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

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

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

By GARLAND D. ELLS[1]

ABSTRACT

The Michigan basin covers about 315,968 km^2. (122,000 sq mi). On the west it is bounded by the Wisconsin arch and Wisconsin dome, and to the north by the Canadian shield. To the southwest it is separated from the Indiana-Illinois basin by the Kankakee arch, and to the southeast it is cutoff from the Appalachian basin by the Findley and Algonquin arches. The basin contains Cambrian, Ordovician, Silurian, Devonian, Mississippian, Pennsylvanian, and remnant Jurassic sediments. Pleistocene glacial drift, as much as 366 m (1,200 ft) thick, blankets virtually all bedrock.

Carboniferous rocks, generally separated into Mississippian and Pennsylvanian in Michigan, form most of the bedrock surface. The combined thickness of these rocks is about 1,158 m (3,800 ft). Because of limited outcrops and the fact that the complete sequence cannot be studied in outcrop, Carboniferous rocks are best known from subsurface investigations made possible from thousands of well records. Though formation names have been derived from outcrop localities, the thickness and characteristics of the rock units have been determined by subsurface studies.

Studies have shown that Mississippian rocks are of marine origin, were deposited under different environments of deposition, and that an erosional unconformity of considerable magnitude separates Mississippian strata from those of the overlying Pennsylvanian system. Pennsylvanian rocks are terrestrial and marine and were deposited under several modes of environment. The original extent and thickness of Pennsylvanian rocks in Michigan is unkown. Also dissected and partly eroded before Pleistocene glaciation, they are now confirmed to the basin interior and cutoff from correlative rocks in other basins. Before Pleistocene glaciation, Jurrassic sediments were deposited over part of the eroded surface.

Most of Michigan's Carboniferous studies have been made with the objective being the exploitation of the contained resources. The nomenclature applied to these rocks has been guided to a considerable extent by the needs of industry rather than from an academic point of view. Regional and inter-basin correlations have been made on the basis of fossil assemblages and similar lithologies. Terms such as "Red Rock," "Triple Gypsum," "Stray Sandstone," serve a useful purpose in the search for economic products. Economic products currently extracted from Michigan's Mississippian rocks include shales, limestone, sandstone, gypsum, natural brines, oil and natural gas, and in some areas, freshwater. In the past Pennsylvanian rocks have provided bituminous coal and small amounts of natural brines. Current economic products are shales and freshwater supplies.

INTRODUCTION

The basin-shaped characteristics of the depositional province known as the Michigan basin have been recognized for nearly 140 years. The basin, as generally defined, includes the Southern Peninsula and eastern part of the Northern Peninsula, eastern Wisconsin, northeastern Illinois, northern Indiana, northeastern Ohio, and western Ontario. The basin covers about 315,968 km^2 (122,000 sq mi), part of which is covered by Lakes Michigan, Huron, St. Clair, and the Michigan part of Lake Erie. The basin is flanked on the west by the Wisconsin arch in central Wisconsin and its northern extension the Wisconsin dome; on the north and northeast by the Canadian shield; on the east and southeast by the Algonquin arch in Ontario and the Findlay arch in northern Ohio; and on the southwest by the Kankakee arch in northern Indiana and northeastern Illinois.

Nearly all Paleozoic systems are present in the basin as well as an area of remnant Mesozoic rock. Except for small scattered outcrops, the bedrock surface of the basin is covered with glacial drift deposited during the Wisconsin stage of the Pleistocene. The drift is as much as 366 m (1,200 ft) thick in some areas, especially where parts of thick terminal moraines may overlie preglacial valleys. Mississippian, Pennsylvanian, and Jurassic sediments form most of the truncated bedrock surface of the Southern Peninsula. Not all formations outcrop. Those that do are of small extent, are widely scattered, and limited to areas of thin drift.

The stratigraphic succession of rocks in the Michigan basin is best known from subsurface studies made possible from the records of thousands of oil- and gas-well borings and other types of wells drilled over the years. Because of limited outcrops which seldom expose more than a few meters of vertical

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section, even in manmade openings such as quarries, most of the Mississippian and Pennsylvanian rock units have been measured from well-record studies. The formation names were derived from localities where the rocks were first noted and studied.

Complete sections of Mississippian and Pennsylvanian rocks are not found in outcrop, nor are the contacts between formations visible at the surface. The combined thickness of these rocks is about 1,158 m (3,800 ft). Because of shifting depocenters during several periods of sedimentation, erosional unconformities between Mississippian, Pennsylvanian, and Jurassic rock, and erosion before Pleistocene time, the combined thickness is not found in any one locale. The distribution of Carboniferous and Jurassic bedrock beneath unconsolidated Pleistocene glacial deposits is shown in figure 1.

Because of the mantle of glacial drift, the events following deposition of Carboniferous rocks are not well known. Subsurface investigations show that a major unconformity exists at the top of Mississippian rocks, at the top of Pennsylvanian rocks that overlie the Mississippian, and at the top of a small area of Jurassic sediments that immediately overlie a part of the eroded Pennsylvanian section. The truncated bedrock surface was scoured and modified by continental glaciers during the Pleistocene Epoch. Studies show that the preglacial bedrock surface was greatly incised by valley systems whose major tributaries led to larger preglacial valleys now occupied by Lakes Michigan and Huron. Bedrock elevations suggest two stages of uplift as evidenced by peneplained surfaces. On the basis of deformation of the Lake Algonquin shoreline, one of several ancient Great Lakes shorelines, an unwarp has been postulated for much of the northeastern part of the Southern Peninsula. The upwarp of the land took place in response to withdrawal of the Pleistocene ice sheet (Stanley, 1945, pp. 11–13). Present-day stream channels are incised in glacial drift and follow a haphazard pattern which may be influenced by glacial features such as moraines. In a few areas, where drift is thin, streams cut through bedrock and may be channeled through part of their course in preglacial valleys.

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 Geological Survey Division, Michigan Department of Natural Resources.

EARLY GEOLOGICAL WORK

The Geological Survey of Michigan was instituted by legislative act in 1838. Douglass Houghton, Michigan's first State Geologist, made his first report to the Legislature in 1838. The sequence of Carboniferous rock which he was able to identify was simply referred to as Upper Sandstones and Coal Measures. With the discovery of coal in 1835 (Cohee and others, 1950) and the drilling of wells for brine to be used in the salt-making process, a considerable nomenclature soon began to develop for Carboniferous formations. A prominent and later State Geologist, Alexander Winchell, introduced in 1869 the term "Mississippian group" for the Carboniferous limestones of the Mississippi River Valley. Not until 1901, however, was the term Mississippian used to designate a part of Carboniferous rocks in Michigan. In 1901, Alfred Lane, another State Geologist, introduced the terms Pennsylvanian and Mississippian and referred both to the Carboniferous. But in Lane's 1904 report, both terms were dropped in favor of Carboniferous, only to reappear again in 1908. The term Carboniferous remained in general Survey usage until 1933. It was then considered obsolete and finally replaced by Mississippian and Pennsylvanian designations.

Rocks now defined as Mississippian and Pennsylvanian have been variously subdivided and grouped by the Survey. Until 1901, most rock divisions now classified as Mississippian were classified as Devonian. After that date, the stratigraphic boundary between Devonian and Mississippian rocks became better defined and has remained virtually the same since then. The stratigraphic nomenclature applied to Mississippian and Pennsylvanian rocks from 1837 to 1956 has been documented in chart form (Martin and Straight, 1956).

