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

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GEOLOGICAL SURVEY PROFESSIONAL PAPER 1110-P

Prepared in cooperation with the
Nebraska Geological Survey,
Conservation and Survey Division
Institute of Agriculture and
Natural Resources,
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Historical review and summary of areal, stratigraphic, structural, and economic geology of Mississippian and Pennsylvanian rocks in Nebraska

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1979

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

By R. R. BURCHETT [1]

ABSTRACT

Nebraska is underlain by rocks of Mississippian and (or) Pennsylvanian age in all but the extreme northeastern part of the State. Only some of the Upper Pennsylvanian strata are exposed; outcrops of these rocks are limited to southeastern Nebraska. The thickness of the Pennsylvanian rocks ranges from a featheredge in northeastern Nebraska to slightly more than 625 m (2,050 ft) in the southeastern part of the State, in the deeper part of the Forest City basin. Outcropping Pennsylvanian rocks have a combined thickness of 244 m (800 ft) and are composed principally of thin to thick beds of shale, sandstone, and limestone. Several thin coal seams occur in both the exposed and deeply buried sequences of Pennsylvanian strata. In ascending order, the Pennsylvanian System in Nebraska is divided into the following series: Morrow(?), Atoka, Des Moines, Missouri, and Virgil. Of these, only the Missouri and Virgil Series are exposed. Pennsylvanian rocks in Nebraska, especially the Missouri Series and the lower part of the Virgil Series, consist of repeated sequences of marine and nonmarine beds. Some of the marine beds contain abundant invertebrate fossils. Shale associated with coal seams contains plant fossils.

Formation of Nebraska's structural features began before and continued through Carboniferous time. Several stratigraphic units recognized in the Forest City basin do not extend over the Nemaha arch, which borders on the west.

Several quarries have been opened into Pennsylvanian limestone and shale. Other important economic products are oil, gas, and water. Although coal was mined for local use at several places, it has not been mined for several years.

INTRODUCTION

Nebraska, in the northern midcontinent part of the United States, is underlain by rocks of Mississippian and (or) Pennsylvanian age in all but the northeastern corner of the State. (See figs. 1 and 2.) However, only some of the Upper Pennsylvanian strata are exposed, and the outcrops of these rocks are restricted to valley sides in the southeastern part of the State (fig. 3). For this reason, the following description of Carboniferous rocks in Nebraska is limited almost entirely to those deposited during Late Pennsylvanian time.

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 Nebraska Geological Survey, Conservation and Survey Division.

HISTORY

The initial recognition and investigation of Carboniferous strata in the northern midcontinent region took place more than a century ago (Owen, 1852, p. 133–138, Sections 20M–40M; Marcou, 1864; Prosser, 1897, p. 12–16; Merrill, 1924, p. 773). However, the first noteworthy report on Pennsylvanian stratigraphy in the Missouri-Kansas-Nebraska region was that by Broadhead (1873). Other important early work was reported by Meek and Hayden (1859), Swallow (1866), Meek (1872), Barbour (1903), Condra (1903), Woodruff (1906), Prosser (1902), Hinds and Greene (1915), and Tilton (1920).

Initially, the State Geological Surveys of the region worked independently in the study, naming, and mapping of geologic units. This independent activity caused duplication of names, confusion in correlation, and demonstrated a need for interstate study. It was followed by cooperative surveys across State lines, by regional correlation, and by the establishment of nomenclature on a priority basis. However, the thick Pleistocene deposits in the northern part of the region and the folding and faulting in the southern midcontinent region made it difficult to run traverses between outcrops and very difficult to correlate the formations in the more or less buried structures. However, by detailed lithologic and faunal study of the outcrops, by logging deep wells drilled for oil and gas, and by test drilling to obtain

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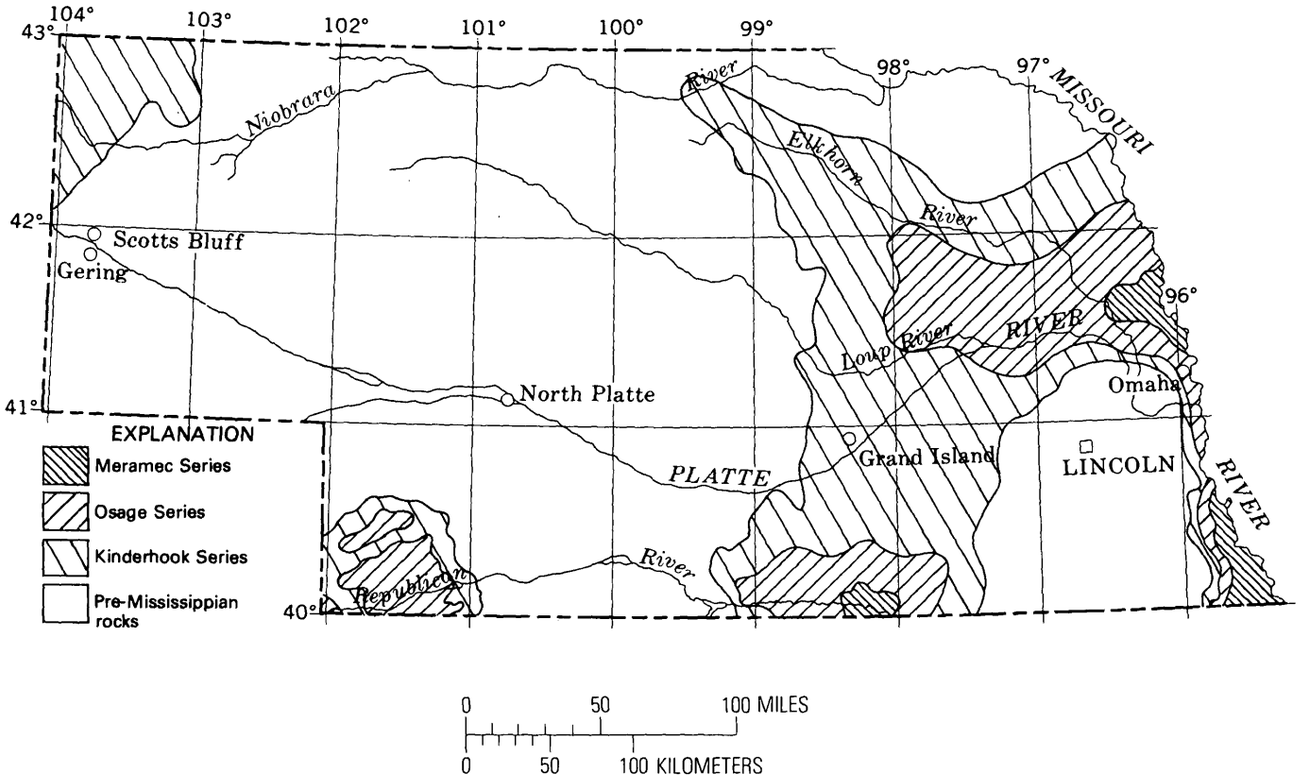

FIGURE 1.—Distribution of the Mississippian System in Nebraska (from Carlson, 1963).

