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

By ROBERT O. FAY, S. A. FRIEDMAN, KENNETH S. JOHNSON, JOHN F. ROBERTS, WILLIAM D. ROSE, *and* PATRICK K. SUTHERLAND

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Oklahoma Geological Survey

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

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ABSTRACT

The Carboniferous rocks of Oklahoma represent both the Mississippian and Pennsylvanian Systems. Sedimentary rocks make up almost all the Carboniferous in the geologic record, although minor occurrences of igneous and metamorphic rocks have been noted. Volcanic ash, pyroclastic flows, and tuff beds are present in Mississippian rocks of the Ouachita Mountains; some low-grade metasedimentary rocks occur in the core area of the Ouachitas.

Oklahoma's three major mountain systems—the Wichita, Arbuckle, and Ouachita—extend through the southern part of the State. They were formed during the Pennsylvanian Period and are adjacent to the Anadarko, Arkoma, Ardmore, and Marietta deep sedimentary basins, which contain the thickest Carboniferous sedimentary rocks. The northern part of the State contains the more stable cratonic shelf areas and the southwest flank of the Ozark uplift in the northeast.

Carboniferous outcrops are limited to the eastern half of Oklahoma. Pennsylvanian rocks are exposed in the Arkoma basin and nearby shelf areas to the north and west as well as in parts of the Arbuckle, Ouachita, and Ozark uplifts and in the Ardmore basin to the south. Mississippian rocks are more limited in extent and are exposed only in the Arbuckle, Ouachita, and Ozark uplifts. In general, Mississippian rocks consist of carbonate rocks and some shales and sandstones, although their lithology varies markedly from one depositional basin to another. The greatest thickness of Mississippian strata is the 3,300 m of flysch sedimentary rocks making up the Stanley Group of the Ouachita basin. Pennsylvanian rocks consist mostly of shale, but beds of sandstone, limestone, conglomerate, coal, and underclay are also present; these rocks attain their greatest thickness, 5,500 m, in the Arkoma basin.

The Pennsylvanian-Permian boundary now is tentatively placed at the top of the Herington Limestone Member of the Oscar Formation by the Oklahoma Geological Survey. This usage places rocks of Gearyan (Wolfcampian) age in the uppermost Pennsylvanian System rather than in the lowermost Permian.

The principal economic resources of Oklahoma's Carboniferous deposits are coal and petroleum products. In 1977, Oklahoma ranked 20th in the Nation in coal production and produced a record 5.3 million short tons. In 1976, the State ranked third in the Nation in natural-gas production (1,710,586 million cubic feet) and fourth in crude-oil production (150,627,000 barrels); an estimated 69 percent of the gas and 60 percent of the oil produced came from Carboniferous rocks.

Less significant economic resources that have been produced from Carboniferous rocks include metallic ores (zinc, lead, and copper) and nonmetallic minerals (limestone, shale, tripoli, sandstone, chat, and iodine). Two major Carboniferous aquifers, the "Boone" (Mississippian) and the Vamoosa (Pennsylvanian), produce large quantities of ground water.

INTRODUCTION

By KENNETH S. JOHNSON

Oklahoma, a region of complex geology, contains a great thickness of Carboniferous sedimentary rocks and underwent major orogenic activity during the Pennsylvanian Period. In the southern part of the State are three major mountain systems—the Wichita, Arbuckle, and Ouachita (fig. 1)—which largely mark the southern boundary of the North American craton. The mountain regions, all of which were formed during Pennsylvanian orogenies, are adjacent to a series of deep sedimentary basins—the Anadarko, Arkoma, Ardmore, and Marietta—which received 5,000 to 7,000 m of Carboniferous sediments. The northern half of the State, on the other hand, contains the more stable cratonic shelf areas and the southwest flank of the Ozark uplift in the northeast. Much of the data presented in this report was collected in the comprehensive studies by Branson (1962), Ham and Wilson (1967), and Frezon and Dixon (1975). The reader is referred to these reports as well as to an atlas by Johnson and others (1972) that contains a series of generalized maps, cross sections, and a text on the geology and mineral resources of Oklahoma.

Outcrops of Carboniferous rocks are limited to the eastern half of Oklahoma (figs. 2, 3). Pennsyl-

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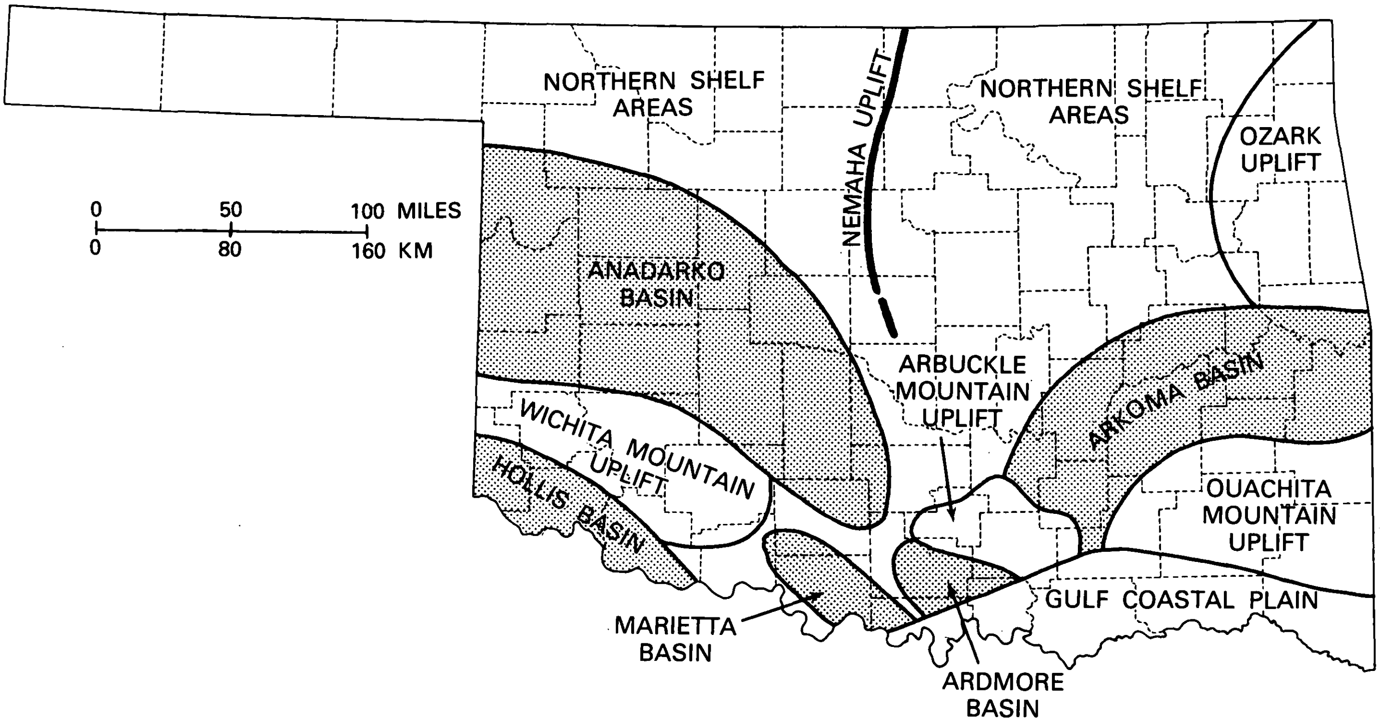


FIGURE 1.—Major geologic provinces of Oklahoma (from Johnson and others, 1972, p. 1).

vanian strata are extensively exposed in the Arkoma basin and nearby shelf areas to the north and west, as well as in parts of the Arbuckle, Ouachita, and Ozark uplifts and in the Ardmore basin to the south. Mississippian strata are more limited and are exposed only in the Arbuckle, Ouachita, and Ozark uplifts.

Carboniferous strata are well exposed in most parts of eastern Oklahoma. The area was not covered by Pleistocene glaciers; thus, only soil and vegetation conceal the beds of sandstone, shale, and limestone that make up almost all the stratigraphic section. Average annual precipitation ranges from about 85 cm in the central part of the State to 110–140 cm in the east.

Regional eastward tilting of the midcontinent of the United States during uplift of the Rocky Mountains in Late Cretaceous and Early Tertiary time established the dominant east-flowing river systems that cross the strike of Carboniferous strata in Oklahoma. The simple dendritic pattern is locally replaced by radial drainage along the flanks of the Ozark uplift and by poorly defined trellis drainage in much of the Ouachita Mountains and the Arkoma basin.

Topographic relief in most of eastern Oklahoma is low to moderate; west-dipping cuestas overlook broad shale plains. Bedrock exposures are abundant, and the many highways and maintained dirt roads provide easy access to them. In the Ozark uplift, the Ouachita Mountains, and parts of the Arkoma basin, the relief is moderate to high (as much as 500 m locally in the Ouachitas). Although bedrock is widely exposed in these provinces, ready access to these exposures is limited largely to the few highways and dirt roads that cross this more rugged terrain.

The stratigraphic nomenclature used in this paper has not been reviewed by the Geologic Names Committee of the U.S. Geological Survey. The nomenclature used here conforms with the current usage of the Oklahoma Geological Survey. The following series designations of the Carboniferous are now used by the Oklahoma Geological Survey: For the Mississippian, they are Kinderhookian and Osagean (Lower) and Meramecian and Chesterian (Upper). For the Pennsylvanian, they are Morrowan and "Atokan" (Lower); Desmoinesian and Missourian (Middle); Virgilian (Upper); and Gearyan (Upper?). Terms such as Springeran, Bendian, Lampasan, Atokan, and Wolfcampian appear to overlap other series and are in controversy. These terms have been used in a group or rock sense in Oklahoma and are placed in quotation marks in this report to indicate questionable usage and the need for restudy.

As noted in the table of contents, this report was prepared by Robert O. Fay, S. A. Friedman, Kenneth S. Johnson, and John F. Roberts, staff members of the Oklahoma Geological Survey; and by Patrick K. Sutherland, School of Geology and Geophysics, University of Oklahoma. William D. Rose, Oklahoma Geological Survey, coordinated the report.

HISTORY OF GEOLOGIC STUDIES

By Robert O. Fay

The early history of geologic studies in Oklahoma began with the Indians, who knew about salt, lead ore, coal, oil seeps, and limestone. The Indians kept no records, but they directed the early explorers to most of the deposits. The Spanish (1541–1803), French (1682–1803), and American (1803–11) explorers recorded many of their findings. For Spanish history, see Shipp (1881), Winship (1896), Thoburn (1916), and Thomas (1928). For French history, see Le Page du Pratz (1758), Parkman (1869), Hyde and Conard (1899), Goodspeed (1904), Bennitt and Stockbridge (1905), Thoburn (1916), Lewis (1924a,b,c), Lyon (1934), Hyde (1948), Beers (1957), and Boone (1968). For American history, see Austin (1804), John Sibley (1805), Lewis and others (1806), Pike (1810), G. C. Sibley (1812), Stoddard (1812), Coues (1895), Thwaites (1908), Thoburn (1916), Barker (1924), Foreman (1930, 1932), Jackson (1966), and Stout (1976).

On April 30, 1803, the Province of Louisiana was purchased from the French by the United States. On March 26, 1804, the land south of lat 33° N. was designated Territory of Orleans, and New Orleans, its capital; the land to the north was designated District of Louisiana, and St. Louis, its capital. On April 30, 1812, the Territory of Orleans became the State of Louisiana. On March 2, 1819, the Arkansas Territory was created, which included present-day Arkansas and Oklahoma; the land to the north was Missouri Territory. On August 10, 1821, Missouri became a State, and the land to the west was known as Missouri Territory. On May 28, 1828, the western part of Arkansas Territory was designated Indian Territory. On June 15, 1836, Arkansas became a State. On November 16, 1907, Indian Territory became the State of Oklahoma. (For more details, see Williams (1904) and Herndon (1922).)

Fort Smith was established in 1817 and became the center for southwestern explorations. Bearss and Gibson (1969) gave a history of Fort Smith. Schoolcraft (1819, 1821), Nuttall (1821), James (1823), Hinton (1834), Featherstonehaugh (1835), Shumard (1853), and Marcou (1854) published some of the earliest accounts of the geology of what is now Oklahoma and adjacent areas.

In his description of rocks near Fort Smith, James (1823, p. 410) first used the name Carboniferous Limestone in what is now Oklahoma: "Conybeare and Phillips [1822] apply this name to the limestone of the English coal measures (p. 340, pl. 1). *Compact limestone* is a name obviously inapplicable to the whole series of calcareous beds, occurring in connexion [sic] with the coal." Hinton (1834) described the general geology of the Ozarks, the Ouachitas, and the Great Plains, summarizing from previous sources. Shumard (1853) described the geology from Fort Smith to the Arbuckles and the region southward, showing the Carboniferous Limestone, below, and the Coal Measures, above. He described the red beds around the Wichita Mountains. Marcou (1854) described the geology along the Canadian River, distinguishing the Carboniferous Limestone, the Coal Measures, and the overlying New Red Sandstone.

The completion of the Missouri, Kansas, and Texas Railroad across Oklahoma in 1872 was followed by the opening of the coal mines at McAlester. Three oil wells were drilled near Chelsea in 1889. Asphaltite was known in the Ouachitas in 1890, and the first oil production in Oklahoma was recorded in 1891. In 1893, tripoli was found near Peoria, Ottawa County.

Chance (1890) studied the Choctaw coal fields. Hill (1891) wrote on the Ouachitas. Haworth and Kirk (1894) studied the Neosho River section. C. R. Keyes (1894, unpub. data) wrote the first formal oil and gas prospectus for John D. Rockefeller. Stevenson (1896) wrote on the geology of Indian Territory. Drake (1897) mapped eastern Oklahoma in 1896, noting accurately many details of the coal geology. Vaughan (1899) published on the Arbuckle Mountains. Taff (1899) described and mapped the McAlester-Lehigh area and described asphalt in the Choctaw Nation, following a treaty of 1897 to map the segregated coal lands in the Choctaw and Chickasaw Nations. White (1899) and Girty (1899) wrote about Taff's collections of invertebrate and plant fossils from near McAlester.

Taff (1899, 1902) continued his work with the help of G. I. Adams, S. H. Ball, J. W. Beede, S. W. Beyer, G. H. Girty, C. N. Gould, R. D. Mesler, G. B. Richardson, M. K. Shaler, C. D. Smith, E. O. Ulrich, and C. D. White. Almost 20 publications resulted on

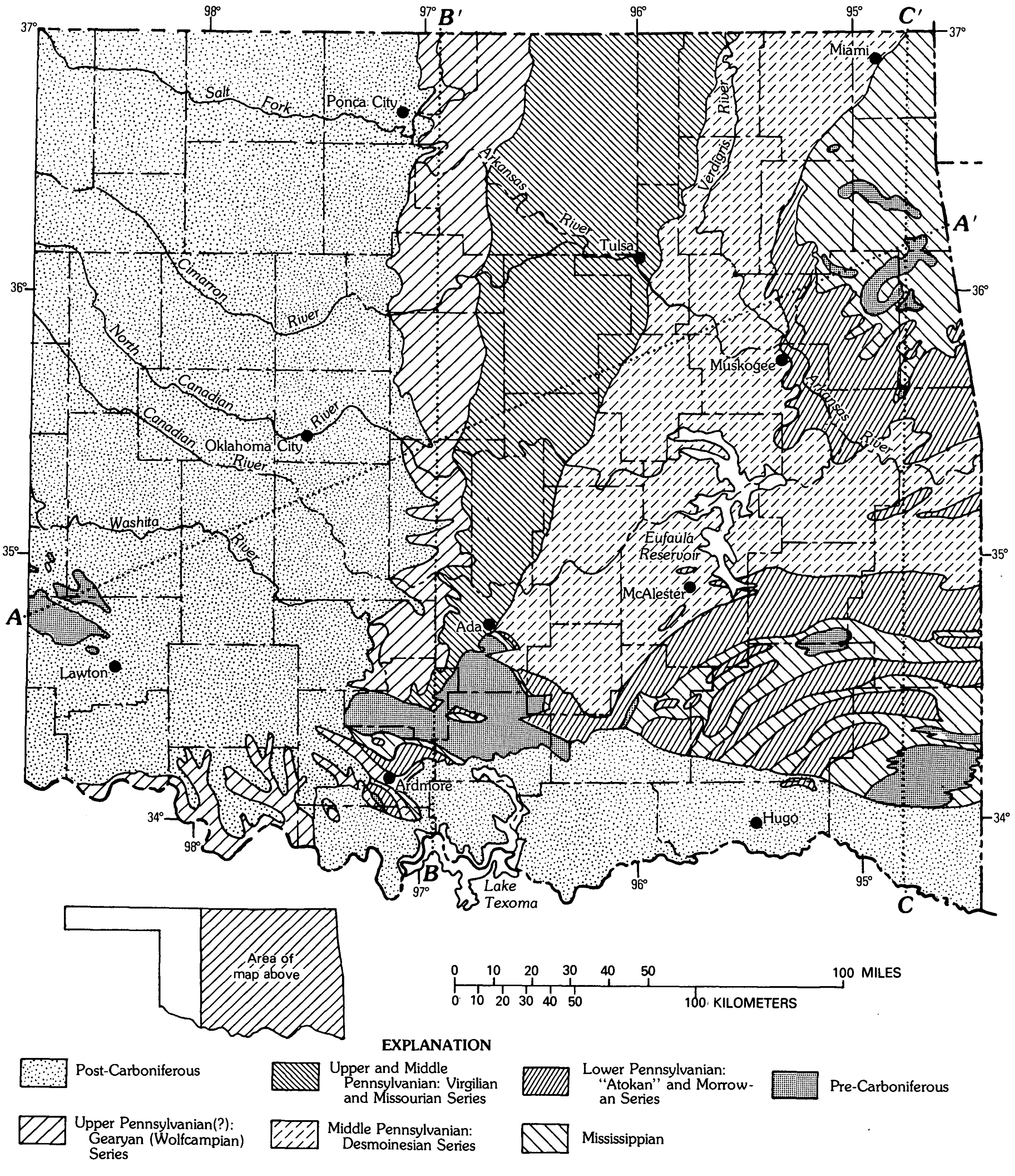


FIGURE 2.—Generalized geologic map showing outcrops of Carboniferous rocks in Oklahoma (from Miser, 1954; Johnson and others, 1972, p. 4). Cross sections shown in figure 3.

