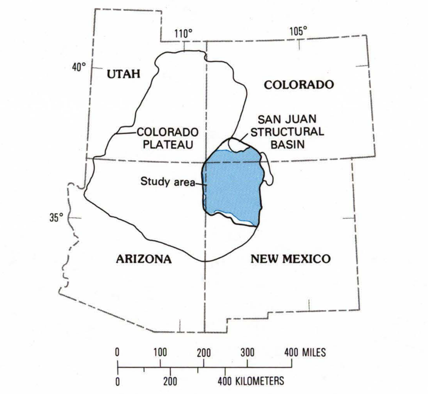


Figure 1. Location of San Juan structural basin and study area.

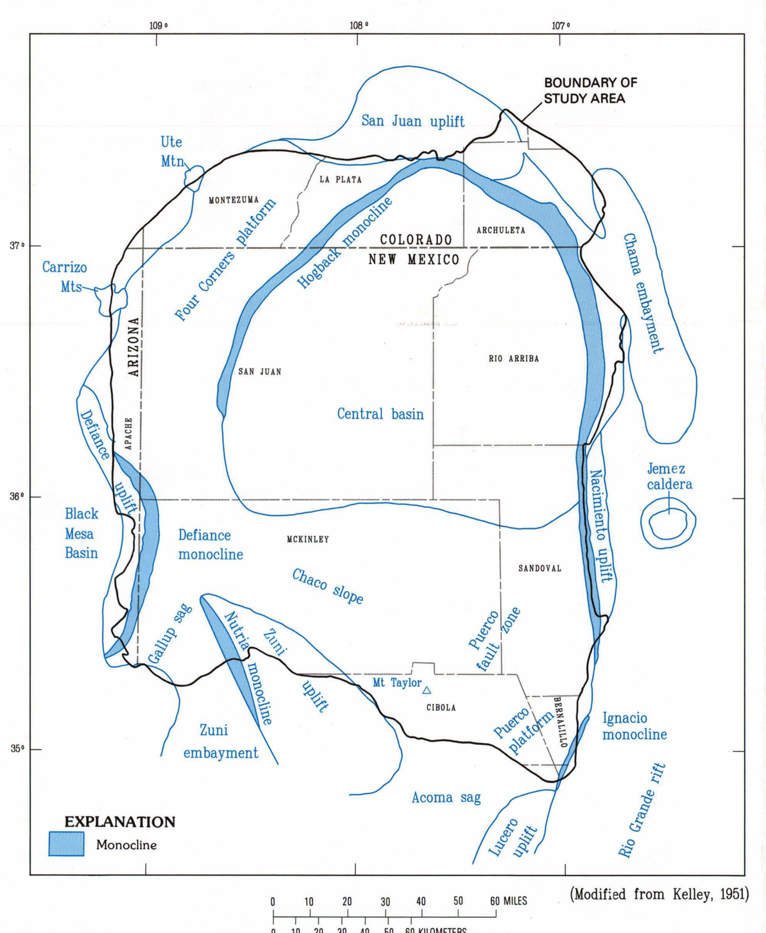
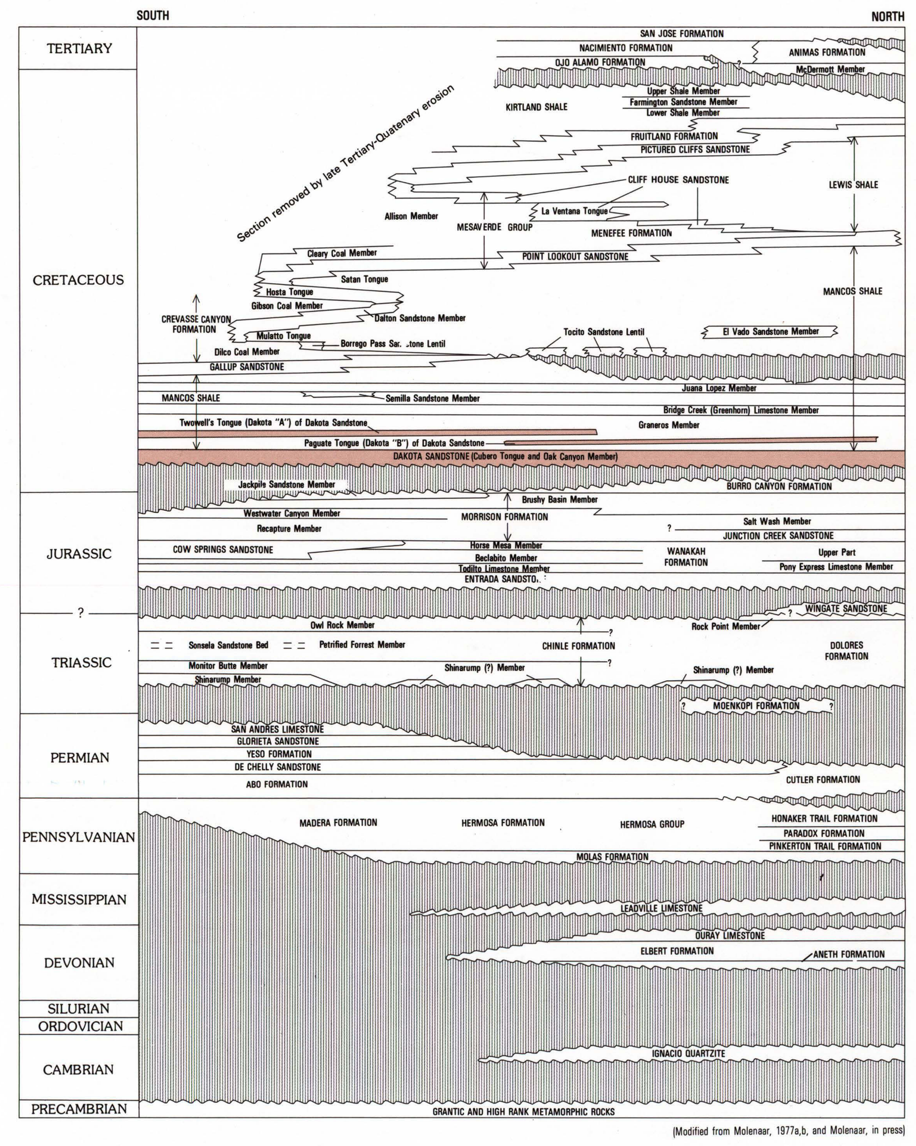


