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# Oklahoma Coal: Resources, Production and Uses

*INSIDE ON PAGE 5*

**OKLAHOMA GEOLOGICAL SURVEY**

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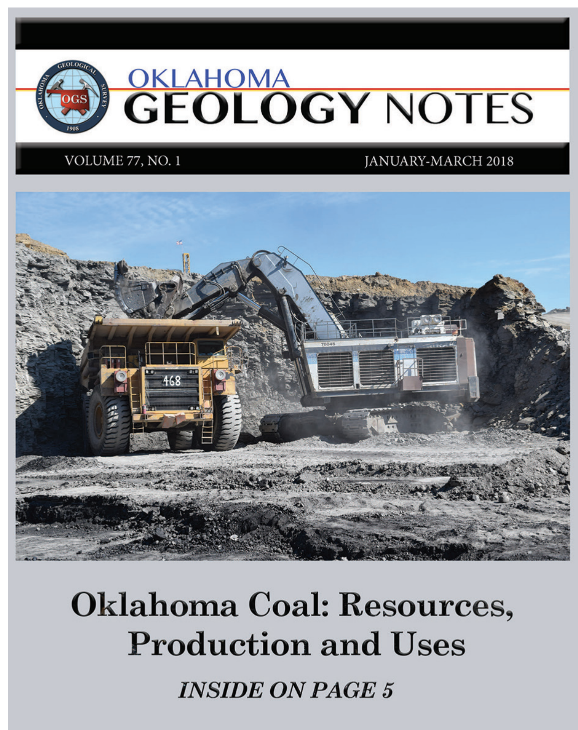


**Cover:** P & H 2250 hydraulic front shovel removing Oakley shale above the Croweburg coal (foreground) in the Phoenix Coal Company Most mine, Nowata County, Oklahoma. Photo taken by Brian Cardott on June 7, 2017.

*Cover Design by Ted Satterfield*

# From The Director

## Oklahoma coal resources, and a new hire

Brian Cardott describes coal production and use in Oklahoma in this edition of the Oklahoma Geology Notes. Annual coal production in Oklahoma has declined by 88% since its peak in 1981. As recently as 1998, coal provided 60% of Oklahoma's electricity. It is still an important energy source in Oklahoma, providing nearly one quarter of electricity generated in the state in 2016. But 95% of that coal was imported from other states (including coal imported in 2015 and burned in 2016), whereas 5% was Oklahoma coal. Yet, as Brian's data show, 84% of the estimated bituminous coal reserves of Oklahoma remain in the ground. This low production percentage shows how important a variety of external factors are to the development of coal, and indeed of any resource.

**Jeremy Boak**
**OGS Director**

Meanwhile, Oklahoma, traditionally known for its hydrocarbon production, has become the state with the second highest installed wind power capacity, after only our neighbor to the south, another traditional hydrocarbon giant. At present, Texas and Oklahoma boast one third of the total installed capacity for wind power in the United States. Nonhydroelectric renewable energy sources (dominated by wind) now generate 26% of our electricity – more than coal. The growth in wind power has been aided by incentives in the form of reduced taxation.

Every energy source faces threats to its continuing production, the most important being cost. Competition from other resources can threaten development of a resource. Environmental concerns can also threaten energy (and indeed all resource) production. These concerns can lead to outright banning of a potential development. More often the environmental challenges which resources face threaten development in part because regulations raise the cost of doing business (and in some cases, reduce the cost, through subsidy, of competing resources). Companies must be able to raise capital and operate with a reasonable return on investment in a world where the variability of markets for any commodity being produced is substantial. The ability to do these things can be limited by environmental restrictions as much as by the economic efficiency of the operation.

We are in a period of energetic debate about the role of regulations and incentives in enabling or constraining development of energy resources and protecting the environment. Some feel that environmental regulations unnecessarily limit the rights of property owners (including royalty holders) to develop resources on their land, with too little benefit to the environment, whereas subsidies and incentives pick winners by political rather than market forces. Others are convinced that the threats of environmental pollution (including carbon dioxide, methane and other greenhouse gases) are very serious, and warrant strong action. Some even believe that hydrocarbon resources must be left in the ground to avoid a disastrous change in Earth's climate.

One of the environmental risks that must be addressed, whatever one's political view on the issues mentioned above, comes from abandoned mine collapses in Oklahoma. Some of these collapsing mine drifts are coal mines, although hard rock mine collapses have also been recorded. These collapses are part of the environmental cost of producing coal or any mined resource, and assigning responsibility for remediation is a complex technical, legal, and regulatory problem.

In February, the Oklahoma Geological Survey (OGS) will be welcoming a new geologist, Netra Regmi, who will study surficial (unconsolidated) sediments in Oklahoma, as well as characterizing a variety of potential hazards such as landslides and rockslides, flooding, and possibly sinkholes due to dissolution of limestone, dolomite, or gypsum below ground. The OGS is dedicated to providing unbiased technical information required to address these problems, and we are pleased to be bringing on board a geoscientist to cover a part of that area of inquiry.

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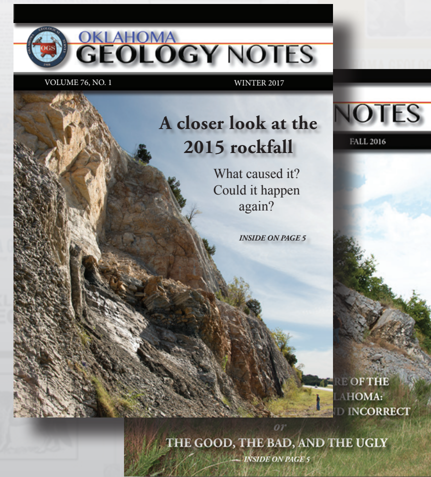


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# Oklahoma Coal: Resources, Production and Uses

By Brian J. Cardott
*Oklahoma Geological Survey*

## INTRODUCTION

Coal is an organic-rich sedimentary rock formed primarily from vascular plants deposited in peat swamps. The bituminous coalfield in eastern Oklahoma covers an area of approximately 14,000 square miles (mi$^2$; 36,260 square kilometers, km$^2$) and can be divided into commercial (8,065 mi$^2$; 20,888 km$^2$) and noncommercial (6,075 mi$^2$; 15,734 km$^2$) areas (**Fig. 1**). The coalfield continues northward into Kansas and eastward into Arkansas and occupies the southern part of the Western Region of the Interior Coal Province of the United States (Campbell, 1917; Friedman, 2010a; East, 2013). Based on physiographic and structural differences, Friedman (1974) divided the Oklahoma coalfield into the northeast Oklahoma shelf ("shelf") and the Arkoma Basin ("basin").

