

# OHIO'S SURFACE ROCKS AND SEDIMENTS

by Alan H. Coogan

*Modified from Chapter 3 of Fossils of Ohio, Ohio Division of Geological Survey Bulletin 70  
(R. M. Feldmann and Merrienne Hackathorn, eds., 1996)*

## INTRODUCTION

This chapter is an overview of the sedimentary rocks and glacial deposits of Ohio as a background for fossil collecting. Sedimentary rocks are rocks deposited in layers at or near the surface of the Earth. The main topics in this chapter are the geologic time scale, the geologic maps of Ohio, characteristics of sedimentary rocks, the geologic history of Ohio, and regional stratigraphy of Ohio. The section on sedimentary rocks includes information on identifying rocks and common stratigraphic concepts.

Because the fossil-bearing rocks represent only a portion of Ohio's total sedimentary deposits, fossils from only portions of the geologic time periods are found in the rocks that are at the surface. Fossils in subsurface rocks are known from rock cores and cuttings from wells drilled deep below the surface. Fossils also are found in relatively recent unconsolidated glacial, river, cave, and lake deposits.

## GEOLOGIC TIME SCALE

The Earth is about 4.5 billion years old, and more than 99 percent of its history took place before any written or oral record could be made. Geologists have been studying the rock layers of the Earth for several hundred years and have devised a framework time scale that arranges the rock layers in units from oldest to youngest. Each rock unit is placed into its relative position compared to other units in the time scale. The unit may then be dated in terms of millions of years before present using radioactive isotopes. The results of two centuries of dating efforts are summarized in the geological time scale (fig. 3-1). There are four main divisions of the time scale. The Cenozoic Era extends from the present to about 66 million years ago and includes glacial and postglacial sediments. The Mesozoic Era extended from 66 to 245 million years ago and has no known representative rocks in Ohio. The Paleozoic Era extended from 245 to 570 million years ago and includes the surface rocks of Ohio. The Precambrian is an informal term for the all the time from 570 million years ago to the origin of the Earth. The eras are subdivided into periods, and the periods into epochs.

Ohio's surface rocks range in age from the Late Ordovician Period (about 455 million years ago) to the Early Permian Period (about 280 million years ago). Nearly all the significant fossil-collecting localities in Ohio are in these Paleozoic-Era rocks. For most of the past 245 million years, during the Mesozoic Era and the Tertiary Period of the Cenozoic Era, Ohio has been subjected to extensive uplift, erosion, and weathering. Within the past 2 million years, sediments of the Quaternary Period were deposited. The Quaternary Period consists of the Pleistocene Epoch, commonly referred to as the Ice Age, and the Holocene Epoch, also called the Recent.

Even the substantial thicknesses of Paleozoic rocks contain evidence of erosional events. Surfaces between the rock layers that indicate erosion or nondeposition are called unconformities. Unconformities result from uplift of the land surface or lowering of sea level. Major unconformities generally are related to collisions of continental plates and mountain building. In relation to present-day Ohio, such events took place mainly to the east. Unconformities and the movement of continental plates (plate tectonics) are described in more detail in later sections of this chapter.

## THE GEOLOGIC MAPS OF OHIO

The map of the bedrock geology of Ohio (fig. 3-2) shows the distribution of Paleozoic rocks at or near the land surface, but beneath any Quaternary sediments. The glacial deposits map (fig. 3-3) of Ohio shows the extent and type of Pleistocene sediments.

