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Geology and Energy Resources of the Arkoma Basin, Oklahoma and Arkansas

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ABSTRACT

The Arkoma basin is a structurally defined basin that underlies an area of about 13,000 sq. mi. It extends from Little Rock, Arkansas, to Atoka, Oklahoma. The rocks in the basin grade upward from dolomite, some limestone, sandstone (Upper Cambrian to Upper Devonian) to shale and limestone (Upper Devonian to Lower Pennsylvanian) to shale, limestone, and sandstone (Lower Pennsylvanian) to shale and sandstone (Middle Pennsylvanian). The sediments that formed rocks in the lower part of the Atoka formation on the south side of the basin were deposited in a deep-water environment. All other sediments in the basin were deposited in shallow-water, littoral, or deltaic environments. Growth faults were restricted to the south side of the basin during Late Mississippian and Morrowan time but became common throughout the basin during Atokan time. During the Ouachita orogeny, the rocks were folded into east-west trending synclines and anticlines, and the anticlines along the southern part of the basin were ruptured by thrust faults. A small amount of oil has been produced from reservoirs of Ordovician, Silurian, and Pennsylvanian age in the extreme southwestern part of the basin. Approximately 4.9 trillion cu. ft. of natural gas have been produced from Ordovician to Pennsylvanian reservoirs. About 280 million short tons of coal have been produced from rocks of Atokan and Des Moinesian age.

INTRODUCTION

The Arkoma basin extends westward from Little Rock, Arkansas, to Atoka, Oklahoma and underlies an area of about 13,000 sq. mi. (Fig. 1). Throughout most of its extent, its northern boundary is marked by the surface trace of a system of normal faults, and its southern boundary by a system of thrust faults, thus, the present configuration of the basin is defined by present structure. Rocks of the same age are similar in lithologic characteristics throughout the length of the basin, but their stratigraphic nomenclature differs between the two states (Fig. 2).

LITHOLOGY AND DEPOSITIONAL ENVIRONMENT

Precambrian Rocks

Basement tests wells drilled in or near the Arkoma basin have penetrated rocks that are similar to the Precambrian igneous rocks exposed in the St. Francois Mountains in southeastern Missouri. In that area, the rocks consist of felsite flows and tuffs, which were intruded by granite and subsequently by diabase and gabbro.

The relative surface relief of the Precambrian rocks is about 2,200 feet in a part of the St. Francois Mountains. The magnitude of the relief of the Precambrian surface in the Arkoma basin is not known, but available evidence indicates that the surface was one of low relief (Fig. 3a).

Upper Cambrian to Upper Devonian Rocks

The basal sandstone of this sequence of Upper Cambrian to Upper Devonian rocks was deposited on a surface of Precambrian rocks during the transgression of a Late Cambrian sea. The overlying rocks in the sequence are about 3,000 feet thick in the north part of the basin and 3,500 feet thick in the south part. They consist mostly of dolomite and some limestone and sandstone, all of which are nearly clay-free, and a few thin beds of light- to medium-gray or greenish-gray shale. Much of the dolomite and limestone contains oolite, oolitic chert, and chert. These sediments were deposited in depositional environments ranging from shallow-water marine to littoral to nonmarine. Other than for a slight amount of southward tilting and slow subsidence, the area of the Arkoma basin must have been structurally stable during Late Cambrian to Late Devonian (Fig. 3b). The minor unconformities between some of the formations may have been structurally induced, but more than likely, they represent local shallow-water marine to nonmarine changes in the depositional environments.

Upper Devonian and Mississippi Rocks

The Upper Devonian and Mississippian sequence is composed of about equal parts of shale and limestone, some of which is cherty. Small amounts of sandstone and siltstone are present in the northern part of the basin. The limestone changes southward to silty limestone, limy siltstone, and shale. All the sediments forming the rocks in the sequence were deposited in a shallow-water marine environment. This sequence may be as much as 1,000 feet thick in the southern part of the basin, whereas rocks of equivalent age in the Ouachita Mountains to the south are more than 5,000 feet thick. The sediments forming these

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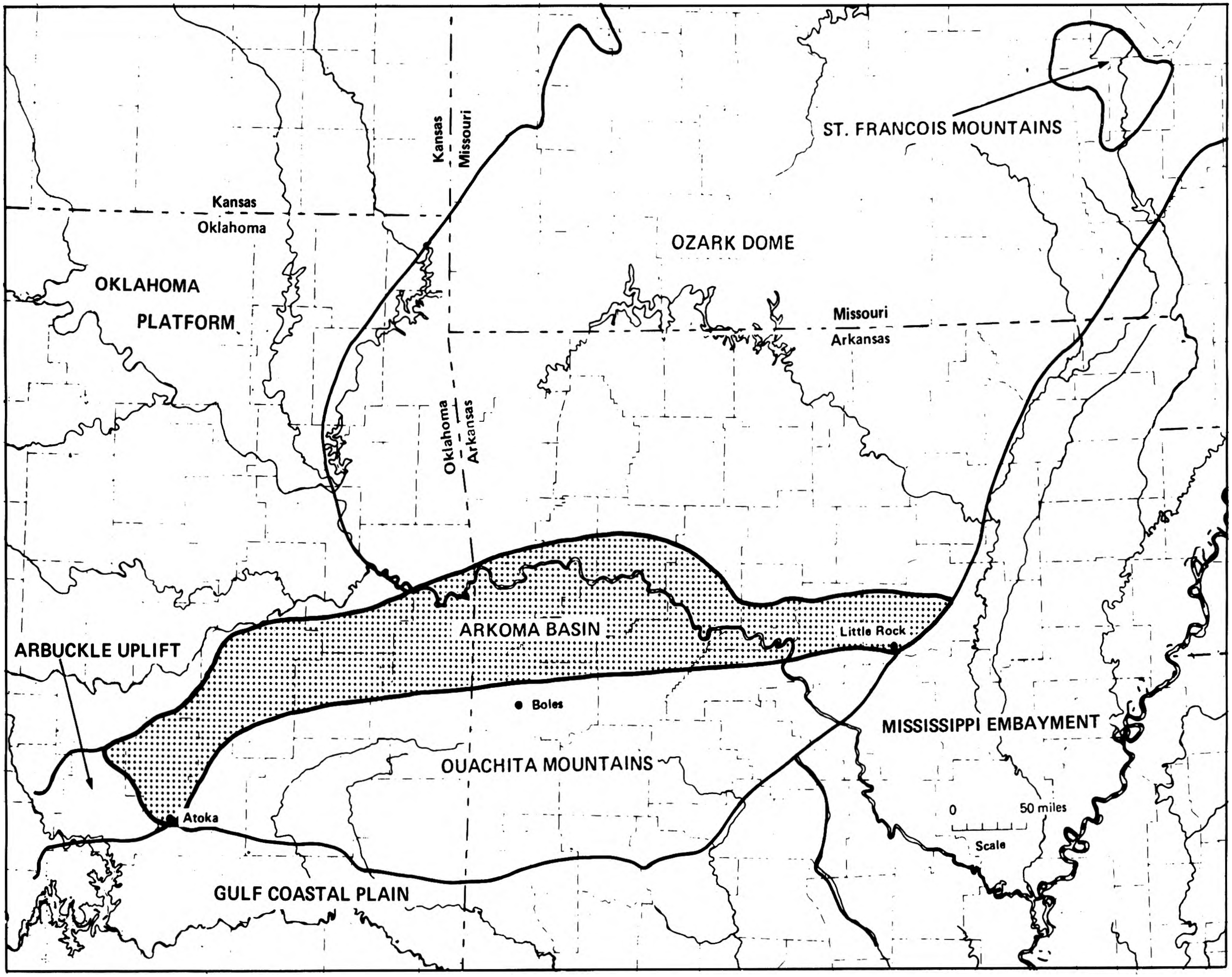

