The Mississippian and Pennsylvanian Systems in the United States—Arkansas

By BOYD R. HALEY, ERNEST E. GLICK, WILLIAM M. CAPLAN, DREW F. HOLBROOK, *and* CHARLES G. STONE

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Historical review and summary of areal, stratigraphic, structural, and economic geology of Mississippian and Pennsylvanian rocks in Arkansas

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THE MISSISSIPPIAN AND PENNSYLVANIAN (CARBONIFEROUS) SYSTEMS IN THE UNITED STATES—ARKANSAS

By BOYD R. HALEY, ERNEST E. GLICK, WILLIAM M. CAPLAN,[1] DREW F. HOLBROOK,[1] and CHARLES G. STONE [1]

ABSTRACT

Rocks of Carboniferous age are exposed in the northwestern third of Arkansas; more than two-thirds of the exposed rocks are of Pennsylvanian age. The contact between Devonian and Carboniferous rocks in most of Arkansas must be paleontologically determined. The area that is now Arkansas received shallow- to deep-water marine deposits until the start of the Ouachita orogeny (Middle Pennsylvanian). Most of the Middle and all of the Upper Pennsylvanian rocks have been removed by erosion. Sill-like lenses of soapstone-serpentine of possible Late Pennsylvanian age are found in Middle Ordovician rocks. Beds of volcanic tuff are present in Upper Mississippian rocks. Hydrothermal quartz veins of Late Pennsylvanian age are abundant in the Ouachita Mountains. Commercial quantities of coal, natural gas, antimony, barium, manganese, mercury, zinc, lead, dimension stone, limestone, slate, and tripoli are present in Carboniferous rocks.

INTRODUCTION

The outcrop area of Carboniferous rocks shown in figure 1 contains rocks of Devonian and Mississippian age and of Early and Middle Pennsylvanian age. The contact between Devonian and Mississippian rocks, as paleontologically determined, is in a rock unit that cannot be lithologically separated in most of Arkansas; hence, Devonian rocks are included in figure 1.

Rocks of Carboniferous age are exposed in the northwestern third of Arkansas; more than two-thirds of the exposed rocks are of Pennsylvanian age. Carboniferous rocks are known to be present to the east under younger rocks in the Mississippi Embayment and to the south under the younger rocks in the Gulf Coastal Plain (fig. 1).

The unit shown in figure 2 as of Morrowan age contains fossils reported to be of youngest Mississippian age in its lowermost parts in areas east of long 92°45′ W. Changing the lithologic and thus the geographic position of the contact between rocks of Mississippian and Pennsylvanian age as shown in figure 2 or on the "Geologic Map of Arkansas" (Haley and others, 1976) did not and does not seem feasible in view of the available evidence.

The area that is now Arkansas received shallow- to deep-water marine and continental deposits until the start of the Ouachita orogeny (Middle Pennsylvanian). The rocks were then folded, faulted, and severely eroded until sediments deposited during Cretaceous and Eocene times covered them to about their present extent. Even though the presently exposed Carboniferous rocks have been almost continuously eroded since late Paleozoic time, they are remarkably fresh where exposed along streams, lakes, roads, and in excavations.

GEOLOGIC INVESTIGATIONS

Early explorers and scientists made references to the rocks in the area that is now Arkansas as early as 1817. However, David D. Owen during the years 1857 to 1860 was the first to publish reports of reconnaissance studies pertaining in part to the rocks of Carboniferous age. Since that time, so many people have worked on the rocks of this age that space does not allow recognition of their reports.

Table 1 lists the names and the publications (concerning Arkansas) of those people who have made major contributions to geologic knowledge about the Carboniferous rocks of the State. These geologists have described rock units and have established nomenclature for these units; most of them have provided geologic maps that have been or will be the basic standard for all subsequent geologic investigations. This table serves as a list of references for this report.

The stratigraphic nomenclature used in this paper has not been reviewed by the Geologic Names Committee of the U.S. Geological Survey. The nomen-

[1] Arkansas Geological Commission, Little Rock, Ark. 72204.

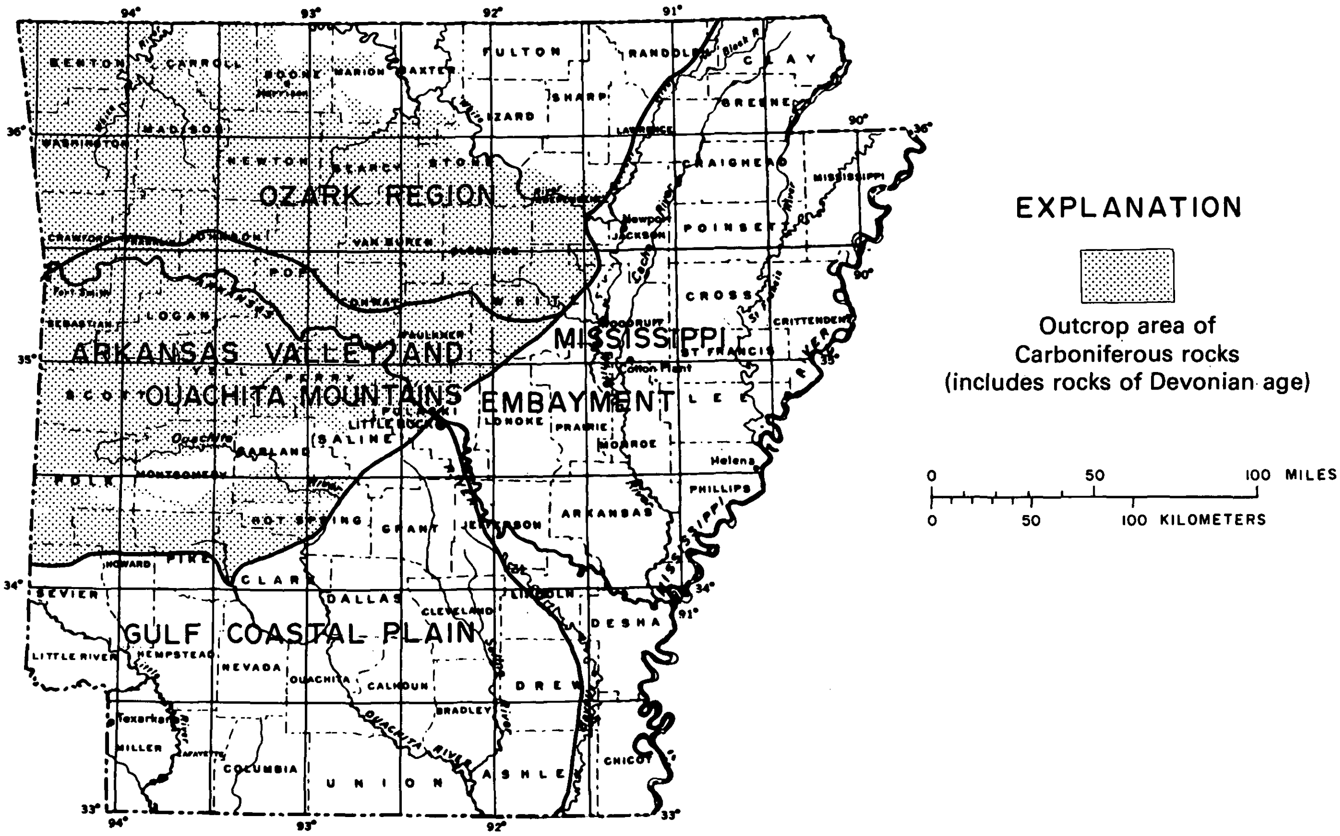

FIGURE 1.—Index map of Arkansas showing physiographic regions and outcrop of Carboniferous rocks.