MISSISSIPPIAN SYSTEM

Early and Late Mississippian rocks are recognized in the Michigan basin. Early Mississippian rocks of Kinderhookian age include most of the Bedford Shale, the Berea Sandstone, Sunbury Shale, and Coldwater Shale. The Coldwater Shale grades upward into the Marshall Sandstone without an apparent time break, and is considered to be of Osagian age. The remaining Mississippian rocks include the Michigan Formation and the overlying Bayport Limestone. The Michigan Formation, which overlies the Marshall Sandstone, appears to grade upward from the Marshall without a break in sedimentation. The Bayport Limestone, the stratigraph-

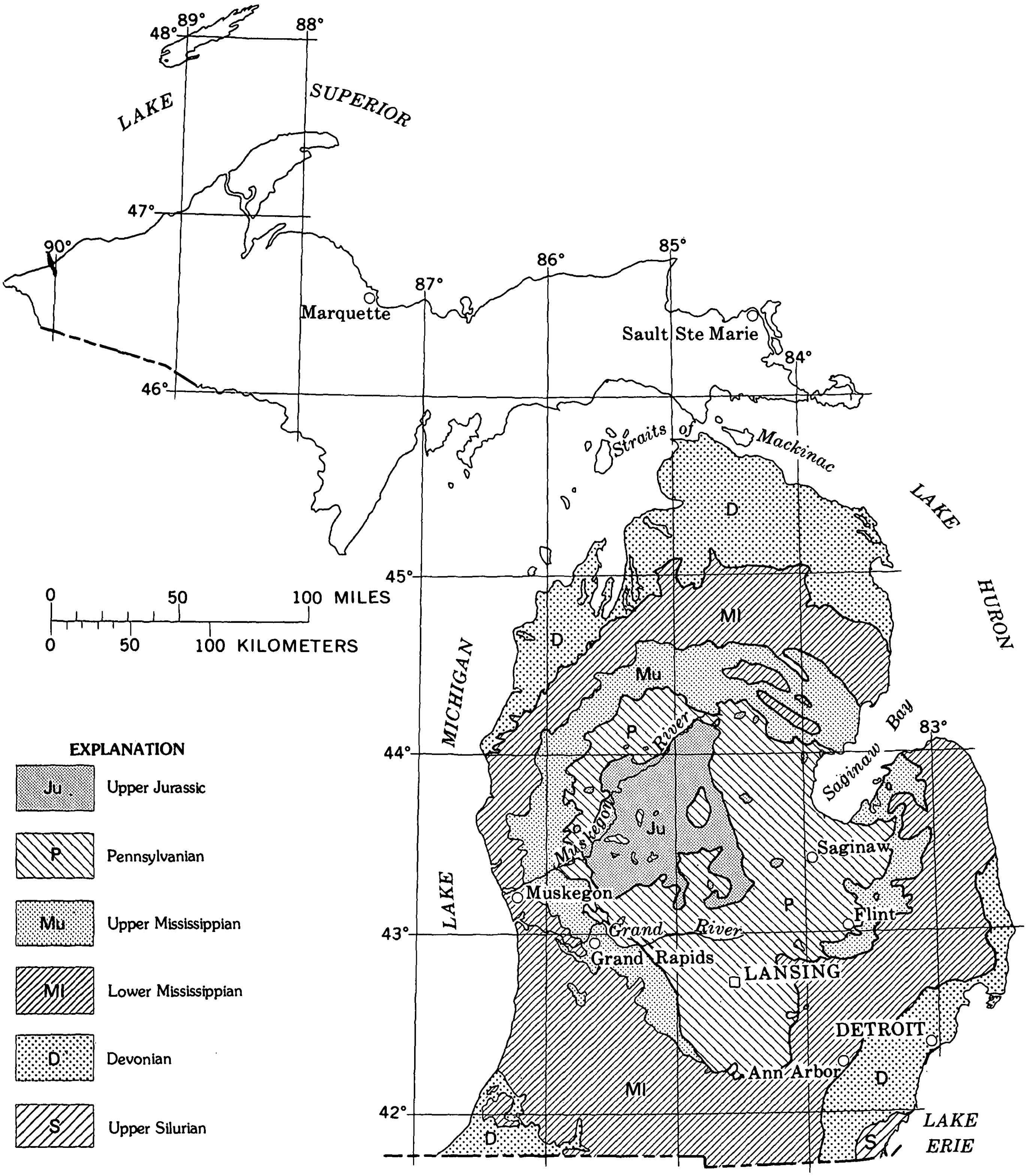

FIGURE 1.—Distribution of Mississippian, Pennsylvanian, and remnant Jurassic bedrock in the Southern Peninsula of Michigan. Jurassic rocks overlie a part of the Pennsylvanian section and are limited to the basin interior. Outermost bedrock areas of the Southern Peninsula are Devonian except for a small area of Upper Silurian strata near the western end of Lake Erie. Distribution of bedrock units adapted from Kelley (1968).

TABLE 1.—*Mississippian nomenclature, 1947–64*

1956 Martin and Straight				1964 Ells and others			
Series		Group	Formation	Series	Group	Formation	Member
Iowan		Meramec Osage	Bayport-Au Gres Limestone Michigan "Michigan Stray"	Meramecian	Grand Rapids	Bayport Limestone Michigan	"Triple Gypsum" Brown Limestone "Stray Sandstone"
Iowan	Kinderhook	Marshall	Napoleon Sandstone Lower Marshall Sandstone	Osagian	Marshall	Marshall Sandstone	Napoleon (Stray Sandstone Member)
Iowan	Kinderhook	Coldwater	Coldwater Shale Richmondville Sandstone Coldwater Limestone "Red Rock"	Kinderhookian	Coldwater	Coldwater Shale	Coldwater Limestone Weir Sandstone "Red Rock"
Iowan	Kinderhook		Sunbury Berea Bedford Ellsworth	Kinderhookian		Sunbury Shale Berea Sandstone Bedford Shale Ellsworth Shale	

ically highest Mississippian rock identified in Michigan, likewise appears to lie conformably on the Michigan Formation. Both are classified as Meramecian or Late Mississippian.

No break in sedimentation is apparent from Devonian into Mississippian time (Cohee and others, 1951); thus the boundary between the two systems is obscure and not well defined lithologically. The boundary is believed to be within the basal few feet of the Bedford Shale in eastern Michigan and the upper part of the Ellsworth Shale of western Michigan. An unconformity of considerable magnitude cuts across Mississippian formations in Michigan. Pennsylvanian sediments were deposited on this eroded surface and were in turn eroded. Table 1 shows the nomenclature commonly applied to Mississippian rocks in Michigan from 1947 to present.

Contact with underlying rocks.—In the Appalachian basin the Devonian-Mississippian boundary is in the basal few feet of the Bedford Shale. The Bedford Shale, Berea Sandstone, and Sunbury Shale of the Appalachian region can be projected into the Michigan basin with considerable confidence, although these formations no longer connect with the Michigan basin. On this basis, and because of the lack of evidence to the contrary, the boundary in Michigan is also placed in the basal few feet of the Bedford (DeWitt, 1970, p. G 10).

In the eastern sector of the Southern Peninsula, the Bedford Shale, the overlying Berea Sandstone, and the Sunbury Shale subcrop in a narrow band beneath the glacial drift and then offshore in Lake Huron. North of Saginaw Bay (fig. 1) they turn inland and again subcrop beneath glacial drift. No outcrops of these rocks are found in the Michigan basin.

In eastern Michigan the gray Bedford Shale lies directly on the black, radioactive Antrim Shale of Devonian age (Chautauquan). The Antrim as defined in eastern Michigan is a facies of most of the greenish-gray Ellsworth Shale of western Michigan. The Bedford and the Berea and Sunbury formations above it thin in a westward direction and merge laterally into the upper approximately 30 m (100 ft) of the Ellsworth Shale.

Contact with overlying rocks.—In the central part of the basin, Mississippian rocks are overlain by sedimentary rocks of Pennsylvanian age which were deposited on an erosion surface. A sizable area of remnant Jurassic rock overlies a part of the Pennsylvanian (fig. 1). According to Cohee (1965), part of these Jurassic sedimentary rocks overlap onto Mississippian strata. Where not immediately overlain by Pennsylvanian or Jurassic rock, Mississippian strata are immediately overlain by Pleistocene glacial deposits. The extent of pre-Pennsylvanian erosion and the amount of sediments that may have been removed is unknown. Though now isolated within the Michigan basin, the continuation of certain Lower and Upper Mississippian rocks into adjacent regions outside the defined limits of the Michigan basin is well established (Cohee and others, 1951).