Three main geologic structures (fig. 3-4) influence the outcrop pattern of the surface rocks in Ohio. A series of positive structural features, the Cincinnati Arch, the Findlay Arch, and the Indiana-Ohio Platform, extend from southwestern Ohio to Lake Erie. The axes of the arches plunge gently to the north-northeast. As a result, Ordovician rocks are at the surface in the vicinity of Cincinnati, but are in the subsurface farther north. Near Dayton, younger, Silurian rocks are at the surface, overlying Ordovician strata. North of Findlay and on the Bass Islands in Lake Erie, even younger Silurian rocks are at the surface. The Ordovician and Silurian rocks that are at the surface in southwestern Ohio are buried hundreds of meters in the subsurface to the north. Northwest of the Findlay Arch, bands of Devonian and Mississippian rocks curve across the northwestern corner of the state. These rocks dip northwestward toward a sedimentary-rock-filled depression called the Michigan Basin. East of the Findlay and Cincinnati Arches, a band of Devonian rocks can be traced from the Ohio River northward through the center of the state to Lake Erie and then eastward along the lake to Pennsylvania and beyond. This north-northeast trend outlines the western edge of the Appalachian Basin. Rocks east of the arches dip eastward (fig. 3-5) into the basin, so that progressively younger rocks are at the surface farther east and older ones are more deeply buried. Silurian rocks that are at the surface on the Findlay Arch are buried 1,200-1,500 meters below the surface near the Ohio-Pennsylvania line. The thickness of Paleozoic rocks ranges from about 760 meters in western Ohio to more than 4,000 meters in southeastern Ohio.

Ohio's geologic maps indicate where fossils of certain ages can be found. In the Cincinnati area are the very fossiliferous Upper Ordovician rocks. Farther north are the moderately fossiliferous Silurian rocks. In the hill country of eastern Ohio are Pennsylvanian and Permian rocks, some of which

Years before present, in millions of years	Eras and duration in years	Periods and duration in years	Area of outcrop in Ohio and principal rock types
1.6	CENOZOIC 66+ million	QUATERNARY 1.5-2 million	northwestern 2/3 of Ohio— unconsolidated sand, gravel, clay
66.4		TERTIARY 62.5 million	NOT PRESENT IN OHIO
144	MESOZOIC 179 million	CRETACEOUS 78 million	
208		JURASSIC 64 million	
245		TRIASSIC 37 million	
286	PALEOZOIC 325 million	PERMIAN 41 million	southeastern Ohio—shale, sandstone, coal, clay, limestone
320		PENNSYLVANIAN 34 million	eastern Ohio—shale, sandstone, coal, clay, limestone
360		MISSISSIPPIAN 40 million	east-central, northeastern, and northwestern- most Ohio—shale, sandstone, limestone
408		DEVONIAN 48 million	central, northeastern, and northwestern Ohio—shale, limestone
438		SILURIAN 30 million	western Ohio—dolomite, limestone, shale
505		ORDOVICIAN 67 million	southwestern Ohio—shale, limestone
570		CAMBRIAN 65 million	NOT EXPOSED IN OHIO
	PRECAMBRIAN 3,400 million		

FIGURE 3-1.—Chart showing divisions of geologic time and their representation in Ohio. Dates are from Palmer (1983). Wavy lines indicate a major unconformity (period of erosion or nondeposition) in Ohio.

are quite fossiliferous. In the areas between are sparsely to very fossiliferous Devonian and Mississippian rocks.

Geologic maps are important to our society as a whole and particularly to fossil collectors and paleontologists. Geologic maps show the location of fossil-bearing formations over large areas. If a fossil hunter is able to read a geologic map,

he or she can identify new and perhaps remote fossil-collecting localities that others may never have visited. The Division of Geological Survey has numerous geologic maps available, including a series of regional geologic maps for the state (Schumacher, 1993; Larsen, 1994; Swinford and Slucher, 1995; others in preparation).

