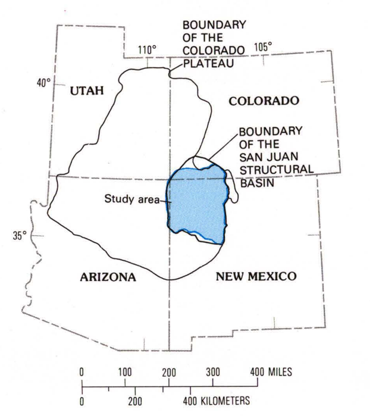


Figure 1. Location of San Juan structural basin, Colorado Plateau, and study area.

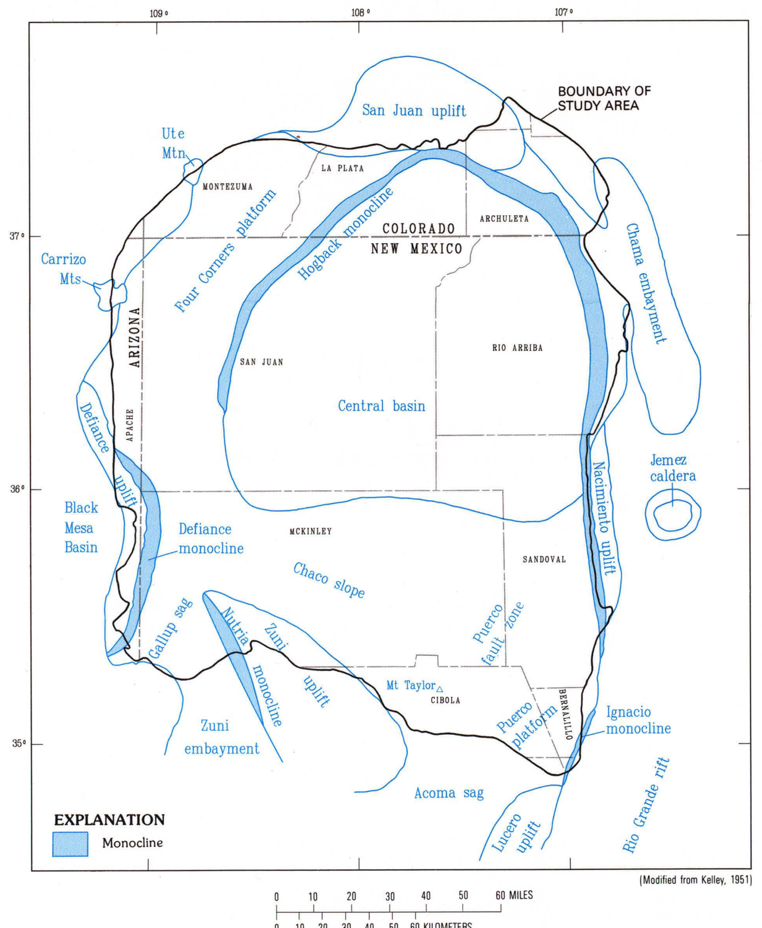
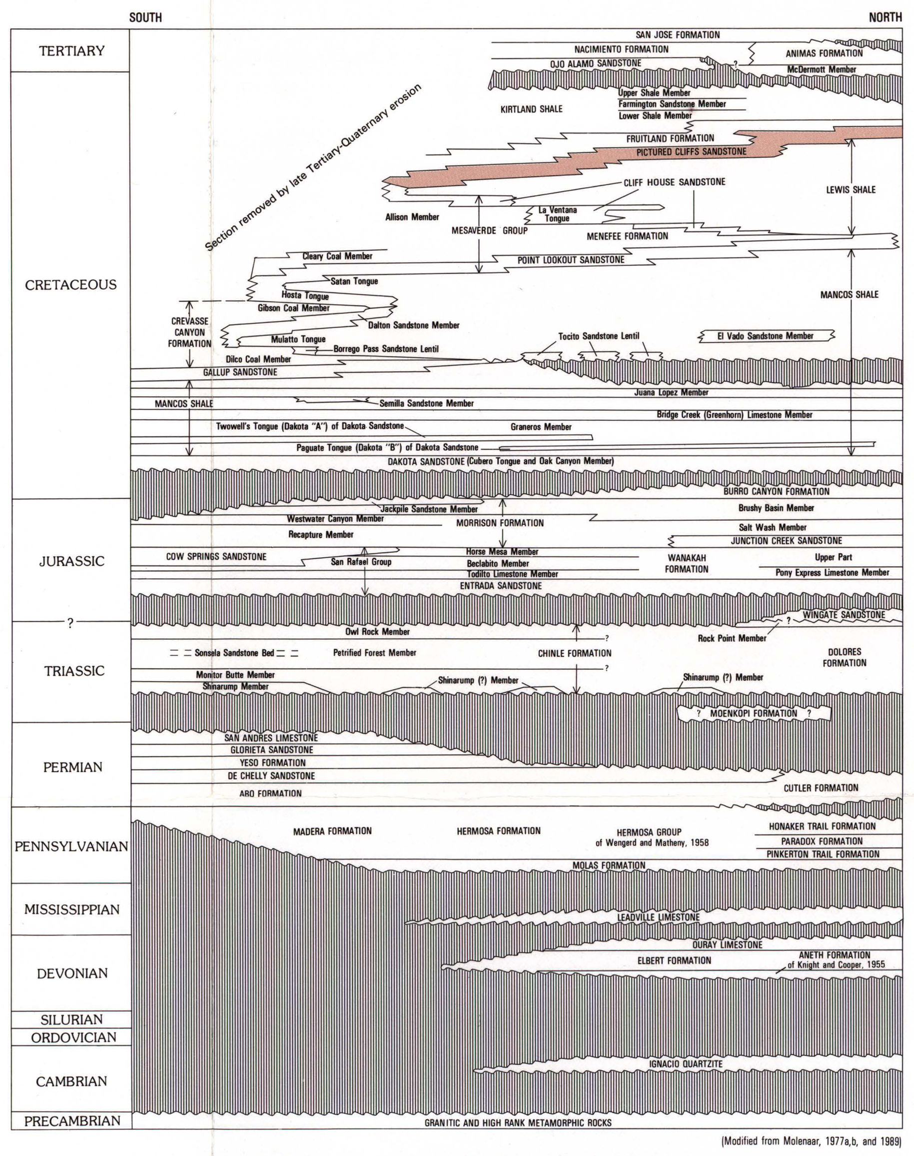