Figure 2. Structural elements of the San Juan structural basin and adjacent areas.



(Modified from Molenaar, 1977a,b, and Molenaar, in press)

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—a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called "Mean Sea Level."

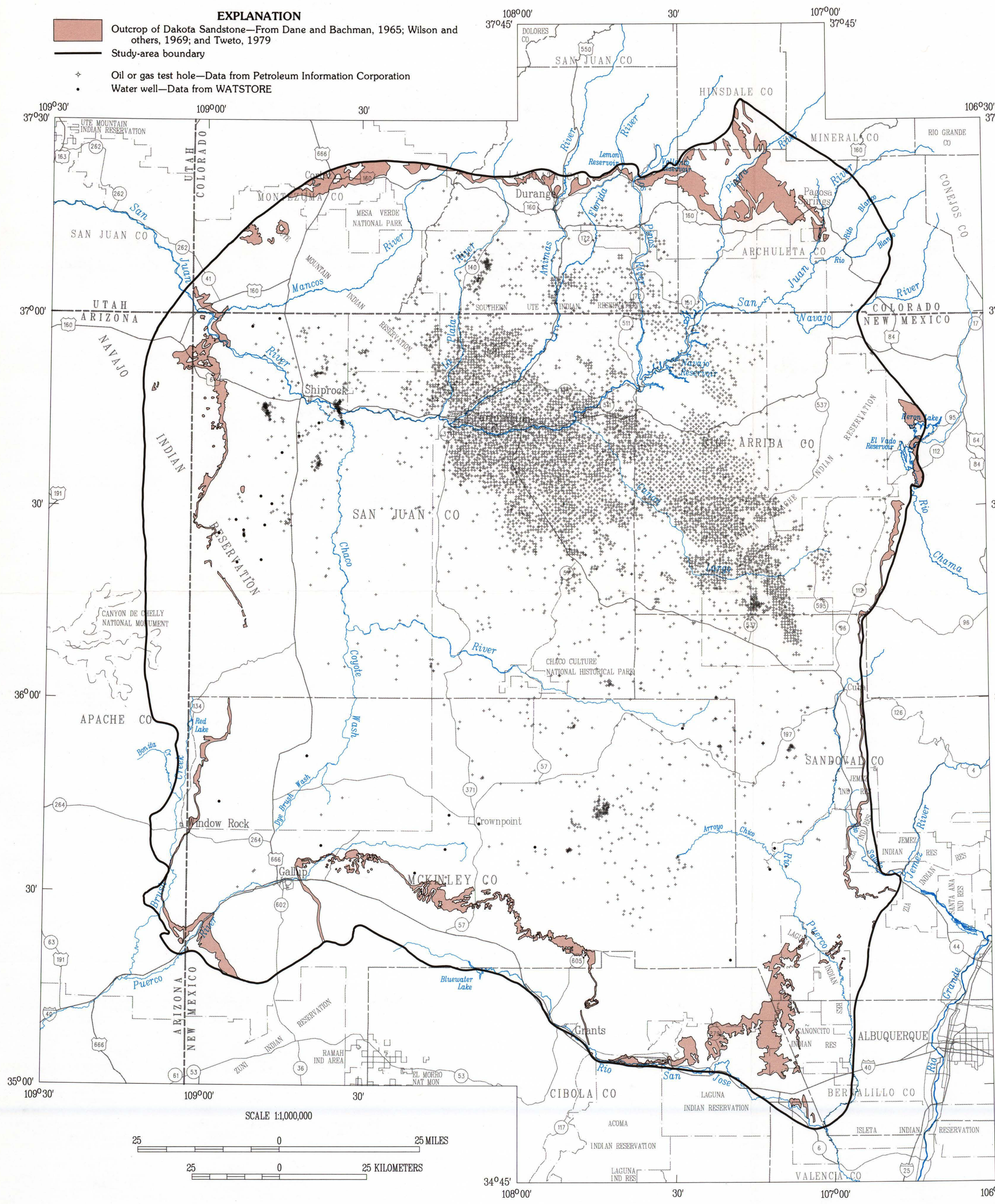


Figure 4. Location of oil or gas test holes and water wells used to compile depth to and altitude of top of the Dakota Sandstone.

