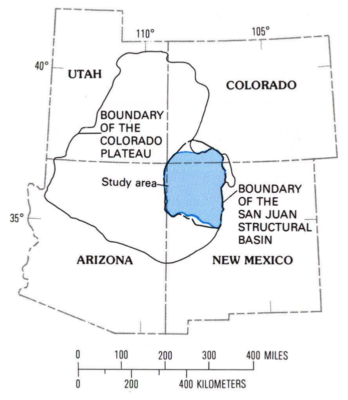


Figure 1. Location of San Juan structural basin, Colorado Plateau, and study area.

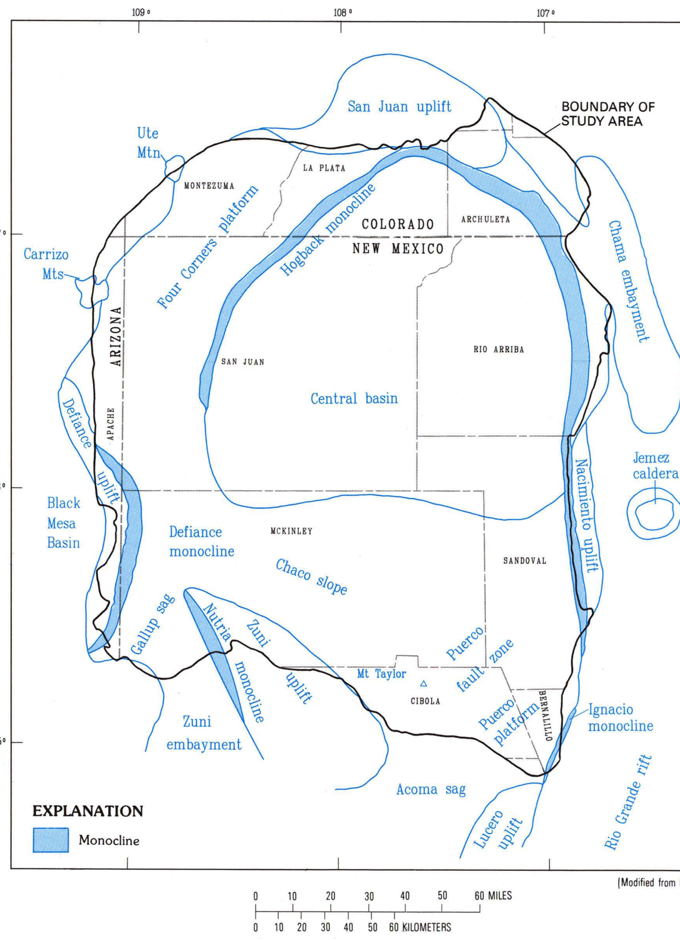
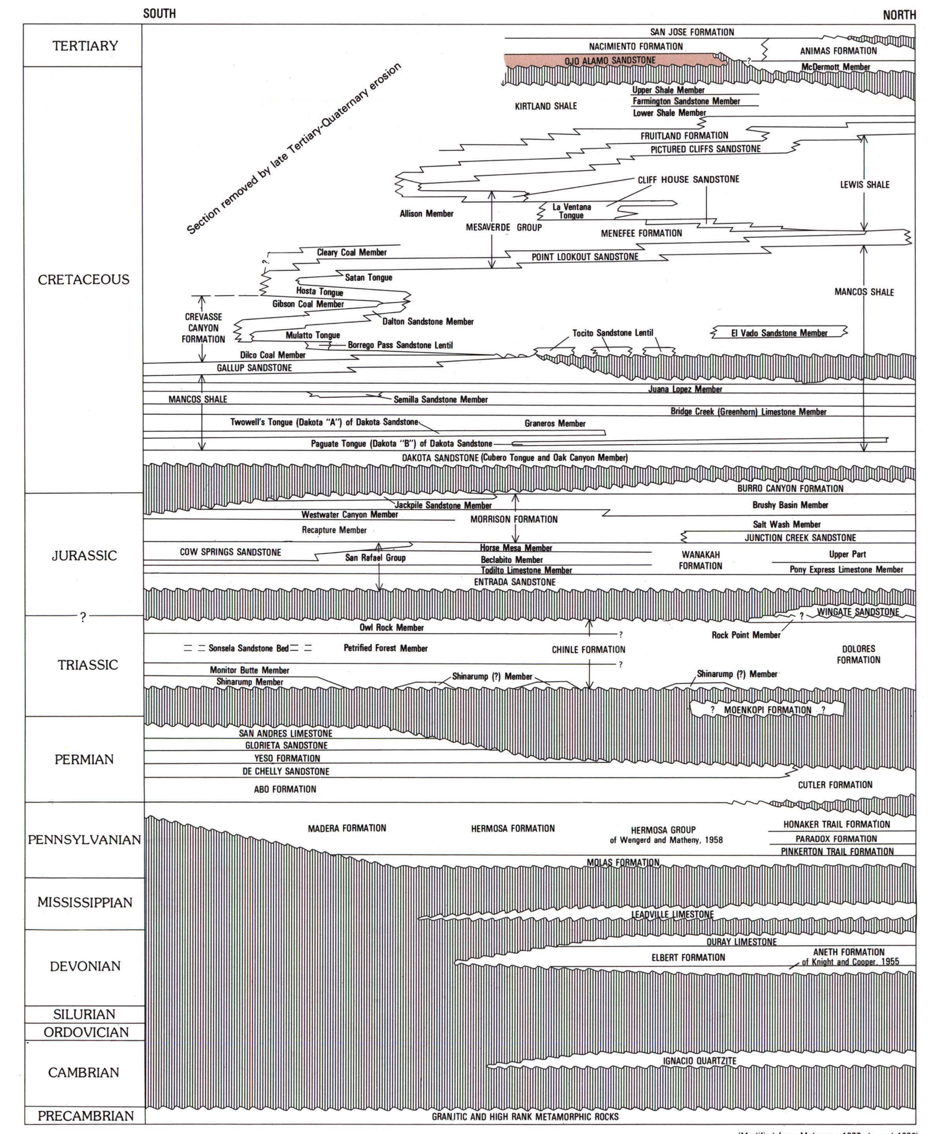


