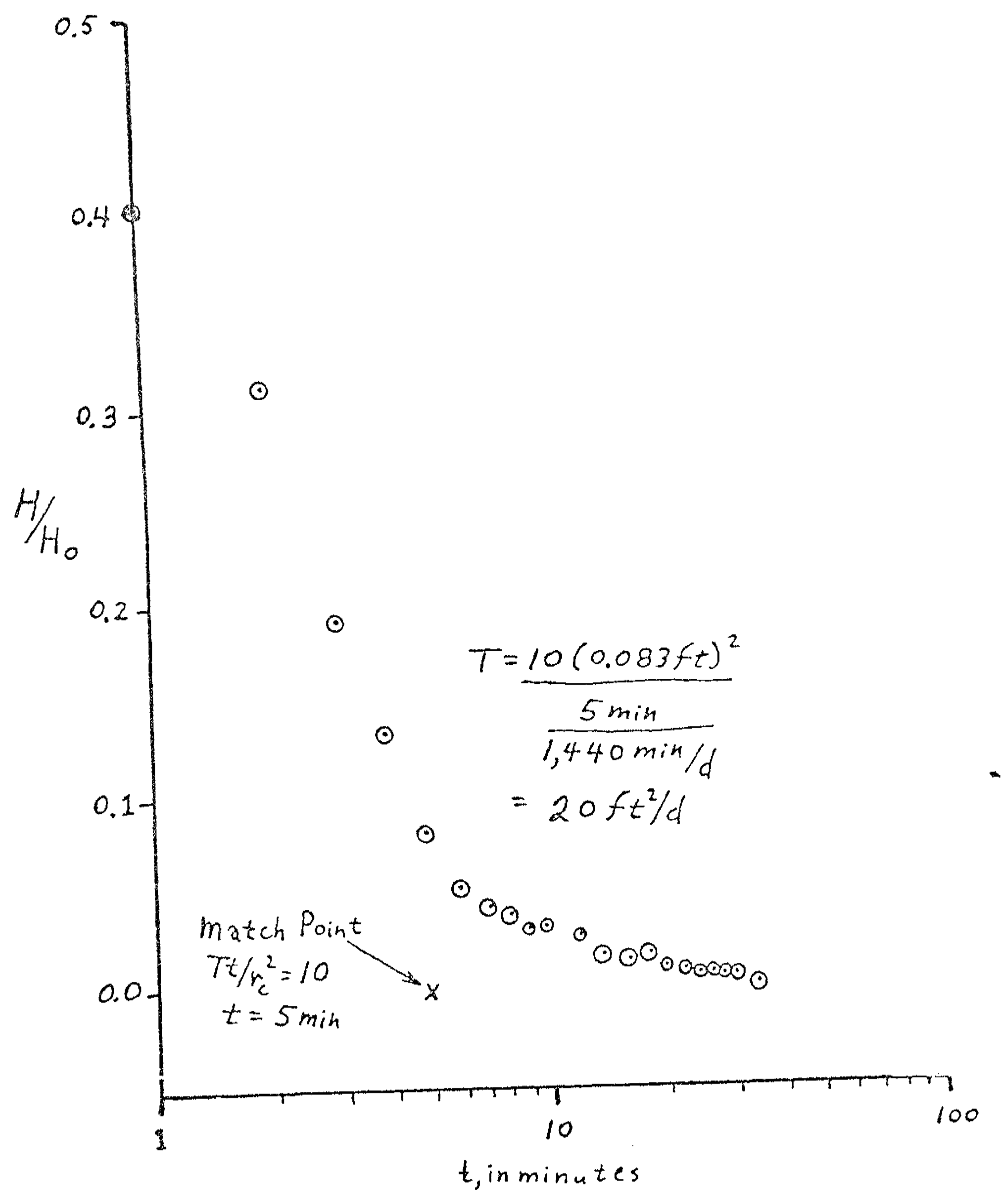


Figure G-6. Data curve of Instantaneous Recharge "Slug" Test, match point, and transmissivity calculation for observation well C1.

APPENDIX H

RECORDS OF WELLS AND SPRINGS

Seventeen wells and nineteen springs in the area were inventoried. Depth to water and total depth in accessible wells was measured with a steel tape. Pumping yields on wells equipped with windmills were measured with a stopwatch and 2-gallon bucket. Discharge from springs was estimated. When possible, water samples were obtained from each well and spring inventoried.