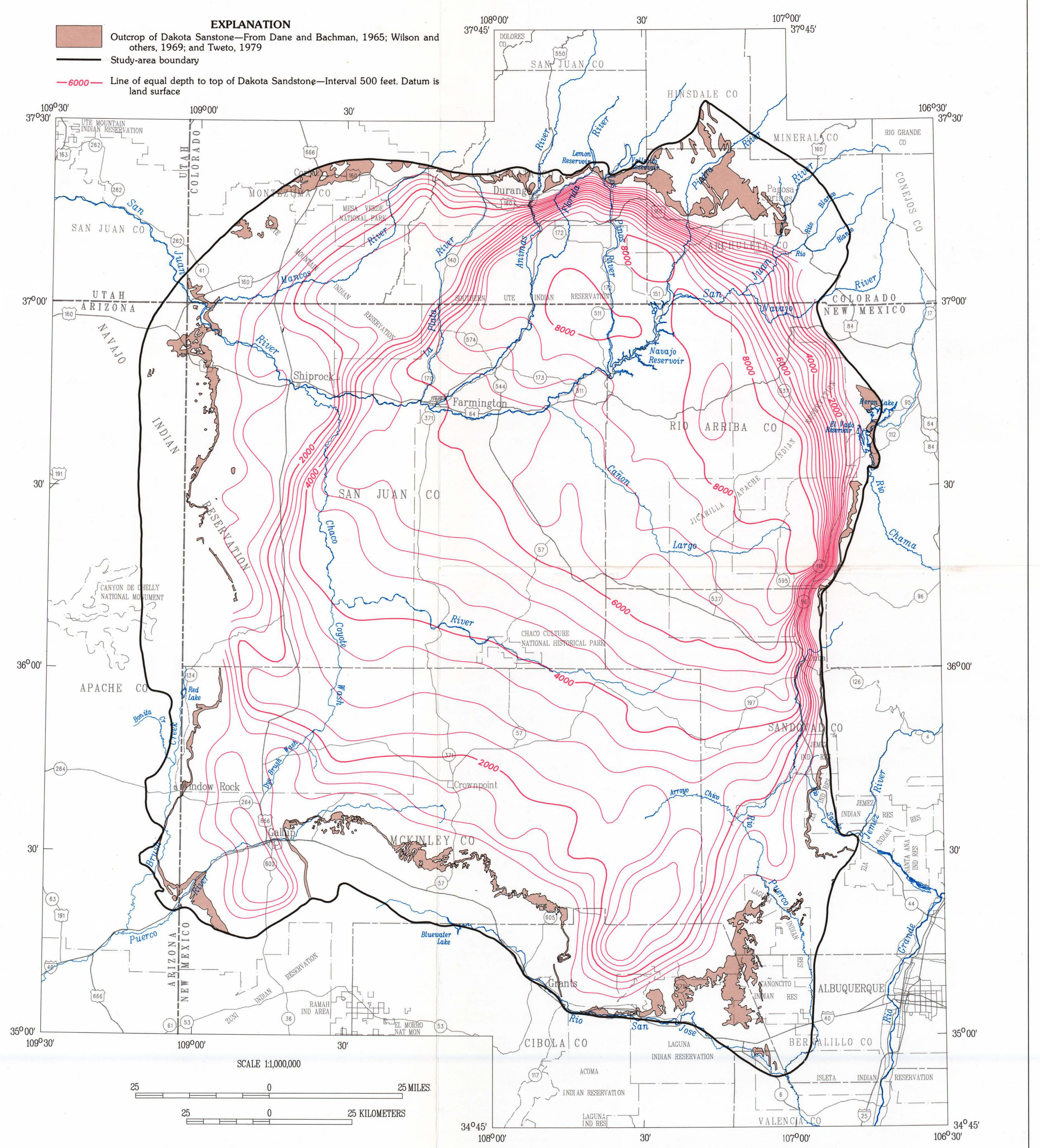


Figure 5. Approximate depth to the top of the Dakota Sandstone.

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.

This report summarizes knowledge about the hydrogeology of the Dakota 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 Water-Data Storage and Retrieval System (WATSTORE) data base, and the Petroleum Information Corporation's data base. All data available for the Dakota 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 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 ranges from 20 to 30 inches, whereas annual precipitation in the lower altitude, Central basin is 8 or fewer 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 of Laramide (Late Cretaceous-early Tertiary) age at the eastern edge of the Colorado Plateau (fig. 1). Structural boundaries of the basin are well defined in many places, whereas in other places, 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 defined by Kelley (1951, p. 124–127). 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 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 DAKOTA SANDSTONE

The Dakota Sandstone generally is thought to be of earliest Late Cretaceous age, although the lowermost part may be of latest Early Cretaceous age (Fassett, 1977, p. 225). The Dakota Sandstone crops out around the basin margins where it typically caps mesas and forms erosion-resistant dip slopes and hogbacks.

The Dakota Sandstone in the San Juan structural basin and vicinity was deposited on a regional erosion surface; the strata represent a transition from continental alluvial-plain deposition in the lower part of the formation to marine shorezone deposition in the upper part. Owen (1973, p. 39–50) presented a comprehensive depositional model for the Dakota Sandstone in the area of the San Juan structural basin.

The Dakota Sandstone unconformably overlies the Brushy Basin Member of the Morrison Formation (Late Jurassic age) throughout much of the basin. However, the Dakota overlies the Westwater Canyon Member of the Morrison in the southwest and the Burro Canyon Formation (Early Cretaceous) in the north (fig. 3). The upper contact of the Dakota is conformable with the Mancos Shale and intertonguing of these two units is common near the contact.

