DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

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

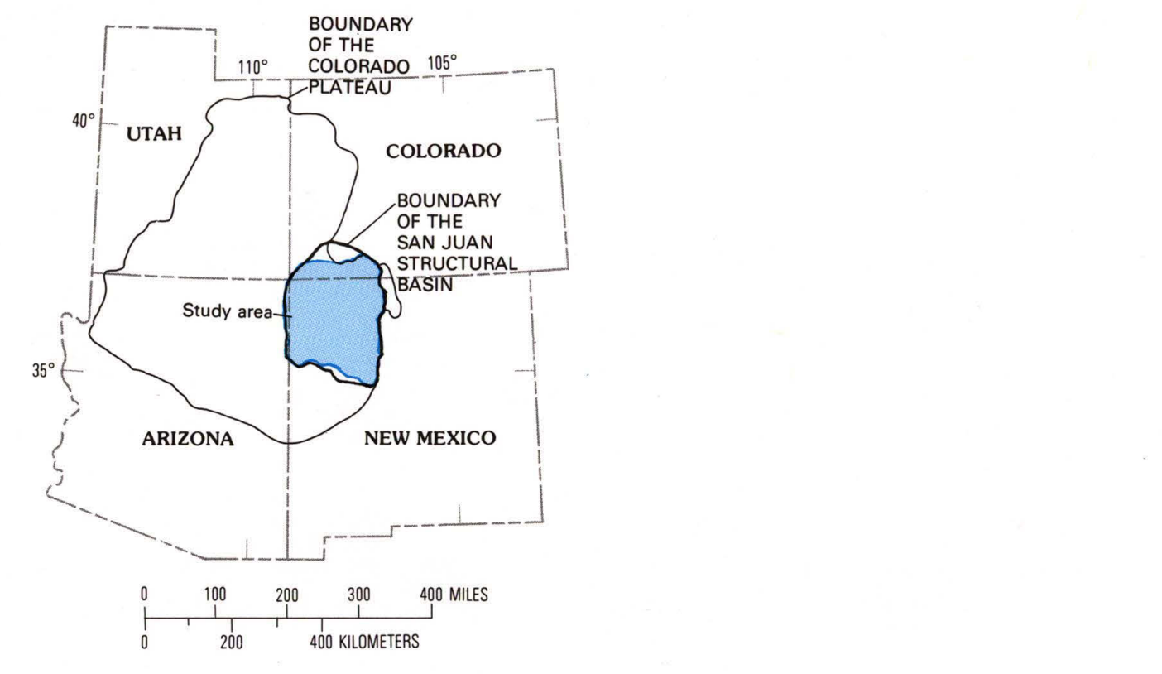
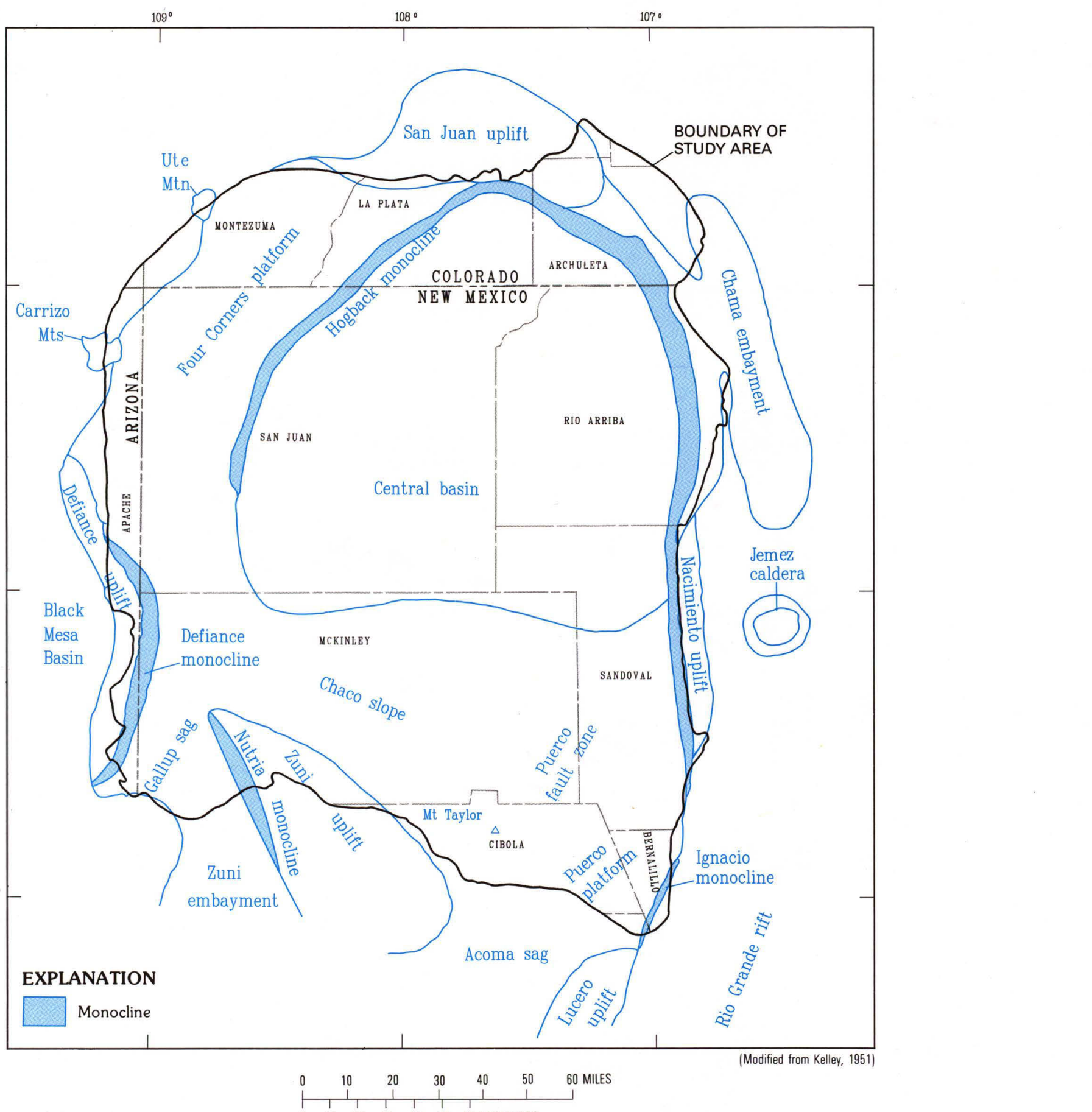


