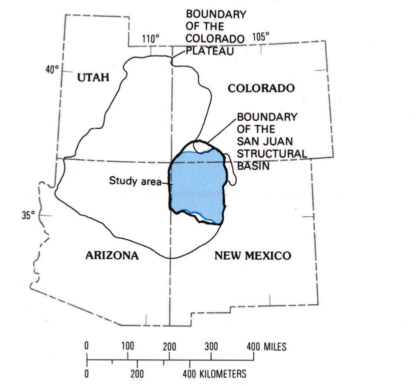

Figure 1. Location of San Juan structural basin, Colorado Plateau, and study area.

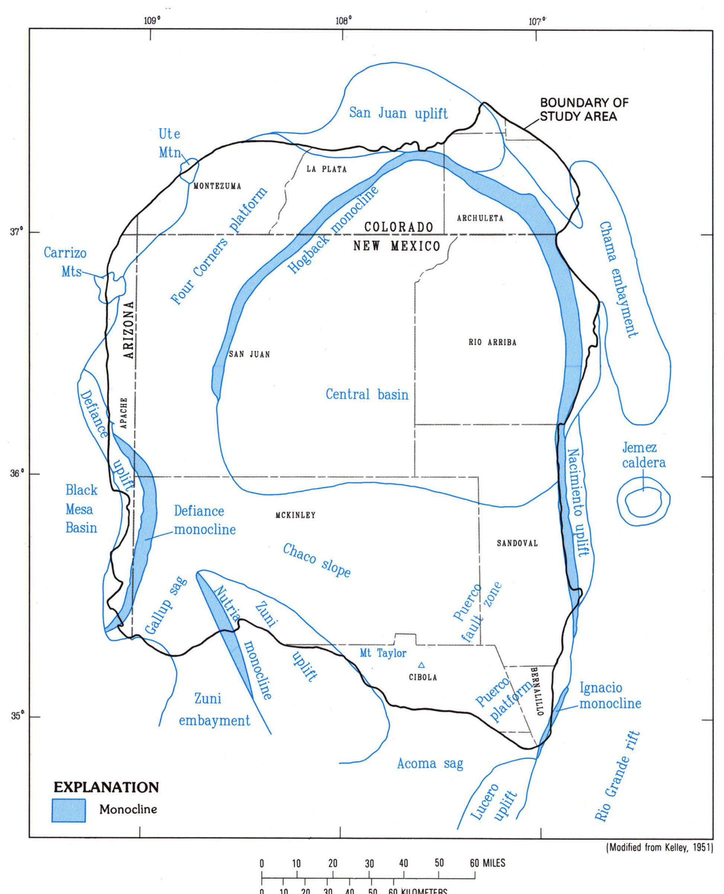

Figure 2. Structural elements of the San Juan structural basin and adjacent areas.

