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

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

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ABSTRACT

Carboniferous rocks crop out only in the eastern one-third of Kansas, but they are present throughout the rest of the State in the subsurface. Because of their economic importance as sources of building materials, industrial and agricultural minerals, metallic ores, and oil and gas, and because of their importance to understanding the geologic history of the Carboniferous of North America, Mississippian and Pennsylvanian rocks have been the subjects of study in Kansas since very early in the exploration and settlement of the area. The first State Geological Survey of Kansas was established in 1864. Concerted effort to refine nomenclature and correlation of these rocks with the Carboniferous of other areas began in the early 1900's and is continuing at present.

Tectonic events that began in early Mississippian time resulted in the pattern of regional structures that is evident in these rocks now. Unconformities separate Mississippian carbonate rocks from underlying Devonian-Mississippian shale and from overlying lower-to-upper Pennsylvanian limestone, shale, and sandstone formations. The contact of the Pennsylvanian rocks with overlying Permian beds is conformable in Kansas.

Although only rocks of Osagean age crop out in southeastern Kansas, rocks of all four stages of the Mississippian occur in the Kansas subsurface, where they are as much as 500 m (1,700 ft) thick. Kinderhookian beds thicken northward, but Osagean and younger beds thicken southward from Kansas. Most of the Mississippian limestone and dolomite were formed in a shallow, marine-shelf environment. Oolitic and bioclastic limestone and dolomite associated with evaporites are common in the section. Shaly, sandy formations are common in the uppermost Mississippian.

Morrowan and Atokan rocks are the oldest Pennsylvanian units present in the Kansas subsurface. They are as thick as 335 m (1,100 ft) in southwestern Kansas. Surface exposures of Desmoinesian, Missourian, and Virgilian are found throughout eastern Kansas, where they comprise 49 formations whose combined thickness averages 750 m (2,460 ft). These middle and upper Pennsylvanian stages are also present in the subsurface.

The repeated occurrence of similar types of rocks in vertical section has led to recognition of cyclothems in the Pennsylvanian of Kansas. The "Kansas cyclothem" consists of five depositional units that record a single transgressive-regressive sequence of events.

The biostratigraphy of Kansas Carboniferous rocks, which is well known in general, is subject to better definition in detail. Correlation of Mississippian rocks has been made on the basis of studies of bryozoans, brachiopods, conodonts, and calcareous foraminifers. Pennsylvanian beds have been correlated mainly on the basis of fusulinid foraminifers and brachiopods. The Pennsylvanian-Permian boundary is still a subject of dispute.

Middle and Upper Pennsylvanian coal is an important natural resource in Kansas. Seventeen of the 42 coal beds in eastern Kansas have economic reserves of medium- to high-sulfur coal. Surface strip mining is the most common method of recovering these thin coal beds.

Oil and natural gas have been produced from the Carboniferous rocks of Kansas since the 1860's, and these formations continue to be the targets of exploratory drilling and sites of experimentation with enhanced recovery methods. Approximately 40 percent of the oil and 10 percent of the gas produced in Kansas have come from these formations.

Lead and zinc ore was an important product of the Mississippian rocks of Kansas until 1970, and there has been renewed interest in mining deep subsurface deposits. Limestone and shale from Middle and Upper Pennsylvanian Series have been used extensively for crushed stone, building stone, cement, and for different clay products in Kansas.

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INTRODUCTION

Carboniferous rocks crop out only in the eastern one-third of Kansas (fig. 1), but they are present throughout the State in the subsurface. Mississippian (lower Carboniferous) rocks are divided into the Lower Mississippian Series, comprising the Kinderhookian and Osagean Stages, and the Upper Mississippian Series, comprising the Meramecian

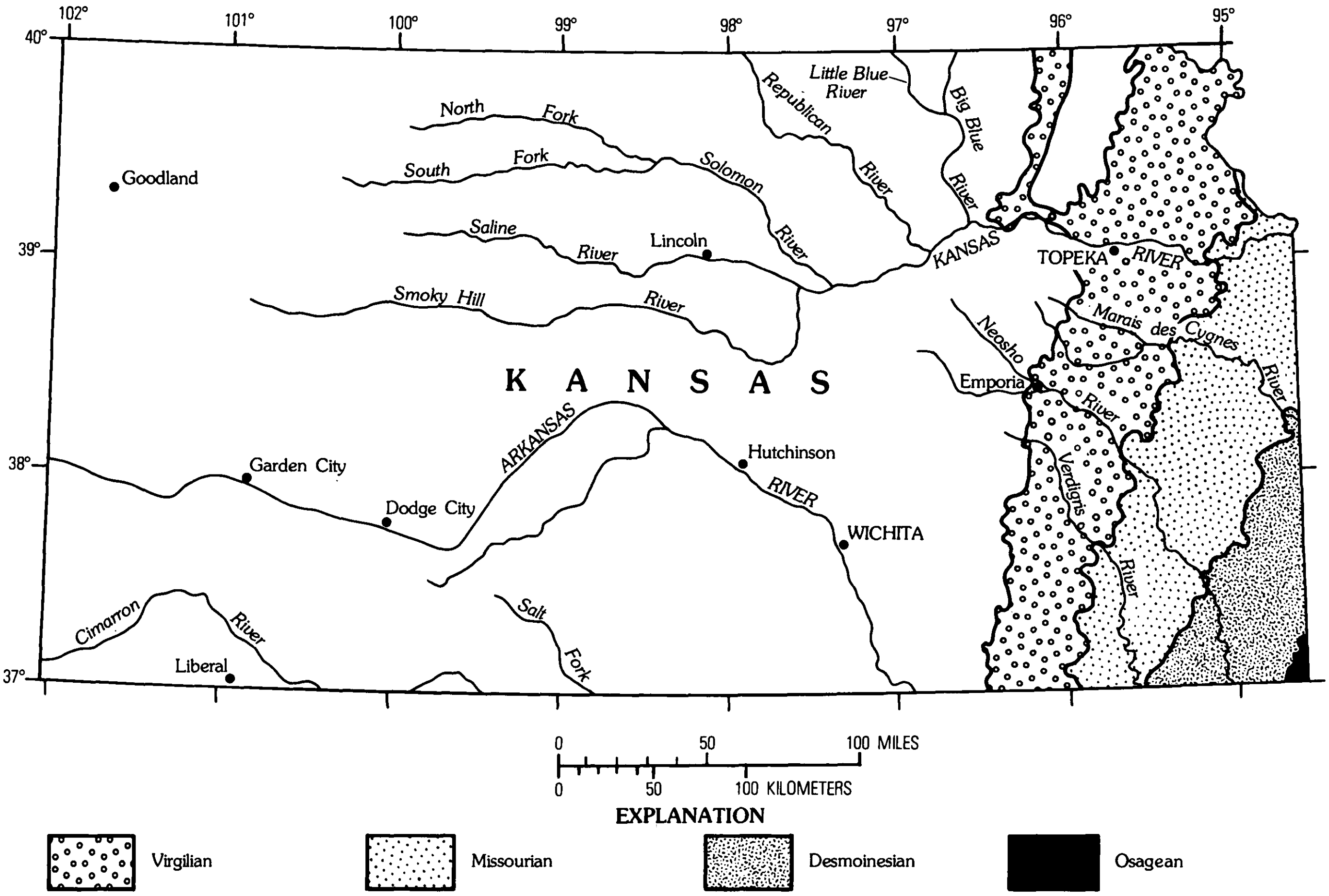

FIGURE 1.—Areas of outcrop of Carboniferous rocks in Kansas. North of the Kansas River and east of the Little Blue River, the surface is partly covered by Pleistocene glacial deposits.

and Chesterian Stages. Pennsylvanian rocks are divided into the Lower Pennsylvanian Series, comprising the Morrowan Stage, the Middle Pennsylvanian Series, comprising the Atokan and Desmoinesian Stages, and the Upper Pennsylvanian Series, comprising the Missourian and Virgilian Stages (fig. 2). Only the Upper and Middle Pennsylvanian and part of the Upper Mississippian are exposed at the surface.

In northeastern Kansas, in the area roughly bounded by the Kansas River on the south and the Big Blue and Little Blue Rivers on the west, the Carboniferous rocks are discontinuously overlain by as much as 100 m (330 ft) of Quaternary deposits, chiefly glacial till and eolian silt; nevertheless, Carboniferous rocks are exposed along most of the principal drainageways. This area coincides with the physiographic region known as the Dissected Till Plains of the Central Lowland.

In the remainder of the outcrop area, south of the Kansas River, Carboniferous rocks generally are overlain only by a thin soil cover, or, along valleys, by 15 m (50 ft) or less of fluvial deposits. The Carboniferous rocks have a slight regional west or northwest dip of about 2 to 6 m per km (10 to 30 ft per mi) in most of this area, which gives rise to gentle east-southeast-facing cuestas. This area of Carboniferous outcrops is part of the Osage Plains and the Cherokee Plain of the Central Lowland.

The effect of Cenozoic events on Carboniferous exposures has been, in eastern Kansas, a slight accentuation of relief and, in northeastern Kansas, the extensive covering of Carboniferous outcrops with glacial till, fluvial and lacustrine deposits, and discontinuous but extensive loess deposits. Loess deposits thin rapidly south of the Kansas River, and they are generally thin or absent in most of southeastern Kansas. Weathering of the Carboniferous rocks during the Cenozoic took place at about the same pace as erosion of the weathered materials, and throughout this area, soils are relatively thin.

The best natural exposures are along the streams

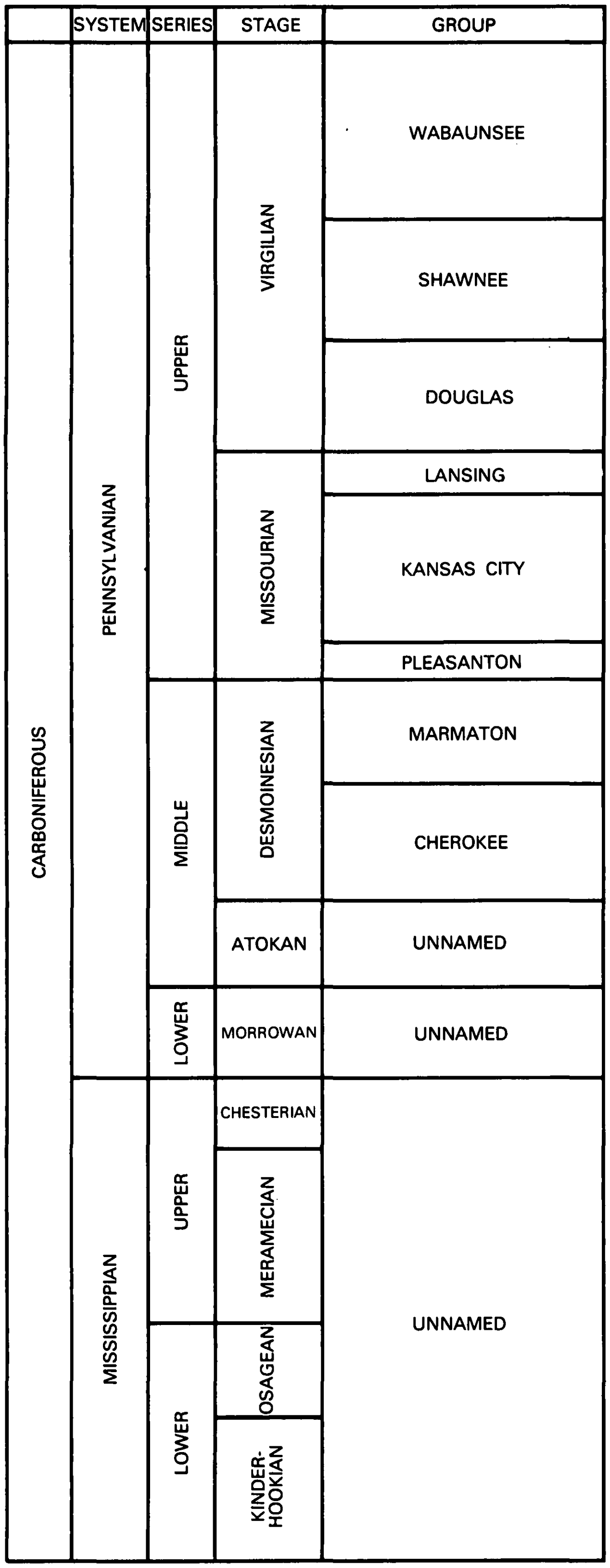

FIGURE 2.—Subdivisions of the Carboniferous in Kansas.

where the Carboniferous rocks are being actively eroded. Many excellent artificial exposures are found along the newer highways, particularly those trending east-west, and in pits and quarries where limestone, shale, sandstone, or coal have been extracted.

Both Mississippian and Pennsylvanian Systems are extremely important in the economy of Kansas as sources of fossil-fuel resources, metallic ores, agricultural minerals, building stone, and ceramic raw materials. Ground-water resources in rocks of the Upper Pennsylvanian Series are important only locally in eastern Kansas. Because of this economic importance, study of Carboniferous rocks began early in the exploration and settlement of eastern Kansas, and this study is continuing today.

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 Kansas Geological Survey.

HISTORY

Explorers, traders, missionaries, and others entering the eastern Kansas Territory in the early 1800's noticed coal-bearing strata there, especially along the route of the Santa Fe Trail and in the drainage tributaries through which they passed. The earliest purposeful stratigraphic studies of Carboniferous rocks in eastern Kansas were begun by G. C. Swallow (1855), the first State Geologist of Missouri, as he extended his study of the geology of Missouri along the west side of the Missouri River into what is now northeastern Kansas.

Swallow also became involved in a dispute over priority for the first recognition of Permian rocks, not only in Kansas, but also on the whole of the North American Continent. The Permian was, at that time, considered to be part of the Carboniferous. Major Frederick Hawn, a military surveyer and geologist stationed at Fort Leavenworth, submitted fossils that he had collected in the course of his work in Kansas to Swallow, and the two, on the basis of Swallow's recognition of the Permian age of the specimens, reported their findings in 1858, only a few days before an announcement of a similar finding by F. B. Meek (Meek and Hayden, 1858) which also was based on fossils submitted to him by Hawn. These early studies had economic implications because of the known occurrence of salt and gypsum in beds of Permian age and the relation of these younger beds to underlying Coal Measures, which were known to be widespread in the midcontinent area, even at that time.