Wells and springs are reported separately in two tables (Tables H-1, H-2). The five observation wells completed by the NMBMMR are reported in Table H-1 and are also discussed in Appendices F and G. Wells and springs which were not visited are not reported in the tables. Wells outside the study area are not reported, but their locations and other pertinent data are specified in the text of the paper.

Table H-1. Records of wells in the Chico Arroyo/Torreon Wash area[1].

Owner/Well Name	Location Number	Ground Elevation m	(ft)	Total Depth m	(ft)	Water Depth m	(ft) -date	Principle Aquifer	Aquifer Thickness m	(ft)	Use	Chemical Analysis(?)	Yield lps	(gpm)	Remarks
BLM/Converted oil test	16N.03W.17.333	1,870	(6,130)	361	(1,840R)	flowing	-6/28/78	Kd	16.8	(55.0R)	S	*	0.32	(5.0E)	earthen tank (see fig.34).
BLM/Abra de Los Cerros	16N.03W.35.131	1,858	(6,091)	14	(47F)	11.1	(36.4F)-6/19/79	Kml	----	-----	Unused	*	-	-	abandoned (see Frontispiece)
NMBMMR/K23	16N.04W.05.331	1,902	(6,235)	76	(250R)	28.4	(93.3F)-8/31/78	Kpl	20.7	(68.0L)	Ob	*	-	-	see Appendices E, F, G.
(?)/Chico Arroyo-Torreon Wash well	16N.04W.11.312	1,834	(6,013)	---	-----	----	----- -6/28/78	Kml	----	-----	S	*	0.03	(0.5E)	one active, two abandoned windmills.
NMBMMR/K21	16N.04W.18.444	1,950	(6,395)	76	(250R)	31.2	(102.2F)-7/27/78	Kpl	43.9	(144.0L)	Ob	*	-	-	see Appendices E, F, G.
BLM/Bonestaka well	16N.04W.36.232	1,876	(6,150)	184	(602R)	flowing	-6/28/78	Kg	3.3	(11.0R)	S,Do	*	12.6	(200.0E)	pipeline from well (see fig. 34; Plate 3).
NMBMMR/K24	16N.03W.02.444	1,923	(6,310)	76	(250R)	36.7	(120.3F)-6/4/79	Kpl	14.9	(49.0L)	Ob	*	-	-	see Appendices E, F, G.
BLM/Pipeline road well	17N.03W.03.422	1,955	(6,411)	75	(247F)	20.1	(66.0F)-8/21/79	Kmfa	----	-----	Unused	*	-	-	abandoned.
(?)/Arroyo Piedra Lumbre well	17N.03W.18.242	1,896	(6,215)	17	(55F)	9.4	(30.7F)-6/28/78	Kmfo (Qalf)	----	-----	S	*	0.13	(2.0F)	see Figure 34.
B.F.Bovey/Torreon Wash well	17N.04W.23.224	1,864	(6,110)	---	-----	----	----- -8/28/78	Kmfa (Qalf)	----	-----	S,Do	*	0.03	(0.5F)	in bottom of Torreon Wash.
NMBMMR/K33	17N.04W.23.243	1,883	(6,175)	72	(240R)	12.6	(41.5F)-9/29/78	Kmfa	1.5	(5.0L)	Ob	*	-	-	see Appendices E, F, G.
Max Tachias/Torreon Wash 2	17N.04W.27.444	1,856	(6,084)	---	-----	----	----- -6/21/79	Kpl	----	-----	S	*	0.15	(2.3F)	south bank of Torreon Wash.
Max Tachias/Torreon Wash 1	17N.04W.34.213	1,853	(6,075)	34	(111F)	12.3	(36.4F)-6/19/79	Kmfo	----	-----	S,Do	*	0.03	(0.5F)	located at seasonal residence.
Navajo Tribe/15B-32	17N.05W.12.423	1,959	(6,422)	103	(343R)	----	----- -6/28/78	Kmfa	4.0	(13.0R)	S	*	0.10	(1.5F)	
NMBMMR/C1	18N.03W.20.311	1,992	(6,530)	51	(170R)	32.4	(106.2F)-6/27/79	Kmfu	4.2	(13.7F)	Ob	*	-	-	see Appendices E, F, G.
Navajo Tribe/15T-341	18N.03W.20.433	2,008	(6,585)	---	-----	----	----- -6/27/79	Kmfu	----	-----	S	*	0.13	(2.0E)	

[1] Location number explained in Figure 1, p. 8.
Abbreviations, F-field measurement, R-reported (USGS, NMEO files, Albuquerque), L-log value, E-estimated; Use: S-stock, Do-domestic, Ob-observation well; Geologic units same as Plate 1.
See Appendices I and J for chemical analyses.