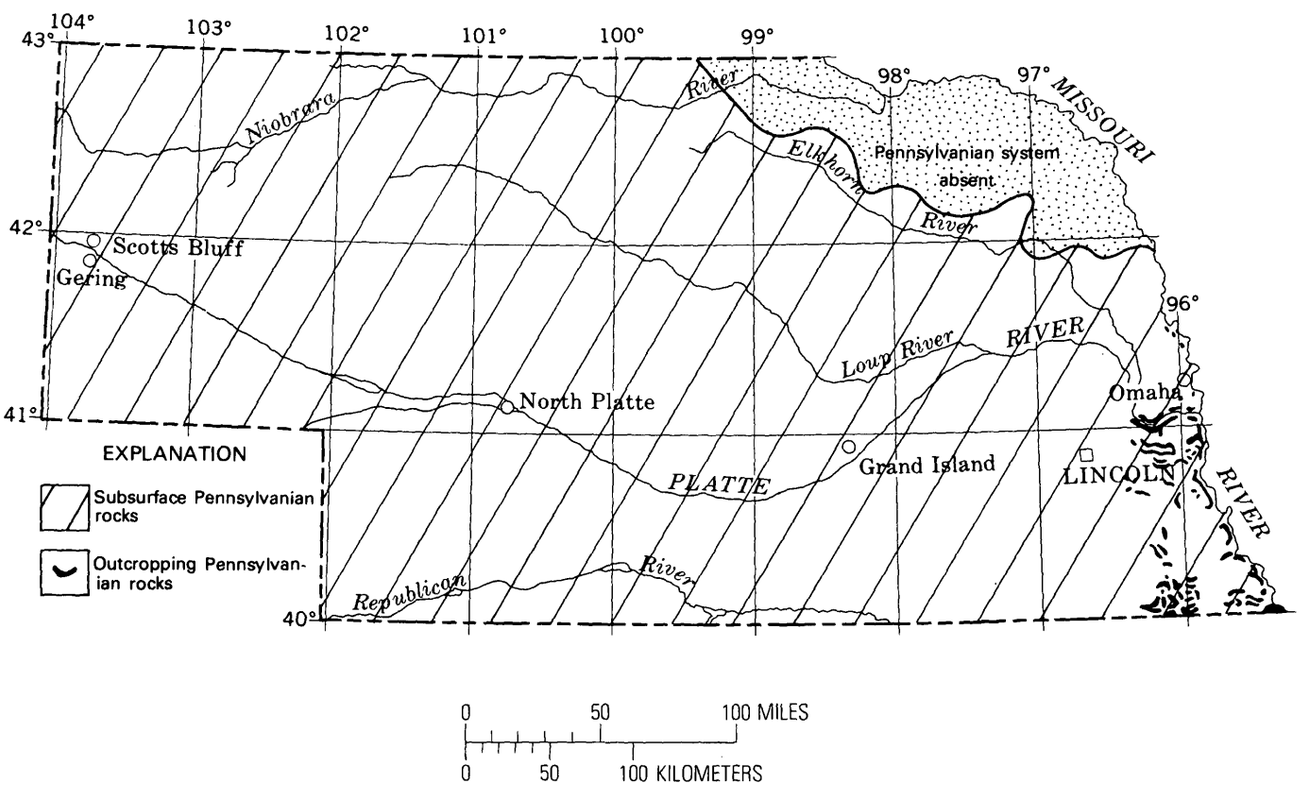

FIGURE 2.—Distribution of the Pennsylvanian System in Nebraska.

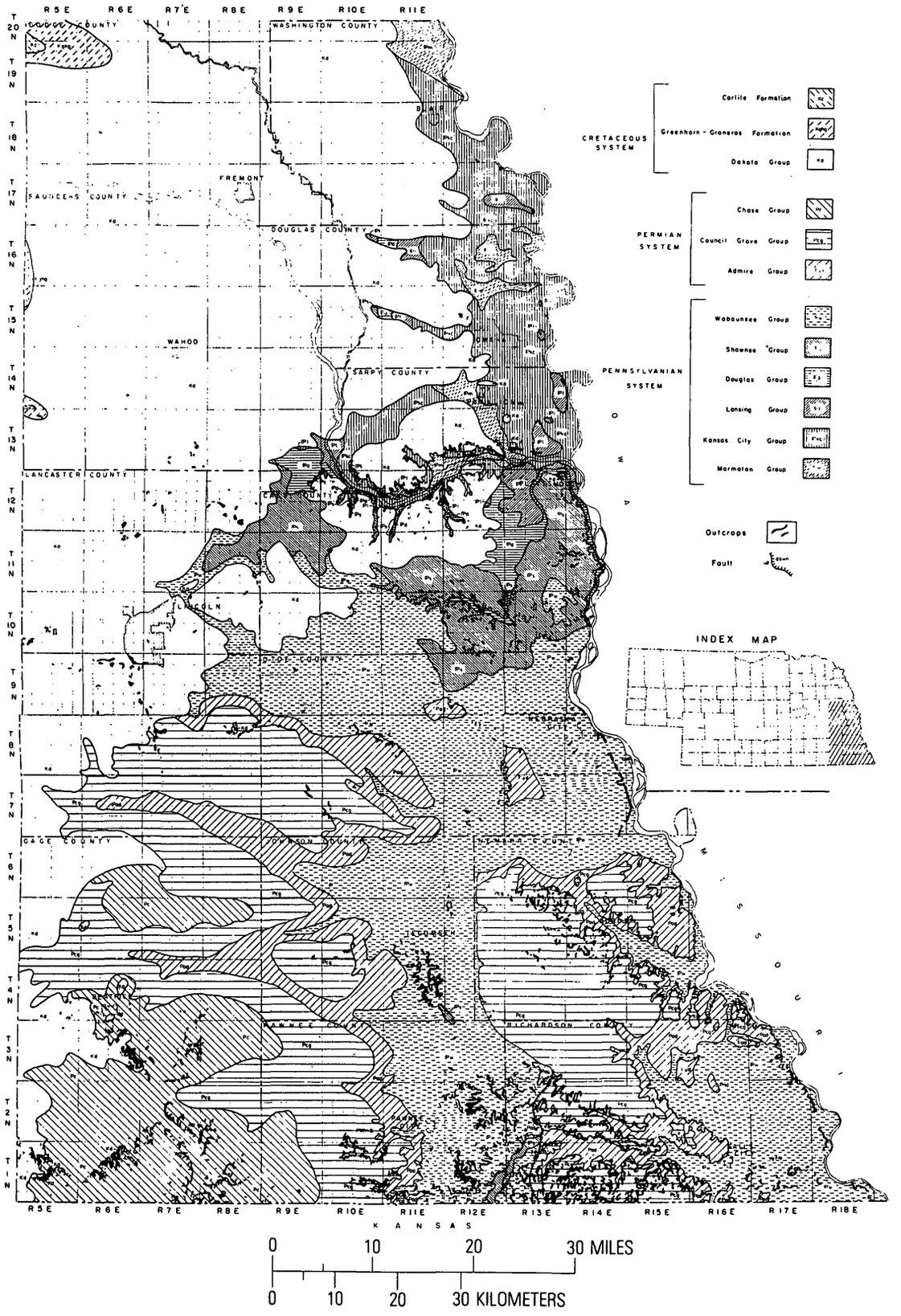

FIGURE 3.—Bedrock geology of southeastern Nebraska.

subsurface information at various locations, factual data were gathered for use in the correlation and classification of the units of the system. This kind of study by the Surveys, with cooperation from oil geologists, established a knowledge of the nature, thickness, and regional occurrence of the subdivisions in the region and gave a sound basis for the description, correlation, and naming of the members, formations, groups, and series. It revealed some errors in the early surveys and reports and, contrary to early interpretation, showed that the formations are comparatively uniform in thickness in the northern part of the region and that most of them were formed as cyclothemal units of marine and continental deposition.

During the past 65 years, but particularly after the appearance of the important paper on the Pennsylvanian of Nebraska by Condra and Bengston (1915), the modern Pennsylvanian classification has emerged. The classification for Nebraska was revised in 1927 (Condra, 1927) and then almost yearly for about 30 years (see especially Condra and Reed, 1943; Condra, 1949; Moore, 1932, 1936, 1944, 1948, 1949; Moore and Newell, 1937; Moore and others, 1944, 1951; Moore and Mudge, 1956; and Kansas Geological Society, 1957). More recent publications include Hershey and others, 1960; Howe and Koenig, 1961; Mudge and Yochelson, 1963; Reed and Burchett, 1964; Burchett and Carlson, 1966; Smith and Burchett 1967; Burchett and Reed, 1967; Jewett, O'Connor, and Zeller, 1968; Burchett, 1968, 1969, 1970, 1971; Fagerstrom and Burchett, 1972; Prichard, 1975; and Burchett, 1977.

GEOLOGIC SETTING

Pennsylvanian rocks in Nebraska rest unconformably on rocks ranging in age from Precambrian to Mississippian. Generally, the unconformity is marked by a basal sand or a detrital zone of angular quartz sand and weathered chert. The pre-Pennsylvanian rocks have been studied in detail by Carlson (1963, 1970).

Pennsylvanian strata in Nebraska are overlain by rocks ranging in age from Permian to Quaternary. Where the Pennsylvanian-Permian contact is visible in southeastern Nebraska, a period of erosion without significant diastrophism is indicated; at least one channel sand of Permian age cuts approximately 30 m (100 ft) into Pennsylvanian rocks. Placement of the Pennsylvanian-Permian boundary has been summarized by Moore (1940, p. 298–305; 1949, p. 19–22) and by Mudge and Yochelson (1962, p. 116–127).