Figure 1. Location of San Juan structural basin, Colorado Plateau, and study area.



(Modified from Kelley, 1951)

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

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, 1990), Morrison Formation (Dam and others, 1990), Gallup Sandstone (Kernodle and others, 1989), and Menefee Formation (Levings and others, 1990) 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 Cliff House 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 Cliff House 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 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, 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 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 were 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 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, in some 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 this sequence 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 CLIFF HOUSE SANDSTONE

The Cliff House Sandstone is of Late Cretaceous age (fig. 3). It crops out around the margins of the central basin and typically caps mesas (as in the Chaco Canyon area and southwest of Cuba, New Mexico) and forms erosion-resistant dip slopes and hogbacks (as on the Hogback monocline in fig. 2). The Cliff House Sandstone, named by Collier (1919) for exposures on Mesa Verde in southwestern Colorado, is the uppermost formation of the classical three-part Mesaverde Group of the San Juan Basin (Point Lookout Sandstone, Menefee Formation, and Cliff House Sandstone).

The Cliff House Sandstone is conformably overlain by and intertongues with the Lewis Shale; both of these units conformably and unconformably overlie the Menefee Formation, with which they locally intertongue (Molenaar, 1977b, p. 164; Craigg, 1980, p. 7). In some areas where Cliff House tongues pinch out, the Lewis Shale may directly overlie the Menefee Formation (Stone and others, 1983, p. 33). In the western part of the basin, near the confluence of Coyote Wash and the Chaco River, the Cliff House merges with the Pictured Cliffs Sandstone, wedging out the Lewis Shale (fig. 3). The Cliff House Sandstone strata consist of several thick sandstone tongues that represent marine shorezone deposits of an overall transgressing shallow sea. Molenaar (1977b, p. 164) noted that these sandstone bodies actually are offlap or regressive deposits formed during stillstands and minor regressions of the shoreline.

Stratigraphy of the Cliff House Sandstone is complex. Nomenclature problems and differing interpretations tend to complicate regional correlations. The unit consists of two major sandstone tongues—La Ventana Tongue and the "Chacra tongue" of informal usage (Molenaar, 1977b, p. 164). Several other minor sandstone tongues of considerably less thickness and areal extent are common (Molenaar, 1977b, p. 164; Stone and others, 1983, sheets 2–4), but pinch out to the northeast.

The major buildup of La Ventana Tongue crops out in the southeastern part of the basin at La Ventana south of Cuba and, according to some authors, it can be traced in subcrop across the basin to outcrops on Hogback Mountain south of the San Juan River (Fassett, 1977; Molenaar, 1977b, p. 164). Other authors report that La Ventana Tongue is a more localized buildup in the southeastern part of the basin, representing deposition in a deltaic environment rather than in a marine beach environment (Mannhard, 1976; Fuchs-Parker, 1977). Maximum thickness of La Ventana Tongue according to Molenaar (1977b, p. 164) is about 800 feet. However, Mannhard (1976, p. 39) and Fuchs-Parker (1977, p. 199) reported a maximum thickness of about 1,000 feet in outcrops along State Highway 44 south of Cuba. Mannhard (1976), Fuchs-Parker (1977), and Tabet and Frost (1979) showed La Ventana Tongue to pinch out about 15 to 20 miles to the west of these outcrops.

