HYDROLOGIC INVESTIGATIONS
ATLAS HA–720–H (SHEET 1 OF 2)

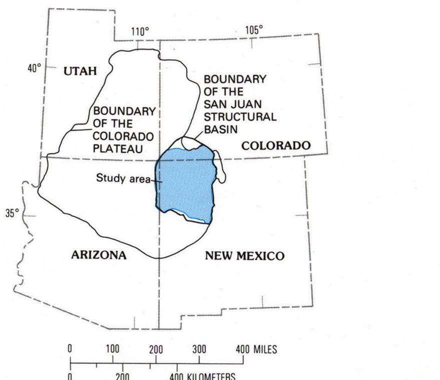

Figure 1. Location of San Juan structural basin, Colorado Plateau, and study area.

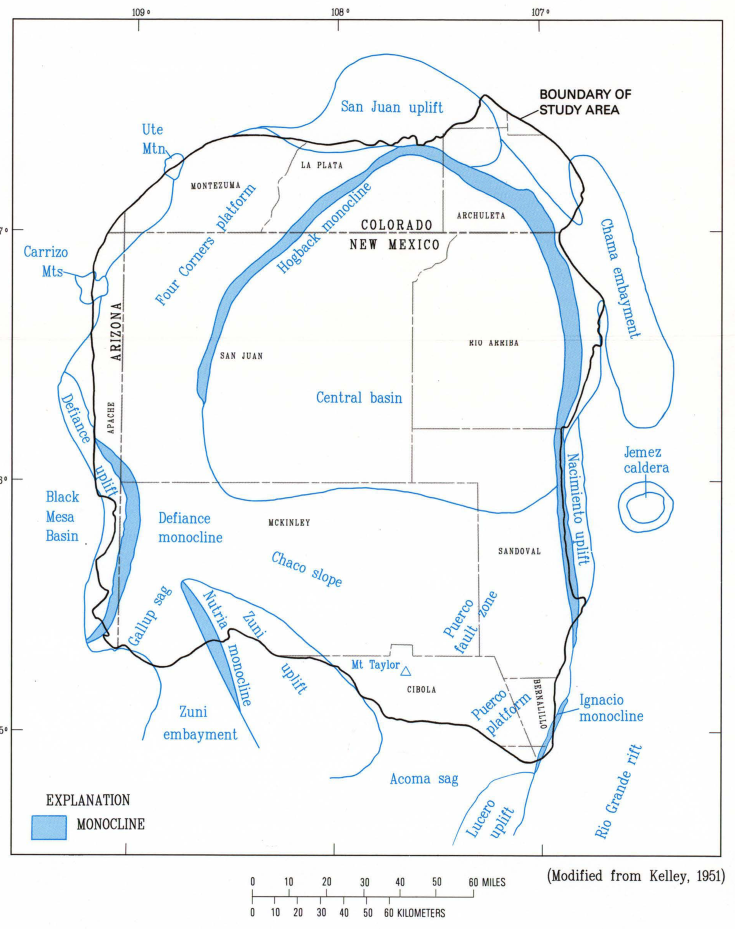

Figure 2. Structural elements of the San Juan structural basin and adjacent areas.