The principal structural features of Nebraska are shown in figure 4. Major movement on many of these features took place in Early Pennsylvanian time.

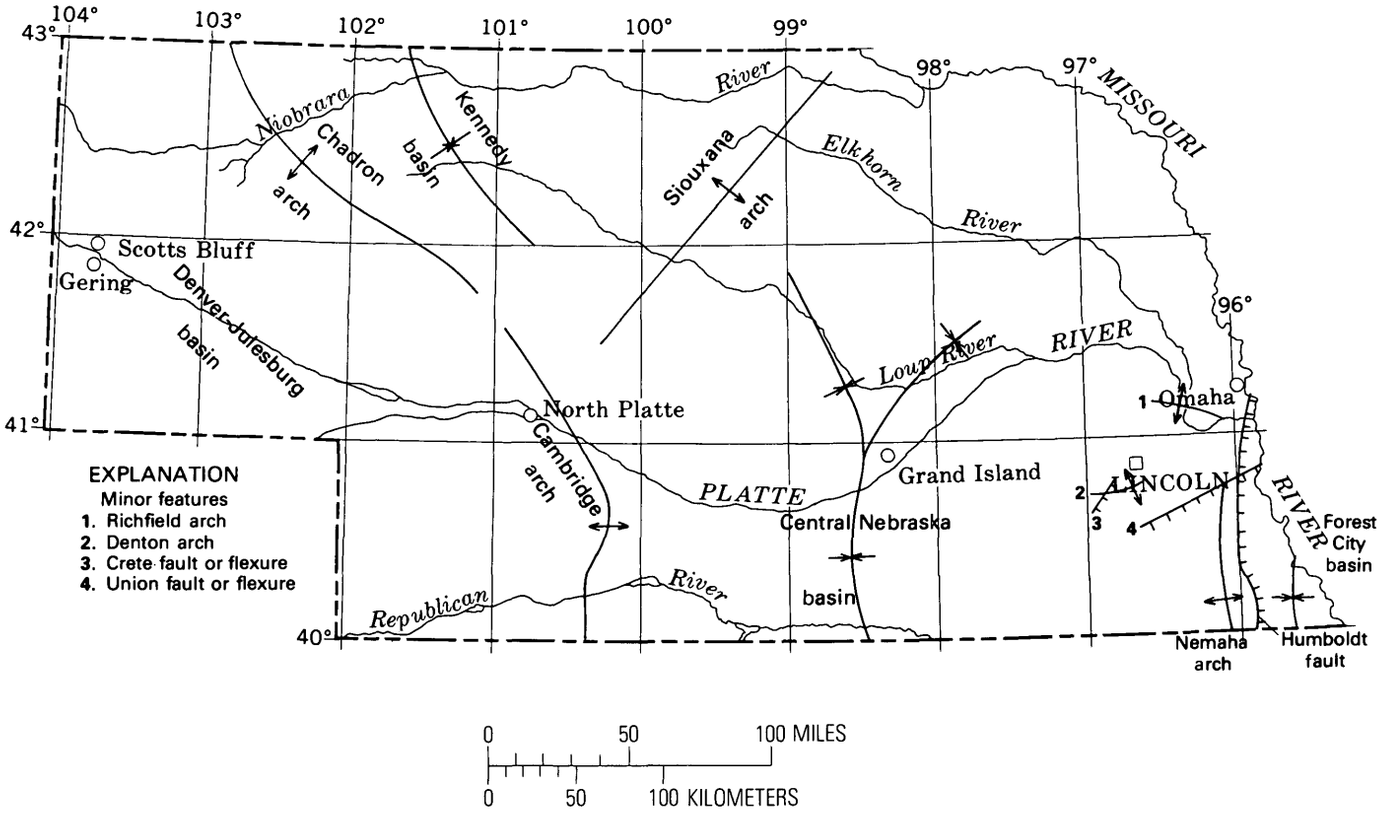

FIGURE 4.—Principal structural features of Nebraska (from Carlson, 1970).

Formation of the Nemaha arch in post-Mississippian pre-Des Moines (Middle Pennsylvanian) time accounts for the unconformable relation of Pennsylvanian strata to the underlying older rocks in eastern Nebraska. This arch extends from the vicinity of Omaha southward across Kansas and into Oklahoma. In much of Johnson and Pawnee Counties, Nebr., and in the adjoining part of Kansas, uplift was so great that all strata from Middle Ordovician to Mississippian age were removed by concurrent and subsequent erosion, resulting in exposure of Precambrian rocks. Although deposition of Pennsylvanian strata in eastern Nebraska began during Atoka time, complete burial of the arch did not take place until early Missouri time. Crustal unrest continued through the deposition of the Pennsylvanian rocks and into deposition of the Permian rocks. Contemporary subsidence of the areas on either side of the arch resulted in deposition of thicker sequences of Pennsylvanian strata in the downwarped basins. Because the area immediately east of the arch subsided at a faster rate, the thickness of Pennsylvanian strata accumulating there was significantly greater than that on the west side. Now known as the Forest City basin, that area of subsidence includes parts of Nebraska, Iowa, Missouri, and Kansas.

Not all the stratigraphic units in the Pennsylvanian sequence are useful as datum planes. For example, the initial clastic sediments were deposited on the irregular surface of older rocks and thus differ in thickness within short distances; furthermore, most individual beds deposited on or close to that surface probably deviated from the horizontal. Only those beds that originally were nearly horizontal, are of large areal extent, and are conformable with underlying and overlying beds are suitable as datums. One such bed is the Hertha Limestone, the base of which was used as the datum plane for the structural contour lines shown in figure 5. Altitudes of the base of the limestone are shown to range from slightly more than 305 m (1,000 ft) above mean sea level in Douglas and Sarpy Counties to slightly more than 91 m (300 ft) below mean sea level in Richardson County, where the basin is deepest. The Table Rock arch, a structural feature in the outcrop area, trends north over the buried Nemaha arch; the east margin of the Table Rock arch is sharply defined by the Humboldt fault and smaller faults associated with it. (See fig. 5.)

LITHOSTRATIGRAPHY OF THE PENNSYLVANIAN SYSTEM

The thickness of Pennsylvanian rocks in Nebraska ranges from a featheredge in the northeastern part of the State to slightly more than 625 m (2,050 ft) in the extreme southeastern part (fig. 6). Outcropping Pennsylvanian rocks have a combined thickness of about 244 m (800 ft), as shown in figure 7.

Composed primarily of thin to thick beds of shale, sandstone, and limestone, the Pennsylvanian sequence in Nebraska is characterized by a definite repetition of cycles of marine shale and limestone alternating with nonmarine deposits. However, lateral lithologic differences are found within the formations.

Pennsylvanian rocks in Nebraska have been divided into five series. In ascending order, these are the Morrow(?), Atoka, Des Moines, Missouri, and Virgil. Of these, only the rocks of the Missouri and Virgil Series are exposed.

MORROW(?) SERIES

The oldest Pennsylvanian rocks in Nebraska have been assigned to the Morrow(?) Series. They may be present in the southwestern part of the State, but definite age relationships have not been established. Rocks of the Morrow(?) Series are not present in the Forest City basin, where each of the four other series has been identified.

ATOKA SERIES

Strata assigned to the Atoka Series are the oldest Pennsylvanian rocks in southeastern Nebraska. In the Forest City basin, they are about 91 m (300 ft) thick and consist mostly of dark shale but include some sandstone layers. Because they do not crop out, they are known only from logs of drill holes.

DES MOINES SERIES

Rocks of the Des Moines Series overlie those of the Atoka Series. They are about 229 m (750 ft) thick in the deepest part of the Forest City basin, are thinner—less than 122 m (400 ft)—at the northern end of the basin, and are very thin or absent over the Nemaha arch. (See fig. 8.) The series has been divided into the older Cherokee Group and the younger Marmaton Group. Like the Atoka Series, the Des Moines Series does not crop out and is known only from logs of drilled holes.