The "Chacra tongue" (informal term) occurs stratigraphically above and is not physically connected to La Ventana Tongue (Fassett, 1977, p. 196). The Chacra tongue is the major buildup of the Cliff House Sandstone found at the type section on Mesa Verde, at Chaco Canyon, and at the Hogback monocline and forms the margins of the central basin (fig. 2). The unit is about 400 feet thick at its type section on Mesa Verde (Collier, 1919, p. 297). Molenaar (1977b, p. 164) reported a range of about 150 to 300 feet in thickness, and Stone and others (1983, p. 33) reported that the thickness of the Chacra tongue throughout most of its extent in New Mexico ranges from 0 to 250 feet.

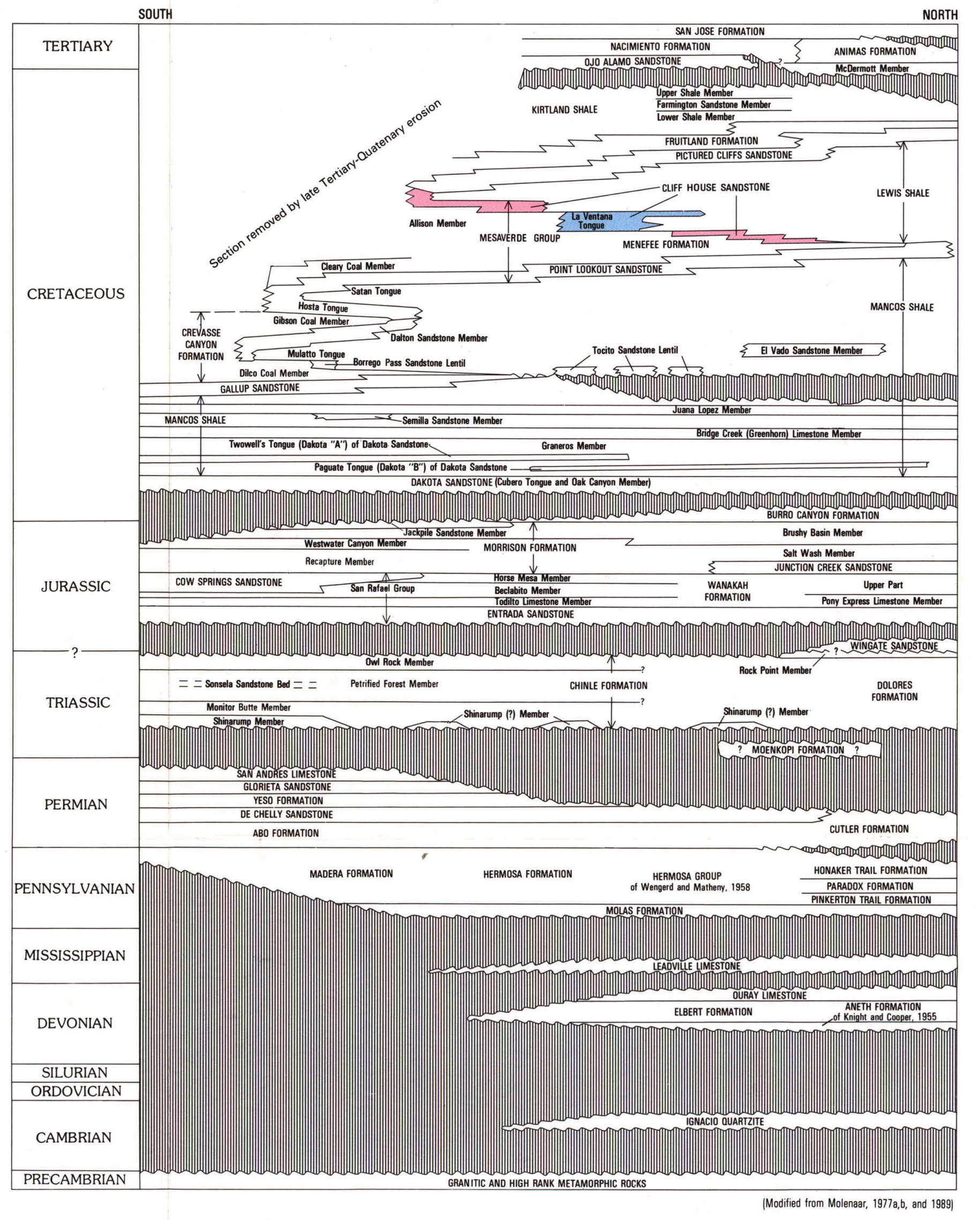
Several other minor tongues of the Cliff House Sandstone of limited areal extent occur in the Lewis Shale northeast of the two major sandstone bodies, La Ventana Tongue and Chacra tongue. Molenaar (1977b, p. 164) reported that the aggregate thickness of these localized bodies is about 300 feet.

