Oklahoma Geological Survey
Charles J. Mankin, Director

Geothermal Resources and Temperature Gradients of Oklahoma

1984

Geothermal data compiled and interpreted by the
OKLAHOMA GEOLOGICAL SURVEY
Map produced by the
National Geophysical Data Center
National Oceanic and Atmospheric Administration
for the
Geothermal and Hydropower Technologies Division
United States Department of Energy

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Base map supplied by the U.S. Geological Survey

Scale 1:500,000
1 centimeter equals 5 kilometers
1 inch equals approximately 8 miles

Contour interval 200 feet
National geodetic vertical datum of 1929
1927 North American datum
Lambert conformal conic projection based on standard parallels 33° and 45°

INTRODUCTION

In September 1980, the Oklahoma Geological Survey, in cooperation with the U.S. Department of Energy, began a program to assess the geothermal potential of the State. This assessment was accomplished through the analysis of calculated temperature gradients from oil- and gas-well bottom-hole temperature information.

The geothermal resources of Oklahoma are classified as low-temperature waters. The U.S. Geological Survey defines low-temperature geothermal resources as those usable concentrations of geothermal waters with temperatures less than 90°C where the geothermal gradient is greater than 25°C/km (1.35°F/100 ft) and the well-head- or spring-water-discharge temperature is a minimum of 10°C (18°F) above the mean annual surface temperature (Reed, 1983). Temperature gradients greater than 35°C/km occur in southeastern Oklahoma whereas in most of Oklahoma, temperature gradients are less than 25°C/km.

Low-temperature waters can be used for space heating, ethanol production, and in some agribusiness activities such as grain drying and (or) greenhouse heating. The application generally depends on production-water characteristics, such as quality, quantity, and temperature, and user requirements.

Shallow (300 m or less) ground water in Oklahoma has a temperature of about 16.7°C (62°F). A number of shallow fresh-water aquifers (fig. 1) are suitable for ground-water heat-pump applications. Several two-well systems (similar to that shown in fig. 2) that involve a production well and a second injection well for returning water to the formation are in use for space heating and cooling of residences and small businesses in central Oklahoma.

The temperature of formation water associated with deep oil-producing zones, 2,500 to 3,500 m below the surface, can exceed 65°C (150°F). The water usually contains very high concentrations of total dissolved solids, but heat could be extracted from the petroleum-associated fluids. A relatively large number of wells drilled by the petroleum industry offer the possibility for developing geothermal energy from boreholes that would normally be plugged. In 1981, for instance, the total number of wells drilled in Oklahoma in search of oil and gas was 11,300, of which 2,826 were noncommercial and were plugged and abandoned. Exploratory or wildcat oil and gas wells totalled 651, of which 405 were noncommercial. Since such holes could not be economically drilled for geothermal applications alone, the availability of these deep wells becomes an important consideration. Once the initial cost of drilling these wells has been borne by industry, the possibility of completing such holes for geothermal use becomes more realistic. The absence of reliable published temperature data, as well as abundant alternative heat sources, has probably contributed to the lack of development of deep (3,000 m or more), low-temperature geothermal waters.

The principal purpose of this map is to provide potential users with approximate temperature-gradient information throughout the State of Oklahoma. These data, in turn, may be used to aid in the development of low-temperature waters for direct-heat applications.

This map portrays representative temperature-gradient information for various regions in Oklahoma. Subsurface temperature measurements used to calculate temperature gradients were obtained from bottom-hole pressure tests in shut-in gas wells, temperature logs of wells, and (or) bottom-hole temperature measurements on well logs. The township is the basic unit for posting gradient information. A gradient value can be a composite of temperature information derived from a number of wells within a township and (or) represent temperature data obtained from a single well. Because of space limitations, not all temperature-gradient values are shown on the map. More detailed information can be found in Cheung (1978).