Interest in economic development of the young State of Kansas led the Kansas legislature in 1864 to authorize the first State Geological Survey of Kansas; Benjamin F. Mudge was State Geologist. The enacting law provided for certain very specific assignments, most of which related to assessment of potentially valuable economic minerals and the suitability of Kansas soils for agriculture. Although this first State Survey was little more than a general reconnaissance, the geologists of that day had a good knowledge of the general stratigraphy of eastern Kansas, most of which involved rocks of late Carboniferous age. This first report included a review of the occurrence of coal, lignite, lime, marble, cement, gypsum, alum, salt, sandstone, lead, zinc, iron, and scattered surface indications of oil. The second State Geological Survey of Kansas began in 1865; G. C. Swallow was the second State Geologist. This work was largely an extension of the fieldwork begun by the Mudge Survey.

On the basis of Swallow's studies of the geology in the extreme southeastern corner of the State, the rocks there were for the first time correctly correlated with the lower Carboniferous "Mississippian" and the lead-bearing strata of southwestern Missouri. In the coal-bearing or upper Carboniferous "Pennsylvanian" rocks, Swallow identified 22 different seams of coal ranging in thickness from 0.3 to 2.1 m (1 to 7 ft). The "Report of the Geological Survey of Miami County, Kansas" (Swallow and Hawn, 1865), was the first geological report actually published by the initial two Geological Surveys in Kansas. The first map of the geology of Kansas was produced by Mudge (1875), in his capacity as a geologist on the State Board of Agriculture. During the period 1866–89, there was no official Geological Survey in Kansas, but work on the upper Carboniferous was proceeding (Broadhead, 1881; Hay, 1887).

After years of development in southwestern Missouri, important deposits of lead and zinc ore were finally discovered in rocks of Mississippian age in southeastern Kansas, near Galena, in 1876. Erasmus Haworth, in 1884, completed a study concerning the geology of Cherokee County in the area of this lead-zinc-mining activity. Continued interest in the economy of the developing State led the Kansas Legislature, in 1889, to pass an appropriation act for the University of Kansas which provided for the establishment of a Geological Survey. In 1895, the University formally established the University Geological Survey of Kansas.

Haworth, who was named to supervise the physical geology and mineralogy division of the new survey, had begun earlier to put students into the field to compile stratigraphic sections along the major streams in southeastern Kansas. The emphasis of this early work was in basic stratigraphy and paleontology to define the areal boundaries of the major geologic subdivisions. The preliminary results of these studies were published in a timely fashion in various issues of the "Kansas University Quarterly" (Haworth, 1894, 1895). A summary of this work, the first comprehensive stratigraphic description, correlation, and section of the Kansas Carboniferous, was published in Volume I, Kansas Geological Survey (Haworth, 1896). Continued refinement, including more detailed description and correction of earlier miscorrelations, was made by these early workers in the process of studying Carboniferous rocks in eastern Kansas and the economically important coal and deposits of oil and gas which they contained (Haworth, 1898). The lead- and zinc-mining activity in extreme southeastern Kansas (Haworth and others, 1904) continued to attract attention. The U.S. Geological Survey (Smith and Seibenthal, 1907) published a folio on the Joplin district of Missouri and Kansas, which included discussions of formation names and ages of important Mississippian limestone and chert units that were being mined.

In 1916, Raymond C. Moore became State Geologist of Kansas. The first report issued under his direction (Moore and Haynes, 1917) was a review of the oil and gas resources of Kansas. Moore's appointment marked the beginning of a period of concerted effort in the refinement of the correlation and nomenclature of Pennsylvanian rocks in Kansas, and of integration of these studies of Kansas formations with those of surrounding States (Moore, 1920, 1929, 1931, 1932a, b, 1933). In 1936, Moore published a stratigraphic classification of the Pennsylvanian rocks of Kansas. The work of many other geologists, whose work is cited by Moore, contributed to this report. This report included a review of early studies of the Pennsylvanian and a redefinition of the Pennsylvanian-Permian boundary, a considerable revision of the previous classification and nomenclature of the Pennsylvanian rocks of eastern Kansas, recognition of work in surrounding States, and an introduction of the concept of repetitive or cyclic sedimentation.

During the 1930's and early 1940's, Moore and other colleagues (Newell, 1935; Abernathy, 1937; Pierce and Courtier, 1938; and Jewett, 1933, 1941, 1945) extended their efforts to refine the classification of middle and upper Pennsylvanian rocks farther south and to integrate work on paleontology and stratigraphy of the Pennsylvanian in adjacent States with that in Kansas. The results of this work were summarized in reports by Moore (Moore, 1948, 1949).

Subsequent work has resulted in the reclassification of several groups and subgroups and in the presentation of a stratigraphic classification that is more acceptable for regional correlations (Moore and Mudge, 1956). Work also continued in the refinement of the Pennsylvanian-Permian boundary, which culminated in a publication by the U.S. Geological Survey (Mudge and Yochelson, 1962). Other stratigraphic work, designed to be more comprehensive and more detailed than earlier studies (Howe, 1956; O'Connor, 1963; Ball, 1964; Jewett and others, 1965), has resulted in other changes in the classification of Upper and Middle Pennsylvanian units. This work continues with recent studies of environments of deposition and of details of stratigraphy of the many limestone, shale, and sandstone units of the Pennsylvanian in surface exposures and in the subsurface.

Although oil had been discovered in southeastern Kansas Middle Pennsylvanian rocks in the 1860's, few wells were drilled below the top of the Mississippian limestone, because this was considered to be the lower limit of potential production. As additional drilling continued, however, more and more wells penetrated the Mississippian, and work was initiated to map the extent of recognizable Mississippian formations in the subsurface of eastern Kansas (Lee, 1939; Lee and Girty, 1940). Earlier work by Moore (1928) on the Mississippian of Missouri strongly influenced the assignment of formation names to Mississippian rocks in Kansas. Two parallel sets of terminology have evolved for the Mississippian rocks in the small area of outcrop in southeasternmost Kansas. One is based on the similarity of these rocks with those in northern Arkansas and Oklahoma (Smith and Siebenthal, 1907; McKnight and Fischer, 1970); the other is based on age equivalency and similarity of these rocks with those of northern Missouri and the Mississippi River valley (Moore, 1928; Kaiser, 1950). The latter has prevailed in later work on the Mississippian in the subsurface of Kansas. Studies of the Mississippian in the subsurface have resulted in the application of these formation names farther west (Clair, 1948; Goebel, 1966, 1968a, 1968b) and in the refinement of the ages of these rocks (Girty, 1940; Thompson and Goebel, 1963, 1968; Goebel, 1967). Studies of the Lower Pennsylvanian and Mississippian rocks in central and western Kansas are continuing today.

GEOLOGIC SETTING

The relationship of the Carboniferous rocks in Kansas to older underlying rocks is indicative of the eventful history of this sequence of rocks. Many tectonic events contributed to the fact that beds as old as Early Mississippian and as young as Late Pennsylvanian are in contact with underlying lower Paleozoic or Precambrian rocks.

Over much of the eastern two-thirds of Kansas, the dark Mississippian-Devonian Chattanooga Shale is in unconformable contact with older rocks. This unit is overlain unconformably by Mississippian carbonate rocks and by Pennsylvanian rocks. The importance of a northern Kansas basinal area and a southeastern Kansas archlike positive area, which existed until Early Mississippian time, is apparent from the distribution and thickness of rocks deposited before that time (Jewett, 1951).

Tectonic events that began early in the Mississippian resulted in the pattern of structures that are apparent in these rocks at present (fig. 3). Most notably, the central Kansas uplift evolved from an older, more subtle, archlike feature in central and northwestern Kansas, and the Nemaha uplift began in eastern Kansas in Late Mississippian time as a strongly positive elongate feature, which today extends from eastern Nebraska to southern Oklahoma (Jewett, 1951).

The continued activity on these positive structural elements and the increased importance of the Anadarko basin in Oklahoma strongly affected patterns of sediment distribution and areas of erosion throughout the Carboniferous. Not until Late Pennsylvanian time did sediments finally cover all these underlying structures (Lee and Merriam, 1954).

Lower Mississippian carbonate rocks, where the basal Chattanooga Shale is absent, rest unconformably on all older deposits. An important period of erosion removed these beds from the Nemaha and central Kansas uplifts near the close of Mississippian time. Upper Mississippian (Chesterian) beds, which are present only in the subsurface of southwestern and southeastern Kansas, are probably unconformable with older rocks, but the nature of their contact with overlying Lower Pennsylvanian, Morrowan, beds is unclear. In some areas, this contact surely is unconformable, but in others, it may represent continuous, but varied, sedimentation or a long period of almost no deposition.

Sedimentation during the Pennsylvanian Period covered progressively larger areas, resulting in overlap of older stratigraphic units by younger ones until areas of uplift were covered. The Missourian

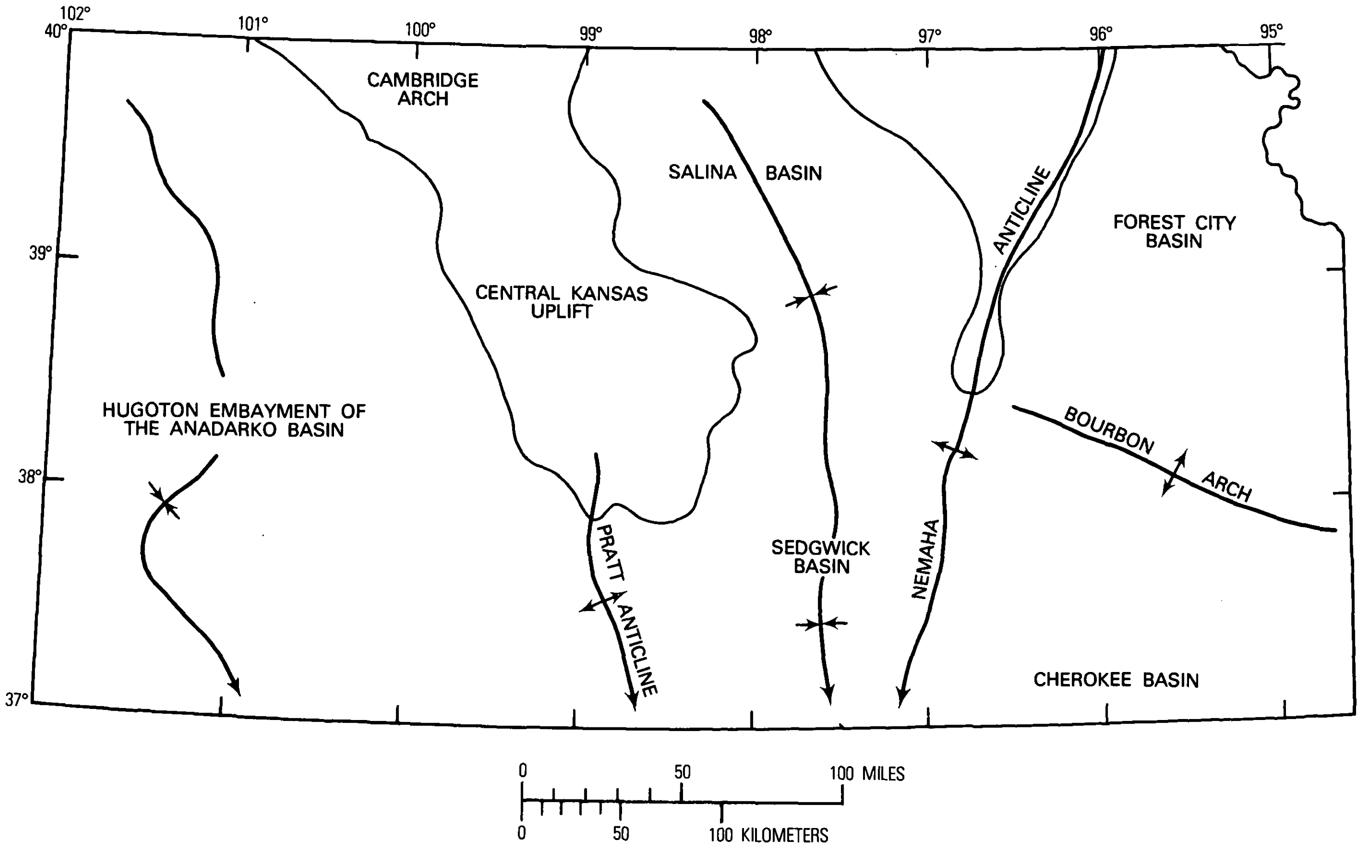

FIGURE 3.—Paleotectonic features of Kansas that were formed in Late Mississippian–Early Pennsylvanian time (modified from Stewart, 1975, fig. 19).

Kansas City Group is in direct contact with Precambrian crystalline rocks over parts of these old positive areas. Considerable local relief was present on the Precambrian terrane, which has been discovered by drilling into buried high areas on the ancient rocks beneath the Pennsylvanian cover (Walters, 1946).

The close of Carboniferous sedimentation in Kansas was not marked by any important tectonic event. The contact of Pennsylvanian with younger Permian beds is conformable, except for local areas on the Nemaha uplift, which may have been the sites of intermittent structural movement and of channel-cutting by terrestrial streams at about this time.

The Pennsylvanian-Permian contact has been chosen by convention to be the top of the Brownville Limestone Member of the Wood Siding Formation of the Virgilian Stage (Moore, 1936). No important discontinuity in the fossil record and no important tectonic event mark this transitional boundary in Kansas. Some States, notably Oklahoma, disagree on the placement of this systemic boundary; in fact, it has been a subject of dispute for a long time (Moore, 1936; Branson, 1962; Mudge and Yochelson, 1962).

After the Carboniferous, no large-scale structural movements have taken place in Kansas, other than regional tilting to the west and overall uplift, which have affected mainly the distribution and character of post-Permian rocks (Merriam, 1963).

LITHOSTRATIGRAPHY

MISSISSIPPIAN

In Kansas, rocks of Mississippian age are exposed at the surface only in the southeastern corner of the State (fig. 1). Consequently, very little detailed mapping of Mississippian formations has been accomplished except at a local level, such as in the Kansas part of the Tri-State mining district. Beds representing all four stages of the Mississippian have been recognized in the Kansas subsurface, and they are as much as approximately 500 m (1,700 ft) thick in southwestern Kansas. Thinner sections of Mississippian rocks are present in most other areas of the State except over the crests of the major uplifts, where Mississippian rocks are absent (Goebel and Stewart, 1978).