Table H-2. Records of springs in the Chico Arroyo/Torreon Wash area[1].

Owner/Spring Name	Location Number	Ground Elevation m	(ft)	Principle Source	Date Visited	Use	Chemical Analysis(?)	Yield lps	(gpm)	Remarks
(?)/Canon Salado	15N.03W.20.133	1,847	(6,055)	Kmm	6/13/79	S	*	0.064	(1.0E)	undeveloped; bottom of arroyo.
(?)/Guadalupe Springs	35°31'50"N. Lat. 107°09'52"W. Long.	1,818	(5,960)	Kml	6/13/79	S	*	0.064	(1.0E)	undeveloped; bottom of arroyo.
Sanchez/Ojo del Padre	35°32'22"N. Lat. 107°09'10"W. Long.	1,792	(5,875)	Kg	6/29/79	S,Do,I	*	0.032	(0.5F)	at Guadalupe; on-off valve.
BLM/Ojo de Los Jaramillo	16N.03W.33.342	1,830	(6,000)	Kmm	6/15/79	S	*	0.032	(0.5F)	enclosed; 3 stock tanks.
BLM/"Rattlesnake Spring"	16N.04W.17.221	1,894	(6,210)	Kmfc	6/11/79	S	*	very low		undeveloped; bottom of arroyo.
Ernest Montoya 2	16N.04W.17.244	1,885	(6,180)	Kmfc	6/11/79	S	*	0.032	(0.5F)	enclosed; stock tank.
BLM/Ojo Atascoso	16N.04W.25.433	1,856	(6,085)	Kmm	6/28/78	S	*	0.064	(1.0E)	enclosed; stock tank.
BLM/Ojo Frio	16N.04W.26.213	1,909	(6,260)	Kms	6/28/78	S	*	0.064	(1.0E)	enclosed; stock tank (see fig. 34).
BLM/Barrel Spring	16N.04W.34.334	2,199	(7,210)	Kmfa	6/13/79	S	*	0.032	(0.5F)	enclosed; stock tank (see fig. 34).
BLM/Ojo de las Yeguas 2	16N.04W.36.324	1,891	(6,200)	Kmm	6/22/78 6/13/79	Unused	-	no flow		stock tank.
BLM/Ojo de las Yeguas 1	16N.04W.36.332	1,897	(6,220)	Kmm	6/13/79	S	*	0.13	(2.0E)	undeveloped; bottom of arroyo.
Joe Montoya 3	16N.05W.13.333	1,946	(6,380)	Kmfc	6/11/79	Unused	*	very low		enclosed; abandoned.
Ernest Montoya 1	16N.05W.13.422	1,928	(6,320)	Kmfc	6/11/79	S	*	0.032	(0.5F)	enclosed; stock tank.
Joe Montoya 1	16N.05W.14.442	1,940	(6,360)	Kmfc	6/11/79	S	*	0.032	(0.5E)	undeveloped; bottom of arroyo.
Joe Montoya 2	16N.05W.15.122	1,934	(6,340)	Kmfc	6/11/79	Unused	-	no flow		ground moist at site.
BLM/Ojo Azabache	16N.05W.15.233	1,856	(6,085)	Kmfc	7/20/78	S	*	0.032	(0.5R)	inside rock house.
BLM/Coal Spring	16N.05W.15.412	1,934	(6,340)	Kmfc	6/11/79	S	*	0.02	(0.25E)	coal/sandstone contact; stock tank.
Sandoval Ranch Spring	16N.05W.16.124	1,934	(6,340)	Kmfc	7/20/78	S	*	0.032	(0.5E)	undeveloped; bottom of arroyo.
Max Tachias/Torreon Wash	17N.04W.34.213	1,845	(6,050)	Kpl	6/25/79	S	*	very low		undeveloped; bottom of Torreon Wash.

[1]Location number explained in Figure 1, p. 8.
Abbreviations. Geologic units same as Plate 1; Use; S -stock, Do -domestic, I -irrigation; Yield; E -estimated, F -measured, R -reported.
See Appendices I and J for chemical analyses.