Figure 2. Structural elements of the San Juan structural basin and adjacent areas.



(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	25.40	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."

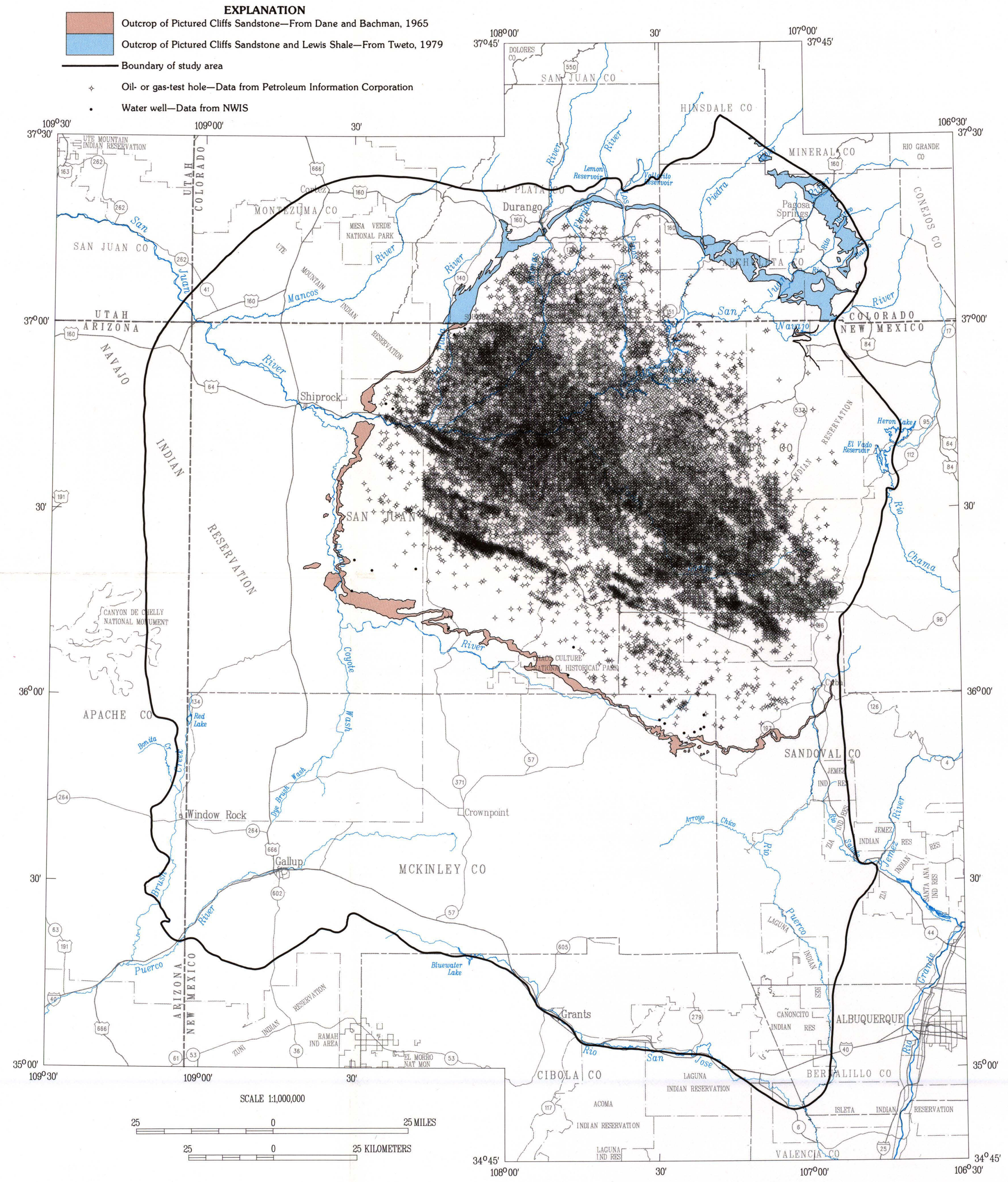


Figure 4. Location of oil- or gas-test holes and water wells used to compile depth to and altitude of the top of the Pictured Cliffs Sandstone.