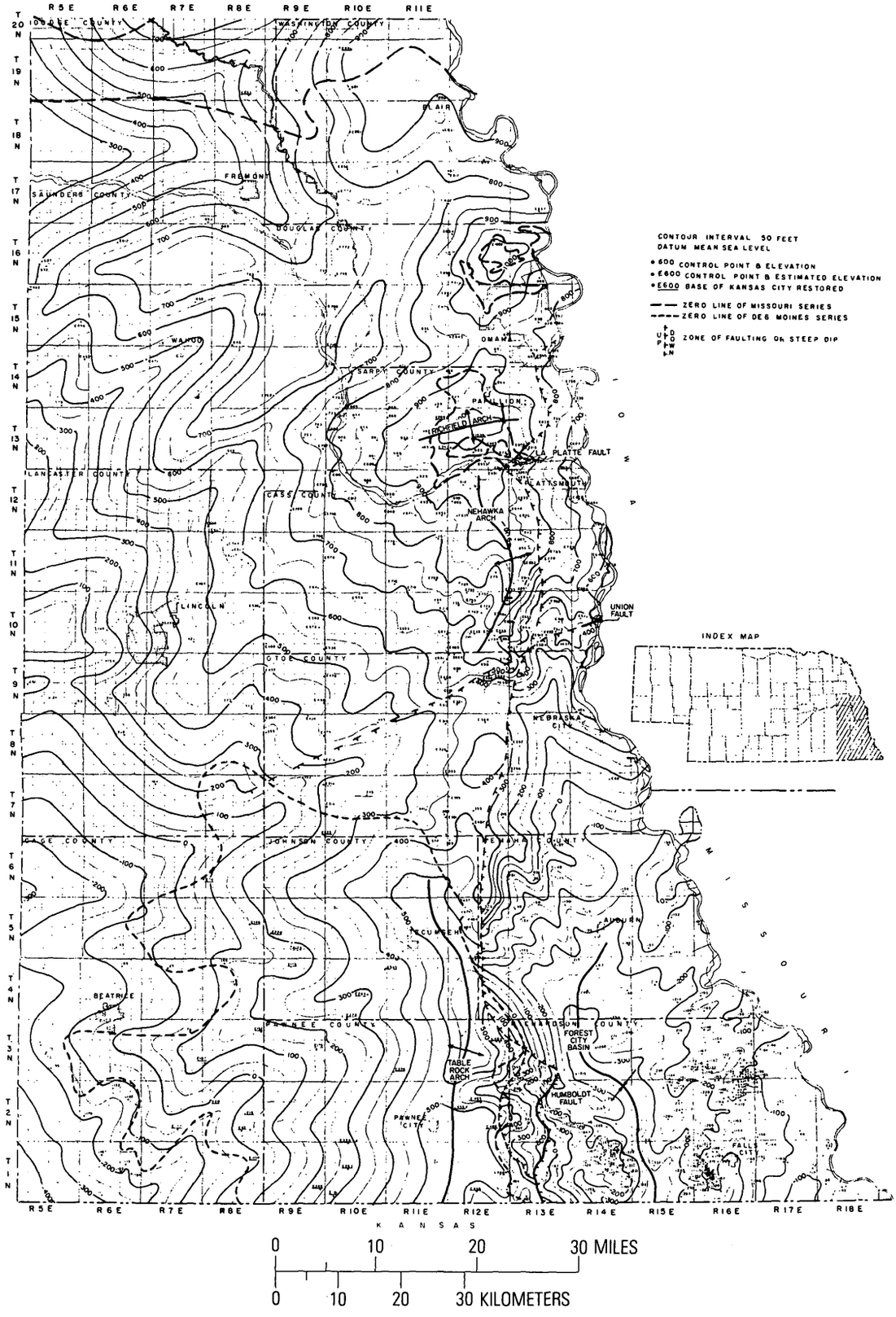

FIGURE 5.—Structure of base of the Hertha Limestone (base of Kansas City Group) in southeastern Nebraska.

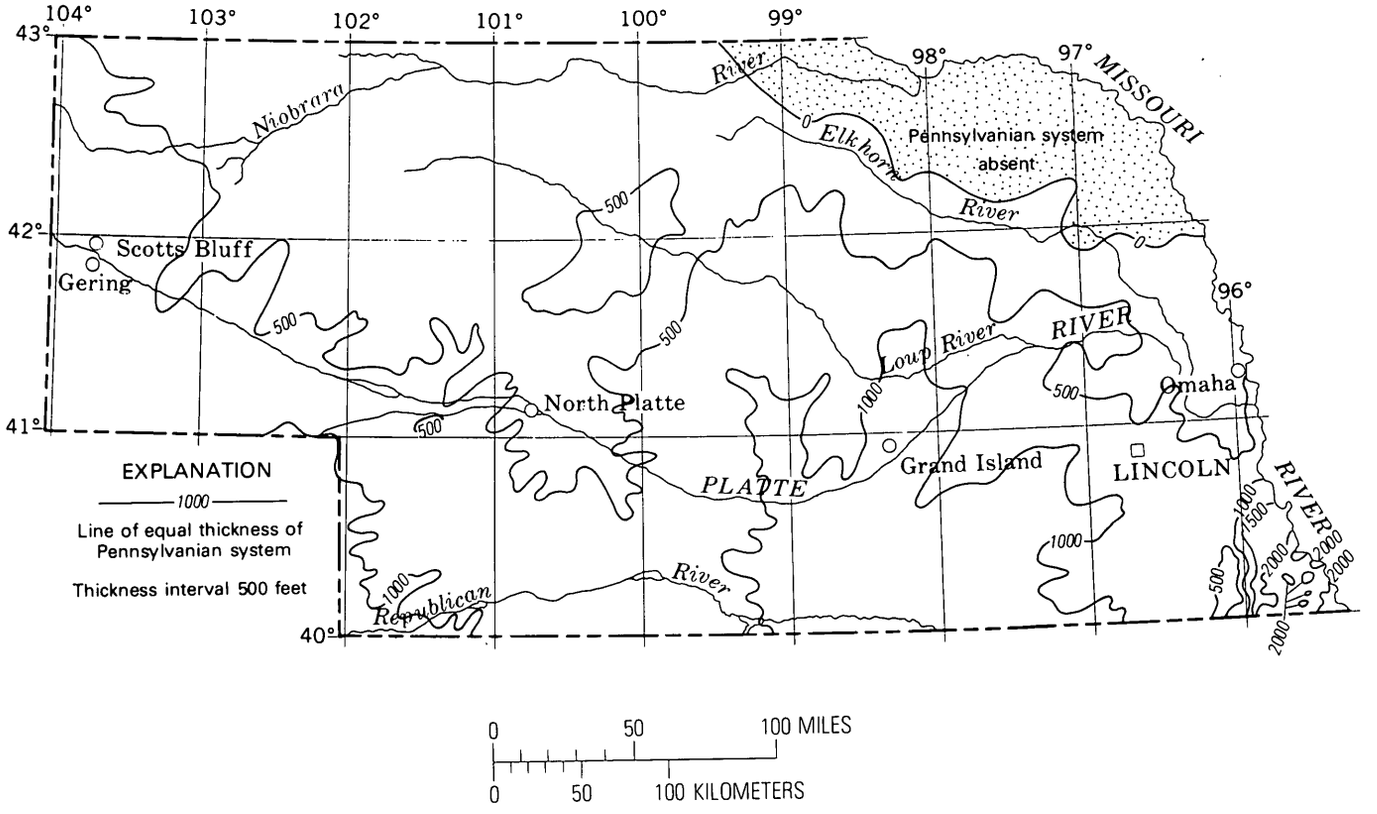

FIGURE 6.—Thickness of the Pennsylvanian System in Nebraska.

CHEROKEE GROUP

The Cherokee Group consists mostly of varicolored shale but includes several beds of sandstone and coal plus a few beds of thin limestone. In the deepest part of the Forest City basin, the group has a maximum thickness of about 175 m (575 ft), and near the northern end of the basin its thickness ranges from about 6.1 m (20 ft) to 76 m (250 ft). Entirely in the subsurface, the Cherokee Group has not been divided into formations in Nebraska.

MARMATON GROUP

Marmaton rocks in southeastern Nebraska consist in large part of varicolored shale but include considerable limestone, some sandstone, and a few thin beds of coal. Thickness of the group ranges from about 53 m (175 ft) in the deeper part of the basin to 35 m (115 ft) in the northern part. Possibly some strata belonging to this group extend westward over the crest of the Nemaha arch. Although the Marmaton Group is somewhat difficult to divide in the subsurface of Nebraska, six formations have been tentatively identified. In ascending order, they are the Fort Scott Limestone, Labette Shale, Pawnee Limestone, Bandera Shale, Altamont Limestone, and Nowata Shale. A disconformity separating Marmaton rocks from the overlying Missouri Series indicates that the upper Marmaton strata were exposed to subaerial erosion before deposition began again in the area.