To the northwest, in the western part of the Upper Peninsula, small outliers of Middle and Upper Ordovician, Middle Silurian, and Middle Devonian rocks are found at Limestone Mountain in Houghton County (Case and Robinson, 1915). Now completely surrounded by Precambrian rock, these outliers show that Paleozoic sediments extended far to the north of their present limits in the Michigan basin. Though Mississippian rocks are now found only in the Southern Peninsula, possibly they, too, once extended far north of their present limits. Devonian and Mississippian strata were deposited in northeastern Illinois as shown by their preservation in fault blocks in the Des Plaines Disturbance, an area north of Chicago, Ill. (Willman, 1962). Except for such isolated locales, these strata were largely truncated during erosion of the pre-Pennsylvanian surface.

According to subsurface data, several hundred feet of Mississippian rocks were eroded from anticlines in the vicinity of Saginaw Bay before deposition of Pennsylvanian rocks. The erosional episodes before Pleistocene glaciation were no doubt complex. The preglacial drainage systems that carried sediments away from the central part of the Michigan basin are not well established in some areas as well control is lacking. In areas of abundant well control, preglacial valleys lead into the valleys now occupied by the Great Lakes.

Structural events involving Carboniferous rocks.—Throughout most of the Michigan basin, anticlines trend in a northwest direction. Early recognition of this fact was useful in the development of the State's oil and gas industry. Oilfield studies show that most anticlines in Michigan were developed during several stages of folding beginning in Middle Ordovician time and continuing, intermittently, into Mississippian. Structure mapping of numerous Mississippian formations and marker beds show similar folding. Michigan's stratigraphically youngest Mississippian formation, the Bayport Limestone, varies in thickness because of the erosional unconformity which separates it from the overlying Pennsylvanian rock. Presumably the Bayport Limestone, and other Mississippian strata which may have been deposited above it but later eroded, was also folded.

Faults have been observed in Pennsylvanian rocks and must also occur in Mississippian rocks. Subsurface investigations show that faulting has taken place along the flanks of such structures as the Howell-Northville anticlines and others included in the Washtenaw anticlinorium (Ells, 1969); Fractures, brecciation, and steep dips which may suggest faulting, have been observed in Ordovician, Silurian, and Devonian rocks, but have not been reported in Mississippian sediments associated with these structures.

Along the Howell anticline near the Howell gas storage field, more than 305 m (1,000 ft) of structural movement has taken place. Over the crest and higher part of the structure, in certain areas, the Berea Sandstone is eroded and found immediately beneath the glacial drift (Ells, 1969). At the northern end of the structure, Pennsylvanian strata are found on both sides of the feature, and it is likely that they, too, were folded and later eroded. The Howell anticline is the most prominent structure in this area of en echelon folds. Recent studies (Wanless and Shideler, 1975) suggest that at the beginning of Morrow time, the anticlinal areas stood above the surrounding depositional plain as a monadnock several hundred feet high, but was buried by the end of Morrow time.

Upper Silurian (Cayugan) salt beds have been dissolved in places along the west edge of the Howell anticline. Solution of salt and subsidence of certain formations appear to have taken place mainly during Devonian time. Solution channels are probably related to fractures associated with the fault zone. Some evidence exists that Mississippian rocks as high in the sequence as the Sunbury Shale were affected in areas of greater subsidence. Contours on the top of this formation show closed depressions over areas of probable salt removal.

Igneous and metamorphic rocks.—There is no evidence in the Michigan basin of igneous actiivty during Mississippian and Pennsylvanian time. A

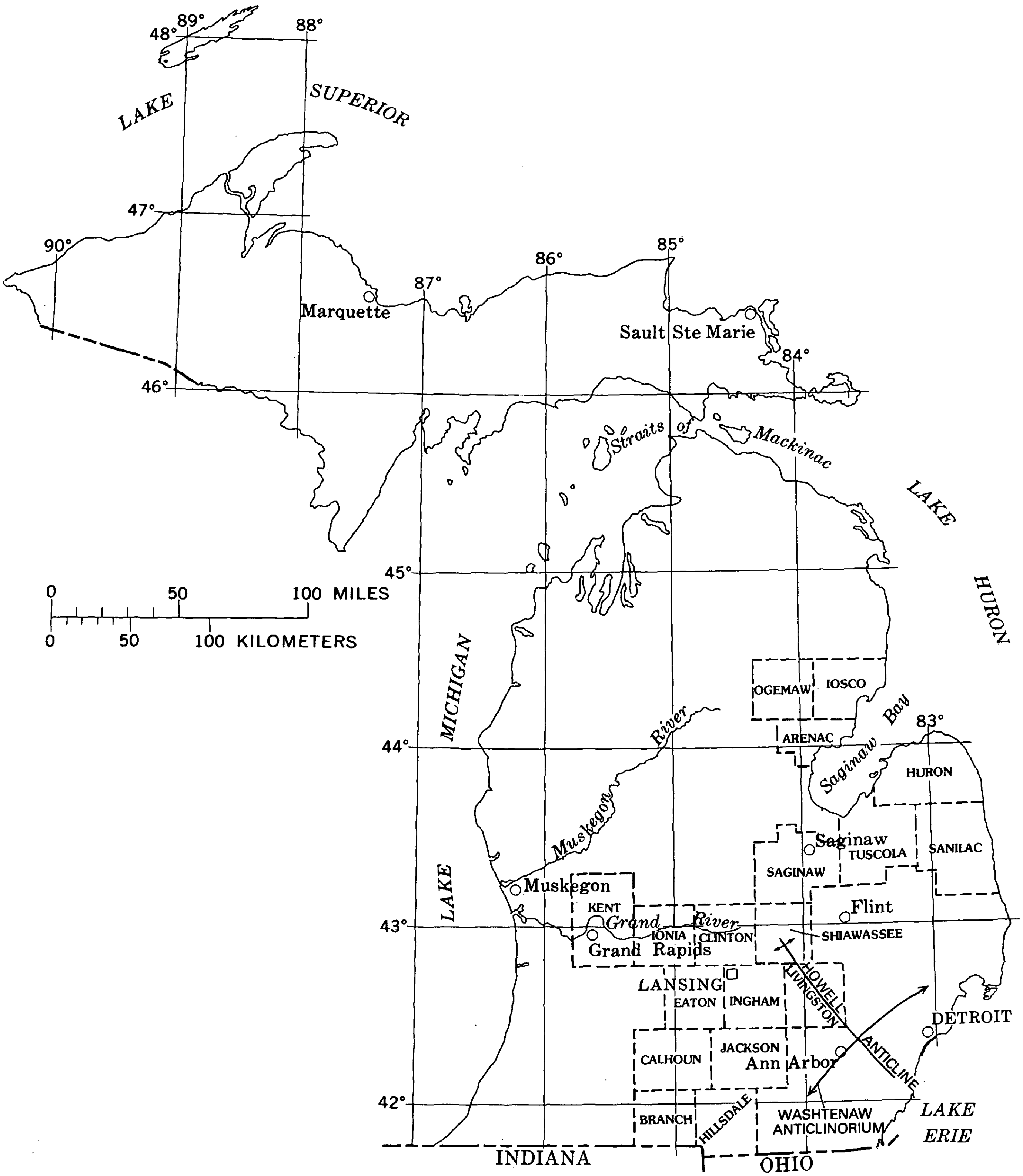

FIGURE 2.—The northwest-trending Howell anticline is one of the most prominent structures associated with the Washtenaw anticlinorium, a region containing several similar-trending structural features that plunge basinward. See figure 1 for areal bedrock geology associated with this feature. Counties having outcrops of Mississippian or Pennsylvanian rock are outlined.

bentonite zone has been noted in Middle Devonian rocks in the basin (Baltrusaitis, 1974) but no ash beds have been found in Mississippian or Pennsylvanian rocks. Rocks of both systems show no signs of alteration that might be related to metamorphism.

MISSISSIPPIAN FORMATIONS

As mentioned earlier, no break in sedimentation is apparent from Late Devonian into Mississippian time. The boundary between the two systems is within the basal part of the Bedford Shale which immediately overlies the Antrim Shale of Devonian age (Chautauquan) in eastern Michigan and the upper part of its correlative, the Ellsworth Shale of western Michigan.