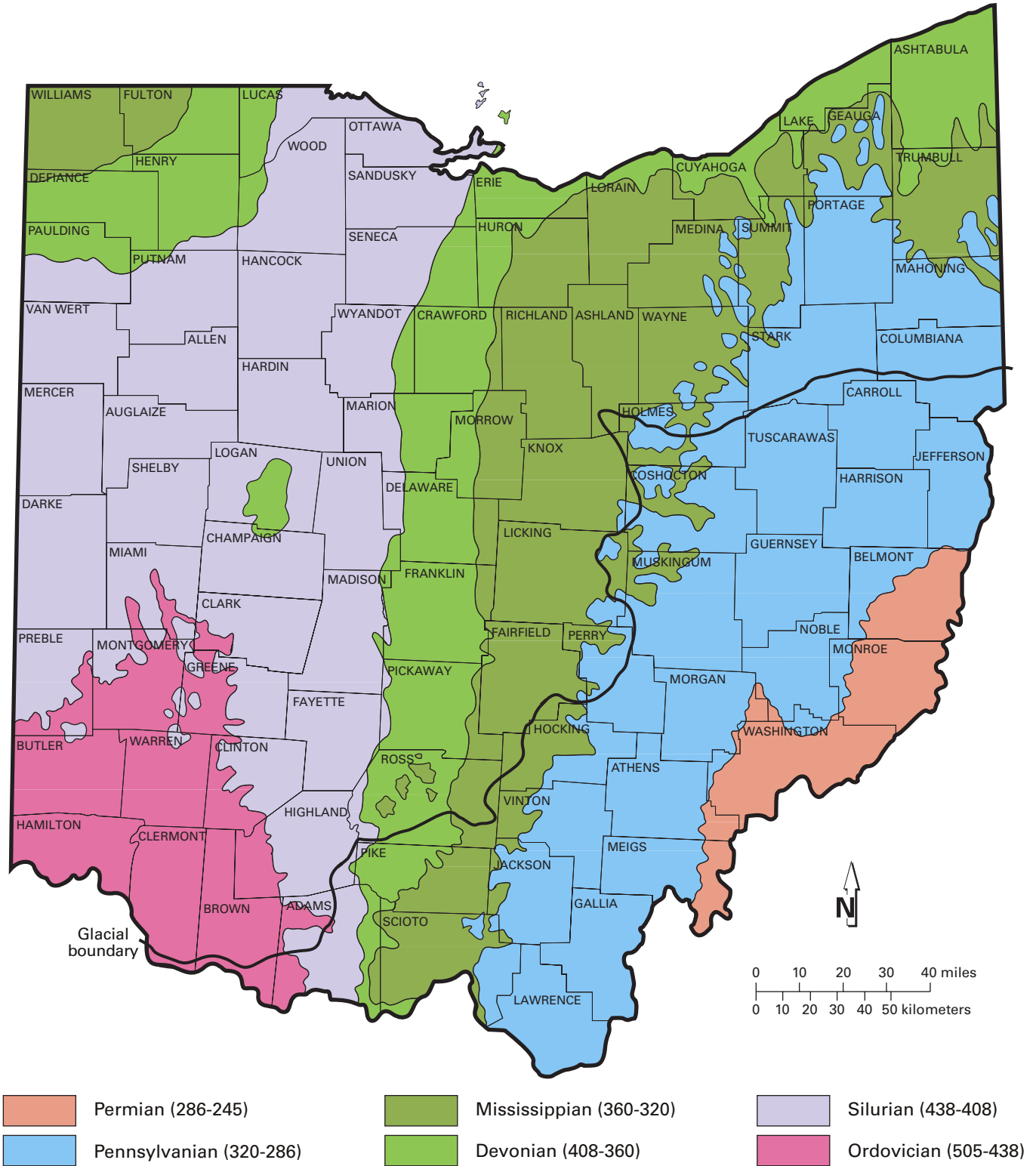


FIGURE 3-2.—Bedrock geology of Ohio, showing the pattern of surface rocks across the state.