Fig. 1. Index map of Arkoma basin and vicinity.

rocks were deposited in a deep-water environment (Fig. 3c).

A down-to-the-south growth fault system along the south side of the basin accounts for the rather abrupt change in lithology and thickness.

Morrowan Rocks

The Morrowan rocks consist of about equal parts of sandstone, shale, and limestone in the western four-fifths of the Arkoma basin but change in facies to sandstone and shale in the eastern one-fifth of the basin. All of the sediments were deposited in a shallow water marine environment.

Along the western two-thirds of the southern edge of the basin, the Hale Formation (lower Morrowan) consists of about 300 feet of limestone, sandstone, and shale, and the overlying Bloyd Shale (upper Morrowan) of about 400 feet of shale, sandstone, and some limestone. To the south, along the northern part of the Ouachita Mountains, the Jackfork Sandstone (lower Morrowan) consists of about 5,000 feet of sandstone and shale, and the overlying Johns Valley Shale (upper Morrowan) of about 3,500 feet of shale and a minor amount of sandstone. The Jackfork and the Johns Valley sediments were deposited in a deep-water marine environment (Fig. 4). The abrupt change in thickness and lithology can be attributed to the growth fault system that started in Mississippian time. A submarine fault scarp, at least 2,300 feet high, must have exposed Middle Ordovician rocks along the southern edge of the basin, as indicated by the individual rock fragments or beds of rock fragments ranging in age from Middle Ordovician to Early Pennsylvanian in the Johns Valley Shale near Boles, Arkansas.

Atokan Rocks

The Atokan rocks consist of about 70 percent shale, 20 percent sandstone, 10 percent siltstone, and a few coal beds. In the northern part of the Arkoma basin, the Atoka Formation can be divided into many repetitive lithologic units that generally grade upward from shale to siltstone to sandstone to, in some places, an overlying coal bed. The lithologic sequence in many of these units corresponds to that of sediments deposited by a prograding delta. Many of these sequences can be identified on electrical logs by the funnel shape of the resistivity (Fig. 5), conductivity, spontaneous potential, gamma-ray, or neutron curves. Regional studies of the rocks in the Atoka Formation have shown that the deltas did not prograde to the south side of the basin until more than half of the Atoka was deposited (Fig. 6). The lower part of the Atoka along the south side of the basin was deposited as prodeltaic, submarine channel, submarine fan, and abyssal plain sediments.

	SERIES	FORMATION	
		Oklahoma	Arkansas
PENNSYLVANIAN	Des Moinesan	Boggy Fm.	Boggy Fm.
		Savanna Fm.	Savanna Fm.
		McAlester Fm.	McAlester Fm.
		Hartshorne Sandstone Upper	
		Hartshorne Sandstone Lower	Hartshorne SS
	Atokan	Lake Murray-Atoka Fms.	Atoka Fm.
	Morrowan	Golf Course-Wapanucka Fms.	Bloyd Fm.
		Springer Fm.	Hale Fm.
MISSISSIPPIAN	Chesterian	Caney Sh	Pitkin Ls. Fayetteville Sh. Batesville Ss. and Hindsville Ls.
	Meramecian		Moorefield Fm.
	Osagean	Sycamore Ls.	Boone Fm.
DEVONIAN	Kinderhookian	Woodford Fm.	Chattanooga Fm.
	Upper		
	Lower	Hunton Gp.: Frisco Ls, Bois d'Arc Ls., Horagan Ls.	Penters Ch.
SILURIAN	Niagaran	Hunton Gp.: Henryhouse Ls.	Lafferty Ls. St. Clair Ls.
	Alexandrian	Hunton Gp.: Chimneyhill Ls.	Brassfield Ls.
ORDOVICIAN	Upper	Sylvan Sh. Fernvale Ls.	Cason Sh. Fernvale Ls.
		Simpson Gp.: Viola Ls.	Kimmswick Ls.
	Middle	Simpson Gp.: Bromide Fm. Tulip Creek Fm. McLish Fm. Oil Creek Fm. Joins Fm.	Plattin Ls. Joachim Dol. St. Peter Ss. Everton Fm.
	Lower	Arbuckle Gp.: West Spring Creek Fm. Kindblade Fm. Cool Creek Fm. McKenzie Hill Fm.	Powell Dol. Cotter Dol. Jefferson City Dol. Roubidoux Fm. Gasconade Dol.
CAMBRIAN	Upper	Arbuckle Gp.: Butterly Dol. Signal Mountain Fm. Royer Dol. Fort Sill Fm.	Eminence Dol. Bonneterre Dol.
		Honey Creek Fm. Reagan Ss.	Lamotte Ss.
PRECAMBRIAN		Granite & Rhyolite	Granite

Fig. 2. Formations present in the Arkoma basin.