TABLE 1.—*Major geologic contributions pertaining to the Carboniferous rocks of Arkansas*

Reference	Area of investigation
Adams, G. I., and Ulrich, E. O., 1905, Description of the Fayetteville quadrangle [Arkansas-Missouri]: U.S. Geol. Survey Geol. Atlas, Folio 119, 6 p.	Ozark region.
Collier, A. J., 1907, The Arkansas coal field. With reports on the paleontology by David White and G. H. Girty: U.S. Geol. Survey Bull. 326, 158 p.	Arkansas Valley.
Glick, E. E. (with Haley, B. R., and others), 1976, Geologic map of Arkansas (see Haley and others, 1976)	Ozark region.
Griswold, L. S., 1892, Whetstones and the novaculites of Arkansas: Arkansas Geol. Survey Ann. Rept., 1890, v. 3, 443 p.	Ouachita Mountains.
Haley, B. R., and others, 1976, Geologic map of Arkansas: Reston, Va., U.S. Geol. Survey, scale 1:500,000.	Ozark region, Arkansas Valley, and Ouachita Mountains.
Henbest, L. G., 1953, Morrow Group and lower Atoka Formation of Arkansas: Am. Assoc. Petroleum Geologists Bull. v. 37, no. 8, p. 1935–1953.	Ozark region.
Hendricks, T. A., and Parks, B. C., 1950, Geology of the Fort Smith district, Arkansas: U.S. Geol. Survey Prof. Paper 221–E, p. 67–94.	Arkansas Valley.
Hopkins: T. C., 1893, Marbles and other limestones: Arkansas Geol. Survey Ann. Rept. 1890, v. 4, 443 p.	Ozark region.
McKnight, E. T., 1935, Zinc and lead deposits of northern Arkansas: U.S. Geol. Survey Bull. 853, 311 p.	Do.
Miser, H. D., 1922, Deposits of manganese ore in the Batesville district, Arkansas: U.S. Geol. Survey Bull. 734, 273 p.	Ozark region.
Miser, H. D., 1929, Geologic map of Arkansas: Little Rock, Arkansas Geol. Survey.	Arkansas Valley and Ouachita Mountains.
Miser, H. D., and Purdue, A. H., 1929, Geology of the De Queen and Caddo Gap quadrangles, Arkansas: U.S. Geol. Survey Bull. 808, 195 p.	Ouachita Mountains.
Purdue, A. H., 1907, Description of the Winslow quadrangle [Arkansas-Indian Territory]: U.S. Geol. Survey Geol. Atlas, Folio 154, 6 p.	Ozark region.
Purdue, A. H., and Miser, H. D., 1916, Description of the Eureka Springs and Harrison quadrangles [Arkansas-Missouri]: U. S. Geol. Survey Geol. Atlas, Folio 202, 22 p.	Do.
Purdue, A. H., and Miser, H. D., 1923, Description of the Hot Springs district [Arkansas]: U.S. Geol. Survey Geol. Atlas, Folio 215, 12 p.	Ouachita Mountains.
Reinemund, J. A., and Danilchik, Walter, 1957, Preliminary geologic map of the Waldron quadrangle and adjacent areas, Scott County, Arkansas: U.S. Geol. Survey Oil and Gas Inv. Map, OM–192, scale 1:48,000.	Arkansas Valley and Ouachita Mountains.
Stone, C. G., (with Haley, B. R., and others), 1976, Geologic map of Arkansas (*see* Haley and others, 1976)	Do.

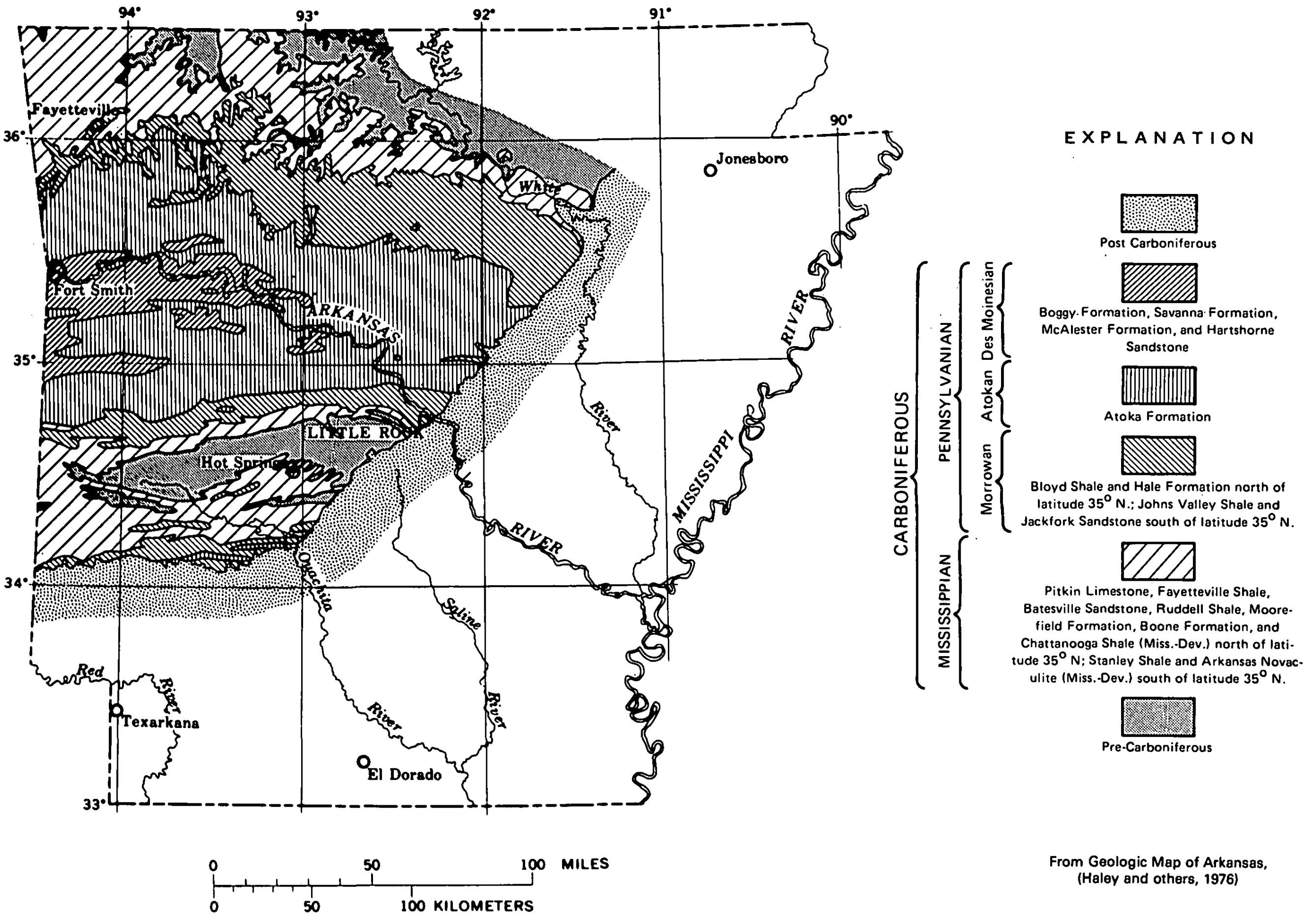

FIGURE 2.—Outcrop map of Carboniferous rocks in Arkansas.

clature used here conforms with the current usage of the Arkansas Geological Commission.