Depending on the availability of the data sources, the temperature gradient was determined by one of the following methods: (1) reliable temperature data at different depths, (2) one reliable value at depth and an assumed near-surface temperature, or (3) corrected bottom-hole temperature and an assumed near-surface temperature. Using one of the above techniques, the temperature gradient was determined for more than 2,000 townships in Oklahoma. These data were contoured to produce a generalized geothermal-gradient map of Oklahoma (fig. 3).

Temperature data derived from bottom-hole-pressure tests and bottom-hole temperature measurements in air-drilled wells are considered to be the most reliable. Unfortunately, pressure tests are limited to predominantly gas-producing regions in the State, and air-drilled-well data are generally restricted to the Arkoma Basin.

Where reliable temperature data are available for essentially one depth in a well, that temperature and an average temperature value at a shallow depth were used to determine the gradient. Temperature-depth plots from reliable temperature data were used to establish an average temperature of 20.6°C (69°F) at 152 m (500 ft) as an upper control value. The mean annual surface temperature was not used as an upper control value, because surface temperature may be affected by soil type, moisture content, vegetation, climate, topography, and (or) ground water.

More than half of the well-temperature data available in Oklahoma comes from bottom-hole temperature measurements reported from oil- and gas-well logs for mud-drilled wells. Generally, these temperature recordings are lower than actual formation temperatures because of the cooling effect of the drilling mud. Therefore, a correction curve was developed for these data by comparing the differences between bottom-hole temperatures and equilibrated temperatures as a function of depth (Cheung, 1978). The correction curve suggests that at depths between 915 and 1,220 m, bottom-hole temperatures approximate formation temperatures and at a depth of 3,050 m the differences between the two temperatures are as much as 17.8°C (32°F).

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BASE MAP EXPLANATION

🟨	Indian reservation
▨	Military reservation
🟩	National recreation area, national wildlife refuge, state park, or state game preserve
🟩	National forest or national grassland

Private land may exist within federal boundaries

—	Interstate highway
—	U.S. highway
—	State highway
—	Other principal roads

POPULATION KEY

OKLAHOMA CITY	more than 100,000
LAWTON	50,000 to 100,000
Ponca City	10,000 to 50,000
Vinita	2,500 to 10,000
Buffalo	less than 2,500

Population indicated by size of letters

✪	State capital
⦿	County seat
○	City, town, or village
✈	Scheduled service airport
🟨	Built-up area shown for towns over 10,000 population

MAP EXPLANATION

Low-Temperature Geothermal Waters

● Area most favorable for development of low-temperature (lower than 90°C) geothermal resources as indicated by above-normal temperature gradients, bottom-hole temperatures, and (or) known and inferred presence of favorable reservoir rocks. Temperature gradients within this area generally exceed 34°C/km. At least three Pennsylvanian sandstone units—the Spiro, Cromwell, and Hartshorne—have potential for geothermal development. A preliminary summary of formation characteristics and minimum water-in-place estimates for the Hartshorne, Spiro, and Cromwell sandstones is listed in table 1.

Formation characteristics and in-place water-volume estimates are only approximations. The formation-water quality is poor, with salinity values that frequently exceed 50,000 mg/L. Site-specific areas, which may be considered for geothermal applications, should be subjected to detailed studies.

Existing knowledge does not permit the inference that thermal water may be found everywhere, nor exclusively, within the gray areas, nor do the boundaries represent certain knowledge of the areal extent of geothermal systems or aquifers.

