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

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

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

By MATTHEW J. AVCIN[1] and DONALD L. KOCH[1]

ABSTRACT

Carboniferous rocks crop out in abundance from southeastern to north-central Iowa. Exposures are less numerous in south-central Iowa and are extremely limited in the west-central and southwestern parts of the State. Early studies were concentrated on Pennsylvanian strata because of the economic importance of their coal deposits. The regional stratigraphy of Pennsylvanian strata had been well summarized in publications of the late 19th and early 20th centuries.

Current interest in energy sources has led to a new interest in evaluation of the State's coal resources. A concerted effort is underway to define the stratigraphy of the Pennsylvanian in greater detail and to interpret the environments of deposition as they relate to the formation and occurrence of coal beds, particularly with respect to variations in thickness and quality of the coal deposits.

Generally, Mississippian strata have received less attention than those of the Pennsylvanian. Recent studies have resulted in recorrelation of the lower part of Mississippian beds with Devonian formations. Diagenetic effects on carbonate beds of north-central Iowa have resulted in repetitive sequences of limestones and dolostones that have led to confusion and miscorrelation of several member units.

Economic products from rocks of the Mississippian and Pennsylvanian Systems are limited to coal, road-constuction materials, brick and tile, soil-conditioner materials, and gypsum. Although nearly 50 oil-gas test wells have been drilled in Carboniferous strata, mostly within the deeper part of the Forest City basin, no economic deposits have been discovered to date.

INTRODUCTION

Carboniferous rocks underlie approximately 60 percent of Iowa's 143,209 km^2 (55,941 mi^2) and are the bedrock over most of this area (fig. 1). The combined maximum thickness recorded for the units assigned to the Mississippian (fig. 2) and Pennsylvanian (fig. 3) is 585 m (1,909 ft).

Because of resistant units, Mississippian rocks are well exposed along many of the streams that flow across the outcrop belt. These natural exposures are supplemented by many quarries in the Mississippian limestones. Regional dip is into the Western Interior (Forest City) basin from the outcrop belt that trends northwest from the southeast corner of Iowa. The outcrop belt arcs around to the west in the north-central part of the State where Cretaceous units overlap Mississippian strata.

Successively younger Pennsylvanian rocks are exposed downdip toward the deeper parts of the basin and are generally more poorly exposed than are Mississippian rocks. The Des Moines series is best exposed along the Des Moines River and in the many small surface mines that roughly parallel its course. Younger Pennsylvanian rocks are exposed in cutbanks along the smaller streams and in scattered quarries in the limestones. Because thick Pleistocene deposits mantle the erosion surface on top of the Carboniferous, exposures are very limited in upland areas away from the major drainageways.

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 Iowa Geological Survey.

LITHOSTRATIGRAPHY

MISSISSIPPIAN

Mississippian formations constitute the bedrock in a diagonal belt 32 to 64 km (20–40 mi) wide from Lee County in the southeast corner of the State northwestward to southeastern Kossuth County in north-central Iowa (fig. 1).

The standard sections of Mississippian rock units are found along the valley of the Mississippi River from southeastern Iowa into southern Illinois and southeastern Missouri. All formational units of the Kinderhook, Osage, and Meramec Series are represented in Iowa (figs. 2, 4). Because units of the Kinderhook vary lithologically from area to area, and because several of the lower units that originally

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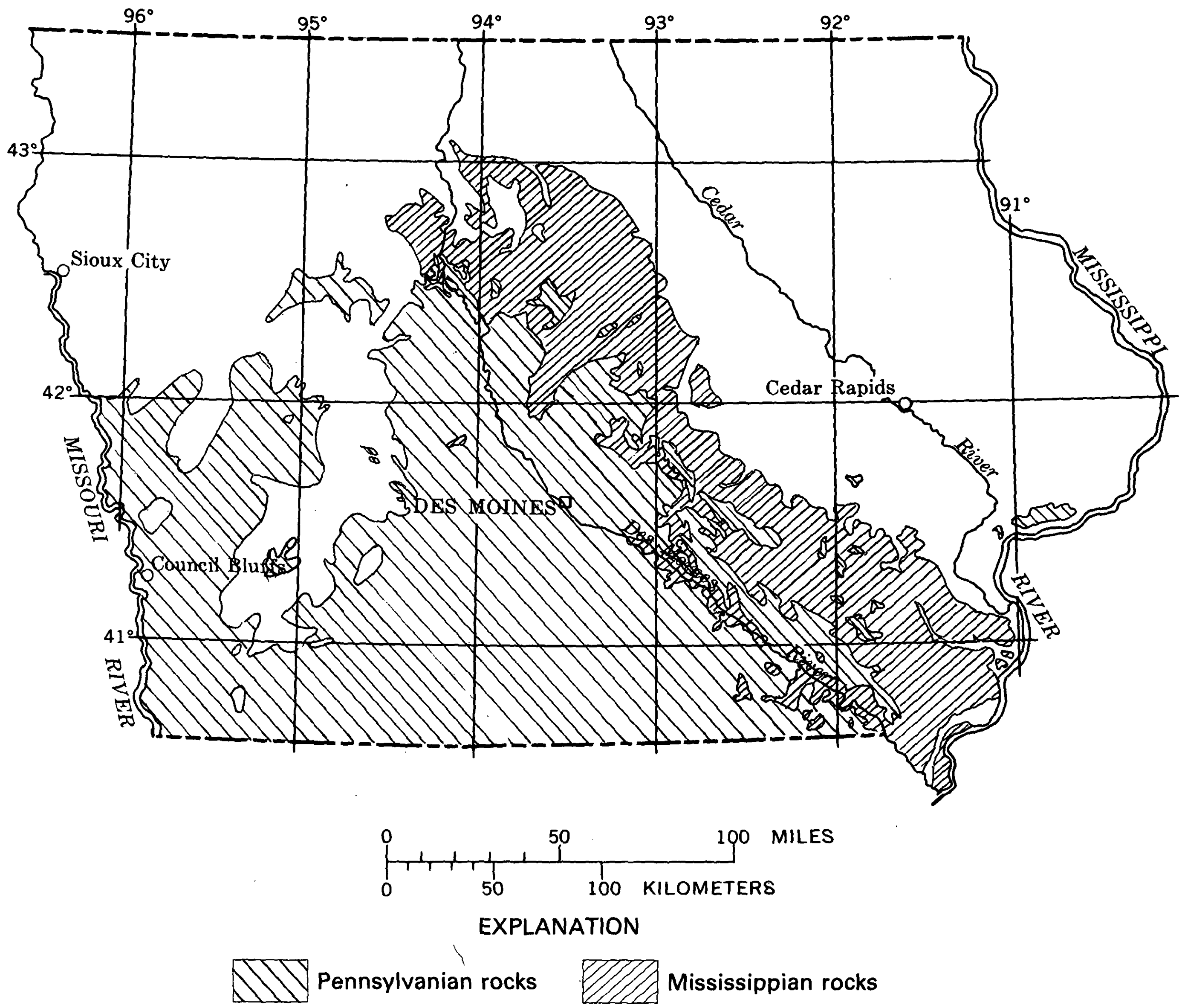

FIGURE 1.—Generalized outcrop pattern of Carboniferous rocks in Iowa.

were correlated as Mississippian are now placed in the Devonian, no standard section has been established for the Kinderhook. The type sections of the Burlington and Keokuk Formations are near those cities in southeastern Iowa. Exposures at Warsaw, Ill., nearly opposite Keokuk, Iowa, provide the type section for the Warsaw Formation. The Spergen, St. Louis, and Ste. Genevieve Formations are represented in Iowa by facies of formations farther south in the Mississippi Valley that are thicker and more uniform in lithology.