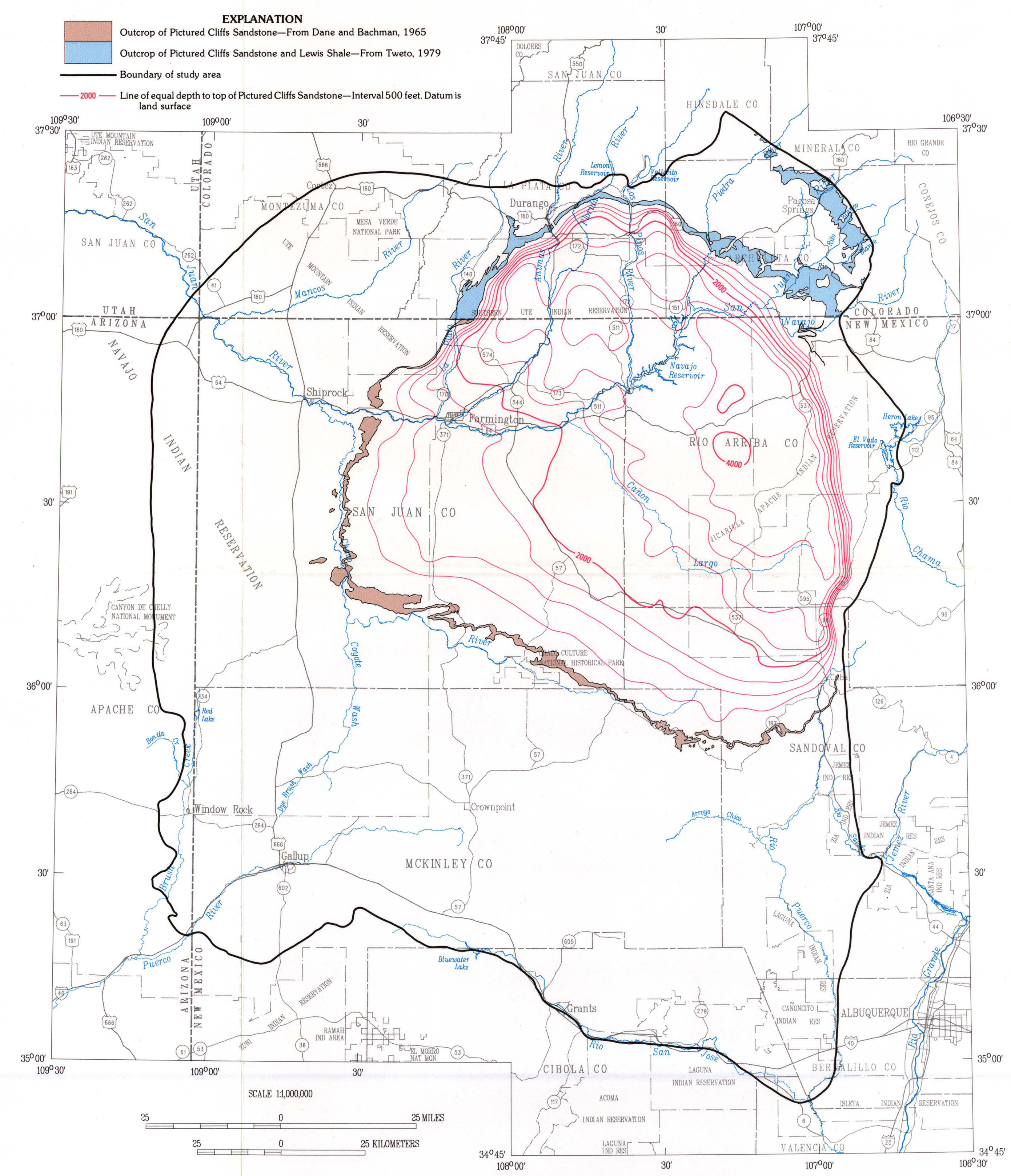


Figure 5. Approximate depth to the top of the Pictured Cliffs Sandstone.