GEOLOGIC SETTING

By ERNEST E. GLICK

The paleontological base of Mississippian rocks is in the Middle Division of the Arkansas Novaculite in the Ouachita Mountains and in the Chattanooga Shale in the Ozark region. North of the limit of the Chattanooga Shale, a thin sandstone at the base of the Mississippian sequence rests on formations of Ordovician, Silurian, or Devonian age. This unit of sandstone, generally less than 0.3 m thick, is thought to be a lag sand or marine regolith that accumulated during late Devonian time. The presence of Devonian conodonts in its lower part and Mississippian conodonts in its upper part in some areas indicates that it was partly reworked during Early Mississippian time.

Deposition in Arkansas was relatively continuous during early and part of middle Carboniferous time, regional breaks being suggestive of sea-level changes until the advent of the Ouachita orogeny in Middle Pennsylvanian time. Growth faults had the greatest magnitude along a northeast-trending zone in west-central Arkansas. The displacement across this zone of faults was large enough to influence the rate and type of deposition, and generally these faults mark the boundary between the area of shelf deposition and the area of trough deposition. The growth-fault system in northeastern Arkansas is thought to be on the western side of the graben formed by the Reelfoot rift system. The fault system in west-central Arkansas may be on the northern side of a rift system that has an extent and existence still subject to conjecture. The time at which the Ouachita orogeny began is difficult to establish, but some of the rocks of Des Moinesian age have sedimentary and structural features that may have resulted from the initial compressional pulse of the orogeny. The orogeny was active by Late Pennsylvanian time and lasted until Late Permian time. All of Arkansas was uplifted, the core area of the Ouachita Mountains

Age				Ozark Mountains and Arkansas Valley		Maximum thickness in meters	Ouachita Mountains		Maximum thickness in meters
Carboniferous	Pennsylvanian	Middle	Des Moinesian	Missing			Missing		
				Boggy Formation		30			
				Savanna Formation	Paris Coal Bed Charleston Coal Bed	595			
				McAlester Formation	Upper Hartshorne Coal Bed Lower Hartshorne Coal Bed	610			
				Hartshorne Sandstone		105			
			unconformity	unconformity					
			Atokan	Atoka Formation		3,952	Atoka Formation	Upper	1,525
								Middle	1,675
								Lower	5,485
		Early	Morrowan	Bloyd Shale	Trace Creek Member Kessler Limestone Member Dye Shale Member Woolsey Member Brentwood Limestone Member	191	Johns Valley Shale		455
				Hale Formation	Prairie Grove Member	94	Jackfork Sandstone		1,830
					unconformity				
					Cane Hill Member	219			
				unconformity					

Age				Ozark Mountains and Arkansas Valley	Maximum thickness in meters	Ouachita Mountains	Maximum thickness in meters
				unconformity			
Carboniferous	Mississippian	Late	Chesterian	Pitkin Limestone	141	Stanley Shale	2,585
				Fayetteville Shale; Wedington Sandstone Member	227		
				Batesville Sandstone; Hindsville Limestone Member	52		
				unconformity			
				Ruddell Shale	30		
			Meramecian	Moorefield Formation	60	Hatton Tuff Lentil; Hot Springs Sandstone Member	
		Early	Osagean	Boone Formation; Short Creek Oolite Member; St. Joe Limestone Member	130	Upper Division Arkansas Novaculite	38
			Kinderhookian	unconformity		Middle Division Arkansas Novaculite	160
				Chattanooga Shale	20		
				unconformity			
Devonian				Clifty Limestone and Penters Chert	24	Lower Division Arkansas Novaculite	125

FIGURE 3.—Correlation chart of Carboniferous rocks in Arkansas.

being elevated more than 9,100 m along the anticlinorium. Compressive features die out northward from the recumbent folds and low- and high-angle thrust faults in the core area to the gentle folds in the Ozark region. During the orogeny, erosion almost kept up with the uplift so that few, if any, high mountains were formed.

After the orogeny and before the transgression of the Cretaceous seas, the rocks in the southern and eastern part of Arkansas were probably eroded to a plane; however, cuestas, hogbacks, and synclinal mountains were formed and continue to be positive features on the landscape. Erosion by the transgressive Cretaceous sea further beveled the plane on top of the Carboniferous rocks and then these rocks were covered by sediments of Cretaceous age. A thin strip of Carboniferous rocks, extending northeastward from Little Rock was later covered by sediments of Tertiary age.

LITHOSTRATIGRAPHY

The stratigraphic divisions of the Carboniferous rocks in Arkansas are listed and correlated in figure 3. The unconformities listed between some of the rock units in northern Arkansas represent only the major fluctuations of sea level. Many unconformities thought to represent lesser fluctuations are not shown.

In the northwestern part of the Ozark region, the contact between the Mississippian and Pennsylvanian rocks has been placed at the base of a conglomerate at the base of the Cane Hill Member of the Hale Formation. Lithologically and paleontologically, the contact is considered to be unconformable. In the northeastern part of the Ozark region, where the Cane Hill is much thicker, the contact has been placed at the base of the conglomerate and has been considered to be unconformable. However, fossils correlatable to only the youngest of European Mississippian forms have been reported from above the basal conglomerate. On the basis of the age of these fossils, some authors have divided the present Cane Hill Member into the Cane Hill Formation of Pennsylvanian age and the underlying Imo Formation of Mississippian age. The proposed Imo Formation, however, is not a mappable or a recognizable lithologic unit, and its top can be established only by the existing upper limit of diagnostic fossils of Mississippian age. Thus, in the northeastern part of the Ozark region, the position and the nature of the contact between Mississippian and Pennsylvanian rocks has yet to be determined.

In the Ouachita Mountains, the contact between Mississippian and Pennsylvanian rocks is placed at the base of the Jackfork Sandstone and is considered to be conformable. The exact paleontological boundary has not been determined, and some of the rocks in the lowermost Jackfork may be of Mississippian age.

In the Ozark region and most of the Arkansas Valley, the Mississippian rocks consist of shale, limestone, cherty limestone, and a lesser amount of sandstone. All are thought to have been deposited in a shallow-water marine environment, only the Batesville and Wedington Sandstones being deposited nearshore.

In the Ouachita Mountains, the Mississippian rocks consist mostly of shale, some graywacke, and subordinate amounts of sandstone and novaculite. All are thought to have been deposited in a deep-water marine environment. The change from shallow-water to deep-water deposition in west-central Arkansas is thought to have been abrupt across a growth fault system shown as the Johns Valley fault system in figure 4.

In the Ozark region and the western part of the Arkansas Valley, rocks of Morrowan age consist of sandstone and shale in the Hale Formation and limestone and shale in the Bloyd Shale. All are thought to have been deposited in a shallow-water marine environment except the Woolsey Member of the Bloyd Shale, which is continental in origin.

In the Ouachita Mountains, the Morrowan rocks consist primarily of sandstone and shale in the Jackfork Sandstone and shale and subordinate amounts of sandstone and conglomerate in the Johns Valley Shale. All are thought to have been deposited in deep water.