The commercial coal belt contains coal beds ≥ 10 in. (≥ 25 cm) thick that are mineable by surface methods at depths < 100 ft (< 30 m) and coal beds ≥ 14 in. (≥ 36 cm) thick that are mineable by underground methods at depths <1,500 ft (< 457 m; Hemish, 1986).

There are about 40 named and several unnamed coal beds in the Oklahoma coalfield. Coal beds are 0.1 to 6.2 ft (0.03 to 1.9 m) thick in the shelf and 0.1 to 7.0 ft (0.03 to 2.1 m) thick in the basin (Hemish, 1988). The thickest known occurrence of coal in the Oklahoma coalfield is an exposure of the Hartshorne coal (10 ft; 3 m) in Latimer County (sec. 35, T. 6 N., R. 18 E.; Wilson, 1970; Hemish,

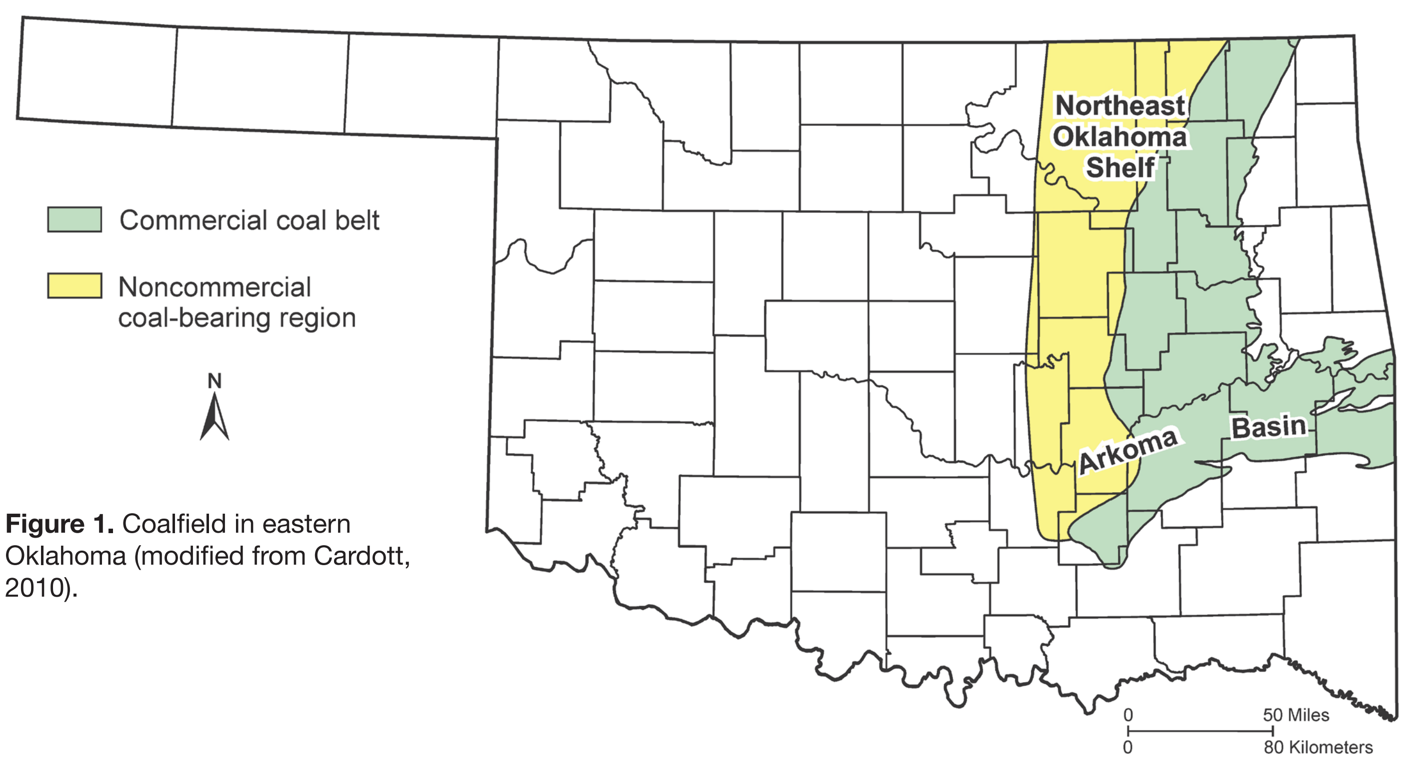


**Figure 1.** Coalfield in eastern Oklahoma (modified from Cardott, 2010).

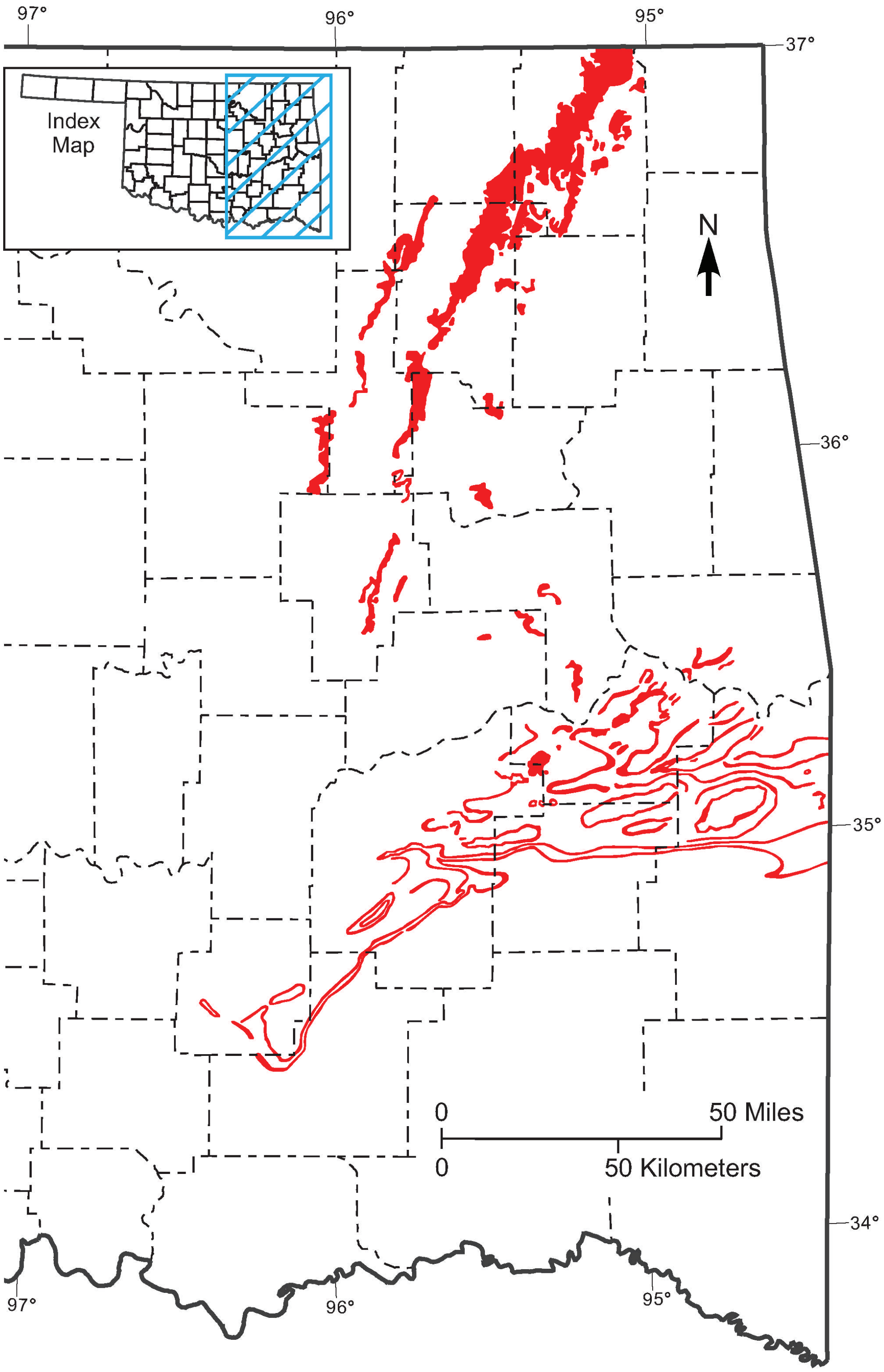


**Figure 2.** Map showing potentially strippable coal beds (red lines) in eastern Oklahoma (modified from Friedman and Woods, 1982).

1999). The thickest known occurrence of coal in the shelf is the Weir-Pittsburg coal (6.2 ft; 1.9 m) in a coal-company drill hole at a depth of 408 ft (124 m) in Craig County (sec. 28, T. 29 N., R. 18 E.; Hemish, 1986, Plate 4; Hemish, 2002).

The noncommercial coal-bearing region has limited information on coal thickness and quality; the region generally contains coal beds that are too thin, of low quality, or too deep for surface mining. Coalbed methane production has been developed in both the commercial coal belt and the noncommercial coal-bearing region (Cardott, 2010, 2013).

**Figure 2** shows coal outcrop and potentially strippable areas in the Oklahoma coalfield (modified from Friedman and Woods, 1982). Coal beds in the shelf strike northeast in outcrop and dip 0.5-2° northwestward from the outcrop to depths ≥ 2,500 ft (≥ 760 m; Johnson, 1974; Friedman, 2010a). Coal beds in the basin are present at the surface and to depths ≥ 5,000 ft (≥ 1,830 m; Iannacchione and Puglio, 1979; Andrews and others, 1998). They are faulted and folded into narrow, northeastward-trending anticlines and broad synclines with dips varying from 3° to nearly vertical (Friedman and Woods, 1982; Friedman, 2010a). Deformation of the Oklahoma coalfield occurred during the Middle Pennsylvanian (Suneson and Stanley, 2017).