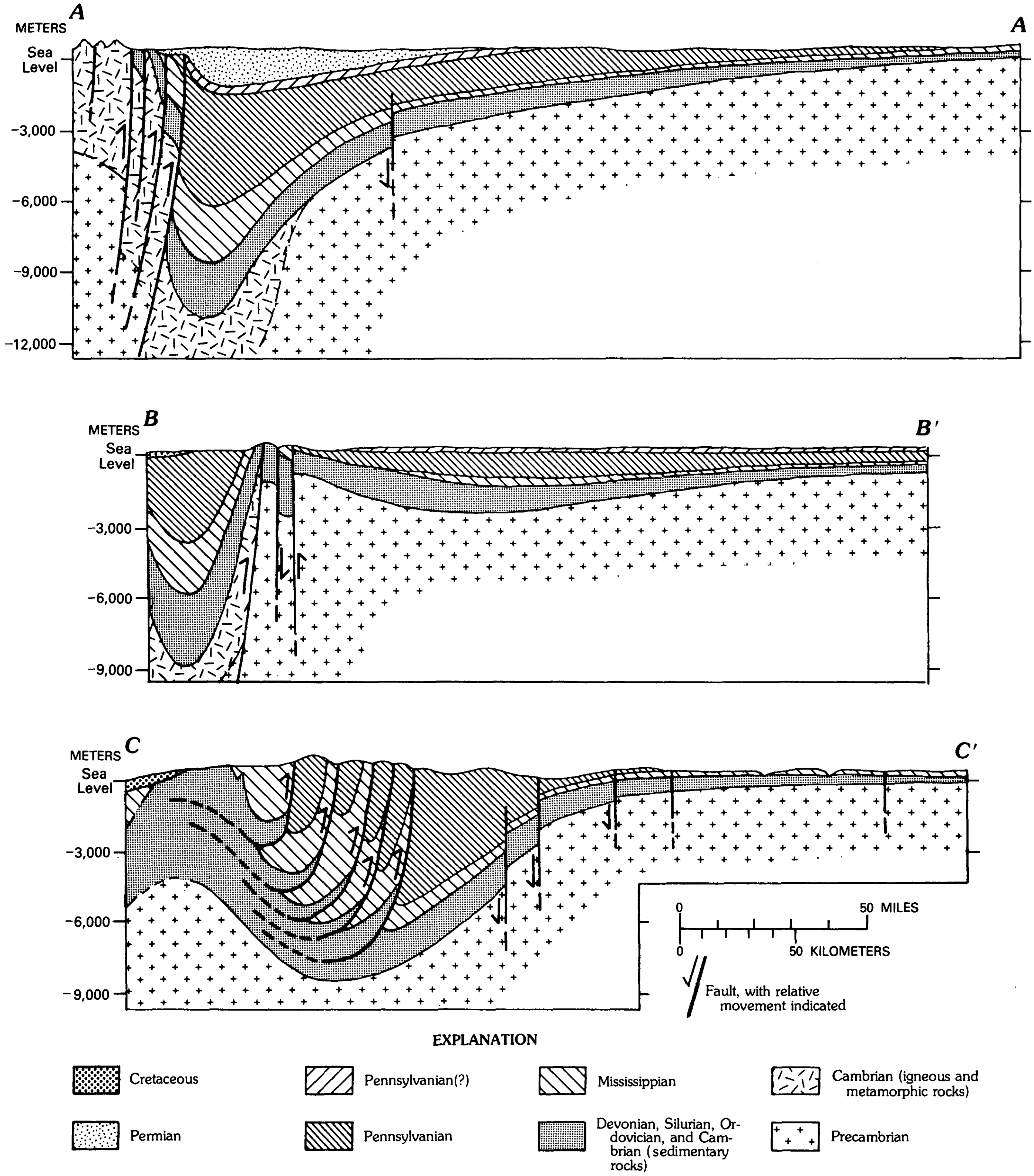


FIGURE 3.—Generalized cross sections through major geologic provinces of Oklahoma (from Johnson and others, 1972, p. 5). Lines of cross sections shown in figure 2.

the Ozarks, the Arkoma basin, the Ouachita Mountains, the Arbuckle Mountains, the Ardmore basin, the Criner Hills, and the Wichita Mountains. Maps of the McAlester, Windingstair, Tuskahoma, and Antlers Quadrangles were never published but were utilized by Miser in preparation of the first geologic map of Oklahoma (1926).

From 1900 to 1910, more than 30 additional articles were published on all phases of the Carboniferous. In 1907, the Miami-Picher zinc field was discovered in Mississippian rocks, and most of the 344 gas wells and 7,850 oil wells in Oklahoma were producing from the Carboniferous strata. The new Oklahoma Geological Survey was established July 25, 1908.

From 1910 to 1930, many changes took place. In April 1912, the Cushing field was discovered; oil production from this field amounted to 3 percent of the world's total for that year. In 1913, most of the 1,052 producing gas wells and 20,620 oil wells in Oklahoma were producing from Carboniferous rocks. Everett Carpenter organized the Empire Gas and Fuel Co. in 1913, hiring 250 geologists and initiating subsurface studies in Oklahoma. The Oklahoma Geological Survey first used automobiles in 1915; previously horses and mules were used. In June 1915, the Oklahoma Corporation Commission first regulated oil production. The American Association of Petroleum Geologists was organized on January 7, 1916, in Norman, Okla. Core drilling was first used in Oklahoma in 1919. The secondary recovery of oil by waterflooding began in 1920. Geophysical work was begun in 1921 and was based upon a method that was used to locate cannons in World War I; the first geophysical company consisted of W. P. Haseman, head of the Physics Department at the University of Oklahoma, and D. W. Ohern, Irving Perrine, and J. C. Karcher. By 1924, micropaleontology had become popular, rotary drilling had been introduced in Oklahoma, and well cuttings were being preserved. In 1929, electric logs were first used. These developments enabled geologists to have a three-dimensional concept of Carboniferous rocks in Oklahoma. A flood of published information followed.

From 1910 to the present, many hundreds of articles have been written on the Carboniferous of Oklahoma. Gould (1925) gave the first stratigraphic index. Branson and Jordan (1964) and Branson and others (1967) published indexes to mapping in Oklahoma. Now, more than 100 surface maps and 250 subsurface maps exist on the Carboniferous of Oklahoma. McKnight and Fischer (1970) and Gibson (1972) provided histories of the Tri-State mineral district and gave extensive bibliographies. From 1958 to the present, K. S. Johnson, E. A. Ham, and others on the Oklahoma Geological Survey staff have compiled annual bibliographies of Oklahoma geology, which have been published in Oklahoma Geology Notes.

Concerning nomenclature and regional stratigraphy, the following are excellent references: Williams (1891), Wilmarth (1925), Moore (1940), Branson (1962), and Frezon and Dixon (1975).

Various workers have assigned different locations for the Pennsylvanian-Permian boundary over the years (see Moore, 1940, figs. 3, 4). On the new geologic maps of Oklahoma, which have been published at a scale of 1:250,000 by the Oklahoma Geological Survey and the U.S. Geological Survey as part of a series of hydrologic atlases, rocks of Gearyan ("Wolfcampian") age have been considered uppermost Pennsylvanian rather than Permian. This usage follows the work of Dott (1932), Green (1936), Branson (1962), Clendening (1971), and Wilson and Rashid (1975). In figure 2 of the present report, Gearyan rocks are included in the map unit showing rocks of questionable Pennsylvanian age.

GEOLOGIC SETTING

By Kenneth S. Johnson

UNDERLYING ROCKS

The base of the Carboniferous throughout most of Oklahoma lies within a dark-gray to black cherty shale of Late Devonian and Early Mississippian age. The shale is called the Woodford Shale in most parts of the State, but the term Chattanooga Shale is used in the northeast on the flanks of the Ozark uplift. In the Ouachita Mountains, the base of the Carboniferous is in the Lower Silurian-Lower Mississippian Arkansas Novaculite, a siliceous chertlike sedimentary rock, the upper part of which is generally equivalent to the Woodford Shale. The Woodford Shale or equivalent strata are absent in parts of the Panhandle, in the Hollis basin, over the Wichita uplift, and over other smaller uplifts; in these areas, younger Mississippian and even Pennsylvanian strata are at the base of the Carboniferous locally.

At the base of the Woodford is a major pre-Upper Devonian unconformity that extends over most of the midcontinent region. The Woodford therefore rests with low-angle unconformity upon strata of Ordovician, Silurian, and Early Devonian age (Tarr and others, 1965). Silurian and Devonian rocks underlie the Woodford Shale or Arkansas Novaculite in the deeper parts of most basins, whereas Ordovician strata underlie the pre-Woodford unconformity on the north flanks of the Arkoma and Anadarko basins and in parts of the Arkoma, Ardmore, and Hollis basins.

In areas where the Woodford Shale or Arkansas Novaculite is present, the Devonian-Mississippian contact is transitional and can be only approximated by micropaleontologic study of pollen and (or) conodonts. Black shale and siliceous sediments were deposited without apparent interruption in most parts of the State from Late Devonian through Early Mississippian (Kinderhookian) time. In the Panhandle and in the Hollis basin, limestones of Osagean through Meramecian age are at the base of the Carboniferous. Mississippian strata were eroded during subsequent Pennsylvanian uplift of the Wichita block and smaller blocks extending northward from the Arbuckle Mountains across central Oklahoma (Hunton arch and Oklahoma City uplift-Nemaha uplift). In these areas, Middle and Upper Pennsylvanian clastic sedimentary rocks lie unconformably upon Cambrian through Devonian sedimentary rocks or, in much of the Wichita uplift, upon a Cambrian basement of granite, rhyolite, and gabbro.

OVERLYING ROCKS

Carboniferous strata are now widely exposed in the eastern third of Oklahoma. In the west, however, Pennsylvanian(?) rocks of Gearyan age are overlain by Lower Permian strata consisting chiefly of red-bed clastic rocks. In southeastern Oklahoma, Permian rocks are absent, and the Carboniferous is overlain by sands of the Trinity Group of Early Cretaceous age.

The contact with overlying Permian strata in western Oklahoma appears to be conformable. The stratigraphic relations and lithologies of rocks on both sides of the boundary indicate that Late Pennsylvanian depositional conditions continued into the Permian without appreciable break, except for a change into red beds.

Cretaceous strata in the southeast rest with angular unconformity upon the folded Carboniferous rocks of the Ouachita system and the Ardmore basin.

STRUCTURAL EVENTS

Carboniferous time in Oklahoma was characterized by formation of deep sedimentary basins and, in the southern half of the State, by formation of the mountain systems. All sedimentary basins—including the Anadarko, Arkoma, Ardmore, Marietta, Hollis basins and the Ouachita geosyncline—had their principal period of downwarping from Late Mississippian through Pennsylvanian time. These basins typically are elongate and now contain some 3,000–12,000 m of sedimentary rocks; Carboniferous strata constitute 50–75 percent of the total thickness in each basin (fig. 3). The three mountain belts—the Wichita, Arbuckle, and Ouachita—were the sites of folding, faulting, and uplift during several orogenic pulses that took place throughout the Pennsylvanian Period. Principal studies upon which we have relied heavily for discussion of structural events are those by Cline and others (1959), Flawn and others (1961), Branson (1962), Ham and others (1964), Ham and Wilson (1967), American Association of Petroleum Geologists and others (1968, 1975), Ham (1969), Frezon and Dixon (1975), and Decker and Black (1976).

During the first half of the Mississippian Period, shallow seas covered all of Oklahoma. Limestone and interbedded chert were the predominant sediments laid down upon the Upper Devonian-Lower Mississippian Woodford Shale in most areas, whereas deposition of the Arkansas Novaculite continued in the Ouachita geosyncline. The widespread beds of Lower Mississippian limestone are the youngest or last of the thick sequence of carbonate rocks that attest general crustal stability in Oklahoma during early and middle Paleozoic time.

In the last half of the Mississippian Period, shale and sandstone were predominant; major sites of deposition were the rapidly subsiding basins in southern Oklahoma. Principal formations of southern Oklahoma (excluding the Ouachitas) are the Sycamore Limestone, Delaware Creek Shale, and Goddard Shale. These strata have a total thickness of 500–2,000 m in the Ardmore and eastern Anadarko basins and nearby areas. The greatest thickness of Mississippian strata is the 3,300 m of flysch sedimentary rocks making up the Stanley Group of the Ouachita basin. Mississippian strata in central and north-central Oklahoma have been largely removed by Early Pennsylvanian uplift and erosion, and the remaining Mississippian rocks consist generally of 50–200 m of cherty limestone that thickens to the west and reaches a thickness of 1,500 m in the western Anadarko basin.

The Pennsylvanian Period was the principal time of crustal unrest in Oklahoma—a time of both orogeny and basinal subsidence in the south and of epeirogenic movement in the north. Preexisting sedimentary rocks and the underlying basement rocks of the Wichita, Arbuckle, and Ouachita Mountain areas were complexly folded, faulted, and thrust upward into major mountains, while the nearby basins subsided more rapidly and received the greatly increased sediment load eroded from the highlands (fig. 3). Orogenies took place during all epochs of the Pennsylvanian Period, but different areas were affected to different degrees by each pulse.

Pennsylvanian rocks comprise mostly marine shale, but beds of sandstone, limestone, conglomerate, coal, and underclay are also present. The strata are commonly 600–1,500 m thick but are as much as 5,000 m thick in the Anadarko basin, 4,500 m in the Ardmore basin, 4,000 m in the Marietta basin, and 5,500 m in the Arkoma basin. In fact, each of these basins, as well as the eastward continuation of the Arkoma basin in Arkansas, contains a greater thickness of Pennsylvanian strata than does any other comparable area in the United States.

The major Pennsylvanian orogeny, commonly called the Wichita orogeny (Morrowan and early "Atokan"), was characterized by strong folding and uplift of as much as 3,000–4,500 m in the Wichitas and in the Criner Hills south of Ardmore. Conglomerate and "granite wash" (a local name given to coarse arkosic detritus) were commonly deposited near major uplifts. These coarse sedimentary rocks grade into sandstone and shale toward the middle of the basins. A broad, north-trending arch across central Oklahoma was raised above sea level during this time; along its axis was a narrow belt of fault-block mountains (Nemaha uplift) extending northward from the Oklahoma City area into Kansas. The uplift was accompanied by erosion that removed part or all the pre-Pennsylvanian sediments from the mountain uplifts and the central Oklahoma arch. In fact, the unconformity at the base of Pennsylvanian rocks is the most profound Paleozoic unconformity in Oklahoma and can be recognized everywhere but in the deeper parts of major basins.

Principal pulses of folding and uplift in the Ouachita Mountains began in Mississippian time and continued into the Permian; these structural movements are referred to as the Ouachita orogeny. The thick sequence of dark-gray shales, cherts, and flysch sedimentary rocks in the Ouachita geosyncline was complexly folded and thrust faulted. The Ouachitas contain a series of south-dipping thrust faults in the northern belt, where the Choctaw fault outlines the frontal (north) edge of the mountain system. In the southern belt, the major faults dip north. After the deformation of the Ouachita trough, basinal downwarping shifted northward into the Arkoma basin during "Atokan" and Desmoinesian time and then ceased after the folding and faulting of the Arkoma basin. Of special importance in the Arkoma basin and northeastern Oklahoma are the coal beds formed during Desmoinesian time.

The last major Pennsylvanian orogeny, called the Arbuckle orogeny, was one of strong compression and uplift during Virgilian time. It affected all mountain areas of the south and is represented by most of the prominent folding in the Ardmore, Marietta, and Anadarko basins. Much of the thrusting in the Ouachita Mountains probably also took place in late Virgilian time. Thus, by the end of the Pennsylvanian Period, the mountain systems of Oklahoma were substantially as we know them today, although subsequent gentle uplift and accompanying erosion have cut more deeply into underlying rocks.

Post-Carboniferous structural movements were largely confined to epeirogenic raising and lowering of broad regions in Oklahoma. In Early Permian time, the Wichitas, Arbuckles, Ouachitas, and Ozarks were still fairly high land areas, and they supplied sand and mud to shallow seas that covered the Anadarko basin and other parts of western Oklahoma. By Late Permian time, the Wichitas were largely buried by sediment derived mainly from the lowland areas of the Ouachitas and Ozarks in the east. Small faults and flexures in Permian sedimentary rocks attest minor movement of preexisting major faults, principally along the margins of sedimentary basins.

During the Cretaceous Period, southern and western parts of Oklahoma were gently depressd to accept the last incursion of marine waters into the State. Formation of the Rocky Mountains in Late Cretaceous and Early Tertiary time elevated the western part of the State, imparting an eastward tilt to the land surface that has persisted to the present.

Major drainage systems of today were initiated during Pleistocene time. Continental glaciers extended southward only to northeastern Kansas, but meltwater from Rocky Mountain glaciers and snowfields provided much of the streamflow that helped strip away post-Carboniferous strata and thus exhume the major mountain systems.