None of the Chester formations are represented in Iowa; the Chester seas probably never extended this far north.

The Mississippian-Devonian boundary is placed at the base of the North Hill Group by the Iowa Geological Survey. A discussion of this boundary in Iowa was presented by Dorheim, Koch, and Parker (1969).

Along the eastern and northeastern edge of the outcrop belt, Kinderhook strata are above formations of the Yellow Spring Group (uppermost Devonian). Along the northern boundary in Hancock and Kossuth Counties, Kinderhook strata are above the Lime Creek Formation (lower Upper Devonian). In western Iowa and eastern Nebraska, Kinderhook strata are above Middle Devonian rocks.

Series	Group	CENTRAL	SOUTHEAST
Meramec		Ste. Genevieve	Ste. Genevieve
		St. Louis	St. Louis Spergen
Osage		Warsaw	Warsaw
		Keokuk	Keokuk
		Burlington	Burlington Formation Cedar Fork Member Haight Creek Member Dolbee Creek Member
Kinderhook		Gilmore City Hampton Formation Iowa Falls Member Eagle City Member Maynes Creek Member	Hampton Formation Wassonville Member
	North Hill Group	Chapin Prospect Hill McCraney	Starrs Cave Prospect Hill McCraney

FIGURE 2.—Nomenclature of Mississippian units in Iowa.

For the most part, the boundary is a transgressive nonconformable contact.

The Mississippian System is unconformably overlain by Lower Pennsylvanian (Cherokee Group) sedimentary rocks throughout most of southeastern Iowa. Jurassic(?) (Fort Dodge Beds) and Lower Cretaceous units were deposited upon the eroded Mississippian surface in north-central Iowa. Pleistocene deposits mantle the Mississippian rocks along the outcrop belt. The following discussion of the Mississippian units of Iowa is based largely upon publications by Parker (1973) and Koch (1973).

KINDERHOOK SERIES

The Kinderhook Series in southeastern Iowa includes the North Hill Group and the superjacent Hampton Formation. A third unit, the Gilmore City Formation, is present above the Hampton in north-central Iowa. The Kinderhook is composed dominantly of carbonate rocks. Siltstone occurs in the North Hill Group and chert in the Hampton.

The North Hill Group (Workman and Gillette, 1956) includes in ascending order: McCraney Limestone, Prospect Hill Siltstone, and Starrs Cave Formation. An interval of dominantly oolitic limestone, the Chapin Formation of north-central Iowa, is equivalent to the Starrs Cave Formation of southeastern Iowa. The McCraney Limestone is a very pale orange to pale-yellowish-brown sublithographic limestone. In southeastern Iowa, it is characterized by the presence of brown medium-grained dolomite in irregular horizontally and vertically oriented planes. The basal part in southeastern Iowa consists of an oolitic crinoidal limestone, which locally contains a coarse brachiopod coquina composed almost entirely of *Chonetes*. The McCraney is present in north-central Iowa only along the eastern outcrop belt. The Prospect Hill Siltstone is a light-greenish-gray medium siltstone containing discontinuous green shaley seams in southeastern Iowa. In north-central Iowa, the formation varies from a dolomitic siltstone along the outcrop belt to a silty dolostone toward the west. The Prospect Hill contains fish teeth, brachiopods, and pelecypods. The Starrs Cave Formation is a very pale orange to pale-gray oolitic limestone, which contains fragmented crinoids, brachiopods, and corals. In north-central Iowa, the equivalent Chapin Formation is dominantly an oolitic limestone near the outcrop belt. Farther west, this interval is a dolostone, and it usually is inseparable from the superjacent Maynes Creek Member of the Hampton Formation.

The Wassonville Limestone Member is the only representative of the Hampton Formation (Laudon, 1931) in southeastern Iowa. The Wassonville consists of pale- to dark-yellowish-brown dolostone. Over most of the area of its occurrence, the Wassonville contains appreciable amounts of light-gray fossiliferous chert. In the extreme southeastern counties, the Wassonville is relatively chert free and is dominantly a dolomitic limestone.

In north-central Iowa, the Hampton Formation includes, in ascending order: Maynes Creek (equivalent to the Wassonville of southeast Iowa), Eagle City, and Iowa Falls Members. Contacts of these members are placed at a change in lithology from dolostone (Maynes Creek Member) to limestone (Eagle City Member) and from limestone to dolostone (Iowa Falls Member). The Maynes Creek is composed of dolostone and chert. Chert generally is present throughout the member near the outcrop belt. Farther west, chert generally is absent in the upper part of the member. At most localities, the upper contact is placed where chert is first observed. This result in apparent variations in thickness that often are extreme. In addition, the upper part is limestone at many localities and is then inseparable from the superjacent Eagle City Member. Where the upper contact is placed at the top of a brown dolostone, the unit is about 40 m (131 ft) thick and thins to about 17 m (56 ft) near the outcrop belt.

The Eagle City-Iowa Falls interval and the overlying Gilmore City Formation constitute the most variable carbonate sequence of the Kinderhook in north-central Iowa. The limestone interval above the Maynes Creek dolostone and beneath the Iowa

SYSTEM	SERIES	GROUP	FORMATION
Pennsylvanian	Virgil	Wabaunsee	French Creek
			Jim Creek
			Friedrich
			Grandharen
			Dry
			Dover
			Langdon
			Maple Hill
			Wamego
			Tarkio
			Willard
			Elmont
			Harveyville
			Reading
			Auburn
			Wakarusa
			Soldier Creek
			Burlingame
			Silver Lake
			Rulo
			Cedar Vale
			Happy Hollow
			White Cloud
			Howard
			Severy
		Shawnee	Topeka
			Calhoun
			Deer Creek
			Tecumseh
			Lecompton
			Kanwaka
			Oread
		Douglas	Lawrence
			Stranger
			Iatan
			Weston
	Missouri	Lansing	Stanton
			Vilas
			Plattsburg
		Kansas City	Bonner Springs
			Wyandotte
			Lane
			Iola
			Chanute
			Drum
			Quivira
			Westerville
			Cherryvale
			Dennis
			Galesburg
			Swope
			Ladore
			Hertha
		Pleasanton	undifferentiated
	Des Moines	Marmaton	Lenapah
			Nowata
			Altamont
			Bandera
			Pawnee
			Labette
			Fort Scott
		Cherokee	undifferentiated

FIGURE 3.—Nomenclature of Pennsylvanian units in Iowa.