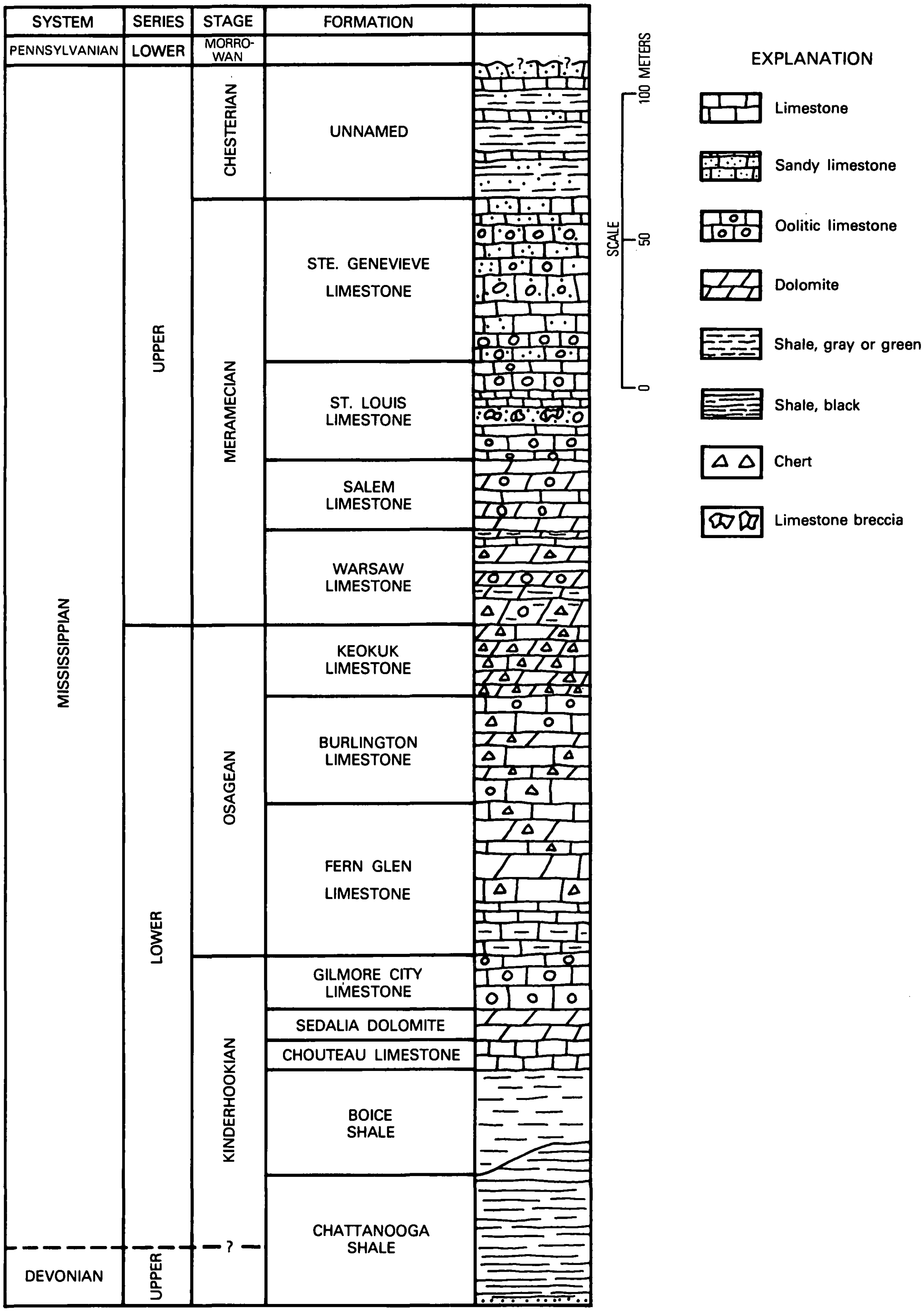

FIGURE 4.—Generalized lithostratigraphic column of Mississippian formations in Kansas (modified from Goebel, 1968b). Thicknesses represented are averages.

The earliest attempts to map the lithologic units within the Mississippian over large areas in Kansas were based on studies of well cuttings and cores (Lee and Girty, 1940). As more data became available, formation names from type areas in Missouri and Iowa were applied to Kansas rocks; however, because these formations in some areas of Kansas are different from the type sections, a rather loose system of names using partly rock-stratigraphic and partly time-stratigraphic terms or letter-designated subdivisions is in use by economic geologists.

The following brief discussion is based on the formal classification recognized by the Kansas Geological Survey, as derived from the works of Lee and Girty (1940) and Lee (1943, 1956), Moore (1957), and Goebel (1966, 1968a, 1968b) (fig. 4).

The contact between the Devonian and the Mississippian Systems is not exposed at the surface in Kansas. It is placed within the Chattanooga Shale, which is present beneath most of eastern and central Kansas. The black Chattanooga Shale and the overlying greenish-gray Boice Shale are more than 75 m (250 ft) thick in northeastern Kansas, but they are not present on the northern end of the Nemaha uplift or in the southeastern corner of Kansas. The Chattanooga Shale is exposed at the surface beneath Mississippian limestone in southwestern Missouri and nearby in Oklahoma.

Kinderhookian limestone and shale are present in the subsurface of eastern Kansas, and successively younger formations overlap older ones northwestward, the formations thickening northward into Nebraska and Iowa. These rocks are absent in the area of outcrop in southeastern Kansas.

In contrast, Mississippian rocks of Osagean and younger age thicken southward, and they overlie Kinderhookian beds with angular unconformity on a regional scale. Osagean rocks consist mainly of coarse-grained crinoidal and finer grained, mixed-fossil, bioclastic limestones, some fine-grained dolomite, and dolomitic limestone, all of which are usually cherty to some degree. In south-central Kansas, in the subsurface, a facies change takes place, and the rocks of equivalent and younger age are reddish and greenish, crinoidal, thin-bedded limestone interbedded with green or gray shale.

Almost all the outcropping Mississippian rocks in southeastern Kansas belong to the Keokuk Formation and have been assigned an Osagean age on the basis of studies of conodonts (Thompson and Goebel, 1968). These beds are cherty limestone and dolomite, fossiliferous limestone, and chert in beds and nodules. One thin oolitic limestone, the "Short Creek Oolite," near the top of the Keokuk, has been mapped in local areas to define structure of the ore-bearing Mississippian in the Tri-State District.

In southeastern Kansas and contiguous areas of Missouri and Oklahoma, the outcropping Osagean and Meramecian rocks, which are estimated to be 90–135 m (300–450 ft) thick, have been designated the "Boone Formation," from studies of rocks in northern Arkansas. Different authors have informally subdivided the "Boone" into 16 beds designated by letters of the alphabet (Fowler and Lyden, 1932), or into seven named members (McKnight and Fischer, 1970), but there is disagreement on where in the section to place the Osagean-Meramecian contact. The Kansas Geological Survey recognizes the "Boone Formation" only as an informal term.

As noted above, rocks of the Upper Mississippian Series may be in disconformable contact with older Mississippian rocks in southeastern Kansas, but elsewhere in the State, this unconformity is not present or is obscure. Beds of the Meramecian and Chesterian Stages, which are only in the subsurface, are themselves separated by an unconformity of regional importance.

Meramecian rocks are as thick as 260 m (850 ft) in southwestern Kansas, but these units are much thinner or are absent in northern Kansas and on the crests of pre-Pennsylvanian structures (Goebel, 1966). Lower Meramecian beds consist of shaly, cherty dolomite and interbedded thin limestone beneath oolitic and bioclastic, slightly cherty limestone. Upper Meramecian beds are silty and sandy fossiliferous or oolitic limestone.

Rocks of the Chesterian Stage in Kansas are confined mainly to southwestern and southeastern parts of the State (Lee and Girty, 1940; Goebel, 1966; Nodine-Zeller and Thompson, 1977). Bioclastic limestone near the outcrop in the southeast is much better known at localities in adjoining States. In the southwest, beds of fine-grained sandy limestone and shaly crinoidal limestone are interbedded with green or gray shale. These beds are more than 100 m (300 ft) thick in southwestern Kansas near the Oklahoma line.

These descriptions of stratigraphic units of Mississippian age in Kansas are based on presently available data. Additional studies, in progress, suggest that some of the lithofacies in western Kansas may be somewhat younger, by as much as a stage, than they were thought to be previously. Environments of deposition of the Mississippian have been described earlier only in very general terms. Later work (Ball, 1966; Goebel, 1968b; Ebanks and others, 1977) has demonstrated that there is much room for expansion and clarification of knowledge about these subsurface rocks, especially because of their economic importance.

PENNSYLVANIAN

Outcrops of Pennsylvanian rocks are widespread in eastern Kansas (fig. 1), and these serve as a standard of reference in the study of deposits of equivalent age in other parts of the Continent. The system in Kansas is divided into Lower, Middle, and Upper Pennsylvanian Series, which comprise five stages, in ascending order: Morrowan, Atokan, Desmoinesian, Missourian, and Virgilian.

LOWER AND MIDDLE PENNSYLVANIAN

Morrowan and Atokan Stages.—Rocks of Morrowan age in Kansas are thought to be restricted to the Hugoton Embayment. Atokan rocks, likewise, are restricted mainly to the subsurface of southwestern Kansas, but some Atokan shale may be present beneath Desmoinesian rocks in southeastern and northeastern Kansas subsurface areas (Stewart, 1975; Nodine-Zeller and Thompson, 1977). Rocks of the Morrowan stage in the subsurface of southwestern Kansas comprise approximately 185 m (600 ft) of shale, limestone, and sandstone. These rocks have been described as the Kearny Formation (Thompson, 1944), and trends in lithostratigraphy have been mapped (McManus, 1959). They are overlapped in western Kansas by rocks of Atokan age, but there is disagreement about the extent of the Atokan and Morrowan rocks in southwestern Kansas (Rascoe, 1962; Stewart, 1975). Rocks of Atokan age in Kansas consist of interbedded dark-gray, black, and dark-brown cherty limestone and dark-gray to black shale, which form a sequence as thick as 150 m (500 ft). The Atokan rocks, where present, are in gradational contact with overlying Desmoinesian rocks.

MIDDLE AND UPPER PENNSYLVANIAN

The Pennsylvanian System on outcrop in eastern Kansas comprises 49 formations that have been divided into 129 formally named members and aggregated into 8 groups and 3 stages of the Middle and Upper Pennsylvanian Series (fig. 5). Middle Pennsylvanian rocks are exposed in southeastern Kansas and belong entirely to the Desmoinesian Stage. A complete sequence of Upper Pennsylvanian rocks is well exposed in eastern Kansas, particularly in the Missouri River valley along the northeastern border and south of the glacial limit at the Kansas River valley, where it serves as the type region for the Missourian and Virgilian Stages of this series. The following summary is derived from Moore (1949), Moore and others (1951), O'Connor (1963), Jewett and others (1968), and from observations by P. H. Heckel.

Middle Pennsylvanian, Desmoinesian Stage.—Rocks of the Desmoinesian Stage are divided, in ascending order, into the Cherokee and Marmaton Groups, which together have an aggregate thickness of 180 to 190 m (600 to 625 ft).

The Cherokee Group rests unconformably on Mississippian carbonate rocks and consists largely of shale and subordinate sandstone, coal beds, and thin limestone beds. Although some cyclothems based on coals have been recognized in the Cherokee, difficulty of mapping has led more recent workers to subdivide the Cherokee into just two formations, Krebs and Cabaniss; only a few well-exposed or persistent sandstones and limestones receive formal member names. The Cherokee Group ranges from 100 to 150 m (325 to 500 ft) in thickness.

The Marmaton Group lies conformably upon the Cherokee. In contrast to the Cherokee, it contains mappable, laterally persistent limestones alternating with laterally persistent sandy shales, which provide the basis for subdivision into eight formations (fig. 5). Each limestone formation is subdivided into members on the basis of persistent thin shales, and the lower three shale formations each contain a formally named local sandstone member. Each limestone and shale formation is usually 6–10 m (20–35 ft) thick, and the Marmaton Group has a total thickness of about 75 m (250 ft).

Upper Pennsylvanian, Missourian Stage.—Rocks of the Missourian Stage, the lower subdivision of the Upper Pennsylvanian Series, are divided into three groups, in ascending order, Pleasanton, Kansas City, and Lansing. Total thickness averages about 200 m (650 ft).

The basal Pleasanton Group rests unconformably on Desmoinesian rocks of the upper Marmaton Group. It is 9–40 m (30–130 ft) thick and consists mainly of shale, but locally thick sandstone is present at the base, and minor sandstone, limestone, and coal, above. Three constituent formations are recognized only in southernmost Kansas, where the Checkerboard Limestone, an important marker unit in Oklahoma, is present between the two terrigenous detrital formations of the Pleasanton.

The Kansas City Group conformably overlies the Pleasanton Group. Like the Marmaton Group, it con-

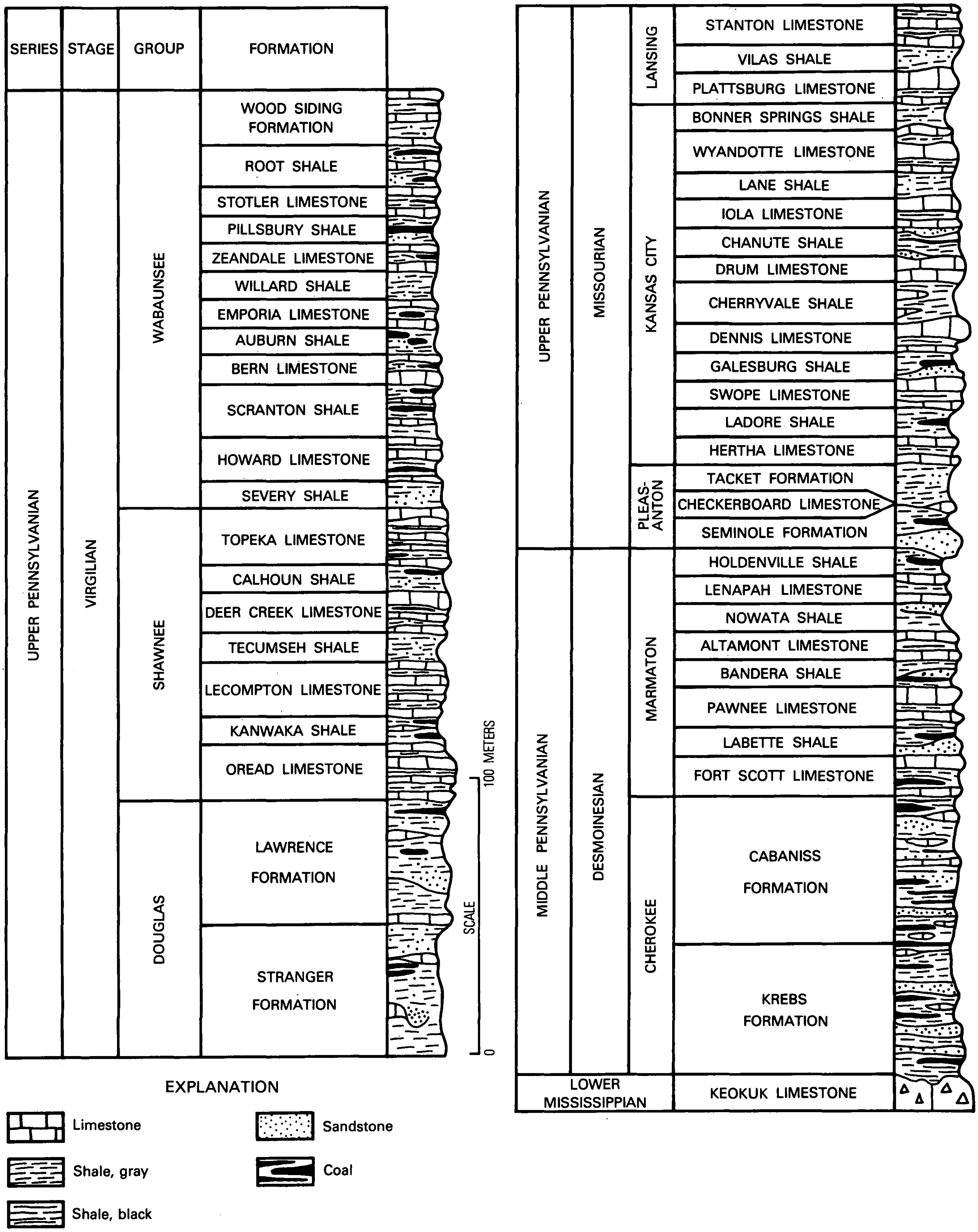

FIGURE 5.—Generalized lithostratigraphic column of Pennsylvanian formations at the surface in eastern Kansas (adapted from Zeller, 1968, pl. 1). Names of members are omitted, but nature of members is indicated by lithic symbols within formations. Thicknesses are only approximate; limestone, black shale and coal are generally expanded at the expense of gray shale and sandstone.