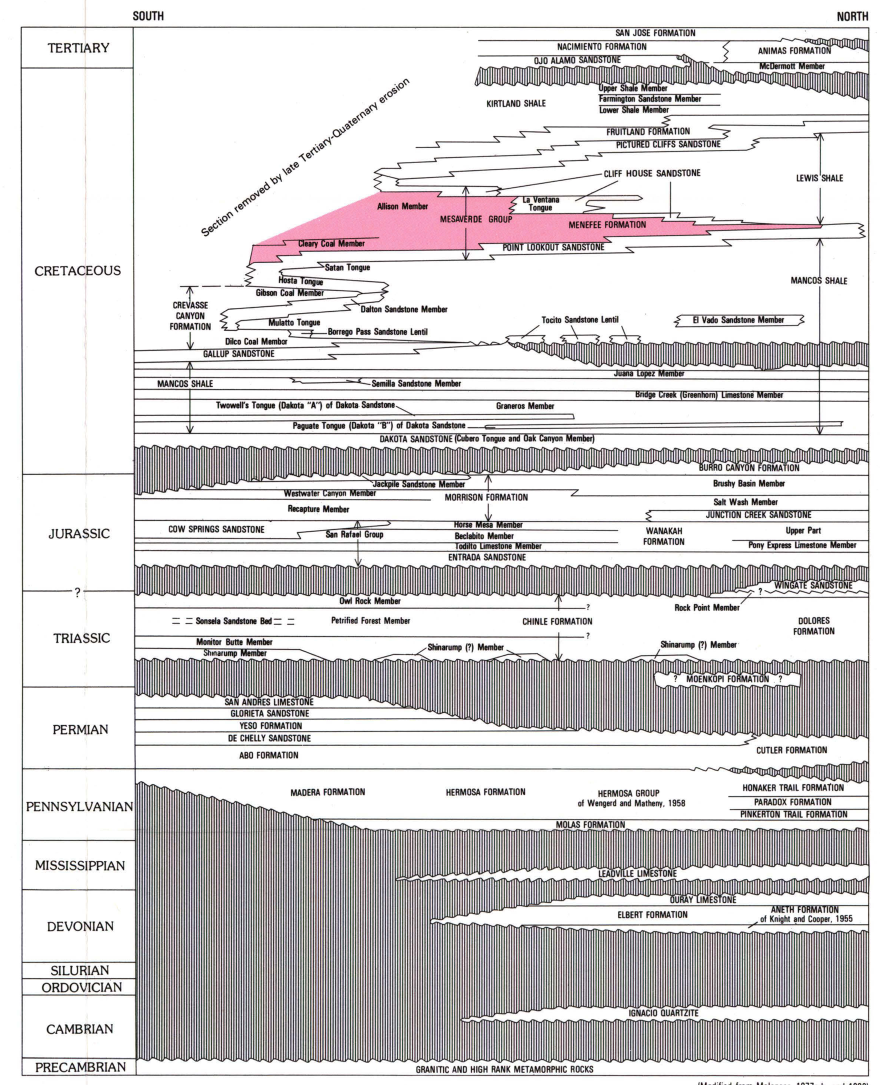

Figure 3. Time- and rock-stratigraphic framework and nomenclature.

CONVERSION FACTORS

Multiply inch-pound unit	By	To obtain metric unit
inch	25.4	millimeter
foot	0.3048	meter
foot per day	0.3048	meter per day
foot squared per day	0.09290	meter squared per day
gallon per minute	0.06309	liter per second
gallon per minute per foot	0.2070	liter per second per meter
mile	1.609	kilometer
pound per square inch	6.8948	kilopascal
square mile	2.590	square kilometer

Temperature in degrees Celsius (°C) can be converted to temperature in degrees Fahrenheit (°F) by using the following equation:

$$°F = 1.8 \times °C + 32$$

Sea level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)—a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called "Sea Level Datum of 1929."

INTRODUCTION

This report is one in a series resulting from the U.S. Geological Survey's Regional Aquifer-System Analysis (RASA) study of the San Juan structural basin that began in October 1984. Previous reports in the series describe the hydrogeology of the Dakota Sandstone (Craigg and others, 1989), Point Lookout Sandstone (Craigg and others, in press), Morrison Formation (Dam and others, 1990), Gallup Sandstone (Kernodle and others, 1989), and Cliff House Sandstone (Thorn and others, in press), in the San Juan structural basin. The purposes of the RASA (Welder, 1986) are to: (1) Define and evaluate the aquifer system; (2) assess the effects of past, present, and potential ground-water use on aquifers and streams; and (3) determine the availability and quality of ground water.

This report summarizes information on the geology and the occurrence and quality of water in the Menefee Formation, one of the primary water-bearing units in the regional aquifer system. Data used in this report were collected during the study or were derived from existing records in the U.S. Geological Survey's computerized National Water Information System (NWIS) data base, the Petroleum Information Corporation's data base, and the Dwight's ENERGYDATA Inc. BRIN data base. Although all data available for the Menefee Formation were considered in formulating the discussions in the text, not all those data could be plotted on the illustrations.

The San Juan structural basin is in New Mexico, Colorado, Arizona, and Utah, and has an area of about 21,600 square miles (fig. 1). The structural basin is about 140 miles wide and about 200 miles long. The study area is that part of the structural basin that contains rocks of Triassic or younger age and, therefore, the study area is less extensive than the structural basin. Triassic through Tertiary sedimentary rocks are emphasized in this study because the major aquifers in the basin are present in these rocks. The study area is about 140 miles wide, 180 miles long, and has an area of about 19,400 square miles.

Altitudes in the study area range from about 4,500 feet in San Juan County, Utah, to about 11,000 feet in Cibola County, New Mexico. Annual precipitation in the high mountainous areas along the north and east margins of the basin is as much as 45 inches, whereas annual precipitation in the lower altitude, Central basin is generally less than 8 inches. Mean annual precipitation in the study area is about 12 inches.

Data obtained from documents published by the U.S. Bureau of the Census, 1980 and 1985, were used to estimate the population of the study area. The population of the study area in 1970 was estimated to be about 134,000. The population rose to about 194,000 in 1980, 212,000 in 1982, 221,000 in 1984, and then fell to about 210,000 in 1985. The economy of the basin is supported by exploration and development of petroleum, natural-gas, coal, and uranium resources; urban enterprise; farming and ranching; tourism; and recreation. The rise and fall in population was related to changes in the economic strength of the mining, petroleum, and natural-gas industries, and support services. Uranium mining and milling activities grew rapidly until the late 1970's when most uranium-mining activity ended in the study area. Likewise, the oil and gas industry prospered until about 1983 and then declined rapidly, also affecting many jobs in support industries.