Figure 2. Structural elements of the San Juan structural basin and adjacent areas.



(Modified from Molenaar, 1977a,b, and 1989)

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. 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. Previous reports in the series describe the hydrology of the Dakota Sandstone (Craigg and others, 1989), Gallup Sandstone (Kernodle and others, 1989), Morrison Formation (Dam and others, 1990), Point Lookout Sandstone (Craigg and others, 1990), Pictured Cliffs Sandstone (Dam and others, 1990), Kirtland Shale and Fruitland Formation (Kernodle and others, 1990), Menefee Formation (Levings and others, 1990), and Cliff House Sandstone (Thorn and others, 1990) in the San Juan structural basin.

This report summarizes information on the geology and the occurrence and quality of water in the Ojo Alamo sandstone, 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 Ojo Alamo Sandstone 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, at the eastern edge of the Colorado Plateau (fig. 1). It has an area of about 21,600 square miles. The basin is about 140 miles wide and about 200 miles long. The study area is that part of the basin that contains rocks of Triassic or younger age. 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 and about 180 miles long; it has an area of about 19,400 square miles.

Altitudes in the study area range from about 4,500 feet in southeastern Utah, to about 11,000 feet in the southeastern part of the basin. The area-weighted mean altitude is about 6,700 feet. Annual precipitation in the high mountainous areas along the north and east margins of the basin is as much as 45 inches; annual precipitation in the lower altitude central basin generally is less than 8 inches. Mean annual precipitation is about 12 inches.

Data obtained from documents published by the U.S. Bureau of the Census (1980 and 1985) were used to calculate the population of the study area. The population in 1970 was calculated to be about 134,000. The population increased to about 194,000 in 1980, 212,000 in 1982, 221,000 in 1984, and then decreased to about 210,000 in 1985. The economy of the basin is supported by exploration for and development of natural gas, petroleum, coal, and uranium resources; urban enterprise; farming and ranching; tourism; and recreation. The rise and fall in population were related to changes in the economic strength of the minerals, oil, and gas industries, and support services. Uranium-mining and -milling activities underwent rapid growth from the 1950's until the late 1970's when most uranium-mining activity came to an abrupt end. Likewise, the oil and gas industry prospered until about 1983 and then declined rapidly.

REGIONAL GEOLOGIC SETTING

The San Juan structural basin is a northwest-trending asymmetric structural depression formed during the Laramide orogeny (Late Cretaceous-early Tertiary time). Structural boundaries of the basin are well defined in many places; the basin merges gradually into adjacent depressions or uplifts in other areas (Kelley, 1951, p. 124). The structural boundaries, as defined by Kelley (1951, p. 124–127), principally consist of large, elongate, domal uplifts; low, marginal platforms; and steeply dipping monoclines (fig. 2). 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 rocks is about 14,000 feet (Fassett and Hinds, 1971, p. 4). These sedimentary rocks dip from the basin margins toward the troughlike structural center of the basin. Older sedimentary rocks crop out around the margin of the basin and are successively overlain by younger rocks toward the center of the basin. Igneous rocks of Tertiary age and various deposits of Quaternary age also are present in the basin.