All of the coal beds in

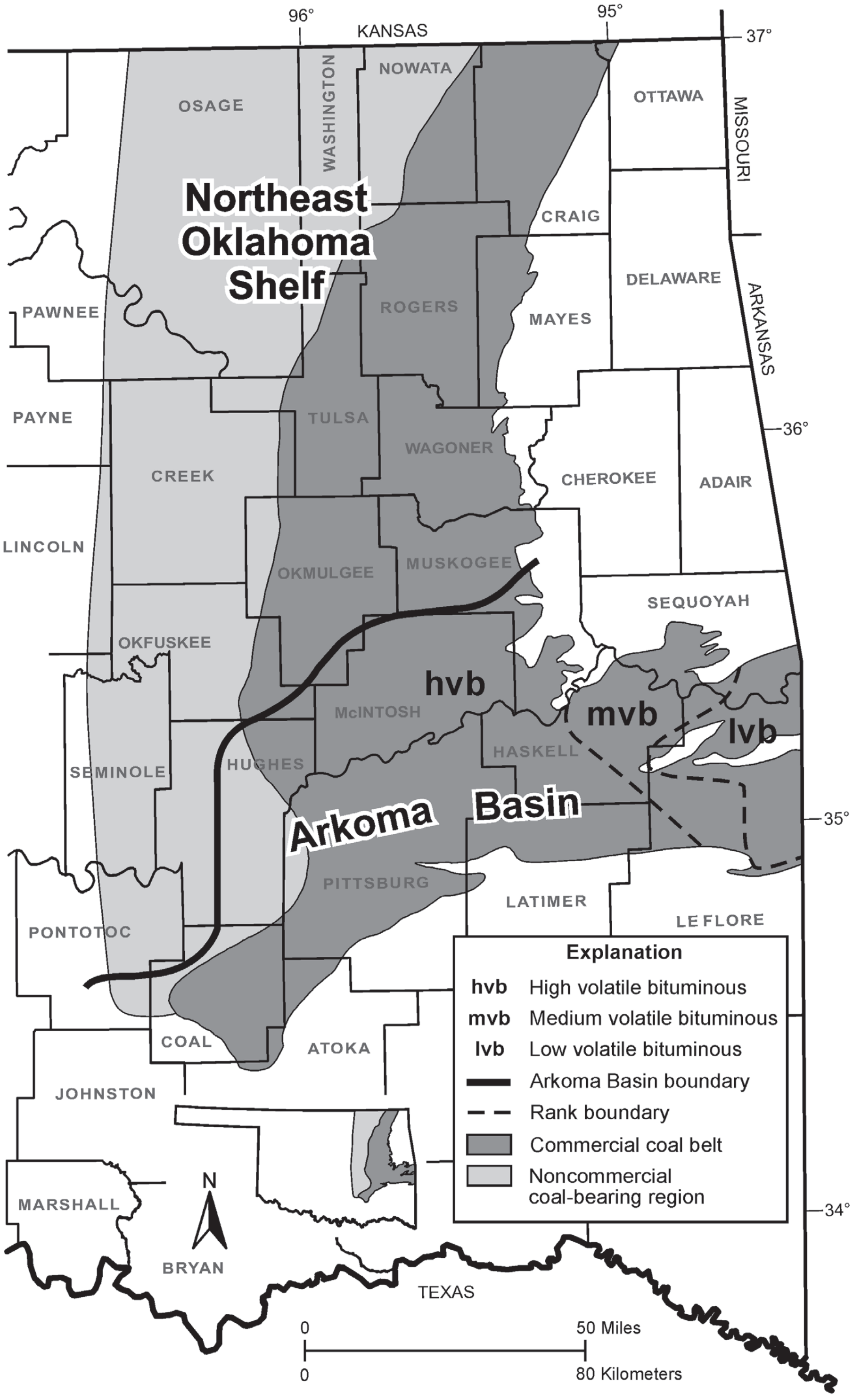


**Figure 3.** Oklahoma coalfield and surface coal rank from all coal beds (from Cardott, 2013).

the Oklahoma coalfield are humic coals derived from peat swamps. Sapropelic coals (cannel or boghead) are spore- or algae-rich and form in standing bodies of water. There are no known sapropelic coal beds in Oklahoma. The age of commercial coal beds in the Oklahoma coalfield is Middle Pennsylvanian (Desmoinesian). Thin, noncommercial coal beds occur in Morrowan, Atokan, Missourian, Virgilian (Pennsylvanian), and Wolfcampian (Permian) strata as well (Cardott, 1989). Several historical coal rank maps are presented in Cardott and others (1986). Oklahoma coal rank, generalized for all coals at or near the surface, ranges from high-volatile bituminous in the shelf and western basin to medium- and low-volatile bituminous in the eastern basin, attaining semianthracite rank at depth (**Fig. 3**; Cardott, 2013). Oklahoma coal rank and quality data are available on the OGS web site (http://www.ou.edu/content/ogs/data/coal.html).

## OKLAHOMA COAL RESOURCES

Resources are an estimate of the presently known deposit while reserves are the economically and technologically recoverable part of resources. Based on estimates by Friedman (1974) and Hemish (1986, 1989, 1990, 1994a, 1998a, 1998b) on 29 coal beds, the remaining identified bituminous coal resources (known or estimated from geologic evidence using measured, indicated and inferred resource categories of reliability; Wood and others, 1983) in beds ≥ 10 in. (≥ 25 cm) thick at <100 ft (< 30 m) deep and ≥ 14 in. (≥ 36 cm) thick at >100 ft (> 30 m)

**Table 1.** Remaining identified bituminous coal resources in Oklahoma (in thousands of short tons).

| County | Original Resources (Friedman, 1974, Tables 21-39) | Remaining Identified Bituminous Coal Resources[1] |
|---|---|---|
| Atoka | 30,428 | 29,619 |
| Coal | 361,265 | 292,875 |
| Craig | 662,460 | 640,092[2] |
| Creek | 15,573 | 15,573[4] |
| Haskell | 1,541,471 | 1,513,681 |
| Latimer | 887,203 | 841,968 |
| Le Flore | 2,040,563 | 1,973,362 |
| Mayes | 31,546 | 31,094[3] |
| McIntosh | 41,563 | 36,319[7] |
| Muskogee | 103,197 | 95,557[6] |
| Nowata | 37,104 | 29,645[2] |
| Okfuskee | 155,968 | 155,964[5] |
| Okmulgee | 421,440 | 340,124[5] |
| Pittsburg | 1,513,445 | 1,383,833 |
| Rogers | 400,060 | 361,821[3] |
| Sequoyah | 30,370 | 27,146 |
| Tulsa | 179,584 | 169,974[4] |
| Wagoner | 140,942 | 128,955[4] |
| Washington | 23,450 | 23,450[4] |
| **Total** | **8,617,632** | **8,091,052** |

[1]As of January 1, 1974 (from Friedman, 1974, OGS SP 74-2; Tables 40-58);

[2]Revised as of January 1, 1979 (from Hemish, 1986, OGS Bulletin 140);

[3]Revised as of January 1, 1981 (from Hemish, 1989, OGS Bulletin 144);

[4]Revised as of January 1, 1982 (from Hemish, 1990, OGS GM-33);

[5]Revised as of January 1, 1987 (from Hemish, 1994, OGS SP 94-3);

[6]Revised as of January 1, 1993 (from Hemish, 1998, OGS SP 98-2);

[7]Revised as of January 1, 1994 (from Hemish, 1998, OGS SP 98-6)