MISSISSIPPIAN AND LOWER PENNSYLVANIAN STRATIGRAPHY

By PATRICK K. SUTHERLAND

Strata of Mississippian and Early Pennsylvanian age crop out in five regions in Oklahoma: (1) the southwestern Ozark region, in the northeast; (2) the frontal Ouachita Mountains; (3) the central Ouachita Mountains, in the southeast; (4) the northeastern Arbuckle Mountains, in the south-central part of the State; and (5) the Ardmore basin and southwestern Arbuckle Mountains, in the south (fig. 4). These areas show marked differences in lithologic character, thickness, and depositional pattern.

OZARK REGION

Mississippian and Lower Pennsylvanian strata in the Ozark region of northeastern Oklahoma are dominated by carbonate rocks. Unconformities are numerous. Represented in figure 5 is a typical shallow-water platform facies, which is thinner than the clastic, geosynclinal facies that crops out in the Ouachita Mountains. The maximum thicknesses recorded for Mississippian formations in the Ozark region of Oklahoma total about 250 m, but the total preserved thickness for the Mississippian in any local area does not exceed 150 m. The maximum recorded thickness for the Lower Pennsylvanian Morrowan Series is 94 m, and that for the "Atokan" Series, about 185 m.

The Upper Mississippian Pitkin Formation is truncated northward by pre-Pennsylvanian erosion and is absent north of T. 18 N. The succeeding Morrowan Series is truncated by pre-Atokan erosion in T. 20 N. In T. 22 N., Desmoinesian strata overlap the "Atoka" Formation and rest directly upon eroded Mississippian strata.

KINDERHOOKIAN, OSAGEAN, AND MERAMECIAN SERIES

The Chattanooga Shale, as much as 20 m thick in northeastern Oklahoma, ranges in age from Late Devonian to Early Mississippian (Kinderhookian) and correlates with the Woodford Shale in southern Oklahoma (Hass, 1956).

The Chattanooga is overlain unconformably by the "Boone" Group, which consists of beds of chert and limestone. This group ranges in age from latest Kinderhookian to early Meramecian but is predominantly Osagean. Included are the St. Joe, Reeds Spring, and Keokuk Formations. Their maximum recorded thicknesses are 12, 55, and 75 m, respectively (Huffman, 1958); the thickness of each averages much less, however, and all are missing in the southern part of the Ozark outcrop area, where the Moorefield Formation rests directly on the Chattanooga. The Keokuk is particularly distinctive lithologically, consisting of white- to buff-weathering chert that forms distinctive fractured rubble surfaces. It contains abundant fossils, mostly in the form of molds and casts. Various formations of the "Boone" Group are overlain unconformably by the Moorefield Formation, the Hindsville Limestone, or, locally, the Fayetteville Shale.

The Moorefield Formation, predominantly of Meramecian age, consists mostly of argillaceous limestones, but other facies include oolitic and pelmatozoan grainstones and calcareous siltstones. Four facies were given local member names by Huffman (1958). The formation has a maximum thickness of about 30 m but is missing in Craig and Ottawa Counties, where the Hindsville rests unconformably on the "Boone" cherts.

CHESTERIAN SERIES

The Hindsville Limestone, Fayetteville Shale, and Pitkin Limestone, all of Chesterian age, form a continuous depositional sequence in the Ozark region. The Hindsville is a widely distributed fossiliferous limestone that rests unconformably on the Moorefield Formation or on the "Boone." It has a maximum thickness of 15 m, but it averages 8–10 m (Huffman, 1958).

The Hindsville Limestone is overlain conformably by the Fayetteville Shale. The Fayetteville consists predominantly of black or gray-green shale, but it is interbedded locally near the base or near the top with dark nodular layers of carbonate mudstone. The formation has a maximum thickness of about 50 m.

The Pitkin Limestone conformably overlies the Fayetteville Shale and shows marked local variations in facies, ranging from crossbedded oolites to skeletal grainstones to dark carbonate mudstones. The formation is typically about 10 m thick but has a maximum observed thickness of 25 m (Huffman, 1958). The formation is unconformably overlain by the Pennsylvanian Sausbee Formation.

POST-CHESTERIAN EROSIONAL SURFACE

The Pitkin Limestone is regionally truncated northward in Oklahoma along a highly irregular line; the most northerly exposures are in T. 18 N., at the southern edge of Mayes County. Farther

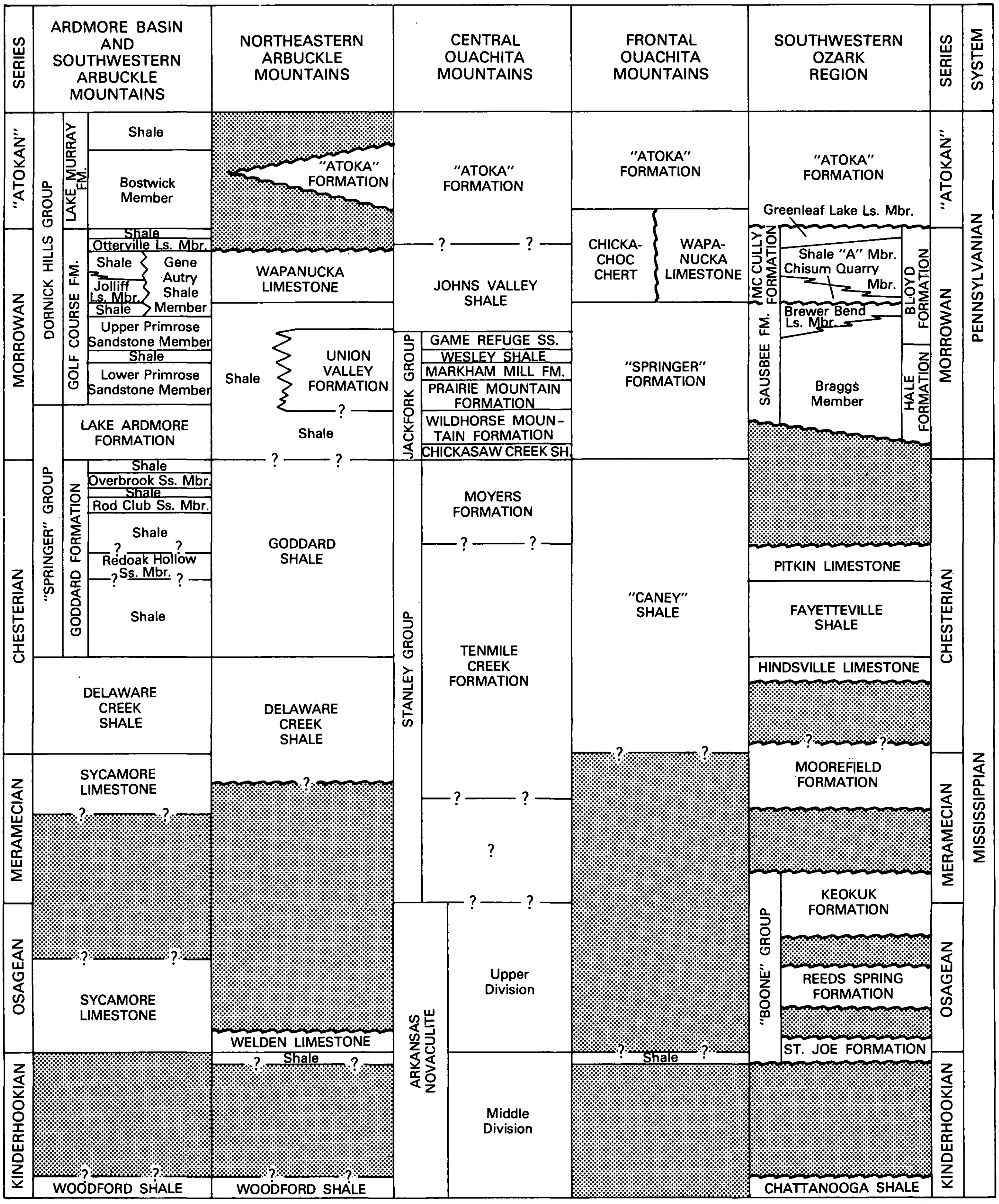


FIGURE 4.—Correlation chart of Mississippian and Lower Pennsylvanian rocks in five outcrop regions of Oklahoma.

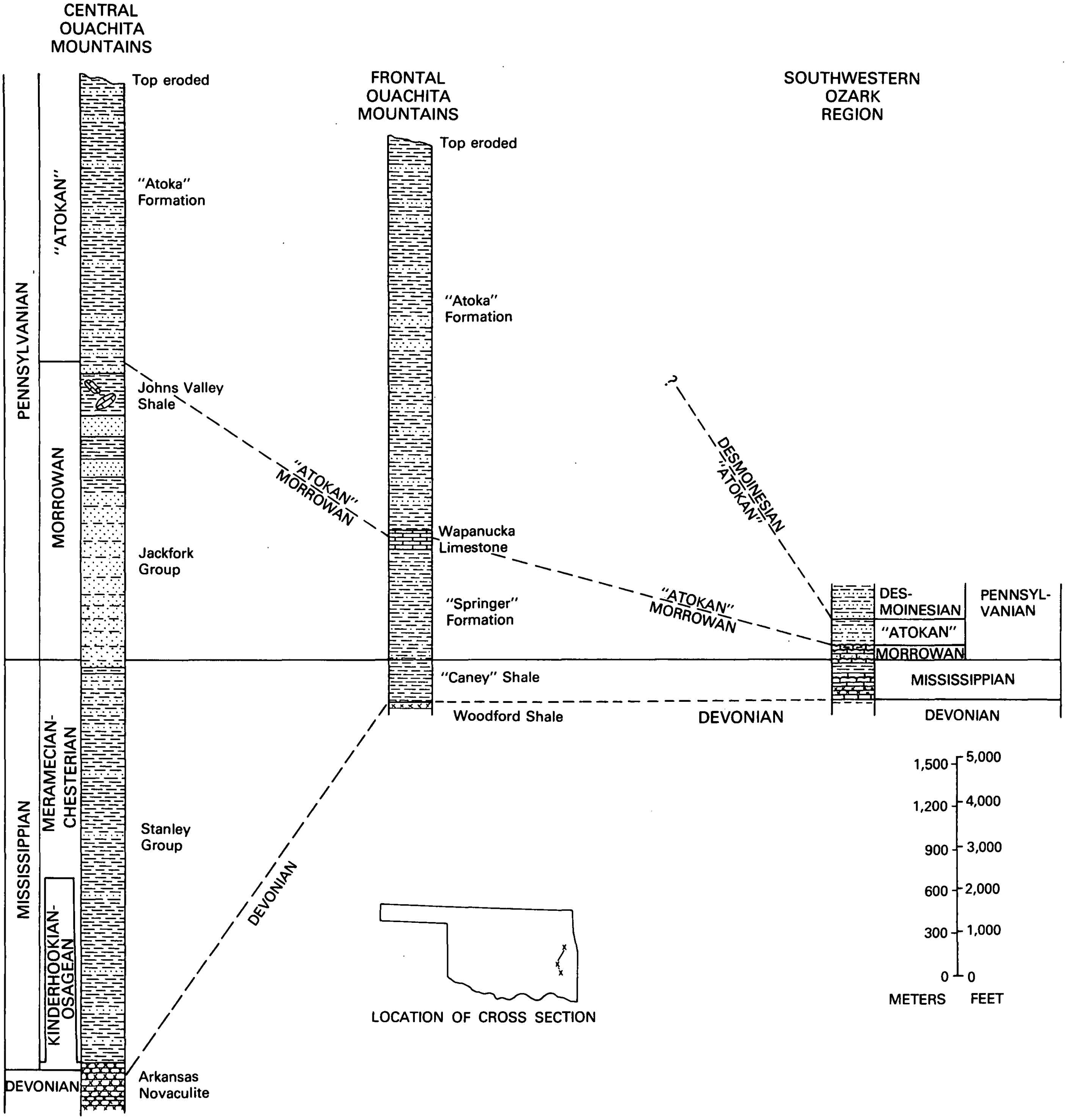


FIGURE 5.—Stratigraphic cross section from central Ouachita Mountains northward to southwestern Ozark region.

north, the Pennsylvanian rests directly on the Fayetteville Shale; locally it rests on the Hindsville Limestone. The post-Mississippian unconformity in northeastern Oklahoma has a regional relief of as much as 25 m (Sutherland and Henry, 1977b).

The magnitude of the post-Pitkin unconformity decreases eastward. In Searcy County, Ark., about 240 km to the east, the Imo Formation of late Chesterian age partly fills the gap (Saunders and others, 1977). The Imo overlies the Pitkin Formation and is in turn overlain unconformably by strata of Morrowan age.

In Arkansas, reworked Pitkin pebbles are found in the Chickasaw Creek Formation at the base of the Jackfork Group.

MORROWAN SERIES

In northwestern Arkansas, the Pennsylvanian Morrowan Series is divided into the Hale and Bloyd Formations (in ascending order). These units can be recognized in Oklahoma only in the eastern half of Adair County. Farther west, the lithologic distinction is lost, as there is a marked westward increase in the percentage of limestone and a corresponding decrease in the percentage of terrigenous-rock types. Sutherland and Henry (1977a) divided this carbonate facies into the Sausbee and McCully Formations on the basis of a regional disconformity at the top of the Sausbee. This break coincides in Washington County, Ark., with a regional unconformity at the base of the Dye Shale Member of the Bloyd Formation. The Sausbee Formation consists typically of skeletal grainstones interbedded with shale (Braggs Member), overlain by beds of algal wackestone and mudstone (Brewer Bend Limestone Member). The formation has a maximum thickness of 61 m. The overlying McCully Formation is composed of interbedded limestones and shales and has a maximum recorded thickness of 23 m.

"ATOKAN" SERIES

The "Atokan" Series, which consists of the "Atoka" Formation, crops out in a wide belt along the south and west flanks of the Ozark dome in northeastern Oklahoma. It consists of interbedded thick shales and thinner sandstones and a few beds of thin discontinuous impure limestone. Wilson (1935) gave member names to six of the ridge-forming sandstones in Muskogee County, but Blythe (1959) was unable to differentiate most of these members in areas north of Muskogee County. The "Atoka" Formation is about 185 m thick in Muskogee County.

The "Atoka" Formation is truncated northward in T. 23 N., R. 19 E., by a regional unconformity at the base of the overlying McAlester Formation.

FRONTAL OUACHITA MOUNTAINS

Describing and interpreting Carboniferous strata in the frontal Ouachitas is complicated by both faulting and lateral facies changes in each of the fault blocks from north to south. The column in figure 4 labeled "Frontal Ouachita Mountains" is a composite section for the several fault blocks north of the Ti Valley fault. The block directly south of the Choctaw fault, the leading edge of the frontal Ouachitas, exposes, in ascending order, the "Caney" (Delaware Creek) Shale, "Springer" (Goddard) Formation, Wapanucka Limestone, and "Atoka" Formation. Farther south, the block south of the Katy Club fault exposes the "Caney," "Springer," Chickachoc Chert, and "Atoka." The block south of the Pine Mountain fault, still north of the Ti Valley fault, exposes the Woodford Shale (Devonian), "Caney," "Springer," and "Atoka."

KINDERHOOKIAN SERIES

Rocks of Kinderhookian age have been reported from only a single locality in the frontal Ouachitas. Hass and Huddle (1965) recovered conodonts of this age from the basal 0.15 m of shale that directly overlies the Woodford Shale at a locality near Pine Top School in Pittsburg County, Okla., between the Pine Mountain and Ti Valley faults.

CHESTERIAN SERIES

The "Caney" Shale of Chesterian age reaches a maximum thickness in the frontal Ouachita Mountains of possibly 275 m, but in the frontal block directly south of the Choctaw fault, only the upper 15 m or so is exposed. Farther south, in the fault block between the Pine Mountain and Ti Valley faults, the "Caney" Shale rests directly on the Woodford Shale.

The Chesterian age assignment for the "Caney" Shale is based on several occurrences of goniatites and microfossils.

MORROWAN SERIES

Overlying the "Caney" Shale is the "Springer" Formation, which contains, at a few localities, goniatites of Morrowan age that correlate with the Hale Formation and the Brentwood Limestone Member of the Bloyd Formation in northwestern Arkansas (Gordon and Stone, 1977). Hendricks and others (1947) stated that the "Springer" apparently rests conformably on the "Caney" but that both units are poorly exposed. The Mississippian-Pennsylvanian boundary has in fact not been established precisely in this outcrop belt. They also reported a thickness of as much as 760 m for the "Springer" in the fault block directly southeast of the Choctaw fault. The "Springer" sequence was recently classed as Goddard (Upper Mississippian) in the Ouachita Mountains by the Oklahoma Geological Survey (see Hart, 1974, sheet 1).

The Wapanucka Limestone overlies the "Springer" in the frontal fault ridges of the Ouachitas, where it consists of interbedded spiculiferous packstones, carbonate mudstones, pelmatozoan and oolitic grainstones, and shales and is typically about 90 m thick. Basinward (southward), successive fault blocks expose changes to the Chickachoc Chert facies, with which the Wapanucka is correlative. This facies consists predominantly of shale interbedded with as much as 10 layers of dark-gray to black spiculite and a few thin beds of spiculiferous limestone. The thickness is typically 180–215 m. Conodonts have been recovered from this facies, as have rare goniatites (Gordon and Sutherland, 1975). The conodonts make possible a correlation between the Chickachoc and Wapanucka (Sutherland and Grayson, 1977). These units are equivalent in age to the Dye Shale and Kessler Limestone Members of the Bloyd Formation plus the lower part of the "Atoka" Formation in northwestern Arkansas and the McCully Formation and lower part of the "Atoka" Formation in northeastern Oklahoma.