REGIONAL GEOLOGIC SETTING OF THE SAN JUAN STRUCTURAL BASIN

The San Juan structural basin is a northwest-trending asymmetrical structural depression formed during the Laramide orogeny (Late Cretaceous-early Tertiary) at the eastern edge of the Colorado Plateau (fig. 1). Structural boundaries of the basin are well defined in many places, whereas, in other areas, the basin merges gradually into adjacent depressions or uplifts (Kelley, 1951, p. 124). The structural boundaries principally consist of large, elongate, domal uplifts; low, marginal platforms; and abrupt monoclines as shown in figure 2 and as defined by Kelley (1951, p. 124–127). Faulting is common, especially in the southeastern part of the basin. Maximum structural relief in the basin is about 10,000 feet (Kelley, 1951, p. 126). The present structural elements of the basin had developed by middle Tertiary time (Kelley, 1951, p. 130).

The San Juan structural basin contains a thick sequence of sedimentary rocks ranging in age from Cambrian through Tertiary, but principally from Pennsylvanian through Tertiary (fig. 3). The maximum thickness of the sequence of rocks is about 14,000 feet (Fassett and Hinds, 1971, p. 4). These sedimentary rocks dip basinward from the basin margins toward the troughlike structural center or deepest part of the basin. Older sedimentary rocks crop out around the basin margins and are successively overlain by younger rocks toward the center of the structural basin. Volcanic rocks of Tertiary age and various deposits of Quaternary age also are present in the basin.

GEOLOGY OF THE MENEFEE FORMATION

The Menefee Formation is of Late Cretaceous age (fig. 3) and crops out beyond the margins of the Central basin. Erosion-resistant sandstones in the Menefee commonly cap isolated buttes and hillocks, whereas softer shale units form slopes and broad valleys or flats. Topography formed on the Menefee typically is rolling to rough, broken and steep, and generally has a badlands appearance. The upper part of the Menefee Formation commonly forms steep slopes below mesas or buttes capped by the erosion-resistant Cliff House Sandstone.

The Menefee Formation, named by Collier (1919) for exposures on Menefee Mountain near Mesa Verde in southwestern Colorado, is the middle unit of the classical three-part Mesaverde Group of the San Juan Basin (Point Lookout Sandstone, Menefee Formation, and Cliff House Sandstone). The Menefee Formation conformably or disconformably overlies the Point Lookout Sandstone and is conformably or disconformably overlain by the Cliff House Sandstone; intertonguing locally occurs at both contacts (Tabet and Frost, 1979; Craigg, 1980; Stone and others, 1983). Some authors have reported the Menefee to be conformably overlain by the Lewis Shale in the southeastern part of the basin (Dane, 1936; Beaumont and others, 1956). South of the pinch-out of the Point Lookout Sandstone in the vicinity of Gallup, New Mexico, the Menefee conformably overlies the Crevasse Canyon Formation (fig. 3).

In general, the Menefee Formation consists of interbedded and repetitive sequences of differing thicknesses of sandstone, siltstone, shale and claystone, carbonaceous shale, and coal beds of differing thicknesses (Collier, 1919; Sears and others, 1936; Mannhard, 1976; Tabet and Frost, 1979; Craigg, 1980). Typically the sandstones are lenticular, light brown to gray, thick to very thick bedded, and fine to medium grained, with clay matrix and various types of cement. The siltstones commonly are tabular, gray, and thin to thick bedded; shales and claystones typically are light-brownish gray and thick to very thick bedded (Mannhard, 1976; Tabet and Frost, 1979; Craigg, 1980).

Thickness of the Menefee Formation increases from north to south. Thickness ranges from zero where the unit pinches out between the Point Lookout and Cliff House Sandstones in Colorado to about 2,000 feet along its southern outcrop area (Molenaar, 1977b, p. 164; Tabet and Frost, 1979).

Data used to compute the depth to and the altitude of the top of the Menefee Formation were obtained primarily from oil- or gas-test holes in the Petroleum Information Corporation's data base with supplemental information from water wells from NWIS and from outcrop altitudes. The locations of the test holes and wells are shown in figure 4. Depth to the Menefee ranges from zero in areas of outcrop to about 6,000 feet in the northeastern part of the study area (fig. 5).

A structure-contour map differs from a depth-to-top map in that a structure-contour map represents some particular geologic horizon referenced to a horizontal datum, thus, the effects of topography are removed. In the configuration of the top surface of the Menefee Formation, the datum used is sea level.

The configuration of the top of the Menefee Formation is shown on the structure-contour map (fig. 6). The overall structure of the basin also is shown in figure 6. For example, the deepest part of the structural basin in the northeast, the Hogback monocline surrounding the Central basin, Chaco slope, Four Corners platform, and the structural sag areas in the south, as delineated in figure 2, are all apparent in figure 6. The top of the Menefee Formation decreases from a maximum altitude of about 8,500 feet above sea level along the north-central basin margin to about 1,000 feet above sea level in the northeastern part of the study area.