Stratigraphy of the Dakota Sandstone is complex. The unit consists of a main sandstone body in the north from which branch various members and tongues depending on location in the San Juan structural basin. The Dakota consists of four members (Landis and others, 1973; Owen, 1973), which, in ascending order, are the Oak Canyon Member, Cubero Tongue, Paguate Tongue, and Twowells Tongue (fig. 3). The two upper sandstone members intertongue with the Graneros Member of the Mancos Shale. Owen and Siemers (1977) and Noon (1980) have attempted to extend these members in the east part of the basin. Petroleum geologists have applied informal terminology to some of the tongues of the Dakota Sandstone, such as "Dakota A" for the Twowells Tongue, and "Dakota B" for the Paguate Tongue (fig. 3).

The Dakota Sandstone contains three principal lithologies. It typically consists of a sequence of buff to brown, cross-bedded, poorly sorted, coarse-grained conglomeratic sandstone and moderately sorted, medium-grained sandstone in the lower part; dark-gray carbonaceous shale with brown siltstone and lenticular sandstone beds in the middle part; and yellowish-tan, fine-grained sandstone interbedded with gray shale in the upper part (fig. 3; Owen, 1973, p. 39–48; Merrick, 1980, p. 45–47).

Thickness of the Dakota Sandstone generally ranges from a few tens of feet to about 500 feet; Stone and others (1983, p. 37), reported that 200 to 300 feet probably is a more common range. Data reported by Stone and others (1983, fig. 66) and Molenaar (1977b, p. 160–161), and data obtained from Petroleum Information Corporation indicate that the thickness of the Dakota generally increases from the west, northwest, and north margins of the basin toward the south, southeast, and east margins.

Data used to compute the depth to and the altitude of the top of the Dakota 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 WATSTORE and from outcrop altitudes. The location of the test holes and wells is shown in figure 4. Because of few data in the southwest part of the area, depth to and altitude of the top of the Dakota were determined from a geologic and structure-contour map prepared by Hackman and Olson (1977).

Depth to the Dakota Sandstone ranges from zero in areas of outcrop to about 8,500 feet in the northeast part of the study area (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 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 Dakota Sandstone, the datum used is sea level.

The altitude and configuration of the top of the Dakota Sandstone is shown on the structure-contour map (fig. 6). Because the Dakota Sandstone also is a key marker bed in the San Juan structural basin, the overall structural pattern of the basin also is shown in figure 6. The top of the Dakota Sandstone decreases from a maximum altitude of about 8,500 feet above sea level along the northern basin margin to about 1,500 feet below sea level in the northeast part of the study area.

WATER IN THE DAKOTA SANDSTONE

The Dakota Sandstone is a source of water for domestic, livestock, and industrial supplies in areas where drilling depths and pumping levels are economically feasible, and where water quality is acceptable. Water wells generally are near the margins of the basin. In much of the rest of the basin, reserves of oil and gas are being produced from the Dakota. Many of the oil and gas production wells also produce water, but the quality is not acceptable for domestic and livestock supplies and most industrial use.

The altitude of the potentiometric surface of water in the Dakota Sandstone 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 these wells only derive water from the Dakota Sandstone. The water-well and spring data were collected from 1950 to 1987. 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 1952 to 1985; the data were obtained from Petroleum Information Corporation. Drill-stem tests were selected for analysis based on length of time for shut-in pressures.

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 Dakota 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 Dakota Sandstone are localized. These areas may represent oil or gas production, injection for disposal of brine, secondary recovery or re-pressurization of producing zones, or uranium-mine dewatering of the underlying Morrison Formation that induces downward flow in the Dakota. Sufficient data do not exist throughout the basin to show water levels for predevelopment conditions. 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 can be determined where sufficient data exist.

Transmissivity and hydraulic-conductivity data for the Dakota Sandstone are few. Transmissivity values of 44 and 85 feet squared per day were reported for aquifer tests northeast of Crownpoint, New Mexico (Dames and Moore, 1977, pls. 4 and 5). Another aquifer test east of Grants indicated a transmissivity of 2,000 feet squared per day (Risser and Lyford, 1983, p. 166). Hydraulic-conductivity values calculated from oil wells in deeper parts of the basin averaged 0.03 foot per day (Reneau and Harris, 1957, p. 43).

The reported or measured discharge from 29 water wells completed in the Dakota Sandstone ranges from 1 to 200 gallons per minute and the median is 13 gallons per minute. The specific capacity of 13 of these wells ranges from 0.03 to 3.67 gallons per minute per foot of drawdown and the median is 0.06 gallon per minute per foot of drawdown. The distribution of these data is shown in figure 8.

