Prepared in cooperation with
Oklahoma Water Resources Board and U.S. Army Corps of Engineers

Abstract

The Boone and Roubidoux aquifers (or their equivalents) are the main sources of fresh groundwater in northeastern Oklahoma. Projected total water demand of both surface water and groundwater in northeastern Oklahoma is expected to increase approximately 56 percent from 2010 to 2060. This report provides an overview of the hydrogeology of northeastern Oklahoma, with an emphasis on the hydrogeologic units composing and surrounding the Boone and Roubidoux aquifers (the Western Interior Plains confining unit, the Boone aquifer, the Ozark confining unit, and the Roubidoux aquifer). This report also provides the hydrogeologic framework for an ongoing (as of 2020) hydrologic investigation to aid the Oklahoma Water Resources Board in determining the maximum annual yields of the Boone and Roubidoux aquifers. As a first step of this ongoing hydrologic investigation, the U.S. Geological Survey, in cooperation with the Oklahoma Water Resources Board and U.S. Army Corps of Engineers, developed hydrogeologic-unit maps, contour maps for the bases of the four hydrogeologic units, and generalized cross sections to further characterize the hydrogeologic framework of the Boone and Roubidoux aquifers. The contour maps illustrate the altitudes of the bases of each hydrogeologic unit. The altitude of the base of the Western Interior Plains confining unit ranged from 1,316 to −6,437 feet (ft) relative to North American Vertical Datum of 1988. The altitude of the base of the Boone aquifer ranged from 1,327 to −6,681 ft. The altitude of the base of the Ozark confining unit ranged from 1,275 to −6,720 ft. The altitude of the base of the Roubidoux aquifer ranged from 403 to −9,488 ft.

Introduction

The Boone and Roubidoux aquifers (or their hydrogeologic-unit equivalents, figs. 1 and 2) are aquifers within the Ozark Plateaus aquifer system underlying approximately 34,000 and 68,000 square miles (mi^2), respectively, of parts of multiple States (Arkansas, Kansas, Missouri, and Oklahoma) (Westerman and others, 2016a). These aquifers are important sources of fresh groundwater in northeastern Oklahoma (Oklahoma Water Resources Board [OWRB], 2012). The Boone aquifer is categorized as a minor aquifer (average well yield less than 50 gallons per minute), and the Roubidoux aquifer is categorized as a major aquifer (average well yield greater than 50 gallons per minute) by the OWRB (2012). Groundwater from the Boone aquifer is used primarily for domestic purposes in addition to some agricultural, commercial, and public water uses, whereas the Roubidoux aquifer is used for industrial purposes and public supply (OWRB, 2012). In 2010, the Grand region and Lower Arkansas region basins, which overlie most of the aquifers in northeastern Oklahoma, used approximately 37,300 acre-feet per year and 201,890 acre-feet per year, respectively, of surface water and groundwater combined (OWRB, 2012).

In 2017, the U.S. Geological Survey (USGS) and OWRB started a hydrologic investigation to determine maximum annual yields of the Boone and Roubidoux aquifers. Determination of the maximum annual yield obtained by a hydrologic investigation is mandatory according to 1973 Oklahoma water law (Oklahoma Statutes Title 82 Section 1020.5). The maximum annual yield is the total amount of fresh groundwater, which is defined by the OWRB as water with less than 5,000 parts per million total dissolved solids, that can be withdrawn per year while allowing a minimum 20-year life of the groundwater basin or aquifer (OWRB, 2010). As of 2020, the maximum annual yields of the Boone and Roubidoux aquifers have not yet been determined. As a first step of this ongoing hydrologic investigation, the USGS, in cooperation with the OWRB and U.S. Army Corps of Engineers, developed hydrogeologic-unit maps, base-of-aquifer contour maps, and generalized cross sections to further characterize the hydrogeologic framework of the Boone and Roubidoux aquifers.