Bedford Shale.—The Bedford Shale and the overlying Berea Sandstone were first identified in Michigan from a well in southeastern Michigan (Rominger, 1876). These formations subcrop beneath the glacial drift and have not been identified at the surface in Michigan. They are correlated with the Bedford, Berea, and Sunbury of Ohio on the basis of lithology and stratigraphic position. They are not continuous from Michigan into Ohio, having been eroded from the Findlay arch in northwestern Ohio and in Ontario, Canada. The Bedford is a silty, gray shale containing numerous stringers of Berea-type sandstone. The upper part of the Berea contains Bedford-type shale stringers; thus the Bedford and Berea are frequently treated as a single formation. Gamma ray-neutron logs show these features but also show a definite separation between the two formations. The Bedford is as much as 61 m (200 ft) thick in eastern Michigan but thins westward and merges into the upper part of the Ellsworth Shale.

Berea Sandstone.—The Berea Sandstone in Michigan has been divided into three lithologic units (Cohee and others, 1951). The lower unit is light gray, fine grained, dolomitic sandstone which is silty and shaly, cemented with silica and dolomite, and is micaceous and pyritic. The middle unit is friable, fine grained sandstone composed of angular quartz grains. The upper unit is lithologically similar to the lower unit but is less shaly and pyritic. The Berea is thickest around Saginaw Bay. Like the underlying Bedford Shale, the Berea thins westward, and about mid-basin it merges into the upper part of the Ellsworth Shale. The thin facies found in the upper part of the Ellsworth is sometimes referred to as "Berea."

The Bedford Shale and Berea Sandstone of northeastern Ohio and northwestern Pennsylvania are associated with deltaic deposition (DeWitt, 1970). As the same formations are correlated with similar rocks occupying the same stratigraphic position in Michigan, the inference is that they are also a part of the same deltaic system. According to Cohee (1965), the clastic materials making up the Bedford and Berea formations came from Ontario and the Canadian shield and were carried into the eastern side of the Michigan basin as deltaic deposits. The name commonly applied to the part of the Southern Peninsula east of Saginaw Bay, where these rocks are thickest and best formed, is "the thumb." Accordingly, Cohee named the Bedford-Berea deltaic deposits the Thumb Delta. The Sunbury Shale, normally not considered a part of the deltaic deposits, lies immediately above the Berea Sandstone.

Sunbury Shale.—The Sunbury Shale is more widespread within the basin and is thickest in the same general area of the basin as the Bedford and Berea formations. More than 30 m (100 ft) thick in the Saginaw Bay region near Lake Huron, the Sunbury is a black to dark-brown shale lithologically similar to the Antrim of Devonian age. First identified by Lane in 1909 from well cuttings, it is known in Michigan only from subsurface studies. It extends over most of the Southern Peninsula, but thins and grades into gray and greenish-gray shales in the top part of the Ellsworth Shale in places in the western and southwestern part of the State.

Coldwater Shale.—The Coldwater Shale is one of the most widespread and thickest of Mississippian formations. Predominantly a gray to bluish-gray shale, it is about 396 m (1,300 ft) thick in the central part of the basin. Named by Lane in 1895 from small exposures along the Coldwater River near Coldwater, Mich., other small outcrops are found at places in Branch and Hillsdale Counties and along the shores of Lake Huron in Huron and Sanilac Counties. The Coldwater Shale extends beneath the drift into northern Indiana and northwestern Ohio. It is correlated with the Borden Group of Indiana and Illinois and the Cuyahoga Group of Ohio.

In the western part of the basin, the Coldwater Shale is similar to upper parts of the underlying Ellsworth Shale. The two formations are separated by a useful marker bed referred to as Coldwater "Red Rock." From 3–6 m (10–20 ft) thick, it consists of red limestone, red shale, dolomite, and glauconitic dolomite. It can be traced eastward above the black Sunbury Shale but does not extend everywhere within the eastern part of the basin. The Coldwater "Red Rock" may be equivalent to the

Rockford Limestone of Indiana and Illinois (Cohee and others, 1951). But according to Lineback (1970, p. 35) the Rockford Limestone is not found in the Michigan basin.

Several facies have been identified within the Coldwater Shale sequence but cannot be traced across the basin. In an area of western Michigan, an argillaceous dolomite zone commonly referred to as the "Coldwater Lime" or "Speckled Dolomite" is about 91 m (300 ft) above the base of the shale (Hale, 1941). This zone grades eastward into shale. On the eastern side of the basin several sandstone beds are found in the upper part of the Coldwater Shale and may correlate with scattered surface exposures near Richmondville in Sanilac County. A silty sandstone interval near the base has been called the Weir Sandstone, but like most of these lenticular sandstone beds, it does not extend for any great distance in the subsurface. The small exposures of Coldwater Shale are not representative of the sequence as known in the subsurface. In the subsurface the Coldwater grades upward into the Marshall Sandstone, thus making the contact between the two formations difficult to define in most areas.

Marshall Sandstone.—The Marshall Sandstone, which overlies the Coldwater Shale, is frequently divided into two members: the lower Marshall and the Napoleon Sandstone. The Marshall Sandstone was named by Winchell in 1861 from outcrops around Marshall, Calhoun County, Mich. At an earlier date (1838), Douglass Houghton, Michigan's first State Geologist, had named the upper part of the Marshall, the Napoleon Sandstone, from exposures around Napoleon, Jackson County, Mich. In 1900, Lane designated these rocks as the upper Marshall Sandstone. The Napoleon persists as a member bed, though there is little need for such a designation.

Because of the indefinite contact between the Marshall and underlying Coldwater Shale in most parts of the basin, thickness values assigned to the entire Marshall section range from 46 to 122 m (150 to 400 ft). Electric-log studies show better definition of the Coldwater Shale-Marshall Sandstone contact than ordinary well-cutting investigations. The Marshall also has silty shale beds that can be best traced by use of electric logs of the gamma-ray type.

The Marshall Sandstone also has affinities with the overlying Michigan Formation. The basal part of the Michigan Formation intergrades with the upper Marshall, particularly in the central part of the basin. A sandstone, most frequently referred to as the "Stray Sandstone" and assigned to the basal part of the Michigan Formation, overlies and interfingers with the lithologically similar sandstone, the Marshall. The boundary between the two sandstones is not easily determined. In the past the "Stray," which produces gas, has been compared with "shoestring sands," or sandbars, such as those in Oklahoma and Kansas (Ball and others, 1941). Modern logging techniques and more abundant well control suggests a variable but blanket-type deposit rather than isolated, linear sandbars. The underlying Marshall, which also produces gas in a few fields, is a blanket-type sandstone body. The so-called "Stray" can be traced into the Napoleon Sandstone of the outcrop area. Evidently there was little, if any, break in deposition from Marshall time into Michigan Formation time.

The Marshall Sandstone is confined to the Southern Peninsula and apparently was removed from a much larger area by pre-Pleistocene erosion. According to Cohee and others (1951), the Marshall Sandstone overlying the Coldwater Shale is probably the time equivalent to the upper part of the Borden Group (Osage) of northern and southern Indiana.

Michigan Formation.—The Michigan Formation, now cut off from correlative rocks in other States, consists of gray to dark-gray and greenish-gray shale, thin beds of limestone, dolomite, sandstone, and anhydrite and gypsum. Originally called Michigan Salt Group by Winchell (1861), the formation was described from exposures at Grand Rapids, Kent County, and from exposures along the shore of Tawas Bay on the west side of Saginaw Bay. Although brines are found in the porous parts of the formation, no bedded halite has been found in the thousands of wells which have now penetrated the section. The name was eventually changed to Michigan Formation.

As previously noted, the basal sandstone of the Michigan Formation intergrades with the upper Marshall in the central basin. Some geologists have described these basal sandstones as reworked Marshall (Newcombe, 1933) thus implying an erosion surface between the "Stray" sandstone and the upper Marshall, or Napoleon Sandstone. The Michigan Formation, now confined to the central part of the basin and cut off from correlative strata in adjacent basins, is believed to be lower Meramac in age. The thickness of this formation is about 183 m (600 ft).