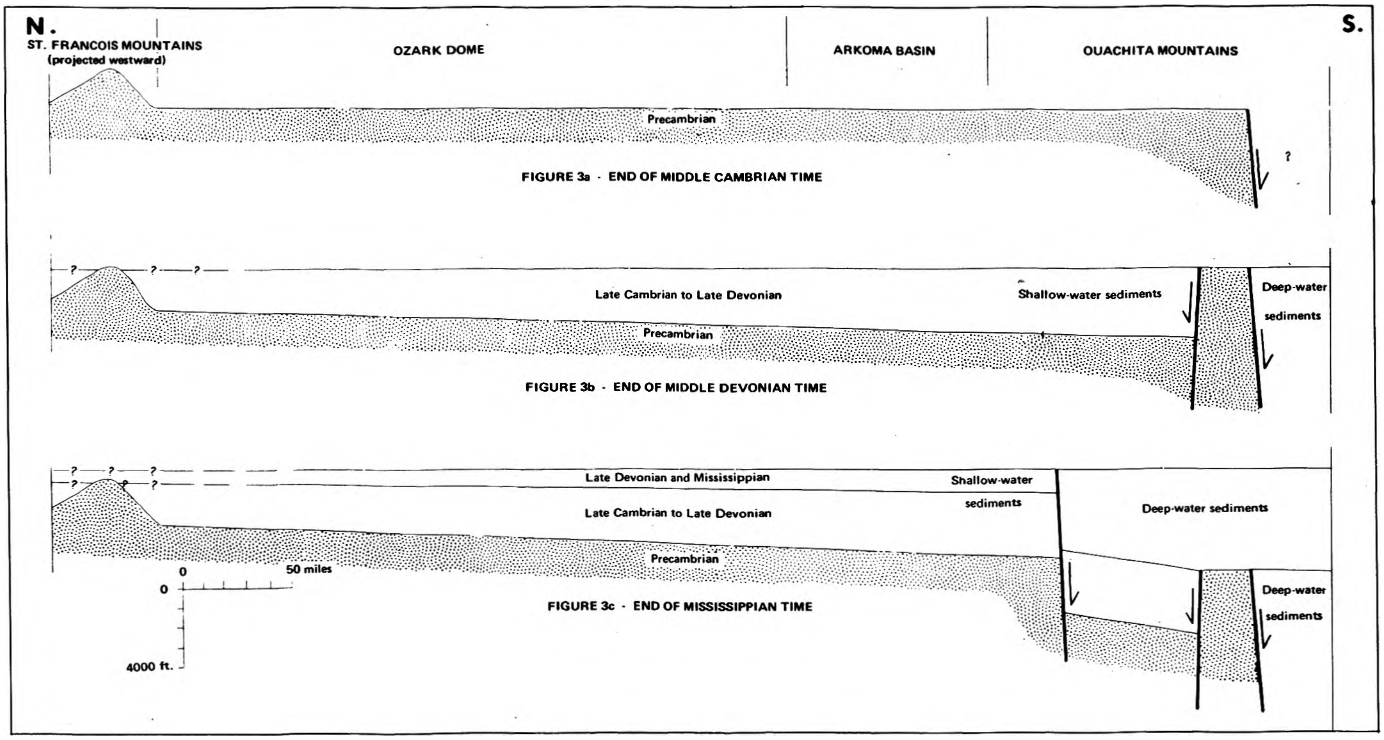

Fig. 3. Schematic cross section of the rocks in the Arkoma basin and vicinity.

Growth faults seem to have been restricted to the southern edge of the basin during Mississippian and Morrowan time, but they began to develop throughout the basin during Atokan time. In Arkansas, sedimentation in the areas of deltaic deposition must have kept pace with the amount of movement along the growth faults, because all the rocks in all parts of the Atoka thicken on the downthrown side (Fig. 7).

Des Moinesian Rocks

The lower part of the Hartshorne Sandstone is the lowest rock unit in the Des Moinesian and unconformably overlies the Atoka Formation (see Figs. 8 and 9).

The rocks are predominantly sandstone with minor amounts of siltstone and shale. Most, if not all, the rocks were deposited in a meandering stream environment. The stream had a westward direction of flow and a meander belt at least 45 miles wide.

Overlying the lower part of the Hartshorne Sandstone is a delta-plain sequence that includes the lower Hartshorne coal bed and, in Oklahoma, the upper part of the Hartshorne Sandstone and the upper Hartshorne coal bed.

The remainder of the Des Moinesian rocks (McAlester, Savanna, and Boggy Formations) consists mostly of shale with subordinate amounts of sandstone and siltstone and a few coal beds. The rocks were deposited in intercalated sequence of prodelta, delta, delta-plain and meander-belt sediments.

STRUCTURE

The Arkoma basin contains anticlines, synclines, normal faults, and thrust faults. The structural relief on the base of the lower part of the Hartshorne Sandstone is more than 4,000 feet.

Folds

In the northern part of the basin, the rocks dip less than 10 degrees, except near normal faults where they may dip as much as 35 degrees. In the southern part of the basin, the rocks on the northern side of some of the anticlines may dip as much as 15 degrees beyond the vertical.

Faults

The normal faults in the Arkoma basin dip north or south at angles 30 to 65 degrees (Fig. 7). The south-dipping faults form the major fault systems and have the largest amount of displacement. The Mulberry fault, which bounds a part of the north side of the basin in Arkansas, has a maximum displacement of 2,500 feet.

