Lithium Resource in the Smackover Formation Brines of Southern Arkansas

Why Is Lithium Important?

Lithium is the lightest of all metals and is listed as a critical element by the U.S. Geological Survey (USGS) because of its importance in renewable energy. Lithium is also used widely in ceramics and glassmaking, along with other manufacturing industries. Lithium demand is expected to increase as the world transitions from hydrocarbon combustion engines to electric vehicles, which currently use lithium in the rechargeable batteries (Bradley and others, 2017).

Where Is Lithium Found?

Lithium is found in some igneous rocks and clay deposits throughout the world and is dissolved in subsurface brines, which are characterized as water with high salinity (Bradley and others, 2017). Lithium-rich brine deposits occur throughout the United States, including in the Smackover Formation. The Smackover Formation is a geologic unit of Jurassic age that extends across the Gulf Coast region from Texas to Florida (fig. 1). The Smackover Formation is approximately 2,000 feet deep at its northern extent to more than 22,000 feet deep further south (American Association of Petroleum Geologists, 2023). Brines, including dissolved lithium, occur within voids—or pore space—between mineral grains of the Smackover

Formation (fig. 2). Generally, the upper part of the Smackover Formation has higher porosity than the lower part and is referred to informally as the Reynolds oolite (Akin and Graves, 1969).

How High Are Lithium Concentrations in the Smackover Formation?

Based on historical (1965 through 2018) and newly collected (2022) brine geochemical data, lithium concentrations range from approximately 1 to 477 milligrams per liter (mg/L) in the Smackover Formation across the Gulf Coast (fig. 1) (Blondes and others, 2023; Knierim and others, 2024a, b). Many wells with brine lithium concentrations greater than 100 mg/L are in southwestern Arkansas, especially in Lafayette, Columbia, and Union Counties. Lithium concentrations greater than 500 mg/L were observed in brine samples collected in the 1960s in southern Arkansas (Blondes and others, 2023); however, these concentrations could not be verified from the source information, and similarly high lithium concentrations were not measured during more recent sampling near the historical locations (Knierim and others, 2024a, b).

Scientists from the USGS and the Arkansas Department of Energy and Environment's Office of the State Geologist visit an oil well with an operator to collect brine samples. Photograph by Katherine Knierim, USGS.