Rocks of Atokan age consist of shale and lesser amounts of sandstone and siltstone, and a few coal beds in the upper part of the formation. Nearly all of the Atoka was deposited in an environment that was essentially shallow-water marine in the Ozark region and deep-water marine in the Ouachita Mountains. The southward transition of shallow- to deep-water deposition was gradational and persisted during all but the later part of Atokan deposition (fig. 4).

Rocks of Des Moinesian age consist of shale and subordinate amounts of sandstone and siltstone and a few beds of limestone and coal. Most of the rocks were deposited in a shallow-water marine environment; the rest were deposited above sea level.

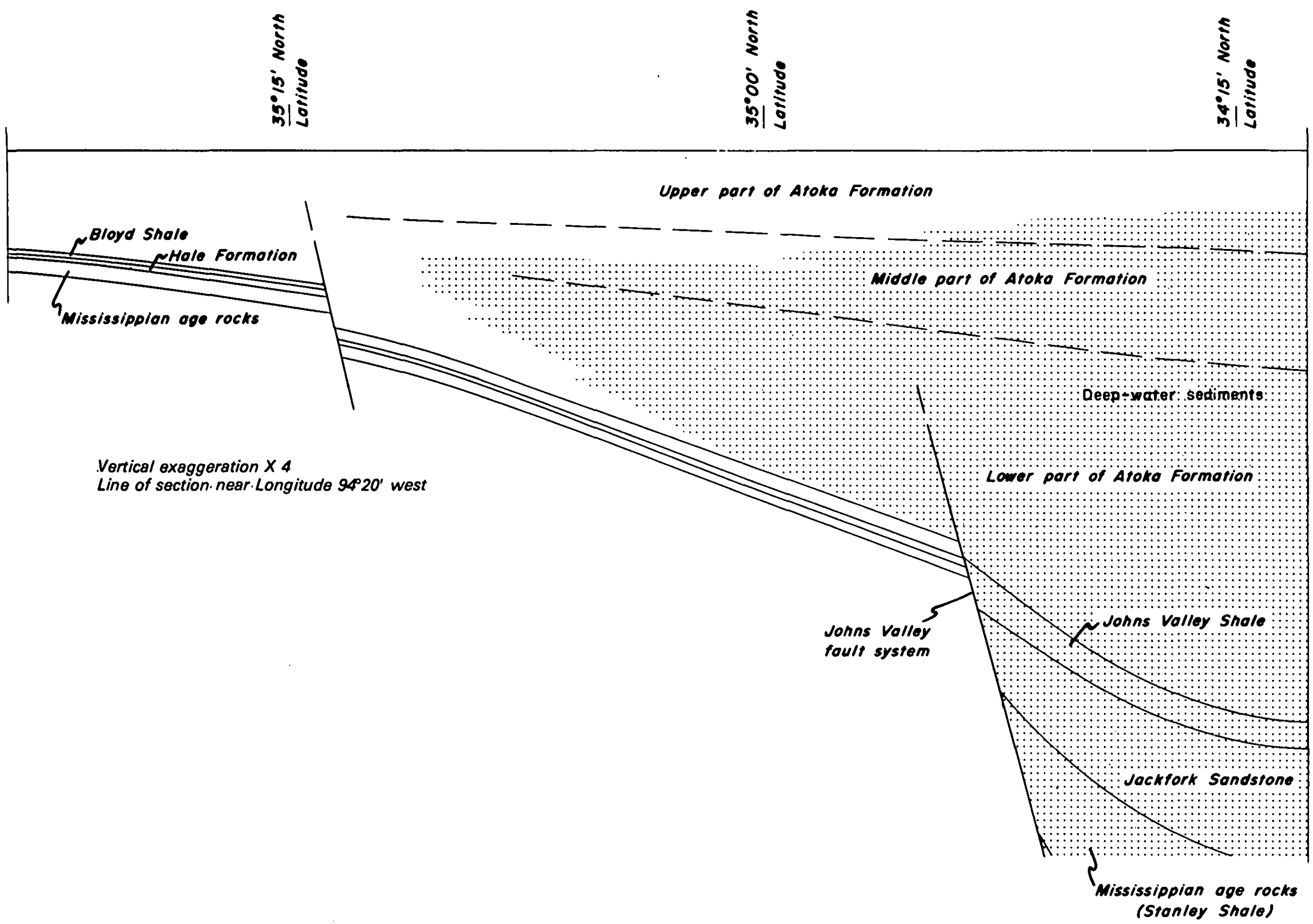

FIGURE 4.—Diagrammatic section of Atokan and older Carboniferous rocks in western Arkansas.

IGNEOUS ROCKS, METAMORPHIC ROCKS, AND VEINS

By CHARLES G. STONE

The only known igneous rocks of possible Late Pennsylvanian age in Arkansas are some soapstone-serpentine sill-like lenses in the Womble and Bigfork Formations about 15 miles west of Little Rock. The serpentine is the autometamorphosed product of an ultrabasic (peridotite) intrusive that was injected into these Ordovician rocks prior to folding processes of the Ouachita orogeny (mostly late Carboniferous).

Beds of volcanic tuff are present in the lower part of the Stanley Shale. They are thickest and most numerous near Hatton in Polk County. In this vicinity, beds of the Hatton Tuff are present in the lower 120 m of the Stanley; some of the individual beds are as much as 30 m thick. A typical bed of tuff grades upward from a coarse-grained crystalline tuff to a fine-grained vitric tuff, and some of the grading may represent reworking by turbidity currents. Potash feldspar, sodic plagioclase, perthite, and quartz are prominent minerals in the crystal tuff and ash, and shards are more common in the vitric tuff. The number and thickness of the beds and the grain size of the tuff decrease north and east of Hatton; therefore, the volcanic source of the tuff is thought to have been to the south or southwest. Radiometric ages on the tuff range from 293 ± 15 m.y. to 322 ± 26 m.y. before present. The older date conforms with the early Chesterian age of the conodont assemblages collected from the interbedded shale.

Beds of tuff composed of sodic plagioclase, volcanic rock fragments, and other materials are present in the uppermost part of the Stanley in Polk, Montgomery, and Garland Counties. Fossils collected from rocks near the tuff beds are of late Chesterian age.

Beds of bentonite (hydromica-montmorillonite), probably derived from volcanic ash falls, are indi-