sists of alternating mappable, laterally persistent limestones and sandy shales, which provide the basis for division into 12 formations (fig. 5). All limestone formations are subdivided into members, mainly on the basis of thin but laterally persistent shales. Certain of the shale formations contain formally named sandstone and limestone members, and thin coal beds. Maximum thickness of the six limestone formations ranges from 10 to 30 m (35–100 ft). Three of these limestone formations disappear southward toward the Oklahoma border (Hertha, Swope, Wyandotte); the other three thin to about 2 m (6 ft) southward at the border. The intervening shale formations range from minimum thicknesses of 1–4 m (3–13 ft), in northeastern Kansas and over thickened facies of the underlying limestones, to 15–60 m (50–200 ft) farther south over thinner facies of the underlying limestones, particularly southward toward the Oklahoma border. Total thickness of the Kansas City Group is about 107 m (350 ft) in east-central Kansas.

The Lansing Group conformably overlies the Kansas City Group. It consists of three formations (fig. 5), which essentially continue the alternation of limestone and shale formations from the Kansas City Group. Both limestone formations are divided into members on the basis of persistent thin shales, and both formations attain maximum thicknesses of 25–36 m (80–120 ft) in southeastern Kansas before thinning southward as they grade into shale and sandstone near the Oklahoma border. The intervening shale formation ranges in thickness from 1 m (3 ft) or less over thick limestone (Plattsburg) facies up to 30 m (100 ft) over thin Plattsburg facies. Total thickness of the Lansing Group ranges from about 24 m (80 ft) in northeastern Kansas to about 60 m (200 ft) in southeastern Kansas.

Two thick Missourian shale and sandstone formations in the Kansas-Oklahoma border region (Coffeyville; Wann) are correlated with several Kansas formations (Tacket through Galesburg; Lane through Stanton, respectively), where intervening limestones pinch out near the Kansas-Oklahoma border.

Upper Pennsylvanian, Virgilian Stage.—Rocks of the Virgilian Stage, the upper subdivision of the Upper Pennsylvanian Series, have an aggregate thickness of about 360 m (1,200 ft) and are divided into three groups, in ascending order, Douglas, Shawnee, and Wabaunsee.

The Douglas Group (fig. 5) consists predominantly of shale and sandstone and subordinate thin limestone beds and coal beds. The group ranges in thickness from 72 m (240 ft) in northeastern Kansas, where sandstone is only locally prominent, to 120 m (400 ft) southward near the Oklahoma border, where sandstone occupies a greater part of the thickness. The Douglas is divided at the most laterally persistent limestone unit into two subequal formations; each formation contains two shale members, two thin limestone members, and a thick local sandstone member. As presently recognized, the Douglas includes the former Pedee Group, rocks that were thought to lie unconformably beneath the overlying part of the Douglas. Stratigraphic relations within the Douglas, as it is presently defined, and between the Douglas and the underlying Lansing Group of the Missourian Stage are now considered to be essentially conformable on a regional scale.

The Shawnee Group is about 100 m (330 ft) thick and conformably overlies the Douglas Group. Like the Marmaton, Kansas City, and Lansing Groups below, it consists of alternating dominantly limestone and dominantly sandy shale strata, which provide the basis for division of the Shawnee into seven formations (fig. 5). Each of the limestone formations is subdivided into at least five members on the basis of thin, laterally persistent shales. These limestone formations range from 6 to 30 m (20–100 ft) in thickness, with an average thickness of 10–20 m (33–66 ft). The shale formations are as thick as 15–45 m (50–150 ft), but only one of them is divided into members. Only the lowermost shale formation shows increased thickening toward Oklahoma like the shale formations below; the upper two shale formations attain maximum thickness in northeastern Kansas and thin southward as well as northward.

The Wabaunsee Group has a thickness of about 150 m (500 ft). It conformably overlies the Shawnee Group and caps the Virgilian Stage and Pennsylvanian System in Kansas. It consists of a greater proportion of sandy shale, containing several thin coal beds, than does the underlying Shawnee Group, but it contains enough persistent thin limestones to allow subdivision into 12 formations (fig. 5). As in several groups below, each limestone formation is subdivided into members on the basis of laterally persistent shales, but these shale members tend to be thicker and more sandy than most of those in limestone formations lower in the section. Some of the shale formations are similarly subdivided on the basis of thin persistent limestones. Limestone formations generally range from 2 to 12 m (7 to 40 ft) in thickness. The shale formations typically are thicker than 10 m (35 ft), and one attains a thickness of nearly 40 m (130 ft). Lower Permian rocks overlie the top of the Wabaunsee Group (Brownville Limestone Member of Wood Siding Formation) with apparent conformity in most places.

FACIES AND DEPOSITIONAL ENVIRONMENTS OF PENNSYLVANIAN ROCKS

Cyclothems have long been recognized in the Middle and Upper Pennsylvanian sequences of eastern Kansas (Moore, 1936, 1949, 1950; Weller, 1958). Moore recognized the basically transgressive-regressive sedimentation responsible for formation of simple cyclothems in the Cherokee and Wabaunsee Groups, in which largely nonmarine sandy shale containing coal alternates with marine shale and limestone, allowing relatively straightforward interpretation of depositional environments. Moore also devised a hierarchical classification of cyclothems of the Wabaunsee type (which became viewed essentially as shale-limestone couplets) grouped to form megacyclothems, or complex but distinctive successions of different shale-limestone couplets, in the Marmaton, Kansas City, Lansing, and Shawnee Groups. Megacyclothems in these groups are nucleated around the limestone formations containing the thin shale members, and the megacyclothem boundaries lie within the intervening sandy shale formations.

More recent work, summarized by Heckel and Baesemann (1975) and Heckel (1977), has shown that only the middle part of the megacyclothem—specifically the "middle" and "upper" limestone members and intervening thin shale member that typically contains a phosphatic black shale facies—occurs commonly enough throughout these groups to have basic genetic significance. Each depositional unit, or "Kansas cyclothem," presently recognized in these groups is nucleated around the limestone formation; it records a single transgressive-regressive marine sequence, consisting, in ascending order, of (1) thick nearshore sandy ("outside") shale (top of underlying shale formation); (2) thin transgressive ("middle") limestone; (3) thin offshore ("core") shale (often containing phosphatic black facies); (4) thick regressive ("upper") limestone; and (5) thick sandy ("outside") shale again (base of overlying shale formation) (fig. 6). The older usage of "cyclothem" in the Marmaton through Shawnee Groups for a shale-limestone couplet within a megacyclothem is abandoned, and the term, "megacyclothem," is applied only to the concept of more complex sequences.

Facies and depositional environments are considered first for the Marmaton through Shawnee Groups within the framework of the basic Kansas cyclothem (Heckel, 1977), with comments on major facies changes (fig. 7) observed along the Midcontinent outcrop belt extending southward into Oklahoma and northward into Missouri, Iowa, and Nebraska.

Nearshore shales.—Nearshore shales comprise mainly those formations that alternate with limestone formations in the cyclic sequence. The fact that these shale formations lie "outside" the "bundle" of limestones and thin shales that constitute the limestone formations caused these shale parts (or "members") of the cyclothem to be termed "outside shales," in a positional sense, before their depositional significance was thoroughly established.

Nearshore shale formations are typically sandy; though variable in thickness, they are usually thick, often attaining 15 m (50 ft) and locally 40 m (130 ft) in thickness. Commonly, they contain thin layers of siltstone and sandstone, which carry macerated plant fragments and only a sparse marine faunal assemblage of low diversity. They locally contain deposits that are demonstrably nonmarine, such as coal and underclay, shale containing well-preserved land-plant fossils, and channel sandstones, all of which lack marine fossils. Outside shales are the units within which Wanless and his coworkers (1970) have mapped many deltaic sequences.

A depositional model in which abundant terrigenous detritus was deposited in a shallow sea by prograding, laterally migrating lobes of a delta readily accounts for the characteristics of these shale formations. Variability in thickness reflects the local extent of each delta lobe. The nonmarine deposits record the subaerial deltaic plain. Rocks containing sparse marine fossils of low diversity record prodelta to delta-front environments where rapid deposition, increased turbidity, and fluctuating salinity reduced the abundance and diversity of marine organisms.

In southeastern Kansas, nearshore shale formations constitute a proportionately greater amount of the total section, and they thicken substantially in the Kansas-Oklahoma border region, in the direction of a major deltaic detrital source farther south in Oklahoma. The only exceptions to this are places in which these shales thin over thickened facies of underlying limestone.

Most nearshore shale formations tend to thin northward into Iowa and Nebraska, away from the major directions of detrital influx farther south in

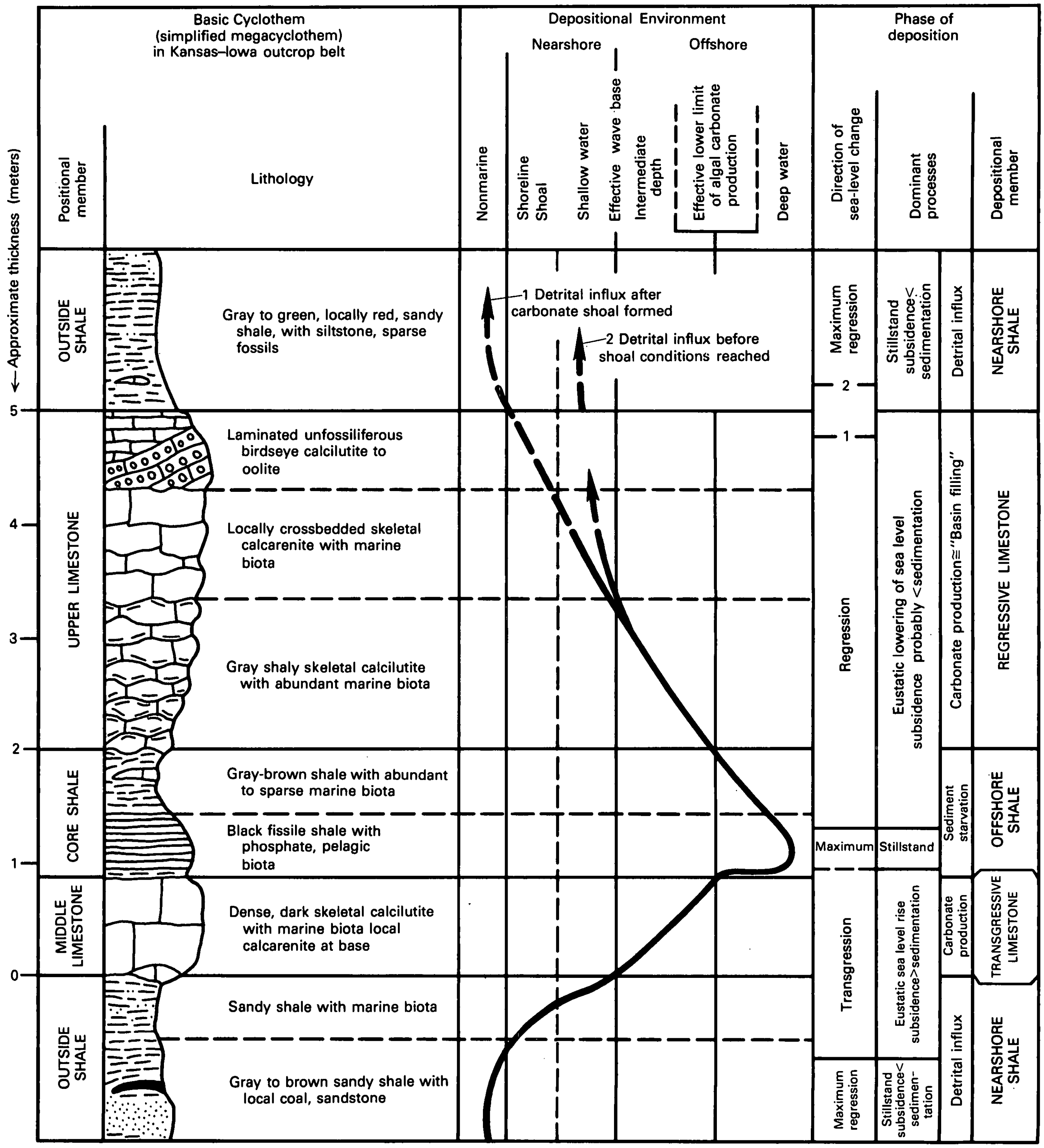

FIGURE 6.—Basic vertical sequence of an individual Kansas Pennsylvanian cyclothem, which is generally characteristic of Marmaton, Kansas City, Lansing, and Shawnee Groups, showing lithology and interpreted environments and phases of deposition. Terms on left for cyclothem members describe position in cyclothem; "middle" and "upper" for limestones derive from megacyclothem classification of Moore (1936, 1949); "outside" and "core" for shales derive from analysis by Heckel and Baesemann (1975). Terms on right for cyclothem members describe phase of deposition and are preferable when environments are reasonably well established (modified from Heckel, 1977, fig. 2).