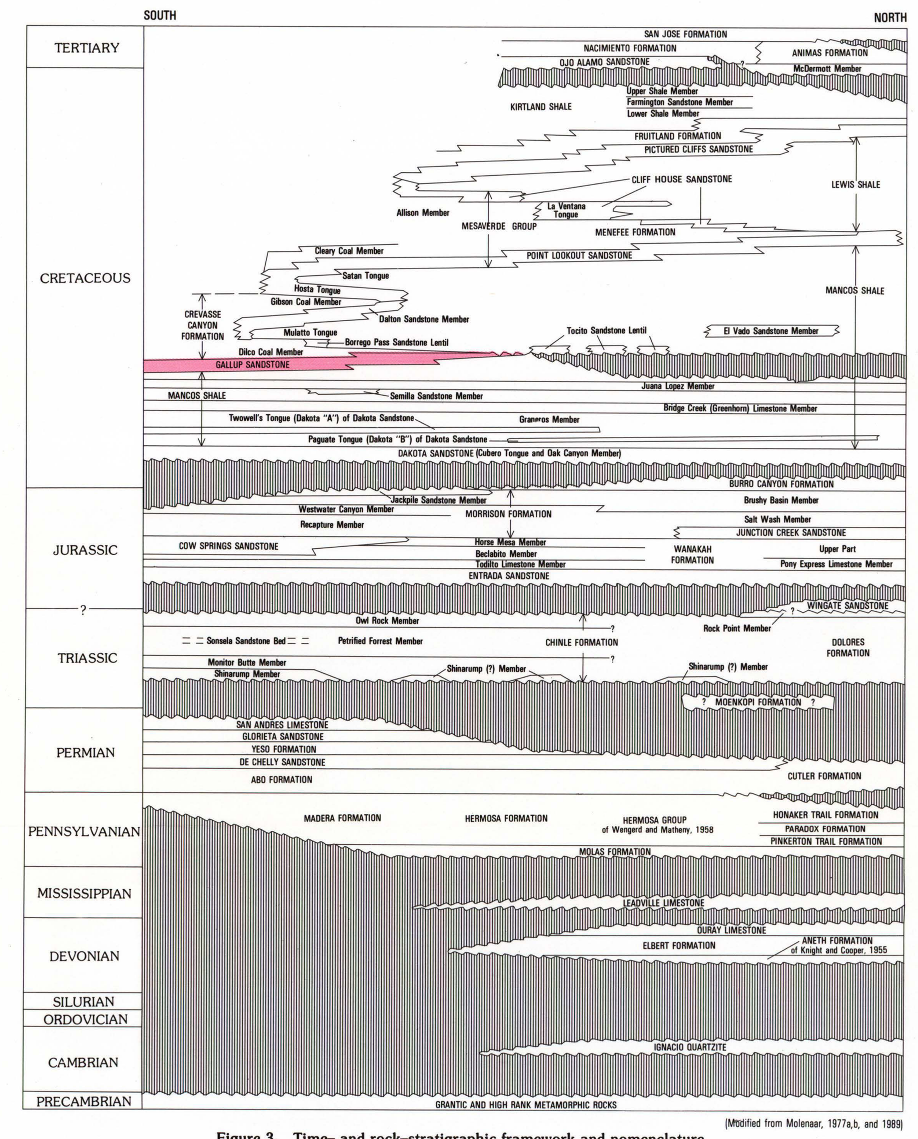

Figure 3. Time– and rock–stratigraphic framework and nomenclature.

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	0.06308	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 hydrology of the Morrison Formation (Dam and others, in press) and the Dakota Sandstone (Craigg and others, in press) in the San Juan structural basin. The purposes of the study (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.

The Gallup Sandstone is one of the primary water-bearing units in the regional aquifer system. The purpose of this report is to summarize information about the hydrogeology of the Gallup Sandstone, of Late Cretaceous age, in the basin. Data used in this report were derived from data collected during the study, from existing records in the U.S. Geological Survey's national, computerized National Water Information System (NWIS) data base, and the Petroleum Information Corporation's data base. All data available for the Gallup Sandstone were included in the discussions in the text; however, not all the data could be plotted on the illustrations.

The San Juan structural basin is located 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 (about the same as the structural basin), 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 southeastern Utah to about 11,000 feet in the southeastern part of the basin. 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 part of the basin is 8 or fewer inches. Mean annual precipitation in the study area is about 12 inches.

The population of the study area in 1980 was about 190,000 (Welder, 1986). The economy of the basin is supported by exploration and development of petroleum, coal, and uranium resources; urban enterprise; farming and ranching; tourism; and recreation.

REGIONAL GEOLOGIC SETTING OF THE SAN JUAN STRUCTURAL BASIN

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; in other places the basin merges gradually into adjacent depressions or uplifts (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 abrupt monoclines (fig. 2). Faulting is common especially in the southeast part of the basin. Maximum structural relief in the basin is about 10,000 feet (Kelley, 1951, p. 126).

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 margin of the basin 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 GALLUP SANDSTONE

The Gallup Sandstone is of Late Cretaceous age (fig. 3; Molenaar, 1973, 1974). The unit has a smaller areal extent than the other major Upper Cretaceous marine sandstones in the San Juan structural basin and occurs only in New Mexico and a small part of Arizona (fig. 4). The Gallup Sandstone crops out in an arcuate pattern around the margins of the southwest half of the basin where it typically forms erosion-resistant cliffs and dip slopes.