WATER IN THE MENEFEE FORMATION

The Menefee Formation is a source of water for domestic and livestock use in areas where drilling depths and pumping levels are economically feasible and where water quality is acceptable. These water wells generally are on or near the outcrop areas. Minor amounts of oil are being produced from channel sandstones in the Menefee in the southern part of the basin (Molenaar, 1977b, p. 166). Some of the oil-production wells also produce water, but the quality usually is not acceptable for domestic and livestock use.

The altitude of the potentiometric surface of the Menefee Formation at selected water wells, springs, and oil- or gas-test holes is shown in figure 7. The altitude of the potentiometric surface in the water wells was determined from measured or reported depths to water or was calculated from pressure-gage readings on flowing wells. Interpretation of completion data for the water wells shown indicates that these wells derive water only from the Menefee Formation. The water-well and spring data were collected from 1953 to 1987. The altitude of the potentiometric surface in oil- or gas-test holes was calculated by analyzing shut-in pressures from drill-stem tests conducted from 1954 to 1985; the data were obtained from Petroleum Information Corporation. Drill-stem tests were selected for analysis if the length of time allowed for the shut-in pressure to stabilize was greater than 1 hour.

The object of a drill-stem test is to determine the potential for oil or gas production, not to determine the potentiometric surface. Therefore, the best water-producing zones commonly are bypassed, with the result that the hydrologic data are from less permeable zones. However, the data generally are all that are available for aquifers in the deeper parts of the basin.

The final shut-in pressure was converted to equivalent-freshwater hydraulic head according to the procedure outlined by Miller (1976, p. 17). The following equation was used:

$$h = (FSIP \times X) - PRD + LS \qquad (1)$$

where
- h is the altitude of the potentiometric surface, in feet above sea level;
- FSIP is the final, bottom-hole shut-in pressure, in pounds per square inch, measured by the pressure-recording device;
- X is a factor to convert FSIP to equivalent-freshwater hydraulic head, in feet;
- PRD is the depth to the pressure-recording device, in feet below land surface; and
- LS is the altitude of the land surface, in feet above sea level.

A factor of 2.307 feet of water per pressure increment of 1 pound per square inch was used for X. This value assumes the water is at a temperature of 4 degrees Celsius with a density of 1.0 gram per cubic centimeter.

Water in the Menefee Formation occurs under both water-table and artesian conditions. Water-table conditions occur where sandstones crop out and artesian conditions occur in isolated channel sands enclosed in shale. Recharge to the water-bearing sands primarily is from vertical leakage of water through confining beds but some recharge is from infiltration of precipitation on outcrops and from infiltration of streamflow.

No areas of stress from ground-water development are known to exist. The water levels shown in figure 7 are the most recent data available. Because these data do not represent a specific time interval, they have not been contoured. General ground-water gradients may be determined for localized areas if sufficient data exist.

The transmissivity of the Menefee Formation depends on the thickness of sandstone lenses penetrated. The range of values reported for nine tests (Stone and others, 1983) is 2.7 to 112 feet squared per day with a median value of 10 feet squared per day. Hydraulic conductivity calculated from oil and gas wells in deeper parts of the basin averages 0.017 foot per day (Reneau and Harris, 1957).

The reported or measured discharge from 81 water wells and seven springs completed in the Menefee Formation ranges from 1 to 55 gallons per minute and the median is 13 gallons per minute. The specific capacity of 37 of these wells ranges from 0.02 to 0.57 gallon per minute per foot of drawdown and the median is 0.11 gallon per minute per foot of drawdown. The distribution of these data is shown in figure 8.

The location of two wells that derive water only from the Menefee Formation and have four or more water-level measurements is shown in figure 9. Reference numbers in figure 9 correlate well locations with hydrographs. The official site identification (SITE ID) used to identify each well in the NWIS data base is posted on the hydrographs. Although both wells are completed in the area where the Menefee Formation is exposed at the surface, they are completed in sand lentils where ground water occurs under artesian conditions. Water levels in these lentils may change rapidly depending on changes in ground-water withdrawal. The hydrograph for well 2 shows such a change. It is not possible to determine if these hydrographs show any long-term changes in ground-water levels because ground-water levels may change rapidly and there are too few water-level measurements to define an envelope for the short-term changes.

QUALITY OF WATER FROM THE MENEFEE FORMATION

Water-quality data discussed in the following section are from the NWIS, Petroleum Information Corporation, and Dwight's ENERGYDATA Inc. BRIN data bases collected during 1948–84. Distribution of data from water wells reflects their location near the outcrop where the drilling depth is economically feasible. Well records were checked to assure, to the extent possible, that a particular sample represents water only from the Menefee Formation and not a mixture of water from other aquifers. Data presented on the illustrations do not represent the total amount of available data for the Menefee Formation. If more than one analysis exists for a single well, the most recent analysis is shown on the illustration. Selected water-quality properties and constituents are presented in table 1. The minimum, maximum, and median values were calculated for the most recent analysis for those wells that have multiple analyses.