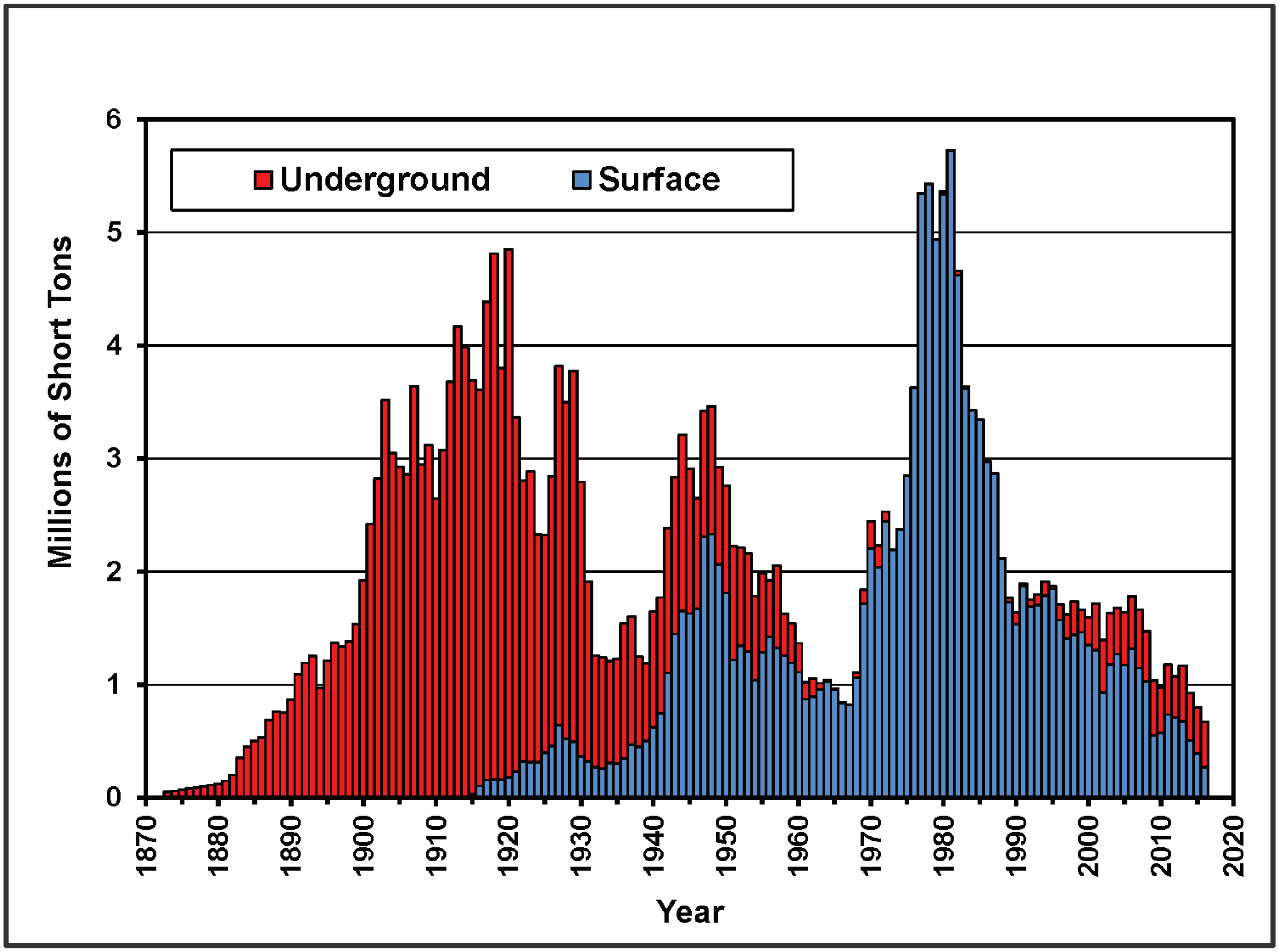


**Figure 4.** Coal production in Oklahoma ,1873–2016 (from Federal and State data discussed in the text).

deep is 8,091,052,000 short tons in 19 counties in eastern Oklahoma (**Table 1**). The 29 commercial coal beds evaluated for resources are the following (in stratigraphic order, youngest to oldest): Cedar Bluff, Tulsa, Dawson, Jenks, Iron Post, Croweburg, Fleming, Mineral, Tebo, Weir-Pittsburg, Wainwright, Bluejacket, Peters Chapel, Secor Rider, Secor, Lower Witteville, Drywood, Rowe, Cavanal, Tullahassee, Spaniard, Upper McAlester (Stigler Rider), McAlester (Stigler), Keefton, Hartshorne, Upper Hartshorne, Lower Hartshorne.

Available coal reserves are impacted by environmental, land-use, technological and geologic restrictions such as towns, streams, power lines, pipelines, cemeteries, and coal beds too thin or too deep (Eggleston and others, 1990; Carter and others, 1995; Carter and others, 2001; Luppens and others, 2009). The U.S. Geological Survey has assessed U.S. coal resources and reserves (Pierce and Dennen, 2009; Shaffer and