Table 1. Summary of Formation Characteristics and Minimum Water-in-Place Estimates For Hartshorne, Spiro, and Cromwell Sandstones (Harrison and others, 1983)

Formation	Average Depth (m)	Average Thickness (m)	Average Porosity (%)	Water-Saturation Range (%)	Average Temperature (°C)[a]	Minimum Water in Place (bbl)[b]
Hartshorne	780	21.3	10	12-58	39.4	640,896,000
Spiro	1,609	11.3	14	10-98	66.1	771,727,000
Cromwell	1,745	13.1	18	5-39	70.	761,424,000

[a] Calculated from uncorrected bottom-hole temperature.
[b] 159 L/bbl or 42 gal/bbl

Temperature-Gradient Information

■ A 22.1°C/km	Gradient determined from reliable temperature data at different depths
■ B 25.3°C/km	Gradient determined from one reliable value at depth and an assumed near-surface temperature
■ C 25.3°C/km	Gradient determined from corrected bottom-hole temperature and an assumed near-surface temperature
□ D 64.5°C/km	Abnormal-temperature gradient within the Morrow-Springer (Lower Pennsylvanian-Upper Mississippian) section, determined from bottom-hole temperatures only
□ E 40.8°C/km	Abnormal-temperature gradient within the Morrow-Springer (Lower Pennsylvanian-Upper Mississippian) section, determined from reported shut-in-pressure tests

(Temperature gradient given in °C/km; shown next to symbol)

⬭	Abnormal-pressure zone

Metric Conversion Factors

1 liter = .2642 gallon
1 meter = 3.281 feet
1 milligram/liter = 1 part per million
°Celsius = 5/9 (°Fahrenheit − 32)
°Fahrenheit = 9/5 °Celsius + 32