GEOLOGY

The Ojo Alamo Sandstone is of early Tertiary (Paleocene) age (fig. 3). It crops out inside the central basin and typically forms cliffs and dipslopes or caps low mesas and forms rounded hills. The majority of Ojo Alamo rocks occur in New Mexico (fig. 4). The unit pinches out in the northwest about halfway between Farmington, New Mexico, and the Colorado State line west of the La Plata River. In the northeast Ojo Alamo outcrops extend into Colorado, where they pinch out a few miles north of the State line, south of Pagosa Springs, Colorado (Fassett, 1974, p. 228). Subsurface studies by Fassett and Hinds (1971, fig. 9 and p. 29) indicate that the Ojo Alamo is not present north of a line connecting the northernmost limits of the Ojo Alamo outcrops (fig. 4).

The Ojo Alamo Sandstone disconformably overlies the Kirtland Shale throughout most of the basin. On the east side, however, the Kirtland Shale has been removed by pre-Ojo Alamo erosion, and the Ojo Alamo disconformably overlies the Fruitland Formation; locally in places where the Fruitland Formation has been removed, the Ojo Alamo rests directly on the Lewis Shale (Fassett, 1974, p. 228). The contact of the Ojo Alamo with underlying rocks has been described by O'Sullivan and others (1972, p. 56) as "a sharp wavy surface of erosion." Fassett and Hinds (1971, p. 28) reported large-scale channeling at the base of the Ojo Alamo and stated that some of these channels cut 50 feet or more into the underlying shales or sandstones of the Kirtland Shale or Fruitland Formation. The Ojo Alamo is conformably overlain by the Nacimiento Formation throughout most of the basin and intertonguing at the contact is common (Fassett and Hinds, 1971, p. 29).

Strata of the Ojo Alamo Sandstone primarily represent overlapping stream-channel deposits (Baltz, 1967, p. 33); flood-plain deposits also are present in the unit (Powell, 1973, p. 116). Powell (1973) presented an alluvial-plain depositional model for the Ojo Alamo.

In general, the Ojo Alamo Sandstone consists of overlapping sheetlike sequences of conglomeratic sandstones and sandstones, which locally contain interbedded shale lenses. The sandstones are arkosic, light brown to rusty brown, or buff and tan, and contain abundant silicified wood. The sandstones are medium to very coarse grained and often conglomeratic, containing pebbles of various compositions that decrease in size and quantity from west to east across the basin (Baltz and West, 1967, p. 17; Fassett and Hinds, 1971, p. 28).

Thickness of the Ojo Alamo Sandstone is variable. Baltz (1967, p. 32) reported that thickness ranges from 70 feet to a maximum of 200 feet. O'Sullivan and others (1972, p. 57) also reported a maximum thickness of 200 feet. Stone and others (1983, p. 31) reported a range of about 70 to 300 feet. In a basinwide study, Fassett and Hinds (1971, p. 28, 29) reported that thickness of the Ojo Alamo varies from about 20 to 400 feet but that a range of 50 to 150 feet is most common. Fassett and Hinds (1971, p. 28) stated that thickness varies according to the number of sandstone beds that constitute the unit at any given location.

Data used to compute the depth to and the altitude of the top of the Ojo Alamo Sandstone were obtained primarily from oil- or gas-test holes from the Petroleum Information Corporation's data base with supplemental information from water wells from NWIS and from outcrop altitudes. The location of the test holes and wells is shown in figure 4.

Depth to the top of the Ojo Alamo Sandstone ranges from zero in areas of outcrop to about 3,500 feet in the southeastern part of the extent of the unit (fig. 5). This map is, in effect, a thickness map of the overlying younger Tertiary units.

A structure-contour map differs from a depth-to-top map in that a structure-contour map represents some particular horizon referenced to a datum, usually sea level; thus, the effects of topography are removed. The altitude of the top of the Ojo Alamo Sandstone, relative to sea level (a structure-contour map), is shown in figure 6. The top of the Ojo Alamo decreases from a maximum altitude of about 8,000 feet above sea level along the northeastern basin margin to about 4,000 feet above sea level in the east-central part of the study area.