"ATOKAN" SERIES

The uppermost parts of the Wapanucka Limestone and the Chickachoc Chert are "Atokan" in age, on the basis of conodonts (Sutherland and Grayson, 1977), and these units are overlain conformably in the frontal Ouachitas by the "Atoka" Formation. In this area, the "Atoka" consists mostly of gray silty, micaceous shale containing a few beds of medium-grained sandstone. The "Atoka" is poorly exposed, and only the lower part is preserved in the frontal Ouachitas, where Hendricks and others (1947) estimated the maximum thickness preserved to be 2,750 m.

CENTRAL OUACHITA MOUNTAINS

KINDERHOOKIAN AND OSAGEAN SERIES

The Kinderhookian and Osagean Series are presumed to be represented in the Ouachita Mountains of Oklahoma; the location depends upon the distribution in Oklahoma of Hass' (1951) middle and upper divisions of the Arkansas Novaculite. Most of the Arkansas Novaculite is Devonian in age, but Hass (1951) recorded a Kinderhookian age on the basis of conodonts for the top 8.5 m of the middle division of the formation at Caddo Gap, Montgomery County, Ark. In addition, he assigned a tentative latest Kinderhookian or Osagean age for another conodont collection made 25 m below the top of the 38-m-thick upper division of the formation at a locality in Polk County, Ark. Thus, Hass considered the upper 47 m of the formation to be Mississippian in age in Arkansas. Hass (1951) quoted H. D. Miser as stating that the upper division of the Arkansas Novaculite occurred in Oklahoma only in McCurtain County. The only conodonts recovered by Hass (1951) from the Arkansas Novaculite on Black Knob Ridge, near Atoka, Okla., were Devonian in age.

MERAMECIAN AND CHESTERIAN SERIES

Rocks of the Stanley Group are conformable with the underlying Arkansas Novaculite in McCurtain County, Okla. (Honess, 1923), and are generally so in the Potato Hills and at Black Knob Ridge, although a local conglomerate is at the base at some localities on Black Knob Ridge (Goldstein and Hendricks, 1962). Nowhere can an unfaulted sequence of the Stanley be seen, but a maximum thickness of 3,300 m has been estimated in the central Ouachitas. The group thins abruptly westward and northward toward the frontal Ouachitas (Cline, 1960). Harlton (1938) divided the Stanley Group into the Tenmile Creek, Moyers, and Chickasaw Creek Formations on the basis of the occurrence of several thin siliceous shales that are apparently widespread and locally mappable. The Stanley is composed predominantly of black shale, but sandstone beds are more common in the upper part. The Chickasaw Creek Formation was originally the basal unit of the Jackfork (Taff, 1902), and this usage is now followed by the Oklahoma Geological Survey (see Briggs, 1973, p. 8, 9).

The Stanley Group contains few fossils. Hass (1950) collected conodonts of Meramecian age from the lower part of the group in both Oklahoma and Arkansas. Higher conodonts, collected from 23 to 45 m above the base of the Stanley in Arkansas, were believed by Hass to be of Meramecian age but are now considered to be of early Chesterian age (Gordon and Stone, 1977). Plant fossils of Chesterian age have been recovered from the upper middle part of the group in Arkansas, and marine invertebrate fossils of Chesterian age have been recovered from erratic blocks of the Stanley in the frontal belt of the Ouachitas in Arkansas (Gordon and Stone, 1977). Also, the assignment of a Chesterian age for most of the Stanley is supported by its stratigraphic position. It is gradational with the overlying Jackfork Group. Chesterian plants, probably reworked, have been collected from the basal beds of the Jackfork (see the following section).

MORROWAN SERIES

The Jackfork Group is conformable with the underlying Stanley Group. Sandstone is the prevailing rock type, although shales make up as much as 40 percent of the group in some areas (Shelburne, 1960). The Jackfork is more resistant to erosion than the underlying Stanley Group, which is composed mostly of shale, and is one of the main ridge-forming units in the Ouachitas. The Jackfork Group is typically 1,750 m thick in the central Oklahoma Ouachitas. Cline (1960) and Shelburne (1960) recorded as much as 1,980 m in northern McCurtain County, Okla. These authors reported that the group thins abruptly northward toward the frontal Ouachitas. The Jackfork was divided by Harlton (1938) into the following formations, listed in ascending order: Wildhorse Mountain, Prairie Mountain, Markham Mill, Wesley, and Game Refuge. However, current usage by the Oklahoma Geological Survey includes the Chickasaw Creek Formation at the base of the Jackfork, according to Taff's (1902) original definition (see Briggs, 1973, p. 8, 9).

The Jackfork Group contains few fossils, and considerable disagreement exists in the literature regarding its precise age. Of particular importance is the recovery from the lowermost beds of the group, a short distance west of Talihina, Okla., of plants of Chesterian age (Gordon and Stone, 1977). These plants are possibly reworked (Gordon and Stone, 1977, p. 81), however, and the sedimentary rocks with which they are associated may be Morrowan in age. Collections of marine invertebrate fossils from the middle and upper parts of the Jackfork Group in the vicinity of Little Rock, Ark., include several poorly preserved but identifiable Morrowan species of goniatites and brachiopods (Gordon and Stone, 1977). The basal Chickasaw Creek Formation in Arkansas contains reworked Pitkin pebbles.

The Johns Valley Shale overlies the Jackfork Group conformably. It is well known for its great variety of erratic limestone boulders, mostly of the Arbuckle facies, that range in age from Cambrian to Early Pennsylvanian and for its huge slump blocks, some more than 900 m in length, of "Caney" Shale. The formation is typically 130–275 m thick in the central Ouachitas in Oklahoma (Cline, 1960). Gordon and Stone (1977) recorded a maximum thickness of 565 m, but they did not give a locality.

An indigenous fauna from the lower part of the Johns Valley Shale, from localities in both Oklahoma and Arkansas, includes cephalopods of the *Branneroceras branneri* zone (Gordon and Stone, 1977). This fauna occurs also in the upper part of the "Springer" Formation in the frontal Ouachitas and in the Brewer Bend Limestone Member of the Sausbee Formation in northeastern Oklahoma. From the middle part of the Johns Valley Shale, Gordon and Stone (1977) recorded the *Axinolobus modulus* goniatite zone. This zone occurs in the frontal Ouachitas in the lower part of the Wapanucka Limestone and in northeastern Oklahoma in the Chisum Quarry Member of the McCully Formation. Distinctive fossils have not yet been reported from the upper part of the Johns Valley.

MORROWAN AND "ATOKAN" SERIES

The "Atoka" Formation in the central Ouachitas consists of interbedded gray shale and fine-grained sandstone commonly having convolute bedding and sole markings. Shelburne (1960) recorded no more than 25-percent sandstone in the Boktukola syncline and a maximum preserved thickness in that area of 2,065 m. The top of the formation is eroded.

The "Atoka" Formation is virtually unfossiliferous in the central Ouachitas. However, L. R. Wilson (oral commun., 1978) reported that all the unit sampled contained palynomorphs of Morrowan age.

NORTHEASTERN ARBUCKLE MOUNTAINS

KINDERHOOKIAN AND OSAGEAN SERIES

The Woodford Shale in the northeastern Arbuckle Mountains is similar to that found in the southwestern Arbuckle Mountains, except that the percentage of chert decreases northeastward. In the northeast, the formation is composed predominantly of platy dark shale interbedded with some chert layers. The regional thickness is about 100–125 m (Ham, 1969). In the northeastern Arbuckle Mountains, the formation is apparently all Late Devonian in age at most localities, but a Kinderhookian conodont fauna has been recovered from the top 0.3 m or less at a few localities (Hass and Huddle, 1965).

The Sycamore Limestone, conspicuous in the southwestern Arbuckles, is absent from the Mill Creek syncline northeastward in the Arbuckle Mountains (Ham, 1969). The same stratigraphic position is locally occupied by the Welden Limestone. It is a buff to gray thick-bedded argillaceous limestone that is moderately fossiliferous. It has a maximum recorded thickness of 1.5 m, but it is typically 0.6 m thick (Barker, 1950). Cooper (1939) described a conodont fauna from this shale that contained 105 different species. This fauna was assigned a late Kinderhookian age by Ormiston and Lane (1976). Probably this pre-Welden shale rests unconformably on the underlying Woodford, and most of the Kinderhookian Series is missing in this area. Ormiston and Lane (1976) gave an early Osagean age to the Welden Limestone on the basis of conodonts.

Branson and Mehl (1941) described a conodont fauna from the basal part of the overlying Delaware Creek Shale (they termed it Caney). They apparently believed that, for the most part, those conodonts represented reworked specimens. Most of their specimens apparently came from the basal sandy, shaly glauconitic zone that, according to Barker (1950), directly overlies a major unconformity. Ormiston and Lane (1976) placed the Branson and Mehl conodont fauna in the lower Osagean. Ham (1969) stated that the regional unconformity at the base of the Delaware Creek Shale in the northeastern part of the Arbuckle Mountains explains the thinness of strata of possible Osagean and Meramecian age and, in part, the extreme thinness of the total Mississippian sequence in this area. Where the Welden Limestone is locally cut out below this unconformity, the basal sandy, glauconitic zone of the Delaware Creek Shale rests directly on the Woodford (Barker, 1950).

MERAMECIAN AND CHESTERIAN SERIES

The Delaware Creek Shale in the northeastern Arbuckle Mountains differs from that found in the southwestern Arbuckles by being friable and not siliceous. It contains the same local abundance of small phosphatic nodules and large calcareous septarian concretions. The formation is much thinner than that in the southwest, reaching a maximum thickness of only 49 m.

The lower 7.5 m of the Delaware Creek Shale is calcareous and fossiliferous locally on the Lawrence uplift (Barker, 1950). Elias (1956) named this occurrence the Ahloso Member of the Caney Shale.

Gordon and Stone (1977, fig. 4) recorded four goniatite zones for the Delaware Creek Shale in this area that ranged in age from late Meramecian to early Chesterian. The lowest calcareous part of the formation is apparently older than the lowest part of the formation in the southwestern Arbuckle Mountains, and it appears to be equivalent in age to the upper part of the Sycamore Limestone in that area.

The Goddard Shale in the northeastern Arbuckle Mountains is more or less similar to the Goddard in the southwestern Arbuckles. However, the percentage of sandstone decreases northeastward, and the thick sandstone members present in the Ardmore basin are lacking. There is also a marked decrease in its interval, which is only about 75 m in the northeastern Arbuckles. Gordon and Stone (1977, fig. 4) recorded three goniatite zones in this area that range in age from middle to late Chesterian.

MORROWAN SERIES

The Mississippian-Pennsylvanian boundary has not been defined in the northeastern Arbuckle Mountains. It falls somewhere within the poorly exposed shales, which are here included partly in the upper part of the Goddard Shale and partly in the lower part of the Morrowan, below the Union Valley Formation or the Wapanucka Limestone (fig. 4).

The Union Valley Formation crops out in a limited area on the Lawrence uplift, in the northernmost Arbuckle Mountains, and it covers an extensive area in the subsurface of the Arkoma basin, northeast of the Arbuckles. Where exposed on the Lawrence uplift, it consists of 45–80 m of sandstone overlain by 3.5–7.5 m of sandy limestone (Barker, 1950).

The limestone at the top of the Union Valley is highly fossiliferous locally. Gordon and Stone (1977, fig. 4) recorded the *Branneroceras branneri* goniatite zone from this interval. This limestone is of middle Morrowan age and is correlative with the Brewer Bend Limestone Member of the Sausbee Formation in northeastern Oklahoma and the upper Primrose Sandstone in the Ardmore basin.

On the northeast flank of the Arbuckle Mountains, the Union Valley Formation is missing on the outcrop, and the Wapanucka Limestone is underlain by 100 m or so of poorly exposed and poorly known shales.

The Wapanucka Limestone in this area includes a wide variety of carbonate-rock types, including crossbedded oolites and skeletal grainstones and packstones. In the more westerly exposures, significant shale interbeds are present. The maximum observed thickness for the Wapanucka in this area is about 55 m, not including underlying shales (Rowett and Sutherland, 1964). The Wapanucka is truncated westward along the south margin of the Franks graben. The Wapanucka is highly fossiliferous and is late Morrowan in age.

"ATOKAN" SERIES

Morrowan rocks are overlain unconformably in the northeastern Arbuckle Mountain area by the

"Atoka" Formation, which consists of thick shales interbedded with thinner fine-grained sandstones. The "Atoka" onlaps westward and is itself truncated farther west by an unconformity at the base of overlying Desmoinesian formations. It ranges in thickness in this area from about 910 m to a featheredge.

ARDMORE BASIN AND SOUTHWESTERN ARBUCKLE MOUNTAINS

KINDERHOOKIAN SERIES

The Woodford Shale consists of interbedded dark shale and chert and is 107–122 m thick over most of its outcrop area in the Arbuckle Mountains. It is Late Devonian in age except for the top 0.3 m or less at a few localities, from which a Kinderhookian conodont fauna was recovered by Hass and Huddle (1965).

OSAGEAN AND MERAMECIAN SERIES

The Sycamore Limestone overlies the Woodford Shale and occurs only in the southwest segments of the Arbuckle Mountains (Ham, 1969). It consists of fine-grained silty limestone interbedded with thin layers of dark-gray shale. It is 115 m thick on the south limb of the Arbuckle anticline and 64 m thick on the north limb (Fay, 1969). The Sycamore Limestone has produced very few identifiable megafossils, and age determinations thus far available are based on a few conodont faunas. These have been reported only from the lowest and the highest strata. Ormiston and Lane (1976) recovered conodonts from four samples from Fay's (1969, p. 68) measured section on the north limb of the Arbuckle anticline. Three of their samples came from the lowermost 17 m of the Sycamore Limestone (64 m total thickness) and indicate an early Osagean age for this part of the formation. The lowermost sample, of earliest Osagean age, was taken 1 m above the base of the formation; it carries the same fauna as that from the Welden Limestone in the northeastern Arbuckle Mountains (Ormiston and Lane, 1976).

The fourth sample described by Ormiston and Lane was from a zone 14 m below the top of the Sycamore Limestone, in the same measured section. They reported conodonts from this zone to be latest Meramecian or early Chesterian in age. The unfossiliferous middle part of the Sycamore Limestone is assumed to be Osagean and (or) Meramecian in age.

CHESTERIAN SERIES

For more than half a century the usage and age of the "Caney" Shale in southern Oklahoma has been controversial. The type locality of the "Caney" in the Ouachita Mountains is in fact a large erratic block in the Johns Valley Shale of Early Pennsylvanian age. The term Caney has now been generally abandoned in both the Arbuckle and Ouachita areas.

The name Delaware Creek was proposed by Elias (1956) as a member of the "Caney" Shale in the northeastern Arbuckle Mountains. This term was more recently used at formation rank throughout the Arbuckle Mountains (Hart, 1974, sheet 1). The Delaware Creek Shale rests directly on the Sycamore Limestone at the northern margin of the Ardmore basin. It consists in this area of dark-gray, partly siliceous shale that weathers to a lighter color than is normal for the formation in the northeastern Arbuckle Mountains. Small phosphatic nodules and large calcareous septarian concretions are locally abundant, but limestone and sandstone are absent (Ham, 1969). The formation ranges in outcrop thickness in this area from 69 m on Oil Creek to 134 m on Henryhouse Creek (Elias, 1956); it is 228 m in the subsurface of the Ardmore basin (Hart, 1974). Gordon and Stone (1977, fig. 4) recorded three goniatite zones in the unit in this area, all early Chesterian in age.

The "Springer" Group overlies the Delaware Creek Shale in the Ardmore basin. It includes both the Goddard Formation (Chesterian) and the Lake Ardmore Formation (Morrowan). The Goddard, named by Westheimer (1956), conformably overlies the Delaware Creek Shale at the north margin of the Ardmore basin. As defined by Elias (1956), the Goddard included only the beds of shale and thin sandstone between the top of the Delaware Creek and the base of the Rod Club Sandstone. Hart (1974, sheet 1) extended the Goddard Formation upward to the base of the Lake Ardmore Formation; in this usage, which is followed here, it includes the Rod Club and Overbrook Sandstones and interbedded shales. The total thickness of the Goddard Formation, as here used, amounts to 1,100 m in the Ardmore basin (Hart, 1974). Named sandstone members distributed upward within the formation include the Redoak Hollow, 8 m thick; the Rod Club, 75–122 m thick; and the Overbrook, 14–30 m thick (Tomlinson and McBee, 1962). These noncalcareous sandstones are all fine grained and well sorted. The lower Goddard shales differ from the Delaware Creek Shale in being more friable and less cliff forming and in containing abundant thin sideritic layers and concretions (Tomlinson and McBee, 1962).

Gordon and Stone (1977, fig. 4) recorded four goniatite zones in that part of the Goddard that lies below the Rod Club Sandstone Member, and these range in age from middle to early-late Chesterian.

MISSISSIPPIAN-PENNSYLVANIAN BOUNDARY

The Mississippian-Pennsylvanian boundary currently is placed arbitrarily at the base of the Lake Ardmore Formation in a sequence of apparently continuous deposition. This assignment is uncertain because few fossils are present in the interval from the base of the Rod Club Sandstone Member of the Goddard Formation to the base of the Primrose Sandstone Member of the overlying Golf Course Formation. Its position is most precisely limited by conodont faunas described by Straka (1972), who recorded conodont faunas of Chesterian age in the Goddard Formation as high as the Rod Club Sandstone. He recovered no diagnostic conodonts from the top of the Rod Club to the base of the Lake Ardmore Formation, but he described what he considered to be definite Pennsylvanian conodonts from the Target Limestone Lentil in the lower part of the Lake Ardmore Formation. He reported the occurrence of the same conodont fauna from the lowermost beds of the type Morrowan Series in northwestern Arkansas. Thus, the Mississippian-Pennsylvanian boundary apparently lies within the 130-m interval that includes the Overbrook Sandstone Member of the Goddard Formation and extends into the lower beds of the Lake Ardmore Formation.