Most of the normal faults in the basin are growth faults because 1) the amount of displacement along the faults increases with depth, and 2) the Atoka formation is thicker on the downthrown

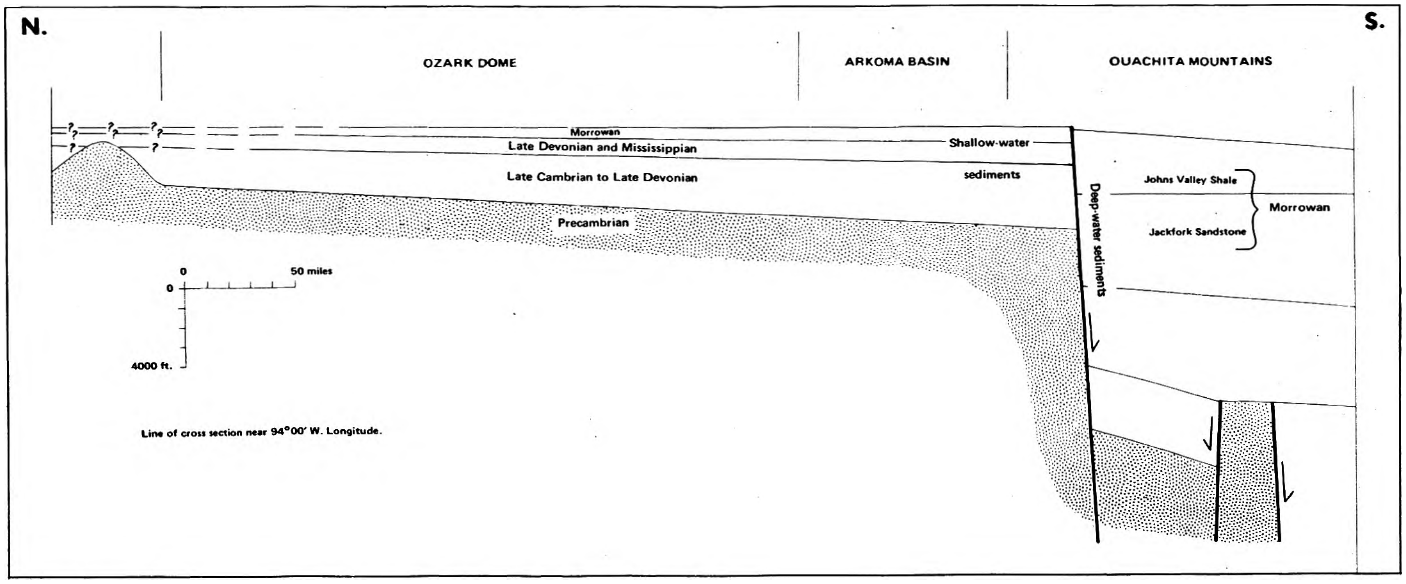

Fig. 4. Schematic cross section of the rocks in the Arkoma basin and vicinity at the end of Morrow time.

side of the faults.

Low- and high-angle thrust faults are present in the southern part of the basin along the crests of many of the anticlines, and the thrust plates of these faults moved northward.

GEOLOGIC HISTORY

Age determination by the potassium-argon method gives age dates of about 1.2 to 1.4 billion years for the Precambrian rocks in the St. Francois Mountains, (Snyder and Wagner, 1961, p. 84). The first sedimentary rock formation overlying the Precambrian in that area and in the Arkoma basin is the Lamotte Sandstone of Late Cambrian age (about 525 m.y.).

After the advancement of the Late Cambrian sea, the area of the basin slowly subsided with a slight southward tilt. Deposition kept pace with the subsidence, as indicated by the accumulation of shallow marine and subaerial deposits. The source of the clastics is conjectural. Some may have come from exposed Precambrian rocks in Missouri to the north, but the volume of sand dictates additional sources, perhaps hundreds of miles to the east or even a greater distance to the north.

During Late Devonian and Mississippian time, the area of the Arkoma basin continued to subside and to tilt to the south. Deposition kept pace with the subsidence, and most, if not all, the sediments were deposited in a shallow-water marine environment. The greater percentage of lime was deposited in the northern part of the basin, and, for the first time, a considerable quantity of clay was deposited throughout the basin. The clay, silt, and a small amount of sand was brought into the area from the north, northeast, and perhaps from the east. Some sediments were transported southward across the down-to-the-south growth fault system that started during late Meramecian or early Chesterian time. This fault system subsequently marked the southern edge of shallow-water deposition during Mississippian and Morrowan time.

During Morrowan time, the area continued to subside and to tilt to the south. Sediments were brought into the basin from the north and northeast, and sand made up an important percentage of the sediments. The sediments in the western four-fifths of the Arkoma basin were deposited in shallow marine seas, beaches, tidal flats, and in some stream channels. The sediments in the eastern one-fifth of the basin were deposited in a deltaic environment of a large river system that drained into the area from the northeast.

During Atokan time (approximately 15 m.y.) the area of the Arkoma basin subsided more than it had in the previous 240 million years since Late Cambrian time (Fig. 6). In the Arkansas part of the basin, the Atoka thickens from about 4,000 feet along the north side to about 21,000 feet along the south side.

Deltas began prograding southward from the north side of the basin during the early part of Atokan time but did not prograde completely across the basin until late Atokan time. South of the deltas, the sediments were deposited as prodelta muds, in submarine channels, or in submarine fans and lobes, and in abyssal plains.