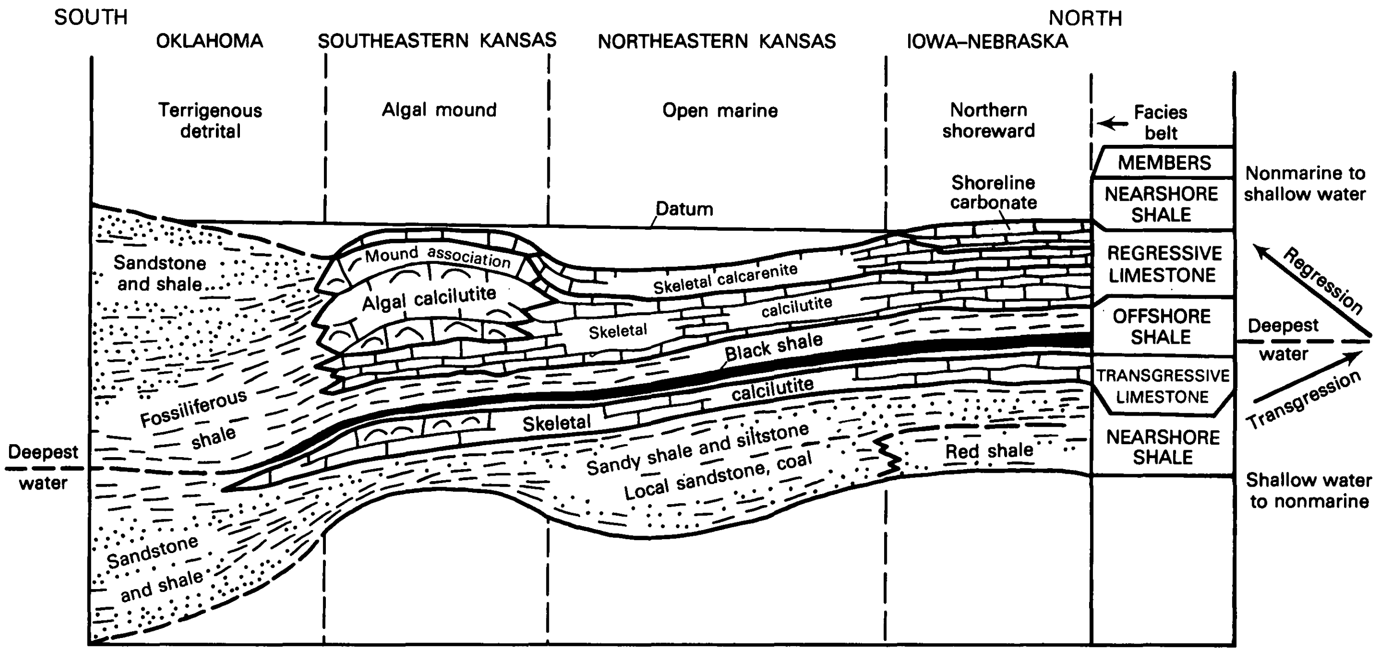

FIGURE 7.—Basic pattern of lateral facies relations in generalized Kansas cyclothem across facies belts exposed along Midcontinent outcrop. Datum is interpreted approximate sea level at time that increased detrital influx terminated deposition of regressive limestone member (modified from Heckel, 1977, fig. 4).

Oklahoma. Some of these shales become more abundantly and diversely fossiliferous, reflecting less detrital influx with its attendant unstable conditions, whereas some become red, which may indicate enough subaerial exposure for oxidation and dehydration of iron minerals.

Transgressive limestones.—Transgressive limestones are the thin (0.3–1.5 m) (1–5 ft) dense dark skeletal calcilutites denoted as the "middle" limestone of Moore's megacyclothem. They carry a diverse and relatively abundant marine biota comprising all the major phyla, although fossils do not seem abundant on outcrop because of the density of the rock. Fine grain size and diverse biota indicate deposition in the open marine environment far enough offshore to be below effective wave base, though above the effective base of the photic zone. If shoal-water facies such as oolite and stromatolite are present with the skeletal calcilutite, they are present only at its base. Aside from a few transgressive limestones that thicken as content of phylloid algae increases in southeastern Kansas, most limestones undergo little lateral facies change either northward or southward. Transgressive limestones generally record widespread marine inundation of the midcontinent and carbonate sediment production mainly at depths below effective wave base, where minor variations in topography on the underlying delta lobes would have caused little lateral variation in texture and composition of the limestone.

Offshore shales.—Offshore shales are thin (0.3–2.0 m) (1–7 ft), laterally persistent, only slightly sandy, gray, and of marine origin. They are included within limestone formations and were termed "core shales" by Heckel and Baesemann (1975) because of their central position within the megacyclothem. They typically contain a black fissile shale facies, which is rich in organic matter and generally contains nodules and laminae of nonskeletal phosphorite and relatively high concentrations of certain heavy metals. The black facies has no definitely benthic fossils, containing instead mainly conodonts in great abundance, fish remains, orbiculoid brachiopods, and other fossils reasonably inferred to have been pelagic or epipelagic. The gray facies typically includes only a sparse assemblage of several benthic invertebrate groups, including echinoderms, in addition to those found in the black facies; only away from the black facies do any of the offshore shales include abundant and diverse fossils. Like transgressive limestones, offshore shales also change laterally very little along the entire length of the outcrop. Those offshore shales in which the black facies disappears laterally have a sparsely fossiliferous, gray facies, which contains phosphate nodules locally.

Thinness in conjunction with great lateral persistence, fineness of detrital grain size, presence of marine fossils, great abundance of conodonts, and conspicuous nonskeletal phosphorite, all point to very slow sedimentation away from detrital influx, far offshore in deeper water. Preservation of abundant organic matter and an absence of benthic fossils in these shales indicate anoxic bottom conditions during their deposition. Lack of bottom oxygen in conjunction with very high concentrations of phosphate and heavy metals is explained by Heckel (1977) as the result of a two-layered quasi-estuarine circulation cell in the Midcontinent Sea, established when water became deep enough to form a thermocline above the bottom and to prevent vertical circulation and replenishment of bottom oxygen. Surface water, which was driven out of this sea by prevailing Pennsylvanian trade winds, was replaced by upwelling currents of phosphate-rich water from the deeper oxygen-minimum zone. This phosphate-rich water had been drawn in below the thermocline from intermediate depths of the open ocean. Nutrients brought into the photic zone by this upwelling promoted immense blooms of plankton, which settled back into the incoming lower water layer. There, massive organic decay further depleted the bottom water of remaining oxygen, continually enriched it in phosphate (as well as in heavy metals that are concentrated by organisms), and ultimately caused deposition of unoxidized organic matter and phosphorite on the sea bottom along with only very small amounts of other sediment to produce the phosphatic black mud facies.

Similar circulation, which concentrated phosphate, but which did not deplete all bottom oxygen, accounts for the sparsely fossiliferous gray facies containing phosphorite nodules. Deposition of terrigenous mud far from shore, probably below the effective limit of algal production of carbonate mud, but without establishment of the oxygen-depleting, quasi-estuarine circulation cell, accounts for the less common, more abundantly and diversely fossiliferous facies of some offshore shale.

Regressive limestones.—Regressive limestones constitute the "upper," sometimes with the "super," limestone members of Moore's megacyclothem. They are generally thicker (as much as 9 m (30 ft)) than transgressive limestones and contain a greater variety of facies.

The lower part of this limestone sequence consists largely of wavy-bedded skeletal calcilutite with many shale partings and containing an abundant and diverse marine biota consisting of elements of all major phyla. Lateral persistence of this facies, in conjunction with fine-grained lithology and diverse biota, indicates that this part of the regressive limestones, like most of the transgressive limestones, was deposited offshore below effective wave base but above the lower limit of algal carbonate production. In places, a type of skeletal calcarenite is present at the base of the regressive limestone. These calcarenites consist entirely of invertebrate grains that show no evidence of grain-abrasion, cross-bedding, or definite algal activity; thus, they probably formed in quiet water below effective wave base and probably below the limit of algal photosynthesis.

The upper parts of regressive limestone members have the most conspicuous lateral variation of facies along the midcontinent outcrop belt (fig. 7), as would be expected in deposits formed in shallow water where minor differences in bottom topography produce conspicuous lateral changes in facies. In northeastern Kansas, most regressive limestone grades upward to skeletal calcarenite that contains various proportions of abraded algal and invertebrate grains, osagia-coated grains, and grains with "micrite envelopes," which resulted from boring by algae; crossbedding is apparent in places. Although this vertical succession records increasing agitation of the water with time as water shallowed above effective wave base, this facies still records a relatively open marine environment. This part of the outcrop belt is thus defined as the "open marine facies belt," where good water circulation and normal marine salinity persisted longest during deposition of the regressive limestone. In places, the tops of some regressive limestones include deposits formed in very shallow water, deposits such as oolite and sparsely fossiliferous laminated calcilutite, which probably record deposition in local lagoons. Paleocaliche has been identified at the top of one regressive limestone.

Northward from Kansas, nearly all regressive limestone grades upward into unfossiliferous, laminated dolomitic calcilutite containing mudcracks and birdseye structures, which indicate shoreline and tidal-flat environments of deposition. This facies defines the "northern shoreward facies belt," which is thickest in Iowa and Nebraska.

In southeastern Kansas, most regressive limestones thicken as they grade upward into phylloid-algal mound facies, which defines the facies belt of that name. Mounds consist primarily of algae-dominated skeletal calcilutite, in which large blades of phylloid red and green algae characteristically shelter spar-filled voids. Mound-associated facies, particularly crossbedded, abraded-grain skeletal calcarenite and oolite, overlie and flank some of the mound facies, reflecting very shallow water over the buildups during later stages of regression.

Southward, in southernmost Kansas and northern Oklahoma, most regressive limestones grade into shale and sandstone, which define the "terrigenous detrital facies belt" and which represent a wide range of offshore to deltaic environments dominated by terrigenous clastic deposits from the Oklahoma detrital source.

Possible controls.—Typical Kansas cyclothems were initiated by influx of abundant terrigenous detrital sediment from encroaching deltaic shorelines, which formed the nearshore shale during a time of relatively shallow water in the Midcontinent Sea. This shallow-water condition could have resulted from either a eustatic fall in sea level or from basin-filling by rapid accumulation of carbonate sediment that formed the regressive limestone, and the subsequent influx of terrigenous detritus that produced the overlying nearshore shale.

Transgression, which resulted from either a eustatic rise in sea level or from an increase in subsidence of the basin, caused retreat of detritus farther away from the deepening basin in Kansas. This transgression allowed a thin layer of relatively pure carbonate to accumulate fairly uniformly over most parts of the inundated delta lobes, probably below effective wave base in deeper water. This process formed the calcilutitic transgressive limestone.

When water became deep enough to inhibit activity of benthic algae and to form a thermocline (perhaps as little as 100 m near the mouth of the sea; see Heckel, 1977), a quasi-estuarine water-circulation cell was set up. This circulation pattern drew phosphate-rich, oxygen-poor water in from intermediate depths of the open ocean, and, through upwelling and the concomitant nutrient-concentrating effect of decay of abundant trapped organic matter, oxygen in bottom water was depleted to various degrees to form both the gray and black phosphatic facies of the offshore shale.

Shallowing of the sea then destroyed the thermocline and broke up the quasi-estuarine cell to allow significant reoxygenation of the bottom and reestablishment of benthic invertebrate and algal carbonate production to initiate formation of the regressive limestone. Eustatic fall of sea level seems most reasonable as a cause of this shallowing because too little sediment to cause significant basin-filling is evident in the offshore shale facies, and tectonic reversal of bottom subsidence, particularly in a cyclic fashion, seems less likely. Continued shallowing of the sea allowed the formation of upper regressive limestone facies in shoal water, lagoons, and tidal flats. Fine terrigenous material from distal ends of progressively encroaching deltas accounts for the abundance of shaly partings in most regressive limestone. The thickness of sediment in the regressive limestone is sufficient to account for a slight relative lowering of sea level by partial filling of the basin with carbonate sediment; it seems insufficient, however, to account, in itself, for the small vertical distance (as little as 6 m, or 12 m, allowing for 50 percent compaction) between the top of the phosphatic black-shale facies and the supratidal facies at the top of the regressive limestone, in light of our present understanding that deposition of this type of phosphorite requires water of substantially greater depth.

Formation of the regressive carbonate facies ceased when the sediment-producing organisms were overwhelmed, in various stages of facies development (depending on topographic position, which was related generally to facies belt), by influx of terrigenous detritus from prograding delta lobes that initiated the succeeding nearshore shale. The cycle then repeated when another relative rise in sea level took place.

Although repeated eustatic rise and fall of sea level from some external control seems to be the simplest explanation for most aspects (and the best for some aspects) of the overall sequence of Kansas cyclothems, this explanation by no means negates the probability that other cyclic mechanisms played a role. In fact, the model of delta progradation, abandonment, and subsequent progradation elsewhere, which has been shown to be applicable to other cyclic sequences by several authors (see Ferm, 1970, for the Appalachian Pennsylvanian), not only explains the complex changes in thickness and facies development in nearshore shales, but this model also probably accounts for the occurrence in some areas of less common "lower" and "fifth" limestone members in Moore's megacyclothem as resulting from production of abundant carbonate sediment during a relatively long-term shift of active delta building away from the Kansas outcrop during the general phase of greatest regression.

Cherokee cyclothems.—The interplay of both depositional models needs only slight modification to account for the simpler cyclothems that Moore (1949, 1950) detected in the Cherokee Group (fig. 5). In the ascending repeated sequence of lithologies—sandstone, sandy shale, underclay, coal, black shale, gray shale, limestone, calcareous shale, sideritic shale—the sandstone through coal part is nonmarine, whereas the black shale through at least the lower calcareous shale part is marine. Those sequences in which phosphatic black shale is lacking may reflect merely local delta abandonment during regression without initiation of a new transgressive cycle. Sequences that contain phosphatic black shale, however, are examples of Kansas cyclothems that are more dominated by nearshore terrigenous sediment than are the limestone-rich cyclothems characteristic of the Marmaton-Missourian-Shawnee section.

Nonmarine delta-plain deposits are very conspicuous in the initial, "nearshore shale" part of Cherokee cyclothems. Transgressive limestone is rarely present above the coals, because few algae or calcareous invertebrates could colonize the generally inimical low-oxygen environment of the deepening sea bottom over partially decayed vegetation of the coal swamp. During transgression, the little detrital sediment that was carried from the increasingly distant shoreline to the drowned swamps in Kansas was incorporated with the shells of the few more tolerant organisms to form the base of the black shale overlying the coal. The remainder of the black shale was deposited during maximum transgression, in depths great enough for establishment of the quasi-estuarine circulation cell that led to formation of non-skeletal phosphate nodules.