GROUND WATER

The Ojo Alamo Sandstone is a source of water for public supply, domestic, and livestock use in areas where drilling depths and pumping levels are economically feasible and where water quality is suitable for these uses. Water wells generally are on or near the outcrop areas.

The altitude of the potentiometric surface of water in the Ojo Alamo Sandstone at selected water wells and springs is shown in figure 7. The altitude of the potentiometric surface in water wells was determined from measured or reported depths to water. Interpretation of completion data for the water wells shown indicates these wells only derive water from the Ojo Alamo Sandstone. The water-well and spring data were collected from 1966 to 1988.

Water in the Ojo Alamo Sandstone occurs under both water-table and artesian conditions although no flowing wells are known to exist. Potential recharge to the aquifer is from infiltration of precipitation on outcrops, from infiltration of streamflow on outcrops, and from vertical leakage of water through confining beds.

Where water from the Ojo Alamo Sandstone is used for public supply, water levels may be significantly affected by withdrawals. The water levels in figure 7 are shown, along with year of measurement, to provide the reader with the most recent data available. Generalized ground-water gradients may be determined for localized areas if sufficient data exist.

The transmissivity of the Ojo Alamo Sandstone ranges from 57 to 164 feet squared per day with a median value of 104 feet squared per day for 10 tests (Brimhall, 1973, p. 206; Anderholm, 1979, p. 29; and Stone and others, 1983, table 5). These data represent wells that are on or near the outcrop and are less than 1,100 feet deep. Data are available for three tests performed on two test wells more than 4,000 feet deep near the center of the basin; transmissivity for these tests ranged from 0.05 to 0.39 foot squared per day with a median value of 0.35 foot squared per day (Mercer, 1969). These data are shown in figure 8.

The reported or measured discharge from 14 water wells (fig. 9) completed in the Ojo Alamo Sandstone ranges from 2 to 180 gallons per minute and the median is 39 gallons per minute. The specific capacity of nine of these wells ranges from 0.01 to 2.04 gallons per minute per foot of drawdown and the median is 0.26 gallon per minute per foot of drawdown.

The location of one well that derives water only from the Ojo Alamo Sandstone and has four or more water-level measurements is shown in figure 10. The reference number in figure 10 correlates well location with hydrograph. The official site identification (SITE ID) used to identify each well in the NWIS data base is posted on the hydrograph. The water-level hydrograph for this well shows long-term changes in water level that have resulted from continued withdrawal of water for use in a public-supply system.

WATER QUALITY

Most of the water-quality data discussed in this report were collected during 1925–83 and are from the NWIS data base. Data from one oil- or gas-test hole are from Dwight's ENERGYDATA Inc. BRIN data base. Well records were checked to assure, to the extent possible, that a particular sample represents water only from the Ojo Alamo Sandstone and not a mixture of water from other aquifers. Data presented in the illustrations do not represent the total quantity of available data for the Ojo Alamo Sandstone. If more than one analysis exists for a single well, the most recent analysis is shown in the illustration. Selected water-quality properties and constituents are presented in table 1. The calculation of the minimum, maximum, and median values was performed using the most recent analysis for wells that had multiple analyses.

Temperature data for water from the Ojo Alamo Sandstone are shown in figure 11 and presented in table 1. Most of the temperature data are from water wells and springs on or near Ojo Alamo Sandstone outcrop.

Selected secondary drinking-water standards (non-enforced contaminant level) are shown in table 2 (U.S. Environmental Protection Agency, 1986b); these standards were exceeded in samples from some wells, as shown by the maximum values listed in table 1. The secondary drinking-water standard for pH is exceeded by 9 of 32 samples (28 percent, table 2). Sulfate concentration in 12 of 32 samples (38 percent) exceeded the standard. Concentrations of chloride, 1 of 33 samples (3 percent), and fluoride, 2 of 31 samples (6 percent), exceed the secondary drinking-water standard. Dissolved-solids concentration exceeded the standard in 22 of 32 samples (69 percent).

Dissolved-solids concentrations in samples from water wells, springs, and one oil- or gas-test hole are shown in figure 12. Two analytical methods were used for determining the dissolved-solids concentrations. The dissolved-solids concentrations for samples from water wells and springs were calculated as the sum of the major ions analyzed in the water and ranged from 56 milligrams per liter to 7,300 milligrams per liter (table 1). The concentration of dissolved solids for water from the oil- or gas-test hole (3,609 milligrams per liter) was analyzed by weighing the residue remaining after evaporation. These data from the oil- or gas-test hole were from Dwight's ENERGYDATA Inc. BRIN data base. Water samples from an oil- or gas-test hole may not be representative of water from water wells completed in the Ojo Alamo Sandstone. However, data from the oil- or gas-test hole do provide a qualitative value of the dissolved-solids concentration of water from the Ojo Alamo Sandstone.