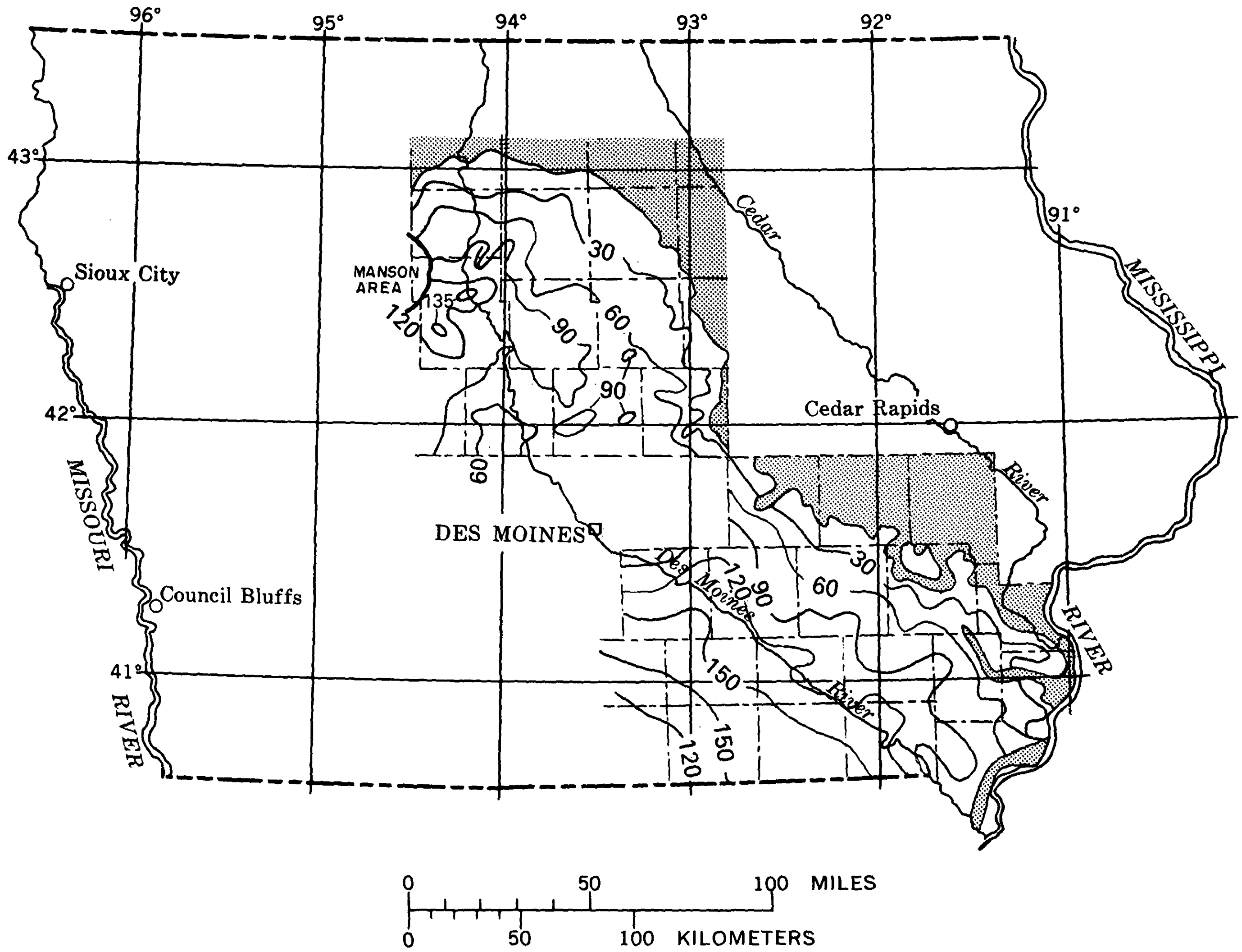

FIGURE 4.—Thickness, in meters, of Mississippian units within and peripheral to the outcrop belt.

Falls dolostone is designated as Eagle City. Along the outcrop belt, the Eagle City generally is an oolitic limestone in the upper part and a micrite in the lower part. It grades westward to micrite and dolomitic micrite containing beds of dolostone. In the subsurface section, the thickness of the Eagle City ranges from about 3.3 m (11 ft) to 17 m (56 ft). This variation in thickness is the result of differences in the vertical extent of dolomitization from one location to another.

The Iowa Falls is a dolostone interval above the Eagle City and beneath the Gilmore City Limestone; apparently, it is a dolomitized lateral equivalent of the Gilmore City as suggested by Thomas (1960). Thicknesses of as little as 3.3 m (11 ft) and as much as 20 m (66 ft) have been interpreted in the subsurface section. Again, the variations in thickness are related principally to differences in the vertical extent of dolomitization. At some locations, no interval of dolostone is present that is correlative with the Iowa Falls.

A composite thickness of 68 m (223 ft) was indicated for the Maynes Creek-Eagle City-Iowa Falls interval by Laudon (1931). As no exposure of the entire sequence was available, composite thicknesses for each unit were obtained by correlating fossil zones and lithologic types from one partial exposure to another presumed to be higher or lower in the section. Multiple facies changes from limestone to dolostone both laterally and vertically generally were unrecognized. Indeed, the contacts as they are identified today usually are gradational contacts from limestone to dolostone or from dolostone to limestone. Drill cuttings show an average of only 37 m (121 ft) for the entire thickness of the Maynes Creek-Eagle City-Iowa Falls interval near the outcrop belt. Toward the west, the average thickness increases to 58 m (190 ft).

The Gilmore City Limestone is conformable above the Hampton formation, and, like the Eagle City, it is composed dominantly of oolitic limestone near the outcrop belt, but toward the west it contains alternating beds of oolitic limestone and biofragmental (crinoidal) limestone. The lower contact generally is gradational with the Iowa Falls. However, where the Iowa Falls dolostone is "absent" it is extremely difficult to identify a lower boundary, and the boundary selected usually is arbitrary. The upper contact is unconformable at different locations with younger Mississippian units or with Pennsylvanian, Cretaceous, or Pleistocene units. Consequently, the thickness of the Gilmore City is extremely variable. Where Osage units are superjacent, the thickness of the Gilmore City is about 45 m (148 ft).

The above discussion of the Hampton and Gilmore City Formations of north-central Iowa clearly shows that the veracity of current nomenclature is questionable. In summary, the following conditions result in a complexity of geologic factors that obfuscate analysis of the stratigraphy of this part of the Mississippian section:

1. Various units have been partly or completely dolomitized, and there is no uniformity, either horizontal or vertical, in the extent of dolomitization.
2. Alternating units of limestone and dolostone are the principal basis upon which formations and members have been identified. Many subsurface sections show an unusually thick formation or a "missing" member where dolomitization has been more extensive.
3. Facies changes from oolitic limestone to biofragmental limestone and micrite within members and formations further complicate correlations.
4. Most of the natural exposures are limited to the eastern outcrop belt. At no exposure is a complete sequence observed.
5. Where complete sequences are present, they are covered by Pennsylvanian, Cretaceous, or Pleistocene strata. Thus, subsurface data must be relied upon for stratigraphic control.