Purpose and Scope

The purpose of this report is to provide an overview of the hydrogeology of northeastern Oklahoma, with an emphasis on the Boone and Roubidoux aquifers. This report focuses on the following hydrogeologic units (listed from youngest to oldest): the Western Interior Plains confining unit, the Boone aquifer, the Ozark confining unit, and the Roubidoux aquifer (figs. 1 and 2). Because these four hydrogeologic units extend beyond Oklahoma, the overview of the hydrogeology of the Boone and Roubidoux aquifers includes parts of Arkansas, Kansas, and Missouri (fig. 1). The primary focus of this report is the area in northeastern Oklahoma that contains the four hydrogeologic units of interest. This report provides the hydrogeologic framework for the ongoing (as of 2020) hydrologic investigation to aid the OWRB in determining the maximum annual yields for both aquifers.

Description of Study Area

The study area for this report consists of the southwest part of the Ozark Plateaus aquifer system that underlies approximately 11,000 mi^2 of a large part of northeastern Oklahoma, as well as parts of Arkansas, Kansas, and Missouri (see inset map in fig. 1). The Boone aquifer is present in approximately 10,700 mi^2 of the study area, and the Roubidoux aquifer is present throughout. The average annual precipitation within the study area from 1981 through 2010 was approximately 46.7 inches per year, and average annual temperatures ranged from highs of 69 degrees Fahrenheit (°F) to lows of 47 °F (PRISM Climate Group, 2019). The average temperatures from 1981 through 2010 for warmer months, such as July, were as high as 90 °F, and the average temperatures for colder months, such as January, were as low as 25 °F (PRISM Climate Group, 2019). The study area is mostly undeveloped and primarily consists of pastureland, deciduous forest, and cropland (USGS, 2011). However, total water demand in northeastern Oklahoma is increasing rapidly, with surface water and groundwater demand for northeastern Oklahoma expected to increase by approximately 56 percent from 2010 to 2060 (OWRB, 2012).

Data Sources

The data used to create the hydrogeologic framework presented in this report were derived and modified from Westerman and others (2016a) and are provided in a companion data release (Russell, 2020). Westerman and others (2016a) created a three-dimensional hydrogeologic framework to describe the regional geology of the Ozark Plateaus aquifer system underlying approximately 70,000 mi^2 of Arkansas, Kansas, Missouri, and Oklahoma. The hydrogeologic framework constructed by Westerman and others (2016a) was derived from more than 23,000 individual altitude points gathered from drillers' logs, geophysical logs, lithologic logs, and borehole data. Additional data used in this report include fault data from the following sources: Stoeser and others (2005), Chandler and others (2009), Marsh and Holland (2016), Westerman and others (2016b), and Hutto and Hatzell (2017). The hydrogeologic-unit names in this report are consistent with those used in Oklahoma (Osborn, 2001; Czarnecki and others, 2009) and may differ from those used in regional reports describing the Ozark Plateaus aquifer system (Imes and Emmett, 1994; Westerman and others, 2016b). For example, the Springfield Plateau aquifer in previous regional reports is referred to as the "Boone aquifer" in Oklahoma (fig. 2).

Methods

The hydrogeologic-unit maps and base-of-aquifer contour maps of the hydrogeologic units of the Boone and Roubidoux aquifers in the study area were created in ArcMap 10.5 by using data from Westerman and others (2016a). The focus of this report is to describe the base of each hydrogeologic unit; therefore, some modifications were made to the hydrogeologic framework published by Westerman and others (2016a), which published data on unit tops. Modifications included merging multiple digital elevation models (DEMs) from Westerman and others (2016a); Westerman and others (2016a) had divided the Roubidoux aquifer into three individual units because it suited the needs of their investigation better. Additional modifications made to the Westerman and others (2016a) DEMs included clipping the data to match their geologic extents.

Cross sections for all hydrogeologic units were constructed using these DEM files modified from Westerman and others (2016a) along with a 10-meter DEM (Gesch and others, 2002; Gesch, 2007; USGS, 2019) for the land-surface elevations. These cross sections were drawn in ArcMap 10.5, and elevations of land surface (USGS, 2019) and hydrogeologic-unit bases (modified from Westerman and others, 2016a, as described above) were extracted from the DEMs by using the Interpolate Shape tool (Esri, 2019a). The extracted elevations were converted to the American Standard Code for Information Interchange (ASCII) format by using the Feature Class Z to ASCII tool (Esri, 2019b) and compiled as graphs in Excel.