The Cliff House Sandstone generally consists of tan, light-brown, or yellowish-brown, thick- to very thick bedded and locally crossbedded sandstone with calcite or silica cement and clay matrix. Grain size ranges from very fine to fine and the sandstones are well to very well sorted (Stone and others, 1983, p. 28, 33). Interbeds of gray shale and silty shale are common (O'Sullivan and Beikman, 1963; Haynes and others, 1972; Craigg, 1980).

Data used to compute the depth to and altitude of the top of the Cliff House Sandstone were obtained primarily from the Petroleum Information Corporation's data base (7,252 wells) with supplemental data from NWIS (34 wells) and from outcrop altitudes. The location of oil- or gas-test holes and water wells is shown in figure 4. Depth to the top of the Cliff House ranges from zero in areas of outcrop to about 6,000 feet near the structural center of the San Juan Basin (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 Cliff House Sandstone, the datum used is sea level.

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



(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."

The configuration of the top of the Cliff House Sandstone 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, the Chaco slope, and the Four Corners platform, as delineated in figure 2, are all apparent in figure 6.

The top of the Cliff House Sandstone decreases from a maximum altitude of about 8,000 feet above sea level along the northern rim of the central basin to about 1,000 feet above sea level near the structural center of the basin. Dip of the Cliff House is steepest where contours are closely spaced, as near the basin margins, and less steep where contours are spaced farther apart, as on the marginal platforms and near the basin center.

WATER IN THE CLIFF HOUSE SANDSTONE

The Cliff House Sandstone 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. Water wells completed in the formation generally are on or near the outcrop areas. Oil and gas are being produced from the Cliff House in some parts of the basin. Many of the oil- or gas-test holes also produce water, but the quality is not acceptable for domestic and livestock use.

The altitude of the potentiometric surface of the Cliff House 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 Cliff House Sandstone. The water-well data were collected from 1964 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 1957 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 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 water 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 Cliff House Sandstone occurs under both water-table and artesian conditions. 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.

No areas of inordinate stress from ground-water development are known to exist. The water levels shown in figure 7 are the most recent data available. General ground-water gradients may be determined for localized areas if sufficient data exist.

Transmissivity and hydraulic-conductivity data for the Cliff House Sandstone are extremely limited. A recovery test on a water well in 1961 gave a transmissivity of 2 feet squared per day (Stone and others, 1983). The average hydraulic conductivity calculated from oil and gas wells in deeper parts of the basin is 0.0015 foot per day (Reneau and Harris, 1957).

The reported or measured discharge from 26 water wells completed in the Cliff House Sandstone ranges from 1 to 40 gallons per minute and the median is 8 gallons per minute. The specific capacity of 14 of these wells ranges from 0.01 to 0.15 gallon 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 locations of six selected water wells that derive water only from the Cliff House Sandstone and have four or more water-level measurements are 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. Hydrographs for these wells primarily show short-term changes in water level. Short-term fluctuations result from periodic changes in discharge from wells and from seasonal changes in recharge. However, well 2, the well with the longest period of record, does show a general decline in water level from 1936 until the early 1950's, followed by a period of lesser decline until 1980 and, finally, a period of generally stable water levels to the present.

Wells 1, 2, and 5 (fig. 9) are located in, or very near, the outcrop of the Cliff House Sandstone. Ground water in the outcrop area is unconfined and changes in water level are small because of the large storage coefficient of the aquifer. Consequently, water levels in these wells show little response to seasonal changes in recharge and discharge. A water-level measurement in 1975 for well 5 reflects drawdown due to nearby ground-water withdrawal, but subsequent measurements (1980–89) show a recovery in water level and very little seasonal change.

Wells 3, 4, and 6 are 3 to 10 miles from the outcrop of the Cliff House Sandstone. The hydrographs for each of these wells indicate that water levels in confined parts of the aquifer are subject to relatively large and rapid fluctuations in response to changes in nearby ground-water withdrawals.

QUALITY OF WATER FROM THE CLIFF HOUSE SANDSTONE

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 1952–84. Distribution of data reflects the locations of water wells near the outcrop where drilling depth is economically feasible. Well records were checked to assure, to the extent possible, that a particular sample represents water only from the Cliff House Sandstone 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 Cliff House Sandstone. 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 data are displayed in figure 10 and presented in table 1. Most of the temperature data are from water wells drilled where the Cliff House Sandstone crops out within the basin. Bottom-hole temperatures obtained during a drill-stem test on two oil- or gas-test holes are shown also.