USGS scientists Andrew Masterson, Colin Doolan, and Katherine Knierim have a tailgate safety meeting prior to sampling brines at a well site. Photograph by Amanda Herzberg, USGS.
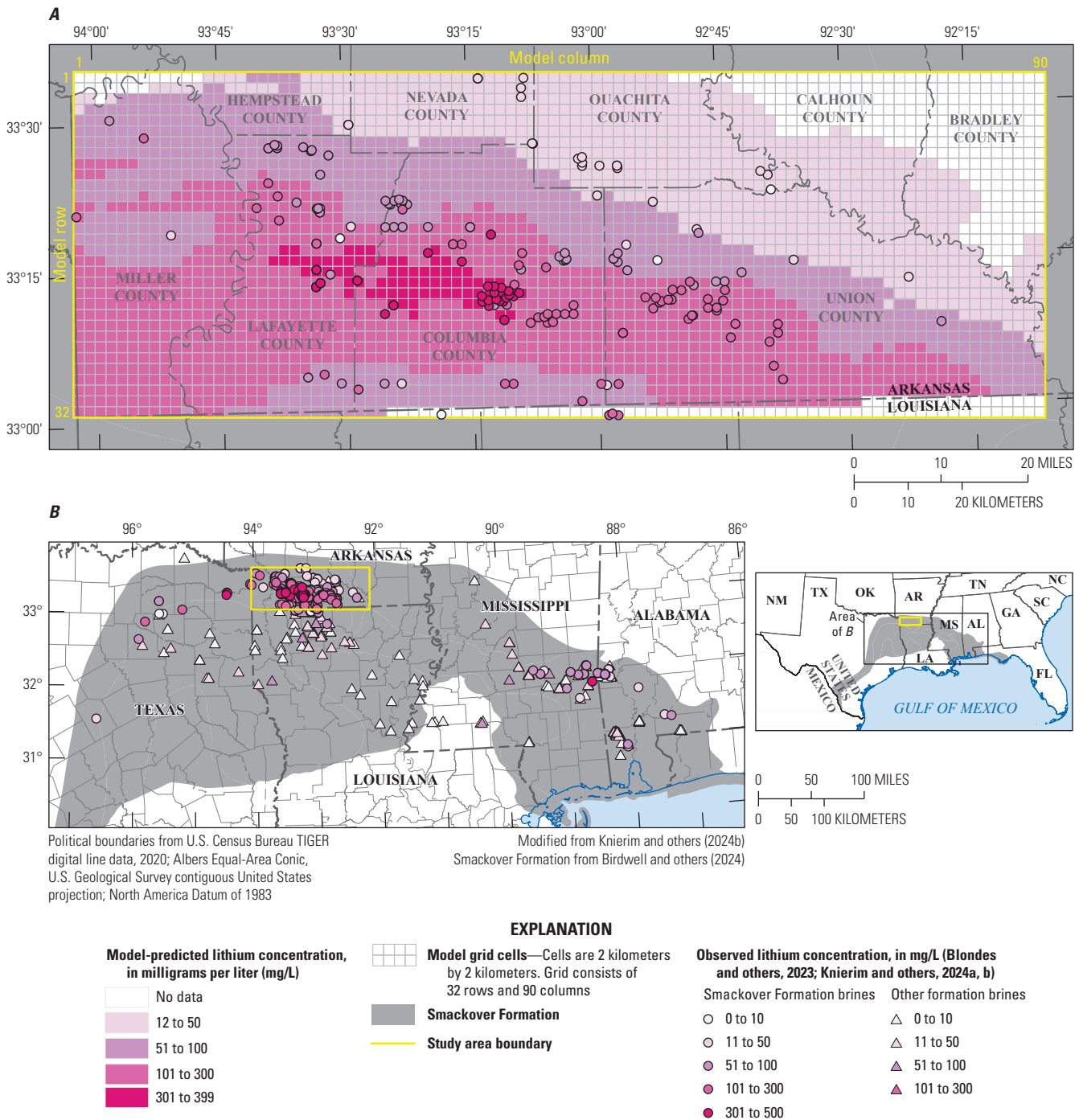
Figure 1. *A, B,* Observed lithium concentrations in brine samples from the Smackover Formation and model-predicted lithium concentrations throughout the Smackover Formation in southern Arkansas and *B,* observed lithium concentrations in brine samples from the Smackover Formation and other geologic units across the Gulf Coast region.

How Do You Measure Lithium in Brine Samples?

Brine is produced as a waste product during petroleum extraction from oil and gas wells. Brine samples are collected from oil, gas, or brine wells, filtered, and analyzed for dissolved lithium and many other constituents in laboratories. In 2022, the USGS, in cooperation with the Arkansas Department of Energy and Environment, Office of the State Geologist, collected brine samples in southern Arkansas for analysis at the USGS Brine Research Instrumentation and Experimental Laboratory (BRInE) in Reston, Virginia (https://www.usgs.gov/labs/brine-research-instrumentation-and-experimental-laboratory) (Knierim and others, 2024a, b). The concentration of lithium is measured based on its dissolved ionic form rather than as a solid.

How Much Lithium Is in the Smackover Formation in Southern Arkansas?