Facies changes are evident within the Michigan Formation. Depositional pinchout of shale beds or merging of shale beds into sandstones is common. However, several key beds show widespread continuity and are useful in mapping subsurface structures. The stratigraphically lowest marker bed, referred to as "brown lime" or "brown dolomite," is about 4.5 m (15 ft) thick and is found from 30 to 46 m (100 to 150 ft) above the "Stray Sandstone" in the central basin areas. Another marker, referred to as "Triple Gyp zone" (Wolcott, unpub. data, 1948) consists of three anhydrite beds separated by thin shale stringers. This zone, about 9 m (30 ft) thick and about 12 m (40 ft) above the "brown lime," is especially evident in electric logs of the gamma ray-neutron type. Other anhydrite beds may be traced for considerable distances.

Bayport Limestone.—The Bayport Limestone is the youngest Mississippian rock identified in Michigan. Originally called Point Au Gres Limestone from small outcrops on the west shore of Saginaw Bay (Douglass, 1841), better exposures were found around Bayport, Huron County, Mich., so the name was changed to Bayport Limestone in 1899 by Lane. Scattered outcrops are found in several areas of the basin but the best exposures are found in quarries in Eaton, Huron, and Arenac Counties.

The Bayport is light buff to brown and contains chert, frequently in spherical-shaped forms along certain bedding planes. The basal part may be arenaceous or may contain thin sandstone beds in some regions. The thickness is variable and generally less than 30 m (100 ft). According to thickness maps (Cohee and others, 1951), the Bayport has been completely removed by pre-Pennsylvanian erosion from several areas of the central part of the basin.

The Bayport is considered to be conformable on the Michigan Formation and is treated as a formation of the Grand Rapids Group. The fauna indicates correlation of the Bayport Limestone with the upper part of the St. Louis Limestone and the Ste. Genevieve Limestone of the Mississippi Valley (Newcombe, 1933). Newcombe also states that the beds can be compared approximately with the Maxville Limestone of Ohio. The Bayport is now isolated and cut off from its correlative sections in adjacent basins.

PENNSYLVANIAN SYSTEM

Pennsylvanian rocks cover an area of approximately 29,784 km^2 (11,500 sq mi) in the central basin (fig. 1). The sequence has been variously divided by different geologists since the coal-bearing measures were first discovered near Jackson, Jackson County, in 1835. The most extensive nomenclature was formulated by Lane in 1901, 1905, and 1908 when Michigan coal was an important resource. Studies were made by Kelly (1933, 1936) in which the cyclothemic nature of the strata was recognized. A more recent evaluation of Michigan's Pennsylvanian sequence was made by Wanless and Shideler (1975) who derived most of the thickness and lithology data from logs of oil-well borings. The nomenclature used in 1861 and at various times through 1975 is shown in table 2. Because Michigan coal measures have little economic import at this time, and records of wells that penetrate these rocks are not definitive in detail, Pennsylvanian rocks are commonly divided into a Saginaw Formation (Pottsville Series) and an overlying Grand River Formation (Conemaugh Series). The Parma Sandstone, long considered the basal formation of the Pennsylvanian section, cannot be traced throughout the basin. Because of its very restricted occurrence, it is treated as an unnamed unit of the Saginaw Formation.

Outcrops of Pennsylvanian strata are extremely limited in the Michigan basin because of the thick cover of Pleistocene glacial drift. A concentration of outcrops is found along the Grand River near the town of Grand Ledge, Eaton County, and along the Grand River valley in the City of Jackson, Jackson County. Most of the knowledge of Michigans' Pennsylvanian section has come from study of coal borings (Andrews and Huddle, 1948; Cohee and others, 1950), from data gathered from coal mines and open pits when they were in operation, and from a large number of oil-well borings. These studies concentrated on the coal resource.

Subsurface studies show erosional unconformities at the top and base of the Pennsylvanian section, so the thickness values vary over different parts of the basin. Thicknesses range from as much as 91 to 152 m (300 to 500 ft) in the Saginaw Bay region to more than 213 m (700 ft) farther west in the basin (Cohee and others, 1951). Thickness determinations are complicated by similar lithologies of sedimentary rocks of Jurassic age which overlie part of the Pennsylvanian section and by the Michigian Formation-Bayport Limestone of Mississippian age which underlies the section.

PENNSYLVANIAN FORMATIONS

The most definitive stratigraphic studies of Michigan's Pennsylvanian system are probably those by Kelly (1930, 1931, 1933, 1936). Kelly recognized the cyclical nature of the many strata and the unconformities which separate many of them. He referred to the coal-bearing interval as the Saginaw Group and presented evidence that the Verne Limestone was a comparatively persistent member and a convenient place to divide the Saginaw Group into pre- and post-Verne cyclical formations (table 2). Occasionally the Verne Limestone can be recognized in well cuttings obtained by cable-tool drilling, but in general pre-Verne and post-Verne cyclical formations are difficult to correlate for any distance. Therefore the Saginaw is treated as a single formation. The Parma Sandstone, long considered the basal formation of the Pennsylvanian, is now treated as an unnamed unit of the Saginaw Formation because of its restricted occurrence and doubtful correlation from region to region. The uppermost division of the Pennsylvanian referred to by Kelly (1936) as the Grand River Group, is mainly a sandstone interval and is treated as a single formation.

Saginaw Formation.—The aggregate thickness of Pennsylvanian rocks is probably 213–229 m (700–750 ft). Most of this thickness is assigned to the Saginaw Formation. The Saginaw is composed of material of freshwater, brackish water, and marine origin. It consists of sandstones, shales, coal, and limestones. According to Kelly (1936, p. 165), and others, individual strata vary in character and thickness within relatively short distances. Numerous unconformities have disrupted cyclothem sequences and in places the complete sequence appears to have been removed by erosion. Coal beds are thin and discontinuous. Recent investigations (Kalliokoski and Welch, 1976), using primarily water-well and oil-well records, show that very few coal occurrences are outside of the six-county area surrounding the tip of Saginaw Bay. This six-county region represents less than half of the areal distribution of Pennsylvanian rocks shown in figure 1.

TABLE 2.—*Pennsylvanian nomenclature in Michigan, 1861–1975*

1861 Winchell	1876 Rominger	1895 Lane	1901 Lane	1905 Cooper	1908 Cooper	1909 Lane	1912 Smith	1931 Newcombe	1933 Kelly
Woodville	Coal measures	Woodville		Woodville absent in Bay County	Woodville absent in Tuscola County	Woodville Ionia suggested	Woodville	"Red Beds" Woodville	Grand River Group: "Red Beds" Ionia Sandstone Eaton Sandstone Woodville Sandstone
Coal measures		Jackson Coal Group	SAGINAW SERIES: Upper Rider Lower Verne Coal Upper Verne Coal Middle Rider Saginaw Coal Lower Rider Lower Coal	SAGINAW: Salzburg Rider Salzburg Coal Upper Rider Upper Verne Coal Lower Verne Rider Lower Verne Coal Middle Rider Saginaw Coal Lower Rider Lower Coal Bangor Rider Bangor Coal	SAGINAW: Reese Coal Unionville Coal Salzburg Rider Salzburg Coal Upper 1 Rider Lower Verne Rider Lower Verne Coal Middle Rider Saginaw Coal Lower Rider Lower Coal Bangor Rider Bangor Coal	Saginaw	Saginaw	Saginaw	SAGNIAW GROUP: Post-Verne Cyclical Formations Verne Pre-Verne Cyclical Formations
Parma		Parma	Parma	Parma	Parma doubtfully represented in Tuscola County	Parma	Parma	Parma	Parma probably restricted to southern area

Grand River Formation.—The Saginaw Formation is considered to be overlain in most areas by sandstones referred to as the Grand River Formation. Grand River sandstones, thought of as a group, include in ascending order the Woodville (Winchell, 1861), Eaton (Kelly, 1936), and Ionia (Lane, 1909). These sandstones are very similar. Little evidence exists to show that they represent a vertical succession of strata as used in the group sense. Laterally, they do not yield to precise correlation.

The Grand River Formation consists predominantly of coarse sandstones with conglomeratic beds near the base. The sandstones are chiefly quartz cemented by siliceous or ferruginous material. Small amounts of feldspar and heavy minerals such as zircon and tourmaline are present. The formation is as much as 30 m (100 ft) thick. Red and brown colors and in some places purplish coloration are characteristic of the beds. According to Kelly (1936, p. 210) the various characteristics of the Grand River sandstones indicate that it was of freshwater origin, that much of the formation was due to river deposition, and that some of the beds are channel sandstones.