others, 2017). Oklahoma's available coal reserves have not been assessed. EIA (2017a, Table 15) provides an estimate of the Demonstrated Reserve Base ("recoverable after excluding coal estimated to be unavailable due to land use restrictions and after applying assumed mining recovery rates") by U.S. state. As of January 1, 2017, the Oklahoma Demonstrated Reserve Base is 1.535 billion short tons (1.393 billion metric tons) of coal divided into 1.222 billion short tons (1.109 billion metric tons) mineable underground and 313 million short tons (284 million metric tons) mineable by surface methods.

## OKLAHOMA COAL PRODUCTION

Gunning (1975) reported that the occurrence of coal in Oklahoma has been known since at least 1719. Hemish (1994b) provided a brief history of coal mining in Oklahoma, while Friedman

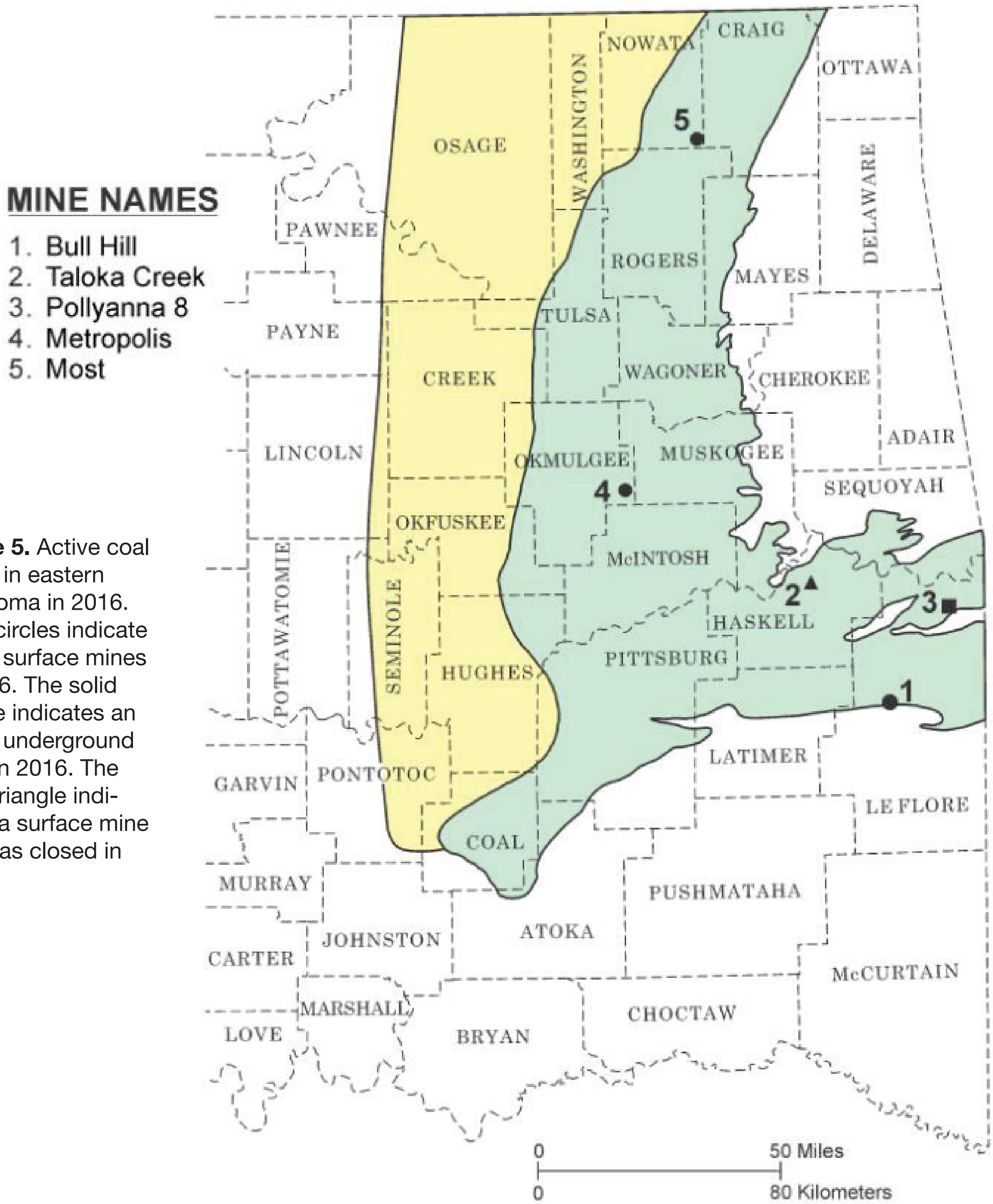


**Figure 5.** Active coal mines in eastern Oklahoma in 2016. Solid circles indicate active surface mines in 2016. The solid square indicates an active underground mine in 2016. The solid triangle indicates a surface mine that was closed in 2016.