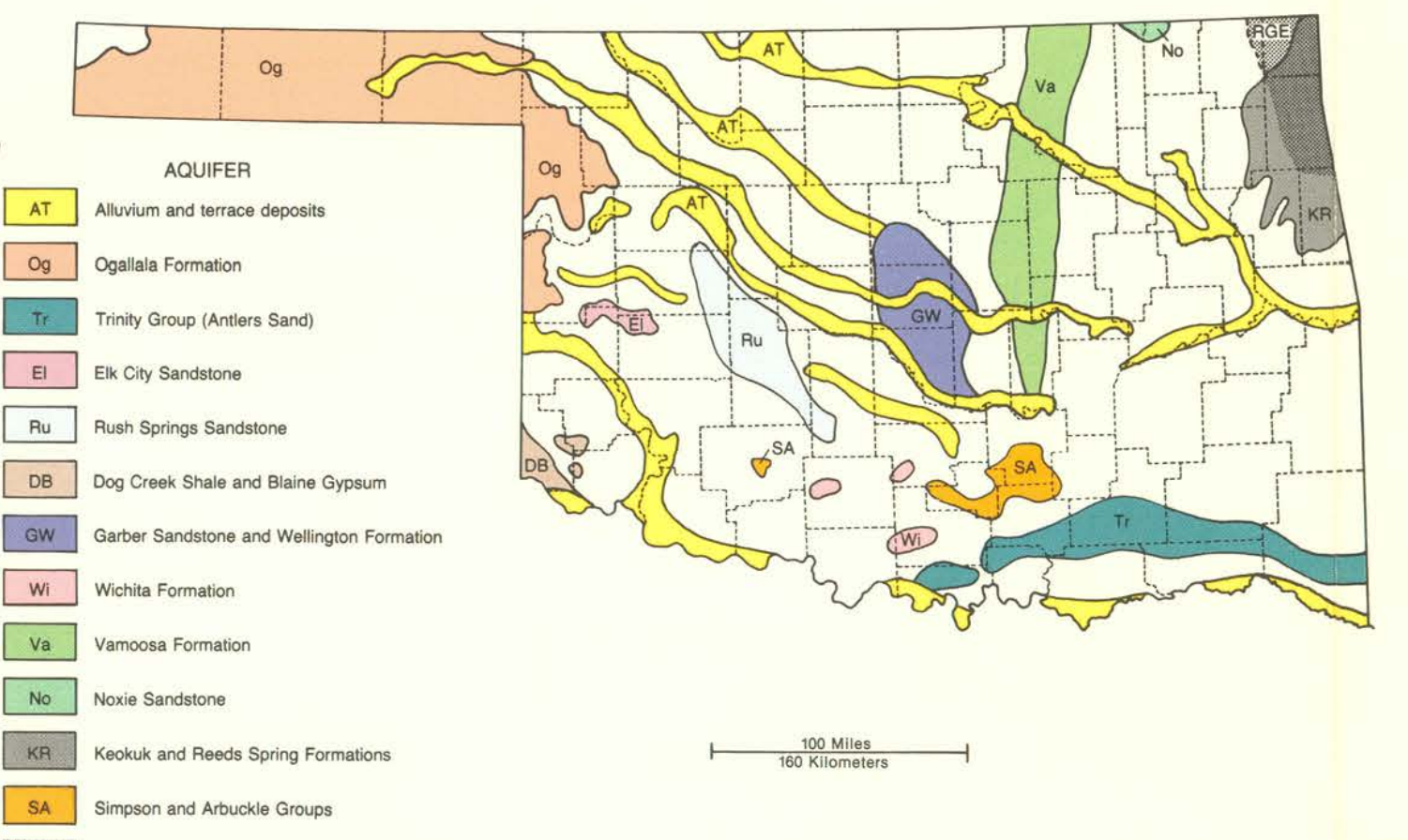

Figure 1. Major sources of ground water in Oklahoma (modified from Johnson and others, 1972, p. 8).

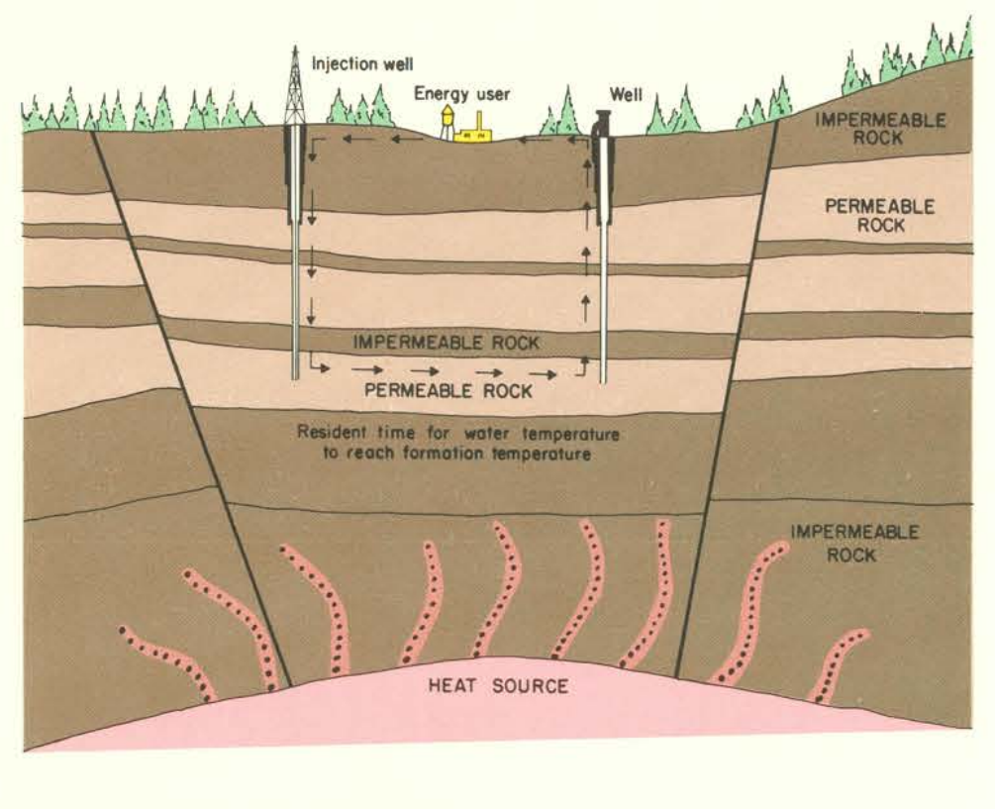

Figure 2. Schematic diagram illustrating possible development of a low-temperature geothermal resource using abandoned oil and (or) gas wells.