The amount of lithium in the subsurface depends on both the volume of brine in the Smackover Formation and the concentration of lithium within that brine. The volume of brine in the Smackover Formation depends on the volume of rock and its porosity (fig. 2). The Reynolds oolite portion of the Smackover Formation varies from 0 feet (that is, pinching out) to more than 400 feet thick across southern Arkansas (fig. 2) (Akin and Graves, 1969). Porosity within the Reynolds oolite ranges from 0.5 to 31 percent, with average values between 10 and 31 percent in the region's oil reservoirs (Nehring Associates, 2019; Li, 2023). Therefore, the volume of brine in the Smackover Formation
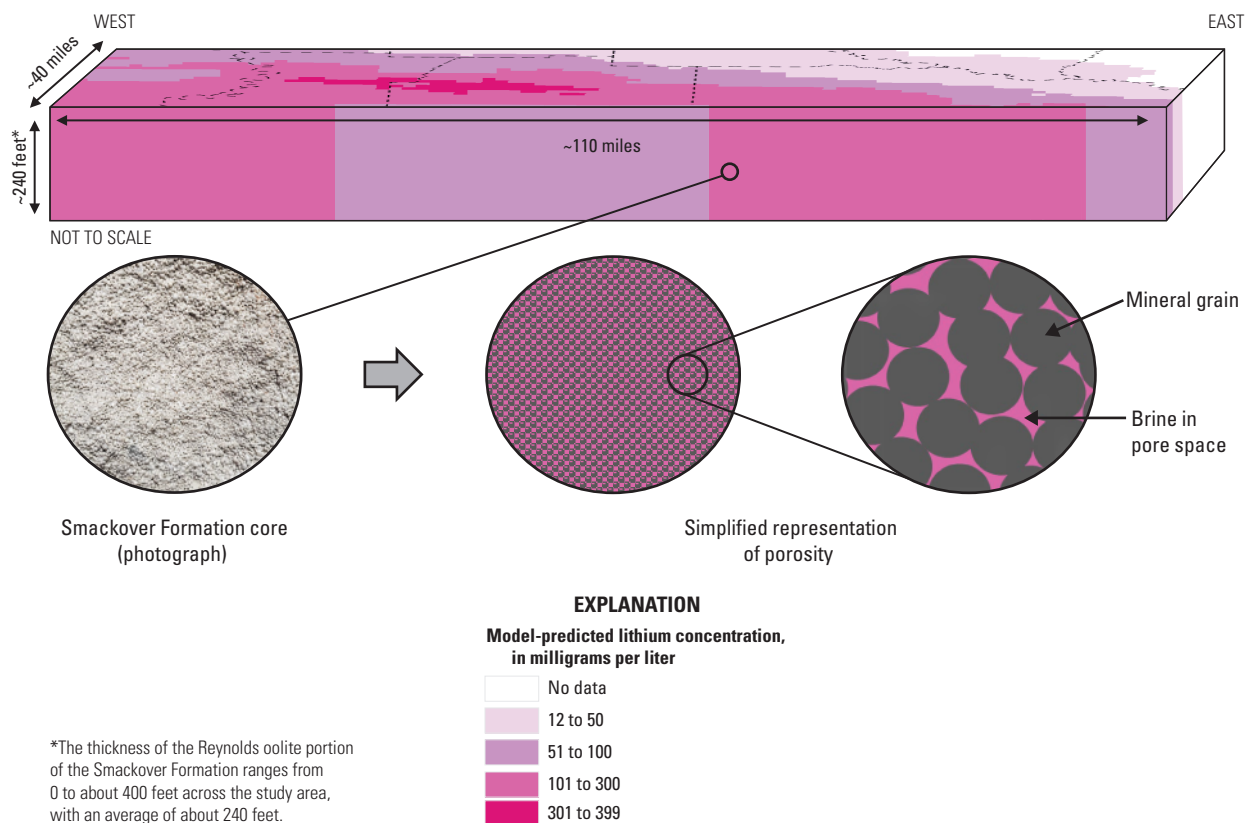
WEST

EAST

~40 miles

~240 feet*

~110 miles

NOT TO SCALE

Mineral grain

Brine in pore space

Smackover Formation core (photograph)

Simplified representation of porosity

EXPLANATION

Model-predicted lithium concentration, in milligrams per liter

	No data
	12 to 50
	51 to 100
	101 to 300
	301 to 399

*The thickness of the Reynolds oolite portion of the Smackover Formation ranges from 0 to about 400 feet across the study area, with an average of about 240 feet.

