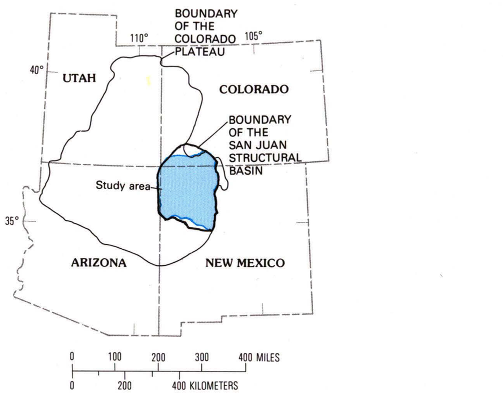

Figure 1. Location of San Juan structural basin, Colorado Plateau, and study area.

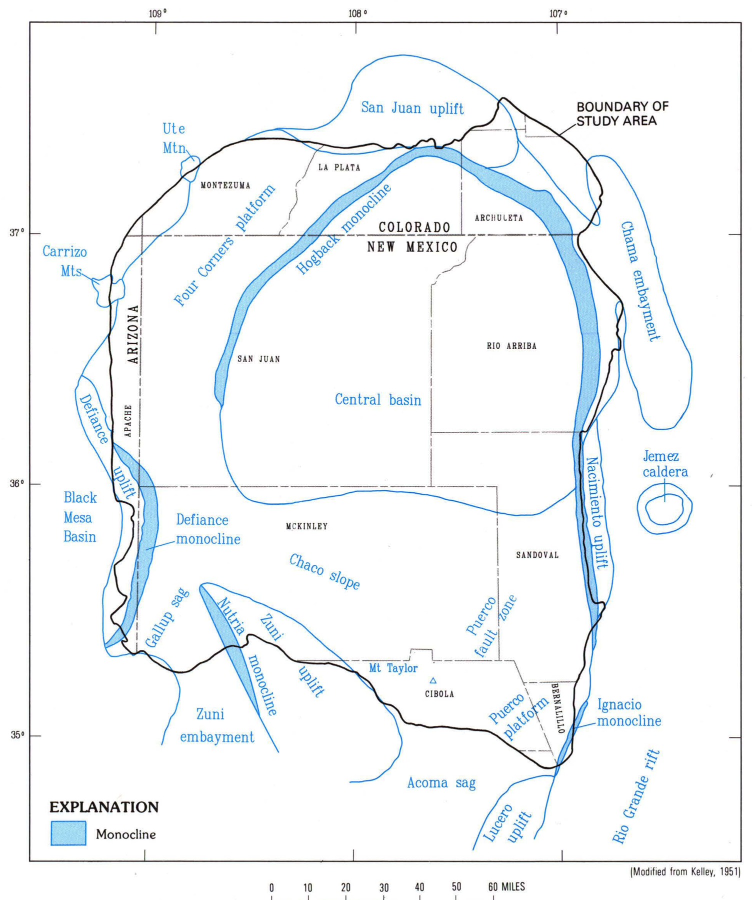

Figure 2. Structural elements of the San Juan structural basin and adjacent areas.