TABLE 2.—Continued

1964 Ells and others		1975 Wanless and Shideler		
		Interval	Formation	Named Unit
Grand River Formation	Ionia Sandstone Eaton Sandstone Woodville Sandstone	C	Grand River Formation	
SAGINAW FORMATION	Verne Limestone	B	Saginaw Formation	Verne Limestone Member
				Verne Coal
		A		Saginaw Coal
			Parma Sandstone Member	

Contact with underlying rocks.—The basin was uplifted and eroded in Late Mississippian time. The Coldwater Shale (Kinderhook) and Marshall Sandstone (Osage)of Early Mississippian age, and the Michigan Formation and Bayport Limestone (Meramac) of Late Mississippian age were eroded from some of the more prominent anticlinal folds. In most areas, Pennsylvanian strata lie on the eroded surface of the Michigan Formation or the Bayport Limestone. In areas where these Late Mississippian rocks were completely removed, Pennsylvanian strata may lie directly on the eroded surface of the Marshall Sandstone. According to Cohee and others (1951) the last folding took place after deposition of Pennsylvanian sediments had ceased. A buff limestone in the lower part of the Saginaw Formation in the central part of the basin (Isabella County) is said to be well enough defined on electric logs of that area to indicate that structure of the Pennsylvanian rocks in general conforms to the underlying Mississippian strata (Cohee and others, 1951).

The Howell anticline, one of the major structures in the Michigan basin, is a complex, faulted, structural feature which plunges to the northwest (fig. 2). It was elevated and the crest stripped of Mississippian strata down to the Berea Sandstone (Kinderhook) in the Howell region, Livingston County (Ells, 1969). Along the southeasterly strike of the structure, successively older strata subcrop beneath Pleistocene glacial drift. Pennsylvanian rocks are not recognized over the crestal part of the structure except at its northern terminus in Livingston County. Presumably Pennsylvanian rocks extended over at least most of the anticlinal area but were removed by erosion. According to Wanless and Shideler (1975, p. 64), the Coldwater Shale of Early Mississippian age underlies the central part of the Howell structure. They state that this elevated area apparently stood above the depositional plain as a monadnock several hundred feet high and was not buried until about 122 m (400 ft) of Lower Pennsylvanian sediment (table 2, interval A) had accumulated around it. By the end of interval A time the monadnock was buried.

Michigan's Pennsylvanian rocks are restricted to the interior of the basin and isolated from the coal basins of Ohio and Illinois. Because of post-Pennsylvanian erosion, the total thickness and original areal distribution of these rocks within the basin is unknown. An extensive study was made by Kelly

(1936, pp 172–76) of Michigan's Pennsylvanian marine fauna, most of which is found in the Verne Limestone. He concluded that the embayment in which the Verne marine member was deposited originally extended from at least the vicinity of Bay City southwestward in a direction approximating the long axis of Saginaw Bay (fig. 1). The extension of the embayment outside the State of Michigan was said to be toward Indiana, Illinois, and Iowa rather than toward Ohio. According to Wanless and Shideler (1975, p. 68), during the time that the Verne Limestone was being deposited in the Michigan basin, the Seville of northern Illinois and the Mercer of northern Ohio were being deposited. The exact positions of the seaways are not known. Pennsylvanian clays are found in solution cavities in Silurian strata near Kankakee and Joilet in northeastern Illinois (Willman, 1962, p. 63). The presence of these clays would seem to support the concept of an embayment which once extended northeastward across the present Kankakee arch and into the Michigan basin.

Contact with overlying rocks.—A sizable area of pre-Pleistocene but post-Pennsylvanian sediments immediately overlies part of the beveled Pennsylvanian surface. Largely confined to the western and northern Pennsylvanian subcrop region (fig. 1), these sediments consist of poorly consolidated red mudstones, greenish-gray mudstones, sandstones, and gypsum, frequently of the selenite variety. These rocks apparently do not crop out anywhere in the Michigan basin so are known only from subsurface studies. Once classified as "Permo-Carboniferous Red Beds" (Newcombe, 1931) and then as Pennsylvanian (Kelly, 1936), they are now classified as Late Jurassic (Kimmeridgian) age (A. T. Cross, oral commun., 1964) on the basis of spores collected from well cuttings. A formal nomenclature has not been established for these Jurassic sedimentary rocks; they are simply referred to as "red beds." The red beds contain spores shown by Cross (1966) to be similar to those in the Fort Dodge Gypsum of Iowa.

The original extent and thickness of the "red beds" in the Michigan basin is unknown. Though mainly overlying Pennsylvanian strata, red-bed sediments directly overlie the eroded surface of the Michigan Formation in some peripheral areas, and are thus confused with these Mississippian strata. Red mudstones and gypsum have also been included in the upper part of the Pennsylvanian section in the subsurface (Kelly, 1936; Wanless and Shidler, 1975, pp 68–69). The base or contact of these Jurassic sedimentary rocks with underlying Mississippian and Pennsylvanian rocks is not everywhere easily identified. Rocks assigned to the "red bed" interval are poorly consolidated and frequently subject to caving and lost circulation problems in drilling. Because of these conditions, well cuttings are few and do not necessarily reflect an accurate vertical succession of strata. They may include a mixture of Mississippian or Pennsylvanian sediments.

A study by Cohee and others (1951) of well logs and samples in the area of "red beds" showed much variation in thickness and an uneven distribution. This suggested that "red bed" sediments were deposited in topographic depressions, possibly under conditions of subaerial erosion, after deposition of Pennsylvanian rocks in Michigan had ceased. He reported thicknesses of 91–122 m (300–400 ft) in some subcrop sectors. Cohee and others (1951) also reported that investigations for water supplies in certain areas in Michigan showed that "red beds" were limited to topographic lows in the bedrock surface. There is some indication that the source of information was unintentionally misquoted and that "red beds" are confined to topographic highs rather than lows.

Except for small, widely scattered outcrops of various age assignments, the bedrock surface of the Michigan basin is covered by Pleistocene glacial drift. The glacial drift directly overlies Pennsylvanian rocks except for those areas directly overlain by remnant Jurassic sedimentary rocks which, in turn, are also covered.

MISSISSIPPIAN-PENNSYLVANIAN ENVIRONMENT OF DEPOSITION

All of Michigan's Mississippian rocks were accumulated in a marine environment. Largely shales and sandstones, they are about 914 m (3,000 ft) thick. At different times, sediments appear to have been supplied from eastern, western, and northern sources, causing intertonguing of sediments or lateral blending of them. No obvious break in sedimentation is apparent from Late Devonian (Chautauquan) time through Late Mississippian (Meramecian) time, although Middle Mississippian rocks have not been identified. Mississippian strata were apparently subject to a variety of depositional environments while they were accumulating in the basin.

On the eastern side of the Michigan basin, the Bedford Shale and overlying Berea Sandstone are invariably interpreted as deltaic deposits which merge westward into the Ellsworth Shale. The Ellsworth Shale was probably derived from a western source. The Sunbury Shale, immediately overlying the Berea Sandstone, is dark brown to black and is thickest in eastern Michigan. This shale, of either shallow or deep-water deposition, represents a different depositional environment from that of the underlying Berea and Bedford formations. The thinning of the Sunbury formation in a general east to west direction across the basin, provides some evidence that the unit represents a transgressive-regressive depositional cycle within Michigan.

The Coldwater Shale, about 396 m (1,300 ft) thick in the central part of the basin, contains thin lenticular siltstones and sandstones, thin limestones, and thin beds of limonite nodules. Several lateral facies within the sequence suggest probable transgressive-regressive episodes. Over much of the basin the upper part of the Coldwater is characterized by an increasing number of thin siltstone or sandstone beds separated by thin shale beds. The alternating nature of these beds foreshadows the deposition of the Marshall Sandstone.

The Marshall Sandstone, which grades upward from the Coldwater Shale formation, also contains Coldwater-type shales in parts of the basin. Shales and silty shales pinch out within the sandstone sequence or merge with sandstone strata. Some beds within the Marshall contain shell coquinas which may be indicative of shallow-water or shoreline deposition. In some areas where the Marshall grades into the overlying Michigan Formation, a thin sandy dolomite or limestone is found at the top of the Marshall.