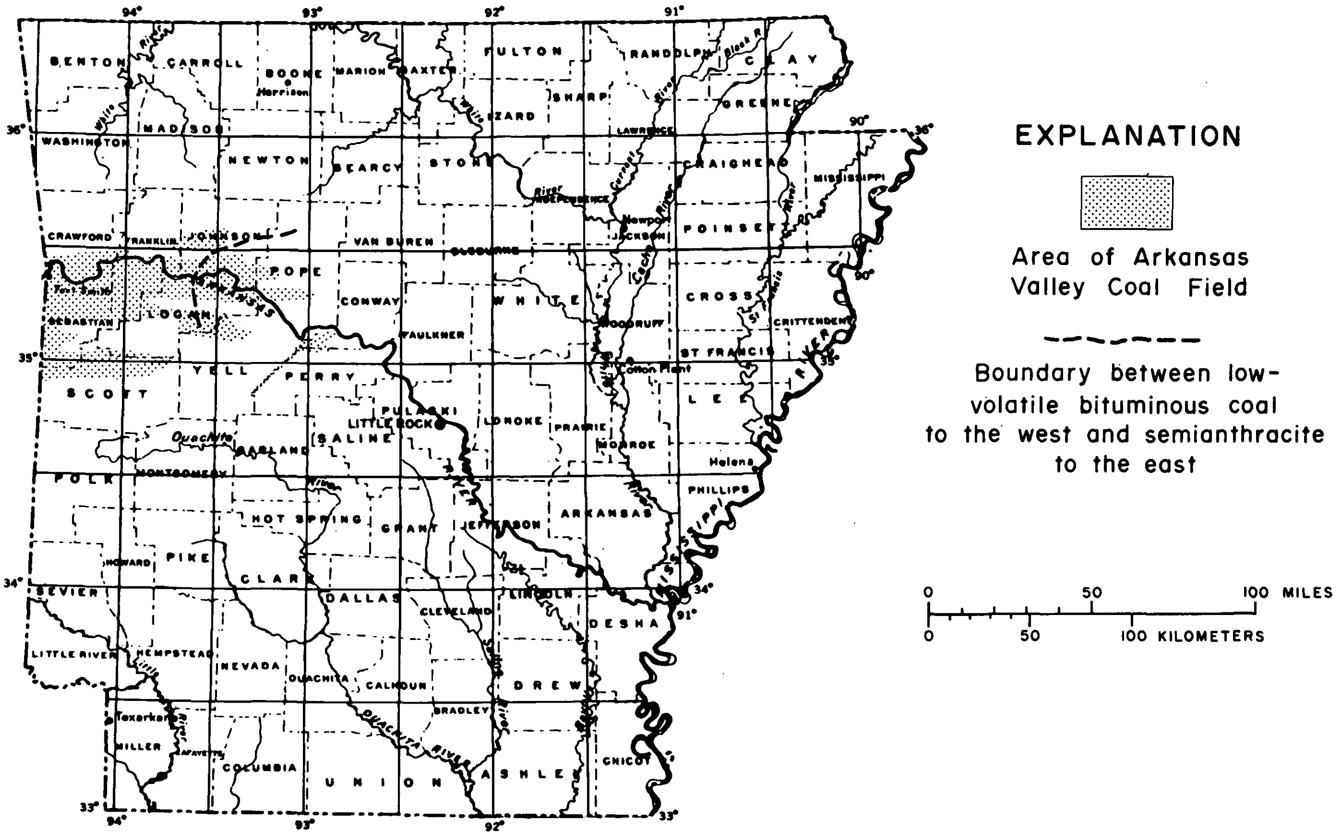

FIGURE 5.—Arkansas Valley coal-field map.

cated by studies of well cuttings from the Bloyd Shale and the lower part of the Atoka Formation in the Arkansas Valley.

A belt of low-rank regional metamorphism (chlorite stage) has affected the Mississippian and Lower Pennsylvanian rocks of the Ouachita Mountains, the area of highest intensity being centered near Little Rock. Hydrothermal quartz veins often containing minor quantities of dickite, adularia feldspar, and chlorite are common in these rocks. Most of the regional metamorphism and the emplacement of the quartz veins are thought to be related to late deformation during the Ouachita orogeny.

ECONOMIC PRODUCTS

COAL

Coal beds are present in the Bloyd Shale in northwestern Arkansas and in the upper part of the Atoka Formation in west-central Arkansas, but nearly all commercial production of coal has been from coal beds in the McAlester and Savanna Formations. The coal in the Arkansas Valley coal field (fig. 5) ranges in rank from low-volatile bituminous to semianthracite. The Baldwin coal bed in the Bloyd Shale is less than 0.4 m thick and has been mined only to supply local demand in Washington County.

The coal beds in the Atoka Formation are less than 0.6 m thick and were mined to supply local demand; however, some of the coal is now being used in the manufacture of dry-cell batteries and as an additive to charcoal briquets.

The Lower Hartshorne coal bed, near the base of the McAlester Formation, ranges in thickness from a featheredge to 1.8 m. It is the most extensive, most mined, and most economically important coal bed in Arkansas. Most of the mined coal was used for steam-generating plants, home heating, and the zinc industry, but present production is used almost exclusively by the metallurgical industry.

The Upper Hartshorne coal bed, about 18.2 m above the base of the McAlester Formation, ranges in thickness from a featheredge to 0.7 m in the southwest part of the Arkansas Valley coal field. It has not been mined.

The Charleston coal bed near the base of the Savanna Formation is less than 0.8 m thick, and in recent years the mined coal has been used as a metallurgical coal.

The Paris coal bed, near the middle of the Savanna Formation, is less than 0.8 m thick. Most of the mined coal was used for steam generating and home heat; however, it could be used as a metallurgical coal.

The distribution of the estimated 2.2 billion short tons of coal in the Arkansas Valley coal field is shown in figure 6. The total production of coal in short tons through 1975 is as follows: Franklin County 13,509,527; Johnson County 17,992,813; Logan County 9,981,039; Pope County 9,313,459; Scott County 958,057; Sebastian County 56,827,873; other counties or small mines 1,114,992; and a State total of 103,697,760.

OIL AND NATURAL GAS

By William M. Caplan

Commercial quantities of oil have not been produced from Carboniferous rocks in northern Arkansas. Oil is present in sandstone and shale of Pennsylvanian age and in concretions and black shale of Mississippian age in northern Arkansas. A solid bitumen deposit is present in sandstone of the Jackfork Sandstone in Scott County. Natural gas has been produced in commercial quantities from the Carboniferous rocks of northern Arkansas since 1902. With few exceptions, the gas is low in sulfur, high in methane, low in nitrogen, and has a heating value of about 1,000 Btu per cu ft (0.028 m^3).

The first well to produce commercially was completed in Sebastian County from the Atoka Formation, and this formation continues to be the most prolific source of natural gas of Carboniferous age. (see table 2).

From 1902 to 1944, 19 gas fields were discovered in the Atoka Formation. In 1944, gas was discovered in the Bloyd Shale in Johnson County, and in 1949, gas was discovered in the Hale Formation in Franklin County.

The first commercial production of gas of Mississippian age was from the Wedington Sandstone, where it was penetrated by a well drilling Franklin County. Commercial quantities of natural gas were first produced in 1962 from the Boone Formation in Crawford County, and additional commercial-quality gas was discovered in 1974 in Johnson County. The Boone production wells also produce gas from the Atokan or Morrowan rocks or both. The gas from the Pennsylvanian and pre-Mississippian rocks in northern Arkansas is similar enough to be commingled in the wells, but the gas from the Boone in some areas is an exception because of a relatively high hydrogen sulfide content.

Commercial deposits of natural gas of Carboniferous age in Arkansas were thought originally to be related entirely to structure, but the importance of stratigraphic and stratigraphic-structural traps as geologic settings has become increasingly significant as more is learned about the region. Exploratory wells drilled on structural prospects alone may miss the buried stream channels and deltaic deposits containing natural gas in trends normal or near normal to the strike of the structural feature.

As of January 1, 1977, the 10 counties of northern Arkansas have 60 gas fields, containing 1,223 wells. Natural gas from rocks of Carboniferous age is or could be produced in 58 of these fields irrespective of any deeper production there.

Cumulative gas production to January 1, 1977, in northern Arkansas is 1,801,722,499 Mcf (50,989$\times 10^6 m^3$). Remaining reserves are estimated to be 1,510,523,000 Mcf (42,748$\times 10^6 m^3$). Both figures pertain mainly to natural gas in the rocks of Carboniferous age.