As originally defined by Sears (1925) and discussed in detail by Dane and others (1957), the Gallup Sandstone, as a formational unit, consists of various rocks including sandstone (the predominant rock type), conglomerate, shale, carbonaceous shale, and coal. The Gallup Sandstone represents the first major regression of the Upper Cretaceous sea in the San Juan structural basin area and also represents deposition in various marine and nonmarine environments.

From its outcrops, the Gallup Sandstone dips toward a northwest-trending cutoff line that extends from the southeast part of the basin, through the central part of the basin, to near Shiprock, New Mexico, in the northwest part of the basin. The Gallup Sandstone is not present northeast of this cutoff line because it has been truncated by a pre-Niobrara erosion surface (Penttila, 1964; Molenaar, 1973, 1974). Thickness of the main body of the Gallup Sandstone decreases from about 600 feet near the outcrops along the southwest margin of the basin to zero along this northwest-trending pre-Niobrara cutoff line. Isolated lenticular sandstone bodies are found in the transgressive Mulatto Tongue of the Mancos Shale northeast of the cutoff line. These isolated sandstone lenses have been referred to by various informal names such as "Basal Niobrara sandstone," "Tocito sandstone," "Transgressive Gallup," and "Stray sandstone" and have been misidentified as parts of the main body of the Gallup Sandstone. Although many of these isolated sandstone bodies are found at stratigraphic horizons that suggest the presence of the Gallup Sandstone, they are not connected to nor are genetically related to the main body of the Gallup Sandstone (Molenaar, 1973, 1974).

Data used to compute the depth to and the altitude of the top of the Gallup Sandstone were obtained primarily from oil and gas test holes from the Petroleum Information Corporation's data base with supplemental information from water wells from NWIS and U.S. Geological Survey files, Albuquerque, New Mexico, and outcrop altitudes. The location of the test holes and wells is shown in figure 4.

Depth to the top of the Gallup Sandstone ranges from zero in areas of outcrop to about 4,500 feet in an area about 20 miles south of the town of Farmington, New Mexico (fig. 5). The rapid increase in depth in the area northeast of Grants, New Mexico, reflects the local topography of Mt. Taylor (fig. 2).

A depth-to-top map differs from a structure-contour map in that a structure-contour map represents a particular geologic horizon referenced to a horizontal datum; thus, the effects of topography are removed. In constructing the structure-contour map of the top surface of the Gallup Sandstone the datum used was sea level.

The approximate altitude and configuration of the top of the Gallup Sandstone are shown on the structure-contour map (fig. 6). The altitude of the top of the Gallup Sandstone decreases from a maximum of about 7,500 feet above sea level northeast of Window Rock, Arizona, to about 1,500 feet above sea level southwest of Farmington, New Mexico (fig. 6).

WATER IN THE GALLUP SANDSTONE

The Gallup Sandstone is a source of water for domestic, livestock, municipal, and industrial supplies in areas where drilling depths and pumping levels are economically feasible and where water quality is suitable for most uses. Water wells generally are near the western and southern margins of the basin. Oil and gas test holes have penetrated the Gallup Sandstone near the northeast edge of the main body. Water is produced in several of these oil or gas fields as a secondary product or for reinjection in secondary recovery and repressurization projects.

The altitude of the potentiometric surface of water in the Gallup Sandstone at selected water wells, springs, and oil or gas test holes is shown in figure 7. The altitude of the potentiometric surface in 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 these wells only derive water from the Gallup Sandstone. The water-well and spring data were collected from 1953 to 1989. The altitude of the potentiometric surface in oil and gas test holes was calculated by analyzing shut-in pressures from drill-stem tests conducted from 1954 to 1983; these data were obtained from Petroleum Information Corporation. Drill-stem tests were selected for analysis on the basis of length of time allowed for shut-in pressures to stabilize.

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

Water in the Gallup Sandstone occurs under both water-table and artesian conditions. Recharge to the aquifer is from infiltration of precipitation and streamflow on outcrops and from vertical leakage of water through confining beds.

Within the basin, areas of stress from ground-water development in the Gallup Sandstone are localized and generally represent areas of withdrawals for municipal supplies. Sufficient data do not exist to allow an estimate of water levels for predevelopment conditions. The water levels in figure 7 are shown, along with year of measurement, to provide the reader with the latest data available. These data have not been contoured because they do not represent a specific time interval. Generalized ground-water gradients can be determined where sufficient data exist.