Temperature of water from the Menefee Formation is displayed in figure 10 and presented in table 1. Most of the temperature data are from water wells drilled where the Menefee Formation crops out within the basin. A bottom-hole temperature obtained during a drill-stem test of an oil- or gas-test hole in the central part of the basin is shown also.

Selected secondary (nonenforced contaminant level) drinking-water standards are shown in table 2 (U.S. Environmental Protection Agency, 1986b). Out of 85 samples analyzed for pH, 44 (52 percent) samples exceeded the secondary drinking-water standard. From a total of 117 samples analyzed for sulfate and 134 samples analyzed for chloride, 47 (40 percent) sulfate samples and 9 (7 percent) chloride samples exceeded the secondary drinking-water standard. The distribution of sulfate samples is displayed in figure 11. Concentrations of sulfate differ greatly between adjacent wells and no apparent trend is evident. From a total of 123 samples analyzed for fluoride, 29 percent exceeded the primary drinking-water standard of 4 milligrams per liter (U.S. Environmental Protection Agency, 1986a) and 45 percent exceeded the secondary drinking-water standard. Concentrations of fluoride are shown in figure 12. The greatest number of samples exceeding both the drinking-water standards are located in the south-central part of the San Juan Basin. Out of 104 samples for dissolved solids 89 (86 percent) exceeded the secondary drinking-water standard.

Dissolved-solids concentrations of water from the Menefee Formation for water wells and oil- and gas-test holes are shown in figure 13 and listed in table 1. The dissolved-solids concentration of water from water wells was calculated from the summation of the major ion concentrations in the water. The dissolved-solids concentration of water obtained during drill-stem tests from oil- or gas-test holes was determined by weighing the residue remaining after evaporation, which is a different technique than the summation of major ions. The data from oil- or gas-test holes were obtained from Dwight's ENERGYDATA Inc. BRIN data base.

The collection of water samples during drill-stem tests does not represent the optimum sampling conditions; however, these data are the only available data in parts of the basin and do provide a qualitative value of the dissolved-solids concentration of water in the Menefee Formation. Generally, the concentration of dissolved solids increases in a downdip direction.

The specific conductance of water can be measured at the sampling site and used to estimate dissolved-solids concentration (Hem, 1985, p. 66–68). Dissolved-solids concentration in water from the Menefee Formation can be estimated by multiplying the field-determined value of specific conductance by 0.66. This number represents the median value of the ratio of dissolved solids to specific conductance for samples from only the Menefee Formation.

Chemical-constituent diagrams for water from the Menefee Formation are displayed in figure 14. Alkalinity is the capacity of the solution to neutralize a strong acid (Hem, 1985, p. 106). Alkalinity from the Menefee Formation consists primarily of the ions bicarbonate and, to a small degree, carbonate. Sodium bicarbonate water is the predominant water type in the basin. In the northern part of the basin, significant concentrations of magnesium, calcium, and sulfate are found in some samples. In the southern and central parts of the basin, water may contain significant concentrations of sulfate ions. Chloride concentration in water throughout the basin is generally insignificant; however, a few samples indicate the presence of chloride but no pattern of occurrence exists.

The variation in water chemistry shown in figure 14 may be the result of wells completed in lenticular sandstones characteristic of the Menefee Formation. The hydraulic connection among these lenticular sandstones is generally poor, causing the localized differences in water chemistry.