Areas underlain by commercial quantities of natural gas in the Atoka Formation and the Morrow Series are shown in figure 7. Areas in which gas is produced from rocks of Mississippian age are not specifically shown in figure 7.

MINERALS

By Drew F. Holbrook

METALLIC MINERALS

ANTIMONY

The antimony district is a belt 4 km wide and 17.6 km long extending across northern Sevier County in southwestern Arkansas. The antimony deposits are present in the tightly folded rocks of the Stanley Formation; the fissure veins tend to be parallel to bedding. The ore bodies are small and lenticular and are known to have a maximum thickness of 1.3 m, a maximum length of 51.7 m, and a maximum width of 22.8 m.

The ore bodies are mainly stibnite-bearing quartz veins in which crystals and crystal masses of stibnite are present in comb quartz. Other primary minerals are native antimony, chalcopyrite, galena, pyrite, sphalerite, jamesonite and zinckenite. Only galena, sphalerite, and pyrite are present throughout the district.

Secondary minerals include cervantite, which is the most abundant, stibiconite, bindheimite, anglesite, cerussite, azurite, malachite, and smithsonite. The gangue minerals are quartz, ankerite, calcite,

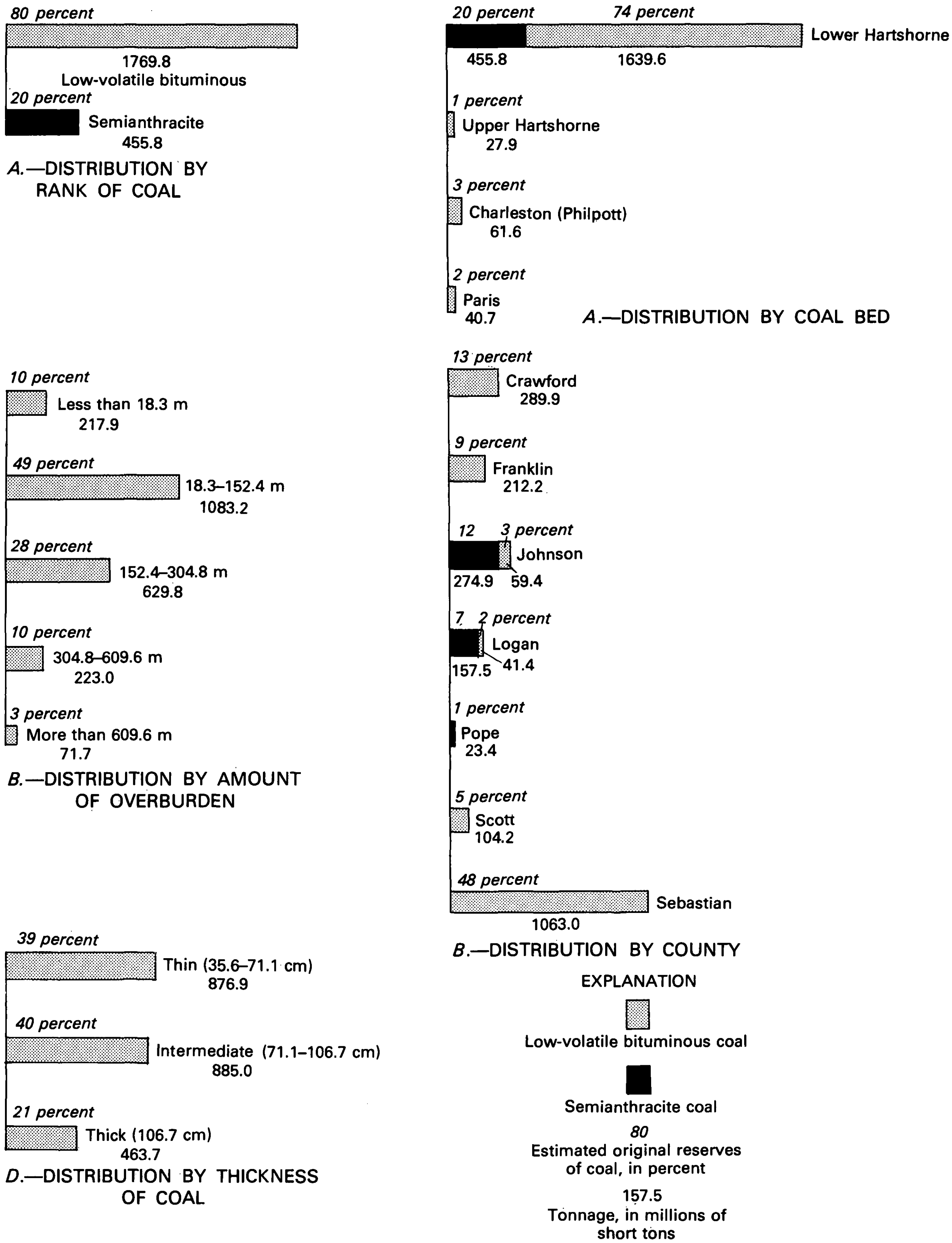

FIGURE 6.—Distribution of estimated original reserves of low-volatile bituminous coal and semianthracite in Arkansas.

TABLE 2.—*Natural-gas wells of economic and historic significance in the Carboniferous rocks of Arkansas*

Company and well	Location (Sec., T., R.)	County	Date completed	Total depth (ft (m))	Production depth (ft (m))	Pay zone	Initial potential in mcfgd ((m³) per day)	Remarks
Choctaw Oil and Gas Co. No. 2 Duncan.	1, 4N., 31W.	Sebastian	Mar. 1902	1,125 (343)	863–873 (263–266)	Atoka	550 (15,565)	Discovery well of Mansfield field and first producer of natural gas in Arkansas.
					1,125 (343)	----do ----		
Arkansas Louisiana Gas Co. No. 1 S. M. Hudson.	15, 10N., 24W.	Johnson	Dec. 1944	6,135 (1,870)	3,402–3,650 (1,037–1,085)	Kessler and Brentwood.	3,500 (99,050)	Drilled in Clarksville field; the first commercial Bloyd producer in Arkansas.
Arkansas Louisiana Gas Co. No. 1 Ralph S. Barton.	27, 9N., 28W.	Franklin	Sept. 1949	6,650 (2,027)	4,850–4,930 (1,478–1,503)	Hale	7,000 (198,100)	Discovery well of Cecil field; the first commercial Hale producer in Arkansas.
Arkansas Western Gas Co. No. 1 F. A. Parsley.	15, 10N., 28W.	----do ----	Oct. 1951	3,896 (1,188)	3,348–3,367 (1,020–1,026)	Morrow	6,000 (169,800)	The first commercial producer from the Wedington or pre-Pennsylvanian rocks in Arkansas.
					3,782–3,814 (1,153–1,163)	Wedington	2,000 (56,000)	
Carter Oil Co. No. 1 L. B. Chronister.	3, 8N., 19W.	Pope	Oct. 1956	5,211 (1,588)	3,917–4,030 (1,194–1,228)	Atoka	(71,800) (2,031,940)	Drilled in Moreland field; it had the largest initial potential of any well drilled in north Arkansas.
					4,469–4,514 (1,362–1,376)	Hale	6,700 (189,610)	
Arkansas Western Gas Co. No. 1 A. Goad.	20, 14N., 29W.	Washington	April 1959	650 (198)	565 (172)	Wedington	460 (13,018)	Discovery well of Brentwood field, but was not completed as a producer. Drilling for additional reserves started in 1977.
Beard Oil Co. No. 1 R. A. Evans.	32, 9N., 11W.	Cleburne	July 1959	3,868 (1,179)	1,956–1,998 (596–609)	Atoka	430 (12,169)	Discovery well of Quitman field; established the easternmost commercial producer in the Arkansas Valley. Field was abandoned in 1964.
Stephens Production Co. No. 1 D. L. Fontaine	32, 9N., 30W.	Crawford	June 1962	6,161 (1,878)	5,755–5,777 (1,754–1,761)	Boone	2,450 (69,335)	Drilled in Kibler field; the first commercial Boone producer in Arkansas.
					5,922–5,952 (1,805–1,815)	Penters	7,500 (212,250)	
Arkansas Western Gas. Co. No. 1 Federal ES 5262.	12, 11N., 25W.	Johnson	Dec. 1973	3,543 (1,080)	1,815–1,850 (553–564)	Hale	6,000 (169,800)	Drilled in Batson field. This well opened the first field that produced Boone gas commercially from more than one well.
					2,578–2,622 (786–799)	Boone }	7,600 (215,080)	
					2,654–2,686 (809–819)	----do ---- }		