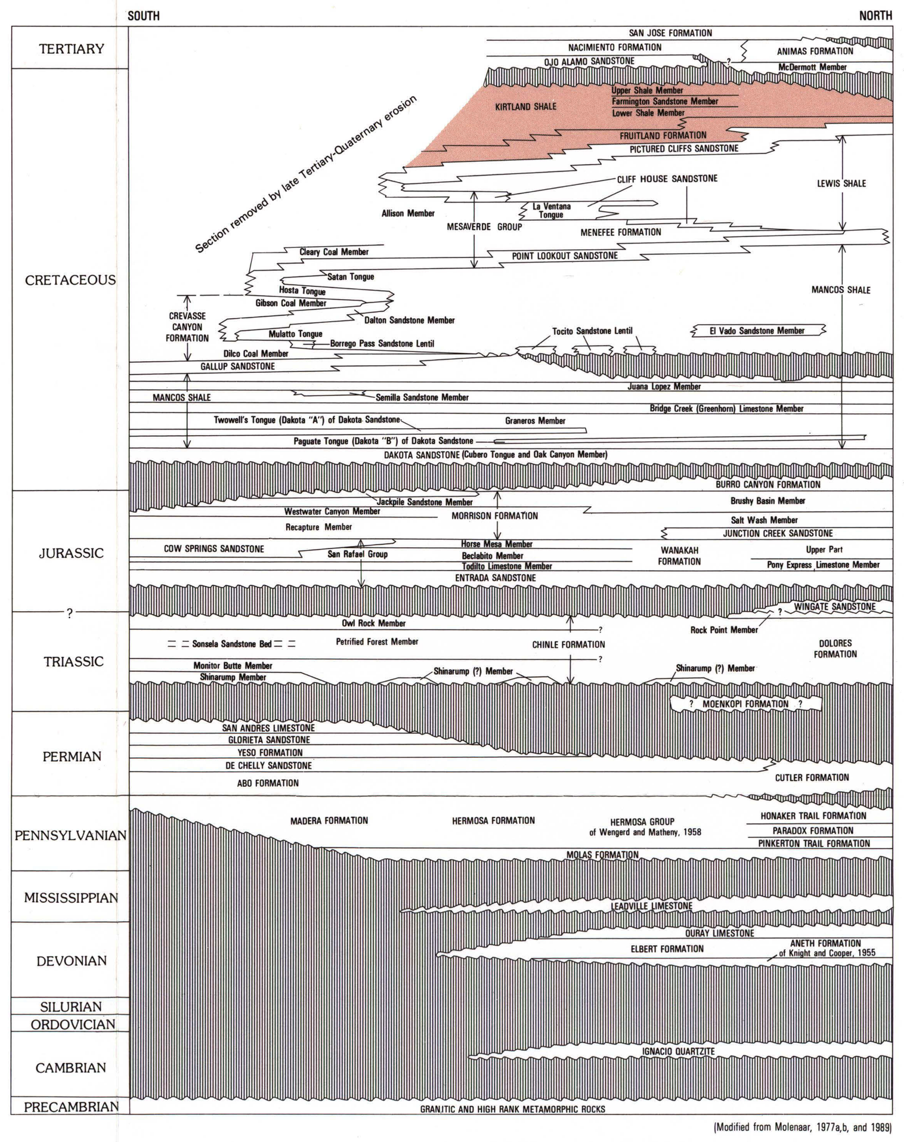

Figure 3. Time– and rock–stratigraphic framework and nomenclature.

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	0.06309	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 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), Pictured Cliffs Sandstone (Dam 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 combined Kirtland Shale and Fruitland Formation, one of the primary water-bearing units in the regional aquifer system. These two formations are treated as a single hydrogeologic unit because they commonly are mapped together, they contain strata of similar lithology, and they have similar hydrologic properties. 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 Kirtland Shale and Fruitland Formation 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 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 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) 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 (fig. 3), but principally from Pennsylvanian through Tertiary. 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 except where locally interrupted by intrabasinal folds and faults. 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 Kirtland Shale and Fruitland Formation, of Late Cretaceous age (Baltz, 1967; Fassett and Hinds, 1971), crop out inside the margins of the central basin. Topography formed on the unit typically varies from rolling to rough, and commonly, badlands are developed. Erosion-resistant sandstones commonly cap isolated buttes and hillocks, whereas softer shaley units form slopes and broad valleys or flats. The upper part of the Kirtland Shale generally forms steep slopes below mesas or buttes that are capped by the overlying erosion-resistant Ojo Alamo Sandstone.

The Kirtland Shale and Fruitland Formation were named by Bauer (1916) for exposures along the San Juan River west of Farmington, New Mexico. The Fruitland Formation conformably overlies the Pictured Cliffs Sandstone, and intertonguing locally occurs at the contact; the Fruitland is conformably overlain by the Kirtland Shale. The Kirtland Shale is unconformably overlain by the Ojo Alamo Sandstone of Tertiary age and the McDermott Member of the Animas Formation of Late Cretaceous age (Baltz, 1967; Fassett and Hinds, 1971; Molenaar, 1977b).

In general, the undivided Kirtland Shale and Fruitland Formation consists of various thicknesses of interbedded and repetitive sequences of nonmarine channel sandstone, siltstone, shale, and claystone. Coal beds and carbonaceous shales are common in the Fruitland Formation. The Kirtland Shale does not contain coal and has been divided into three members, which in ascending order are: the lower shale member, Farmington Sandstone Member, and upper shale member (fig. 3; Bauer, 1916).