In the area of the deltaic environment, deposi-

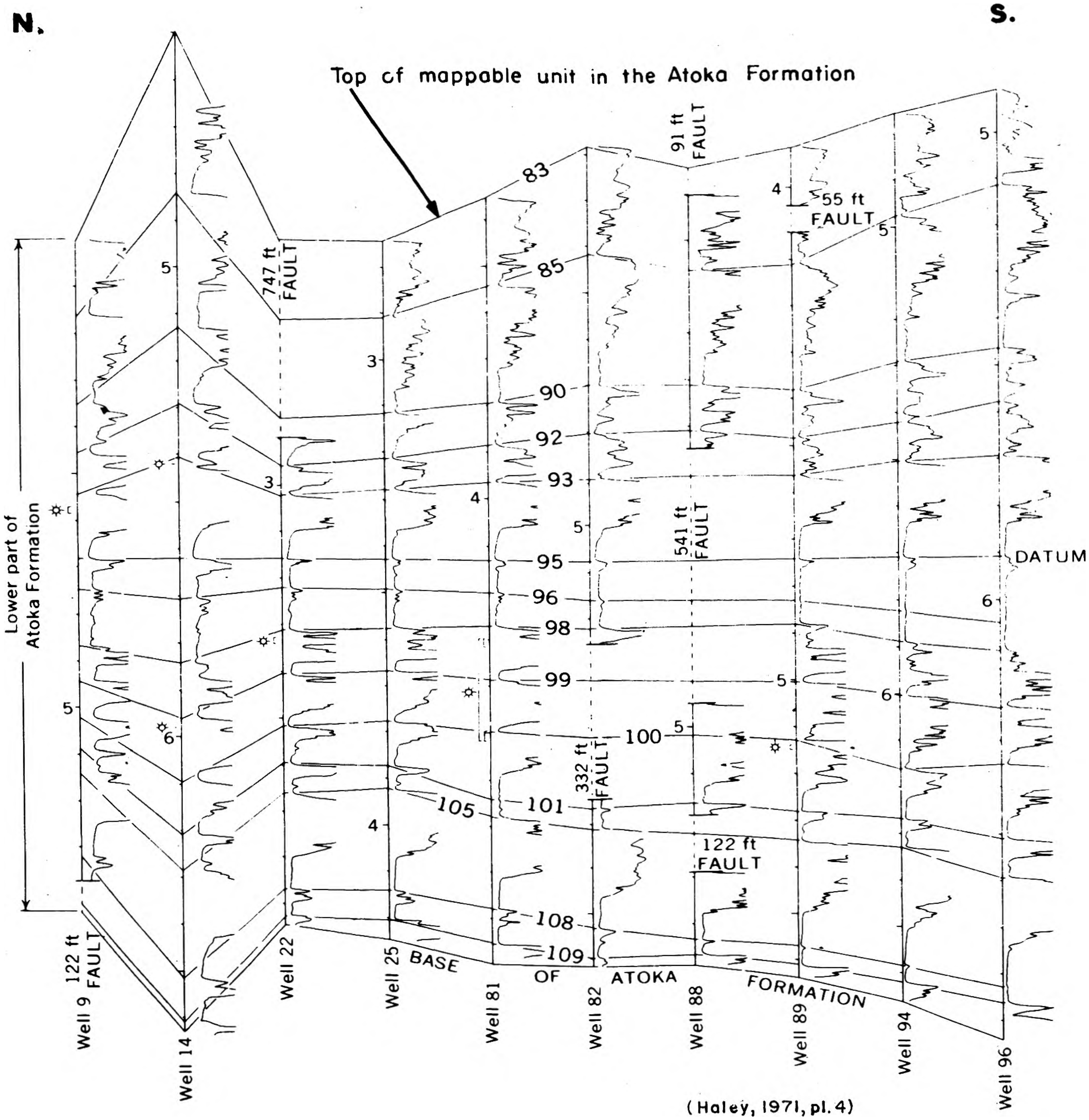

Fig. 5. Electrical log correlation of the Atoka formation near 94°05'W. longitude.

tion kept pace with the amount of movement along the growth faults. In the area of the deep-water environment, deposition did not keep pace with the movement along the growth faults at all times, but caught up with the total amount of movement along the faults by late Atokan time when deltaic deposits extended over the entire area of the Arkoma basin.

Regional uplift, probably related to the early stages of the Ouachita orogeny, started in very late Atokan time and by the beginning of Des Moinesian time had changed the physical characteristics of the Arkoma basin. The area was at or just above sea level and was surrounded by higher land areas to the south, east, and north with open seas to the west. A major meandering river crossed the area from east to west and deposited the lower part of the Hartshorne Sandstone. A delta plain was developed on which the lower Hartshorne coal bed was deposited. After the deposition of these units,