Following deposition of the Marshall Sandstone, the basin continued to receive clastic material but became more restricted. During this phase, sediments now assigned to the Michigan Formation were deposited. The formation, about 183 m (600 ft) thick is made up of shale beds, anhydrite beds, and lesser numbers of sandstone, dolomite, and limestone beds. Several of the anhydrite beds and at least one of the limestone beds within the formation have widespread lateral continuity within the basin. The youngest Mississippian unit, the Bayport Limestone, is conformable with the underlying Michigan Formation and represents a return to more normal marine conditions. The Bayport is very irregular in thickness and distribution because of erosion during post-Bayport pre-Pennsylvanian uplift near the close of Mississippian time.

Pennsylvanian rocks in the Michigan basin are primary clastics deposited upon an eroded surface of Mississippian rocks. Sediments were deposited under deltaic and swamp conditions, some of which resulted in thin coal beds. Cyclic deposition is evident within the coal-bearing interval, and marine inundations are evident as shown by fossiliferous limestones. Unconformities which cut out parts of cyclothems appear to be frequent. Channel sandstones which suggest deposition by river systems have been identified. Red and green shales and gypsum have been identified as Pennsylvanian in parts of the basin. But as similar rock assemblages are found in the Michigan Formation which underlies parts of the Pennsylvanian sequence, the age of these rocks may be misidentified. The upper noncoal bearing part of the Pennsylvanian is mainly sandstone. The source area for these and the underlying clastics is considered to be eastern and northern highlands.

The original thickness and extent of Pennsylvanian rocks once covering Michigan is unknown. The Verne Limestone, which is carbonaceous and has an abundant marine fauna, has been correlated with the Seville Limestone of Illinois and a part of the Mercer Formation of Ohio. A seaway of unknown dimensions undoubtably connected the Michigan, Illinois, and Appalachian basins. Following deposition of Pennsylvanian rocks in the Michigan basin, the region was uplifted and eroded. Erosion was severe and the Pennsylvanian surface was heavily dissected by stream valleys. The thickest sections of Pennsylvanian rock with a maximum of about 229 m (750 ft) are found in the central part of the basin. The entire Pennsylvanian section is now confined to the interior of the basin and isolated from correlative rocks in other depositional basins. A remnant section of Jurassic-age rocks overlies a part of the Pennsylvanian sequence. These rocks are overlain by Pleistocene glacial drift.

The presence of Mesozoic rocks in Michigan is of special interest. Now remote from other Mesozoic strata, these remnant Late Jurassic sedimentary rocks overlie a part of the eroded Pennsylvanian surface and overlap onto parts of the eroded Mississippian rocks. In turn, they were apparently eroded before Pleistocene glaciation and burial beneath Pleistocene glacial deposits. Formerly classfied as "Permo-carboniferous Red Beds" and later as Pennsylvanian "Red Beds," they have now been identified on the basis of palynologic evidence. The lithology of these red beds, possibly as much as 122 m (400 ft) thick, consists of poorly consolidated red and green clays and shales, sandstones, and some gypsum. The stratigraphic order of these different lithologies is uncertain. The lower boundary is also uncertain because similar lithologies have been, or are, included in underlying Mississippian or Pennsylvanian formations. Palynologic studies do confirm their age assignment at least down to the controversial lower boundary. Whether these sediments accumulated in depressions as valley fill or in playa lakes as suggested by Cohee (1965), or are confined to Pennsylvanian topographic highs, or covered a much larger part of the Michigan basin, awaits further research.

ECONOMIC PRODUCTS

Valuable resources have been extracted from Michigan's Mississippian and Pennsylvanian rocks for many years. Though no metallic ores are found in either system, certain Mississippian formations have supplied shales suitable for use in cement and brick and tile manufacture; sandstones and limestones for construction and aggregate use; natural saline brines used in salt and chemical manufacture; and gypsum for use in various gypsum-based products. Mississippian rocks, primarily the sandstones, have also produced significant volumes of natural gas and petroleum. In certain areas of the State, Mississippian sandstones also are valuable and important sources of freshwater. Michigan's Pennsylvanian rocks, have fewer usable mineral resources, but were once important as a source of coal. In the early days of salt production (1860) from the evaporation of brines, brines from basal Pennsylvanian formations were used along with those from Upper Mississippian sandstones. The Pennsylvanian brines were subsequently abandoned in favor of the more concentrated salines of the underlying Mississippian sandstones. Pennsylvanian rocks are also the source of shales for brick and tile manufacture. In years past, sandstones were quarried at a few locales for building stone. In certain areas of the State, the upper part of the Pennsylvanian section serves as an important source of freshwater. The economic products currently extracted from Carboniferous rocks and other informative data are summarized.[2]

Sandstones.—Mississippian sandstones (Napoleon Sandstone member of the Marshall Sandstone) are quarried at three locations near Napoleon, Jackson County, Mich. The product is rough and dressed dimension stone which is used in various construction projects. Current production has averaged about 5,000 short tons (4,500 t) per year over the past 3 years. Historically, a number of quarries have been operated in the past throughout the outcrop area of the Marshall-Napoleon Sandstone in the southern part of the State. Small amounts of Pennsylvanian sandstone (Ionia Sandstone-Grand River Formation) were once quarried at Ionia, Ionia County, and possibly at other areas.

Shale.—Pennsylvanian shales from the Saginaw Formation are quarried in three locations. The shale mined in Clinton and Eaton County is ground and used in the manufacture of vitrified field and sewer tile. That produced in Shiawassee County is ground and used to manufacture bricks. The annual production from these operations in both 1974 and 1975 amounted to 100,000 short tons (90,000 t). In the past, Pennsylvanian shales were also quarried in Ingham and Jackson counties for use in brick and tile manufacturing.

Limestones.—Mississippian Bayport Limestone has been quarried for many years in several parts of the State. Currently seven quarries are in operation. From quarries in Arenac, Eaton, Huron, and Jackson Counties, limestone production in 1974, 1975 and 1976 ranged from more than 1.1 to nearly 1.4 million short tons (1.26 million t). Most of the limestone is used as construction aggregate but some of high purity is used in the beet-sugar refining process.

Gypsum.—Gypsum beds of the Michigan Formation (Late Mississippian) have been mined for more than 100 years. Presently five gypsum mines are in operation; two shallow underground mines in Kent County and three open-pit operations in Iosco County. Annual production figures have been kept since 1868. Before 1868, 146,528 short tons (131,875 t) were mined. Total gypsum mined in Michigan through 1975 is 66,162,294 tons (59,546,065 t). The largest recorded annual tonnage was produced in 1973 when 1,882,257 tons (1,694,032 t) were mined. Most of the gypsum is exported out of the State for processing. Michigan has ranked in first place in the United States in the production of gypsum in all but 7 years since 1945, and in at least second place since 1926.

Petroleum and natural gas.—Mississippian rocks have produced significant amounts of petroleum and natural gas. The State's first commercial oil field was discovered in Berea Sandstone reservoir rocks at Saginaw, Mich. in 1925. In 1925 and 1926, 100 percent of the State's oil production, 98,000 barrels, came from this field. In 1927, production from the

[2] Information on economic products other than petroleum and natural gas supplied by Milton Gere, Economic Geologist, Geological Survey Division, Michigan Department of Natural Resources.

Berea Sandstone was 434,000 barrels. In the same year, however, oil was discovered in Devonian formations, and exploration for Mississippian Berea Sandstone accumulations became less important. Since 1927, other Berea reservoirs have been found. Annual oil production from these rocks continues to decrease and amounted to only 22,921 barrels in 1976. Total cumulative Mississippian oil production through 1976 amounted to 2,546,556 barrels.

Until recent years, the Michigan Stray-Napoleon-Marshall sandstones were the principal Mississippian gas-producing reservoir rocks. The first recorded gas production was in 1931 when 46,232 Mcf (thousand cubic feet) was reported. By 1947, annual production was recorded as 19,817,437 Mcf. Since that year, production has declined each year and amounted to only 169,433 Mcf in 1976. Total cumulative Mississippian gas production through 1976 amounts to 213,538,591 Mcf. Though most of the larger Mississippian gas traps appear to have been found, smaller accumulations, are occasionally found.