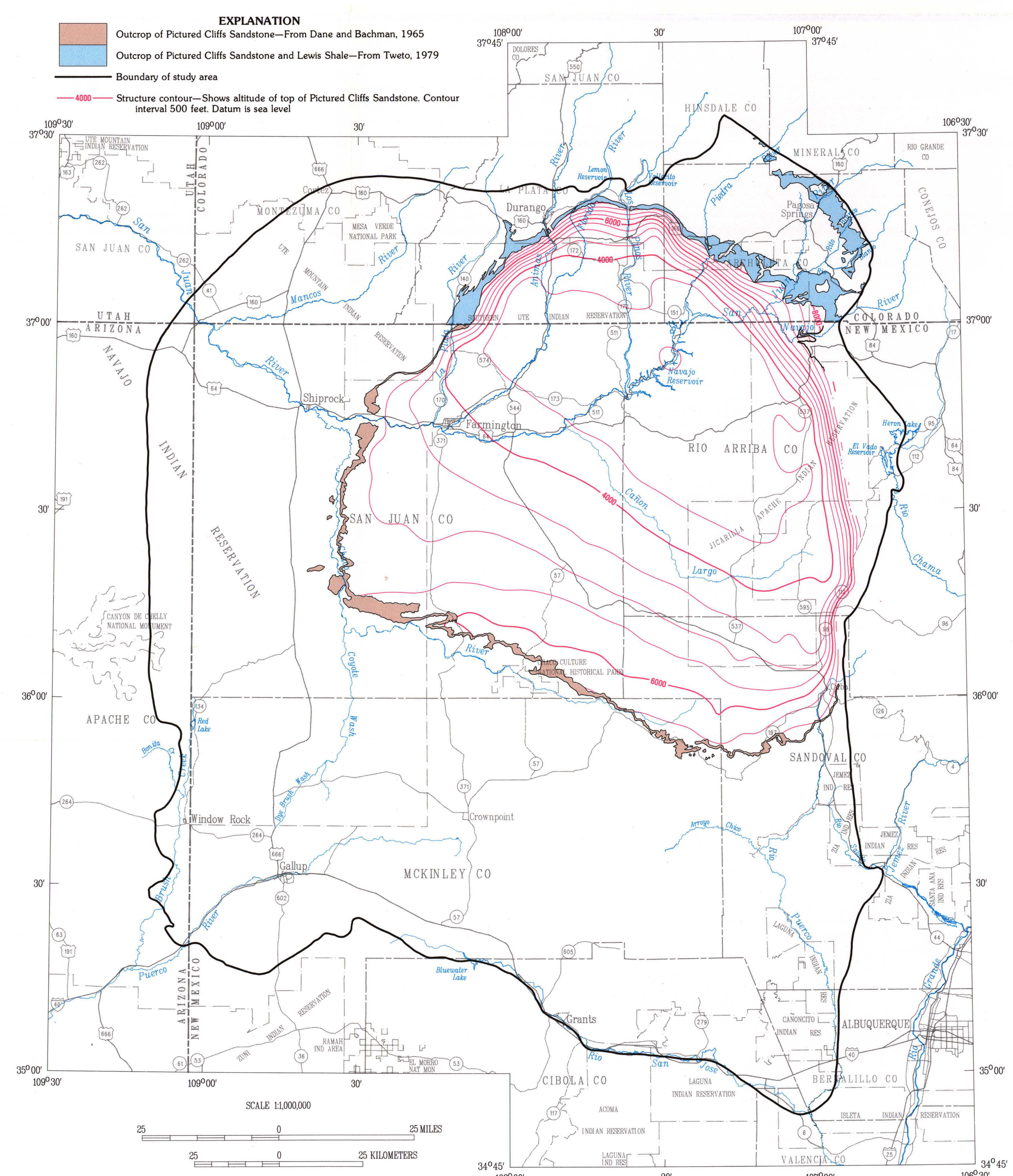


Figure 6. Approximate altitude and configuration of the top of the Pictured Cliffs Sandstone.