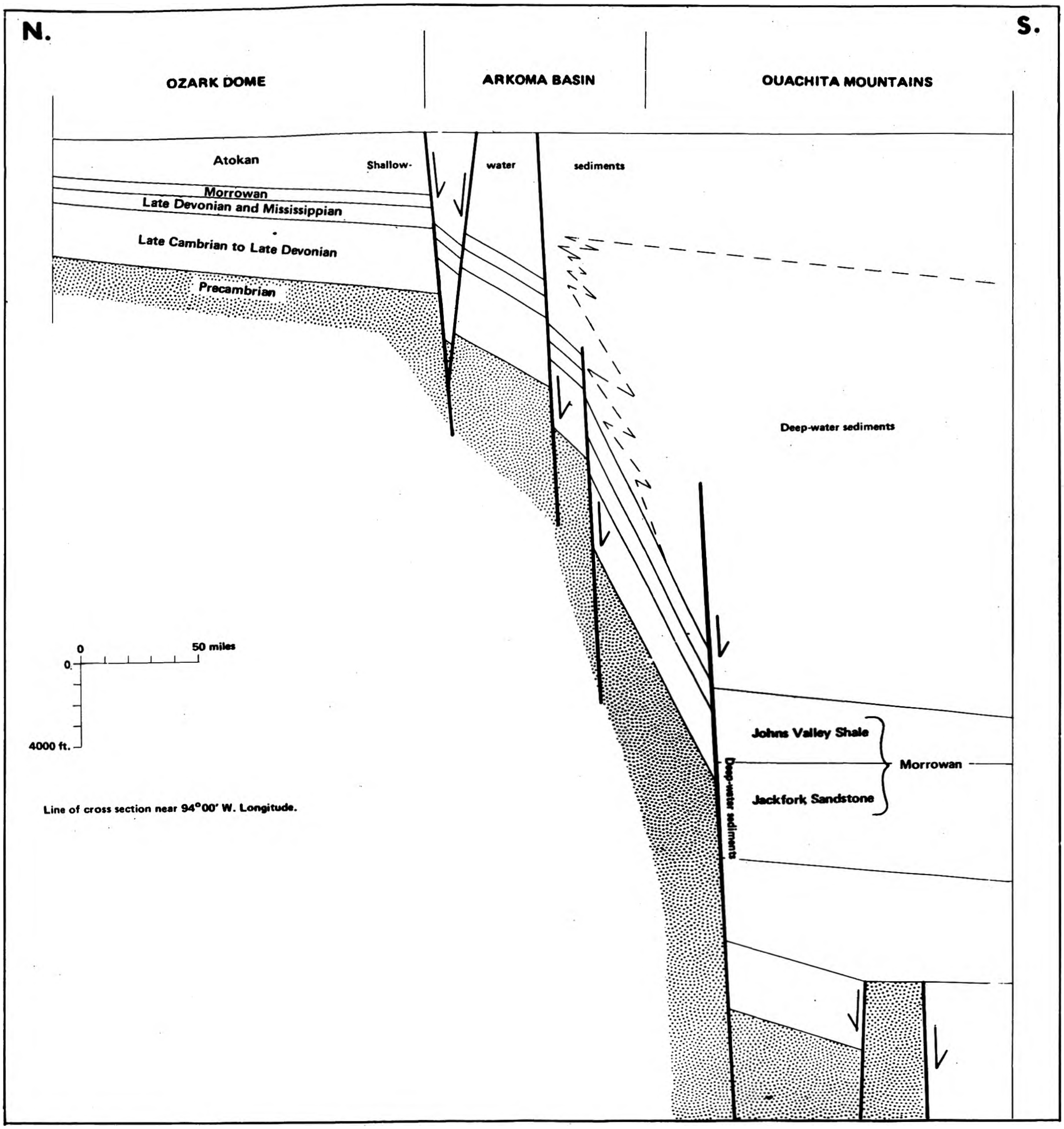

Fig. 6. Schematic cross section of the rocks in the Arkoma basin and vicinity at the end of Atoka time.

the area of the basin began to slowly subside with a slight tilt to the west. During the rest of the Des Moinesian time, each marine sea that transgressed into the area from the west was filled by deltaic sediments from the south, east, and north.

Pennsylvanian-age rocks younger than Des Moinesian are not now present in the area of the Arkoma basin, and available evidence indicates that they never were deposited in the area. Only the extreme eastern end of the Arkoma basin now

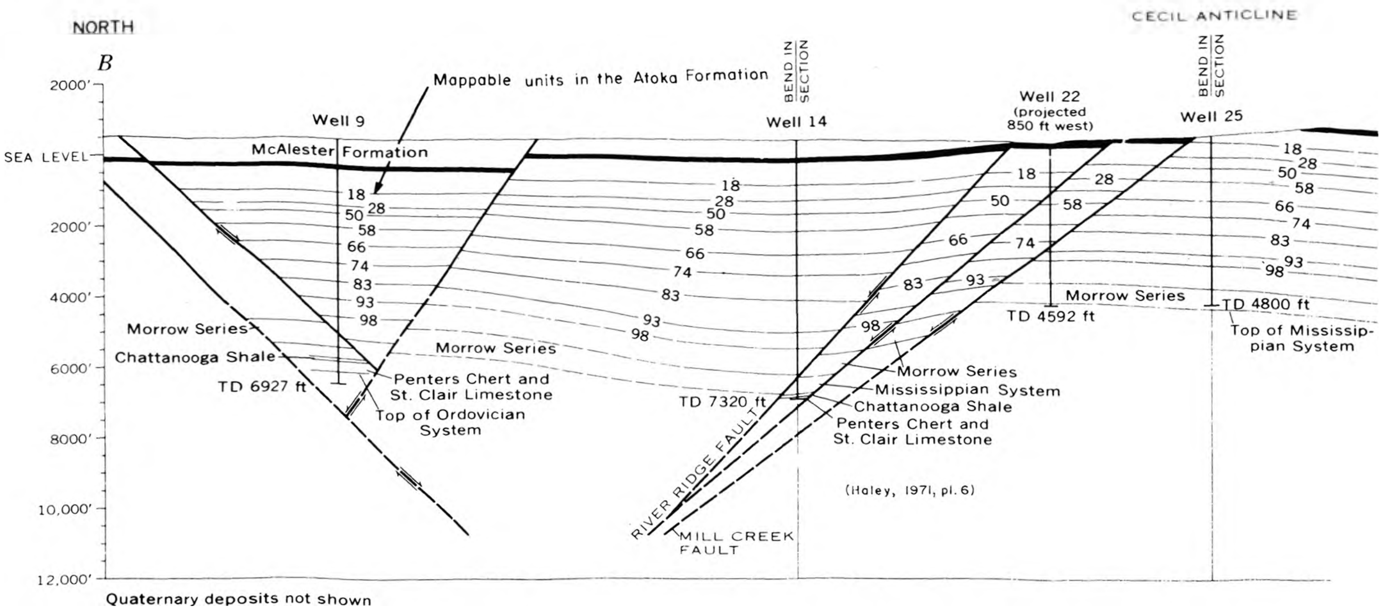

Fig. 7. Structural cross section of the rocks near 92°05'W. longitude.

Fig. 8. Stream channel deposits of the Hartshorne Sandstone overlying prodelta deposits of the Atoka Formation.

is covered by rocks of Late Cretaceous, Paleocene or Eocene age, and lithologic evidence indicates that the depositional boundary of the sediments forming these rocks did not extend very far to the west of the present boundary. Therefore, most of the Arkoma basin may have been above sea level since late Des Moinesian time.