MISSOURI SERIES

The oldest outcropping rocks of Pennsylvanian age in Nebraska belong to the Missouri Series. They consist mainly of interbedded limestone and shale but include a few beds of sandstone. Individual beds of this series have a large areal extent and can be traced from one outcrop to another. The upper boundary of this series is unconformable with the overlying Virgil Series. The lower boundary is regionally disconformable with the underlying Des Moines Series. As shown in figure 9, the thickness of this series is slightly more than 91 m (300 ft) near the center of the Forest City basin and is about 61 m (200 ft) thick in the northern part of the basin. Three groups composing the series are, from oldest to youngest, the Pleasanton, Kansas City, and Lansing.

PLEASANTON GROUP

Most of the rocks of the Pleasanton Group are mottled red and green shales; some sandstone is also

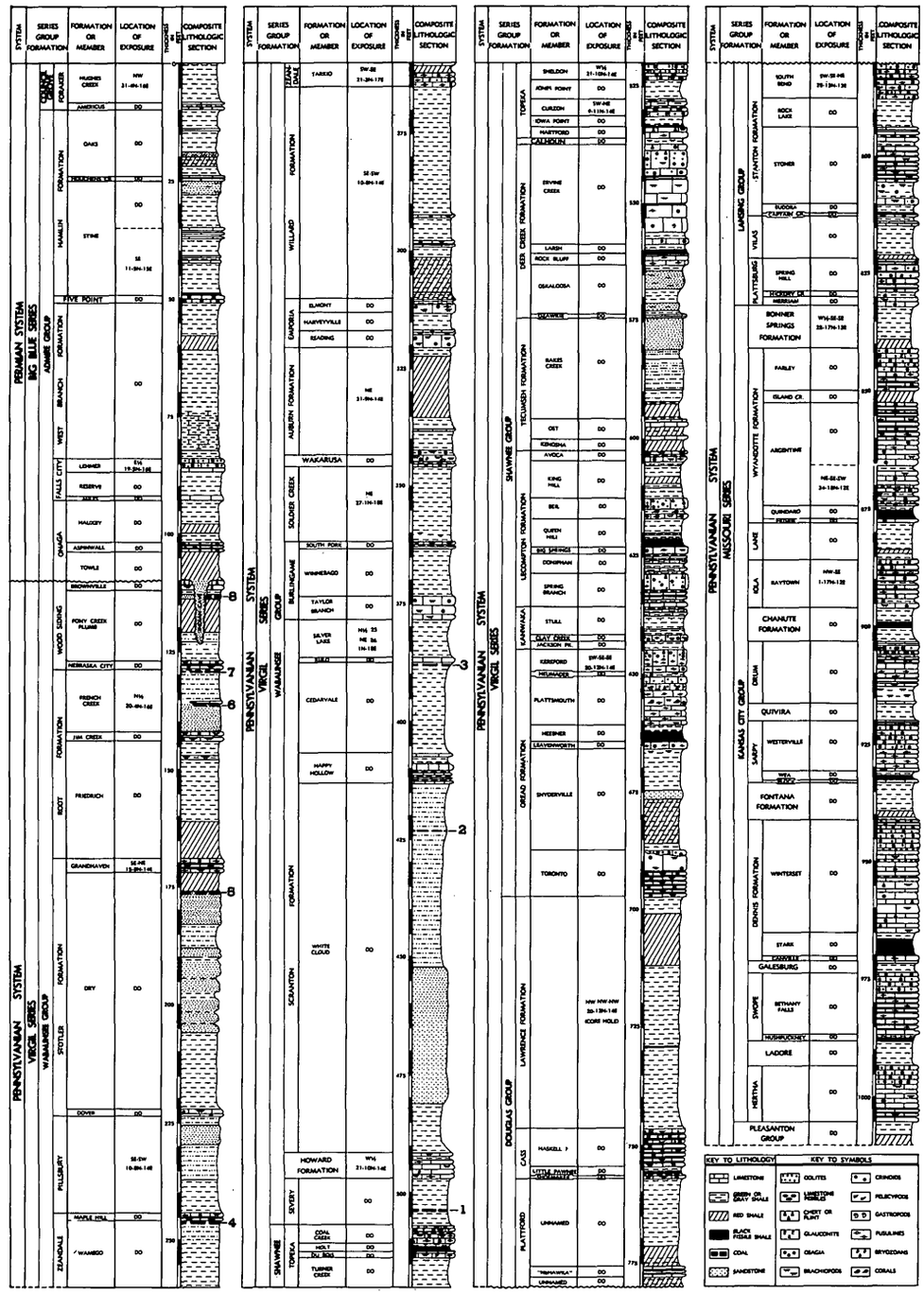

FIGURE 7.—Composite section of outcropping Upper Pennsylvanian and Lower Permian rocks in southeastern Nebraska.

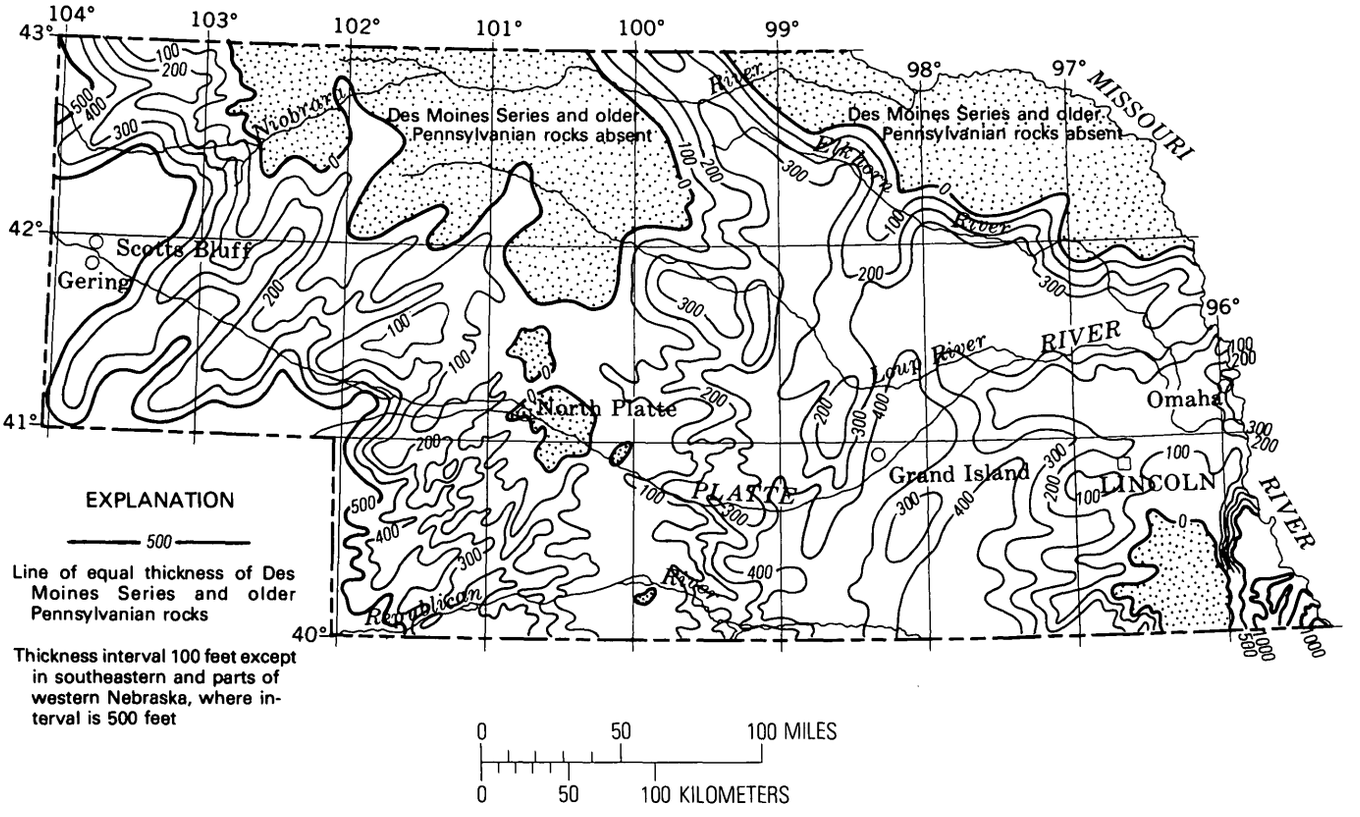

FIGURE 8.—Thickness of the Des Moines series and older Pennsylvanian rocks in Nebraska.