Thickness of the combined Kirtland Shale and Fruitland Formation ranges from zero on the east side of the basin, because of pre-Ojo Alamo Sandstone erosion, to a maximum of about 2,000 feet in the northwestern part of the basin (Fassett and Hinds, 1971, p. 22,26; Molenaar, 1977b, p. 165). A basinwide thickness map of the undivided Kirtland Shale and Fruitland Formation is shown in figure 4. Thickness of the Kirtland Shale ranges from zero in the east to about 1,500 feet in the northwest; the lower shale member, Farmington Sandstone Member, and upper shale member each are as much as 500 feet thick (Fassett and Hinds, 1971, p. 26; Molenaar, 1977b, p. 165; Stone and others, 1983, p. 31). The Fruitland Formation ranges in thickness from zero in the east to about 500 feet in the northwest (Fassett and Hinds, 1971, p. 23) and averages about 300–350 feet thick (Molenaar, 1977b, p. 165).

Data used to compute the depth to and the altitude of the top of the Kirtland Shale and Fruitland Formation 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 5.

Depth to the Kirtland Shale and Fruitland Formation ranges from zero in areas of outcrop to about 3,500 feet in the east-central part of the structural basin (fig. 6). The configuration of the top of the Kirtland Shale and Fruitland Formation is shown on the structure-contour map (fig. 7). 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. In the configuration of the top surface of the Kirtland Shale and Fruitland Formation, the datum used is sea level. The overall structural pattern of that part of the basin underlain by the Kirtland Shale and Fruitland Formation also is shown in figure 7. The top of the Kirtland Shale and Fruitland Formation decreases from a maximum altitude of about 8,000 feet above sea level along the northeastern basin margin to about 3,500 feet above sea level in the east-central part of the structural basin.

GROUND WATER

The combined Kirtland Shale and Fruitland Formation 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. The mining of coal and production of coal-bed methane from the Fruitland Formation in parts of the basin also have resulted in significant quantities of water produced as a secondary product. In localized areas, surface mining of coal has resulted in dewatering of the unit within the immediate mine area. The production of coal-bed methane from the Fruitland Formation has been initiated on a limited scale; however, the projected production of methane in the next few years may result in significant quantities of water produced as a secondary product. The production of this water will result in the depressurization of areas of the Fruitland Formation in southern Colorado and extreme northern New Mexico.

The altitude of the potentiometric surface of the Kirtland Shale and Fruitland Formation at selected water wells and oil- or gas-test holes is shown in figure 8. The altitude of the potentiometric surface in the 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 Kirtland Shale and Fruitland Formation. The water-well data were collected from 1980 to 1987. 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 1954 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 principal objective of a drill-stem test is to determine the potential for oil or gas production. Therefore, the best water-producing zones commonly are bypassed, with the result that the hydraulic data are from probable oil or gas production zones rather than water-producing zones. The interval tested is unrelated to permeability or the possibility of water production. However, the data generally are all that are available for aquifers in the deeper parts of the basin.

During a drill-stem test a specific interval is isolated by packers. After a period of formation-fluid flow into the drill-stem tool, the flow is stopped. This "shutting in" of the formation causes the formation pressure to recover and stabilize at its static level. Pressure data used in this report were obtained after a minimum recovery time of 1 hour. 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 is based on the assumption that the water is at a temperature of 4 degrees Celsius with a density of 1.0 gram per cubic centimeter.

Water in the Kirtland Shale and Fruitland Formation 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 or other adjacent beds.

To date (1989), no large-scale areas of stress from ground-water development are known to exist. Water levels in figure 8 are shown, along with year of measurement, to provide the most recent data available. Generalized potentiometric-surface gradients may be determined for localized areas if sufficient data exist.

Reported transmissivity and hydraulic-conductivity data for the Kirtland Shale and Fruitland Formation are limited to tests conducted on five wells. The transmissivity ranges from 0.6 to 130 feet squared per day (Stone and others, 1983, table 5). The only hydraulic conductivity calculated from the tests was 0.00001 foot per day.

The reported or measured discharge from 10 water wells completed in the Kirtland Shale and Fruitland Formation ranges from 1 to 12 gallons per minute and the median is 4 gallons per minute. The specific capacity of six of these wells ranges from 0.01 to 0.42 gallon per minute per foot of drawdown and the median is 0.03 gallon per minute per foot of drawdown. The distribution of these data is shown in figure 9.