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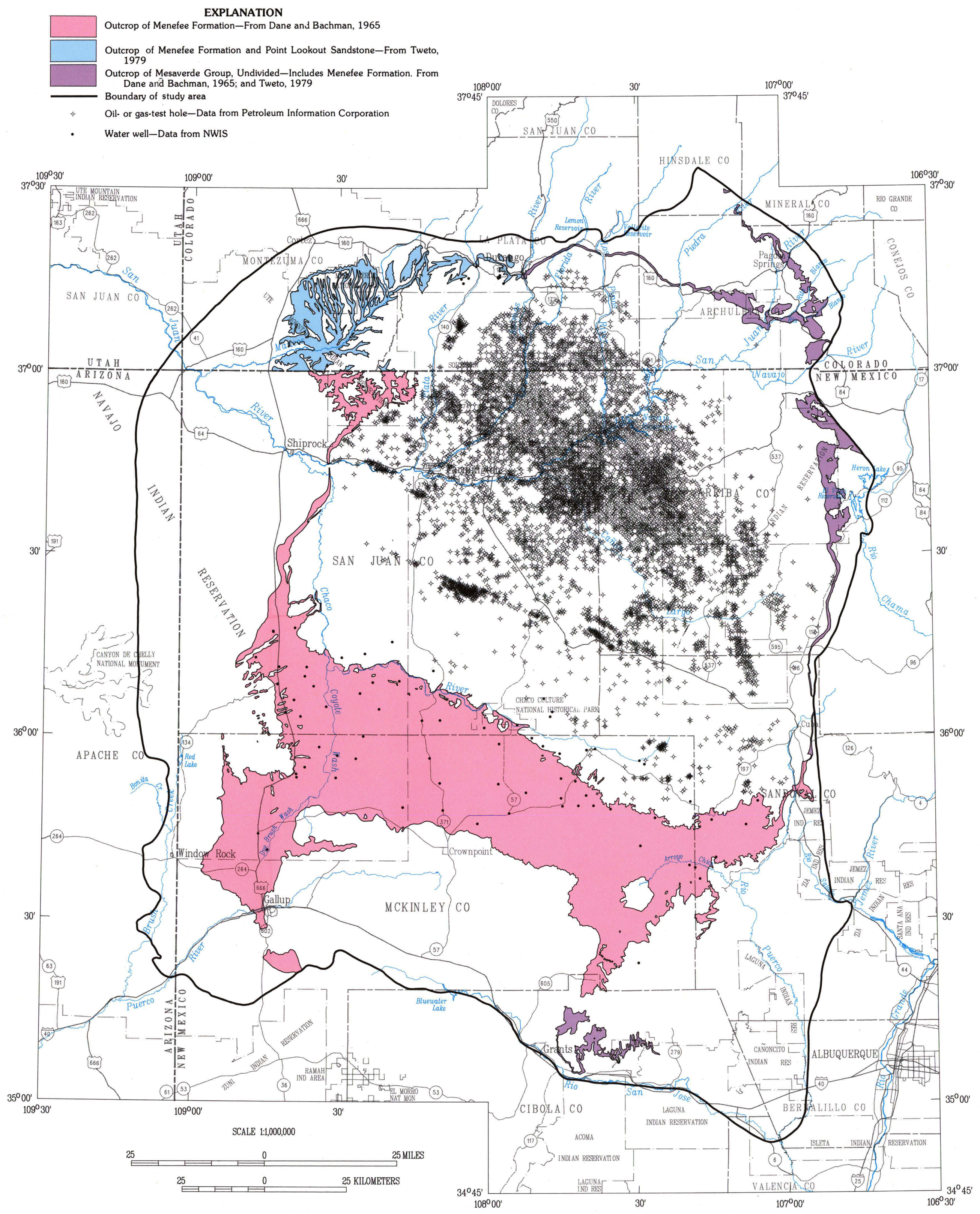

Figure 4. Location of oil- or gas-test holes and water wells used to compile depth to and altitude of the top of the Menefee Formation.