The location of eight selected water wells that derive water only from the Dakota Sandstone and that have four or more water-level measurements is shown in figure 9. The water-level hydrographs for these wells show 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 long-term climatic variations.

The three wells in Colorado are near the outcrop of the Dakota Sandstone. Water levels in these wells respond quickly to changes in recharge, which is a function of the precipitation and evapotranspiration. The hydrographs for these wells indicate that 1985 was a year of increased recharge. The long-term hydrograph for well 370410108583701 indicates that the increased recharge may be a major but infrequent event for that area.

The three wells clustered in the south-central part of the study area—wells 354158108125801, 354035108071801, and 353700107563901—are in an area where the Dakota Sandstone has for years been used for domestic and livestock water supplies. The hydrographs for these wells show a continual slow decline in water level resulting from the steady withdrawal of water from the aquifer.

The hydrograph for well 353642107110201 shows seasonal fluctuations in response to changes in discharge from the well. This well is away from the outcrop and in an area where there is minimal withdrawal of water from the Dakota Sandstone. The period of record is too short to reflect changes in recharge.

Well 351257107190901 is near the outcrop in the southeast part of the study area. The large variations in water level shown on the hydrograph are the result of nearby mining activity rather than changes in recharge rates.

QUALITY OF WATER FROM THE DAKOTA SANDSTONE

Water-quality data generally are available for water wells near outcrop areas; the data have been collected during the past 40 years. Most water wells completed in the Dakota Sandstone are used for domestic and livestock supplies (Stone and others, 1983, p. 38). Many wells completed in the Dakota Sandstone also are completed in the underlying Morrison Formation, which generally contains less mineralized water than does the Dakota Sandstone. All data were examined to assure that a particular sample represents water only from the Dakota Sandstone.

Specific conductance of sampled water from the Dakota Sandstone ranged from 347 to 12,100 microsiemens per centimeter at 25 degrees Celsius (fig. 10). The median specific conductance was 2,340 microsiemens per centimeter.

Values of pH ranged from 7.1 to 9.7 (fig. 10) with a median value of 8.3 for 28 measurements, indicating neutral to alkaline water. The range of pH in most ground water in the United States is from 6.0 to 8.5; values greater than 9.0 are known to occur but are unusual (Hem, 1985, p. 64). Water with a pH greater than 9.0 is undesirable for domestic or irrigation supplies (U.S. Environmental Protection Agency, 1976, p. 178–181). Eight pH values were greater than 8.5, of which two were greater than 9.0 (fig. 10).

The temperature of ground water is extremely variable (fig. 11). The data shown in figure 11 are from two sources, water wells and oil or gas test holes. Temperatures of water from the water wells ranged from 10.0 to 50.0 degrees Celsius and are representative of the formation temperature in shallower parts of the basin.

Data from the oil and gas test holes are bottom-hole temperatures generally measured during drill-stem tests. The accuracy of these data is unknown; however, they are the only data available in the deeper parts of the basin. The temperatures in oil or gas test holes ranged from 34 to 92 degrees Celsius.

Water from the Dakota Sandstone generally is a sodium sulfate or sodium bicarbonate type, as shown by chemical-constituent diagrams (fig. 12). Sodium is the dominant cation in water samples from all wells. Sulfate is the dominant anion except for samples from two wells north of the San Juan River in the northwest part of the basin and two wells in the south part in which bicarbonate is dominant (fig. 12). Sulfate concentrations exceeded the U.S. Environmental Protection Agency (1977b) recommended secondary maximum concentration level for drinking water (250 milligrams per liter) in water from 26 of 44 water wells throughout the basin (fig. 13).

Dissolved-fluoride concentrations ranged from 0.2 to 10.0 milligrams per liter (fig. 13). The median value was 1.1 milligrams per liter. Dissolved-fluoride concentrations generally are less than 2.0 milligrams per liter except for the northwestern part of the basin where concentrations range from 2.1 to 10.0 milligrams per liter (fig. 13). The primary (maximum permissible concentration) and secondary (recommended) drinking water standards for fluoride are 4.0 and 2.0 milligrams per liter, respectively (U.S. Environmental Protection Agency, 1986a, 1986b). Fluoride is toxic at concentrations between 5 and 10 milligrams per liter if consumed for a long time (Freeze and Cherry, 1979, p. 387).