The location of eight water wells that derive water only from the Kirtland Shale and Fruitland Formation 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 discharge from wells, from discontinuation of discharge from wells, and from changes in rates of recharge due to climatic variations. Water levels in wells completed in the Kirtland Shale and Fruitland Formation also are affected by mining of coal and production of natural gas. Changes in ground-water levels resulting from these activities may be either short or long term.

All of the wells for which water-level hydrographs are shown are completed in the outcrop area of the Kirtland Shale and Fruitland Formation. Water-level changes in wells completed in the unconfined part of the aquifer at the outcrop generally are more suppressed than changes in similar wells completed in confined parts of the aquifer. The ability of a well to yield water and the amount of water withdrawn from the well also affect the magnitude of change in water level in the well. With the exception of one well, number 6, all of the reported water-level fluctuations are less than 20 feet. One-half of the wells have water-level changes of less than 5 feet during the period of record. Wells 6 and 7 use windmill-powered lifts to withdraw water for livestock use; the other wells are used exclusively for ground-water-level monitoring. Well 6 has a small specific capacity of 0.01 gallon per minute per foot of drawdown (fig. 9); hence, ground-water levels in well 6 may show great variation depending on the pattern of ground-water withdrawal.

WATER QUALITY

Water-quality data collected during 1949–84 and discussed in the following section are from the NWIS data base for water wells and from the Petroleum Information Corporation's data base and Dwight's ENERGYDATA Inc. BRIN data base for the oil- or gas-test holes. Distribution of data reflects the location of available data. Downdip from the outcrop, water wells are usually completed in Tertiary sandstones that overlie the Kirtland Shale and Fruitland Formation. Well records were checked to assure, to the extent possible, that a particular sample represents water only from the Kirtland Shale and Fruitland Formation and not a mixture of water from other aquifers. Water-quality data presented on the illustrations do not represent the total amount of available data for the Kirtland Shale and Fruitland Formation. 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 concentrations was performed using the most recent analysis for wells that had multiple analyses.

Temperature data for water from the Kirtland Shale and Fruitland Formation are shown in figure 11 and summarized in table 1. Most of the temperatures are from water wells drilled where the Kirtland Shale and Fruitland Formation crops out. Temperatures of water from three oil- or gas-test holes in the north-central part of the basin represent bottom-hole temperatures taken during drill-stem tests.

Primary (maximum enforced contaminant level) drinking-water standards are shown in table 2 (U.S. Environmental Protection Agency, 1986a). Fluoride concentration in 5 of 30 samples (17 percent) and nitrate concentration in 1 of 19 (5 percent) exceeded the standards shown in table 2. Selected secondary (nonenforced contaminant level) drinking-water standards are shown in table 3 (U.S. Environmental Protection Agency, 1986b); these standards are exceeded by the maximum concentrations of all constituents listed in table 1.

The secondary drinking-water standard for pH is exceeded by 7 of 29 samples (24 percent, table 3). Sulfate concentration in 8 of 30 samples (27 percent) and chloride concentration in 13 of 30 samples (43 percent) exceeded the standard in table 3. Concentrations of fluoride, 9 of 30 samples (30 percent), and dissolved solids, 25 of 30 (83 percent), exceeded the secondary drinking-water standard.

Dissolved-solids concentrations in samples from water wells and oil- or gas-test holes are shown in figure 12. Two analytical methods were used to determine dissolved-solids concentrations. The dissolved-solids concentrations for samples from water wells were calculated as the sum of the major ions and ranged from 310 milligrams per liter to 29,000 milligrams per liter (table 1). The concentrations of dissolved solids for water from the oil- or gas-test holes were analyzed by weighing the residue remaining after evaporation and ranged from 4,262 milligrams per liter to 22,011 milligrams per liter. These data from oil- or gas-test holes were obtained from Dwight's ENERGYDATA Inc. BRIN data base. Water samples from oil- or gas-test holes may not be representative of water from wells completed in the Kirtland Shale and Fruitland Formation. However, data from the oil- or gas-test holes do provide a qualitative value of the dissolved-solids concentration of water from the Kirtland Shale and Fruitland Formation.