MORROWAN SERIES

The Lake Ardmore Formation consists, in the northern part of the Ardmore basin, of 152 m of shales interbedded with three beds of ridge-forming fine-grained sandstone (Tomlinson and McBee, 1962). Each of these sandstone intervals is 9–21 m thick. The Target Limestone Lentil, referred to in the previous section, is about 15 m above the base; it is only about 1 m thick and is poorly exposed along a distance of 3 km or so in the northern part of the Ardmore basin.

The Golf Course Formation includes the members listed as follows, in ascending order: Primrose Sandstone, Gene Autry Shale (in the north only), Jolliff Limestone (in the south only), and Otterville Limestone. The Golf Course attains a thickness of about 610 m (Tomlinson and McBee, 1962).

The Primrose Sandstone Member is 46–76 m thick and differs from the underlying beds of sandstone of the "Springer" Group in being distinctly calcareous in several zones. Two goniatite occurrences indicate an early to middle Morrowan age, the upper being the *Branneroceras branneri* zone (Gordon and Stone, 1977, fig. 4).

North of Ardmore, the Primrose is overlain by the Gene Autry Shale Member, which is about 360 m thick. The Gene Autry contains the late Morrowan *Axinolobus modulus* goniatite fauna in the lower part.

South of Ardmore, a thin shale overlies the Primrose, which is in turn overlain by the distinctive Jolliff Limestone Member. The Jolliff is highly variable in character and thickness. A basal limestone-cobble conglomerate as much as 9 m thick occurs typically, as do irregularly distributed higher conglomerates, packstones, and carbonate mudstones. The formation varies in thickness from 6 to 39 m by lateral replacement of the lower part of the overlying shale (Cromwell, 1975).

The unnamed shale between the Jolliff and Otterville Limestone Members is as much as 137 m thick. The Otterville is either covered or missing in the area west of Ardmore, and the covered (and apparent shale) interval between the Jolliff and the base of the Bostwick Member of the Lake Ardmore Formation is as thick as 360 m (Cromwell, 1975).

The Otterville ranges from 2.5 to 6 m in thickness and consists of fossiliferous oolitic grainstones. It is overlain by an unnamed shale as much as 91 m thick that extends to the base of the Bostwick.

The Jolliff Limestone Member contains the *Axinolobus modulus* goniatite fauna. The interval from the Jolliff to the shale above the Otterville is late Morrowan in age and correlates with the whole of the McCully Formation in northeastern Oklahoma.

"ATOKAN" SERIES

This series in the Ardmore basin includes that part of the Lake Murray Formation that extends from the base of the Bostwick Member to the base of the Lester Limestone. The Bostwick Member, composed of beds of conglomerate, sandstone, limestone, and intercalated shale, has a maximum thickness of 152 m (Cromwell, 1975). Limestone-cobble conglomerate in the south grades into chert-pebble conglomerate in the central part of the Ardmore basin. This part of the sequence is characterized by marked lateral facies changes. The Bostwick is the most conspicuous ridge-forming unit in the southern Ardmore basin.

The "Atokan" age assignment of the Bostwick is based primarily on fusulinids. Waddell (1966) defined his Fusulinid Zone I as including the Bostwick

Member and part of the overlying shale. This zone is characterized by the occurrence of several species of *Fusulinella*.

Overlying the Bostwick, an unnamed shale, which has a maximum thickness of 228 m, was included in the "Atokan" Series by Waddell (1966). He placed the base of the Desmoinesian Series at the base of the Lester Limestone Member of the Lake Murray Formation, on the basis of the lowest occurrence in the Ardmore basin of the genera *Fusulina* and *Wedekindellina*.

MIDDLE AND UPPER PENNSYLVANIAN STRATIGRAPHY

By S. A. Friedman

As defined in this report, the Middle Pennsylvanian consists of the Desmoinesian and Missourian Series, and the Upper Pennsylvanian consists of the Virgilian and Gearyan(?) Series. As explained previously, Gearyan rocks are now tentatively referred to the uppermost Pennsylvanian by the Oklahoma Geological Survey; traditionally, most workers have placed them in the Lower Permian.

Strata of Desmoinesian age crop out in the Arkoma basin, the northern Oklahoma shelf, and the Ardmore basin. Strata of Missourian and Virgilian age are exposed mainly in the shelf area and in the Ardmore basin but are absent because of erosion in the Arkoma basin. Rocks of Gearyan age are present in the western part of the northern shelf area. Differences in lithology, thickness, structure, and depositional environments help in distinguishing these strata in the shelf and basin areas. Figure 6 shows the general stratigraphic relationships of these Middle and Upper Pennsylvanian rocks.

Earlier workers believed that widespread unconformities are present within the Pennsylvanian of Oklahoma. During the last 10 years, detailed stratigraphic mapping has shown that local disconformable surfaces exist at the bases of channels filled with sandstone and chert conglomerate and that progressive overlap and offlap northward and northwestward are responsible for the erroneous interpretation of regional unconformities within these units.

Some units of the Desmoinesian Series contain many thick beds of sandstone in the Arkoma basin that do not persist northward into the northern Oklahoma shelf. Beds of Desmoinesian, Missourian, and Virgilian limestone are more numerous and thicker north of Tulsa in the shelf area than they are south of Tulsa and farther south in the Arkoma basin area. Some of the upper Desmoinesian sandstones and shales are thick in the western part of the Arkoma basin but thin northward, where they are replaced by limestones and shales in the shelf area. The entire Desmoinesian sequence is only one-seventh as thick on the shelf as it is in the Arkoma basin.

Generally, rocks of the Desmoinesian Series have been assigned to three groups, in ascending order, the Krebs, Cabaniss, and Marmaton (fig. 6). Rocks of the Missourian Series have been assigned to two groups, in ascending order, the Skiatook and Ochelata (fig. 6).

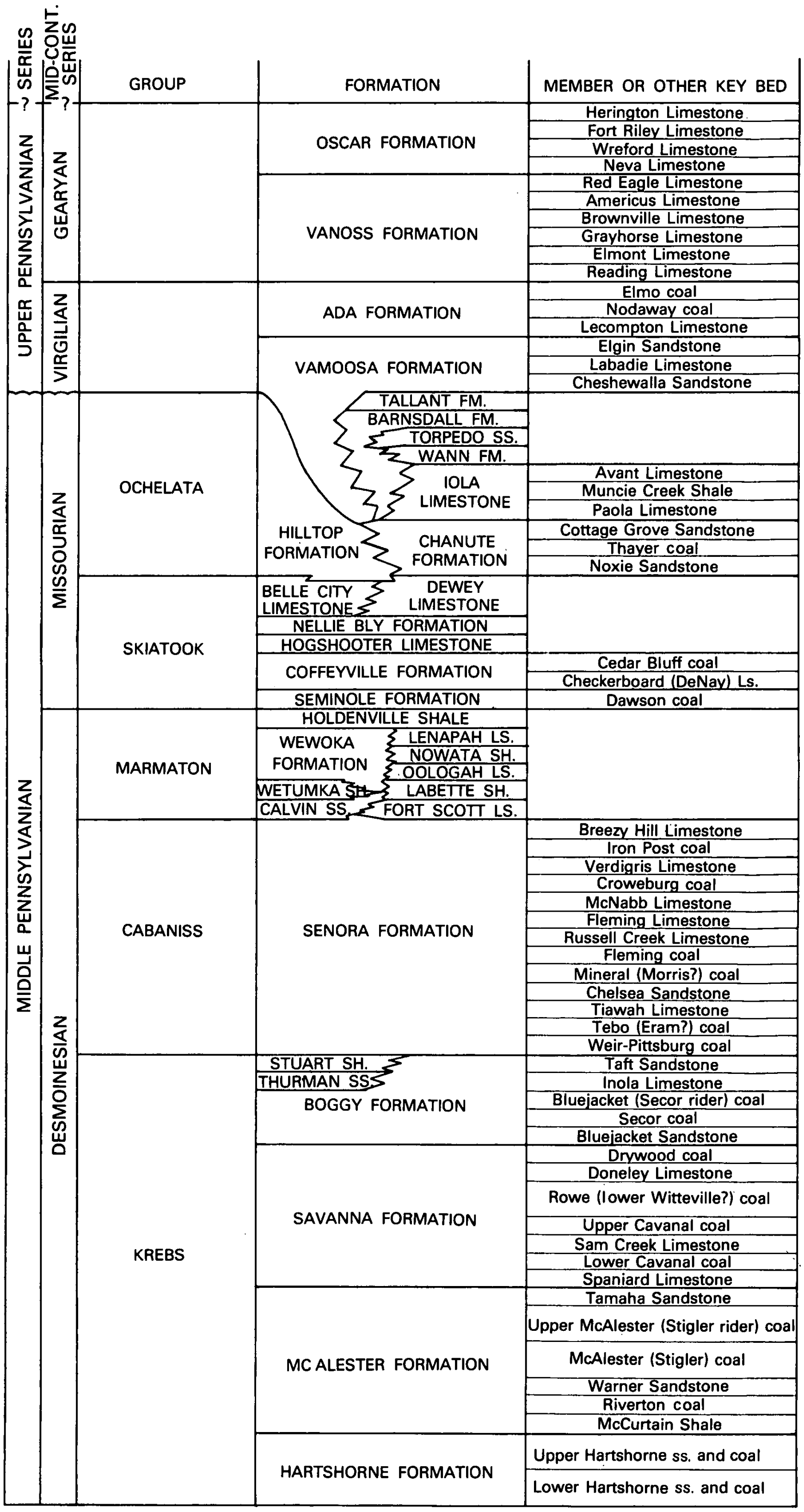
ARKOMA BASIN

DESMOINESIAN SERIES

In any one region of the Arkoma basin, the maximum thickness of Desmoinesian shale, sandstone, and relatively thin beds of coal and underclay is 2,000 m. The series is thickest in synclines just north of the Choctaw fault, where the basal Hartshorne Formation attains a maximum thickness of 910 m of sandstone, shale, and a major coal bed. Geologists believe that the Hartshorne was deposited within a deltaic system whose source was to the east and that most of the McAlester and Boggy Formations were deposited within deltaic systems that originated to the north, on the northern Oklahoma shelf. The Thurman Sandstone and the Stuart Shale apparently had southern sources, and they overlap underlying strata in the northern shelf area. At least two deltaic systems in the Senora Formation have eastern sources.

The Hartshorne Formation conformably overlies the "Atoka" Formation ("Atokan" Series) and is only 7.5 m thick at the northern part of the basin. In places at the southwestern end of the basin, the Hartshorne is absent because of pre-Desmoinesian erosion. Plant compressions (mostly ferns) and casts and molds of upright tree trunks are found in the shale and sandstone members, and roots and rootlets, in the underclay of the Hartshorne Formation. The Hartshorne coal is 1.5–3 m thick at the western end and 2 m thick at the southeastern corner of this basin. The Hartshorne coal probably is absent north of Muskogee in the shelf area.

The McAlester Formation conformably overlies the Hartshorne Formation and has a maximum thickness of 760 m in the southeastern part of the basin; it is only 60 m thick in the northern part. This formation consists of many beds of medium- to dark-gray silty or clayey shale, gray sandstone,



SERIES	MID-CONT. SERIES	GROUP	FORMATION		MEMBER OR OTHER KEY BED
UPPER PENNSYLVANIAN	GEARYAN		OSCAR FORMATION		Herington Limestone
					Fort Riley Limestone
					Wreford Limestone
					Neva Limestone
			VANOSS FORMATION		Red Eagle Limestone
					Americus Limestone
					Brownville Limestone
					Grayhorse Limestone
					Elmont Limestone
					Reading Limestone
	VIRGILIAN		ADA FORMATION		Elmo coal
					Nodaway coal
					Lecompton Limestone
			VAMOOSA FORMATION		Elgin Sandstone
					Labadie Limestone
					Cheshewalla Sandstone
MIDDLE PENNSYLVANIAN	MISSOURIAN	OCHELATA	HILLTOP FORMATION	TALLANT FM.	
				BARNSDALL FM.	
				TORPEDO SS.	
				WANN FM.	
				IOLA LIMESTONE	Avant Limestone
					Muncie Creek Shale
					Paola Limestone
				CHANUTE FORMATION	Cottage Grove Sandstone
					Thayer coal
					Noxie Sandstone
		SKIATOOK	BELLE CITY LIMESTONE	DEWEY LIMESTONE	
			NELLIE BLY FORMATION		
			HOGSHOOTER LIMESTONE		
			COFFEYVILLE FORMATION		Cedar Bluff coal
					Checkerboard (DeNay) Ls.
			SEMINOLE FORMATION		Dawson coal
	DESMOINESIAN	MARMATON	HOLDENVILLE SHALE		
			WEWOKA FORMATION	LENAPAH LS.	
				NOWATA SH.	
				OOLOGAH LS.	
			WETUMKA SH.	LABETTE SH.	
			CALVIN SS.	FORT SCOTT LS.	
		CABANISS	SENORA FORMATION		Breezy Hill Limestone
					Iron Post coal
					Verdigris Limestone
					Croweburg coal
					McNabb Limestone
					Fleming Limestone
					Russell Creek Limestone
					Fleming coal
					Mineral (Morris?) coal
					Chelsea Sandstone
					Tiawah Limestone
					Tebo (Eram?) coal
					Weir-Pittsburg coal
		KREBS	STUART SH.		Taft Sandstone
			THURMAN SS		Inola Limestone
			BOGGY FORMATION		Bluejacket (Secor rider) coal
					Secor coal
					Bluejacket Sandstone
			SAVANNA FORMATION		Drywood coal
					Doneley Limestone
					Rowe (lower Witteville?) coal
					Upper Cavanal coal
					Sam Creek Limestone
					Lower Cavanal coal
					Spaniard Limestone
			MC ALESTER FORMATION		Tamaha Sandstone
					Upper McAlester (Stigler rider) coal
					McAlester (Stigler) coal
					Warner Sandstone
					Riverton coal
					McCurtain Shale
			HARTSHORNE FORMATION		Upper Hartshorne ss. and coal
					Lower Hartshorne ss. and coal

FIGURE 6.—Generalized stratigraphic chart of Middle and Upper Pennsylvanian rocks in Oklahoma.

coal, and underclay in cyclic sequences. The McAlester (Stigler) coal occurs in the upper third of the formation. The coal is as much as 1.5 m thick in the western part of the basin, 1 m thick at McAlester in the central part, and about 0.5 m thick in the eastern part. The coal thins in the northern part of the basin and is absent on the shelf area north of Muskogee.

The Savanna Formation conformably overlies the McAlester Formation, except at places where local disconformities were formed by channel sandstones. The Savanna consists mainly of shales and sandstones and attains a maximum thickness of about 600 m in the southeastern and southwestern parts of the Arkoma basin. Along the northern part of the basin, this formation is only 76 m thick. Thin coal and underclay beds are present in the Savanna Formation. Upright tree trunks have been preserved in some of these beds. In the basin, the lower and upper Cavanal, Rowe, and lower Witteville coals are important coal beds of the Savanna.

The Boggy Formation consists mainly of sandstones and shales, and it conformably overlies the Savanna Formation except at places where the basal Bluejacket Sandstone Member occupies erosional channels. The Boggy reaches a maximum thickness of 900 m where fully preserved in the McAlester area, and it is at least 600 m thick at each end of the Arkoma basin. It contains one major coal (the Secor) and underclay bed in the basin. The Boggy is only 60 m thick in the northern part of the basin.

The overlying Thurman Sandstone underlies the Stuart Shale, at the top of the Krebs Group, in the western part of the basin. Both formations contain chert-conglomerate, sandstone, and shale beds, but the Thurman contains a greater quantity of sandstone. The maximum thicknesses of each formation are found in the west-central part of the basin, where the Thurman is 76 m thick and the Stuart, 115 m. The Stuart overlaps the Thurman northward, where it overlies the Boggy Formation. Both the Stuart and the Thurman are confined to the Arkoma basin.

The overlying Senora Formation in the northwestern part of the Arkoma basin consists of 45–275 m of sandstones and shales.

The overlying Calvin Sandstone, Wetumka Shale, and Wewoka Formation are composed of sandstones and shales that are mostly restricted to the basin area and thin northward. The Calvin is composed mostly of sandstone and shale that have a maximum thickness of about 120 m. The Wetumka conformably overlies and overlaps the Calvin northward and is composed mostly of shales and some sandstones and siltstones. Its maximum thickness is about 60 m. The Wewoka conformably overlies and overlaps the Wetumka and the Calvin northward and attains a maximum thickness of about 215 m; it consists of limestone, chert conglomerate, sandstone, and calcareous shale. Northward, the Wewoka clastic rocks are fine grained, and the formation thins. The Holdenville Shale is present in a small area in the northwesternmost part of the Arkoma basin, where it overlies the Wewoka Formation conformably and attains a thickness of 79 m.

NORTHERN OKLAHOMA SHELF

Undoubtedly an unconformity is present at the base of the Desmoinesian Series in places that had been exposed to pre-Desmoinesian erosion in the northern Oklahoma shelf and Arkoma basin areas; it is progressively younger northward. Nondeposition and erosion resulted in progressive northward and northwestward thinning or absence of strata of Desmoinesian through Gearyan age that crop out in the shelf area.

DESMOINESIAN SERIES

The Hartshorne Formation is 15–30 m thick in the southernmost part of the northern shelf or homocline area. It is less than 15 m thick in T. 14 N., south of Muskogee, and is probably absent at, and north of, Tulsa.

The McAlester Formation conformably overlies the Hartshorne at most places but overlaps it northward in the shelf area. The contact between the Hartshorne and McAlester has been controversial, but recent workers have agreed to use the top of the Hartshorne coal or the upper Hartshorne coal as the boundary (McDaniel, 1961; Oakes and Knechtel, 1948; American Association of Petroleum Geologists and others, 1978).