Figure 2. Idealized representation showing a "box model" of the Reynolds oolite portion of the Smackover Formation in southern Arkansas. The box model illustrates how the calculated amount of lithium in the subsurface (table 1) depends on both the volume of brine contained within the pore space of the Smackover Formation and the spatial variation in predicted lithium concentrations from the machine-learning model.

of southern Arkansas was calculated by using porosity values of 10, 20, and 30 percent to illustrate the possible range in the brine volume (table 1) (Knierim and others, 2024b).

The concentration of lithium in brines was predicted across southern Arkansas by using a machine-learning model that incorporated lithium concentration data and geologic information (fig. 1) (Knierim and others, 2024b). Machine learning can identify complex patterns in datasets (Kuhn and Johnson, 2016) and use the information to predict lithium concentrations in areas where samples are unavailable (fig. 1) (Knierim and others, 2024b). The variations in the machine-learning models were used to create "low," "median," and "high" lithium concentration prediction maps, providing a range of values that quantify uncertainty in the predictions of lithium concentration (table 1) (Knierim and others, 2024b). Lithium concentrations were predicted at a model resolution of about 1.5 square miles, making them unsuitable for quantifying lithium at specific locations. However, the machine-learning predictions provide a way to estimate how lithium concentrations vary spatially across a region (fig. 1).

Between 5.1 and 19.0 million metric tons of lithium are calculated to be present in the brines of the Smackover Formation in southern Arkansas (table 1) (Knierim and others, 2024b). The range in possible total lithium reflects the uncertainty in machine-learning predictions of lithium concentrations and the range of Smackover Formation porosity. This estimate quantifies the in-place lithium resource and does not consider the technological and economic feasibility of extracting the lithium from the brines. Additionally, based on the predicted concentrations of lithium and brine production data, in 2022, approximately 5,000 metric tons of dissolved lithium was brought to the surface in brines as part of the existing waste stream associated with the oil, gas, and brine industries in southern Arkansas (Knierim and others, 2024b).
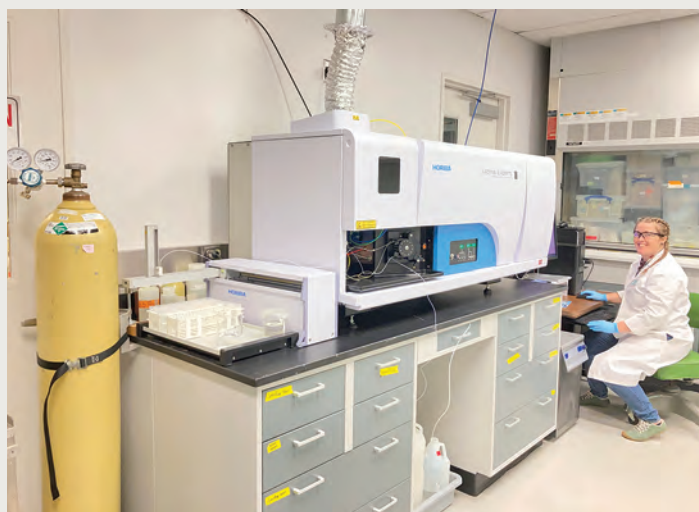
USGS scientist Amanda Herzberg analyzes brine samples on the Inductively Coupled Plasma Optical Emission Spectrometer in the USGS BRInE laboratory. Photograph by Amanda Herzberg, USGS.

Table 1. Calculated amount of lithium in brines of the Smackover Formation, based on porosity ranging from 10 to 30 percent and low, median, and high machine-learning model predictions of lithium concentrations (modified from Knierim and others, 2024b).

Porosity (percent)	Brine volume (trillion liters)	Machine-learning model	Average predicted lithium concentration from all cells in the model (milligrams per liter)	Calculated lithium (million metric tons)
10	65	Low	96	5.1
	65	Median	107	5.7
	65	High	119	6.3
20	130	Low	96	10
	130	Median	107	11
	130	High	119	13
30	200	Low	96	15
	200	Median	107	17
	200	High	119	19

USGS scientists Bonnie McDevitt, Amanda Herzberg, Madalyn Blondes, and Colin Doolan process brine samples at a mobile field station. Photograph by Katherine Knierim, USGS.

Acknowledgments

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