Transmissivity and storage-coefficient data for the Gallup Sandstone are available from drawdown and recovery tests conducted at 17 wells in the study area (Stone and others, 1983, table 5; U.S. Geological Survey files, Albuquerque, New Mexico). Values of transmissivity range from 15 to 390 feet squared per day; the median is 123 feet squared per day. Values of storage coefficient calculated from aquifer tests at four wells range from 0.000002 to 0.000033. The values of transmissivity and storage coefficient are shown in figure 8.

The reported or measured discharge from 32 water wells completed in the Gallup Sandstone ranges from 1 to 645 gallons per minute and the median is 30 gallons per minute. The specific capacity of 13 of these wells ranges from 0.12 to 2.10 gallons per minute per foot of drawdown and the median is 0.46 gallon per minute per foot of drawdown. These data are shown in figure 9.

The location of eight selected water wells that derive water only from the Gallup Sandstone and that have four or more water-level measurements is shown in figure 10. Reference numbers in figure 10 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. The water-level hydrographs for these eight wells show both short- and long-term changes in water level. Short-term fluctuations primarily result from periodic changes in discharge from wells and from seasonal changes in recharge. Long-term changes primarily result from prolonged ground-water discharge from wells, from discontinuation of discharge from wells, and from changes in rates of recharge due to climatic variations.

Most of the hydrographs show declines in potentiometric heads that have resulted from prolonged ground-water withdrawals for public water supplies. However, well 8 shows a rapid recovery in potentiometric head. A reduction in water quality was reported for this well in 1972 and, therefore, the discontinued or decreased withdrawal of water from this well and other nearby wells may have resulted in the increase in potentiometric head.

The hydrographs for wells 5, 6, and 7 show rapid fluctuations in potentiometric head caused by changes in rates of ground-water withdrawal. Well 7, located in the southeastern part of the study area, supplies an extensive (distances of as much as 15 air miles) network of livestock water tanks. This well is completed in or very near to one of the faults in the Puerco fault zone (fig. 2). Numerous faults occur between this well and the outcrop area of the Gallup Sandstone about 3 miles to the southeast. The altitude of the outcrop area is about 5,900 feet above sea level; therefore the loss in potentiometric head from well 7 to the outcrop is about 400 feet. A test well (SITE ID 353458107132201) was drilled in October 1987 to better define the potentiometric heads in the Gallup Sandstone in this part of the study area. The test well is located about 1 mile northwest of well 7 and on the basinward side of the Puerco fault zone. The potentiometric head in the test well has remained virtually constant at about 6,500 feet above sea level (fig. 7), about 200 feet higher than in well 7. Because the test well is located northwest of the fault zone, the potentiometric head probably is more representative of the potentiometric head in the Gallup Sandstone in the southeastern part of the study area.

QUALITY OF WATER FROM THE GALLUP SANDSTONE

Physical and chemical data used to describe the quality of water in the Gallup Sandstone are available for 1948 to 1986. These data are stored in the NWIS and Petroleum Information Corporation's data bases. The number of samples, minimum, maximum, and median values for selected water-quality properties and constituents are listed in table 1. The temperature data shown in figure 11 are from selected water wells and oil or gas test holes. The temperature of ground water is variable (table 1 and fig. 11). Temperature of water from 51 water wells, which ranged from 6.5 to 39.0 degrees Celsius, is the temperature in shallower parts of the basin. Temperature of water from three oil or gas test holes, which ranged from 28 to 58 degrees Celsius, represents bottom-hole temperatures measured during drill-stem tests.

Selected primary drinking-water standards are shown in table 2 (U.S. Environmental Protection Agency, 1986a). Two of 72 samples contained fluoride concentrations greater than the primary drinking-water standard of 4 milligrams per liter. All samples analyzed for nitrate concentration were less than the drinking-water standard of 10 milligrams per liter as nitrogen (tables 1 and 2).

Secondary drinking-water standards are shown in table 3 (U.S. Environmental Protection Agency, 1986b). Values of specific conductance and pH are shown in figure 12. Water from 57 wells was analyzed for pH and selected data are plotted on figure 12. The pH of 10 samples exceeded the secondary drinking-water standard of 8.5 pH units (table 3).