The specific conductance of water can be easily measured with a meter at a sampling site. Because specific conductance correlates with dissolved-solids concentration (Hem, 1985, p. 66–68), an estimate of the dissolved-solids concentration in water from the Ojo Alamo Sandstone can be determined by multiplying the specific conductance by 0.68. This number represents the median value of the ratio of dissolved solids to specific conductance for samples from only the Ojo Alamo Sandstone.

Chemical-constituent diagrams for samples from the Ojo Alamo Sandstone are shown in figure 13. The relative concentrations of major ions are similar, due to the proximity of the water wells and springs to the outcrop, with the exception of the northeasternmost well, which displays the greatest major ion concentration. Water from the Ojo Alamo Sandstone is a sodium bicarbonate sulfate type. Two springs located in the westernmost section of Sandoval County indicate the presence of a calcium sulfate type water. Bicarbonate ions, and to a small degree, carbonate ions, constitute alkalinity in water from the Ojo Alamo Sandstone. Alkalinity is the capacity of the solution to neutralize a strong acid (Hem, 1985, p. 106).

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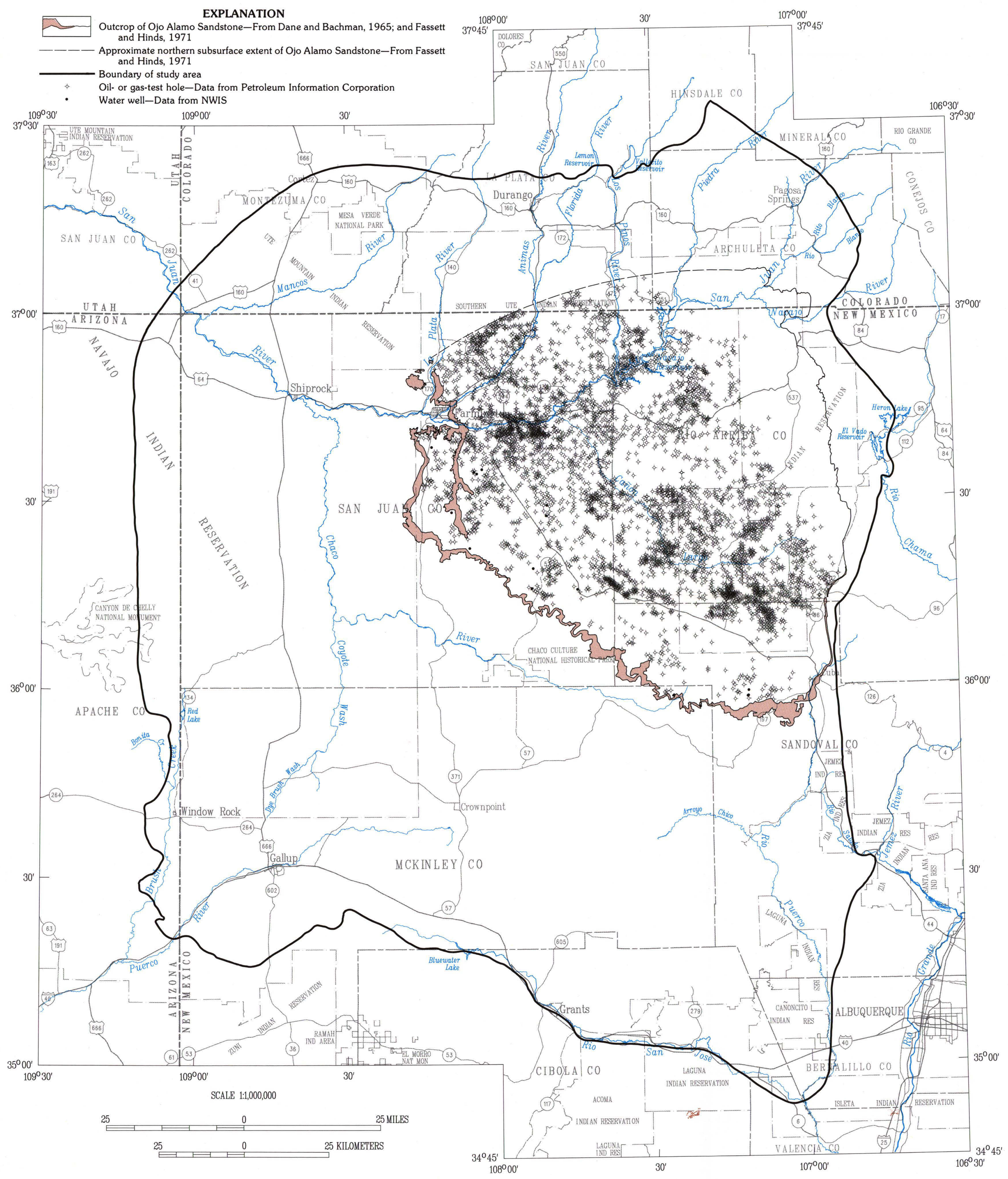