The specific conductance of water can be easily measured with a meter at the 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 Kirtland Shale and Fruitland Formation can be determined by multiplying the specific conductance by 0.67. This number represents the median value of the ratio of dissolved solids to specific conductance for samples from only the Kirtland Shale and Fruitland Formation.

Chemical-constituent diagrams for samples from the Kirtland Shale and Fruitland Formation are shown in figure 13. Most of the water wells are located within the area of outcrop. Concentrations of sodium, chloride, alkalinity, and sulfate are large and display a wide range of variation. Alkalinity of water from the Kirtland Shale and Fruitland Formation is derived primarily from bicarbonate ions. Alkalinity is the capacity of the solution to neutralize a strong acid (Hem, 1985, p. 106). Ion concentrations and water types were variable even within closely spaced water wells as shown from samples collected just north of Chaco Culture National Historical Park and east of Shiprock.

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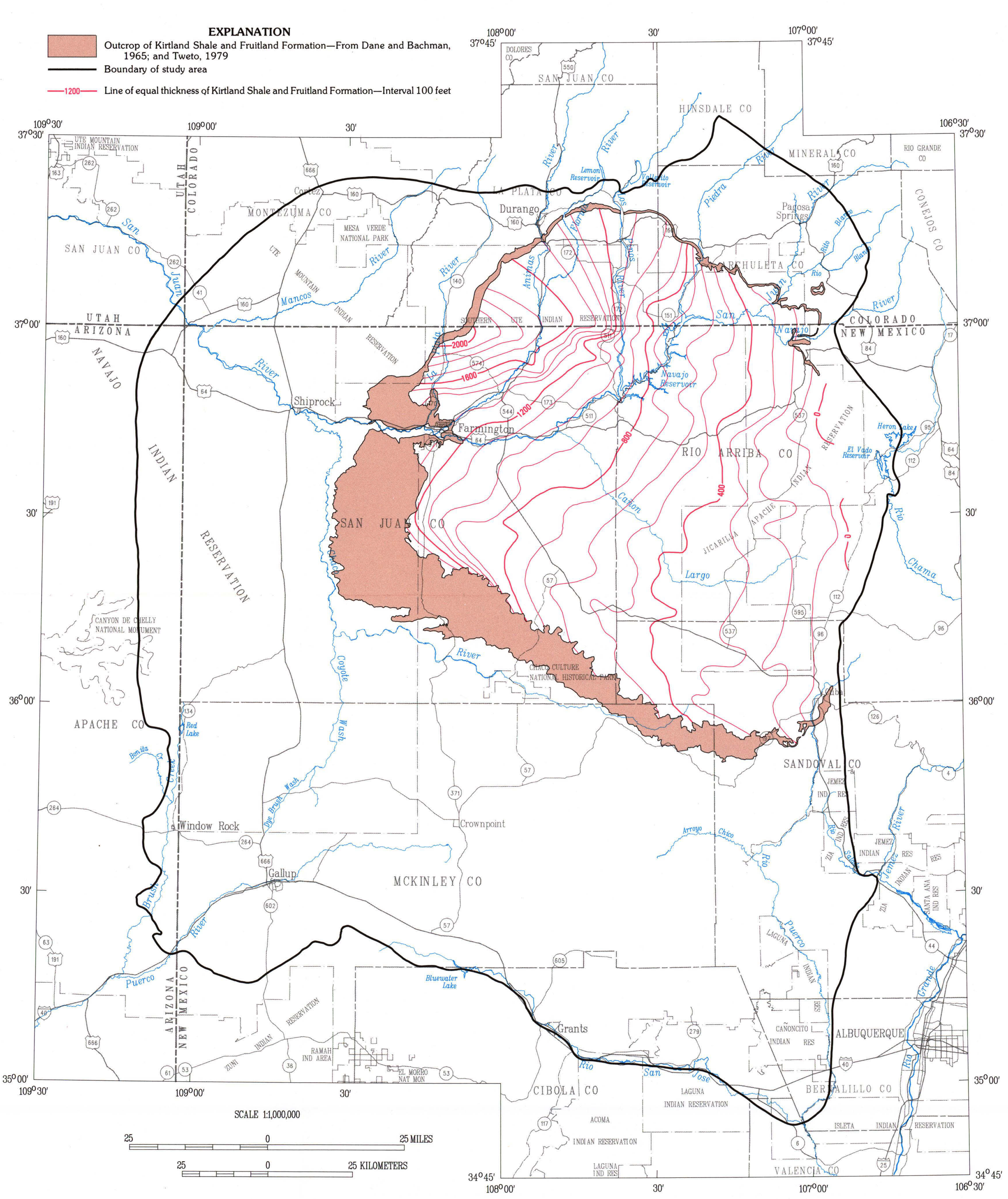

Figure 4. Approximate thickness of the Kirtland Shale and Fruitland Formation (modified from Fassett and Hinds, 1971, fig. 11).