The Ouachita orogeny is thought to have ended

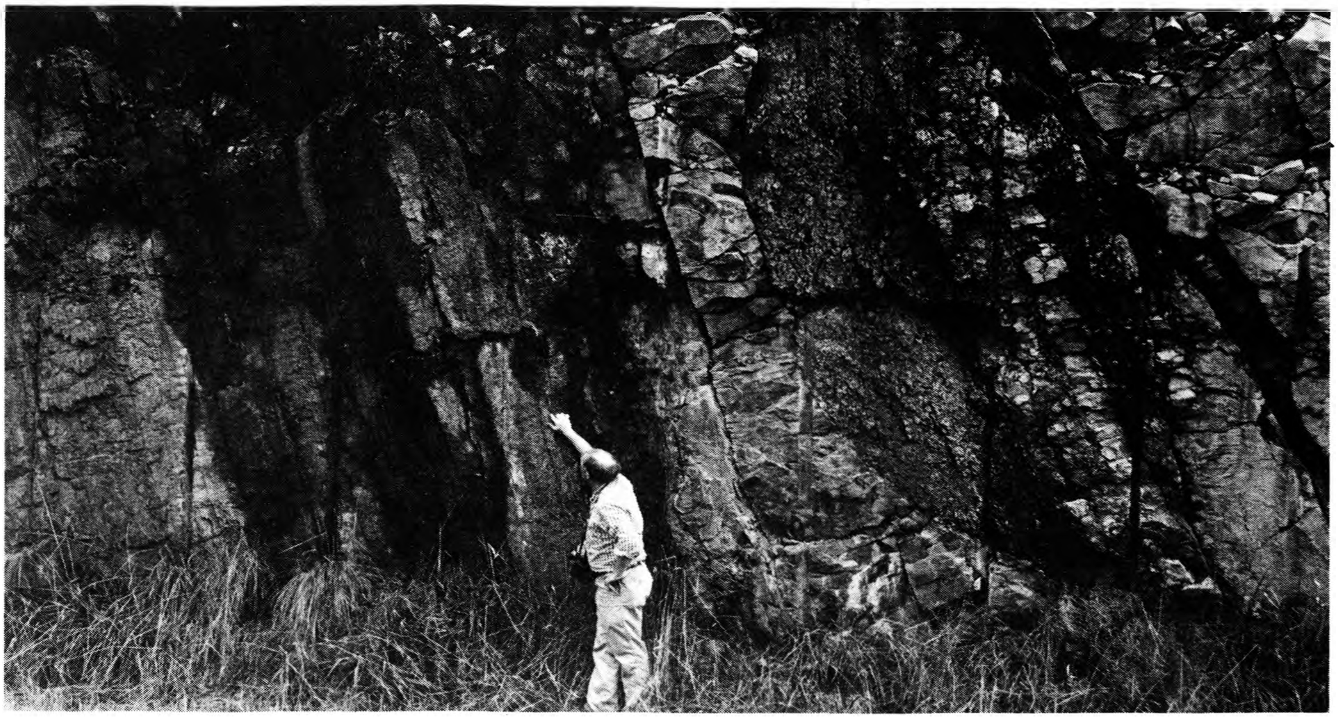

Fig. 9. Prodelta deposits of the Atoka Formation (left) and stream channel deposits of the overlying Hartshorne Sandstone (right) (NW ¼ NE ¼ Sec. 22, T6N, R31W, Arkansas). Man's index finger is on the contact. Note the shale and sandstone pebble conglomerate in the channel to the right of the man.

in Permian time. During the orogeny, the rocks in the Arkoma basin were folded into generally east-west trending synclines and anticlines; the intensity of folding increased southward. In the southern part of the basin, many of the anticlines are northward-yielding and are ruptured along their crests by northward-moving thrust faults.

ECONOMIC GEOLOGY

Oil and Natural Gas

A small amount of oil has been produced from rocks of Ordovician, Silurian, and Pennsylvanian age in the extreme southwestern part of the Arkoma basin (Fig. 10). Blebs and streaks of what appears to be dead oil have been noted by the author from wells that penetrated rocks of Ordovician to Mississippian age elsewhere in the basin.

Commercial quantities of natural gas were discovered in 1902 in western Arkansas and in 1904 in eastern Oklahoma. The gas initially was produced from sandstone reservoirs in the upper part of the Atoka Formation and from the Hartshorne Sandstone, but gas is now being produced from sandstone reservoirs in all parts of Atokan and Morrowan rocks, from sandstone and limestone reservoirs in Mississippian rocks, and from limestone and dolomite reservoirs in Devonian and Silurian rocks. In the area of the Arkoma basin, the natural gas from different age reservoirs is remarkedly similar in chemical composition. It is high in methane, low in sulfur, nitrogen, carbon-dioxide, and hydrogen-sulfide, and it has a heating value of about 1,000 Btu per cu ft. However, just to the north of the Arkoma basin, in Johnson County, Arkansas, natural gas produced from Mississippian rocks (Boone Formation) in the Batson Field must be scrubbed of hydrogen-sulfide before it is put into the pipeline.

Atokan reservoirs have been producing and will continue to produce most of the gas, and Morrowan reservoirs are the next best producers. Porosity and permeability trends in these sandstone reservoirs are the controlling factors in the commercial production of gas. Structure may have some influence on the location of the gas fields, but gas is produced from synclines as well as from anticlines. Generally, the gas produced from Devonian and Silurian reservoirs is from areas in which 1) the rock units are thin, 2) most of the rock is dolomite, and 3) movement along a nearby normal fault has placed Pennsylvanian rocks next to the reservoir.