Hughes (1977) recognized that the greatest thickenings of units of the Hampton Formation and of the Gilmore City Formation are mutually exclusive, which further demonstrates that formations and members are diagenetic and (or) depositional facies of each other. The recognized stratigraphic discrepancies can be resolved only through applied petrographic studies such as those of Hughes (1977) and Lloyd (1973).

OSAGE SERIES

The Osage Series in Iowa includes the Burlington Limestone (Hall, 1857), Keokuk Limestone (Owen, 1852), and Warsaw Formation (Hall, 1857). The Osage is composed dominantly of cherty limestone and dolostone containing minor beds of shale. The detailed stratigraphy of and conformable relationships between the Burlington and Keokuk and the Keokuk and Warsaw in southeastern Iowa were described by Harris and Parker (1964).

The members of the Burlington Limestone are, in ascending order: Dolbee Creek, Haight Creek, and Cedar Fork. In general, the Dolbee Creek Member (Laudon's *Cactocrinus* zone in the type area, but including his underlying zones where the member is thick) is a coarsely crystalline crinoidal limestone with a small amount of chert. *Spirifer grimesi* and fragments of bryozoans are common. This unit is thickest (5.7 m; 19 ft) in extreme southeastern Iowa and is absent in central and north-central Iowa. The Haight Creek Member (Laudon's *Physetocrinus* zone) is highly cherty and contains both dolostone and limestone beds. The base of this unit is marked by a dolostone that contains greenish-black glauconite grains or pellets. In southeastern Iowa, the Haight Creek has a rather uniform thickness of about 15 m (49 ft). Towards the north and west, this member is superjacent to Kinderhook beds, and where glauconite is absent, it is difficult to discriminate between the biofragmental limestone of the lower Burlington and the similar lithology of the subjacent Gilmore City. The Cedar Fork (Laudon's *Dizygocrinus* and *Pentremites* zones) is a coarsely crystalline crinoidal limestone similar to the Dolbee Creek. However, the *Dizygocrinus* zone commonly contains abundant soft flakes of glauconite, which gives the limestone a green color, and the *Pentremites* zone is cherty. In southeast Iowa, the Cedar Fork ranges from 3.3 to 10 m (11 to 33 ft) in thickness. In north-central Iowa, where dolomite content increases and both the carbonate and chert become darker, the member generally is not differentiated.

The Keokuk Limestone in southeastern Iowa consists of cherty crinoidal carbonate beds in the lower part ("Montrose Cherts" of Keyes, 1894) and fossiliferous cherty carbonate beds and interbedded fossiliferous shale in the upper part. The "Montrose

Cherts" are easily distinguished from the relatively noncherty Cedar Fork Member of the Burlington Limestone. Also, chert in the Keokuk usually contains abundant spicular fossil fragments that serve to distinguish the Keokuk from the dominantly crinoidal chert of the Burlington. Shale beds in the Keokuk increase in number and thickness upward, grading into the gray Warsaw shale, and dolostone beds replace the limestone. In subsurface usage, the upper boundary of the Keokuk generally is placed at the top of the uppermost carbonate bed. In extreme southeastern counties, the Keokuk averages about 25 m (82 ft) in thickness. In north-central Iowa, the Keokuk usually is undifferentiated from the Warsaw.

The Warsaw Formation is characterized by shale and argillaceous dolostone. Geodes that principally contain quartz are common in the southeastern outcrop belt. Chalcedonic chert and crystalline quartz, dominantly of geode origin, are particularly abundant in the subsurface toward the west-northwest where argillaceous dolostone is dominant over shale. The average thickness for the Warsaw is 17 m (56 ft) in southeastern Iowa. In north-central Iowa, the maximum thickness of the Keokuk-Warsaw interval is approximately 25 m (82 ft). The Warsaw is unconformably overlain by the Spergen and St. Louis Formations.

MERAMEC SERIES

The Meramec Series contains the youngest Mississippian rocks in Iowa, in ascending order: Spergen (Salem) Limestone (Ulrich, 1905), St. Louis Limestone (Engelmann, 1847), and Ste. Genevieve Limestone (Shumard, 1860). The rocks of the Meramec units are more varied than those of the Kinderhook and Osage. In southeastern Iowa, the Meramec overlies older Mississippian strata unconformably and overlaps formations as old as the North Hill Group (Kinderhook). The upper boundary constitutes a post-Mississippian erosional surface that is unconformably overlain by the Pennsylvanian Cherokee Group and by Pleistocene deposits in southeastern Iowa. Post-Mississippian—pre-Pennsylvanian erosion removed Meramec strata over much of north-central Iowa, and pre-Cretaceous and Pleistocene erosion further reduced the area of occurrence of these units. Only the St. Louis Limestone and the Ste. Genevieve Limestone are recognized in north-central Iowa.

The Spergen (Salem) Limestone is a brownish-gray micaceous dolomitic limestone that has a minor quartz sand fraction. It is restricted to southern Iowa by the pre-St. Louis unconformity. The Spergen often has been confused with the basal St. Louis. The average thickness is 6.6 m (22 ft).

The St. Louis Limestone in southeastern Iowa is dominantly a micritic limestone; it has a lower zone of brown arenaceous dolostone that in the subsurface contains a high percentage of anhydrite and gypsum. The high degree of brecciation of the carbonate rocks in the outcrop section probably is the result of dissolution of the evaporites and subsequent collapse. The average thickness is 17 m (56 ft), although thicknesses of 41.6 m (136 ft) are recorded within the evaporite areas. In north-central Iowa, sandstone generally is dominant in the lower part of the formation; the maximum recorded thickness is 18 m (59 ft).

The Ste. Genevieve in southern Iowa is composed of fine-grained limestone that has a high percentage of quartz sand. In central Iowa, the unit is represented mainly by green and red shale and thin beds of fine-grained limestone. The contact relationships with the subjacent St. Louis are unclear, and both the thickness and distribution of the unit vary greatly because of post-Mississippian erosion.

DEPOSITIONAL ENVIRONMENTS OF MISSISSIPPIAN ROCKS

The beginning of Mississippian time was a period of general emergence; no evidence of localized uplift has been found. The region was a broad plain, modified somewhat by differential erosion. Shallow restricted seas are evidenced by the distribution of the formations of the North Hill Group. Depositional regimes for the Hampton and Gilmore City include offshore marine, unrestricted shoal, restricted shoal, restricted nearshore, and tidal environments. The nearly pure biofragmental carbonate rocks of the Osage were deposited in a shallow shelf environment. The shales of the Warsaw are the termination of a clastic wedge from the east. Carbonate deposition continued into the lower Meramec. However, an evaporite facies is present in the lower St. Louis. The normal marine carbonate rocks of the upper St. Louis and the Ste. Genevieve contain an increase in sand and shale northward, culminating in a shale facies of the Ste. Genevieve in north-central Iowa. No evidence of Chester deposition has been recognized in Iowa. At the end of Mississippian time, this region was a landmass of low relief undergoing erosion and karst formation. The Mississippian surface was further modified by uplift, which continued into Pennsylvanian time.