APPENDIX I

RESULTS OF CHEMICAL ANALYSES OF WATER SAMPLES

All chemical analyses of water were performed by the NMBMMR. Total-dissolved-solids contents of less than about 7,000 ppm are numerically equivalent to contents in milligrams per liter (mg/L). Chemical analyses of well waters and spring waters are given in two separate tables (Tables I-1 and I-2, respectively). Abbreviations for major dissolved ions include, HCO_3 = bicarbonate, Cl = chloride, SO_4 = sulfate, Na = sodium, K = potassium, Mg = magnesium, Ca = calcium, and TDS = total-dissolved-solids content.

Table I-1. Results of chemical analyses (ppm) of water from wells in the Chico Arroyo/Torreon Wash area[1].

Owner/Well Name	Sample Number	Analysis Date	HCO_3	Cl	SO_4	Na	K	Mg	Ca	TDS	Specific Conductance (μmhos/cm) field	lab
Navajo Tribe/15B-32	SC-1	10/78	960	220	72	530	2.2	0.25	2.7	1,790	1,800	2,040
Arroyo Piedra Lumbre Well	SC-2	10/78	564	15	2,274	1,150	4.4	53	123	4,185	4,000	4,440
B. P. Hovey Well	SC-3	6/79	363	15	146	168	2.6	5.2	38	750	1,200	------
Chico Arroyo/Torreon Wash Well	SC-4	6/79	294	76	874	442	1.2	43.5	32.6	1,770	2,000	2,000
BLM/Converted oil test	SC-5	10/78	336	98	789	620	2.7	1.4	3	1,855	2,500	2,730
BLM/Homestake Well	SC-6	10/78	218	8	27	109.5	0.7	0.15	3.3	390	580	500
NMBMMR/R21	SC-12	10/78	315	3.8	90	150	3.25	1.5	7.8	415	580	527
NMBMMR/R23	SC-13	10/78	328	6.8	260	175	3.7	15.5	40.1	667	980	895
NMBMMR/R32	SC-14	10/78	1,750	1,220	3,650	3,140	4.4	18.4	24.8	9,210	7,000	9,790
B. P. Hovey/Torreon Wash well	SC-15	10/78	702	529	5,979	3,300	15.75	65.0	32	10,272	8,000	9,790
NMBMMR/R24	SC-17	6/79	847	30	85	350	81.5	0.72	6.1	2,160	1,100	------
NMBMMR/C1	SC-18	6/79	616	13	1,116	820	9.6	1.6	9.0	2,600	3,000	------
Navajo Tribe/15T-541	SC-19	6/79	1,080	53	355	648	8.5	0.57	2.0	2,260	2,200	------
BLM/Abra de Los Cerros	SC-31	6/79	343	56	1,842	1,020	35	4.9	4.5	4,195	3,500	3,500
Max Tachias/Torreon Wash 1	SC-32	6/79	210	684	3,190	1,640	13.3	169	184	6,290	5,000	------
BLM/Pipeline Road Well	SC-33	6/79	720	81	970	225	4	2.7	4.9	2,066	3,000	3,000
Max Tachias/Torreon Wash 2	SC-34	6/79	1,807	255	302.5	920	2.9	33.5	5	3,352	2,600	2,600

[1]Locations of wells given in Table H-1. Abbreviations for dissolved solids given in introduction to this Appendix. Precision as reported by laboratory.

Table I-2. Results of chemical analyses (ppm) of water from springs in the Chico Arroyo/Torreon Wash area[1].

Owner/Spring Name	Sample Number	Analysis Date	HCO_3	Cl	SO_4	Na	K	Mg	Ca	TDS	Specific Conductance (µmhos/cm) (field)	(lab)
BLM/Ojo Atascoso	SC-7	7/78	198	15	472	304	4.6	0.85	4.1	994	1,200	1,600
BLM/Ojo Frio	SC-8	8/78	300	4	48	141.5	0.6	0.2	2.7	328	560	640
BLM/Ojo Azabache	SC-10	8/78	335	27	1,270	759	1.85	0.65	5.01	2,250	1,050	1,250
Sandoval Ranch Spring	SC-11	8/78	188	19	132	112	3.2	6.0	16	386	350	450
BLM/"Rattlesnake Spring"	SC-20	6/79	632	38	1,003	692	25.3	23.3	38.3	2,460	2,500	-----
Ernest Montoya 1	SC-21	6/79	243	8	133	89	3.9	15.5	31	550	700	---
Ernest Montoya 2	SC-22	6/79	233	13	351	155	3.3	24.5	54.7	846	820	---
Joe Montoya 1	SC-23	6/79	360	36	1,134	635	5.0	9.5	29.8	2,420	2,500	-----
Joe Montoya 3	SC-24	6/79	1,700	74	1,134	700	27.5	35	351	4,060	3,000	-----
BLM/Coal Spring	SC-25	6/79	233	18	106	196	1.4	0.6	5	660	800	---
BLM/Barrel Spring	SC-26	6/79	530	5	28	226	2.1	1.2	5.3	845	900	---
(?)/Canon Salado	SC-27	6/79	315	0.51	1,854	325	0.24	59	512	3,105	3,000	-----
(?)/Guadalupe Springs	SC-28	6/79	226	10	2,765	800	4.0	132	318	4,270	4,000	-----
BLM/Ojo de las Yeguas 1	SC-29	6/79	304	8	57	129	4.7	0.41	3.7	740	800	---
BLM/Ojo de Los Jaramillo	SC-30	7/79	457	46	709	435	4.7	28	41.6	1,740	2,000	-----
Max Tachias/Torreon Wash	SC-35	7/79	1,580	255	920	1,090	26	25	24	3,973	3,700	-----
Sanchez/Ojo del Padre	SC-36	7/79	407	2	54.8	136	1.2	17.5	9	626	600	---