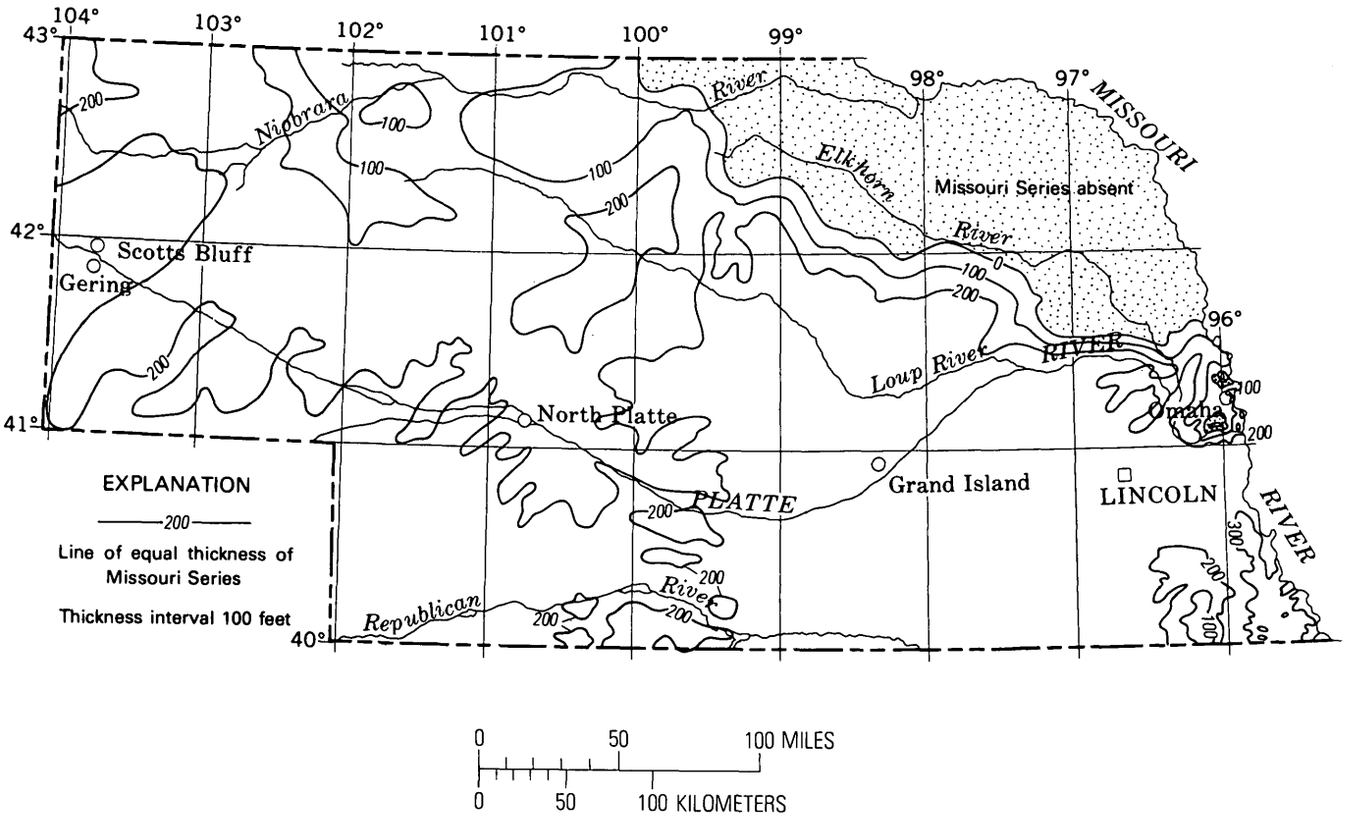

FIGURE 9.—Thickness of the Missouri Series in Nebraska.

present. Resting unconformably on rocks of the Marmaton Group, these clastic sediments range in thickness from a featheredge to about 8 m (25 ft) in southeastern Nebraska and do not crop out anywhere in the Nebraska part of the Forest City basin.

KANSAS CITY GROUP

Rocks of the Kansas City Group consist of cyclically alternating limestone and shale. In Cass, Sarpy, Saunders, and Washington Counties, where this group is exposed, its minimum thickness is about 49 m (160 ft), and, in the subsurface of southeastern Nebraska, its maximum thickness is about 79 m (260 ft). The lower half of the group is missing over the Nemaha arch. From oldest to youngest, the 14 formations composing the group are as follows: Hertha Limestone, Ladore Shale, Swope Limestone, Galesburg Shale, Dennis Limestone, Fontana Shale, Sarpy Limestone, Quivira Shale, Drum Limestone, Chanute Shale, Iola Limestone, Lane Shale, Wyandotte Limestone, and Bonner Springs Shale. (See fig. 7.)

LANSING GROUP

Limestone and shale are the principal constituents of the Lansing Group. Where this group crops out in Douglas, Sarpy, and Saunders Counties, it has a maximum thickness of about 15 m (50 ft), and, in the deeper part of the Forest City basin, its thickness is as much as 18 m (60 ft). Of the three formations composing this group, the Plattsburg Limestone is the lowest, the Vilas Shale is the middle, and the Stanton Limestone is the highest. The upper surface of the Stanton is an unconformity that separates the Missouri Series from the overlying Virgil Series.

VIRGIL SERIES

The youngest exposed Pennsylvanian rocks in Nebraska constitute the Virgil Series. These rocks are marked at the upper and lower boundaries by unconformities and are cyclical, as are those in the Missouri Series. The Virgil rocks consist mainly of shale, limestone, sandstone, and thin coal. Outcrops are widespread in southeastern Nebraska where some of the upper beds have been removed by erosion over the Nemaha arch and in the northern end of the Forest City basin. As shown by figure 10, the thickness of the Virgil ranges from a featheredge at the northern end of the basin to a little more than 244 m (800 ft) in the deeper part of the Forest City basin. The Virgil Series is divided into three groups in Ne-