At the southern border of the shelf area, in T. 10 N., Muskogee County, the McAlester Formation is 137 m thick (Oakes, 1977), and in T. 15 N., at Muskogee, it is only 55 m thick (Oakes, 1977). Northward, the basal McCurtain Shale Member probably is absent. The Riverton coal, miscorrelated with the upper Hartshorne coal by Branson (1962, p. 441), is probably a thin coal underlying the Warner Sandstone Member (Branson and others, 1965). The principal coal in the McAlester is the Stigler, which is not present north of Muskogee. In Ottawa County, only the Warner Sandstone Member is recognized, and the McAlester Formation is possibly only about 18 m thick at the Kansas border.

The overlying Savanna Formation consists mostly of 30–140 m of shale and sandstone in the northern shelf area. The principal key beds of the Savanna are the Spaniard Limestone, Sam Creek Limestone, Rowe coal, Doneley Limestone, and Drywood coal. The Savanna is only 30 m thick at the Kansas border but is 140 m thick in southern Muskogee County.

The Boggy Formation overlies the Savanna Formation conformably, although channel-fill sandstone in the basal Bluejacket Sandstone Member indicates a local disconformity. The Boggy is about 210 m thick in Muskogee County, in the southern part of the shelf area. Northward in Craig County, the Boggy is only about 44 m thick. Key beds of the Boggy, besides the basal Bluejacket Sandstone, are, in ascending order, the Secor coal, Bluejacket coal, Inola Limestone, and Taft Sandstone. The Secor coal has not been identified north of Wagoner County, and the Bluejacket coal has been recognized in Craig County. These coals are possibly correlative, as each overlies the Bluejacket Sandstone Member.

Apparently the Stuart Shale overlies the Boggy Formation conformably in the southern parts of the shelf, but it is not present north of T. 13 N.

At most other places in the northern Oklahoma shelf area, the Senora Formation conformably overlies the Boggy. The Senora consists of approximately 46–305 m of sandstone, shale, coal, underclay, and limestone in conspicuously cyclical sequences. In the southern part of the shelf area, key beds are the Eram, Morris, and Croweburg coals. In the central part, key beds are the Chelsea Sandstone; the Mineral, Croweburg, and Iron Post coals; and the McNabb and Verdigris Limestones. In the northern part, key beds are the Weir-Pittsburg, Tebo, Mineral, Fleming, Croweburg, and Iron Post coals; and the Tiawah, Russell Creek, McNabb, Verdigris, and Breezy Hill Limestones. The limestones are light to dark gray, fine grained, massive, and dense; they contain marine invertebrates and algae. The coal beds are thin, but they do attain thicknesses of 0.25–1 m, where they constitute recoverable coal reserves and have been mined. Some of the limestone beds are as much as 9 m thick in the northern part of the shelf area.

The northward change of lithofacies to beds of fine-grained clastic rocks and limestone and the northward thinning in the Marmaton Group are no less dramatic than in the underlying Cabaniss Group (Senora Formation). But the Marmaton is thinner, has fewer named units, and is easier to map. It is about 210 m thick at the Kansas border and about 245 m thick at the Arkansas River.

South of the Arkansas River, in the shelf area, the Marmaton Group comprises, in ascending order, the Calvin Sandstone, Wetumka Shale, Wewoka Formation, Lenapah Limestone, and Holdenville Shale. North of the Arkansas River, the Fort Scott Limestone was reported to underlie the Calvin Sandstone (Oakes, 1952). However, some earlier workers confused the Breezy Hill with the lower member of the Fort Scott. Thus, the Breezy Hill Limestone possibly extends as far south as Tulsa, Wagoner, and Muskogee Counties.

The Labette Shale of the shelf is probably equivalent in part to the Calvin Sandstone and Wetumka Shale. The Oologah Limestone conformably overlies the Labette Shale and is in turn overlain by the Nowata Shale. The Lenapah Limestone conformably overlies the Nowata. The Wewoka Formation consists of beds of sandstone and calcareous shale, believed to be lateral equivalents of the Labette Shale, Oologah Limestone, Nowata Shale, and Lenapah Limestone. The Holdenville Shale conformably overlies the Wewoka and the Lenapah and is the top formation of the Marmaton Group. Key units in this group are shown in figure 6. The Calvin, Wetumka, Wewoka, Nowata, and Holdenville thin northward, and the Fort Scott, Labette, Oologah, and Lenapah thicken northward.

MISSOURIAN SERIES

The Seminole Formation, the basal formation of the Skiatook Group, probably overlies the Holdenville Shale conformably. In places where chert conglomerate and sandstone fill channels at its base, the Seminole is in local disconformable contact with the Holdenville, Lenapah, and Nowata Formations. The local disconformities led earlier writers to select this contact as the Desmoinesian-Missourian boundary because they believed it was a regional unconformity (Oakes, 1952, p. 48–54). The Seminole is 36 m thick in the southern part of the shelf area and about 6 m thick at the Kansas border. It contains a few thin beds of coal in addition to the Dawson coal, a commercial seam in Tulsa and Rogers Counties.

The Coffeyville Formation conformably overlies the Seminole Formation. At its base is the dark-gray finely crystalline fossiliferous Checkerboard Limestone Member. The Checkerboard is probably the equivalent of the DeNay Limestone of the southern part of the northern shelf area; it is present from Okmulgee County northward into Kansas. The

Coffeyville consists mainly of 45–140 m of shale, sandstone, and chert conglomerate. The thickest part of this formation is in Tulsa County and vicinity. It is present in the central and northern part of the northern shelf-homocline area and is equivalent to the Francis Formation (restricted) in the southern part of the shelf area (Hart, 1974, sheet 1), where it is only 6–21 m thick. The thin Cedar Bluff coal is present below a sandstone at the top of the formation in Washington County (Oakes, 1940, p. 38).

The Hogshooter Limestone conformably overlies the Coffeyville Formation. Locally, the Hogshooter attains a thickness of 15 m, but at most places the formation is only 1.5 m thick. It contains invertebrate fossils and phosphatic nodules. Generally, the Hogshooter is thicker in the northern part of the shelf area, in Tulsa and Washington Counties, than in the southern part, where it is absent locally.

The Nellie Bly Formation, 25–167 m thick, conformably overlies the Hogshooter Limestone. The Nellie Bly consists of shale, sandstone, and, in the southern part of the shelf, chert and limestone conglomerate. The formation thins northward and contains thin limestone beds at the top.

The Dewey Limestone forms the top unit of the Skiatook Group. It conformably overlies the Nellie Bly and grades southward into the Belle City Limestone and the base of the Hilltop Formation of the overlying Ochelata Group. The Dewey consists of limestone and shale 6–18 m thick near the Kansas border and calcareous sandstone and sandy limestone in the southern part of the shelf area. The Belle City Limestone, 3–6 m thick, is found only in the southern part of the shelf area.

The Chanute Formation, 4–58 m thick, is the basal unit of the Ochelata Group and contains the members listed as follows, in ascending order: Noxie Sandstone, Thayer coal, and Cottage Grove Sandstone. In the northern part of the shelf area, it also contains a basal limestone conglomerate and a gray shale. At some places, the Chanute (probably in channels) disconformably overlies the Dewey Limestone, the Nellie Bly Formation, and the Hogshooter. Apparently the Chanute grades laterally into the Hilltop Formation between Interstate Highway 40 and the Arbuckle Mountains (Hart, 1974, sheet 1; Bingham and Moore, 1975, sheet 1).

The overlying Iola Limestone, 1–30 m thick, contains three members, the Paola Limestone, Muncie Creek Shale, and Avant Limestone, in ascending order. The Iola conformably overlies the Chanute in the northern part of the shelf area. Southward, the Iola apparently grades laterally into the lower part of the Barnsdall Formation.

The Wann Formation, 15–122 m thick, conformably overlies the Iola Limestone and consists of units of shale, sandstone, and thin fossiliferous limestone. The Wann thins and apparently grades laterally southward into the Barnsdall Formation. The Wann is overlain conformably by the Torpedo Sandstone, which consists of 0–18 m of sandstone and 0–29 m of shale. The Torpedo apparently thins and grades laterally southward into the Barnsdall. The Barnsdall crops out in the central and northern part of the shelf area, where it is 14–61 m thick; it grades into the Chanute Formation, Iola Limestone, and Wann Formation. South of Interstate Highway 40, the Hilltop Formation, which is about 21 m thick, occurs at about the same position as the Barnsdall, and the two formations intergrade.

The Tallant Formation conformably overlies the Barnsdall Formation and consists of 23–61 m of gray and brown shales and sandstones. It thins southward and is cut out south of T. 13 N. by channels in the overlying Vamoosa Formation, the basal unit of the Virgilian Series.

VIRGILIAN SERIES

The outcropping part of the Upper Pennsylvanian Virgilian Series consists of the Vamoosa Formation, 76–210 m thick, overlain by the Ada Formation, 30–122 m thick.

The Vamoosa Formation consists of brown and gray shales and light-gray limestones in the northern part of the northern Oklahoma shelf and light-brown sandstones and chert conglomerates that fill channels in the southern part of the shelf. A maximum thickness of 210 m of the formation crops out in Okfuskee County, but the Vamoosa is not as thick in Osage and Creek Counties. The formation overlaps the entire Ochelata Group and, thus, probably overlies the Missourian Series unconformably (Ries, 1954, p. 81). However, a basal shale of the Vamoosa overlies the Tallant Formation conformably at some places.

The Ada Formation consists of beds of sandstone, limestone, chert and limestone conglomerates, and brown shale. The Ada conformably overlies the Vamoosa except near Ada, where a large channel cuts out the Vamoosa. In parts of the shelf area to the south, the Ada is the correlative of the Collings Ranch Conglomerate (Hart, 1974, sheet 1).

GEARYAN SERIES

The Gearyan Series is included tentatively at the top of the Pennsylvanian System in Oklahoma, because its flora and fauna are similar to those of other Upper Pennsylvanian strata and it conformably overlies the strata of the Virgilian Series. The Gearyan comprises the Vanoss Formation and the Oscar Formation, which conformably overlies the Vanoss.

The Vanoss Formation consists of beds of shale, red-brown arkosic sandstone, limestone, limestone and chert conglomerates, and coal. It is 76–183 m thick. Thin units of limestone and of shale are common north of the Canadian River in the northern part of the shelf area, and units of conglomerate and sandstone, in the southern part. However, the formation is thickest in the northern part. Many of the lithologic units in this formation are red.

The Oscar Formation conformably overlies the Vanoss and consists of limestone, shale, arkosic sandstone, and conglomerate beds. Its thickness increases from 91 m in the southern part of the shelf to 213 m in the northern part. The Oscar arkosic sandstones and conglomerates are present near the Arbuckle Mountains. As currently recognized by the Oklahoma Geological Survey, the Herington Limestone Member is the highest stratigraphic unit of the Oscar Formation and, therefore, of the Pennsylvanian System in Oklahoma. It is conformably overlain by Permian strata.

ARDMORE BASIN

Only the Desmoinesian and Missourian Series are represented in the Ardmore basin, the former by the Deese Group and the latter by the Hoxbar Group (see Hart, 1974, sheet 1). The stratigraphy of these rock groups in this basin is complex, little described, and little understood. Lithologies grade in short distances from limestone and chert conglomerates to sandstones and shales containing many thin beds of limestone.

The Deese Group attains a total thickness of about 2,950 m and is considered equivalent to the lower Franks Conglomerate and to the lower part of the upper Franks Conglomerate (Hart, 1974, sheet 1). The Hoxbar Group is about 850 m thick and is probably equivalent to the upper part of the upper Franks Conglomerate (Hart, 1974, sheet 1).

IGNEOUS AND METAMORPHIC ROCKS

By Kenneth S. Johnson

Igneous and metamorphic rocks of Carboniferous age are sparse in Oklahoma. Veins, as open-space fracture fillings, consist mainly of quartz and contain lesser amounts of barite and calcite; some of the veins contain lead, zinc, and copper sulfides. The veins are chiefly in the Ouachita Mountains, but some also are present in the Wichita, Arbuckle, and Ozark uplifts. Introduction of the vein material probably took place during late stages of deformation, late in the Pennsylvanian Period; Miser (1959) showed a similarity between the abundance of quartz veins and degree of metamorphism in the Ouachita Mountains. Some workers believe that the zinc and lead deposits of the Tri-State district in northeastern Oklahoma also may have been emplaced in Middle or Late Pennsylvanian time.

Volcanic ash and pyroclastic flows are present in the Stanley Shale (Upper Mississippian) of the Ouachita Mountains. Tuff beds that range in thickness from 7 to 40 m were deposited in the deep-marine basin as interbeds with flysch sediments. Whole-rock samples analyzed for rubidium and strontium isotopes yielded an isochron age of 310 ± 15 m.y. (Mose, 1969), and associated conodonts show a late Mississippian age.

Low-grade metasedimentary rocks in the core area of the Ouachita Mountains were apparently metamorphosed mainly during the Pennsylvanian orogeny. Shales, sandstones, and impure limestones of Ordovician age were dynamically metamorphosed under considerable shearing stress at relatively low temperatures into slate, phyllite, schist, metasandstone, and graphitic marble (Goldstein, 1975). Age determinations from micas range from Devonian to Early Permian; the younger Pennsylvanian and Early Permian ages probably represent the time of deformation in the Ouachita Mountains.

ECONOMIC RESOURCES

COAL

By S. A. Friedman

Coal-bearing strata of Middle and Late Pennsylvanian age in eastern Oklahoma occur in an area of approximately 36,000 km^2 in the southern part of the western region of the interior coal province of the United States (Campbell, 1917) (fig. 7).

An area of approximately 20,000 km^2 contains at least 24 coal beds, 20 of which have been formally named. These beds are 0.25–2 m thick, and they are of commercial value, or have been during the past 104 years. Figure 6 shows the positions of the coal beds within the Middle and Upper Pennsylvanian stratigraphic framework. The identified bituminous-coal resources are shown by county in figure 7. Low- and medium-volatile bituminous coals occur in the eastern part of the Arkoma basin, and

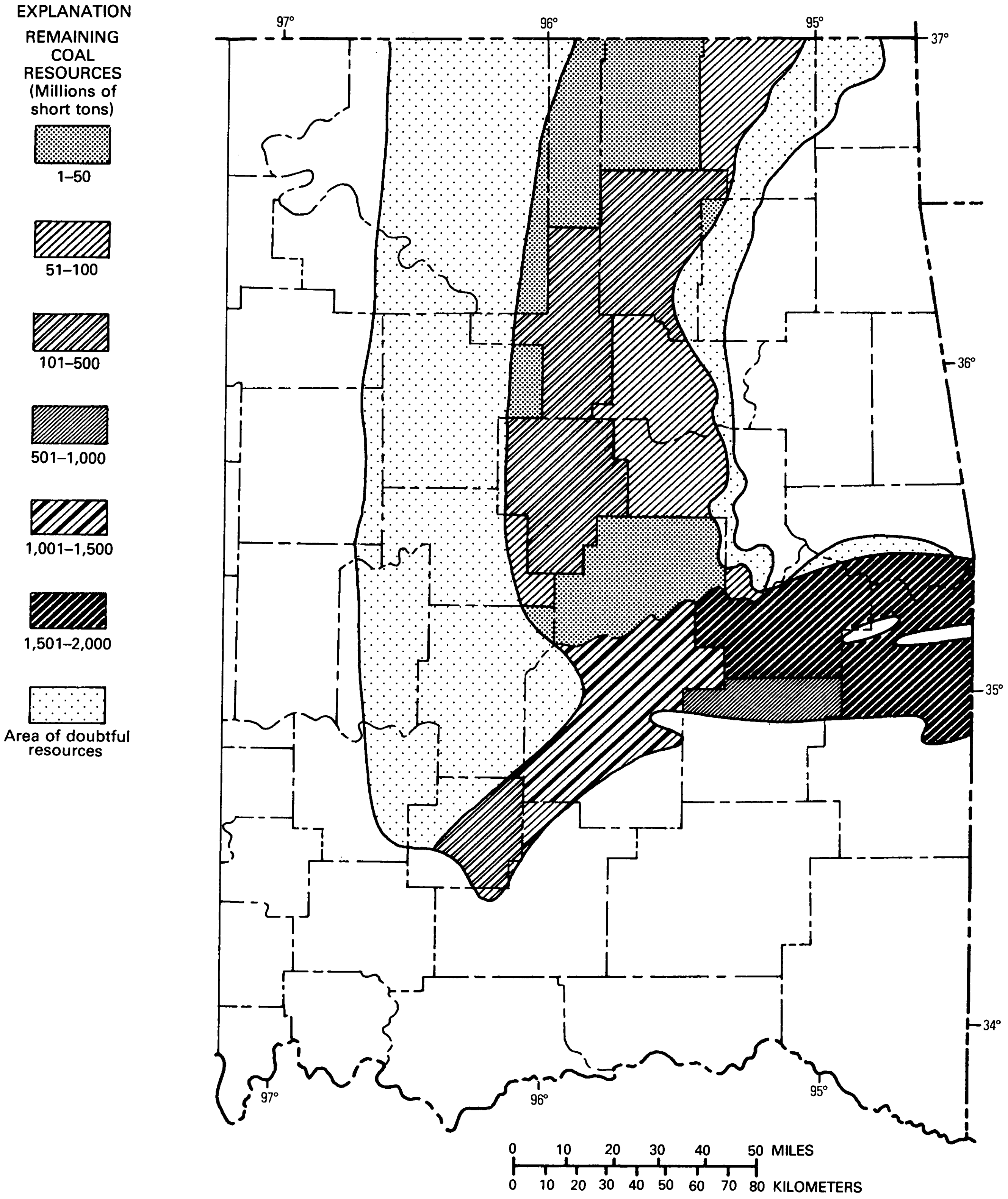


FIGURE 7.—Distribution of remaining coal resources in Oklahoma part of western region of interior coal province.

high-volatile bituminous coals are present in the western part of the basin and in the northern Oklahoma shelf area.