The concentrations of dissolved sulfate exceeded the secondary drinking-water standard of 250 milligrams per liter (table 3) in 48 of 77 samples; the median value (table 1) is greater than the standard. Concentrations of dissolved chloride generally are small; however, in one sample chloride exceeded the standard of 250 milligrams per liter. The secondary standard for fluoride of 2 milligrams per liter (table 3) was exceeded in 10 of 72 samples. Concentrations of dissolved solids generally are large; the standard of 500 milligrams per liter was exceeded in 56 of 75 samples.

The concentration of dissolved solids in water from the Gallup Sandstone ranged from 210 to 6,000 milligrams per liter (table 1). Concentrations of dissolved solids are shown in figure 13. The specific conductance of water can be easily measured at a sampling site. Measurements of specific conductance can be used to estimate dissolved-solids concentrations because specific conductance correlates with the dissolved-solids concentration (Hem, 1985, p. 67). Approximate values of dissolved-solids concentrations can be determined by multiplying the specific conductance by 0.67, an average ratio of dissolved solids to specific conductance derived from values for 75 samples.

The distribution of chemical constituents dissolved in water is shown in figure 14. Sodium and sulfate are the predominant ions in most of the water samples from the Gallup Sandstone.

Water from the Gallup generally is hard to very hard. Hardness, expressed as an equivalent quantity of calcium carbonate, is classified as very hard if water contains more than 180 milligrams per liter of calcium carbonate (Durfor and Becker, 1964, p. 27); 39 percent of the samples were classified as very hard water.

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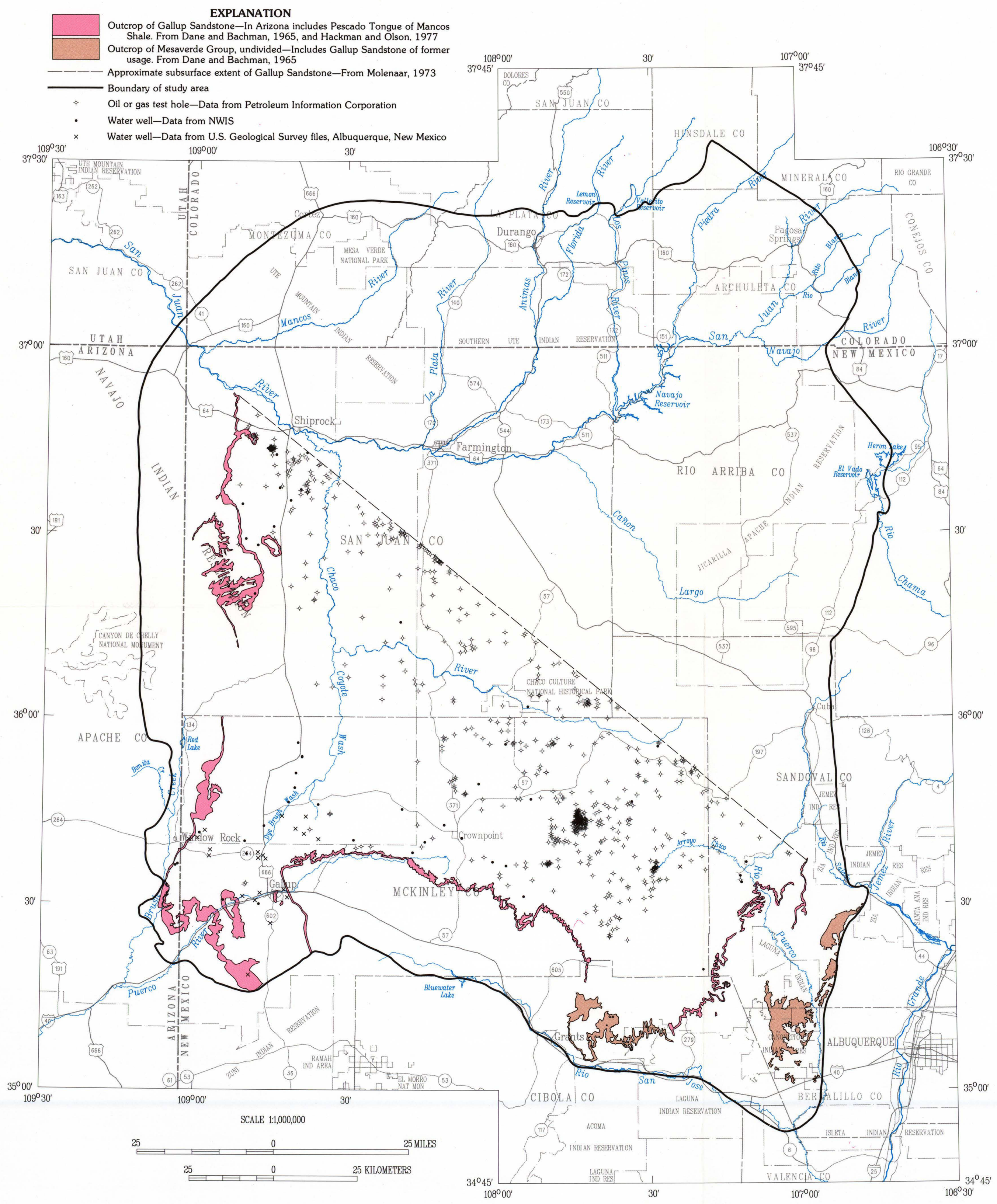