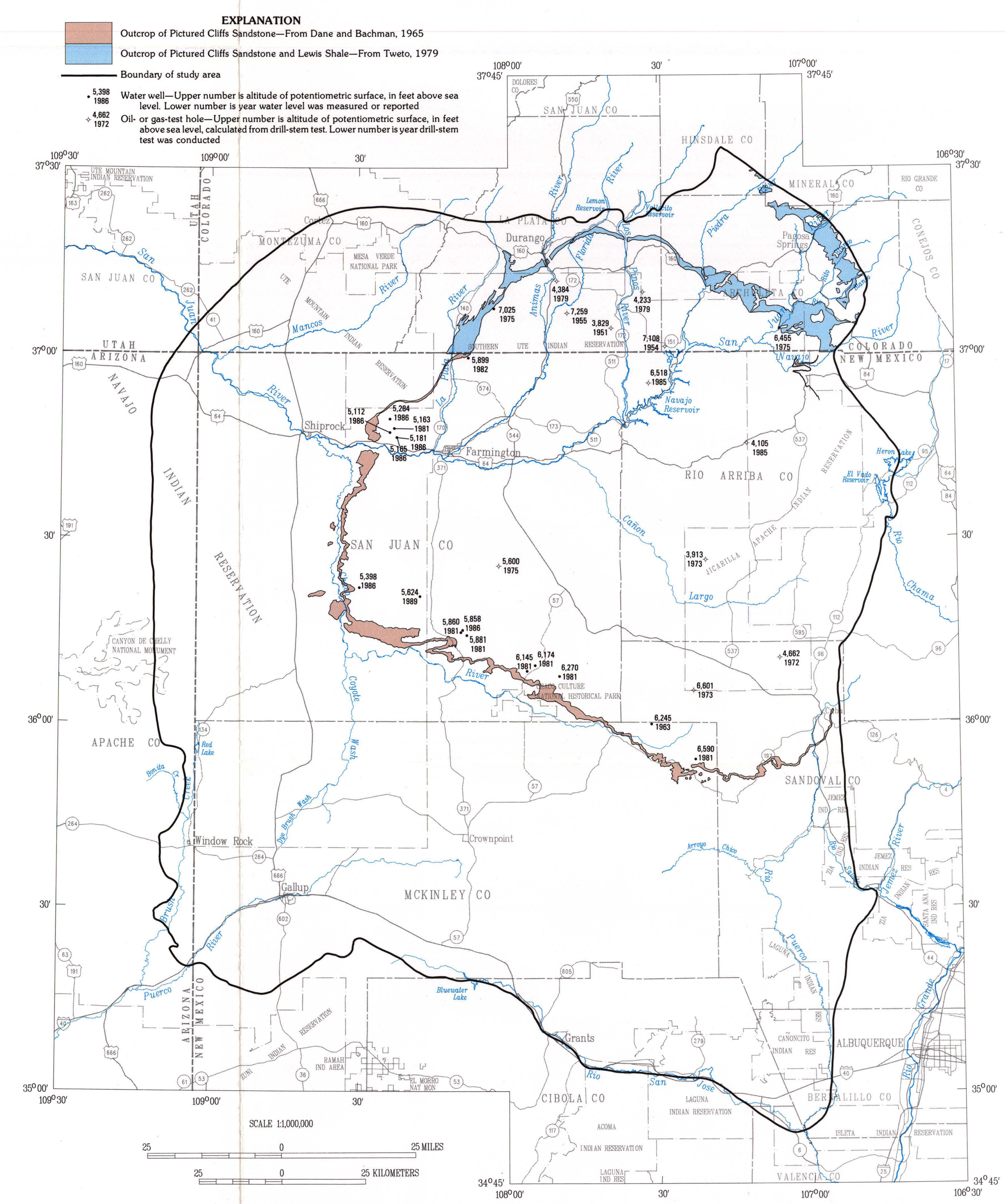


Figure 7. Altitude of potentiometric surface of the Pictured Cliffs Sandstone at selected water wells and oil- or gas-test holes.

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 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. Previous reports in this series describe the hydrogeology 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), Kirtland Shale and Fruitland Formation (Kernodle and others, 1990), Menefee Formation (Levings and others, 1990), Cliff House Sandstone (Thorn and others, 1990), and Ojo Alamo 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 Pictured Cliffs Sandstone, one of the primary water-bearing units in the regional aquifer system. Data used in this report were collected during the RASA study or 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 Pictured Cliffs 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 in New Mexico, Colorado, Arizona, and Utah 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 and younger age; therefore, the study area is less extensive than the structural basin. Triassic through Tertiary sedimentary rocks are emphasized in this study because these units are the major aquifers in the basin. 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. 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, whereas annual precipitation in the lower altitude, central basin is generally 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 declined to about 210,000 in 1985. The economy of the basin is supported by exploration 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 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) at the eastern edge of the Colorado Plateau (fig. 1). Structural boundaries of the basin are well defined in many places, whereas the basin merges gradually into adjacent depressions or uplifts in other areas (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 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 largely 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

The Pictured Cliffs Sandstone is of Late Cretaceous age. It crops out inside the margins of the central basin where it caps mesas and buttes or forms erosion-resistant dipslopes. The Pictured Cliffs Sandstone typically is a cliff former, except along the southern outcrop belt, where commonly the only way to determine its presence is by drilling. The Pictured Cliffs Sandstone was named by Holmes (1877, p. 248) for exposures near the San Juan River, between Shiprock and Farmington, New Mexico.

The Pictured Cliffs Sandstone is a regressive marine coastal-barrier deposit (Molenaar, 1977b, p. 165). It conformably overlies the Lewis Shale (fig. 3). The contact is characterized by a distinct offshore marine transition zone consisting of interbedded thin sandstones, siltstones, and shales (Reeside, 1924, p. 19; Fassett and Hinds, 1971, p. 8). The Fruitland Formation (Late Cretaceous) conformably overlies the Pictured Cliffs, and intertonguing locally occurs between these two units (Fassett and Hinds, 1971, p. 8).

The Pictured Cliffs Sandstone generally consists of an upward-coarsening sequence of light-gray to yellowish-gray, thick- to very thick bedded, very fine to medium-grained, locally crossbedded and bioturbated sandstone. Thin interbeds of dark marine shale also are present, especially in the lower part of the unit (Baltz, 1967, p. 17–18; Fassett and Hinds, 1971, p. 8).