NATURE OF MISSISSIPPIAN-PENNSYLVANIAN CONTACT

The Cherokee Group unconformably overlies units of the Meramec and Osage Series throughout most of its areal extent. However, Pennsylvanian outliers overlie progressively older Mississippian, Devonian, and Silurian units to the northeast. In some outcrops and cores, a regolith is present on top of the Mississippian. A typical exposure of this interval consists of 1.5–2.4 m (5–8 ft) of St. Louis in a quarry north of Keosauqua (SE¼ sec. 36, T. 70 N., R. 10 W., Van Buren County). The heavily iron stained irregular upper surface of the St. Louis has as much as 0.6 m (2 ft) of relief. This surface is overlain by a green clay as much as 2.4 m (8 ft) thick which contains corroded limestone "clasts" in the lower part. The limestone "clasts" decrease in size and disappear about midway up, and the clay becomes noncalcareous slightly farther up. Next is an interval of approximately 6 m (20 ft) of dark-gray silty shale of Pennsylvanian age, which in turn is overlain by about 45 cm (18 in.) of highly pyritic coal. The contact between the dark-gray shale and the green clay is sharp and occasionally shows erosional reworking of the green clay into the superjacent dark-gray shale. Where this regolith attains a thickness of 4.5–7.5 m (15–25 ft) in the subsurface, the central part of the clay is usually dark red.

Although the contact relationships definitely indicate that the surface of the Mississippian was eroded, its present configuration, which is a composite of original topography and post-Pennsylvanian deformation, gives no hint of its configuration at the beginning of Pennsylvanian deposition. Preliminary data suggest that the Mississippian surface was slightly undulatory and of low relief, with locally prominent positive features.

PENNSYLVANIAN

Rocks of Pennsylvanian age occupy an area of 51,000 km^2 (20,000 mi^2) in the southwestern third of Iowa, and they form the bedrock over a significant part of this area. The Pennsylvanian System in Iowa is divided, in ascending order, into the Des Moines, Missouri, and Virgil Series (fig. 3).

DES MOINES SERIES

Rocks of the Des Moines Series crop out in a broad northwest-trending band on both sides of the Des Moines River and form scattered outliers along the northeast margin of this band. Exposures along the southern part of the Des Moines River serve as the type area for the Des Moines Series. The maximum reported thickness for this series is approximately 275 m (900 ft), in the subsurface of southwestern Iowa.

The Des Moines Series is divided into two groups, the Cherokee and the overlying Marmaton. The Cherokee Group unconformably overlies Mississippian rocks of the Osage and Meramec Series and is dominated by a sequence of dark shale and siltstone. Sandstone, lighter colored shale, coal, limestone, and black phosphatic shale, in decreasing order of abundance, complete the suite of lithologies represented in the Cherokee Group. Although the Cherokee reaches a maximum thickness of approximately 230 m (750 ft) in southwest Iowa, no formational subdivisions are differentiated. However, informal names have been applied to some persistent limestones and coals in the upper part of the group, particularly in south-central and southeastern Iowa.

Recent work in southeastern Iowa indicates that a significant part of the lower Cherokee Group may be Atokan in age, and an outlier exposed near Davenport on the Mississippi River is even older. No attempt has been made at this time to redefine the boundaries of the Cherokee Group either lithostratigraphically or chronostratigraphically.

The 45-m (145-ft)-thick Marmonton Group in Iowa has been divided into 7 formations; 14 members are recognized. Although shale and sandstone are dominant, persistent limestones account for eight of the named members and permit subdivision of the Marmaton. Several coals are recognized and have been named. However, only the Mystic Coal has significant reserves.

MISSOURI SERIES

Rocks of the Missouri Series are divided into three groups, in ascending order, the Pleasanton, Kansas City, and Lansing. The series is approximately 93 m (305 ft) thick.

The Pleasanton Group is poorly understood in Iowa; it is defined as the interval between the base of the overlying Hertha Limestone and the unconformity at the top of the subjacent Des Moines Series. Over much of the State, the unconformity is not apparent, but Cline (1941, p. 70) placed the unconformity at the base of the Chariton Conglomerate in Appanoose County. The thickness of the Pleasanton Group is variable but is believed to reach a maximum of approximately 12 m (40 ft) in the subsurface. Shale and minor sandstone are dominant. The interval also contains several thin limestones, one of which is named, and one named coal.

The Kansas City Group is the thickest of the three groups of the Missouri Series at approximately 66 m (215 ft) and conformably overlies the Pleasanton Group. Fourteen formations have been defined in the alternating sequence of shales and limestones. Similarly, four of the limestone and two of the shale formations have been divided into alternating limestone and shale members. The shale formations range in thickness from 1.5 to 4.5 m (5 to 14.5 ft). The limestone formations range in thickness from 0.6 to 8.5 m (2 to 27.5 ft).

The conformable superjacent Lansing Group continues the alternating series of limestone and shale found in the Kansas City Group. The two limestone formations and one shale formation have a maximum total thickness of 15 m (50 ft).

VIRGIL SERIES

The rocks of the Virgil Series are divided into three groups, in ascending order, the Douglas, Shawnee, and Wabaunsee. The maximum thickness for the series is about 150 m (500 ft).

The Douglas Group in Iowa is a highly variable unit consisting of 5.5–25 m (18–80 ft) of shale, siltstone, and locally limestone. Although four formations are officially recognized in Iowa, these units are very difficult to recognize, except locally. Hershey and others (1960) included the Pedee Group with the Douglas and indicated that the basal unconformity cannot be found.

The Shawnee Group continues the alternating sequence of limestone and shale shown by the Kansas City and Lansing Groups. Seven formations are recognized, which have a total maximum thickness of 55 m (180 ft). The unit is conformable with the underlying Douglas Group. All but one of the formations, the Calhoun, have been divided into members, on the basis of alternating limestone and shale. Thirty-six members have been recognized; the limestone formations contain at least seven members, and the shale formations, three members. The shale formations range in thickness from 1 to 7 m (3 to 22 ft), and the limestone formations, from 3.5 to 11 m (11 to 35 ft).

The Wabaunsee Group has a maximum thickness of about 65 m (210 ft) and conformably overlies the Shawnee Group. Although this group is divided into 25 formations on the basis of an alternating sequence of limestone and shale, shale is dominant. Secondary lithologies, in order of abundance, are siltstone, sandstone, and coal; no members are recognized, but the coals have been informally named. Limestone formations are relatively thin, having an average thickness of 1 m (3 ft) and a range of 0.3–3.5 m (1–12 ft) in thickness. Thicknesses of shale formations range from 1 to 30 m (3 to 100 ft). The group thins toward the northeast.