[1] Locations of springs given in Table H-2. Abbreviations for dissolved solids given in introduction to this Appendix. Precision as reported by laboratory.

APPENDIX J

DATA REDUCTION FOR PIPER DIAGRAMS

Chemical data were reduced for plotting on Piper Diagrams by means of a computer program (on file at NMBMMR). Input consisted of raw concentrations, in equivalent parts per million (epm), of the cations calcium, magnesium, and sodium plus potassium, and of the anions carbonate plus bicarbonate, sulfate, and chlorine. Output is in the form of a table (Table J-1) giving the sample number, raw data, and percentages of the ions for plotting purposes. Location and identification of all samples are given in Appendix H. Abbreviations for the dissolved ions are given in Appendix I. Piper Diagrams appear with discussions of the aquifers.

Table J-1. DATA REDUCTION FOR PIPER DIAGRAMS

SAMPLE NUMBER	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
SC-01	0.130	0.020	23.060	23.210	0.560	0.086	99.354	15.730	1.490	6.210	23.430	67.136	6.359	26.504
SC-02	6.130	4.360	50.110	60.600	10.116	7.195	82.690	9.240	47.340	0.420	57.000	16.211	83.053	0.737
SC-03	1.890	0.470	7.380	9.740	19.405	4.825	75.770	5.950	3.040	0.420	9.410	63.231	32.306	4.463
SC-04	1.620	3.580	19.250	24.450	6.626	14.642	78.732	4.820	18.200	2.140	25.160	19.157	72.337	8.506
SC-05	0.150	0.110	27.040	27.300	0.549	0.403	99.048	5.500	16.430	2.760	24.690	22.276	66.545	11.179
SC-06	0.160	0.010	4.780	4.950	3.232	0.202	96.566	4.240	0.560	0.230	5.030	84.294	11.133	4.573
SC-07	0.200	0.070	13.340	13.610	1.470	0.514	98.016	3.460	9.830	0.420	13.710	25.237	71.699	3.063
SC-08	0.020	0.020	6.180	6.220	0.322	0.322	99.357	5.430	1.000	0.110	6.540	83.028	15.291	1.682
SC-10	0.250	0.050	33.050	33.350	0.750	0.150	99.100	6.220	26.670	0.760	33.650	18.484	79.257	2.259
SC-11	0.800	0.490	4.950	6.240	12.821	7.853	79.327	3.010	2.750	0.530	6.290	47.854	43.720	8.426
SC-12	0.380	0.040	6.610	7.030	5.405	0.569	94.026	5.000	1.900	0.100	7.000	71.429	27.143	1.429
SC-13	2.000	1.270	7.700	10.970	18.232	11.577	70.191	5.370	5.440	0.190	11.000	48.818	49.455	1.727
SC-14	1.240	1.510	136.700	139.450	0.889	1.083	98.028	28.680	76.000	34.410	139.090	20.620	54.641	24.739
SC-15	1.600	5.300	143.900	150.800	1.061	3.515	95.424	11.510	124.500	14.920	150.930	7.626	82.489	9.885
SC-17	0.300	0.060	17.300	17.660	1.699	0.340	97.961	15.170	1.760	0.850	17.780	85.321	9.899	4.781
SC-18	0.450	0.130	35.910	36.490	1.233	0.356	98.411	10.100	23.230	0.370	33.700	29.970	68.932	1.098
SC-19	0.100	0.050	28.410	28.560	0.350	0.175	99.475	21.060	7.380	1.490	29.930	70.364	24.658	4.978
SC-20	1.910	1.920	28.570	32.400	5.895	5.926	88.179	10.690	20.880	1.070	32.640	32.751	63.971	3.278
SC-21	1.540	1.280	3.970	6.790	22.680	18.851	58.468	3.980	2.770	0.230	6.980	57.020	39.685	3.295
SC-22	2.730	2.020	6.820	11.570	23.596	17.459	58.946	3.800	7.310	0.370	11.480	33.101	63.676	3.223