About 4.9 trillion cu ft of gas have been produced

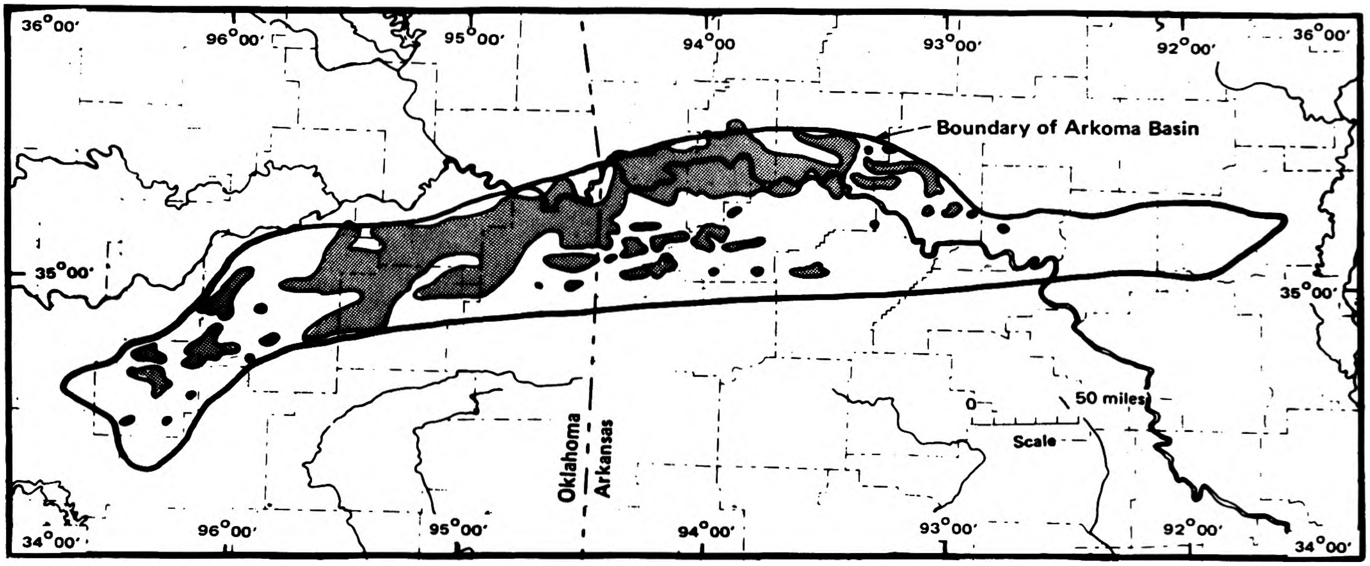

Fig. 10. Generalized map of the gas fields in the Arkoma basin.

since 1902 from the reservoirs in the Arkoma basin. If one-half of the gas has been produced, then an estimated 4.9 trillion cu ft of gas remain in the area.

Coal

Coal has been mined on a commercial basis in the Arkoma basin since 1870 (Fig. 11). Most of the coal has been produced from the lower Hartshorne coal bed near the base of the Des Moinesian-age rocks. The coal ranges in rank from high-volatile bituminous coal in the western part of the basin to semianthracite in the eastern part (Fig. 11).

On an as-received basis, the coal in the lower Hartshorne coal bed generally has less than 4 percent sulfur, less than 8 percent ash, and a Btu content of about 13,600 per pound.

Most of the mined coal is shipped out of the basin area and is blended with other coal to make metallurgial coke. The remaining coal is mined for domestic use, manufacture of briquets, and as a source of carbon.

The original reserves of coal in the Arkoma basin are estimated to be 4.8 billion short tons, of which an estimated 280 million tons have been produced since 1870.

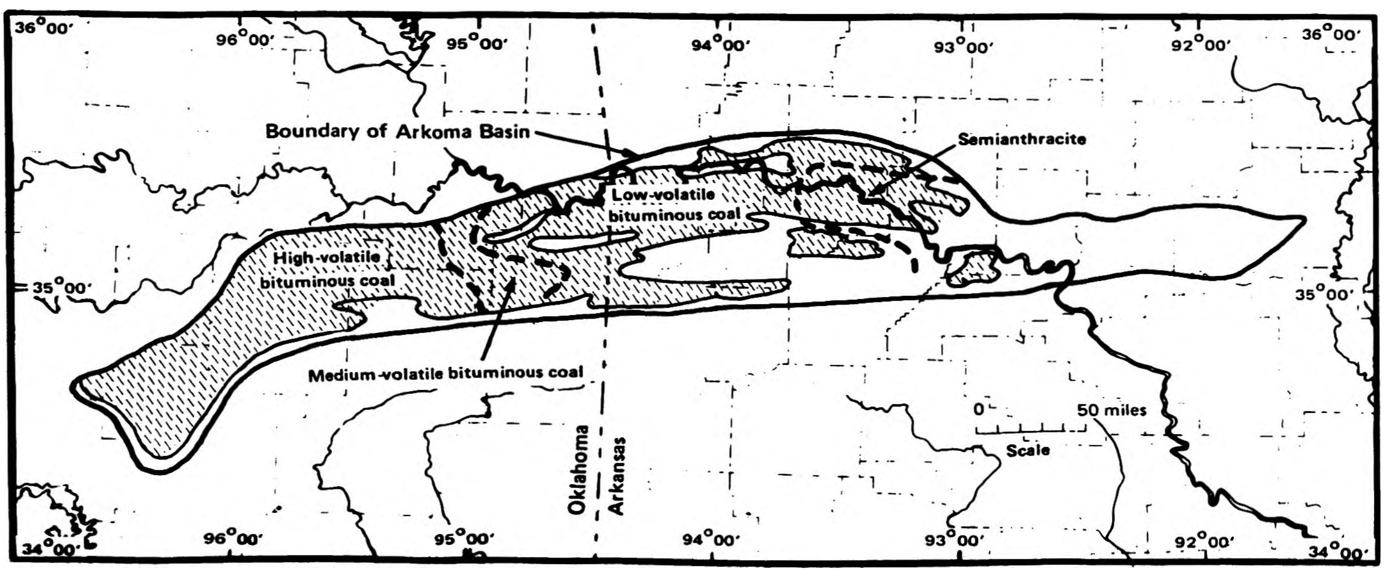

Fig. 11. Generalized map of the coal fields in the Arkoma basin.

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