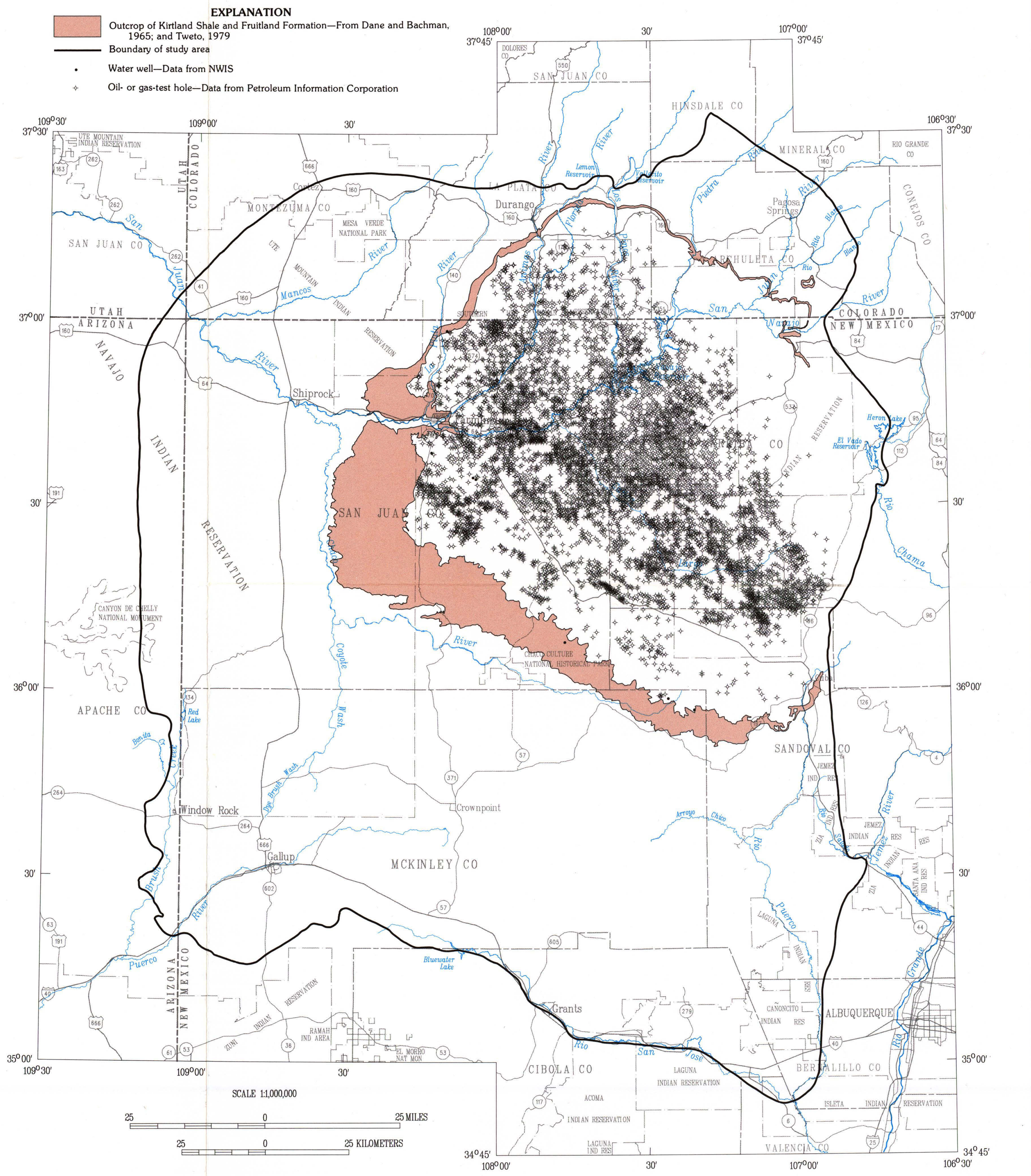

Figure 5. Location of oil- or gas-test holes and water wells used to compile depth to and altitude of the top of the Kirtland Shale.