SC-23	1.490	0.780	27.750	30.020	4.963	2.598	92.438	5.900	23.600	1.010	30.510	19.338	77.352	3.310
SC-24	17.610	2.880	31.150	51.640	34.101	5.577	60.321	27.820	23.610	2.010	53.440	52.058	44.180	3.761
SC-25	0.250	0.050	8.560	8.860	2.822	0.564	96.614	4.380	2.210	0.510	7.100	61.690	31.127	7.183
SC-26	0.260	0.100	9.880	10.240	2.539	0.977	96.484	9.020	0.580	0.140	9.740	92.608	5.955	1.437
SC-27	25.550	4.850	14.380	44.780	57.057	10.831	32.113	5.160	38.600	0.510	44.270	11.656	87.192	1.152
SC-28	15.600	10.860	37.900	64.360	24.239	16.874	58.888	3.780	57.520	0.280	61.580	6.138	93.407	0.455
SC-29	0.180	0.030	5.730	5.940	3.030	0.505	96.465	4.990	1.190	0.220	6.400	77.969	18.594	3.437
SC-30	2.070	2.300	19.040	23.410	8.842	9.825	81.333	7.490	14.760	1.300	23.550	31.805	62.675	5.520
SC-31	0.220	0.400	45.270	45.890	0.479	0.872	98.649	7.870	38.450	1.570	47.890	16.433	80.288	3.278
SC-32	8.930	13.900	71.940	94.770	9.423	14.667	75.910	3.440	66.210	19.380	89.030	3.864	74.368	21.768
SC-33	0.240	0.220	33.810	34.270	0.700	0.642	98.658	12.560	20.190	2.280	35.030	35.855	57.636	6.509
SC-34	0.250	2.760	40.090	43.100	0.580	6.404	93.016	29.610	6.290	7.200	43.100	68.701	14.594	16.705
SC-35	3.690	2.060	48.070	53.820	6.856	3.828	89.316	25.840	19.150	7.200	52.190	49.511	36.693	13.796
SC-36	0.450	1.450	5.940	7.840	5.740	18.495	75.765	6.030	1.140	0.060	7.230	83.402	15.768	0.830

APPENDIX K

SOURCE OF SUBSURFACE DATA

Electric logs from drill holes were used to select formation tops, obtain thicknesses, aid in construction of the regional cross-section (Plate 2), and to derive general information on rock types. These logs, along with other pertinent information derived from them, are listed below. All the logs are on file at the NMBMMR.

The general procedure for describing each log is the following:

Drill hole number or name, Company or Agency, legal description; ground elevation; formation in which hole was spudded; formation tops. date drilled.

The following wells and data were used in constructing the regional cross-section (Plate 2). Numbers correspond to those on the cross section.

1. #1 Federal Tract 16, Hughes and Hughes, McKinley County, 1,980 FSL, 698FWL, Sec8, T16N, R5W; ground elevation, 1,990 m (6,523 ft); spudded in Cleary Coal Member, Menefee Formation; top of Point Lookout Sandstone, 107 m (350 ft); top of Satan Tongue, Mancos Shale, 188 m (615 ft); top of Hosta Tongue, 271 m (890 ft); top of Mulatto Tongue, Mancos Shale, 281 m (920 ft); top of Gallup Sandstone, 421 m (1,380 ft). drilled, 7/20/66.

2. Cabezon #1, Refiner's Petroleum, Sandoval County, 1,980 FNL, 1,980 FEL, Sec29, T17N, R4W; ground elevation, 1,959 m (6,423 ft); spudded in Allison Member, Menefee Formation; top of Point Lookout Sandstone, 180 m (590 ft); top of Satan Tongue, Mancos Shale, 237 m (778 ft); top of Dakota Sandstone, 804 m (2,635 ft); top of Morrison Formation, 848 m (2,780 ft). drilled, 6/21 - 7/20/71.