Figure 4. Location of oil- or gas-test holes and water wells used to compile depth to and altitude of the top of the Ojo Alamo Sandstone.

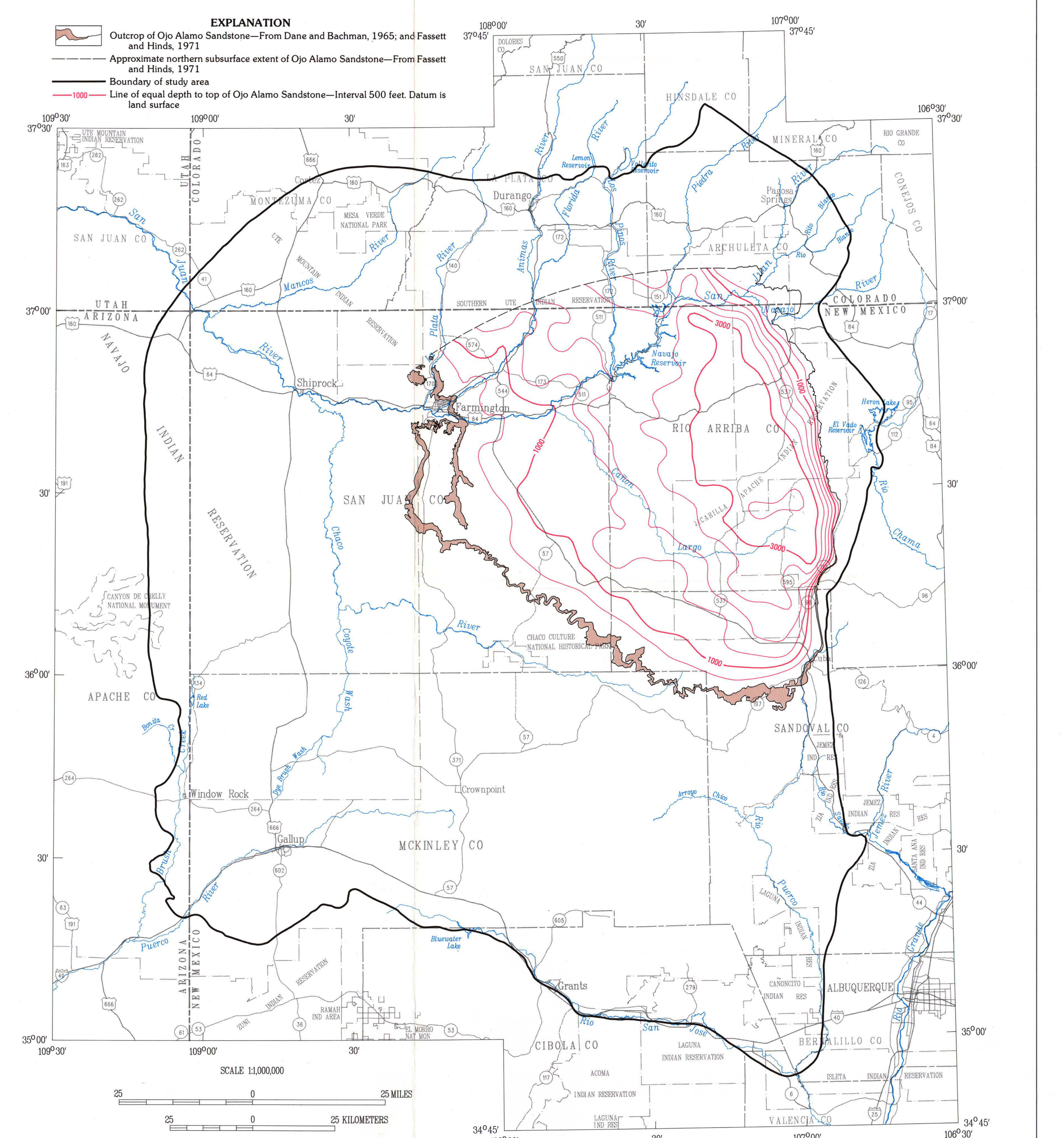

Figure 5. Approximate depth to the top of the Ojo Alamo Sandstone.