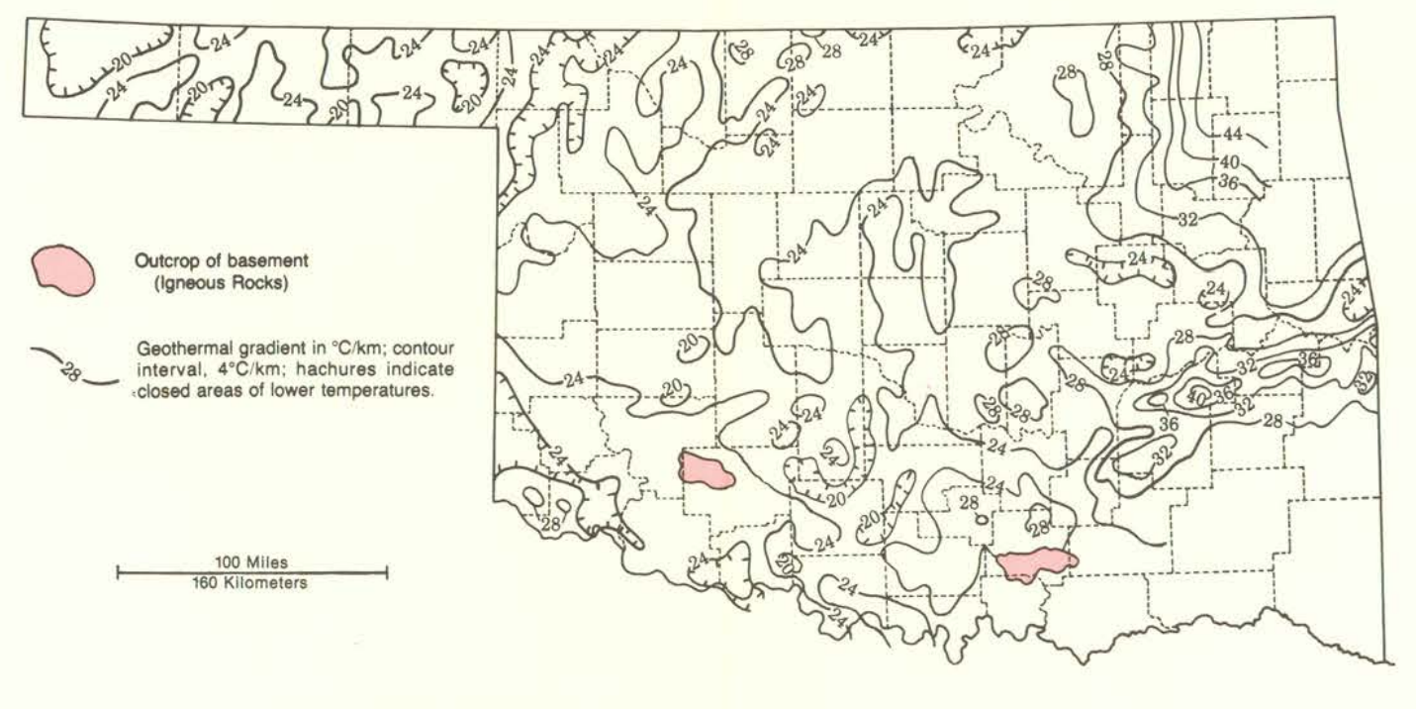

Figure 3. Geothermal-gradient map of Oklahoma (modified from Cheung, 1979).