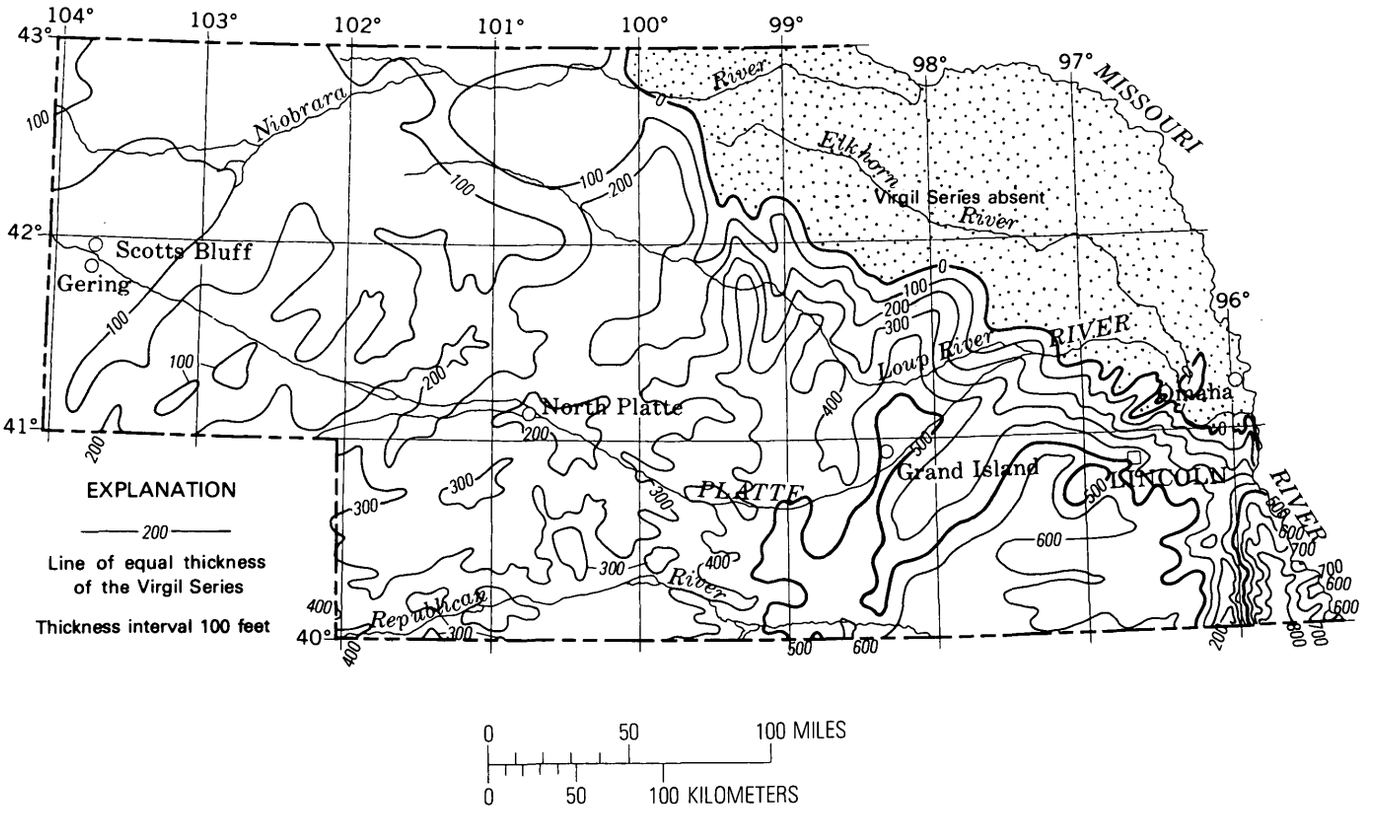

FIGURE 10.—Thickness of the Virgil Series in Nebraska.

braska, from oldest to youngest: Douglas Group, Shawnee Group, and Wabaunsee Group . (See fig. 7.)

DOUGLAS GROUP

The Douglas Group consists mostly of shale interbedded with some limestone but also includes some sandstone and a few beds of thin coal. Where the group crops out in Cass and Sarpy Counties, it is about 18 m (60 ft) thick, but in the subsurface it thickens southward to a maximum of 46 m (150 ft) in Richardson County. In ascending order, the Douglas Group is composed of the Plattford Shale, Cass Limestone, and Lawrence Shale.

SHAWNEE GROUP

Conformably overlying the Douglas Group is a distinctive cyclic sequence, the Shawnee Group, which consists mainly of limestone interbedded with several layers of shale and a few layers of sandstone. This group crops out in Cass, Otoe, Pawnee, and Saunders Counties. Its thickness ranges from 53 m (175 ft) on the Nemaha arch to 76 m (250 ft) in the Forest City basin. From oldest to youngest, the Shawnee Group comprises the following seven formations: Oread Limestone, Kanwaka Shale, Lecompton Limestone, Tecumseh Shale, Deer Creek Limestone, Calhoun Shale, and Topeka Limestone.

WABAUNSEE GROUP

Although the Wabaunsee Group includes several thin persistent layers of limestone and a few very thin coal beds, it consists mostly of shale, sandy shale, and sandstone. Outcrops occur in Cass, Johnson, Nemaha, Otoe, Pawnee, and Richardson Counties; wherever the basal beds are exposed, the Wabaunsee Group conformably overlies the Shawnee Group. Exposures of the group's upper boundary indicate that a period of erosion preceded deposition of the overlying rocks of Permian age. Locally, channels incised as much as 30 m (100 ft) into Wabaunsee rocks are filled with Permian sandstone. In the northern part of the Forest City basin and over the Nemaha arch, the upper part of the Wabaunsee Group either was not deposited or was removed by pre-Permian erosion. The maximum thickness of the group is about 122 m (400 ft). From oldest to youngest, the following 14 formations constitute the Wabaunsee Group: Severy Shale, Howard Limestone, Scranton Shale, Burlingame Limestone, Soldier Creek Shale, Wakarusa Limestone, Auburn Shale, Emporia Limestone, Willard Shale, Zeandale Limestone, Pillsbury Shale, Stotler Limestone, Root Shale, and Wood Siding Formation.

ENVIRONMENTS OF DEPOSITION

Pennsylvanian rocks in Nebraska, especially the Missouri Series and the lower part of the Virgil Series, consist of repeated sequences of beds. Such evidence for cyclic sedimentation characterizes the Pennsylvanian rocks throughout much of the midcontinent area.

Discovery of cyclic sedimentation is credited to Udden (1912), who noted that certain sequences of Pennsylvanian strata exposed in the Peoria quadrangle of western Illinois were clearly divisible into four parts, the same order of parts being repeated several times. Because one of the parts was a bed of coal and another a bed of limestone, each sequence, or cycle, indicated an alternation of nonmarine and marine deposition. A cycle was defined as all the strata between the base of one coal bed and the base of the next younger coal bed.

Weller (1930, 1931), who believed that diastrophism accounted for cyclical Pennsylvanian sedimentation, redefined a cycle. According to him (1931, p. 163), an ideal cycle consists of nine parts, listed from oldest (1.) to youngest (9.) as follows:

9. Shale containing "ironstone" bands in upper part and thin limestone layers in lower part.
8. Limestone.
7. Calcareous shale.
6. Black "fissile" shale.
5. Coal.
4. Underclay.
3. Fresh-water limestone.
2. Sandy and micaceous shale.
1. Sandstone with unconformity at the base.

In 1931, the Illinois State Geological Survey sponsored a symposium on cyclic sedimentation in the Pennsylvanian System. Those who attended included R. C. Moore, F. B. Plummer, D. B. Reger, G. H. Ashley, W. E. Stout, H. R. Wanless, and J. M. Weller, each of whom presented papers describing evidence for cyclic sedimentation in his part of the Central United States. The Illinois State Geological Survey published these papers in its Bulletin 60 (Weller, 1931).

Soon after the symposium, Wanless and Weller (1932) proposed that cyclic repetitions of strata, or "cyclothems," could be used to confirm interbasin and possibly regional correlations.

In 1936, Moore presented a slightly different, more detailed description of an ideal cyclothem. His sequence of beds, also listed oldest (.0) to youngest (.9), was as follows (1936, pp. 24–25) .

.9 Shale (and coal).
.8 Shale, typically with molluscan fauna.

.7 Limestone, algal, molluscan, or with mixed molluscan and molluscoid fauna.
.6 Shale, molluscoids dominant.
.5 Limestone, contains fusulinids, associated commonly with molluscoids.
.4 Shale, molluscoids dominant.
.3 Limestone, molluscan, or with mixed molluscan and molluscoid fauna.
.2 Shale, typically with molluscan fauna.
.1 *c.* Coal.
.1 *b.* Underclay.
.1 *a.* Shale, may contain land plant fossils.
.0 Sandstone.

In the same publication, Moore introduced the term "megacyclothem" for "a cycle of cyclothems." According to him, each cyclothem in a megacyclothem could be distinguished by the type of limestone it included. The limestone beds in cyclothems composing a megacyclothem were designated, in ascending order, as "lower," "middle," "upper," and "super" limestone sequences. Later regional studies showed that in a few localities the lower or upper parts of some megacyclothems are missing.

Moore's cyclothemic and megacyclothemic classification for Upper Pennsylvanian strata has aided the understanding of the changing environmental conditions during deposition of these beds.

Examination of sequential relationships in the Upper Pennsylvanian of the Nebraska part of the Forest City basin indicates that the megacyclothems differ somewhat from the ideal. If sedimentation took place during the early part of the megacycle, it usually was interrupted one or more times, resulting in the removal, by erosion, of most or all beds that had been deposited since the beginning of the megacycle. Thus, the early part of the megacyclothem generally is either thin or lacking. On the other hand, the middle and upper parts of the megacyclothems appear to be complete, or nearly so, and the sequence of beds is similar to that in the ideal megacyclothem already described.