Then shallowing of the sea brought about deposition of the gray shale as the bottom became reoxygenated. Further shallowing allowed limestone (equivalent to the regressive limestone of later cyclothems) to form, as algae and more invertebrates became established. The final units (calcareous shale and sideritic shale) are the initial prodeltaic and delta-front deposits of the succeeding nearshore shale, which prograded seaward rapidly enough to prevent the underlying regressive limestone (where present at all) from becoming very thick or developing shoal-water facies.

Wabaunsee cyclothems.—The cyclothems described by Moore (1936, 1949, 1950) in the Wabaunsee Group are basically alternations of nearshore sandy shale containing nonmarine sandstone and coal, with marine limestone and thin marine shale beds. The lowest limestone formation (Howard) (fig. 5) contains a black shale (and gray shale) between a thin dense limestone, below, and a thicker limestone, above, which is similar to the typical Kansas cyclothems in older groups (Moore, 1936, p. 206).

Unlike the relationship between cyclothems and lithic subdivisions in lower groups, Wabaunsee nearshore shales above the Howard comprise both the shale formations and the shale members of the more recently named limestone formations, whereas the limestone part of the cyclothem is composed of a single limestone member, whether or not it is grouped with another limestone member in a limestone formation (compare Moore, 1949, p. 180–181, with Zeller, 1968, pl. 1). Black phosphatic shale has not been reported from any Wabaunsee unit above the Howard, and the possible presence of nonblack offshore shale is not established at this time. Thus, which of the higher Wabaunsee cyclothems resulted from major transgressive-regressive events and which are merely the result of local delta abandonment during general regression is not known. One would suspect, however, that laterally persistent limestone that contains a persistent medial shale bed might represent the former, whereas limestone of limited extent might represent the latter.

BIOSTRATIGRAPHY

MISSISSIPPIAN

No comprehensive paleontologic study of the outcropping Mississippian limestones in southeastern Kansas has been accomplished. Girty (cited in Smith and Siebenthal, 1907) recognized rocks in the Missouri-Kansas border area that are equivalent in age to the Keokuk Formation (Upper Osagean) of the upper Mississippi River valley on the basis of fossil brachiopods, bryozoans, and corals. Thompson and Goebel (1968) have recovered conodonts at two localities from limestone in surface exposures of the Mississippian sequence in Cherokee County, which indicate that these rocks are equivalent in age to the Keokuk Formation. Nodine-Zeller and Thompson (1977) have discussed endothyrid foraminifers and conodonts in a core from a depth of 15–23 m (50–76 ft) near outcrops in Cherokee County, which suggest that the uppermost Mississippian in the core is Chesterian in age and that it overlies rocks of Meramecian age.

Girty (1940) recognized rocks in the subsurface of Kansas that are equivalent in age to those of all four stages of the Mississippian in the Mississippi River valley area; his studies were based on fossil invertebrates, mainly bryozoans and brachiopods, in cores from wells drilled in Kansas.

Thompson and Goebel (1963, 1968), and Goebel (1966) studied the conodont biostratigraphy of Mississippian rocks in well cores from western Kansas.

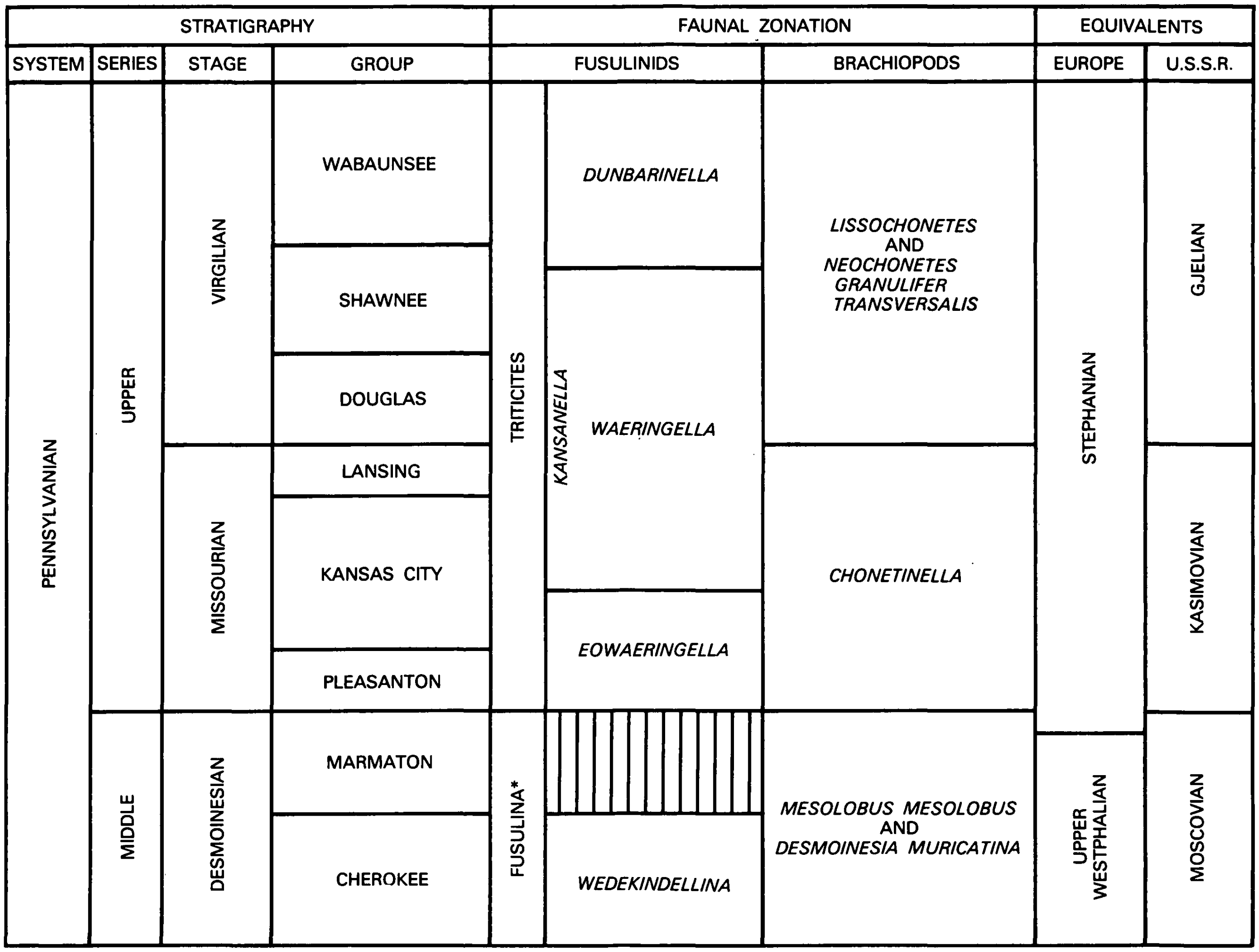

FIGURE 8.—Chronostratigraphic chart of outcropping Pennsylvanian rocks in Kansas.

On the basis of assemblages of conodonts that are only partly comparable with those of similar age in the type areas of the Mississippi River valley, they revised somewhat the earlier work of Lee and Girty (1940) and extended the knowledge of lithostratigraphy of these subsurface beds. Their results are complementary to unpublished work by Selk and Ciriacks (1968). Zeller (*in* Ebanks, Euwer, and Nodine-Zeller, 1977) has identified rocks of Meramecian age, on the basis of endothyrid foraminifers, from well cores in Hodgeman County, western Kansas. There is much room for future work in rectifying the lithostratigraphic correlations of petroleum geologists by using the scanty biostratigraphic determinations now available in western Kansas; also, some disagreement exists between the ages assigned to certain Mississippian beds on the basis of assemblages of conodonts and those assigned on the basis of calcareous microfossils (D. E. Nodine-Zeller, unpub. data, 1978).

PENNSYLVANIAN

Beds of Morrowan age have been recognized in the subsurface of southwestern Kansas by Thompson (1944) through identification of *Millerella* and forms that would now be assigned to *Eostaffella* in a well core. Dark limestone and shale above this Morrowan shale and sandstone sequence have received very little paleontologic study, but McManus (1959, p. 49) mentioned the presence of *Fusulinella* sp. in these rocks. If *Fusulinella* is the only fusulinid found in these rocks they could be considered as tentatively Atokan in age. However, the genus *Fusulinella* ranges from upper Atokan to upper Desmoinesian (Douglas, 1977, p. 476, fig. 5). Basal Pennsylvanian beds in the subsurface of northeastern Kansas have also been assigned to the Atokan, but there are no paleontologic data to confirm this.

The oldest Pennsylvanian rocks that crop out in Kansas are thin beds of dark shale of possible Atokan age, which occur only in isolated areas on the eroded surface of Mississippian limestone in southeastern Cherokee County (Stewart, 1975). Paleontologic data for this age assignment do not exist; in fact, these beds, where present, are not formally distinguished from the overlying Cherokee Group (Desmoinesian) because of similarity of lithology of the two and the lack of paleontologic or palynologic studies to define the extent of their contact. Stratigraphy and invertebrate paleontology of the Desmoinesian formations in southeastern Kansas are described in reports by Jewett (1945) for the Marmaton Group, and by Williams (1938) and Howe (1956) for the Cherokee Group.

Subdivisions of the outcropping Pennsylvanian strata in Kansas are based on the occurrence of widely recognized fusulinid genera and on evidence of physical breaks in the sedimentologic record (Moore, 1936, 1949; Moore and others, 1944) (fig. 8). The contact between Middle Pennsylvanian (Desmoinesian) and Upper Pennsylvanian (Missourian) rocks is placed at the base of the Hepler Sandstone Member of the Seminole Formation, basal unit of the Pleasanton Group, because this boundary has been thought to separate the zones of *Triticites*, above, and *Fusulina*, below; this contact may correspond to a regional disconformity (Moore and others, 1944). One species, *Fusulina fallsensis*, however, has been found only in the lower Missourian Bethany Falls Limestone Member of the Swope Limestone (fig. 5) (Thompson and others, 1956; Thompson, 1957) associated with *Eowaeringella ultimata* (fig. 8). This occurrence is below the first appearance of *Triticites*, in the Winterset Limestone Member of the Dennis Limestone (fig. 5), so the generic ranges of *Fusulina* and *Triticites* do not overlap here. This relationship raises a question regarding both the temporal magnitude of the physical break at the base of the Pleasanton and the placement of the Desmoinesian-Missourian boundary. Missourian and Virgilian beds are distinguished on the basis of paleontology (see fig. 8) and differences in the lithologic character of cyclic rock sequences (Jewett and others, 1968).

One of the most interesting areas of biostratigraphic work in Kansas has been in recognition of the Pennsylvanian-Permian boundary. History of the changing placement of this boundary was reviewed by Moore (1949). Mudge and Yochelson (1962) studied the paleontology of beds above and below this important datum, which presently is placed at the top of the Brownville Limestone Member of the Wood Siding Formation, and concluded that this assignment is arbitrary but that it is justified on the basis of practicality, long-time usage, and some paleontologic evidence.

The Pennsylvanian-Permian contact continues to be a subject of controversy, mainly because of differences in opinion between paleontologists and palynologists. Studies of palynomorphs have led some workers to suggest that all of the Gearyan stage (Lower Permian) in Kansas should be included in the Pennsylvanian, the systemic boundary being placed much higher in the section than at present (Clendening, 1971, 1975; Wilson and Rashid, 1971). Several papers referring to the paleontologic and palynologic aspects of this boundary in Kansas are included in a recent symposium (Barlow, 1975), which is important here, because the Pennsylvanian-Permian boundary in Kansas has long been the popular one in America. Unfortunately, many biostratigraphers persist in arguing about the relative merits of diverse fossil groups, which may be stratigraphically or ecologically incompatible and therefore do not justify arbitrary juggling of chronostratigraphic boundaries.

The status of biostratigraphically useful fossils (land plants, fusulinids, sponges, corals, bryozoans, brachiopods, bivalves, gastropods, cephalopods, trilobites, ostracodes, and crinoids) that are applicable to the Pennsylvanian in Kansas was given by Moore and others (1944, p. 668–678). Additional notations and references to the paleontology of the outcropping Pennsylvanian rocks in Kansas may be found in Moore and others (1951), Thompson (1957), and Jewett and others (1968). The taxonomic groups listed above are abundant and diverse in Pennsylvanian rocks of Kansas, but there have been few detailed biostratigraphic studies of occurrences of these fossils in Kansas since the 1944 summary by Moore.

Studies by Cridland and others (1963) on land plants, by Jeffords (1947) and Cocke (1970) on corals, and by Strimple (1951), Strimple and Moore (1971), and Moore and Jeffords (1967) on crinoids suggest that these groups could be of some biostratigraphic value, but much remains to be done. It would be especially valuable to have other summaries, such as that given by Moore and Strimple (1973, table 1) for Early Pennsylvanian crinoids. Cephalopods, a particularly useful biostratigraphic fossil for the Carboniferous, should be studied more thoroughly in Kansas, as only one of the eight genera of ammonites (*Prouddenites*), listed as indicative of Pennsylvanian faunal zones by Moore and others

(1944), was reported by Miller and others (1957) to occur in Kansas.

The importance of studies of palynomorphs in recognition of the Pennsylvanian-Permian boundary has already been mentioned, and they will be valuable in future biostratigraphic subdivisions of these systems. Numerous studies of conodonts in Pennsylvanian rocks of adjacent States have biostratigraphic application to the Kansas section (Lane, 1967; Henry, 1970; Lane and Straka, 1974). Within Kansas, conodonts have been used more commonly to interpret environments of deposition represented by the cyclic sequences of rocks in the Upper Pennsylvanian (Von Bitter, 1972; Baesemann, 1973; Heckel and Baesemann, 1975; Perlmutter, 1975; and Wood, 1977). From these studies, we should be able ultimately to develop a better understanding of the biostratigraphic significance of these enigmatic fossils.

Concerning fusulinids, Wilde (1975, p. 123) suggested that the basic pattern of stratigraphic zonation based on fusulinids has been established for decades but that refinement of zones continues. This is particularly true of the Virgilian of Kansas, where very little careful biostratigraphic work has been published.

Calcareous phylloid algae are important constituents of middle and upper Pennsylvanian limestone in Kansas (Johnson, 1946; Harbaugh, 1960; Wray, 1964). Although these fossils have not been particularly useful in studies of biostratigraphy, other fossil algae, such as *Komia,* may be useful for recognizing certain time-stratigraphic subdivisions of the Pennsylvanian (D. E. Nodine-Zeller, unpub. data, 1979).