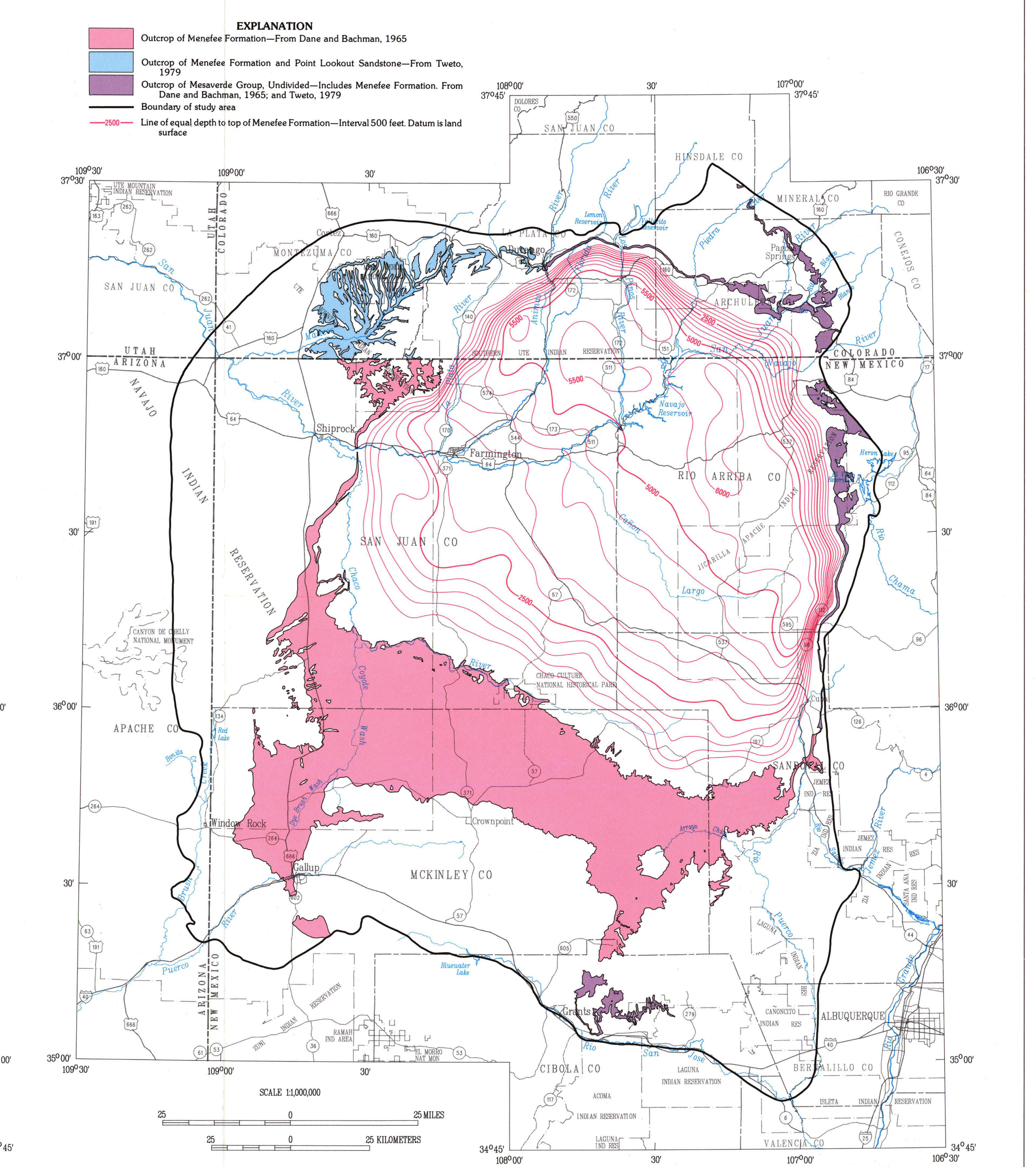

Figure 5. Approximate depth to the top of the Menefee Formation.

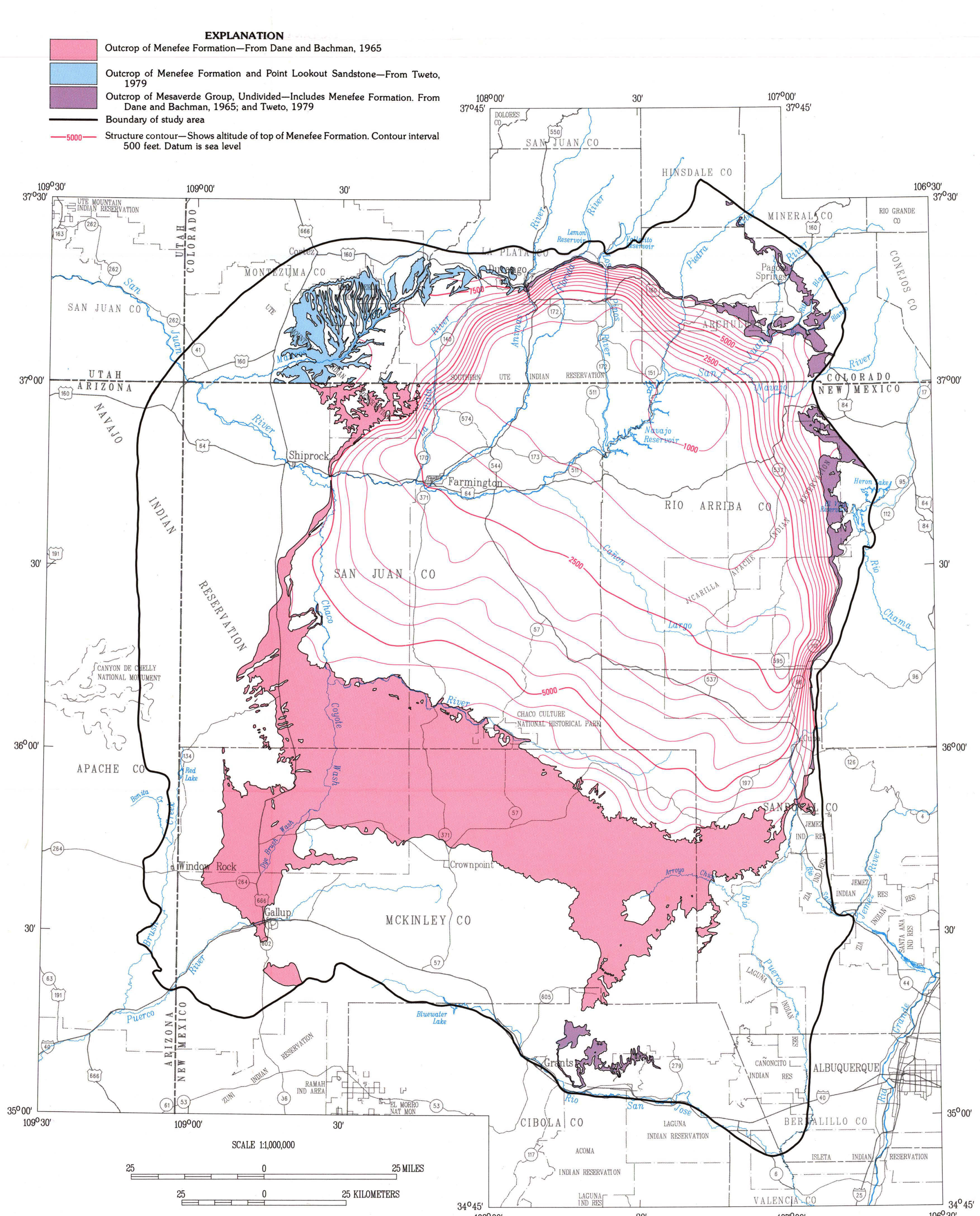

Figure 6. Approximate altitude and configuration of the top of the Menefee Formation.