Thickness of the Pictured Cliffs Sandstone is variable. Molenaar (1977a) reported a maximum thickness of 400 feet, but also reported (1977b, p. 165) that the average thickness is much less. Fassett and Hinds (1971, p. 17) stated that thickness ranges from 0 feet on the east side of the San Juan structural basin to about 400 feet in the north-central part of the basin. Stone and others (1983, p. 33) reported a range in thickness of 25 to 280 feet in New Mexico.

Data used to compute the depth to and the altitude of the top of the Pictured Cliffs Sandstone were obtained primarily from oil- or gas- test holes from the Petroleum Information Corporation's data base with supplemental information about 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 Pictured Cliffs Sandstone ranges from zero in areas of outcrop to more than 4,000 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 Pictured Cliffs Sandstone, the datum used is sea level.

The configuration of the top of the Pictured Cliffs Sandstone is shown on the structure-contour map (fig. 6). The overall structural pattern of that part of the basin underlain by the Pictured Cliffs Sandstone also is shown in figure 6. The top of the Pictured Cliffs Sandstone decreases from a maximum altitude of about 8,000 feet above sea level along the north-central basin margin to about 3,000 feet above sea level in the northeastern part of the study area.

GROUND WATER

The Pictured Cliffs Sandstone is a source of water for livestock 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. The Pictured Cliffs is a major gas-producing reservoir in parts of the basin. Water is produced as a secondary product from these gas wells, but the quality generally is not acceptable for livestock use and is either reinjected, as a means of disposal or for maintenance of reservoir pressures, or is evaporated from disposal ponds. Water from oil or gas wells producing from other geologic units is also disposed of in the Pictured Cliffs.

The altitude of the potentiometric surface of the Pictured Cliffs Sandstone at selected water wells 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 Pictured Cliffs Sandstone. The water-well data were collected from 1963 to 1989. 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 1951 to 1985; the data were obtained from Petroleum Information Corporation. Drill-stem tests were selected for analysis if the length of time allowed for shut-in pressures to stabilize was greater than 1 hour.

The object of the 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:

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

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 is based on the assumption that the water is pure water at a temperature of 4 degrees Celsius with a density of 1.0 gram per cubic centimeter.

Water in the Pictured Cliffs Sandstone occurs under both water-table and artesian conditions. 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.

Water from the Pictured Cliffs Sandstone is primarily used for livestock consumption. As a result, no areas of ground-water-level decline are known to exist. The water levels in figure 7 are shown, along with year of measurement, to provide the reader with the most recent data available. General ground-water gradients may be determined for localized areas if sufficient data exist.

Reported transmissivity and hydraulic-conductivity data for the Pictured Cliffs Sandstone are few. The range of transmissivity from five tests is 0.001 to 3 feet squared per day (Stone and others, 1983, table 5). The hydraulic-conductivity values calculated from oil and gas wells in deeper parts of the basin average 0.007 foot per day (Reneau and Harris, 1957).

The reported or measured discharge from 12 water wells completed in the Pictured Cliffs Sandstone ranges from 1 to 20 gallons per minute and the median is 1 gallon per minute. The specific capacity of seven of these wells ranges from less than 0.01 to 0.70 gallon per minute per foot of drawdown and the median is 0.01 gallon per minute per foot of drawdown. The distribution of these data is shown in figure 8.

The location of six selected water wells that derive water only from the Pictured Cliffs Sandstone and that have four or more water-level measurements is shown in figure 9. Reference numbers on 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. The water-level hydrographs for these wells show only short-term changes in water level even though the period of record is as much as 38 years for one of the wells. Short-term fluctuations primarily result from periodic changes in discharge from wells and from seasonal changes in recharge. Long-term changes primarily would 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.