Description of Hydrogeologic Units

The Western Interior Plains confining unit is exposed at the surface within much of the northwestern and southern parts of this report's study area where it has not eroded away (fig. 1). This confining unit has a mean thickness of 1,125 feet (ft) within the study area (Westerman and others, 2016a), and it is composed of Pennsylvanian-age and Mississippian-age limestone, shale, and sandstone (Imes and Emmett, 1994) (fig. 2). These Mississippian-age rocks are relatively impermeable; however, there is a possibility that the more permeable rocks, such as the limestone or sandstone, could contain permeable zones on a local scale (Imes and Emmett, 1994).

The rocks composing the Boone aquifer are exposed at land surface in much of the study area (fig. 1). The Boone aquifer is mostly an unconfined aquifer except where it is confined by the Western Interior Plains confining unit in the southern and northwestern parts of the study area. The aquifer is composed of carbonate rocks with a mean thickness of 254 ft over the study area (Westerman and others, 2016a). These carbonate rocks consist mostly of Mississippian-age limestone, notably the Boone, Keokuk, and Moorefield Formations in Oklahoma (Imes and Emmett, 1994) (fig. 2). The Boone aquifer is karstic and therefore contains sinkholes, caves, and enlarged fractures (Kresic, 2013).

The low-permeability Ozark confining unit underlies the Boone aquifer and is relatively thin, having a mean thickness of 37 ft over the study area (Westerman and others, 2016a). This confining unit has outcrop areas in river valleys in the study area (fig. 1). The Ozark confining unit is composed primarily of the Chattanooga Shale of Devonian age, but the Northview Shale equivalent and Compton Limestone equivalent of Mississippian age and the Woodford Chert of Devonian age are also present in some parts of the study area (Imes and Emmett, 1994) (fig. 2).

The Roubidoux aquifer underlies the Ozark confining unit and is composed of mostly Ordovician-age and Cambrian-age dolomites with interbedded limestone and sandstone (Imes and Emmett, 1994; Westerman and others, 2016b) (fig. 2). Within the study area, the mean thickness of the rocks containing the Roubidoux aquifer is 1,562 ft (Westerman and others, 2016a). The Roubidoux aquifer is typically more than several hundred feet below land surface within the study area. However, the rocks that compose this aquifer are exposed at land surface around Beaver Lake in Arkansas, along tributaries of Elk River in Missouri and Arkansas, and along parts of the Illinois River and Baron Fork in Oklahoma (fig. 1). The Roubidoux aquifer is also confined by the St. Francois confining unit beneath it, which is composed of shale, siltstone, dolostone, and limestone of Cambrian age (Imes and Emmett, 1994).

Faulting occurs throughout the study area, but only major faults are shown in figure 1. These major faults include the Seneca Fault, the Bentonville-Pea Ridge Fault, and the Drakes Creek Fault. The Seneca Fault is the prominent fault within Oklahoma, stretching from Mayes County through Delaware and Ottawa Counties and into Missouri (fig. 1). These faults are important because they can act as catalysts within karst systems by allowing for conduits or caves to form (Kresic, 2013). Multiple publications such as Huffman (1958), Marcher and Bingham (1971), and Marsh and Holland (2016) have described faults within northeastern Oklahoma; however, the depths of these faults are unknown.

Cross Sections

Three hydrogeologic cross sections (north to south [*A* to *A′*], southwest to northeast [*B* to *B′*], and west to east [*C* to *C′*]; fig. 1) were drawn with 57 times vertical exaggeration to illustrate the dip of hydrogeologic units in the subsurface (fig. 3). The cross sections do not include fault data because there is scant information on the angle and extent of the mapped faults. The dashed lines within the rocks composing the Roubidoux aquifer show hydrogeologic subunits from Westerman and others (2016a, 2016b) (fig. 3).