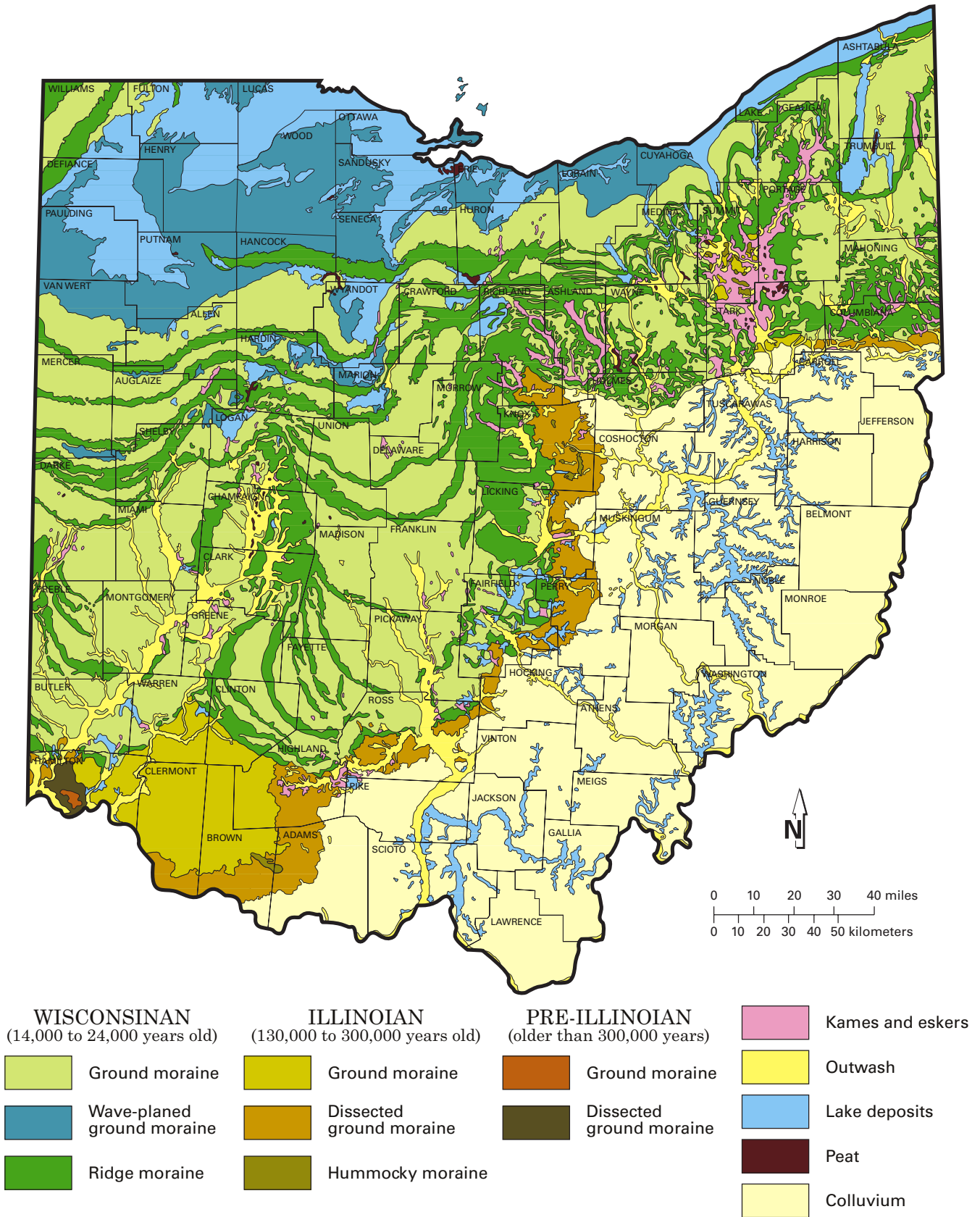


FIGURE 3-3.—Glacial deposits of Ohio. The terms Wisconsinan and Illinoian are subdivisions (ages) of the Pleistocene Epoch.