(1990) provided a brief history of coal production in Oklahoma. With the introduction of the Missouri-Kansas-Texas Railroad in 1872, the earliest record of commercial coal production in Indian Territory was 50,000 short tons (45,359 metric tons) produced in 1873 by subsurface methods (Eavenson, 1942). Annual Oklahoma coal production amounts are reported in the following publications: 1873-1879 (Eavenson, 1942); 1880-1923 (USGS Mineral Resources of the United States); 1924-1931 (USBM Mineral Resources of the United States); 1932-1948 (USBM Minerals Yearbook); 1949-present (Oklahoma Department of Mines annual report). Annual Oklahoma coal production by county is available in a spreadsheet on the OGS web site (http://www.ou.edu/content/ogs/data/coal.html).

From 1873 to 2016, 299,234,593 short tons (271,461,056 metric tons) of bituminous coal were produced from underground and surface mines in the Indian Territory and Oklahoma (Federal and State data; **Fig. 4**). From 1873 to 1914 the coal production in Indian Territory and Oklahoma was strictly by underground methods. Coal production from

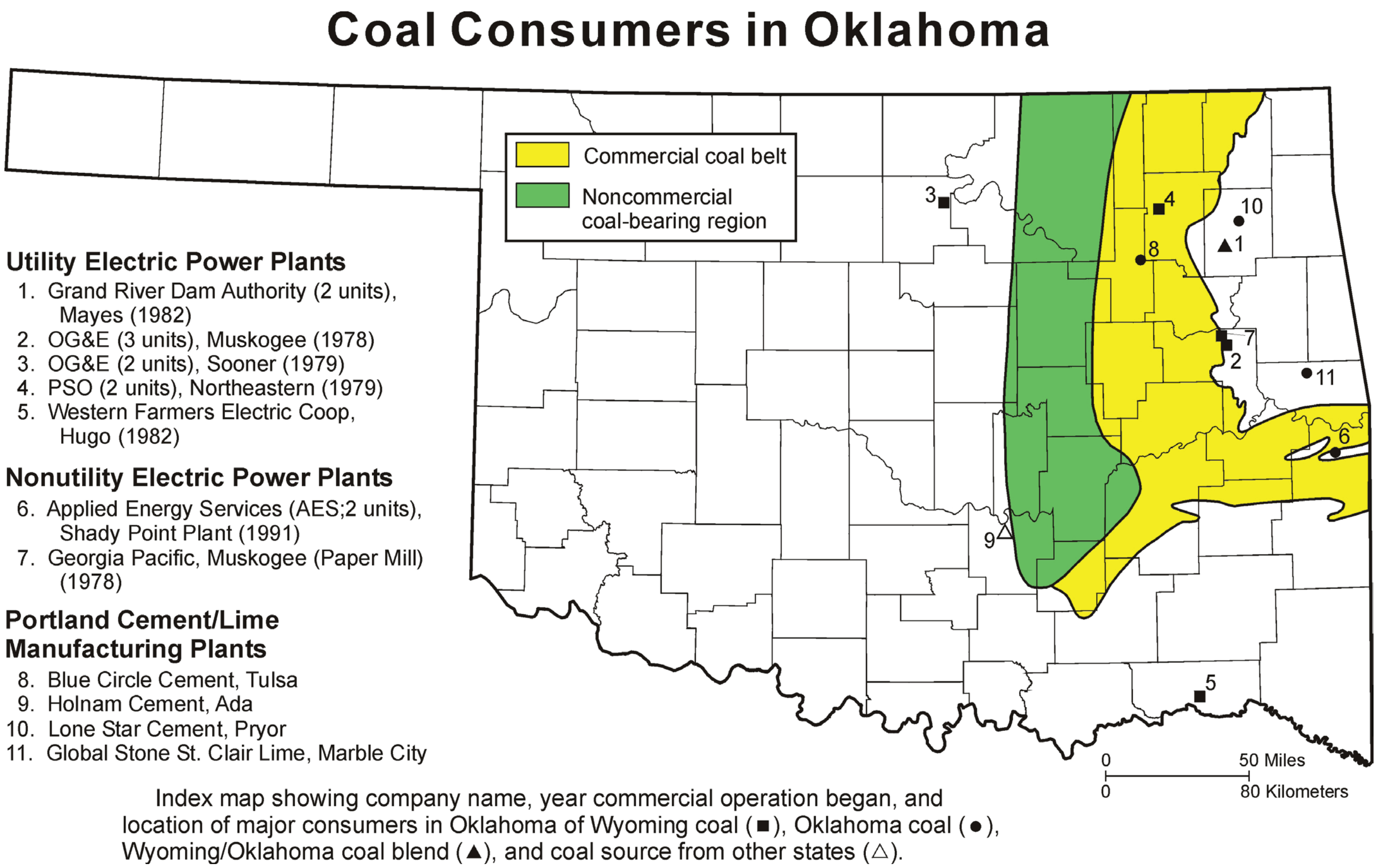


**Figure 6.** Coal consumers in Oklahoma (from Boyd and Cardott, 2001).

surface mines surpassed underground mines in 1943. Maps showing the locations of abandoned underground coal mines in Oklahoma prior to 1979 are in Hendricks (1937, 1939), Knechtel (1937, 1949), Dane and others (1938), Oakes and Knechtel (1948), Dunham and Trumbull (1955), Hemish (1990), and Friedman (1994a, 1996, 2006, 2008, 2010b).

Peak annual coal production in Oklahoma was 5.73 million short tons (5.20 million metric tons) in 1981, with smaller production peaks during and immediately following World War I and World War II. In 2016, 670,610 short tons (608,367 metric tons) of bituminous coal were produced in Oklahoma from five mines (four surface, one underground; **Fig. 5**), which is the lowest annual coal production since 1886 when 534,580 short tons (484,962 metric tons) of bituminous coal were produced (USGS, 1912). Oklahoma coal production ranked 22$^{nd}$ out of 25 coal-producing states in 2015 (EIA, 2017b). Coal production by origin state and by destination state is in EIA (2017c).