3. F. F. Kelly State #1, Plymouth Oil Company, Sandoval County, 660 FNL, 1,980 FEL, Sec32, T18N, R4W; ground elevation, 1,977 m (6,482 ft); spudded in "Upper Member", Menefee Formation; top of Point Lookout Sandstone, 359 m (1,178 ft); top of Mancos Shale, 396 m (1,298 ft); top of Dakota Sandstone, 1,003 m (3,290 ft); top of Morrison Formation, 1,049 m (3,440 ft). drilled, 4/13 - 5/21/53.

4. Torreon #1, Reynold's Mining Company, Sandoval County, 1,980 FSL, 660 FWL, Sec 22, T18N, R4W; ground elevation, 1,943 m (6,372 ft); spudded in "Upper Member", Menefee Formation; top of Point Lookout Sandstone, 379 m (1,243 ft); top of Mancos Shale, 406 m (1,332 ft); top of Dakota Sandstone, 1,031 m (3,380 ft); top of Morrison Formation, 1,075 m (3,525 ft). drilled, 2/1/56.

5. Ann #14, Kreatschman and Stowe, Sandoval County, 660 FNL, 1,980 FWL, Sec33m T18N, R3W; ground elevation, 1,970 m (6,459 ft); spudded in "Upper Member", Menefee Formation; top of Point Lookout Sandstone, 299 m (980 ft); top of Mancos Shale, 323 m (1,o60 ft); top of Dakota Sandstone, 939 m (3,080 ft); top of Morrison Formation, 982 m (3,220 ft). drilled, 8/3/67.

The following wells and data were used to construct thickness and depth to top maps (Fig. 18, p. 47 and Fig. 19, p. 49).

R11 Torreon, NMBMMR, McKinley County, SE¼, NW¼, Sec29, T16N, R5W; ground elevation, 1,993 m (6,535 ft); spudded in Cleary Coal Member, Menefee Formation; top of Point Lookout Sandstone, 15 m (50 ft). drilled, 5/24/78.

R12 Torreon, NMBMMR, McKinley County, NW¼, NE¼, Sec21, T16N, R5W; ground elevation, 1,989 m (6,520 ft); spudded in Cleary Coal Member, Menefee Formation; top of Point Lookout Sandstone, 20 m (66 ft), drilled, 5/29/78.

R13 Torreon, NMBMMR, McKinley County, SW¼, NW¼, Sec26, T16N, R5W; ground elevation, 2,022 m (6,630 ft); spudded in Cleary Coal Member, Menefee Formation; top of Point Lookout Sandstone, 20 m (66 ft). drilled, 5/17/78.

R23 Torreon, NMBMMR, Sandoval County, SW¼, SW¼, Sec6, T16N, R4W; ground elevation, 1,900 m (6,230 ft); spudded in Cleary Coal Member, Menefee Formation; top of Point Lookout Sandstone, 55 m (180 ft). drilled, 6/20/78.

R24 Torreon, NMBMMR, McKinley County, SE¼, NE¼, Sec2, T16N, R5W; ground elevation, 1,934 m (6,340 ft); spudded in Cleary Coal Member, Menefee Formation; top of Point Lookout Sandstone, 54 m (177 ft). drilled, 6/22/78.

R32 Torreon, NMBMMR, Sandoval County, NW¼, SE¼, Sec23, T17N, R4W; ground elevation, 1,882 m (6,170 ft); all in Menefee Formation. drilled, 4/19/78.

R33 Torreon, NMBMMR, Sandoval County, SW¼, NW¼, Sec31, T17N, R3W; ground elavtion, 1,915 m (6,280 ft); spudded in Cleary Coal Member, Menefee Formation; top of Point Lookout Sandstone, 32 m (105 ft). drilled, 4/19/78.

R42 Torreon, NMBMMR, Sandoval County, SW¼, NW¼, Sec17, T17N, R3W; ground elavtion, 1,902 m (6,235 ft); all in Menefee Formation. drilled, 7/7/78.

C5 Torreon, NMBMMR, Sandoval County, NW¼, NW¼, Sec5, T17N, R4W; ground elevation, 1,864 m (6,110 ft); not logged (core hole); spudded in Cleary Coal Member, Menefee Formation; top of Point Lookout Sandstone, 45 m (147 ft). drilled, 5/78.

C6 Torreon, NMBMMR, McKinley County, NE¼, NW¼, Sec17, T16N, R5W; ground elevation, 1,949 m (6,390 ft); not logged (core hole); spudded in Cleary Coal Member, Menefee Formation; top of Point Lookout Sandstone, 43 m (140 ft). drilled, 7/78.