The hydrogeologic units in these cross sections dip westward and southward (fig. 3). In the southern part of the study area where these units dip below the Western Interior Plains confining unit, the rocks composing the Boone aquifer can reach depths in excess of 2,000 ft below land surface (fig. 3*A*). The cross sections show the effects of erosion due to streams, which have completely removed the rocks composing the Boone aquifer and the Ozark confining unit in the Illinois River and Baron Fork (fig. 3*A*). Erosion has also caused thinning or complete removal of some older units, such as where the upper part of the rocks composing the Roubidoux aquifer is absent in the northern part of cross section *A* to *A′* and in all of cross section *C* to *C′* (fig. 3*A* and *C*).

Contour Maps

Contour maps of the Western Interior Plains confining unit, Boone aquifer, Ozark confining unit, and Roubidoux aquifer (fig. 4) illustrate the altitude of the base of each hydrogeologic unit. The contour maps of the bases of the four hydrogeologic units were drawn using 100-ft contour intervals with 200-ft contour index intervals presented throughout the extent of each unit. The contour interval was increased to 200-ft contour intervals at the southern end of each contour map, where hydrogeologic units dip steeply. In some areas the hydrogeologic units have been completely removed by erosion and were labeled with "unit not present" on the maps.

The altitude of the base of the Western Interior Plains confining unit ranged from 1,316 to −6,437 ft relative to North American Vertical Datum of 1988 (fig. 4*A*). The altitude of the base of the Boone aquifer ranged from 1,327 to −6,681 ft (fig. 4*B*). The altitude of the base of the Ozark confining unit ranged from 1,275 to −6,720 ft (fig. 4*C*). The altitude of the base of the Roubidoux aquifer ranged from 403 to −9,488 ft (fig. 4*D*).

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EXPLANATION OF HYDROGEOLOGIC UNITS