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 values listed in table 1. From a total of 46 samples for pH, 10 (22 percent) exceeded the standard (table 2). From a total of 49 samples for sulfate, 32 (65 percent) exceeded the secondary drinking-water standard. Five samples out of 51 samples (10 percent) for chloride exceeded the standard. From 49 samples for fluoride, 17 samples (35 percent) exceeded the secondary drinking-water standard. Ten out of 49 fluoride samples (20 percent) exceeded the primary drinking-water standard of 4 milligrams per liter (U.S. Environmental Protection Agency, 1986a). From a total of 39 samples, 35 (90 percent) exceeded the secondary drinking-water standard for dissolved solids.

Dissolved-solids concentrations of water from the Cliff House Sandstone for water wells and oil- and gas-test holes are shown in figure 11 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 Cliff House Sandstone. 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 Cliff House Sandstone can be estimated by multiplying the field-determined value of specific conductance by 0.69. This number represents the median value of the ratio of dissolved solids to specific conductance for samples from only the Cliff House Sandstone.

Chemical-constituent diagrams for water from the Cliff House Sandstone are shown in figure 12. Most samples are from wells within or near the area of outcrop of the Cliff House Sandstone. Alkalinity, shown in figure 12 as the sum of bicarbonate and carbonate ions, is the capacity of the solution to neutralize a strong acid (Hem, 1985, p. 106). Alkalinity of water from the Cliff House Sandstone consists primarily of the ions bicarbonate and, to a smaller degree, carbonate. Dominant ions in water from the Cliff House Sandstone are sodium, sulfate, and bicarbonate. Calcium, magnesium, and chloride concentrations do not present any significant pattern of occurrence.