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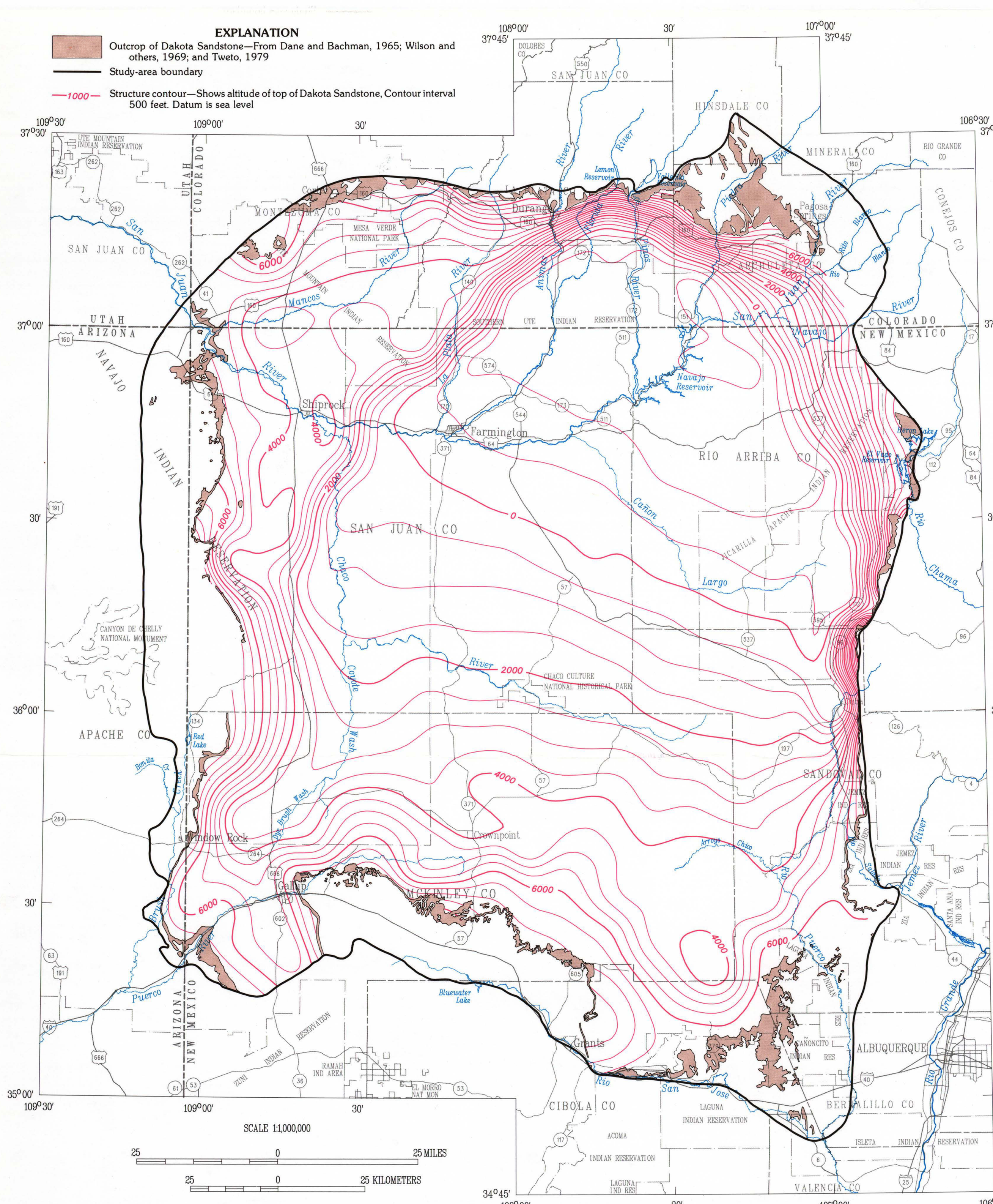

Figure 6. Approximate altitude and configuration of the top of the Dakota Sandstone.