Numbered from earliest (1.) to latest (7.), the succession of depositional events constituting most of the Nebraska megacyclothems is interpreted to have been about as follows:

7. Deposition of shale and sand under conditions of rapid accumulation and progressive return to nonmarine environment; swamp development in coastal plain.
6. Deposition of the "super" limestone in an increasingly brackish environment; only small to moderate amounts of argillaceous and siliceous impurities derived from adjacent land areas.
5. Deposition of dark shale in shallow seawater under conditions of slow accumulation of argillaceous and siliceous erosional products from adjacent land areas.
4. Deposition of the "upper" limestone when swamp drainage ceased and seawater cleared; shallowing of the sea resulted in formation of oolites in limestone and eventual cessation of carbonate deposition.
3. Deposition of black fissile shale when headward erosion of streams caused drainage of inland swamps and inflow of humic material to the sea.
2. Simultaneous deposition of thin "middle" limestone and shoreward expansion of inland swampy areas.
1. Simultaneous deposition of gray-green and red shale in a marine nearshore environment and formation of inland swamps.

The several rock groups composing the Upper Pennsylvanian in Nebraska differ somewhat in those parts of the complete megacyclothem of Moore (1936, pp. 24–25) that are represented, as indicated below:

Kansas City Group.—Part including "lower" limestone consistently absent; parts including "middle" and "upper" limestone sequences always present. Although the part that includes the "super" limestone sequence is generally present, it is absent from some megacycles.

Lansing Group.—All four limestone sequences generally represented.

Douglas Group.—Consists mostly of shale but includes the Cass Limestone, which is made up of a "middle" and an "upper" limestone separated by black fissile shale.

Shawnee Group.—All four limestone sequences generally represented.

Wabaunsee Group.—Consists primarily of shale, sandy shale, and sandstone interbedded with thin to moderately thick marine limestone that generally occurs in pairs. The lower limestone of each pair commonly is the thicker and more persistent; the upper commonly is less pure and is discontinuous. Absent from the Wabaunsee Group are limestone beds of the "lower" and "middle" limestone sequences, and also absent is the black fissile shale ordinarily associated with the "middle" limestone sequence. All the limestones in the group probably are thin representatives of the "upper" and "super" limestone sequences.

BIOSTRATIGRAPHY

Some of the marine beds in the Upper Pennsylvanian of Nebraska contain abundant fossils of invertebrates. Brachiopods, pelecypods, gastropods, crinoids, corals, bryozoans, and fusilinids are the more common types. A few fossils of trilobites and ostracodes also are found in these rocks. Publications by Condra (1903), Dunbar and Condra (1927; 1932), Miller, Dunbar, and Condra (1933), and Pabian (1970) describe the fossil fauna present in exposed Upper Pennsylvanian rocks.

Terrestrial beds, particularly those associated with coal, commonly contain fossil plant remains. Leaves of the ferns *Neuropteris Loshi* Brongt. and *Neuropteris hirsuta* Lesq., stems of rushes, and stems of *Calamites* were reported (Hayden, 1868, p. 327–329) from beds associated with coal seams at Brownville in Nemaha County and at Rulo in Richardson County. However, no detailed studies of the fossil flora have been made to date.

ECONOMIC PRODUCTS

COAL

Discovery of coal outcrops in southeastern Nebraska in the 1850's prompted wild claims about an inexhaustible supply of fuel reserves underlying that part of the State. Nor were the claimants quieted when F. H. Hayden (1868), a geologist from the University of Pennsylvania, conducted a survey of the area and concluded that no coal beds thick enough for large mining operations existed above drainage level. Even after borings failed to reveal coal beds more than a foot or two thick, many people were still convinced that workable supplies remained to be discovered.

Meanwhile, several small drift mines were being operated, but each supplied only enough coal for local use until, in 1906, the Honey Creek mine was opened in a seam 66 cm (26 in) thick. Located about 6.4 km (4 miles) southwest of Peru in Nemaha County, this was one of the few commercial mines to be operated in the State. Coal thickness was as much as 91 cm (36 in), but, in parts of the mine, the seam was too thin to be extracted profitably. Mining operations continued for only a year or two.

The oldest coal beds in Nebraska are in the Cherokee and Marmaton Groups, which make up the upper part of the Des Moines Series. Because neither of these groups crop out, the existence of the coal beds in them is known only from the results of test drilling. At least nine coal beds have been identified at depths ranging from 305 m (1,000 ft) to 701 m (2,300 ft) below land surface. Burchett (1977, p. 60) estimated that 7.7×10^9 metric tons (8.5 billion tons) of deeply buried coal are in southeastern Nebraska.

As many as eight coal beds are known in the Wabaunsee Group, the youngest of the three groups composing the Virgil Series. One or more of these coal beds crop out in each of the following counties: Cass, Otoe, Johnson, Nemaha, Pawnee, and Richardson. From oldest to youngest, these coals are known as the Nodaway, White Cloud, Elmo, Wamego, Dry, French Creek, Lorton, and Honey Creek (Burchett, 1977), as shown in figure 7. All but the last are very thin to thin, ranging in thickness from 3 cm (0.1 ft) to 0.37 m (1.2 ft). As stated earlier, the Honey Creek Coal is known to be as much as 91 cm (36 in) thick in the mine of the same name. The Nodaway, Elmo, Wamego, Lorton, and Honey Creek coals have the greatest lateral extent but differ in thickness from place to place. All have been mined, but only the Honey Creek supplied more coal than that needed for a few households. Burchett (1977, p. 38–55) estimated that 9.25×10^9 metric tons (10.2 million tons) of coal in southeastern Nebraska has an overburden that is less than 15.2 m (50 ft) thick.

All coal in the Pennsylvanian rocks in the Nebraska part of the Forest City basin is black and is either bituminous or subbituminous. It has a medium to high sulfur content.

OIL AND GAS

Oil production from Pennsylvanian age rocks beneath Dundy, Frontier, Furnas, Harlan, Hayes, Hitchcock, Lincoln, and Red Willow Counties in southwestern Nebraska is from zones ranging in depth from 914 m (3,000 ft) to 1,372 m (4,500 ft) below land surface. These zones occur in the Cherokee, Marmaton, Lansing-Kansas City, Douglas, and Shawnee Groups. Of the 9.825×10^5 kl (6,180,500 bbl) of oil produced in Nebraska in 1976, about 3.46×10^5 kl (2,176,600 barrels) were from rocks of Pennsylvanian age.

Volumes of gas produced were not measured.

SHALE

Pennsylvanian shale formerly was used in the manufacture of brick and tile at three Nebraska locations—Table Rock in Pawnee County, Humboldt in Richardson County, and Nebraska City in Otoe County. At the Nebraska City plant, which was the most recent to discontinue operations, Wabaunsee Group shale was used also for producing lightweight aggregate. Currently, shale of the Lansing Group is

being used in the manufacture of cement at a plant near Louisville in Cass County.

LIMESTONE

About 200 quarries, 26 of which were active in 1976, have been opened in limestone beds of Pennsylvanian age. Three-fourths of these quarries are in Cass County; the others are in Johnson, Otoe, Pawnee, Richardson, Sarpy, and Washington Counties. Of the currently operated quarries, 20 are in Cass County, 3 are in Sarpy, 1 is in Saunders, and 2 are in Washington. Total production from these four counties, in 1975, was 3.45×10^6 metric tons (3.8 million tons).

Seven companies operate the 20 active quarries in Cass County. Production is from the Kansas City, Lansing, Douglas, and Shawnee Groups. Limestone from two quarries operated by the same company is used in the manufacture of cement. Most of the production from the other quarries is used as crushed stone for concrete aggregate, asphalt aggregate, road surfacing, riprap, and agricultural lime. The remainder is used for wallstone or is finely ground for use as filter or as a feed supplement.

The three limestone quarries in Sarpy County are in the Kansas City Group. Their production is used for road surfacing, riprap, and wallstone.

The only limestone quarry in Saunders County is in the Lansing and Douglas Groups. Its production is used for concrete aggregate, asphalt aggregate, road surfacing, agricultural lime, riprap, and wallstone.

A single company operates both of the limestone quarries in Washington County. Production is from the Kansas City Group and is used for concrete aggregate, asphalt aggregate, road surfacing, agricultural lime, and riprap.

WATER

In areas where Pennsylvanian strata are the uppermost bedrock, water generally can be obtained from the overlying glacial drift or from stream alluvium. However, in some places, wells have been extended into the Pennsylvanian limestone and sandstone where the mantling deposits either are not water bearing or yield less water than needed. Yields from bedrock generally are small.

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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 GOVERNMENT PRINTING OFFICE, WASHINGTON : 1979

UNITED STATES DEPARTMENT OF THE INTERIOR

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GEOLOGICAL SURVEY

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FOREWORD

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

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

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

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

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.

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