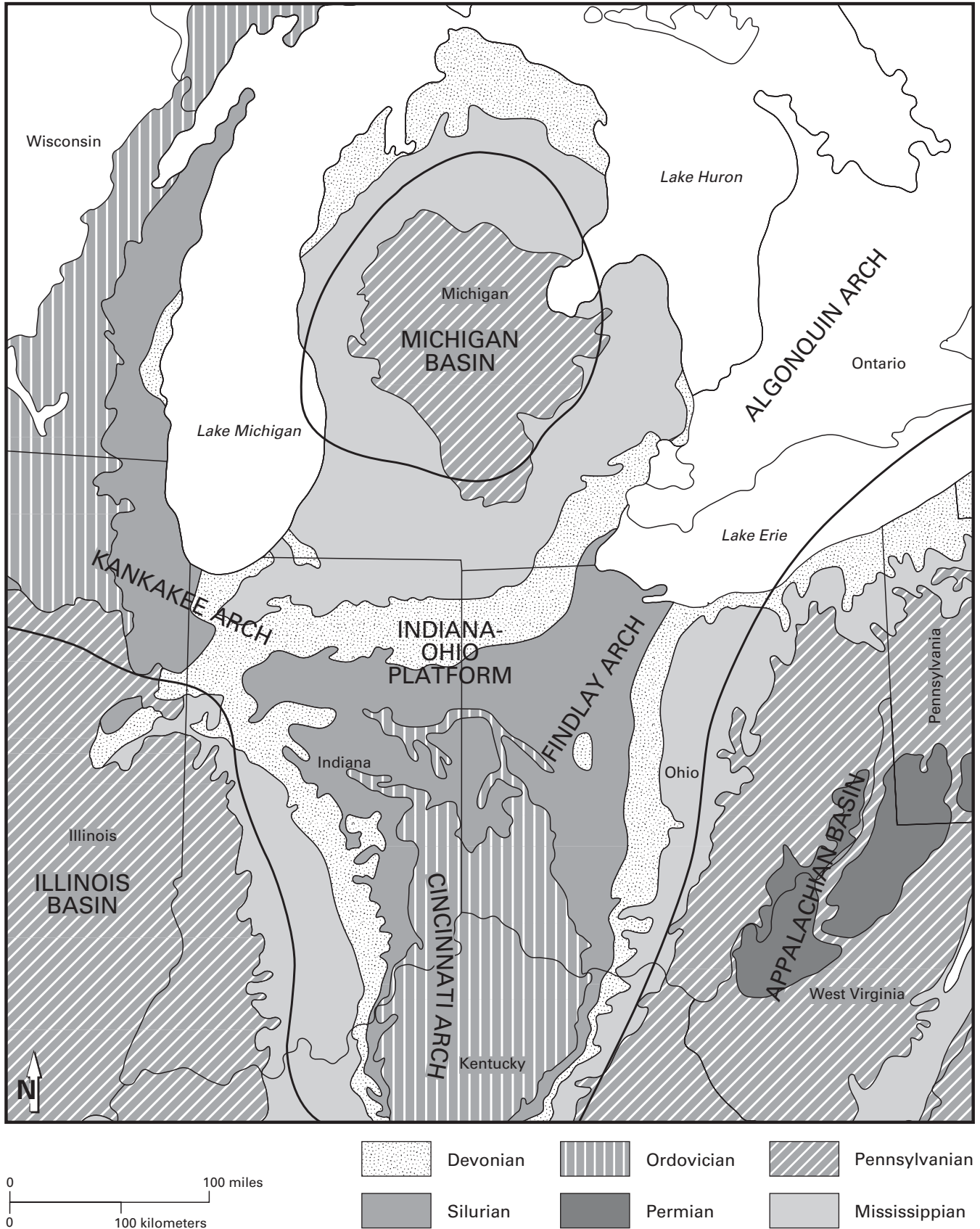


FIGURE 3-4.—Regional geologic structures of Ohio and adjacent states (from Carlson, 1991, fig. 4).