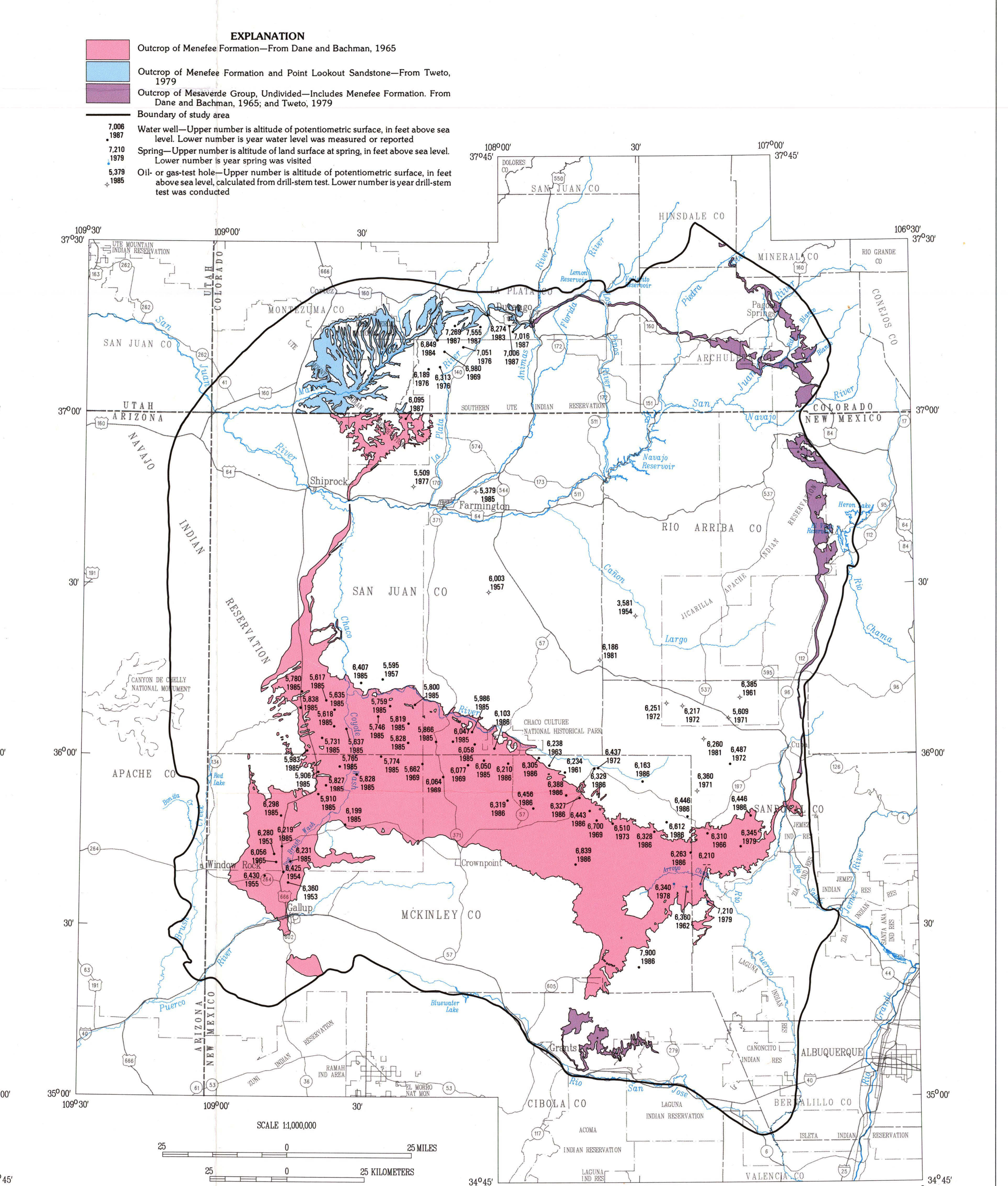

Figure 7. Altitude of potentiometric surface of the Menefee Formation at selected water wells, springs, and oil or gas test holes.

Base from U.S. Geological Survey, 1:100,000 Digital Data
Universal Transverse Mercator Projection, zone 12

HYDROGEOLOGY OF THE MENEFEE FORMATION IN THE SAN JUAN STRUCTURAL BASIN, NEW MEXICO, COLORADO, ARIZONA, AND UTAH

By
Gary W. Levings, Steven D. Craigg, William L. Dam,
John Michael Kernodle, and Conde' R. Thorn

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