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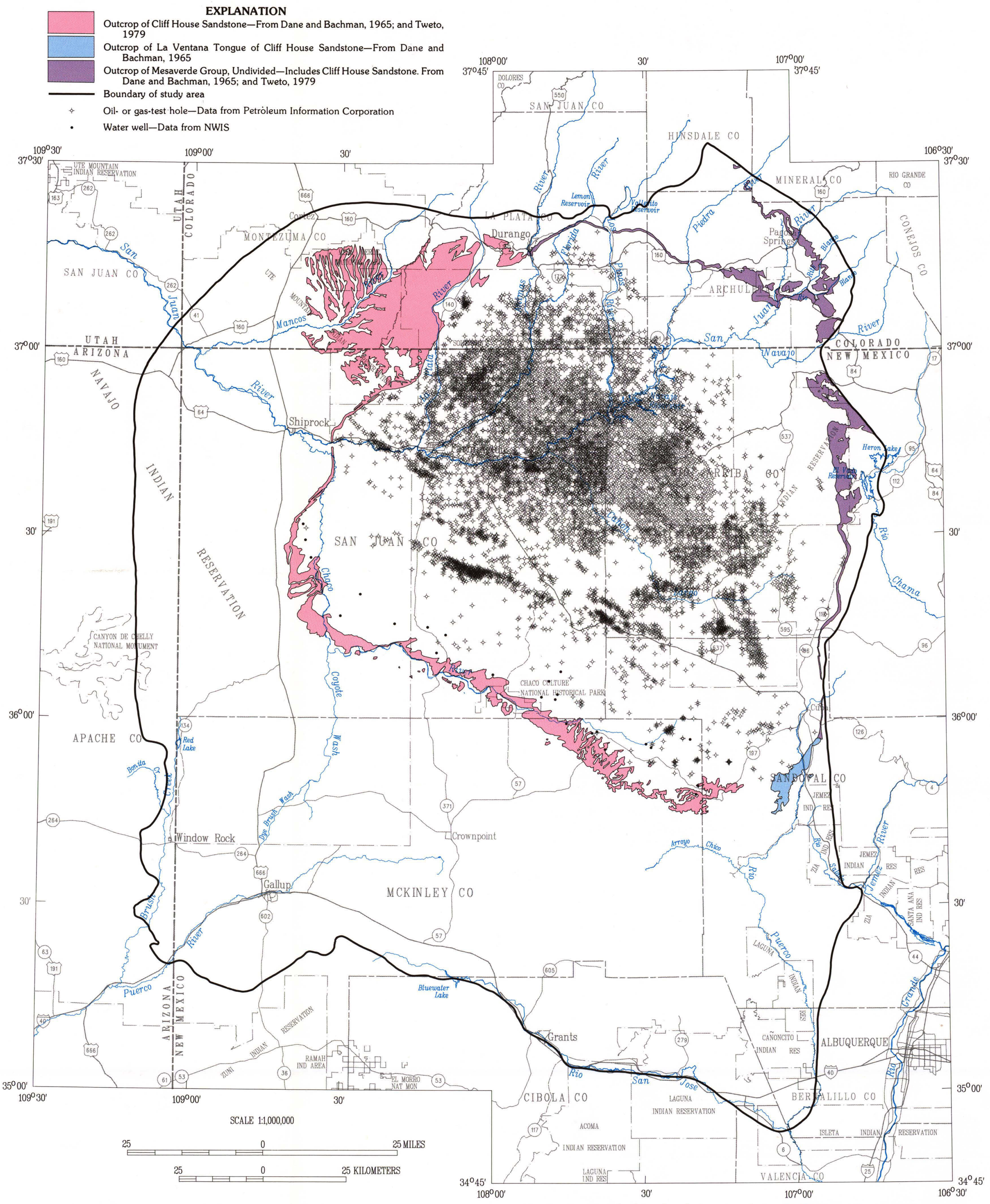
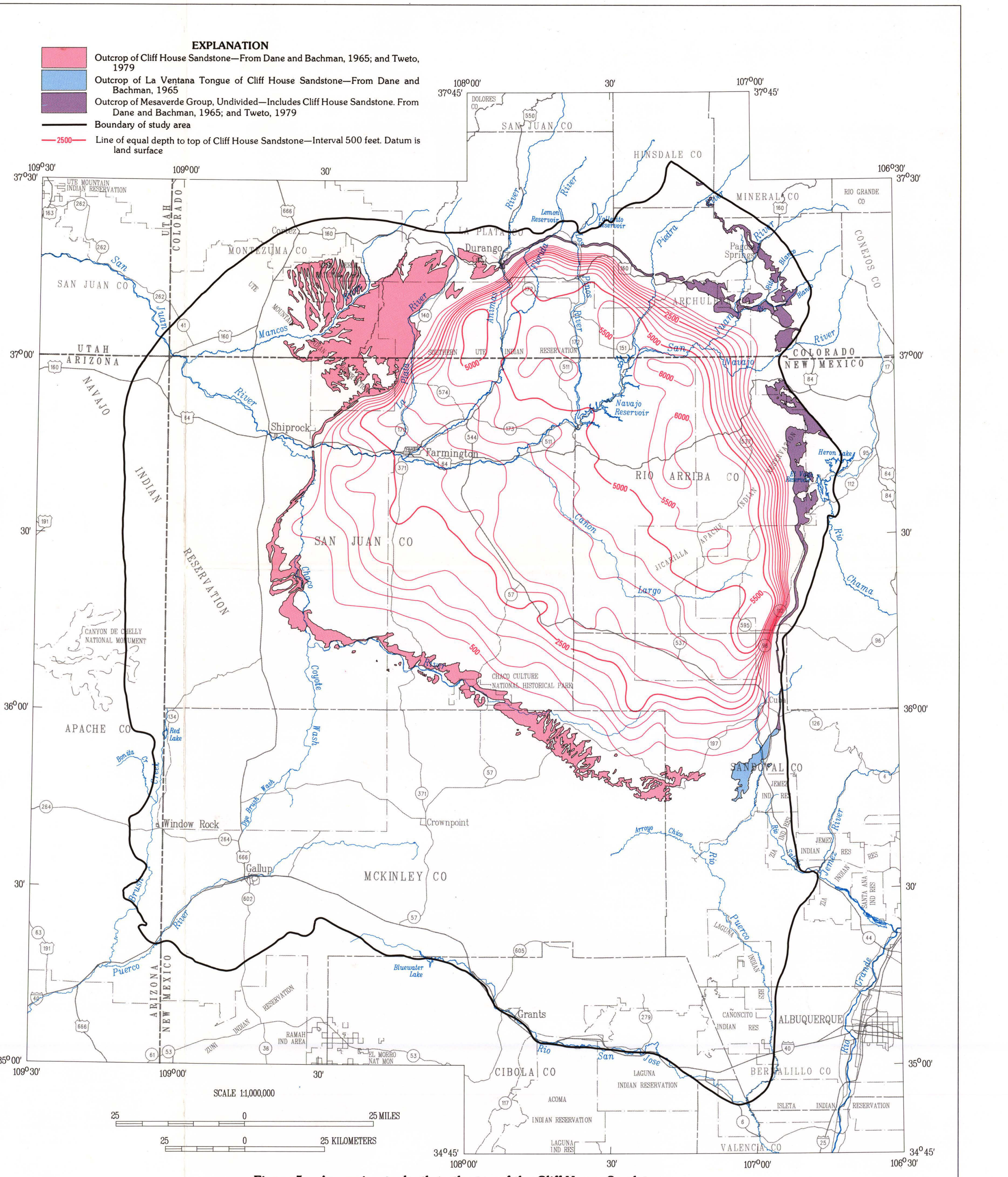