Figure 4. Location of oil or gas test holes and water wells used to compile depth to and altitude of the top of the Gallup Sandstone.

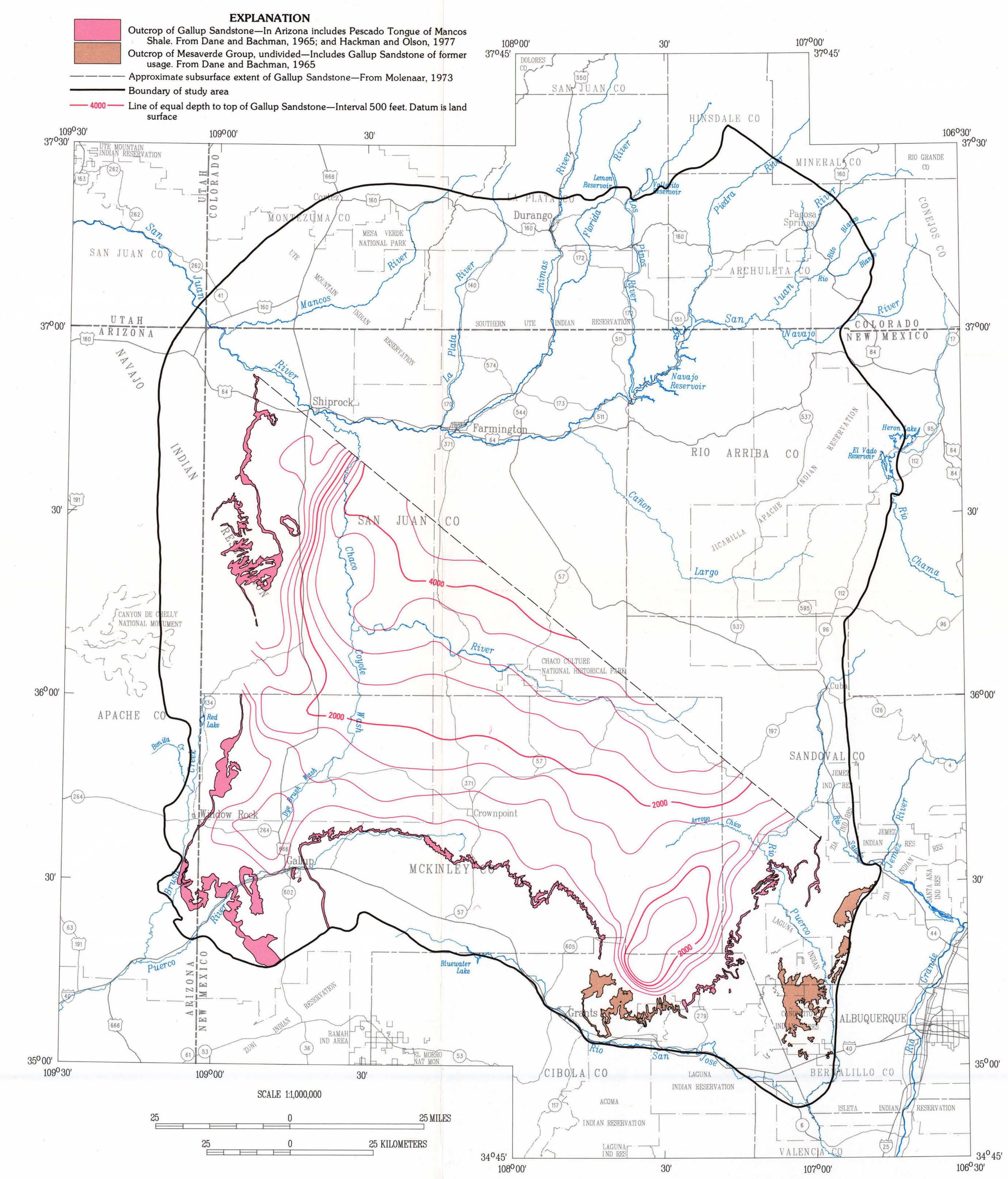

Figure 5. Approximate depth to the top of the Gallup Sandstone.