Geologic period	Northeastern Oklahoma	Northern Arkansas	Southwestern Missouri	Southeastern Kansas	Hydrogeologic units/systems: regional naming conventions	Hydrogeologic units: Oklahoma naming conventions	Map abbreviations and colors
Pennsylvanian	Marmaton Group Cabiniss Group[1] Krebs Group Atoka Formation Bloyd Shale Hale Formation	McAlester Formation Hartshorne Sandstone Atoka Formation Bloyd Shale Hale Formation	Kansas City Group Pleasanton Formation Marmaton Group Cherokee Group	Kansas City Group Pleasanton Formation Marmaton Group Cherokee Group	Western Interior Plains confining system	Western Interior Plains confining unit[2]	Wipcu
Mississippian	Pitkin Limestone Fayetteville Shale Batesville Sandstone Hindsville Limestone	Pitkin Limestone Fayetteville Shale Batesville Sandstone	Fayetteville Shale Batesville Sandstone Hindsville Limestone Carterville Formation	Not present			
	Moorefield Formation[3] Keokuk Limestone[4] Boone Formation Reeds Spring Member St. Joe Limestone Member	Moorefield Formation Boone Formation Reeds Spring Member St. Joe Limestone Member	St. Louis Limestone Salem Formation Warsaw Limestone Keokuk Limestone Burlington Limestone Elsey Formation Reeds Spring Formation Pierson Limestone	St. Louis Limestone Salem Formation Warsaw Limestone Keokuk Limestone Burlington Limestone Fern Glen Limestone	Springfield Plateau aquifer Ozark Plateaus aquifer system	Boone aquifer	Ba
	Northview Shale equivalent Compton Limestone equivalent	Not present	Northview Shale Sedalia Limestone Compton Limestone	Chouteau Limestone	Ozark confining unit	Ozark confining unit	Ocu
Devonian	Woodford Chert Chattanooga Shale	Chattanooga Shale	Chattanooga Shale	Chattanooga Shale			
	Sallisaw Formation Frisco Limestone	Clifty Limestone Penters Chert	Callaway Limestone Fortune Formation[5]		Upper part of Ozark aquifer	Roubidoux aquifer	Ra
Silurian	St. Clair Limestone	Lafferty Limestone St. Clair Limestone Brassfield Limestone					
Ordovician	Sylvan Shale Fernvale Limestone Viola Limestone Fite Limestone Tyner Formation Burgen Sandstone* Smithville Formation equivalent	Cason Shale Fernvale Limestone Kimmswick Limestone Plattin Limestone Joachim Dolomite St. Peter Sandstone Everton Formation Smithville Formation	Kimmswick Limestone Plattin Limestone Joachim Dolomite St. Peter Sandstone Everton Formation Smithville Formation				
	Arbuckle Group: Powell Dolomite	Powell Dolomite	Powell Dolomite	Arbuckle Group: Powell Dolomite			
	Arbuckle Group: Cotter Dolomite Jefferson City Dolomite	Cotter Dolomite Jefferson City Dolomite	Cotter Dolomite Jefferson City Dolomite	Arbuckle Group: Cotter Dolomite Jefferson City Dolomite	Middle part of Ozark aquifer		
	Arbuckle Group: Roubidoux Formation Gasconade Dolomite Gunter Sandstone Member	Roubidoux Formation Gasconade Dolomite Van Buren Formation Gunter Sandstone Member	Roubidoux Formation Gasconade Dolomite Gunter Sandstone Member	Arbuckle Group: Roubidoux Formation Gasconade Dolomite Gunter Sandstone Member	Lower part of Ozark aquifer		
Cambrian	Arbuckle Group: Eminence Dolomite Potosi Dolomite	Eminence Dolomite Potosi Dolomite	Eminence Dolomite Potosi Dolomite	Arbuckle Group: Eminence Dolomite Potosi Dolomite			
	Doe Run Dolomite[4] Derby Dolomite[1] Davis Formation[1]	Doe Run Dolomite[1] Derby Dolomite[1] Davis Formation[1]	Doe Run Formation Derby Formation Davis Formation	Doe Run Dolomite[1] Derby Dolomite[1] Davis Formation[1]	St. Francois confining unit	St. Francois confining unit	Sfcu
	Bonneterre Dolomite Reagan Sandstone** Lamotte Sandstone	Bonneterre Dolomite Reagan Sandstone[1] Lamotte Sandstone	Bonneterre Formation Reagan Sandstone Lamotte Sandstone	Bonneterre Dolomite Reagan Sandstone Lamotte Sandstone	St. Francois aquifer	St. Francois aquifer	Sfa
Precambrian	Spavinaw Granite[4]	Spavinaw terrane (informal)	Spavinaw terrane (informal)	Spavinaw terrane (informal)	Basement confining unit	Basement confining unit	Bcu
	Precambrian igneous and metamorphic rocks						

*Part of the Simpson Group.
**Part of the Timbered Hills Group.
[1]Unit follows usage of Imes and Emmett (1994).
[2]Unit follows naming convention used in Czarnecki and others (2009).
[3]Moorefield Formation has less shale and therefore a higher permeability in Oklahoma, so it is not a part of the Western Interior Plains confining unit within Oklahoma (Imes and Emmett, 1994).
[4]Unit follows usage of Oklahoma Water Resources Board (Osborn, 2001).
[5]Unit follows usage of Missouri Department of Natural Resources (Thompson, 2001).

Figure 2. Geologic and hydrogeologic units of the Boone and Roubidoux aquifers and comparisons of nomenclature between this study and previous studies (modified from Imes and Emmett, 1994; Osborn, 2001; Thompson, 2001; Czarnecki and others, 2009; Westerman and others, 2016b).

Datum

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Elevation, as used in this report, refers to distance above the vertical datum.