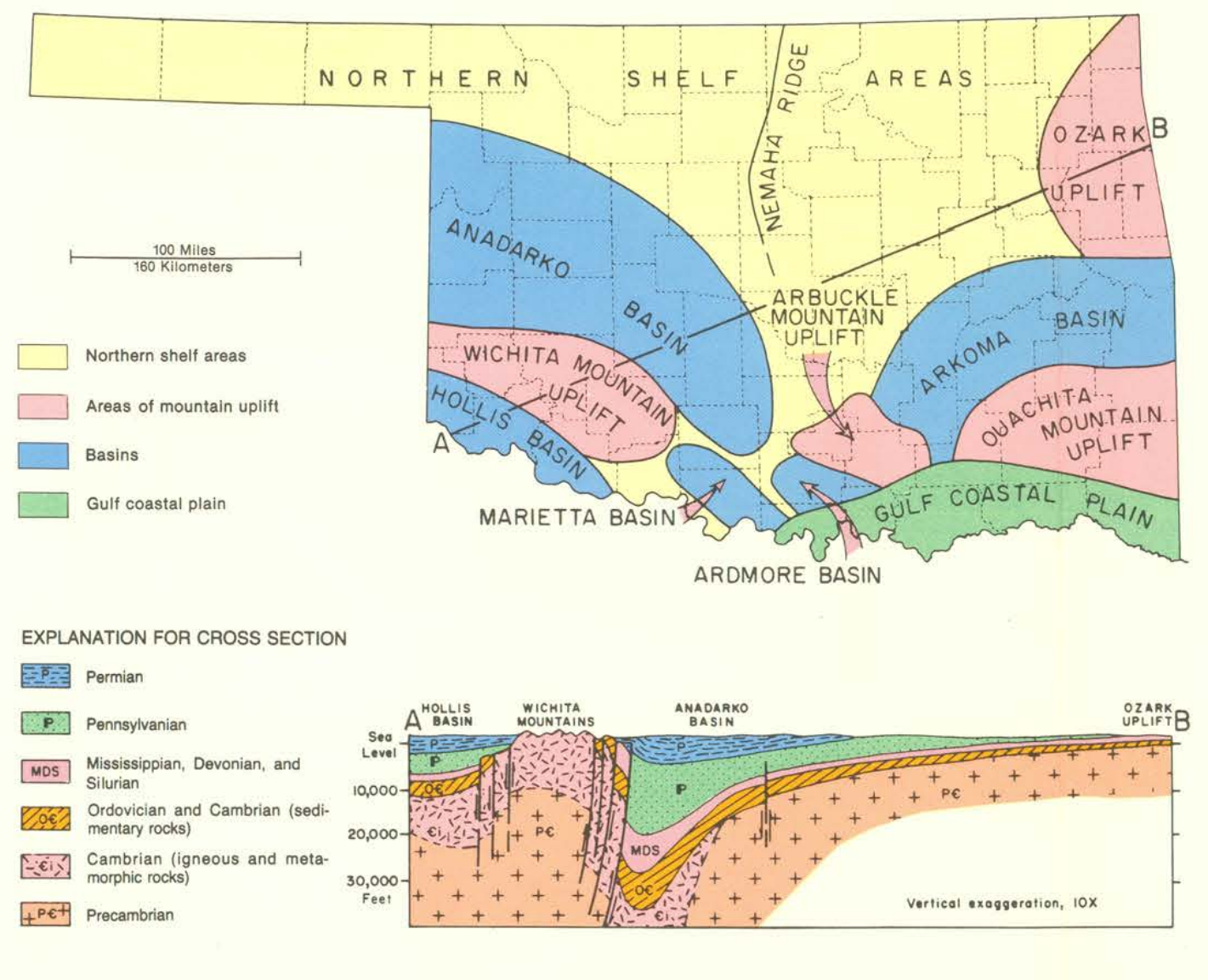

Figure 4. Major geologic and tectonic provinces of Oklahoma.