The top of the Virgil Series coincides with the beginning of an extensive break in the depositional record in Iowa. An angular unconformity marks the contact between the Pennsylvanian and overlying units. Rocks of questionable Jurassic age overlie the Pennsylvanian in several areas in the vicinity of Fort Dodge. Although this thin sequence of red and green shale covers only about 90 to 130 km^2 (35–50 mi^2), it is important because of the industry based on the associated gypsum deposits. The remainder of the Pennsylvanian is overlain either by Cretaceous or Quaternary clastic deposits. The Cretaceous discontinuously overlies the Pennsylvanian in the western third of the State and is in turn overlain by the Quaternary, which overlies the Pennsylvanian wherever the Cretaceous is absent.

FACIES AND DEPOSITIONAL ENVIRONMENTS OF PENNSYLVANIAN ROCKS

The Pennsylvanian section in Iowa is less well understood than are rocks of equivalent age in nearby States, particularly Kansas and Illinois. This lack of understanding results from a paucity of exposures due to a thick Quaternary cover, from local structure, from rapid lateral and vertical facies changes, and from the limited number of geophysical logs available from drill holes that penetrate the entire Pennsylvanian sequence. Currently, the Iowa Geological Survey is attacking part of the problem by means of a coring program in the Des Moines Series to evaluate the coal resources of the State. The data obtained from this program have served as the basis for the Des Moines Series part of this discussion. Similarly, an earlier study of highway construction materials by Hershey and others (1960) provided the data for the discussion of the Missouri and Virgil Series.

In the Cherokee Group, the rapid facies changes result from the interaction of several factors, including original topography, an overall transgression that persisted through the Des Moines Series, and repeated widespread eustatic fluctuations of sea level. In the southeastern part of the State, the oldest Pennsylvanian sedimentary rocks are terrestrial to marginal marine and are dominated by dark-gray shale, siltstone of various shades of gray, small-scale channel sandstone, and interbedded siltstone and sandstone. Successive cyclic units indicate a gradually increasing marine influence, as shown by the progressive appearance of *Lingula*, nodular septarian limestones, light-gray to gray-green shale containing calcareous marine fossils, bedded marine fossiliferous limestone, and phosphatic black shale. Concomitantly, the dark-gray shale and darker siltstone decrease in dominance and eventually disappear, and the size of the channel sands increase. Throughout the Cherokee, clastic sediments were transported into the basin from two directions. In the southeastern part of the basin, transport was from the northeast, whereas in the northern part of the basin, transport was from the north.

The first appearance of the various lithologies was not synchronous over the entire area but varied locally depending on original topography of the site of deposition and the proximity of the shoreline. The marine influence was felt earlier in the west and southwest than in the southeast. Similarly, the Cherokee Group thickens to the west, the most dramatic thickening being in the lowermost part of the unit. These lowermost beds may be older in the west; however, at present, their age is undetermined.

In the upper part of the Cherokee Group, original topography no longer exerted much influence because of the filling of topographic lows on the original surface. Contemporaneously, the overall transgression had progressed far enough so that laterally persistent marine limestone and phosphatic black shale began to form, and the sequence of lithologies began to resemble the cyclothems of the Eastern Interior Basin. A good discussion of the Eastern Interior Basin cyclothems may be found in Hopkins and Simon (1975, p. 173). Like the cyclothems of the Eastern Interior Basin, the upper Cherokee cyclothems of Iowa rarely contain all the lithologies attributed to the idealized sequence. The one outstanding difference between the upper Cherokee Group cyclothems and those of the Eastern Interior Basin, is that the units in Iowa, particularly the coals, generally are much thinner.

The general trend toward open marine conditions continued upward into the Marmaton Group. Because of the surface of low relief that existed during deposition of the Marmaton, the transgressive-regressive cycles produced by eustatic sea-level changes formed thin but laterally continuous shallow-water marine deposits, particularly limestone and shale. Minor deeper water sedimentation is indicated by the presence of phosphatic, slaty black shale, according to Heckel (1977). The sandstone, thick siltstone, and nonfossiliferous shale represent prodeltaic and lower delta-plain deposits. Although the Marmaton is predominantly clastic, insufficient data are available to define the direction of transport, but a northeasterly source is currently favored. Only one coal, the Mystic, reaches a significant thickness—75 cm (2.5 ft)—in the Marmaton Group, despite the fact that subaerial conditions existed several times; the thinness of the coal beds perhaps indicates insufficient time or an unfavorable environment for the formation of peat.

During deposition of the Missouri Series, marine conditions predominated, the characteristics of each cycle being determined by the water depth during the transgressive phase and the position of the shoreline at maximum regression. The Pleasanton Group is poorly defined in Iowa. It includes shale and siltstone and some sandstone, and it contains the Exline Limestone and the Ovid coal. These units indicate a minor transgression during which the incoming waters remained relatively shallow, followed by a regressive phase during which the shoreline migrated through Iowa and the Ovid coal was deposited.

In the overlying Kansas City and Lansing Groups, limestone and marine shale are dominant, and several of the cyclothems (such as the Swope Limestone) show characteristics of the "Kansas cyclothem" as described by Heckel (1977). However, not all the transgressions reached sufficient depth to produce phosphatic black shale, and there appears to have been an irregular upward trend of decreasing water depth during the transgressive phase. Concomitantly, an increase in the deposition of shallow-water clastic materials took place, and subaerial conditions prevailed at least once, in the Chanute Shale.

This trend toward decreasing water depth continued into the base of the Virgil Series, where the Douglas Group cannot be divided because of the suppression of limestone which elsewhere serves as a basis for recognition of members. The Douglas Group, like the Pleasanton Group, represents a minor eustatic event, during which the water remained shallow, and regressive prodeltaic shale was dominant.

The Shawnee Group reflects the earlier pattern of the Kansas City Group and is a dominantly marine section containing widespread thick limestone beds and several phosphatic black shale beds. The black shales indicate several deep-water transgressive events separated by shallower water transgressive and regressive but generally marine deposits.

Rocks of the Wabaunsee Group record a return toward shallowing water, possibly as a result of basin filling. The Severy Shale, which is the lowermost formation of the Wabaunsee Group, has a phosphatic black shale indicating deep marine conditions, but the black shale almost immediately overlies a coal, which illustrates a reversion to an upper Cherokee depositional pattern. Above this sequence there is a marked increase in nearshore sediments, particularly prodeltaic shale, and a general decrease in limestone deposits.

With the exception of a series of thin isolated units exposed near Fort Dodge, which have been tentatively assigned to the Jurassic, no record of deposition exists from the top of the Virgil Series to the base of the Dakota Group of the Cretaceous.

ECONOMIC PRODUCTS

PRODUCTS FROM MISSISSIPPIAN ROCKS

Mississippian rocks are a significant source of industrial minerals in Iowa. About 25 percent of the stone used for road construction and maintenance is derived from Mississippian strata, principally the Hampton, Burlington, and Gilmore City Formations, in 23 counties. A substantial amount of the stone production is for agricultural lime. Although most of the stone is from surface quarries, six underground mines are in operation.

Gypsum is mined from the lower St. Louis at a single location in south-central Iowa. The gypsum is used as a retarder by cement plants in Des Moines, and some of it is pelletized (together with finely crushed limestone and bentonite) for use as a soil conditioner.