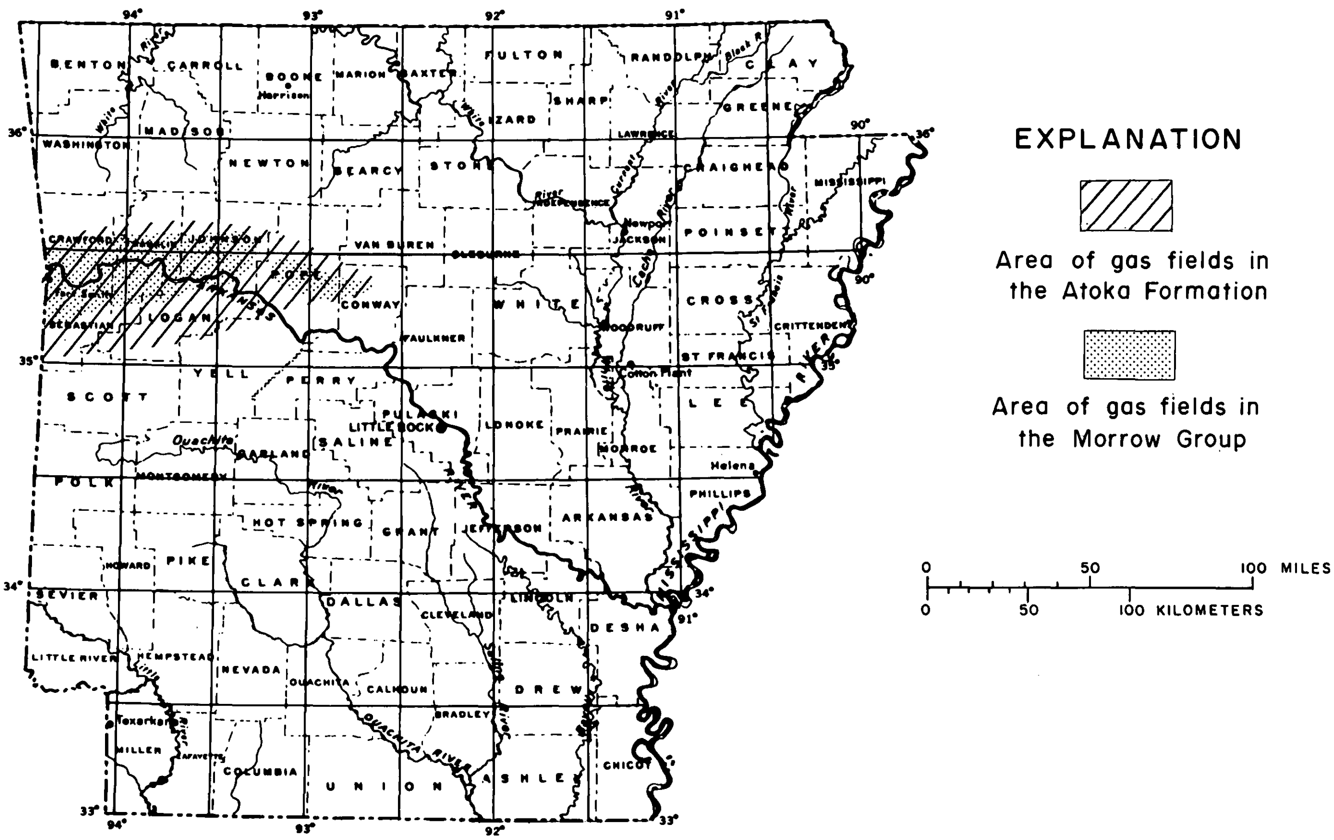

FIGURE 7.—Gas-field map of Arkansas.

siderite, chlorite, and dickite. Stibnite and the other primary minerals were deposited from hypogene solutions that moved along thrust-fault planes or subparallel fractures. The antimony mineralization probably took place after most of the quartz veins had been emplaced.

Production of antimony during the period 1873 to 1947 was sporadic and generally coincided with exceptionally high market prices. The total reported amount of antimony produced during the 70 years is only 589 short tons.

BARIUM

Barite (barium sulfate) has been produced from the Magnet Cove district in Hot Spring County and from the Pigeon Roost Mountain and Fancy Hill districts in Montgomery County. The barite deposits are in the lowermost part of the Stanley Formation. Generally the base of the barite deposit is within 6 m of the top of the Arkansas Novaculite. Most of the barite deposits are less than 30.4 m thick, but a few are as thick as 91.2 m.

The individual barite deposits contain several types of ore, which, in order of abundance, are as follows: (1) gray to dark-gray finely crystalline ore; (2) gray granular to dense ore; (3) nodular ore, as much as 5 cm in diameter; and (4) the least common type, a dark-gray to black granular ore.

Barite has been continuously produced in Arkansas since 1944. Through 1976, ten million short tons has been produced, almost all of which came from the Magnet Cove district. All the barite produced is used as a weighting agent in drilling mud.

MANGANESE

Manganese is present in Carboniferous rocks in Garland, Hot Springs, Saline, and Pulaski Counties; however, the larger deposits are in Montgomery and Polk Counties in an east-trending belt about 11.2 km wide and 56 km long. The manganese deposits are present in the Lower, Middle, and Upper Divisions of the Arkansas Novaculite. The ore bodies are small, the largest estimated to contain 50,000 short tons. The manganese ore is present as nodules, pockets, and short irregular veins ranging in thickness from a few centimeters to 1.2 m.

The ore bodies consist mainly of psilomelane, pyrolusite, manganite, and wad; two or more of these minerals are intimately mixed in the same deposit. Other minerals associated with the manganese minerals are limonite, goethite, native copper, cuprite, chrysocolla, turquoise, malachite, pyrite, lithiophorite, wavellite, variscite, dufrenite, barite, and quartz.

Manganese is present in the St. Joe Member of the Boone Formation in a few places in Izard, Searcy, and Stone Counties. Manganese was mined intermittently in western Arkansas from 1885 to 1959; production was mainly during a few years of high market prices and totaled only 6,000 short tons.