EXPLANATION

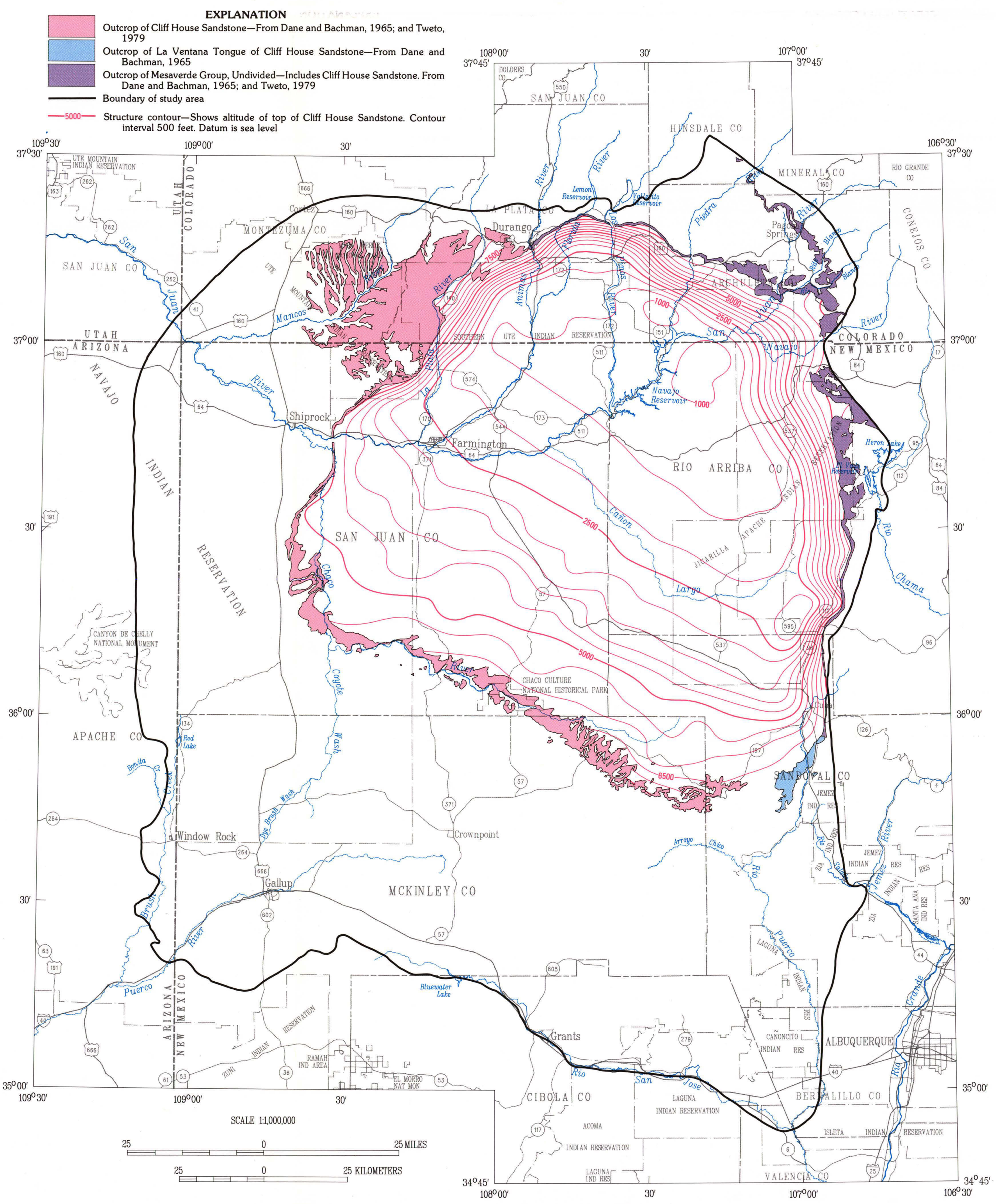
- ▨ Outcrop of Cliff House Sandstone—From Dane and Bachman, 1965; and Tweto, 1979
- ▨ Outcrop of La Ventana Tongue of Cliff House Sandstone—From Dane and Bachman, 1965
- ▨ Outcrop of Mesaverde Group, Undivided—Includes Cliff House Sandstone. From Dane and Bachman, 1965; and Tweto, 1979
- — Boundary of study area
- ✧ Oil- or gas-test hole—Data from Petroleum Information Corporation
- • Water well—Data from NWIS