IC-1, Pioneer Nuclear, Inc., Sandoval County, NW¼, SE¼, Sec34, T16N, R4W; ground elevation, 2,173 m (7,125 ft); spudded in Cleary Coal Member, Menefee Formation; top of Point Lookout Sandstone, 112 m (367 ft); top of Mancos Shale, 135 m (442 ft). drilled, 1975(?).

#2 Federal Tract 15, Hughes and Hughes, McKinley County, 1,660 FSL, 1,980 FEL, Sec16, T16N, R5W; ground elevation, 1,936 m (6,346 ft); spudded in Cleary Coal Member, Menefee Formation; top of Point Lookout Sandstone, 24 m (78 ft); top of Mancos Shale, 65 m (212 ft). drilled, 7/16/66.

IC-11, Pioneer Nuclear, Inc., McKinley County, SW¼, NW¼, Sec32, T16N, R5W; ground elevation, 2,031 m (6,660 ft); spudded in Cleary Coal Member, Menefee Formation; top of Point Lookout Sandstone, 31 m (102 ft); top of Mancos Shale, 95 m (312 ft). drilled, 1975(?).

Torreon Core Hole #2, Tenneco Oil Company, Sandoval County, SE¼, NW¼, Sec5, T17N, R3W; ground elevation, 1,954 m (6,408 ft); spudded in Allison Member, Menefee Formation; top of Point Lookout Sandstone, 261 m (854 ft); top of Mancos Shale, 292 m (956 ft). drilled, 5/23/67.

Sandoval Federal #1, Sun Oil Company, Sandoval County, 330 FSL, 990 FWL, Sec24, T18N, R3W; ground elevation, 2,001 m (6,562 ft); spudded in "Upper Member", Menefee Formation; top of Point Lookout Sandstone, 336 m (1,102 ft); top of Mancos Shale, 367 m (1,204 ft); top of Dakota Sandstone, 1,000 m (3,280 ft); top of Morrison Formation, 1,043 m (3,420 ft). drilled, 6/9/71.

Torreon Core Hole #7, Tenneco Oil Company, Sandoval County, 910 FNL, 1,190 FWL, Sec34, T18N, R3W; ground elevation, 1,972 m (6,466 ft); spudded in Allison Member, Menefee Formation; top of Point Lookout Sandstone, 261 m (856 ft); top of Mancos Shale, 292 m (957 ft). drilled, 8/7/68.

Glazebrook #1, Bernard King, McKinley County, 990 FSL, 990 FEL, Sec25, T18N, R5W; ground elevation 2,077 m (6,810 ft); spudded in Cliff House Sandstone; top of Point Lookout Sandstone, 457 m (1,500 ft); top of Mancos Shale, 497 m (1,630 ft). drilled, 5/12/57.

APPENDIX L

RESULTS OF CORE ANALYSES

Five core samples from two of the NMBMMR Torreon coal test-holes (C5, C6) were analyzed commercially (by Core Laboratories, Inc., Farmington) for porosity and horizontal and vertical permeability. Three of the samples were taken from the Point Lookout Sandstone, and two were taken from channel sandstones in the Menefee Formation (Cleary Coal Member). Results of these hydrologic tests are summarized in Table L-1.

Table L-1. Results of core analyses (see Appendix D).

Sample Number	Core Number[1]	Formation[2]	Depth of Sample Below Ground Surface m	(ft)	Distance of Sample Below Top of Rock Unit m	(ft)	Permeability (millidarcys)[3] Horizontal	Vertical	Porosity (percent)
1	C5	Kpl	58.5	(191.8)	13.1	(43.1)	8.5	3.5	20.4
2	C5	Kmfc	26.4	(86.6)	0.09	(0.3)	210	98	26.4
3	C6	Kpl	45.9	(150.5)	3.4	(11.2)	0.81	0.72	18.2
4	C6	Kpl	66.7	(218.8)	24.2	(79.5)	8.9	5.4	21.3
5	C6	Kmfc	11.5	(37.6)	2.0	(6.6)	163	314	26.3

[1] Locations of core holes.
C5: SW¼, NW¼, NW¼, sec. 5, T16N, R4W.
C6: NE¼, NE¼, NW¼, sec. 17, T16N, R5W.

[2] Abbreviations same as in Plate 1.

[3] Precision as reported by Core Lab.

This thesis is accepted on behalf of the faculty of the

Institute by the following committee:

Date 9 April 1980