MERCURY

The mercury district is a belt 9.6 km wide and 48 km long extending eastward from Howard County to Clark County in southwestern Arkansas. The mercury deposits are about equally divided in the sandstone of the uppermost Stanley Formation and the lowermost Jackfork Sandstone. Most of the ore bodies are small, the largest being 30.4 m long, 9.1 m wide, and 36.5 m deep. Cinnabar is present as a finely crystalline ore coating on fracture surfaces, coarsely crystalline ore filling larger fractures, and sparingly, finely crystalline ore filling pore spaces in the sandstone. Other primary minerals are dickite, quartz, pyrite, siderite, stibnite, barite, and calcite. Secondary mercury minerals and iron oxides are present near the surface.

Active mining in the mercury district took place mostly during the years 1931 to 1946 and has been only intermittent since then. The total amount of mercury produced is estimated to be 12,500 flasks (946,250 lb).

VANADIUM

Vanadium ore is in local concentrations within large areas of argillic alteration near Wilson Springs in Garland County. Within such areas, fenite feldspathic breccias and metamorphosed sedimentary rocks have been altered and mineralized. Rocks of the Mississippian part of the Arkansas Novaculite may have been mineralized in the Wilson Spring area and also in similar ore concentrations near Magnet Cove in Hot Spring County. The vanadium rarely occurs as discrete vanadium minerals but generally as a vicarious element in several rock-forming minerals and their alteration products.

ZINC AND LEAD

Zinc and lead deposits are present in flat-lying carbonate rocks in the Ozark region and in folded shale and sandstone in the Ouachita Mountains.

In the Ozark region, the zinc and lead deposits are mostly in Newton County, a few being present in Searcy, Marion, and Boone Counties. Lead deposits are found in the Batesville Sandstone, but most of the lead and zinc deposits are in the Boone Formation. The ore deposits are in fracture zones, along joint systems, in irregularly shaped masses parallel to bedding of the host rock, and in some fault zones.

The ore bodies are primarily sphalerite and galena together with some chalcopyrite, pyrite, and marcasite. Secondary minerals are smithsonite, calamine (hemimorphite), cerussite, and traces of malachite, azurite, and aurichalcite. The galena is very low in silver, and the sphalerite contains small amounts of iron and cadmium.

From 1902 to 1962, the reported amount of zinc concentrates is 29,900 short tons. From 1907 to 1959, the reported amount of lead concentrates is 2,000 short tons.

In the Ouachita Mountains, small deposits of lead and zinc are present in mineralized quartz veins in the Stanley Formation in Sevier County, in the Stanley and the Arkansas Novaculite in Hot Spring County, and in the Jackfork Sandstone in Pulaski County. Galena, sphalerite, and chalcopyrite are the principal minerals. Small amounts of silver were present in the galena in all areas, larger amounts being associated with freiburgite in Pulaski County.

The amount of zinc and lead produced from the mines in these counties is unknown.

NONMETALLIC MINERALS

DIMENSION STONE

Dimension stone is being produced from sandstone in the Hartshorne Sandstone in Logan, Franklin, Pope, and Johnson Counties and in the Batesville Sandstone in Stone and Independence Counties. Black marble has been produced from the Pitkin Limestone and the Fayetteville Shale in Stone and Independence Counties, and gray marble, from the Boone Formation in Independence County.

LIMESTONE

High-calcium limestone is quarried from the Boone Formation in Independence County. It is in contiguous beds having an aggregate thickness of 33.7 m, and the quarried product is converted to lime. Limestone is also quarried from the Boone Formation and the Pitkin Limestone; the product is used as aggregate stone for construction purposes.

SLATE

Slate has been quarried from the Stanley Formation in Garland County, but its poor weathering characteristics precluded its use as an exterior finish. Slate is quarried from the Stanley in Montgomery County, where it is crushed and ground for use as roofing granules.

TRIPOLI

Tripoli is a microcrystalline finely particulate friable form of silica. Deposits of tripoli are present in the Boone Formation in Benton, Washington, and Madison Counties, the largest being in Benton County. The tripoli is the siliceous remnants of weathered calcareous chert layers. Deposits of tripoli are also present in the Upper Division of the Arkansas Novaculite in Pulaski, Garland, Montgomery, and Polk Counties, but most of it has been produced from Garland County. The tripoli is formed by the weathering of calcium carbonate from the novaculite.

The Mississippian and Pennsylvanian (Carboniferous) Systems in the United States

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ON THE COVER

Swamp-forest landscape at time of coal formation: lepidodendrons (left), sigillarias (in the center), calamites, and cordaites (right), in addition to tree ferns and other ferns. Near the base of the largest *Lepidodendron* (left) is a large dragonfly (70-cm wingspread). (Reproduced from frontispiece in Kukuk, Paul (1938), "Geologie des Niederrheinisch-Westfälischen Steinkohlengebietes" by permission of Springer-Verlag, New York, Inc.)

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GEOLOGICAL SURVEY

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FOREWORD

The year 1979 is not only the Centennial of the U.S. Geological Survey—it is also the year for the quadrennial meeting of the International Congress on Carboniferous Stratigraphy and Geology, which meets in the United States for its ninth session. This session is the first time that the major international congress, first organized in 1927, has met outside Europe. For this reason it is particularly appropriate that the Carboniferous Congress closely consider the Mississippian and Pennsylvanian Systems; American usage of these terms does not conform with the more traditional European usage of the term "Carboniferous."

In the spring of 1976, shortly after accepting the invitation to meet in the United States, the Permanent Committee for the Congress requested that a summary of American Carboniferous geology be prepared. The Geological Survey had already prepared Professional Paper 853, "Paleotectonic Investigations of the Pennsylvanian System in the United States," and was preparing Professional Paper 1010, "Paleotectonic Investigations of the Mississippian System in the United States." These major works emphasize geologic structures and draw heavily on subsurface data. The Permanent Committee also hoped for a report that would emphasize surface outcrops and provide more information on historical development, economic products, and other matters not considered in detail in Professional Papers 853 and 1010.

Because the U.S. Geological Survey did not possess all the information necessary to prepare such a work, the Chief Geologist turned to the Association of American State Geologists. An enthusiastic agreement was reached that those States in which Mississippian or Pennsylvanian rocks are exposed would provide the requested summaries; each State Geologist would be responsible for the preparation of the chapter on his State. In some States, the State Geologist himself became the sole author or wrote in conjunction with his colleagues; in others, the work was done by those in academic or commercial fields. A few State Geologists invited individuals within the U.S. Geological Survey to prepare the summaries for their States.

Although the authors followed guidelines closely, a diversity in outlook and approach may be found among these papers, for each has its own unique geographic view. In general, the papers conform to U.S. Geological Survey format. Most geologists have given measurements in metric units, following current practice; several authors, however, have used both metric and inch-pound measurements in indicating thickness of strata, isopach intervals, and similar data.

FOREWORD

This series of contributions differs from typical U.S. Geological Survey stratigraphic studies in that these manuscripts have not been examined by the Geologic Names Committee of the Survey. This committee is charged with insuring consistent usage of formational and other stratigraphic names in U.S. Geological Survey publications. Because the names in these papers on the Carboniferous are those used by the State agencies, it would have been inappropriate for the Geologic Names Committee to take any action.

The Geological Survey has had a long tradition of warm cooperation with the State geological agencies. Cooperative projects are well known and mutually appreciated. The Carboniferous Congress has provided yet another opportunity for State and Federal scientific cooperation. This series of reports has incorporated much new geologic information and for many years will aid man's wise utilization of the resources of the Earth.

H William Menard

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