Most of the larger Mississippian, Michigan Stray-Napoleon-Marshall gas pools have been converted to underground gas-storage reservoirs. Owned and operated by gas utility companies, Michigan utilities have pioneered the conversion of suitable oil and gas traps to natural gas storage. Fifteen Mississippian gas pools, yielding from more than a billion to as much as nearly 52 billion cubic feet of native gas before conversion, are now in active use.

Freshwater reservoirs.—Where Mississippian and Pennsylvanian rocks have been flushed of naturally occurring brines, the sandstones serve as freshwater reservoirs or aquifers. Covered by varying thicknesses of glacial drift, these areas are found mainly around the subcrop margins in the southern part of the basin. Down-dip toward the center of the basin they become progressively saline.

Natural brines.—Natural brines from Mississippian rocks, primarily the Marshall Sandstone, were once extensively used for the manufacture of salt (NaCl) and other chemical products. Whereas most brines used in Michigan's extensive chemical industry are now produced from Devonian or Silurian rocks, virtually all Marshall Sandstone brine wells have been abandoned and plugged.

Coal.—Bituminous coal, though not now produced, was mined from various coal beds in the Saginaw Formation for more than 100 years. As many as 38 coal mines were in operation at one time during the years 1905, 1906, and 1908. Volume of coal production fluctuated; the largest annual tonnage was produced from 37 mines which were in operation in 1907. The tonnage that year was 2,035,855 tons (1,832,270 t). Coal production figures exist for 1860 through 1953 and for the year 1975. From 1947 through 1952 only one mine was in operation and this was closed in 1952. Total Michigan coal production has amounted to 46,316,580 short tons (41,684,922 t). Production data for the year 1975 relate to the reopening of a small open-pit mine where a small amount of cannel coal was removed and sold locally for fireplace fuel. Currently no coal is actively mined in the State.

There has been some renewed interest in Michigan's coal reserves. A recent U.S. Bureau of Mines open-file report (Kalliokoski and Welch, 1976, p. 30) places Michigan coal reserves at approximately 126.5 million short tons (113.9 million t). The bulk of Michigan's coal is only accessible through underground mining. Coal seams are thin, generally less than 1 m (3 ft), and frequently discontinuous. Water problems and possible hazards associated with oil- and gas-test borings throughout many parts of the coal-bearing region impose additional limitations to underground mining. Near-surface coal seams usually require the removal of large volumes of glacial drift and rock overburden. Present-day economics and environmental considerations do not favor the revival of Michigan's coal industry.

OUTCROP LOCALITIES

A blanket of Pleistocene glacial drift covers all the bedrock surface of Michigan. Mississippian and Pennsylvanian rocks are exposed at the surface in a few locales, but the outcrops are small in vertical and lateral extent. Exposures of Mississippian rocks are found in 12 of the 68 Southern Peninsula Counties, namely: Arenac, Branch, Calhoun, Eaton, Hillsdale, Huron, Iosco, Jackson, Kent, Ogemaw, Sanilac, and Tuscola. Pennsylvanian outcrops are found in Arenac, Calhoun, Clinton, Huron, Ingham, Ionia, Jackson, Saginaw, and Shiawassee Counties. A list of reported exposures and type localities of Michigan's Mississippian and Pennsylvanian rocks in the aforementioned counties has been documented by Martin and Straight (1956, pp. 198–243). The location of these counties is shown in figure 2.

Quarries or mines afford the best opportunity to view partial sections of Michigan's Mississippian and Pennsylvanian rocks and to collect fossils. A selected list of quarries and possible fossil-collecting localities follows[3]:

Coldwater Shale (Mississippian):

1. Old abandoned Wolverine Portland Cement Co. shale pit. Located approximately 2 miles south and 2 miles west of Coldwater, Mich., in the C NW¼ sec. 32, T. 6 S., R. 6 W., Branch County.
2. Old abandoned Peerless Portland Cement Co. shale pit. Located approximately 2 miles south and 0.7 miles east of Union City, Mich., in the SE¼ NE¼ NE¼ sec. 16, T. 5 S., R. 7 W., Branch County.
3. Old abandoned grindstone quarries in and about the community of Grindstone City, Mich., in sec. 25, T. 19 N., R. 13 E., Huron County.

Marshall Sandstone (Mississippian):

1. Long abandoned Hanover quarry, approximately 1 mile south and 1.6 miles west of Hanover, Mich. Located in the NE¼ NW¼ sec. 31, T. 4 S., R. 2 W., Jackson County.
2. Active quarry located approximately 0.5 miles east of Napoleon, Mich. in the NW¼ NE¼ sec. 6, T. 4 S., R. 2 E., Jackson County.

Michigan Formation (Mississippian):

1. Gypsum quarries of the Michigan Gypsum Co. Located approximately 4 miles south and 2 miles east of Whittemore, Mich. in the C SW¼ sec. 25, T. 21 N., R. 5 E.; C N½ NW¼ and C S½ sec. 31, T. 21 N., R. 6 E., Iosco County.
2. Gypsum quarry of National Gypsum Co. Located approximately 2 miles east and 1.1 mile north of National City, Mich., in sec. 35, T. 22 N., R. 6 E., Iosco County.
3. Gypsum quarry of the United States Gypsum Co. Located just west of Alabaster, Mich. in sec. 27, T. 21 N., R. 7 E., Iosco County.

Bayport Limestone (Mississippian):

1. Limestone quarry of Wallace Stone Co. Located approximately 2.5 miles east and 1 mile south of Bayport, Mich. in secs. 5 and 6, T. 16 N., R. 10 E., Huron County.
2. Limestone quarry of Arenac County Road Commission. Located approximately 2.5 miles and 2 miles east of AuGres, Mich. Located in the NW¼, Sec. 5, T. 19 N., R. 7 E., Arenac County.
3. Limestone quarry of Cheney Limestone Co. Located approximately 1 mile west and 0.1 mile north of Bellevue, Mich., in the SE¼ NE¼ sec. 29, T. 1 N., R. 6 W., Eaton County.

Saginaw Formation (Pennsylvanian):

1. Shale pits of the Grand Ledge Clay Products Co. One pit is located about 1.5 miles northwest of Grand Ledge, Mich. in the SW¼ NE¼ sec. 3, T. 4 N., R. 4 W., Eaton County. Another pit is located about 2.5 miles northwest of Grand Ledge in the NE¼ SW¼ sec. 34, T. 5 N., R. 4 W., Clinton County.
2. Shale pits of Michigan Brick Inc. Located about 1.5 miles northeast of Corunna, Mich. in the E½ of sec. 22, T. 7 N., R. 3 E., Shiawassee County.

[3] Selection of quarry sites prepared by H. O. Sorensen, Economic Geologist, Geological Survey Division, Michigan Department of Natural Resources.

Grand River Formation (Pennsylvanian):

1. Exposures of Eaton Sandstone are found along the north bank of the Grand River in the northwest part of the town of Grand Ledge. Also in the immediate vicinity are abandoned pits and quarries showing exposures of Eaton Sandstone, several thin coal seams, Verne Limestone, underclays, and shales assigned to the Saginaw Formation or Saginaw Group of Kelly (1936).
2. Exposures of Ionia Sandstone, also a part of the Grand River Formation are found in old abandoned quarries, approximately 3.5 miles east of Ionia, Mich., near the south banks of the Grand River in the SW¼ NW¼ sec. 23, T. 7 N., R. 6 W., Ionia County.

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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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B. Pennsylvania and New York, by William E. Edmunds, Thomas M. Berg, William D. Sevon, Robert C. Piotrowski, Louis Heyman, and Lawrence V. Rickard

C. Virginia, by Kenneth J. Englund

D. West Virginia and Maryland, by Thomas Arkle, Jr., Dennis R. Beissell, Richard E. Larese, Edward B. Nuhfer, Douglas G. Patchen, Richard A. Smosna, William H. Gillespie, Richard Lund, Warren Norton, and Herman W. Pfefferkorn

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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.

H William Menard

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Director, U.S. Geological Survey

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