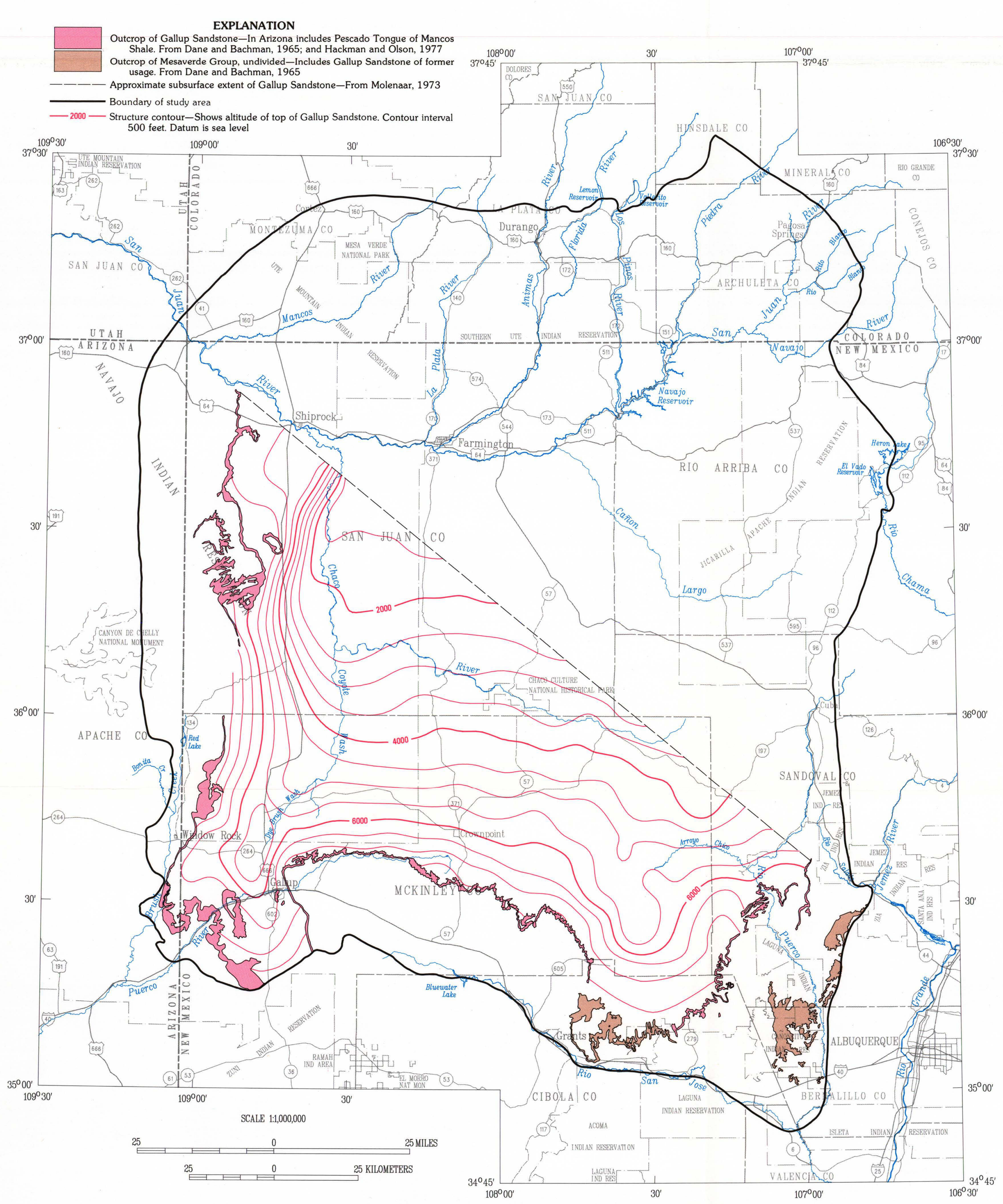

Figure 6. Approximate altitude and configuration of the top of the Gallup Sandstone.