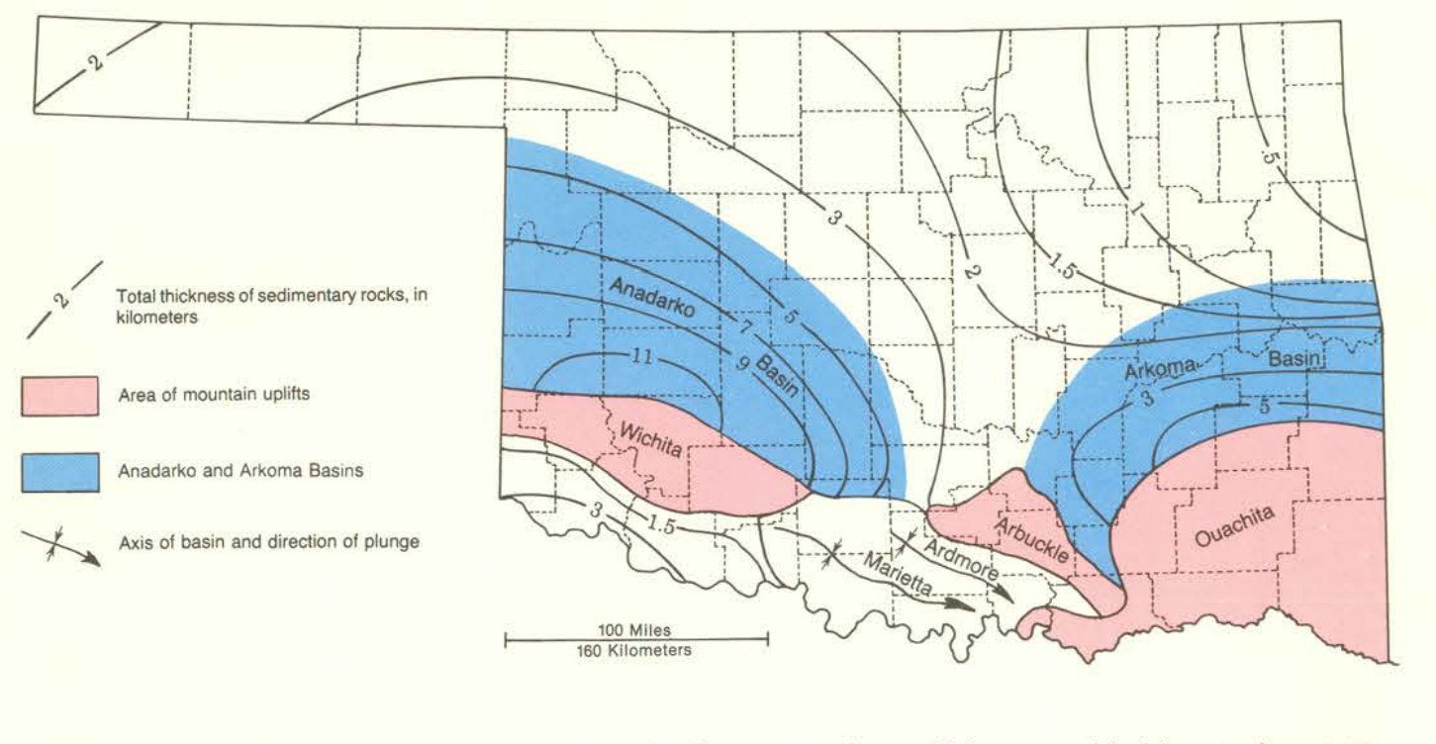

Figure 5. Generalized map showing total thickness of sedimentary rocks in Oklahoma (modified from Jordan, 1967). Sedimentary rocks overlie a basement of Precambrian and Cambrian igneous and metamorphic rocks. Sedimentary rocks over Wichita Mountain Uplift are generally thin (0 to 0.6 km); sedimentary rocks over Arbuckle Mountain Uplift range from 0 to 4 km thick; sedimentary rocks in Ouachita Mountain Uplift are 6 to 9 km thick; sedimentary rocks in the Ardmore and Marietta Basins are 6 to 9 km and 3 to 6 km thick, respectively.