## OKLAHOMA COAL USES

Bituminous coal produced in Oklahoma was used initially as steam coal for locomotives. The primary use of Oklahoma coal both in-state and out-of-state has been as fuel for steam used in electric power plants and for coke used in steel production. The quality and rank made the coal beneficial as a coking coal for use in the steel industry (Friedman, 1990). Trumbull (1957) reported that 45% of the coal produced in Oklahoma in 1952 was used to produce coke. Oklahoma coal has also been used as process heat in cement and lime kilns, paper mills, and an automobile plant, as well as for chemical feedstock or the production of briquettes (Friedman, 1990). Friedman (1990, p.162) reported that “Since 1981 the coal industry in Oklahoma has lost its premium, coking-coal markets, and it has not been able to compete in the rapidly expanding international steam coal markets.” Boyd and Cardott (2001) summarized the in-state coal-fired power plants (**Fig. 6**). In 1998, Oklahoma utility electricity generation by

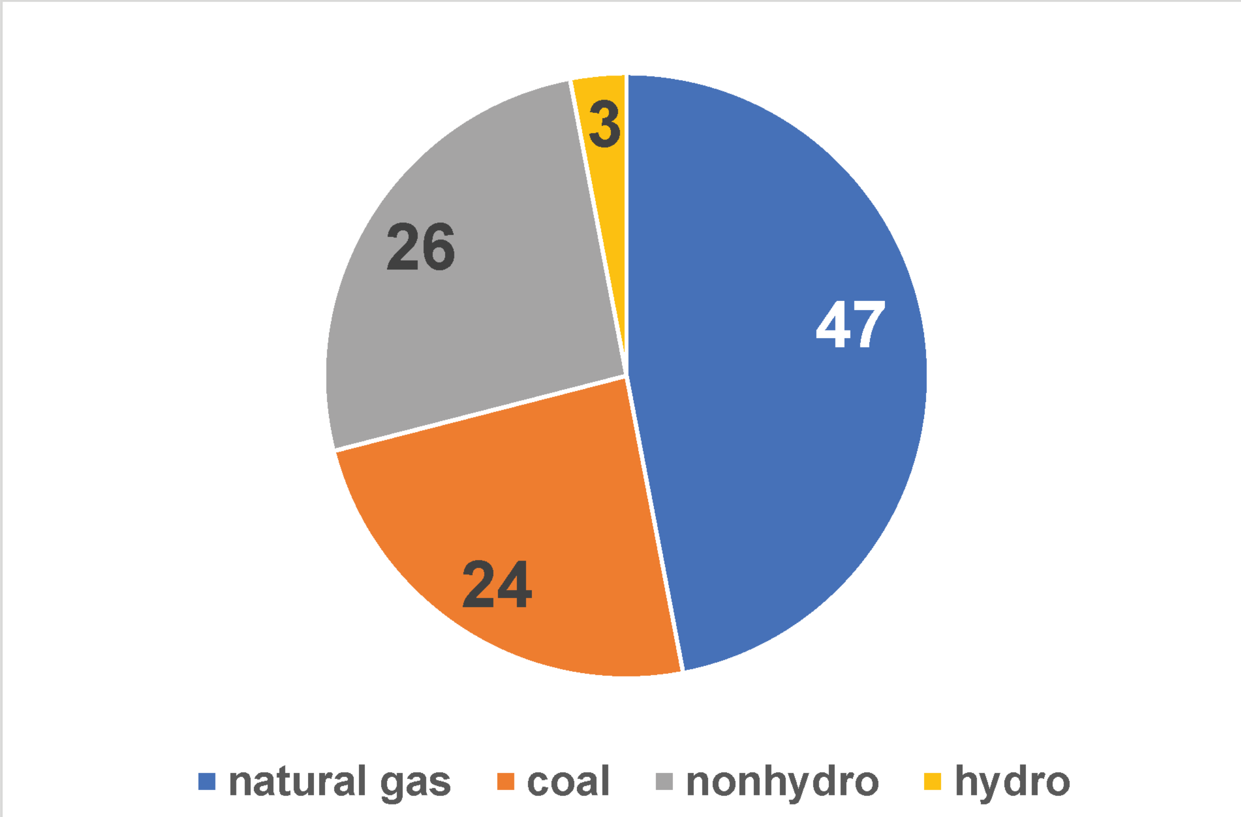


**Figure 7.** 2016 Oklahoma net electricity generation by source (natural gas, coal [subbituminous and bituminous], nonhydroelectric renewables [wind, other biomass, solar thermal and photovoltaic], hydro-electric)(EIA, 2017e).

Table 2. Oklahoma coal-fired power plant 2016 fuel consumption (EIA, 2017d, f).

| Power Plant | Plant ID | Bituminous coal (short tons) | Subbituminous coal (short tons) |
|---|---|---|---|
| Grand River Dam Authority | 165 | | 1,722,631 |
| OG&E Muskogee | 2952 | | 4,018,677 |
| OG&E Sooner | 6095 | | 2,497,320 |
| PSO Northeastern | 2963 | | 1,389,467 |
| Western Farmers Hugo | 6772 | | 1,348,447 |
| AES Shady Point | 10671 | 614,204 | 578,925 |
| Total | | 614,204 | 11,555,467 |

primary energy source was distributed as follows: 60% coal, 33% natural gas, 7% hydroelectric (Boyd and Cardott, 2001). **Figure 7** shows Oklahoma net electricity generation by source (includes electric utilities electric generator and combined heat and power [industrial power, electric power, and commercial power]) in 2016.

In 2016, the Applied Energy Services (AES) Shady Point fluidized-bed combustion non-utility, co-generation plant near Spiro, Oklahoma (Friedman, 1994b), used 578,925 short tons (525,192 metric tons) of subbituminous coal from Wyoming and 614,204 short tons (557,196 metric tons) of bituminous coal from Oklahoma and other states to generate electricity and provide food-grade carbon dioxide (**Table 2**). The AES plant is the primary user of Oklahoma coal. In 2016, Oklahoma imported 10.6 million short tons (9.6 million metric tons) of subbituminous coal by railroad from Wyoming (EIA, 2017c), while 11.6 million short tons (10.5 million metric tons) of subbituminous coal (including stockpiles leftover from purchases in 2015) were used by coal-fired power plants in 2016 (**Table 2**; EIA, 2017d, f).

In addition to well-known uses of coal such as electric power generation (combustion), process heat, coke manufacture in the steel industry (carbonization), and gasification and liquefaction (conversion; EIA, 2017g), there are lesser-known uses of coal such as for plastics, dyes, synthetic rubber, medicine, perfumes, paint thinner, insecticides, and many others described in the coal byproducts tree illustration (Schweinfurth, 2003, 2009). Future potential uses of Oklahoma bituminous coal may include these applications.

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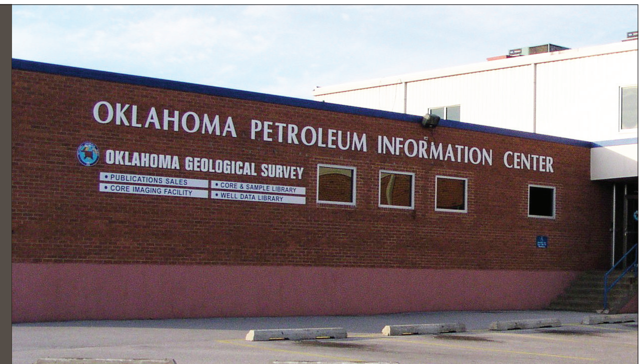
# About the Author

Brian established the Organic Petrography Laboratory (OPL) at the Oklahoma Geological Survey in 1981. His primary research involves gas shales and tight oil (primarily the Late Devonian–Early Mississippian Woodford Shale), coalbed methane, and the petrologic characterization of coals, hydrocarbon source rocks, and solid hydrocarbons (e.g., asphaltites and asphaltic pyrobitumens) of Oklahoma.