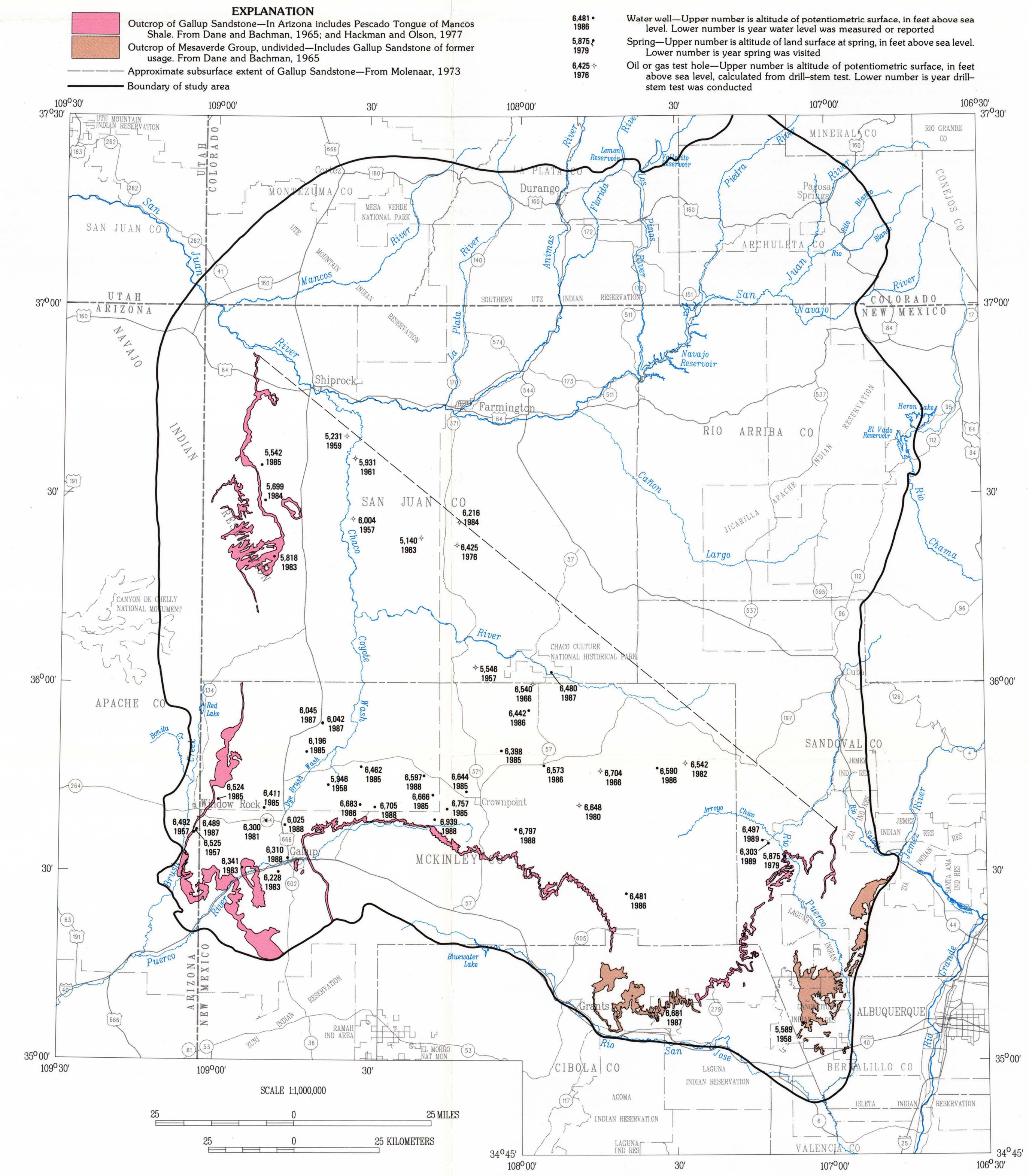

Figure 7. Altitude of potentiometric surface of water in the Gallup Sandstone at selected water wells, springs, and oil or gas test holes.

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

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

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1989

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