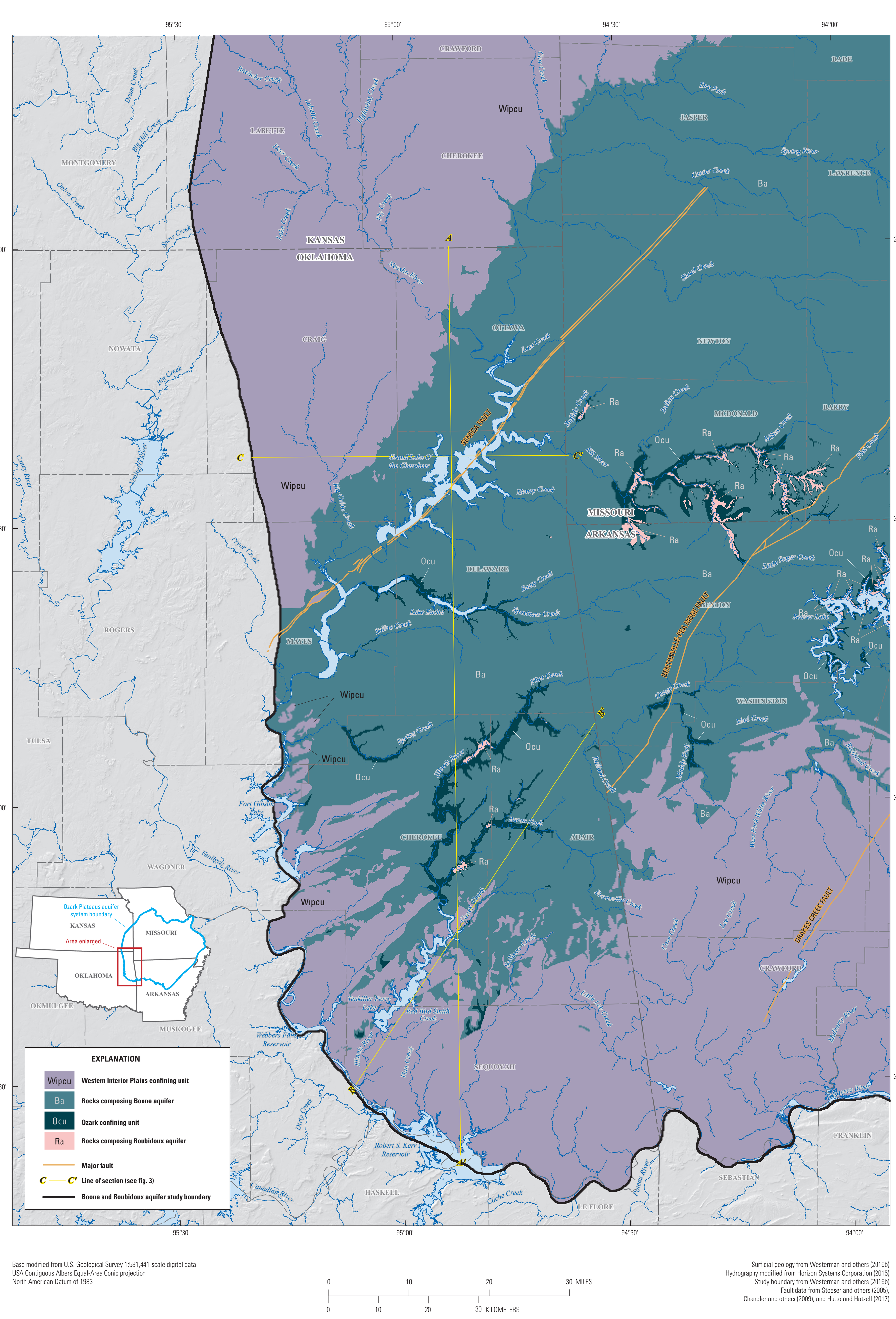

Figure 1. Surficial extents of hydrogeologic units and cross-section and major fault locations in the northeastern Oklahoma study area.