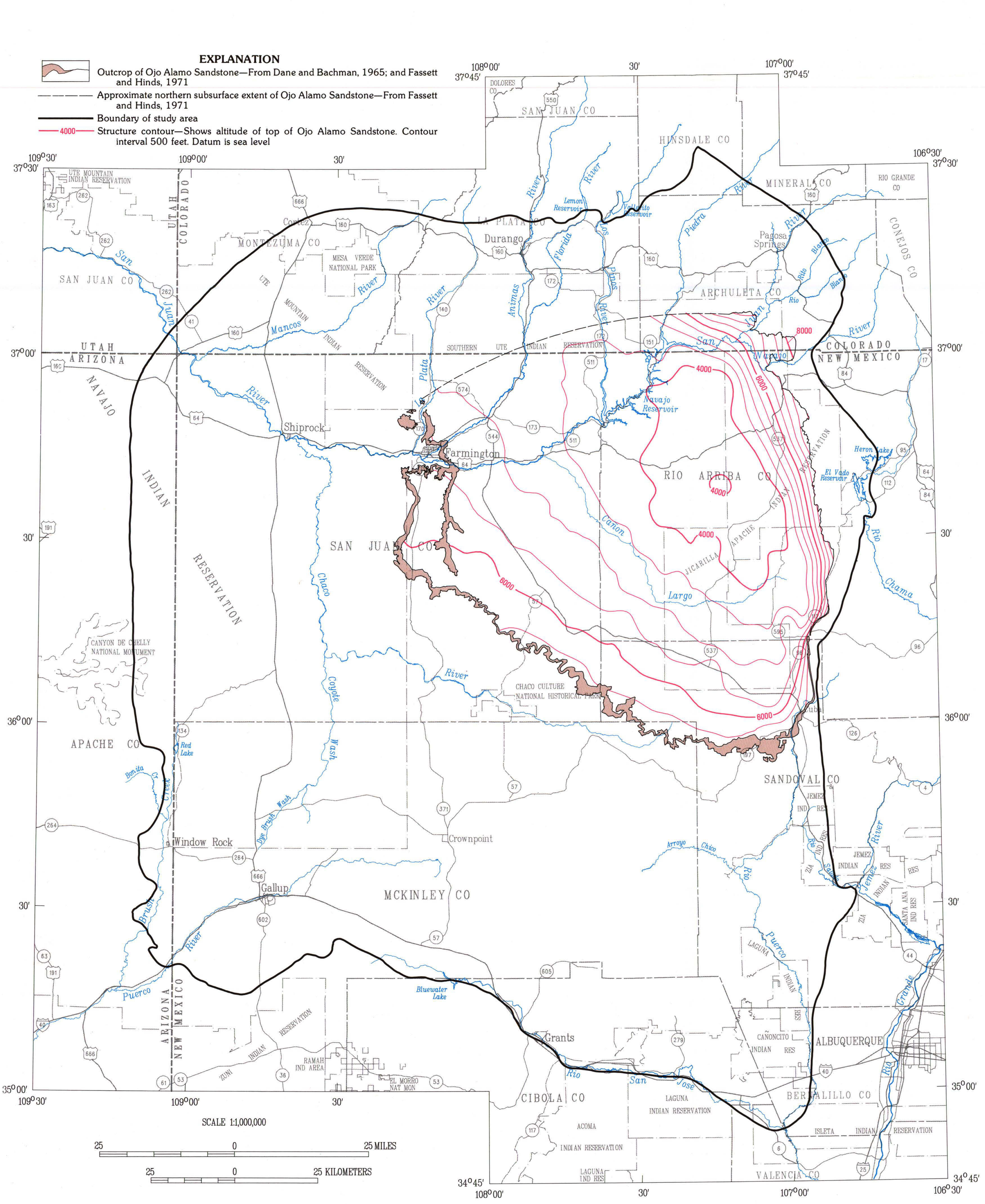

Figure 6. Approximate altitude and configuration of the top of the Ojo Alamo Sandstone.