Much research utilizing fossils of the Kansas Pennsylvanian in recent years has been to aid in the interpretation of facies and environments of deposition (Toomey, 1969; Heckel, 1975; Senich, 1975, 1978). Other studies have dealt with ecological aspects of fossil populations (Koepnick and Kaesler, 1971; Brondos and Kaesler, 1976; Songsirikul, 1977) and with "community" ecology (Scott, 1973; Pearce, 1973). Although these studies are needed and should be encouraged, the need is also great for monographic studies of different phyla, classes, orders, etc., and for studies of the complete preserved fossil assemblage by a team of specialists (that is, faunal studies). Examples of faunal studies are those by Williams (1938) on the Desmoinesian invertebrates of southeastern Kansas and by Mudge and Yochelson (1962) on Upper Pennsylvanian and Lower Permian rocks of Kansas. Investigations like those by Cooper and Grant (1972–1977) on the Permian brachiopods of west Texas and by Sutherland and Harlow (1973) on the Pennsylvanian brachiopods of New Mexico are examples of the type of monographic studies needed.

Future studies should use large collections to evaluate existing taxa (Koch, 1977) and to create new ones. This use will provide a firmer biological basis for taxa, and biology is needed in biostratigraphy as well as in the other areas of paleobiologic research. Three studies (two on brachiopods and one on sponges) illustrate the advantages of studying large collections. An ecological study of some "in situ" chonetellids from the Tacket Formation (Missourian), using hundreds of specimens from a single stratigraphic and geographic locality in southeastern Kansas, suggests that *Chonetinella flemingi* and *Chonetinella alata* are end members of a single species (R. R. West, unpub. data, 1978). The second study (Gundrum, 1977) showed that in a large collection (hundreds of specimens) from a single stratigraphic and geographic locality, specimens of *Mesolobus mesolobus* cannot be separated from those of *Eolissochonetes bilobatus.* Lastly, a careful examination of silicified specimens of some Missourian heliosponges suggests that certain established taxa possess many overlapping characteristics and that revision is needed (Gundrum, in press). If this is true for brachiopods and sponges, it is very probably true also for other biologic groups. The ease of collecting abundant fossils from most localities in the Kansas Pennsylvanian should facilitate studies of large collections.

Further advances in studies, in Kansas, of the biostratigraphy of Pennsylvanian rocks, which comprise interbedded marine, transitional, and nonmarine rocks, awaits integration of knowledge of different groups of fossils and better definition of species and higher taxa on the basis of sound biological concepts. In the future, the composite standard technique (Shaw, 1964) may well provide the most practical basis for biostratigraphic subdivision of the Kansas Pennsylvanian.

FOSSIL COLLECTING

Excellent fossil collecting is available from Pennsylvanian rocks in Kansas. Some references given here (for example, Williams, 1938; Mudge and Yochelson, 1962; Ball, 1964) have good descriptions of localities, most of which are still accessible. Merriam (1963) has provided road logs for outcrops in different parts of the State, especially along major highways. Guidebooks of the Kansas Geological Society that deal with outcrops in eastern Kansas, especially in the Kansas River valley and from Kansas City southward to Oklahoma, are very useful. Topographic and geologic maps and other information are available at the Kansas Geological Survey in Lawrence.

ECONOMIC PRODUCTS

COAL

Rocks of the Middle and Upper Pennsylvanian Series in Kansas include the economically important coal beds that were mined in the past and the economically important reserves of coal yet to be mined. At least 42 coal beds are present in the Pennsylvanian strata of Kansas, and 17 of these beds have economic coal reserves.

One coal bed, the Weir-Pittsburg coal, has accounted for approximately 180 million metric tons (200 million short tons) of total Kansas production. Production from this coal bed was in Cherokee and Crawford Counties, primarily by room-and-pillar mining (Abernathy, 1944; Young, 1925, p. 60–96). Besides the Weir-Pittsburg coal, other important Cherokee Group coals that have been extensively mined include the Mineral, Fleming, Croweburg, Bevier, and Mulky coals. These coals, described by Pierce and Courtier (1938) and Howe (1956), have accounted for an additional 64 million metric tons (70 million short tons) of production, mainly by surface mining. A petrographic study by Hambleton (1953) related the characteristics of these Cherokee coals to their potential for utilization.

Two other important commercial coals in Kansas are the Mulberry coal of the Marmaton Group (Schoewe, 1955) and the Nodaway coal of the Wabaunsee Group (Schoewe, 1946). Approximately 8 million metric tons (9 million short tons) of Mulberry coal was mined, mainly in Linn County, and nearly 11 million metric tons (12 million short tons) of Nodaway coal. Most of the Nodaway coal was mined in Osage County by old longwall methods (Young, 1925, p. 118–119), whereas the Mulberry coal was recovered chiefly by area strip mining.

Two characteristics of Kansas coal that control its economic development are the thinness of the coal beds and the high sulfur content of the coal. All coal reserves in Kansas are medium-to-high-sulfur coal (more than 1 percent sulfur) (Allen, 1925); 3 to 5 percent sulfur content is common in most commercial coals. Most of the coal beds are thin, that is, less than 71 cm (28 in.); in the future, most of the coal mined in Kansas probably will be recovered by surface-mining methods. Several areas of strippable coal and most of the Weir-Pittsburgh coal beds are of intermediate thickness, that is, 71–107 cm (28–42 in.).

The demonstrated reserve base of bituminous coal for strip mining totals 905 million metric tons (998 million short tons) under less than 30 m (100 ft) of overburden (Brady and others, 1976). For coal beds having an overburden-to-coal thickness ratio of 30:1 or less, the demonstrated reserve base is 477 million metric tons (526 million short tons). In addition, 1,647 million metric tons (1,816 million short tons) of inferred coal reserves is under 30 m (100 ft) of overburden; of this total, 720 million metric tons (794 million short tons) has a stripping ratio of 30:1 or less. General distribution of the areas in Kansas having coal reserves is shown in figure 9.

During the 1970's, coal-mining activity has been almost entirely in southeastern Kansas in Linn, Bourbon, Crawford, and Cherokee Counties, where coal of the Cherokee Group is surface mined. Total recorded coal production for Kansas is approximately 260 million metric tons (287 million short tons) through 1976 (fig. 10). Of this total, nearly 68 percent was won by subsurface mining methods; since 1963, however, all coal mining in Kansas has been by surface methods, mainly area strip mining.

PETROLEUM

Mississippian and Pennsylvanian rocks in the subsurface of Kansas have been extremely important as sources and reservoirs of oil and natural gas. The first well drilled for oil and gas west of the Mississippi River was completed in 1860, producing oil from Middle Pennsylvanian sandstone at about 100 m (300 ft) near Paola in Miami County (Jewett and Abernathy, 1945). Among the latest and best oil and gas discoveries in the State are those in Mississippian and Pennsylvanian limestone in western Kansas.

Middle Pennsylvanian sandstone of the Cherokee Group was the focal point of early exploration in southeastern Kansas (fig. 11). The famous "shoestring sands" (Rich, 1923; Bass, 1937) of that area were economically very important in the early flush production of oil and gas and the accompanying industrial development. As primary production declined, these same fields were the sites of early waterflooding activity, which resulted in many techniques presently in use elsewhere. In recent times, the third, or tertiary, phase of operations has begun in these same fields. Many of them still contain millions of barrels of oil, which is producible only by

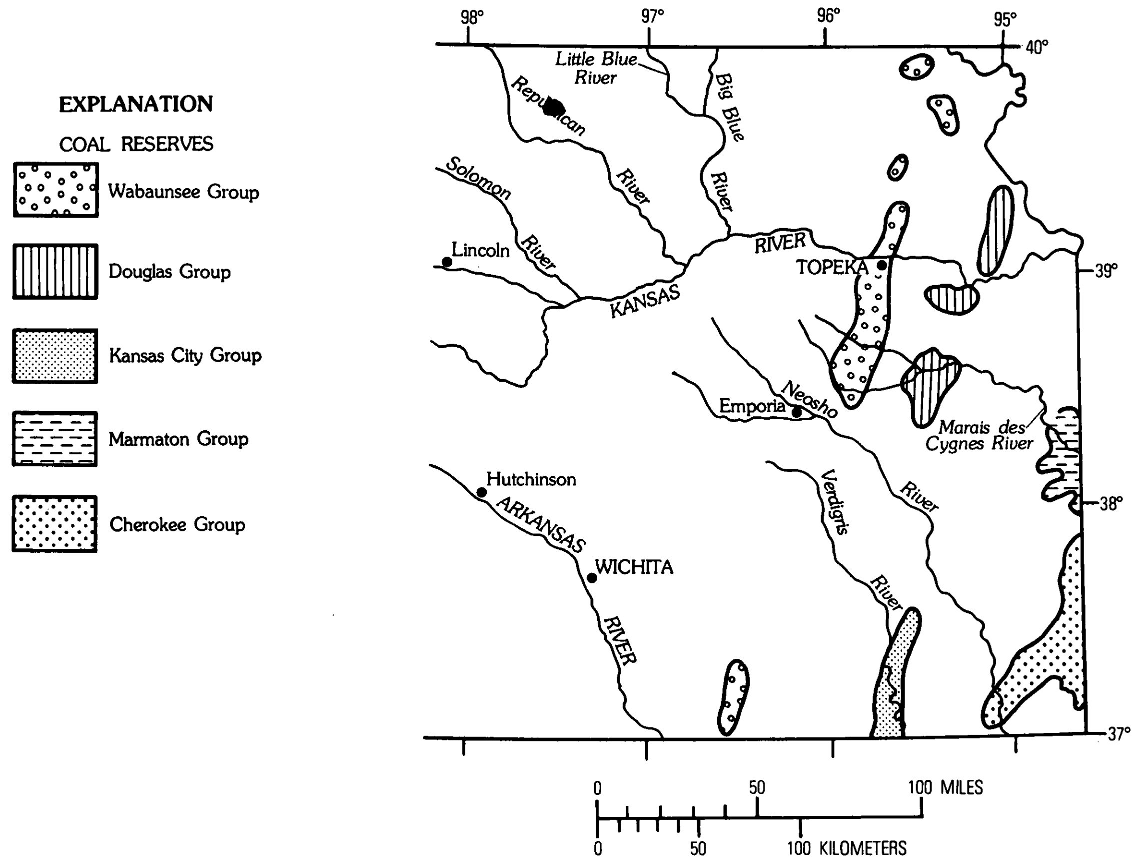

FIGURE 9.—Areas of strippable coal reserves beneath overburden of 30 m (100 ft) thickness or less. Formations in which coal reserves occur in the various areas are shown by patterns (Brady, and others, 1976).

methods such as thermal stimulation or the injection of surfactant chemicals. Cherokee sandstone also contains near-surface deposits of heavy oil and surface occurrences of tar sand in the Kansas-Missouri border area, which may be important as future energy resources (Ebanks and others, 1977).

Large amounts of oil and gas have also been produced from Upper Pennsylvanian rocks of central and western Kansas on or near major uplifts in the subsurface (fig. 11). These units of the Missourian and Virgilian Stages comprise limestone and sandstone reservoirs that usually have discontinuous porosity. The result is that many fields produce from combination structural-stratigraphic traps, at depths of 900–1,400 m (3,000–4,600 ft), both as fields having but one producing formation and as those in which the Pennsylvanian traps occur above deeper zones of production in Mississippian or Ordovician formations (Moore and Jewett, 1942; Merriam and Goebel, 1956). Almost one trillion cubic feet of gas has been produced from Upper Pennsylvanian lime-

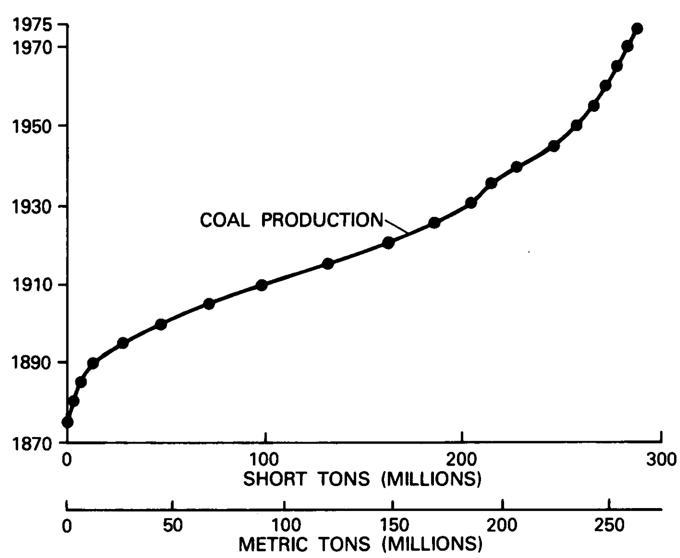

FIGURE 10.—Cumulative production of coal in Kansas. Almost all the coal produced has come from rocks of Pennsylvanian age.

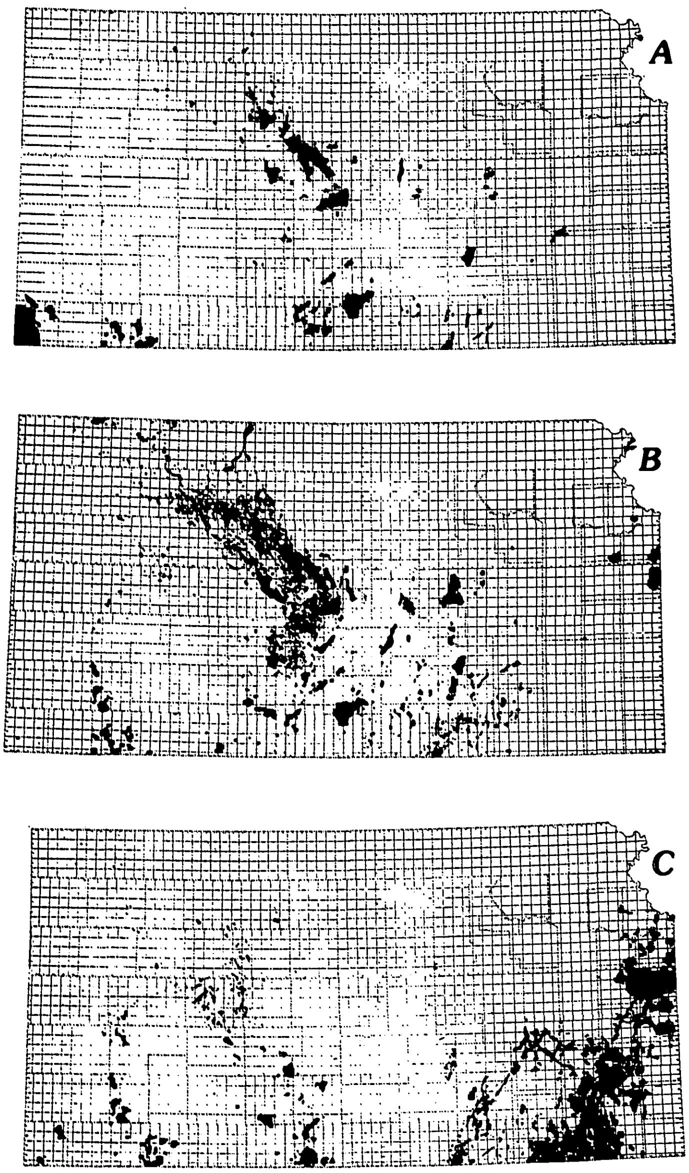

FIGURE 11.—Areas of production of oil from subsurface Upper and Middle Pennsylvanian rocks in Kansas: A. (upper) production from Wabaunsee, Shawnee, and Douglas Groups; B. (middle) production from Lansing and Kansas City Groups; C. (lower) production from Marmaton and Cherokee Groups (Ebanks, 1974, figs. 10, 11; Ebanks, 1975, fig. 12).

stone in one especially important field, the Greenwood Field, on the Colorado-Kansas border, partly underlying the famous Permian Hugoton gas field (Beene, 1977).