Brian has written more than 60 articles and books on coal, coalbed methane, gas shales, unconventional energy resources, hydrocarbon source rocks, solid hydrocarbons, organic weathering, vitrinite reflectance, and graptolite reflectance.

Brian is a member of The Society for Organic Petrology (serving as President, 1995-1996), International Committee for Coal and Organic Petrology, American Association of Petroleum Geologists (serving as President of the Energy Minerals Division, 2004-2005), Geological Society of America, Oklahoma City Geological Society, and Tulsa Geological Society.

# OKLAHOMA PETROLEUM INFORMATION CENTER




## "Bringing Together Drill Cores, Well Logs, Well Data, Publications And Services."

### Activities and Services

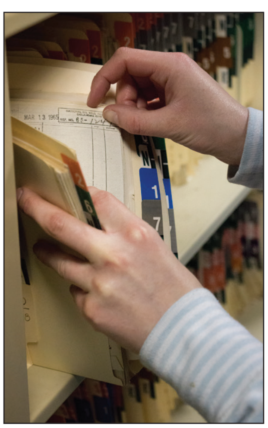
The Oklahoma Geological Survey's Oklahoma Petroleum Information Center (OPIC) is a 192,916 square-foot facility that houses approximately 500,000 boxes of core and cuttings from Oklahoma and elsewhere; an extensive repository of Oklahoma petroleum data; and the Geological Survey's publication sales office.

The OPIC facility is open Monday through Friday from 8AM to 5PM.

### Core and Sample Facility

As Oklahoma seeks to maximize the recovery of oil and gas from new, existing, and shut-in wells, these data resources play an ever more important role.

In addition to being a valuable source of information for hydrocarbon exploration and production activities, OPIC's collections are used in many other ways. In particular, the use and appreciation of these materials is increasing because they are a major resource for groundwater studies, land-use change analyses, $CO_2$ sequestration research, archaeological investigation, and environmental studies.



### Well Data Library

The OGS Well Data Library is the State's official repository for full-scale (5 inches to 100 feet) paper logs from more than 450,000 wells, with new logs added daily. In addition to hard copy logs, a backup collection of logs is available on microfiche as well.

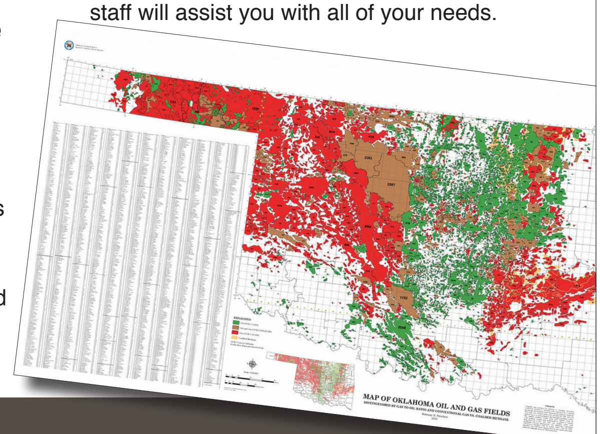
Also in the collection are 126,000 strip logs dating from the 1890s which have been recently digitized. In addition, the library maintains a hard copy of 1002A completion reports from 1904 to the 1990s; multiple sets of scout tickets; completion cards for Oklahoma wells; and hard copies of aerial photos dating from 1934-1986 that are filed by county, township and range.

### Publication Sales Office

The Oklahoma Geological Survey's Publication Sales Office is also located at OPIC. There you can purchase any USGS 7.5 minute quadrangle map of the state, a variety of other USGS maps and all inprint maps and publications produced by the OGS, representing nearly a century's worth of research and mapping.

OGS publications are used by hikers, campers, hunters, school and scout groups, those who enjoy outdoor activities. We have a resource room especially for K-12 teachers, which provides free access to rocks, minerals, fossils, and curricula for classroom use. OPIC is a resource for public officials planning highways and facilities, as well as those engaged in urban planning, water development, alternative energy, and other projects for economic development and civic improvement.

Our friendly and knowledgeable OPIC staff will assist you with all of your needs.

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# BLOSSM in Oklahoma

## WHAT IS BLOSSM?

The BLOSSM in Oklahoma project (Bridging Local Outreach & Seismic Signal Monitoring) aims to provide educational resources to public schools and free-choice learning environments, to foster scientific literacy, and to develop a community of citizen-scientists.

We plan to distribute 100 Raspberry Shake seismographs throughout the state in a three-phased deployment plan, and conduct professional development workshops for teachers during the Regional and Statewide Rollouts. Data collected from these seismographs are freely available to the public, and also supplement the Oklahoma Geological Survey (OGS) statewide seismic monitoring network in regions of the state where coverage is sparse.

## WHAT IS A RASPBERRY SHAKE?

A Raspberry Shake seismograph is made up of (1) a geophone sensor that detects weak vibrations, (2) a circuit board that collects the data that the sensor detects, and (3) a Raspberry Pi mini-computer.

It is an all-in-one personal seismograph that can detect vibrations from earthquakes, even ones that are not normally felt by people. It works the same way as conventional seismic monitoring equipment, but at a small fraction of the cost.

## WHERE WILL THEY BE DEPLOYED?

Some of our pilot sites will serve as regional hubs, where we will conduct professional development workshops for teachers who are interested in acquiring a seismograph to use in their classrooms. We will work with teachers to develop curricula that align with the Oklahoma Academic Science Standards.

## HOW DO I GET A RASPBERRY SHAKE?

If you're interested in becoming involved, please contact us to see if you qualify for a free Raspberry Shake seismograph, provided by the BLOSSM in Oklahoma project. Alternatively, you may shop the manufacturer's online store directly, by scanning the QR code; please be sure to mention the OGS in the Order Notes when checking out.

## WHAT IF I HAVE MORE QUESTIONS?

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# Looking Down the Road

## Coming up next in *The Oklahoma Geology Notes*

### A Geoarchaeological Lithic Provenance Study at the OGS

In the next issue of the Oklahoma Geology Notes, Richard Tarver, OGS Data and Collections Manager, presents an article about how an OGS geoarchaeological examination into the intersection of prehistoric human activity and the natural resources of Oklahoma could expand our understanding of the lifeways of North America's indigenous cultural groups.