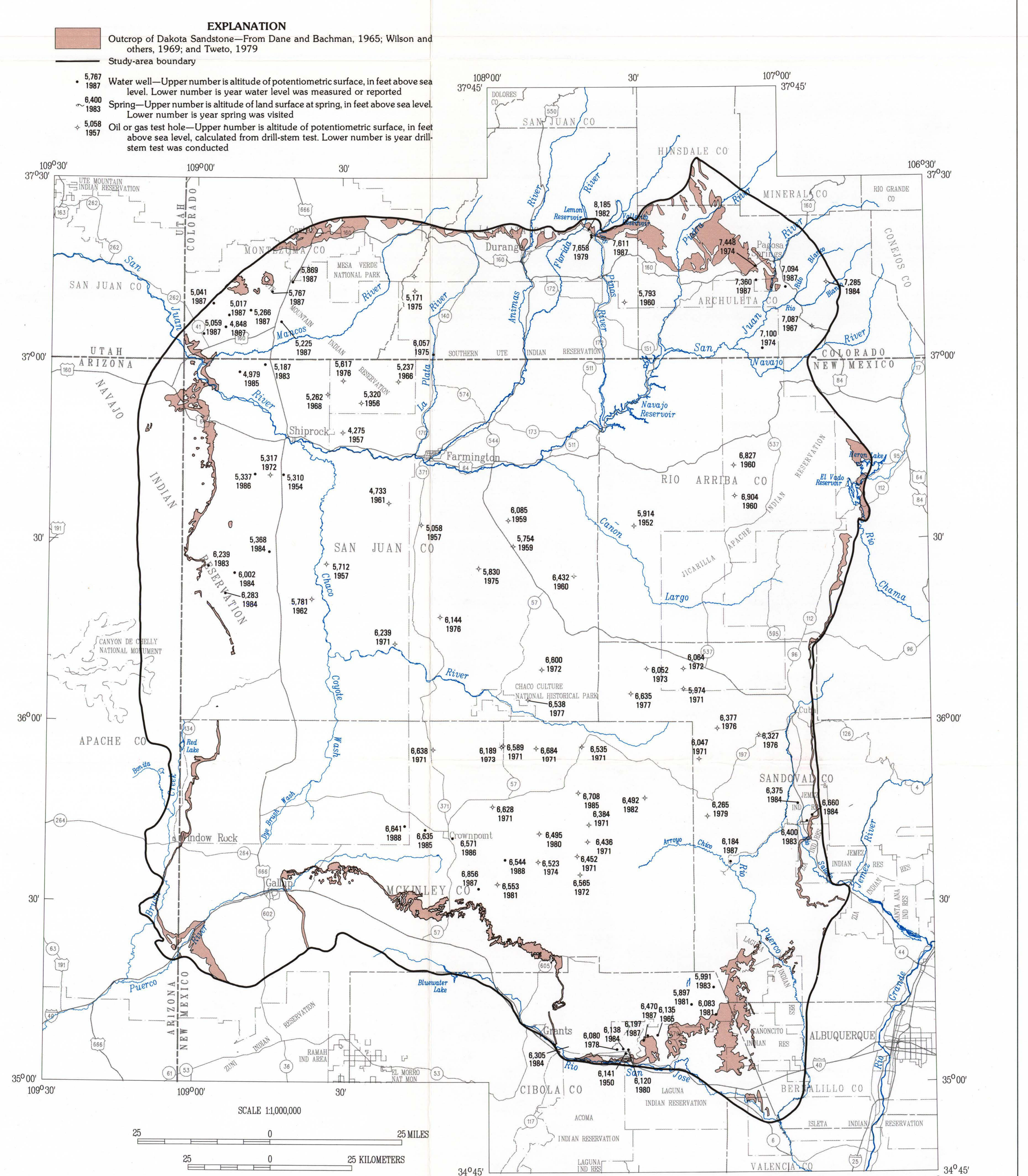

Figure 7. Altitude of potentiometric surface of water in the Dakota Sandstone at selected water wells, springs, and oil or gas test holes.

Base from U.S. Geological Survey

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

By
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