Five of the six wells for which hydrographs are shown were test wells completed as water-level observation wells. Only one well, number 3, was completed as a production well. The tested production rate of water from the observation wells ranges from 0.14 to 0.73 gallon per minute and the specific capacities are all less than 0.01 gallon per minute per foot of drawdown. As a result, water levels in the observation wells respond slowly to local and regional water-level changes in the aquifer. In contrast, well 3, which is used to supply water for livestock use, is reported to yield about 10 gallons per minute and have a specific capacity of 0.02 gallon per minute per foot of drawdown. Water levels in this well fluctuate rapidly over a range of almost 100 feet, depending on withdrawals; however, there does not appear to have been a long-term change in water level.

WATER QUALITY

Water-quality data collected during 1951–80 and discussed in the following section are from the NWIS, Petroleum Information Corporation, and Dwight's ENERGYDATA Inc. BRIN data bases. Distribution of data from water wells reflects their location near the outcrop where drilling depth is economically feasible. However, the distribution of data from oil- or gas-test holes is primarily in the deeper parts of the basin. Well records were checked to assure, to the extent possible, that a particular sample represents water only from the Pictured Cliffs Sandstone and not a mixture of water from other aquifers. In some instances the density of data was too great to display for a single well, test holes, or group of closely spaced wells, in which case the most recent analysis was chosen to be shown on the illustrations. Selected water-quality properties and constituents are presented in table 1; the calculation of the minimum, maximum, and median concentrations was performed using the most recent analysis from wells that had multiple analyses.

Temperature data are displayed in figure 10 and presented in table 1. Most of the temperature data are from water wells drilled where the Pictured Cliffs Sandstone crops out within the basin. Bottom-hole temperatures obtained during a drill-stem test on three oil- or gas-test holes in the eastern part of the basin also are shown in figure 10.

Selected secondary (nonenforced contaminant level) drinking-water standards are shown in table 2 (U.S. Environmental Protection Agency, 1986b); these standards have all been exceeded as shown by the maximum concentrations listed in table 1. The secondary drinking-water standard for pH is exceeded by 7 of 30 samples (23 percent, table 2). Sulfate concentration in 14 of 34 samples (41 percent) exceeded the sulfate standard. Concentrations of chloride, 26 of 35 samples (74 percent), and fluoride, 12 of 29 samples (41 percent), exceeded the secondary drinking-water standard. Fluoride concentrations in 2 of 29 samples (7 percent) exceeded the primary drinking-water standard of 4 milligrams per liter (U.S. Environmental Protection Agency, 1986a). Thirty of 31 samples (97 percent) had concentrations of dissolved solids exceeding the standard shown in table 3.

Chloride concentrations in samples from water wells and oil- or gas-test holes are shown in figure 11. Most samples from water wells were in the vicinity of the Pictured Cliffs Sandstone outcrop, except for four wells near the town of Farmington. A wide range of values exists with no discernible pattern of concentrations evident. The largest chloride concentration (47,000 milligrams per liter) was at an oil- or gas-test hole in the central part of the basin adjacent to the Rio Arriba-San Juan County line. The smallest concentrations of chloride (less than 100 milligrams per liter) were near the southern, northwestern, and western outcrop areas.

Dissolved-solids concentrations in samples from water wells and from oil- or gas-test holes are shown in figure 12. Dissolved-solids concentration of water from water wells was calculated from the summation of the major ion concentrations in the water. 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, 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 Pictured Cliffs Sandstone.

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 Pictured Cliffs Sandstone can be estimated by multiplying the field-determined value of specific conductance by 0.61. This number represents the median value of the ratio of dissolved solids to specific conductance for samples from only the Pictured Cliffs Sandstone.

Chemical-constituent diagrams for water from the Pictured Cliffs Sandstone are shown in figure 13. Near outcrops, the concentrations of sodium, alkalinity, and sulfate are large relative to other constituents. Alkalinity of water from the Pictured Cliffs Sandstone is derived primarily from bicarbonate ions. Alkalinity is the capacity of the solution to neutralize a strong acid (Hem, 1985, p. 106). Downgradient from outcrop areas, the concentration of sodium and chloride ions is large. The prevailing water type was sodium bicarbonate in 7 wells and sodium chloride in 10 wells. Ion concentrations and water types were variable even within closely spaced water wells as shown in the areas north of Chaco Culture National Historical Park and east of Shiprock.

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

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

By
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Gary W. Levings, and Steven D. Craigg

1990

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