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


EXPLANATION

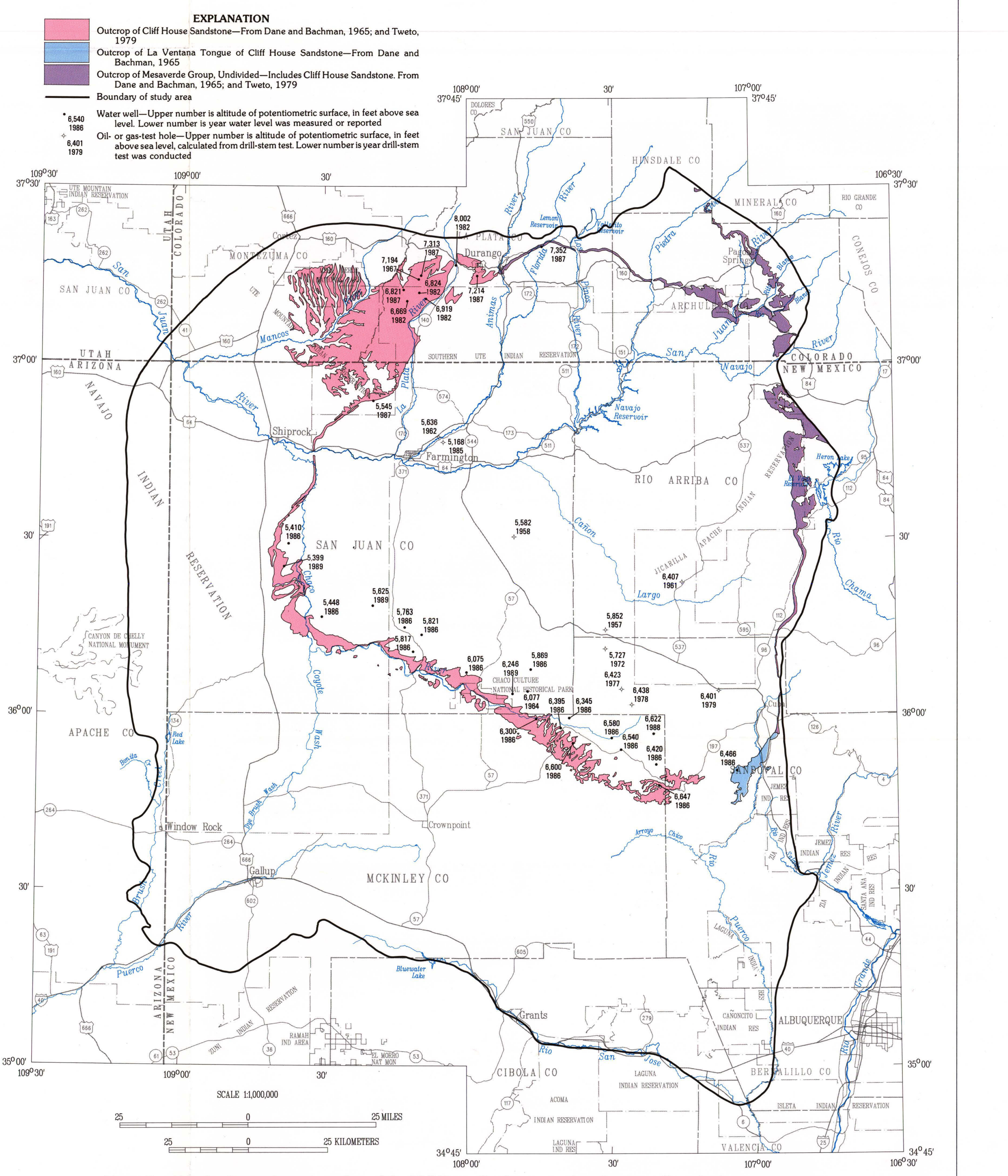
- ▨ Outcrop of Cliff House Sandstone—From Dane and Bachman, 1965; and Tweto, 1979
- ▨ Outcrop of La Ventana Tongue of Cliff House Sandstone—From Dane and Bachman, 1965
- ▨ Outcrop of Mesaverde Group, Undivided—Includes Cliff House Sandstone. From Dane and Bachman, 1965; and Tweto, 1979
- — Boundary of study area
- —2500— Line of equal depth to top of Cliff House Sandstone—Interval 500 feet. Datum is land surface

Figure 5. Approximate depth to the top of the Cliff House Sandstone.


EXPLANATION

- ▨ Outcrop of Cliff House Sandstone—From Dane and Bachman, 1965; and Tweto, 1979
- ▨ Outcrop of La Ventana Tongue of Cliff House Sandstone—From Dane and Bachman, 1965
- ▨ Outcrop of Mesaverde Group, Undivided—Includes Cliff House Sandstone. From Dane and Bachman, 1965; and Tweto, 1979
- — Boundary of study area
- —5000— Structure contour—Shows altitude of top of Cliff House Sandstone. Contour interval 500 feet. Datum is sea level

Figure 6. Approximate altitude and configuration of the top of the Cliff House Sandstone.


EXPLANATION

- ▨ Outcrop of Cliff House Sandstone—From Dane and Bachman, 1965; and Tweto, 1979
- ▨ Outcrop of La Ventana Tongue of Cliff House Sandstone—From Dane and Bachman, 1965
- ▨ Outcrop of Mesaverde Group, Undivided—Includes Cliff House Sandstone. From Dane and Bachman, 1965; and Tweto, 1979
- — Boundary of study area
- • 6,540 / 1986 Water well—Upper number is altitude of potentiometric surface, in feet above sea level. Lower number is year water level was measured or reported
- ✧ 6,401 / 1979 Oil- or gas-test hole—Upper number is altitude of potentiometric surface, in feet above sea level, calculated from drill-stem test. Lower number is year drill-stem test was conducted

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

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By

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