Most of the coals are moderately dull to moderately bright banded, and the lithotypes are thin banded. Vitrain is sparse, and bright attritus is abundant. The thickest vitrain (5 mm) occurs in the Croweburg coal, and the brightest attritus, in the Stigler coal.

The most recent estimate by the Oklahoma Geological Survey indicates that 7,700 million short tons of coal constitutes the original identified resources; 500 million tons has been mined and lost in mining, leaving 7,200 million tons as remaining resources, of which only 2,300 million tons is considered to be net recoverable reserves (Friedman, 1974). Most of the resources are contained in the Hartshorne coals, in the base of the Desmoinesian Krebs Group (fig. 6). The Hartshorne, McAlester, Stigler, and Croweburg coals contain most of the low-sulfur (1-percent sulfur or less) coal and all the coking coal in the State. Other coals, in isolated occurrences, are low in sulfur, and many coals show a free swelling index of 5–9 but are high in sulfur and ash. Most Oklahoma coals yield low ash-fusion temperatures (800° C–1,160° C).

Desmoinesian coal beds are found in the Arkoma basin in a clastic sequence 1,800 m thick and in the northern Oklahoma shelf area in a sequence 300 m thick. In the Arkoma basin, coal-bearing strata crop out on the flanks of plunging, broadly folded synclines and of some sharply folded and faulted anticlines. Folds commonly plunge only 1°–3°, but coal beds on the flanks of the folds dip 3°–65°. In the northern Oklahoma shelf area, the strata show a west-northwestward regional dip of ½°–2° but also show superimposed folds and structures associated with channel-fill sandstone that cause beds to attain dips of approximately 5°.

The presence of coal in Oklahoma had been noted as early as 1821, according to Trumbull (1957, p. 361), but mining on a commercial scale did not begin until the Missouri-Kansas-Texas Railroad was built through McAlester in 1872. Coal production in Oklahoma increased gradually until 1900. Then it increased sharply, although in spurts, culminating in 4.85 million tons of coal in 1920 for a record high that was not surpassed for 57 years. Most of the coal production during these times was from underground mines in the Arkoma basin, including the Henryetta district.

Production decreased sharply during the economic depression of the 1930's, and it increased during the wartime economy of the 1940's, peaking at 3.2 million tons in 1946, when the Henryetta district led with 37 percent of the total. Thirty years later (1976), that figure was exceeded when coal production reached 3.6 million tons. In 1977, a new record high was set at 5.3 million tons.

Strip mining has been the principal method of coal mining in Oklahoma since 1942 and has been the exclusive method of mining since 1972, except for one tandem auger mine. Several companies have indicated plans for underground coal production in the Arkoma basin by 1980.

Approximately 35 strip mines produced coal from 12 beds in Oklahoma in 1977. During 1976, 28 strip mines produced coal from 12 beds; 48 percent of this production was from the Iron Post coal (table 1). From 18 to 32 percent of the coal produced from 1972 through 1976 was used for coke manufacture in Texas, Colorado, Ohio, Pennsylvania, and Japan. Steam electricity-generating plants in Kansas and Missouri accounted for the increased coal use in 1972–77; thus, the percentage of coking-coal production in Oklahoma (table 2) decreased.

Less than 1 percent of the State's 1976 production was from coal beds dipping more than 18°. Most (91 percent) of the production was from beds dipping less than 5°, and 8 percent was from beds dipping 5°–18°. The thickness of coal beds mined in 1976 was 0.25–1.8 m, and the maximum thickness of overburden at strip mines was 36 m.

TABLE 1.—*Oklahoma coal production, by bed, 1976*

Coal bed	Short tons	Percentage of total
Iron Post	1,719,596	48
Croweburg	665,899	19
Mineral	450,441	13
Stigler	239,601	7
Upper Hartshorne and Lower Hartshorne (combined)	228,159	6
Secor and Secor rider	95,843	3
Weir-Pittsburg	58,233	2
Rowe	27,790	1
Cavanal	19,447	1
McAlester	12,541	<1
Totals	3,517,550	100

TABLE 2.—*Estimated uses of Oklahoma coal, 1972–76*

Year	Coking coal production		Steam coal and other coal production
	Short tons	Percentage of total	Short tons
1972	680,000	27	1,850,211
1973	606,828	28	1,587,842
1974	582,455	25	1,792,230
1975	910,004	32	1,940,423
1976	665,924	18	2,960,757

Most Oklahoma coal mines produced less than 100,000 short tons in 1976. Only Peabody Coal Co.'s Rogers County No. 2 mine produced more than 1 million tons (in 1976 and in 1977), and this coal (the Iron Post) was consumed in steam electricity-generating plants out of State. Garland Coal and Mining Co. ranked second in production but produced less than 50,000 tons, all of which was used for coke manufacture out of State.

In 1976, Oklahoma ranked 20th in coal resources and production in the United States. The reported cumulative coal production from Oklahoma from 1873 through 1977 is 212 million short tons.

PETROLEUM

By John F. Roberts

In Oklahoma, the oil produced from Carboniferous rocks is estimated to constitute 60 percent of total cumulative production in the State, as well as 60 percent of current production and remaining recoverable reserves. Natural gas produced from the Carboniferous is estimated to constitute 69 percent of total cumulative production, current production, and remaining recoverable reserves in the State. These estimates are based on those furnished by the American Petroleum Institute and the American Gas Association.

The recorded cumulative production of crude oil in Oklahoma to January 1, 1977, is 11,487,173,000 barrels (42 U.S. gallons per barrel). The value of this oil is estimated to be $27,015,173,000.

Oil production during 1976 was 150,627,000 barrels, valued at $1,432,463,000. Peak production was 277,775,000 barrels, valued at $397,200,000, during 1927. Annual production and value through 1976 are shown in figure 8.

Natural-gas production in Oklahoma from 1906 through 1976 totaled 40,030,023 million ft^3, and its value was $6,289,820,000. Natural-gas production during 1976 was 1,710,586 million ft^3, and its value was $858,714,000. Peak natural-gas production was in 1972 (1,806,887 million cubic feet, valued at $294,523,000). These statistics are shown in figure 9.

During 1976, Oklahoma's total petroleum products amounted to 94 percent of the State's total mineral production and had a value of $2.5 billion. This value includes $208 million from natural gasoline, hydrocarbons that have been recycled by repressuring of reservoirs, and liquefied petroleum gases not included in crude-oil production and values given in figure 8.

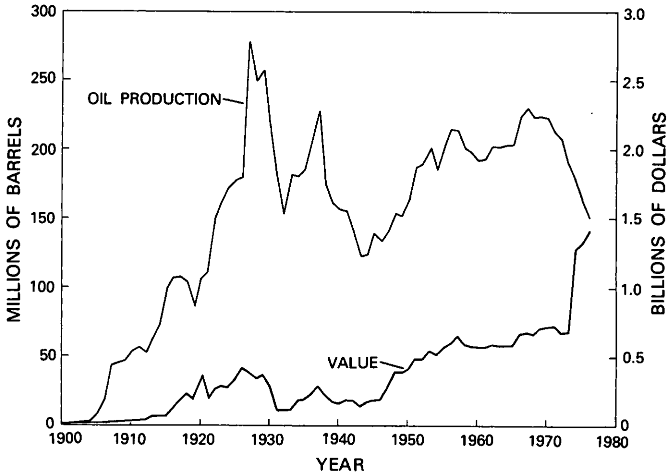


FIGURE 8.—Crude-oil production and value in Oklahoma, 1891–1976.

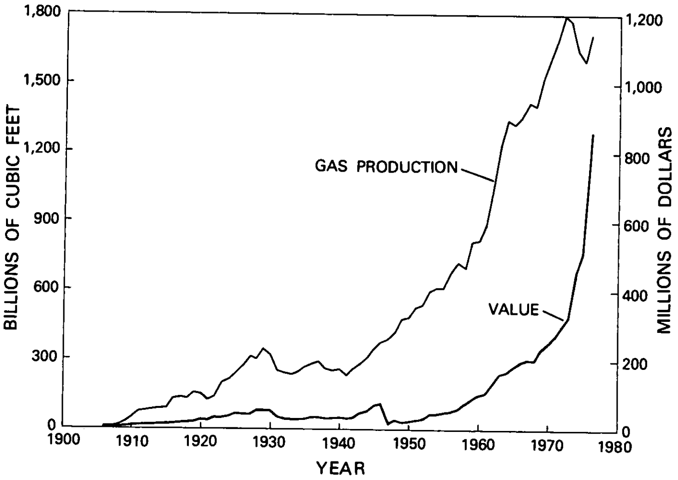


FIGURE 9.—Natural-gas production and value in Oklahoma, 1906–76.

Oklahoma liquid-petroleum production accounted for 5.4 percent of the United States total for 1976; natural-gas production accounted for 8.5 percent.

Since 1889, when Oklahoma's first producing well was drilled, more than 300,000 wells have been drilled in the State. Oil and (or) gas has been produced from more than 218,000 of these wells. In 1976, 12 crude-oil refineries, 83 natural-gas-processing plants, and 8 petrochemical plants were operating in Oklahoma; at least 43,200 persons were directly engaged in these operations. Thus, the petroleum industry continues to have a significant effect on the economy of Oklahoma. Figure 10 shows the extent of the State's producing areas as well as the location of giant oil and gas fields.

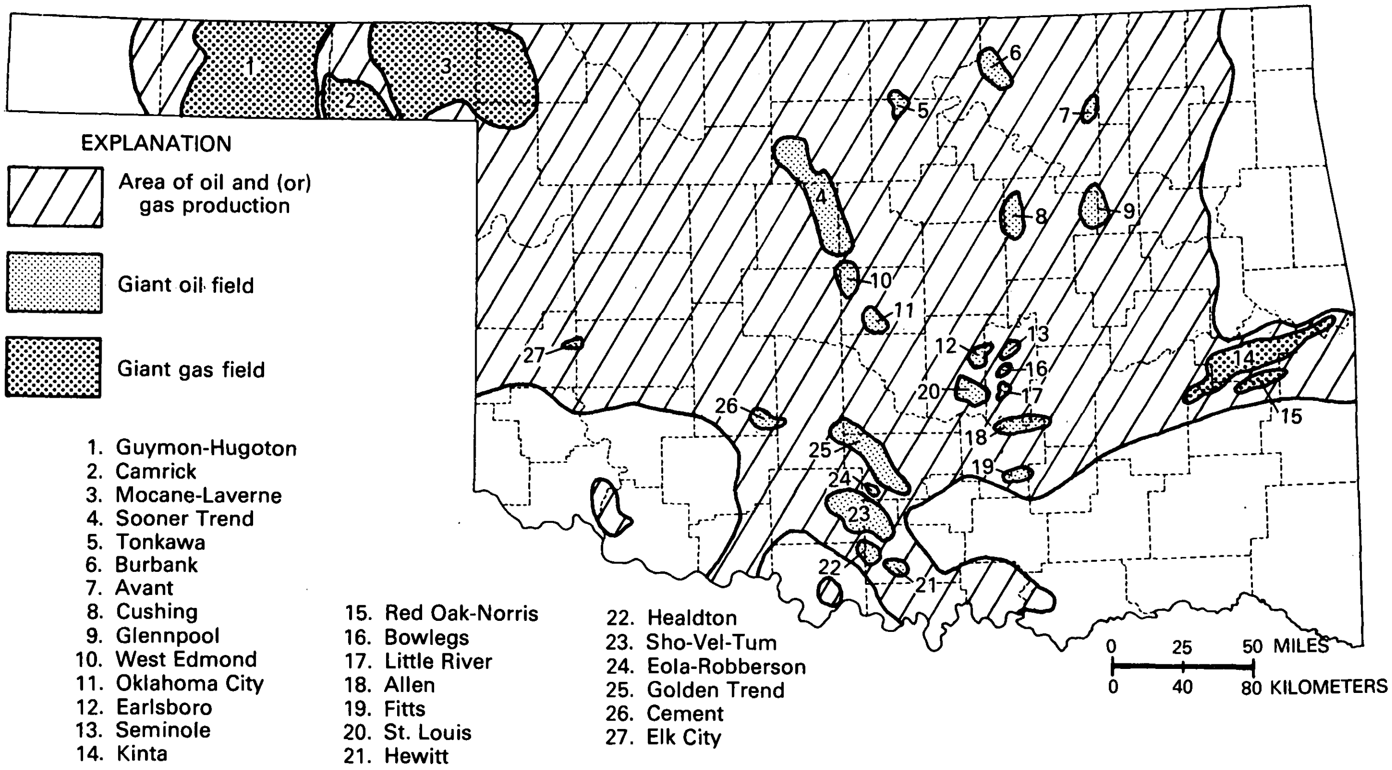


FIGURE 10.—Generalized oil and gas map of Oklahoma showing extent of productive areas and giant fields (from Johnson and others, 1972, p. 7).

Man's deepest penetration into the earth—9,583 m—was accomplished by the drilling of the Lone Star Producing Co. 1 Rogers Unit in sec. 27, T. 10 N., R. 19 W., Washita County, western Oklahoma. At this depth, in rocks of the Arbuckle Group (Ordovician), molten sulfur entered and surged up through the drill pipe; upon cooling, it crystallized in the drill pipe and caused the bottom part of the hole to be lost. The well was then plugged back to 3,962 m and completed as a gas well in Pennsylvanian rocks. The well was drilled near the axis of the deep Anadarko basin in western Oklahoma.

Oil and (or) gas has been produced from 72 of the State's 77 counties (see fig. 10). In addition to the areas of basement-rock outcrops in the Arbuckle Mountains in south-central Oklahoma and the Wichita Mountains in the southwest, the three areas that seem unlikely to produce significant hydrocarbons are the Hollis basin, the Ozark uplift, and the Ouachita Mountains.

Within the Hollis basin, in extreme southwestern Oklahoma, exploratory efforts have been largely unsuccessful in obtaining commercial production. One reason may be the lack of suitable reservoir beds. Future efforts in this rather sparsely drilled area might lead to recognition of areas where the conditions are better for the accumulation of petroleum, however.

In northeastern Oklahoma, the southwest flank of the large Ozark uplift exposes Mississippian limestones covering thin remnants of older Paleozoic sedimentary rocks over shallow Precambrian granites. Significant petroleum accumulation seems unlikely, although many outcrops and quarries in the limestone beds show heavy residual oil in joints and fissures.

In southeastern Oklahoma, the Ouachita Mountain system extends westward from Arkansas and curves southwestward to disappear under the Cretaceous overlap. South of the Choctaw fault, a structurally complex series of Pennsylvanian shales, siltstones, and sandstones is underlain by an equally complex sequence of Mississippian and older Paleozoic calcareous shales, limestones, and cherts. In the past, several asphalt mines were worked commercially in these rocks. In the western part of the region, a few noncommercial shallow oil wells have been completed in Carboniferous rocks. A few gas wells of questionable commercial value are scattered throughout the region; they produce from beds of thick, low-porosity and low-permeability sandstone and siltstone of Carboniferous age as well as from fractured chert of older formations. The economic potential of this sparsely drilled region depends on successful exploratory discoveries and on the feasibility of new methods to extract gas from these rocks of low permeability. Gas, not oil, is the mode of hydrocarbon occurrence in the deeper zones throughout the region, owing to the low-grade metamorphism that has driven out the heavier hydrocarbons.

In Oklahoma, hydrocarbons are produced from every series of the Carboniferous, but Pennsylvanian rocks account for approximately 75 percent of the Carboniferous total. The most prolific series is the Desmoinesian of Middle Pennsylvanian age. Both oil and gas are produced from Desmoinesian rocks, predominantly from sandstones associated with the cyclic sedimentation that also contains the commercial coals mined in northeastern Oklahoma. In this part of the State, the depths to these sandstone beds are as much as about 1,000 m. Equivalent beds of productive sandstone are found in most producing areas of Oklahoma, at depths of more than 3,000 m in the west-central part. None of these individual sandstone beds is continuous over a broad area. The sandstones originated as a series of deltaic deposits combined with accompanying nearshore and offshore bars and channel sands. Some production has been obtained from carbonate rocks that may have been reefal in part; these rocks are generally oolitic or oolicastic.

Next in productive importance are the many beds of sandstone within the "Atokan" and Morrowan Series of Early Pennsylvanian age. These older deposits are not as widespread as the Desmoinesian because more parts of the State served as areas of nondeposition and (or) erosion during this time. Producing sandstone beds extend to depths of 4,000 m and more in the western part of Oklahoma. These beds are not as clearly deltaic in nature as those of the younger sandstone but are more like channel and offshore deposits. The Morrowan Series contains some persistent carbonate rocks, but where productive, the facies is sandy.

Hydrocarbon accumulation in these Pennsylvanian sandstones typically is due to combinations of structural and stratigraphic traps. Facies changes from permeable sandstones to impermeable shales are the predominant entrapping mechanism. Anticlinal structures, such as local uplifts or differential compaction, contribute to accumulations. These structural features aid exploration techniques both in subsurface mapping and in seismic interpretations. Within a given reservoir, minor faulting may or may not limit production.

In the Mississippian System, limestone is the predominant rock type, followed by shale and sandstone. Sandstone in the uppermost part of the Chesterian Series, the "Springer," produces over wide areas in southern and west-central Oklahoma from several thick sections indicative of large offshore bars. In north-central Oklahoma, another widespread sandstone contributes considerable production.

Hydrocarbon accumulation in Meramecian carbonate is attributable locally to intercrystalline porosity combined with extensive vertical fractures. The fractures are due to deep-seated movement, as structure maps indicate no appreciable faulting.