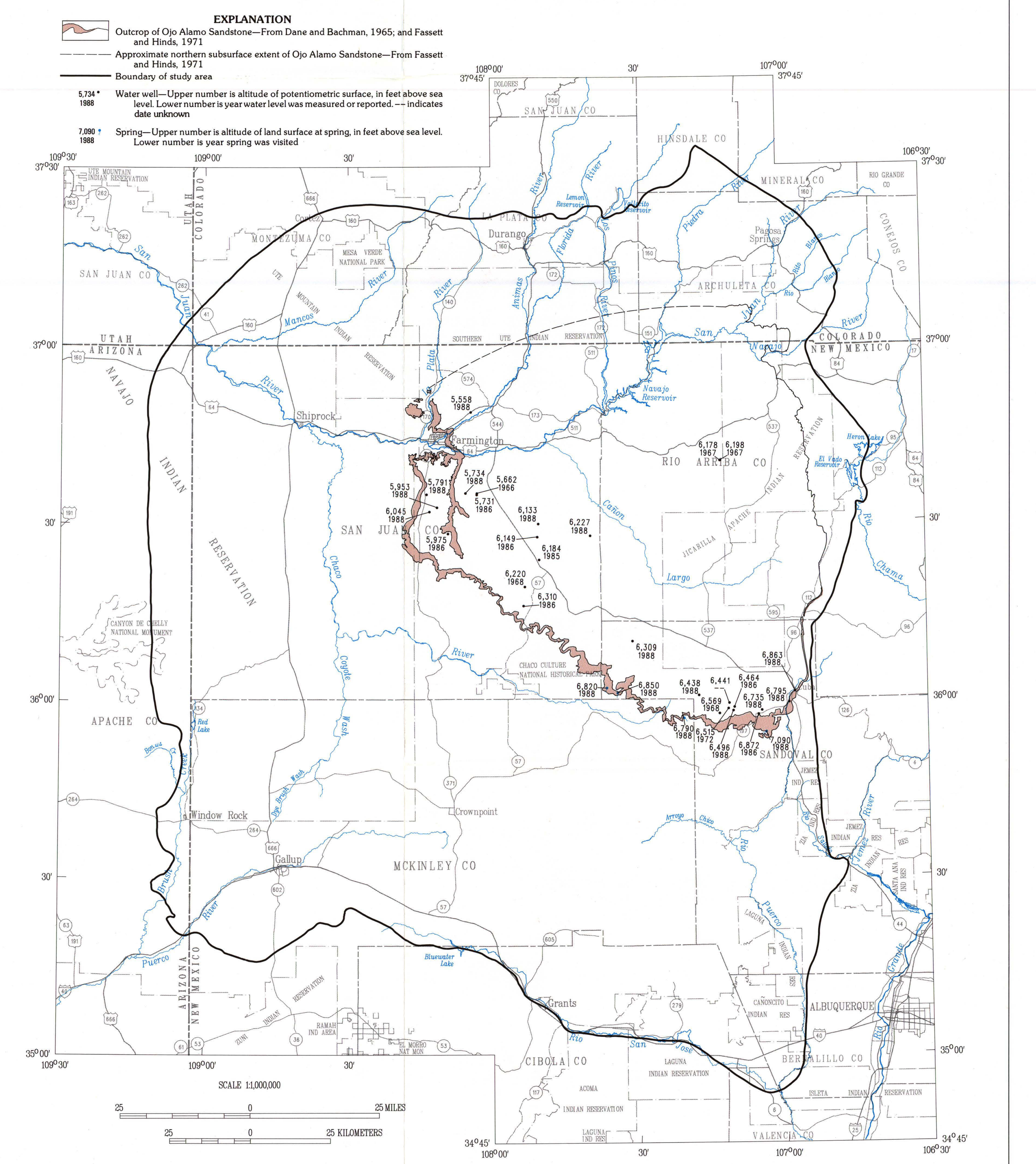

Figure 7. Altitude of potentiometric surface of water in the Ojo Alamo Sandstone at selected water wells and springs.

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

INTERIOR—GEOLOGICAL SURVEY, RESTON, VA—1990

HYDROGEOLOGY OF THE OJO ALAMO SANDSTONE IN THE SAN JUAN STRUCTURAL BASIN, NEW MEXICO, COLORADO, ARIZONA, AND UTAH

By

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

1990

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