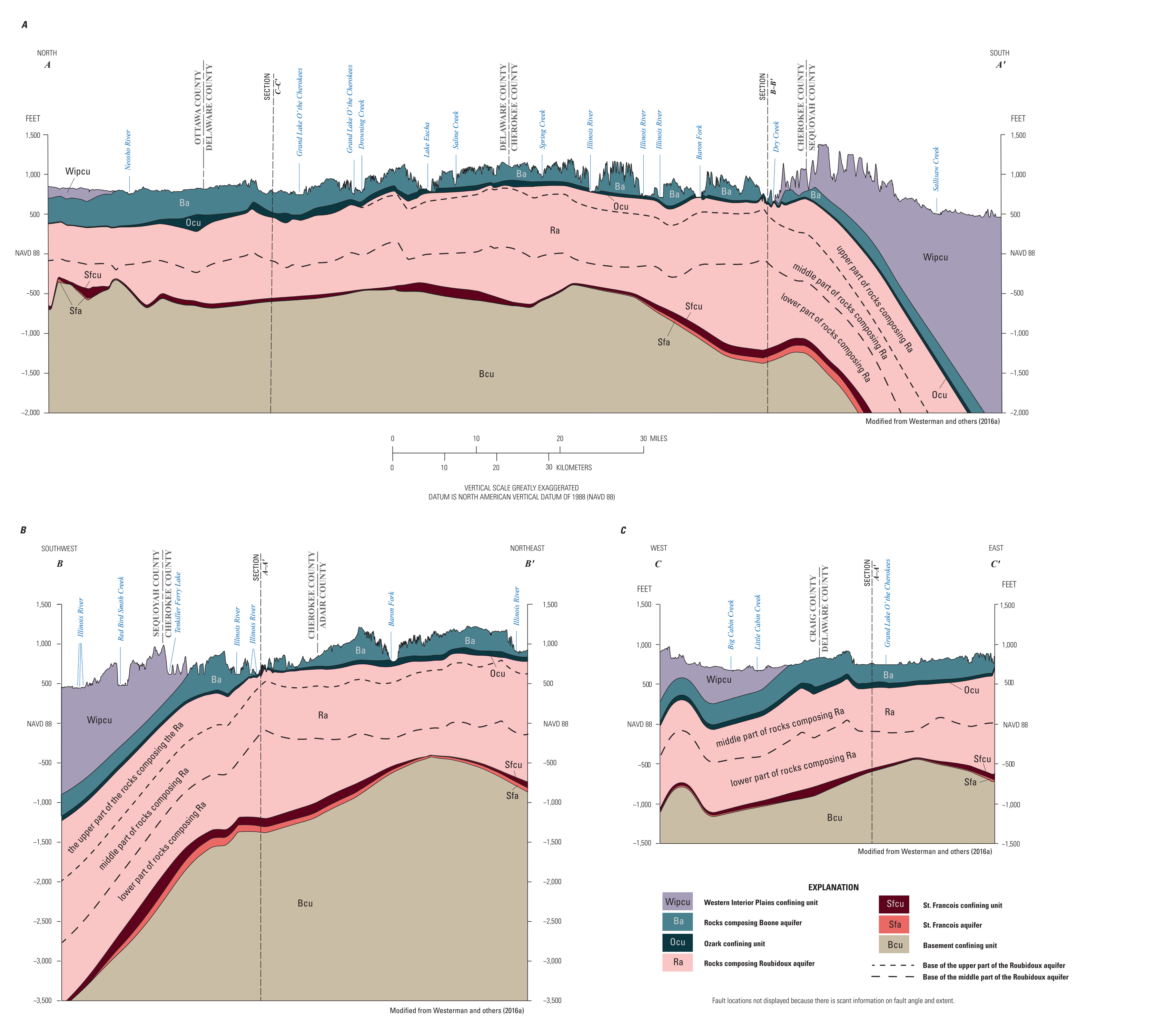

Figure 3. Hydrogeologic cross sections for *A*, line of section *A* to *A′*, from north to south; *B*, line of section *B* to *B′*, from southwest to northeast; and *C*, line of section *C* to *C′*, from west to east.

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Hydrogeologic Units, Contour Maps, and Cross Sections of the Boone and Roubidoux Aquifers, Northeastern Oklahoma, 2020

By
Cory A. Russell and Jacob W. Stivers

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