Production from Osagean rocks is limited to north-central Oklahoma, where deeply eroded limestone beds have furnished an erratic reservoir called the "Mississippi Chat." Hydrocarbons are produced from highly fractured, overturned, and faulted Kinderhookian chert in a small area in southern Oklahoma.

In 1884, the Cherokee and Choctaw Indian Nations entered into agreements with eastern U.S. interests to drill for oil in northeastern and eastern parts of their territories. In 1889, oil was found in three of these wells in the northeastern area, near Chelsea. Some wells were also drilled in Muskogee in 1894.

The first well to produce oil in commercial quantities, however, was drilled in 1897 in what is now a park at Bartlesville. The well, the Cudahy Oil Co. 1 Nellie Johnstone, was drilled to 402 m in a Pennsylvanian sandstone. It produced commercially until 1946.

During the early years of this century, many large fields were discovered and developed in northeastern Oklahoma, all producing oil and (or) gas from beds of Pennsylvanian sandstone. The locations were chosen by random methods or by offsetting existing production. Many natural-gas fields were discovered in east-central Oklahoma. Exploration then began in south-central Oklahoma. Here, locations were chosen near the many known oil seeps and asphaltic deposits. Considerable production was obtained from Permian sandstones at depths of less than 100 m, but deeper drilling soon found the more productive Pennsylvanian sandstones. By 1907, the new State of Oklahoma was the Nation's leading producer of petroleum.

During the years 1908–20, the production of oil increased and exceeded demand, which resulted in depressed prices. Voluntary efforts by producers to limit production succeeded to a small extent, so that prices stabilized at higher levels. During this period, operators discovered that the services of geologists could significantly increase their successes in locating new fields and in developing older fields. Most of the production at this time came from Carboniferous rocks, but deeper drilling was adding pre-Carboniferous production.

Exploration and development from 1920 to 1930 resulted in the addition of many prolific fields, but prices remained stable until 1929, when the nearly simultaneous discoveries and development of the Seminole, Oklahoma City, and East Texas fields depressed prices to all-time lows.

During the 1930's, the practice of forced prorationing was instigated in Oklahoma. Regulatory agencies in other States adopted this policy, and prices were stabilized. At about this time, the Interstate Oil Compact Commission was formed, with headquarters in Oklahoma City. During the rest of this decade, significant discoveries and extensions continued to be made, production continued to exceed demand, and prorationing continued to drop production to even lower levels.

During the war years, demand for all petroleum products increased dramatically. Demand for petroleum slackened in the postwar years but increased gradually as reserves in Oklahoma and the Nation continued to decline.

State oil production reached a postwar peak in 1967, and its steady decline since that time is a direct reflection of new discoveries not keeping pace with depletion. This production decline cannot be reversed, but it will be slowed by future discoveries and by the development of better methods to recover a greater percentage of the oil remaining in the reservoirs.

METALLIC ORES

By Kenneth S. Johnson

The world-famous Tri-State zinc and lead deposits of northeastern Oklahoma (fig. 11) and adjacent parts of Kansas and Missouri are found in Mississippian carbonate rocks on the west flank of the Ozarks (Brockie and others, 1968; McKnight and Fischer, 1970). Sphalerite and galena occur in blanket deposits and in breccia zones that are flat-lying or that follow the predominant northeast- and northwest-trending joint systems. The host rock is cherty limestone and dolomite of the Keokuk and Warsaw Formations (Osagean and Meramecian), which sometimes are collectively referred to as the "Boone" Formation or Group. Controversy still exists about the origin and age of mineralization and paragenesis, although workers generally favor theories of emplacement coincident either with Middle and Late Pennsylvanian orogenies in the Arbuckle and Ouachita Mountains or with Late Cretaceous igneous activity of the Mississippi Valley region.

The Tri-State district, which has produced more than $2 billion worth of zinc and lead since 1848, is one of the greatest mining districts in the world. Approximately 5.2 million tons of zinc and 1.3 million tons of lead have been produced in Ottawa County, which contains the Oklahoma part of the district. Oklahoma led the United States in zinc production almost every year from 1918 through 1945. The recoverable grade of ore produced each year since 1907 ranged from about 1.5 to 4.5 percent zinc and from about 0.4 to 1.5 percent lead. The depletion of higher grade ores and decline of the market price caused Oklahoma production to fall sharply in recent years, until the last commercial mine ceased operations and was abandoned late in 1970. Production came from underground mines in Oklahoma, generally at depths of 30–100 m, and all that remains to indicate this past mining are the abandoned mines and the large piles of chat, or crushed stone, removed during milling of the ores.

Other small vein deposits of lead, zinc, and (or) copper minerals scattered in the Ouachita, Arbuckle, and Wichita Mountains and in the Ozark region are perhaps of Middle or Late Pennsylvanian age.

NONMETALLIC MINERALS

By Kenneth S. Johnson

Principal nonmetallic-mineral resources in Mississippian and Pennsylvanian rocks are limestone and shale. Resources being produced in lesser quantities are tripoli, sandstone, chat, iodine, and ground water (fig. 11).

Limestone.—Thick Mississippian limestone units crop out extensively in the Ozarks and in scattered parts of the Arbuckle Mountains. Pennsylvanian limestone units are thinner, typically 2–15 m thick, and they cap a series of subparallel escarpments in northeastern Oklahoma and in small parts of the Ouachita and Arbuckle Mountains. These limestone units are not of exceptional purity, but they are widely used in the construction industry as a source of aggregate, cement, and dimension stone. Mississippian and Pennsylvanian limestones are currently being worked in about 30 quarries and 1 underground mine.

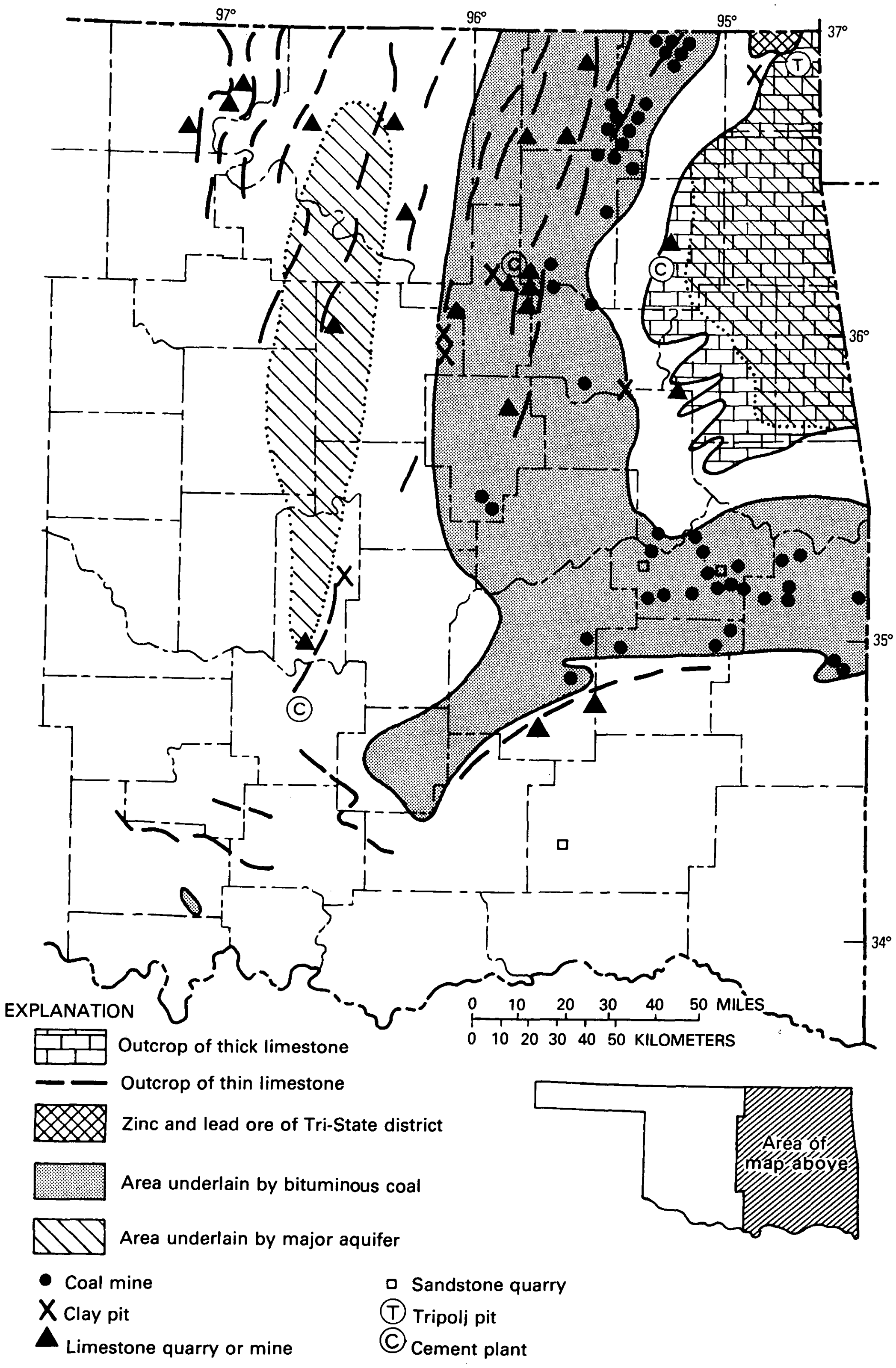


FIGURE 11.—Distribution of principal nonpetroleum mineral resources in Carboniferous rocks of Oklahoma (from Johnson, 1969; Johnson and others, 1972, p. 6).

Shale.—Pennsylvanian shale units that are 10–100 m thick and consist mainly of illite, chlorite, and quartz are a major source of raw material for the manufacture of fired-clay products in Oklahoma. Red brick and cement are the principal products made from these shales, but clay pipe, expanded lightweight aggregate, and pottery are also being produced. Nearly 10 shale pits are now being operated in Pennsylvanian shale beds, and 1 pit is being worked in a Mississippian shale. Underclay beneath Desmoinesian coal beds is generally 0.3–1.0 m thick, and a recent study indicates that it may be suitable locally for making light-colored brick and low-grade refractories.

Tripoli.—Moderately large deposits of tripoli, a lightweight form of silica rock used chiefly for abrasive and absorbent properties, are being mined from small open pits in Ottawa County in the northeast. Tripoli occurs as lenses 1–4 m thick in cherty limestones of the Mississippian "Boone" Group.

Sandstone.—Thin-bedded and well-cemented Pennsylvanian sandstone beds in parts of eastern Oklahoma have been quarried for building stone. Gray, brown, and buff stone is slabbed by splitting it along micaceous bedding planes.

Chat.—Chat is the name applied locally to the crushed chert, limestone, and dolomite produced as a byproduct of milling zinc and lead ores from the Mississippian "Boone" Group in the Tri-State district of northeastern Oklahoma. The large piles of this waste material are now being used extensively as crushed stone for road metal, railroad ballast, and concrete aggregate.

Iodine.—Early in 1977, iodine production began near Woodward in northwestern Oklahoma. Production is from natural brines in the basal Pennsylvanian (Morrowan) sandstones at a depth of about 2,100 m. The concentration of iodine in the brines ranges from 10 to 700 ppm and averages about 300 ppm. The 909,000 kg of iodine produced annually at this plant will supply more than one-third of the Nation's requirements.

Ground water.—Two major ground-water aquifers occur in Carboniferous rocks. The Mississippian Keokuk and Reeds Spring Formations (sometimes referred to the "Boone" Formation or Group) consist of fractured cherty limestone that yields large quantities of good water to shallow wells and springs in the Ozark uplift area of the northeast. The second major aquifer is the Pennsylvanian Vamoosa Formation (Virgilian), which consists of sandstone, shale, and conglomerate in the central and north-central part of the State.

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2001

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

U.S. DEPARTMENT OF THE INTERIOR
March 3, 1849

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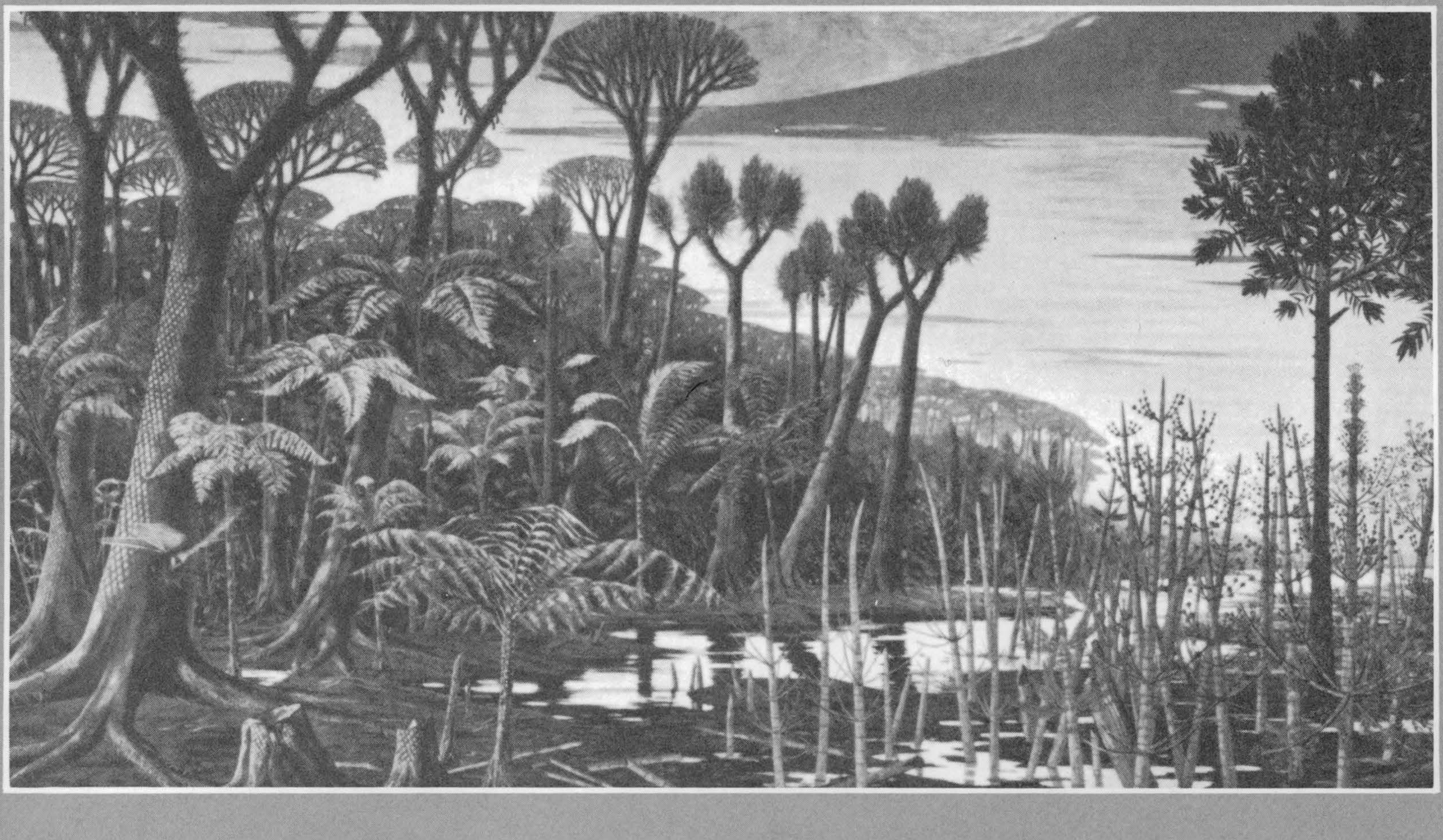

GEOLOGICAL SURVEY PROFESSIONAL PAPER 1110–M–DD

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.)

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

M. Iowa, by Matthew J. Avcin and Donald L. Koch
N. Missouri, by Thomas L. Thompson
O. Arkansas, by Boyd R. Haley, Ernest E. Glick, William M. Caplan, Drew F. Holbrook, and Charles G. Stone
P. Nebraska, by R. R. Burchett
Q. Kansas, by William J. Ebanks, Jr., Lawrence L. Brady, Philip H. Heckel, Howard G. O'Connor, George A. Sanderson, Ronald R. West, and Frank W. Wilson
R. Oklahoma, by Robert O. Fay, S. A. Friedman, Kenneth S. Johnson, John F. Roberts, William D. Rose, and Patrick K. Sutherland
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V. Colorado, by John Chronic
W. New Mexico, by Augustus K. Armstrong, Frank E. Kottlowski, Wendell J. Stewart, Bernard L. Mamet, Elmer H. Baltz, Jr., W. Terry Siemers, and Sam Thompson III
X. Montana, by Donald L. Smith and Ernest H. Gilmour
Y. Utah, by John E. Welsh and Harold J. Bissell
Z. Arizona, by H. Wesley Peirce
AA. Idaho, by Betty Skipp, W. J. Sando, and W. E. Hall
BB. Nevada, by E. R. Larson and Ralph L. Langenheim, Jr., *with a section on* Paleontology, by Joseph Lintz, Jr.
CC. California, Oregon, and Washington, by Richard B. Saul, Oliver E. Bowen, Calvin H. Stevens, George C. Dunne, Richard G. Randall, Ronald W. Kistler, Warren J. Nokleberg, Jad A. D'Allura, Eldridge M. Moores, Rodney Watkins, Ewart M. Baldwin, Ernest H. Gilmour, and Wilbert R. Danner
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U.S. DEPARTMENT OF THE INTERIOR
March 3, 1849

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1979

UNITED STATES DEPARTMENT OF THE INTERIOR

CECIL D. ANDRUS, *Secretary*

GEOLOGICAL SURVEY

H. William Menard, ***Director***

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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

H. William Menard
Director, U.S. Geological Survey

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