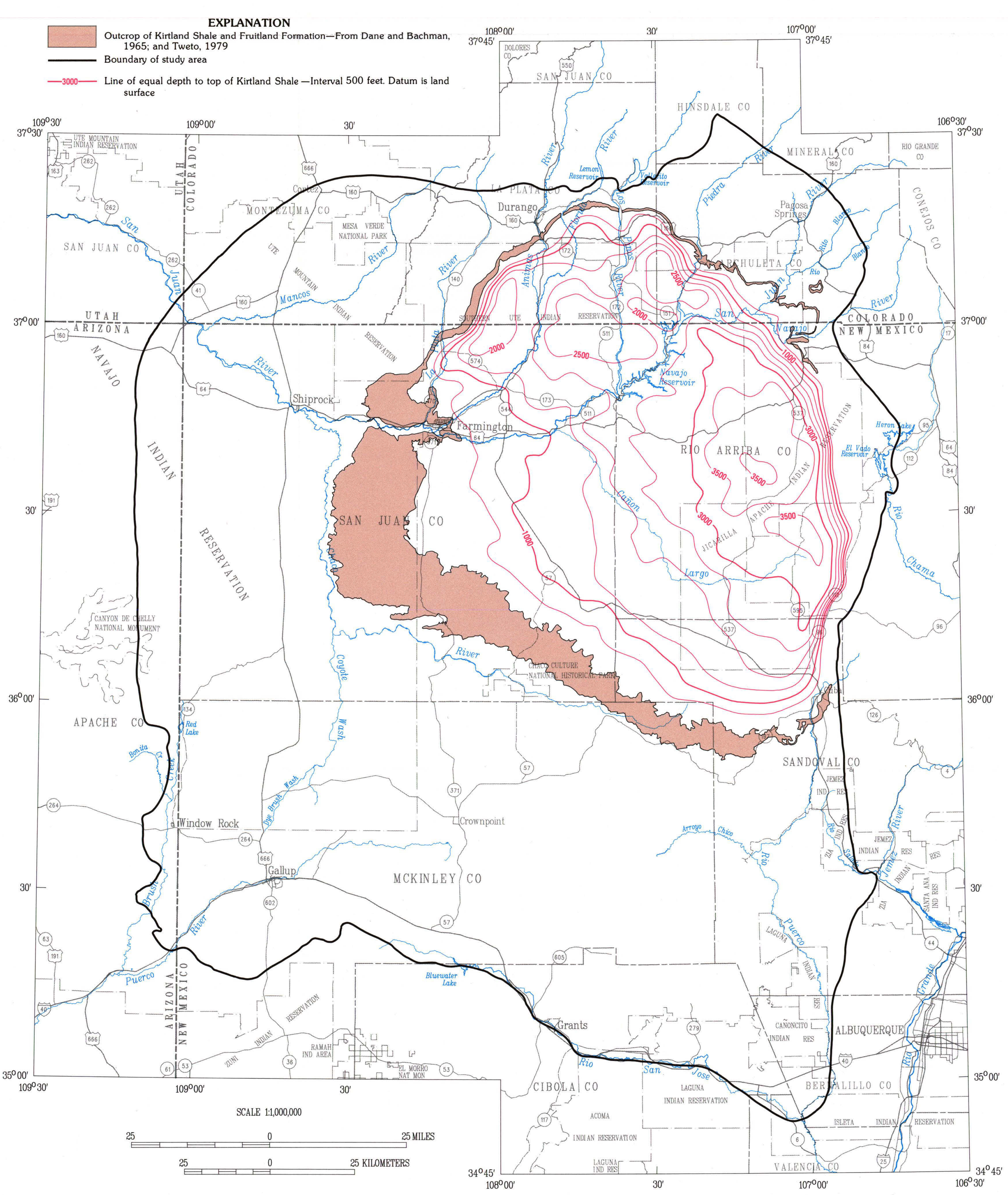

Figure 6. Approximate depth to the top of the Kirtland Shale.