Lower Pennsylvanian sandstone and Mississippian carbonate oil and gas reservoirs are principally in southwestern and south-central counties (fig. 12), where they are important in local structural or stratigraphic traps in basinal areas at depths of 1,350–1,800 m (4,500–6,000 ft). The variability of

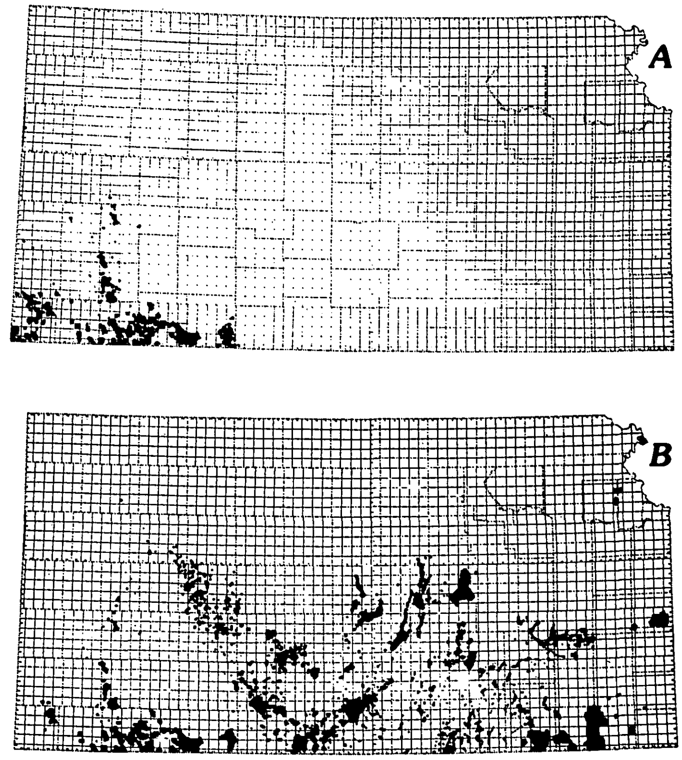

FIGURE 12.—Areas of production of oil from subsurface Lower Pennsylvanian and from Mississippian rocks in Kansas: A, (upper) production from "Atoka" and "Morrow" rocks; B, (lower) production from Mississippian (undifferentiated) rocks (Ebanks, 1974, fig. 13; Ebanks, 1975, fig. 8).

limestone and dolomite lithofacies in the Mississippian sequence and the complex diagenesis that has taken place in these rocks provide almost endless opportunities for imaginative exploration for oil and gas.

Oil and gas in Mississippian rocks tend to be in "trends" of favorably porous and permeable lithofacies within the overall interval of limestone and dolomite. In south-central Kansas, the most important types are those related to paleogeomorphic features and those in which fracturing of cherty rocks of the Osagian Stage has enhanced the permeability of the reservoir. Farther northwest, production is found in subunconformity traps in which lower Meramecian dolomite and dolomitic limestone are present beneath Middle Pennsylvanian shale. To the southwest, in slightly younger Meramecian beds, the oil and gas are trapped in oolitic and bioclastic limestone. Farther south, near the Oklahoma border, sandy limestone of Chesterian age forms oil and gas traps over local structurally high areas or in porosity-pinchout traps (Kansas Geological Society, 1956, 1959, 1965).

Cumulative oil production in Kansas at the end of 1976 was about 4.7 billion barrels, and cumulative gas production amounted to more than 23 trillion cubic feet. Of these total amounts, approximately 40 percent of the oil and 10 percent of the gas are estimated to have been produced from Pennsylvanian and Mississippian formations (Beene, 1977). The brightest prospects for future discoveries are also in these producing zones.

METALLIC ORES

Large amounts of zinc and lead were mined from the Mississippian rocks in southeastern Kansas. An early summary of the geology, mineralogy, and mining techniques used here was given by Haworth and others (1904). Ore bodies in Kansas, along with the zinc and lead deposits of southwestern Missouri and northeastern Oklahoma, make up the large Tri-State District (Brockie and others, 1968). This district was the major producer of zinc in the world for many years and has produced more than 2 billion dollars worth of lead and zinc. The most important field in this district was the Picher, in Oklahoma and Kansas (Lyden, 1950; McKnight and Fischer, 1970).

The Kansas part of the district has produced more than 2.6 million metric tons (29 million short tons) of zinc having an estimated value of 436 million dollars, and 590 thousand metric tons (650 thousand short tons) of lead worth nearly 91 million dollars (data from Martin, 1946, and U.S. Bureau of Mines Yearbooks, 1946–75). Cumulative production of these metals is shown in figure 13.

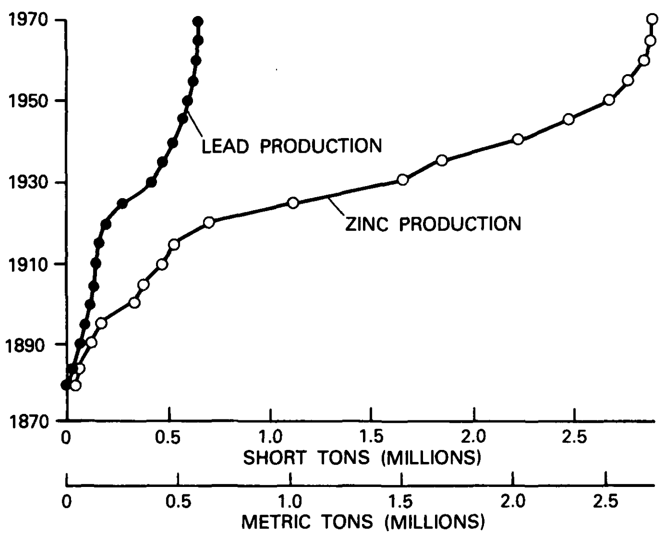

FIGURE 13.—Cumulative production of recoverable lead and zinc from mines in Kansas (data from Martin, 1946; U.S. Bureau of Mines minerals yearbook, 1946–70).

Ore bodies of the Tri-State District are restricted almost entirely to rocks of Mississippian age, specifically, to the Keokuk and Warsaw formations (fig. 4) (Moore, 1928; Brockie and others, 1968). Important studies of the relationship of the ores to the stratigraphy and structure include works by Fowler and Lyden (1932), Fowler (1938), and Moore and others (1939). Early geophysical investigations of the district were reported by Jakosky and others (1942), and later research into these indirect methods of exploration was reported by Hambleton and others (1959). In general, exploratory drilling has been necessary to the discovery of deeply buried ore bodies.

Within the Tri-State area, sphalerite and galena are the commercial ore minerals; however, many other minerals are associated with the ores, including chalcopyrite, wurtzite, and enargite (McKnight and Fischer, 1970, p. 101–124). Forms of the ore bodies have been described by Brockie and others (1968, p. 421–425) as assuming three basic shapes: (1) irregular, relatively narrow, long ore "runs" of varying heights; (2) circular "runs"; and (3) flat-lying, generally tabular bodies called "sheet ground" that cover large areas. The most important ore bodies in the district were the elongated "long runs."

Kansas production of lead and zinc ended in 1970. Low-grade ore and new antipollution standards contributed to the cessation of operations in the Tri-State District. Recently, renewal of interest in exploring for mineral deposits in the subsurface west of the areas previously mined has resulted in extensive drilling. Results of this drilling are not presently known.

LIMESTONE AND OTHER NONMETALLIC MINERALS

Limestone and shale of the Middle and Upper Pennsylvanian Series have been used extensively in Kansas. Limestone is used throughout eastern Kansas for different construction projects, especially as concrete aggregate and road metal, also as agricultural lime. In addition, limestone is used for cement manufacture at five different locations.

At least 20 different limestone units of Pennsylvanian age are presently used for crushed stone in Kansas. Total tonnage of crushed stone from Pennsylvanian rocks in 1976 is estimated at 12.1 million metric tons (13.4 million short tons), which has a value of approximately 29 million dollars. Important limestone units used for crushed stone are listed below:

Limestone Member	*Limestone Formation*
Ervine Creek	Deer Creek
Plattsmouth	Oread
Stoner	Stanton
Captain Creek	Stanton
Argentine	Wyandotte
Raytown	Iola
Bethany Falls	Swope
Laberdie	Pawnee

Three limestone members are presently mined by underground methods, the Bethany Falls, Argentine, and Plattsmouth. All present underground limestone mines are using, or plan to use, the mined space for commercial storage, and this use is considered in the pillar placement and design of their mine plan. Underground mined space is being used extensively for storage in the Kansas City and Atchison areas. Figure 14 shows locations of the large mines and quarries in Kansas.

Dimension stone was extensively quarried from Pennsylvanian rocks in Kansas in the past. Local limestone and sandstone were used to construct

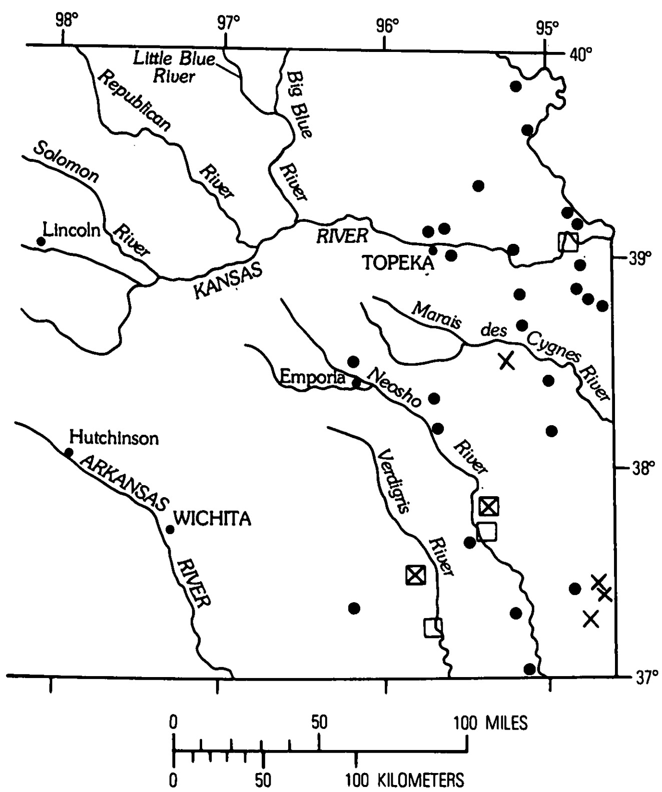

FIGURE 14.—Locations of large quarries and mines from which limestone is obtained, and locations of plants where cement and clay products are manufactured in Kansas. ● Limestone quarry or mine (100,000 metric tons, plus); □ cement plant; × clay products plant.

many of the buildings seen in the towns of eastern Kansas; the more important units of Middle and Late Pennsylvanian age are listed below (Risser, 1960; Grisafe, 1976):

Rock member	*Formation*	*Area of main use*
Utopia Limestone	Howard Limestone.	Eastern Kansas, sidewalks.
Hartford Limestone.	Topeka Limestone	Topeka area.
Big Springs Limestone.	Lecompton Limestone.	Lecompton area.
Kereford Limestone.	Oread Limestone	Atchison area.
Toronto Limestone	Oread Limestone	Atchison area.
Iatan Limestone	Stranger Formation.	Leavenworth area.
Raytown Limestone	Iola Limestone	Several localities.
Westerville Limestone.	Cherryvale Shale	Kansas City.
Bandera Quarry Sandstone.	Bandera Shale	Eastern Kansas many areas.

Of all the units quarried, the Bandera Quarry Sandstone was the most extensively worked; it was produced commercially in Crawford, Bourbon, Labette, and Neosho Counties. At present, Pennsylvanian rocks are used only as local rubble-stone; no commercial cut-stone quarries are now in existence. All the dimension stone presently produced in Kansas is from quarries in Lower Permian rocks.

Portland cement is manufactured at five different locations in Kansas, and all the plants use Pennsylvanian limestone. In addition, portland cement was formerly produced at 11 other locations, and natural cement was produced at one plant, all from Pennsylvanian limestone. The Raytown Limestone Member of the Iola Limestone is used for cement manufacture at two locations in Kansas. In addition, the Argentine Limestone Member of the Wyandotte Limestone, the Drum Limestone, and the Stanton Limestone are each utilized at other cement plants in Kansas. Figure 14 shows locations of cement plants in Kansas. Production from Pennsylvanian limestone and shale has accounted for an estimated cumulative total of 82.3 million metric tons (90.7 million short tons) of cement through 1976, having a total value of nearly 1,270 million dollars (Schoewe, 1958; U.S. Bureau of Mines Yearbooks 1957–1975; and Kansas Geological Survey estimates.)

Brick, sewer tile, pottery, and lightweight aggregate are all products made in Kansas from clay and shale of Pennsylvanian age. Extensive shale deposits are present in eastern Kansas, which led to widespread use of the shale for brick manufacture. Between 1868 and 1888, nearly every town in eastern

Kansas had a new plant starting the manufacture of brick (Douglas, 1910).

Six plants are now in operation in Kansas that utilize Pennsylvanian shale and clay for the manufacture of different clay products (fig. 14). As mentioned above, shale is also used in the manufacture of cement at the five portland cement plants. The geologic units used for the different clay products include the Krebs Formation and Cabaniss Formation of the Cherokee Group, the Lane Shale and the Bonner Springs Shale of the Kansas City Group, and the Weston Shale Member of the Stranger Formation in the Douglas Group.

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

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ON THE COVER

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

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

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N. Missouri, by Thomas L. Thompson
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GEOLOGICAL SURVEY PROFESSIONAL PAPER 1110-M-DD

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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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