PRODUCTS FROM PENNSYLVANIAN ROCKS

Coal mining started in several areas of Iowa in the early 1840's (figs. 5, 6). The coal was used locally for home heating and for smithing operations. Production increased steadily as coal replaced wood fuel both for the home and the Des Moines

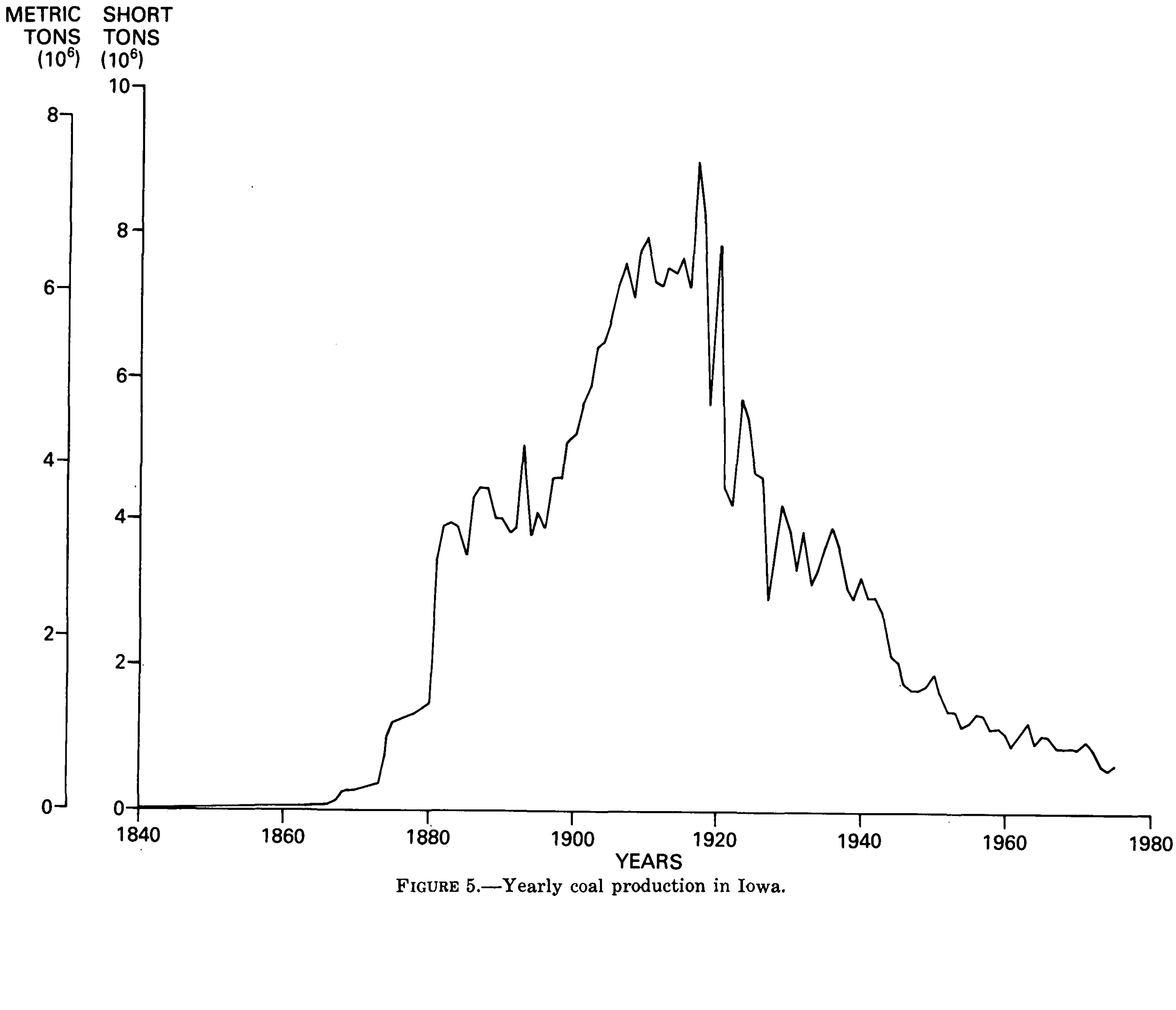

FIGURE 5.—Yearly coal production in Iowa.

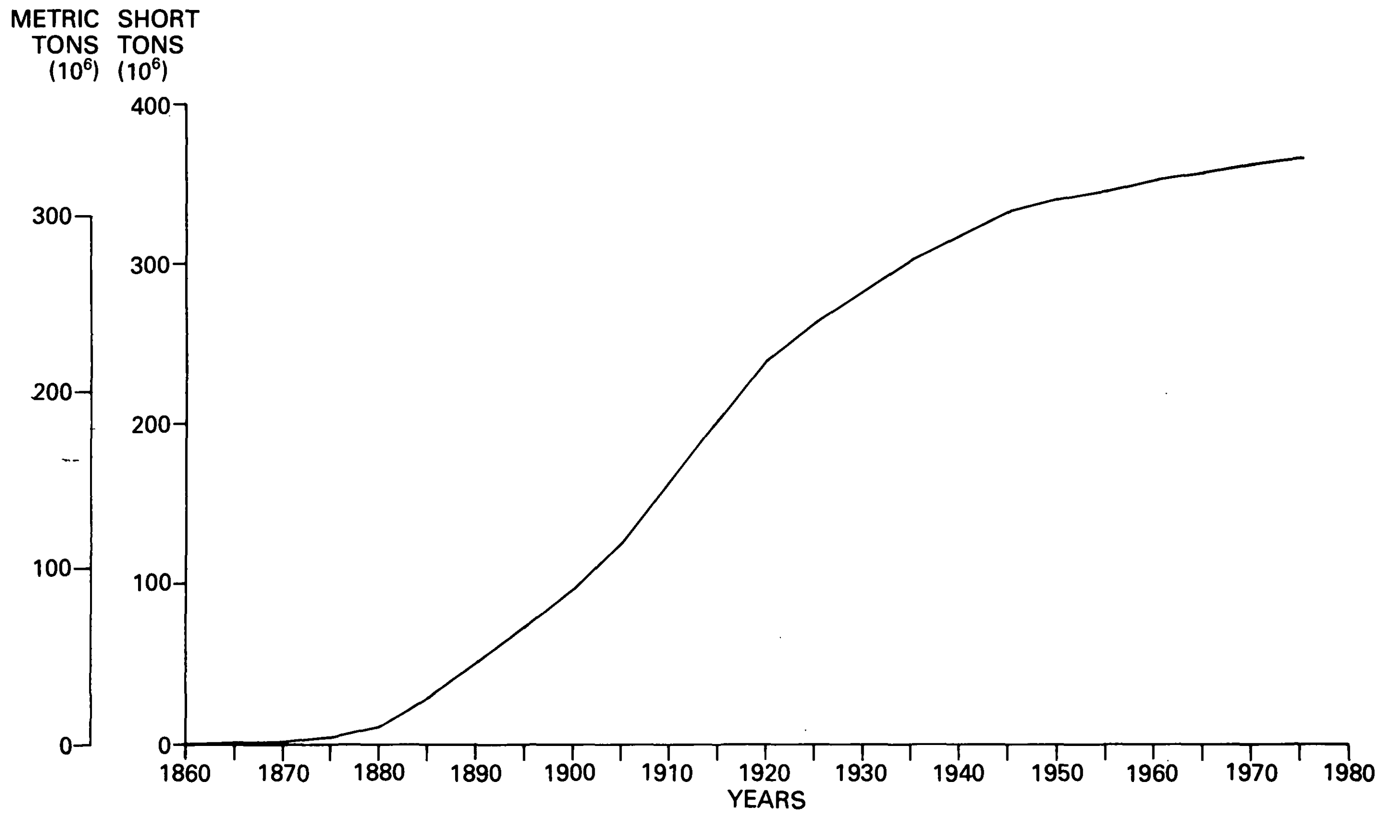

FIGURE 6.—Cumulative coal production in Iowa.