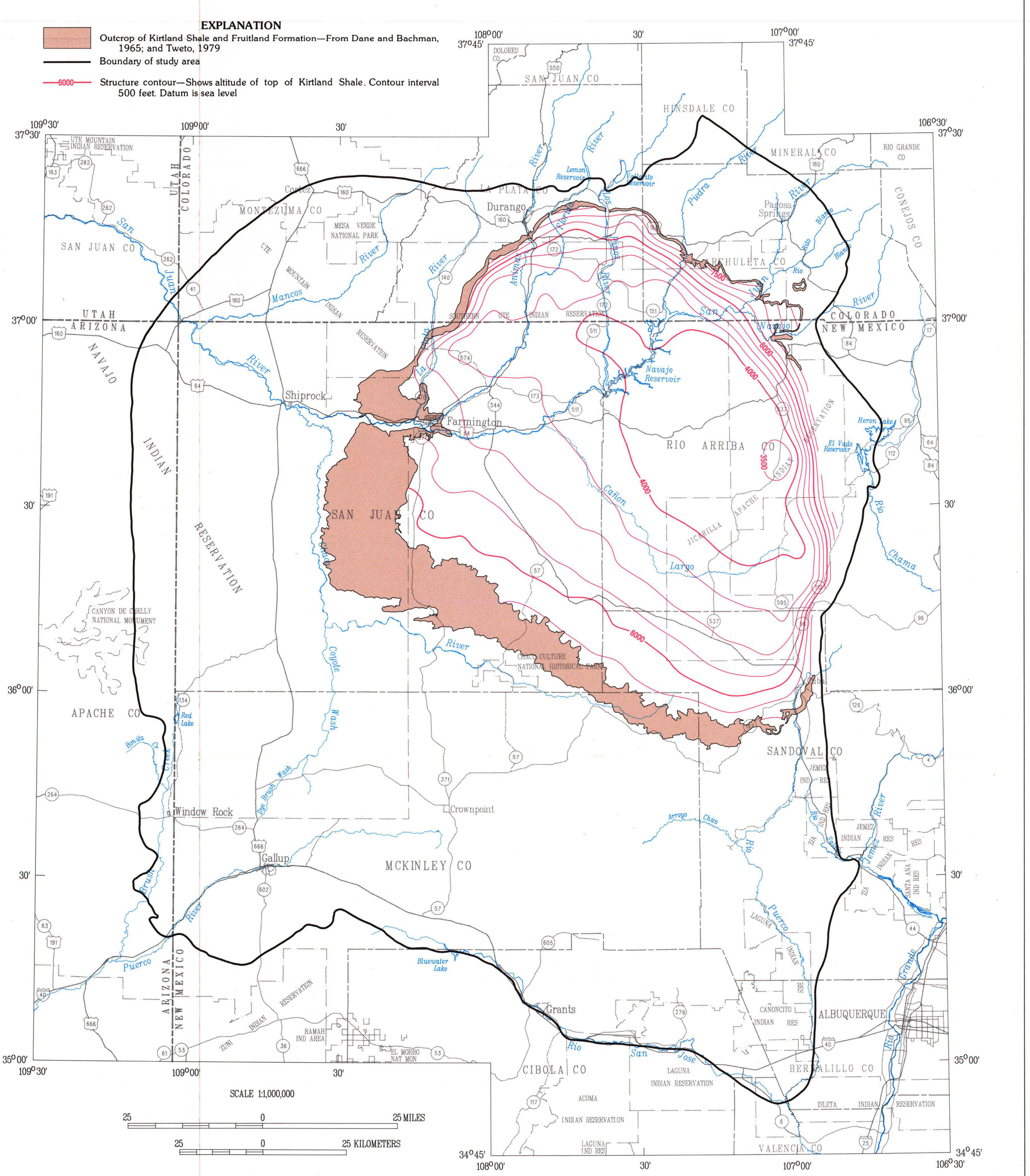

Figure 7. Approximate altitude and configuration of the top of the Kirtland Shale.

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

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HYDROGEOLOGY OF THE KIRTLAND SHALE AND FRUITLAND FORMATION IN THE SAN JUAN STRUCTURAL BASIN, NEW MEXICO, COLORADO, ARIZONA, AND UTAH

By
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1990

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