riverboats, but it did not top 100,000 tons per year until the late 1860's. About this time, the coal industry in Iowa began to accelerate because of the coming of the railroads, and it continued to expand until the early 1900's. The State Mining Inspectors office was established in 1880 with the responsibility of collecting production data. The unprecedented increase in coal production between 1880 and 1881 probably is related more to inaccurate prior records than to an actual increase in tonnage.

By the early 1900's, the industry was beginning to peak, although it had its best year in 1917 in response to war conditions. In 1900, the population of Iowa had reached 2,232,000; it grew only moderately thereafter to the present level of approximately 2,870,000. Agriculture has been the dominant economic endeavor; industrial development slowed when it became obvious that the State had insufficient natural resources to support large industry, removed as it was from the main markets to the east. These trends created a ceiling on the development of Iowa coal, and a long-term decline was assured by events outside the State.

The principal pressure on the industry was competition for its traditional markets from out-of-state coal, which was cheaper, either because of easier mining conditions or better applied technology combined with economies resulting from larger operations and thicker coal beds. In addition, as oil and gas became readily available they began to compete with coal. Without a large industrial base to serve as a safe market, the industry slowly slid back to production levels comparable with those of the 1860's and early 1870's. The industry today supplies small amounts of coal on short-term contracts and the spot market to local utilities.

In spite of its inherent disadvantages, namely, high sulfur content and high mining cost, Iowa coal production should be rejuvenated in the near future. This prediction is based on the large remaining reserves in the State, rising mining costs elsewhere as easily mined coal is exhausted, and increasing shipping costs attendant on moving large volumes of coal and the necessary upgrading of roadbeds. Therefore, the cumulative production curve should show a steepening; the only remaining question is when?

In addition to coal, Pennsylvanian strata yield limestone and clay. Limestone is produced in 13 counties in southwestern Iowa, primarily as crushed stone. Most of the production is used as bituminous and concrete aggregate, roadstone, and road base, although significant quantities are utilized as agricultural limestone and in the manufacture of cement.

Clay is utilized in the manufacture of tile, brick, and cement. Accurate production information for either clay or limestone cannot be obtained because in many of the counties the industries are so small that publication of production figures would result in the release of information considered proprietary by the industry.

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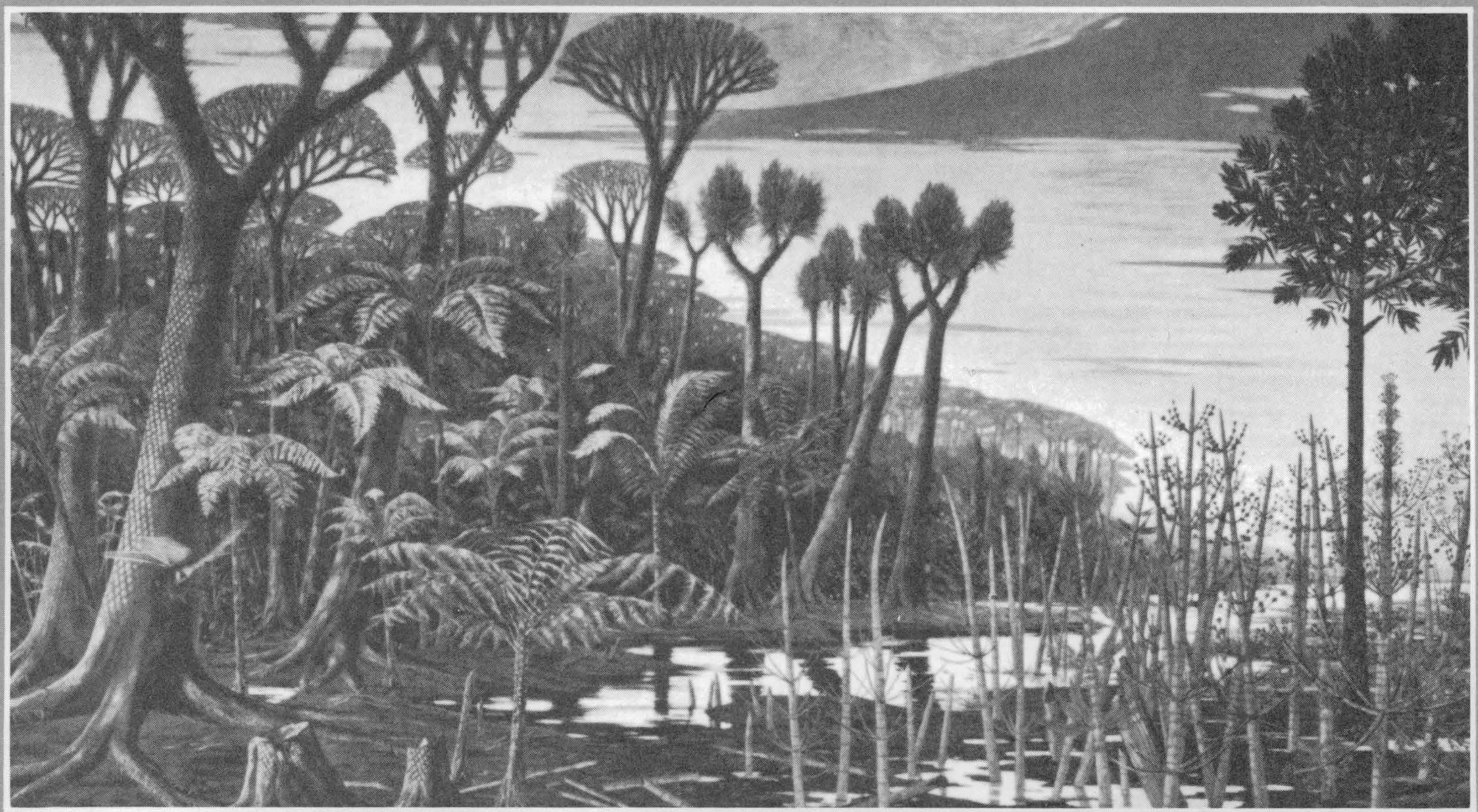
The Mississippian and Pennsylvanian (Carboniferous) Systems in the United States



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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.)

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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
Director, U.S. Geological Survey

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