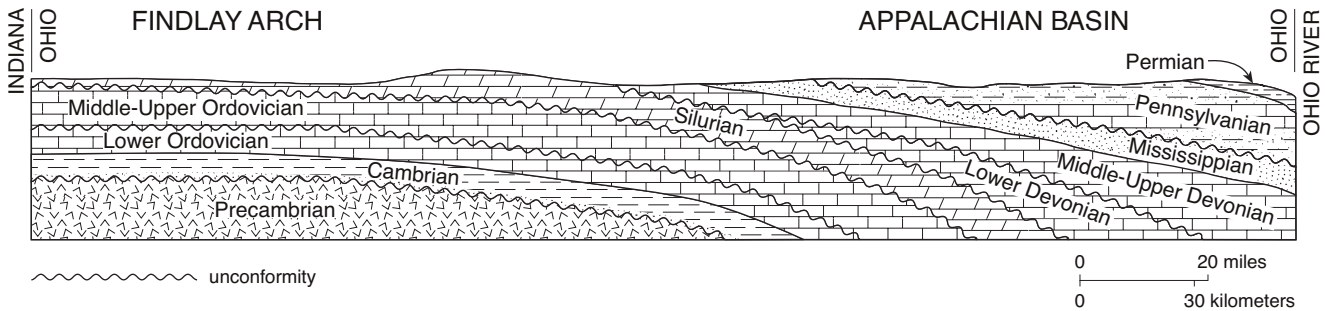


FIGURE 3-5.—Cross section through the rocks of central Ohio from the Indiana-Ohio border to the Ohio River.

## CHARACTERISTICS OF SEDIMENTARY ROCKS

The primary characteristic of sedimentary rocks is that they are stratified, that is, deposited layer upon layer. A bed is a layer of rock, commonly less than  $\frac{1}{2}$  meter thick, that has a distinct surface, or bedding plane, that separates it from other beds above and below it. Thinner layers, commonly less than 1 cm thick, are called laminae. Beds record changes in sedimentary conditions at the time of deposition or changes due to subsequent burial of the bed by later sediments.

### ROCK TYPES

There are two main types of sedimentary rocks: siliciclastic and chemical (tables 3-1 and 3-2). Siliciclastic rocks consist of weathered particles of pre-existing siliceous rocks that were eroded and transported by rivers and deposited in alluvial plains, deltas, and open seas as fragmental sediments (see fig. 3-8). Siliciclastic sediments are lithified (hardened into rock) by compaction and cementation by minerals precipitated from sea or ground water. Chemical rocks, as the term is used in this chapter, form by the precipitation of minerals from sea water or by the cementation of fragments of seashells. The precipitates are mainly calcite, silica, gypsum, anhydrite, and halite, or salt. The shells of many fossil organisms are made of calcite. Calcite may be replaced by the mineral dolomite or by silica. More information on the rocks and minerals of Ohio is provided in Carlson (1991).

TABLE 3.1.—NAMES FOR SILICICLASTIC SEDIMENTS AND ROCKS

Particle name	Particle size	Rock name
pebble or larger	>2 mm	conglomerate if fragments are rounded, breccia if fragments are angular
sand	1/16-2 mm	sandstone
silt	1/16-1/256 mm	siltstone (particles barely discernible; has gritty feel)
clay	<1/256 mm	shale or clay shale if laminated, claystone if massive (particles not discernible; has smooth feel)

For many types of sedimentary rocks, the names are formed by adding “-stone” to the sediment name, for example, sand/sandstone. Other rock names are mineralogical terms (such as dolomite) or century-old names (such as breccia, shale) used by builders, quarrymen, and stonemasons.

Rocks may have other distinctive characteristics that are used for identification. These characteristics may be added as modifiers to the basic rock name. For example, rock color can be important and may be part of the description, as in black shale. The kind of cement also can be added—for example, calcareous (calcite cement) shale, ferruginous (iron-rich cement) sandstone, or siliceous (silica cement) limestone. Other constituents, such as fossil richness (fossiliferous), and combinations of several characteristics may be included in rock descriptions. An example of a carefully described rock might be: fossiliferous, ferruginous, and calcareous red siltstone.

TABLE 3.2.—NAMES FOR CHEMICAL ROCKS

Mineral name	Chemical composition	Rock name
calcite or aragonite	calcium carbonate, $\text{CaCO}_3$	limestone <sup>1</sup>
dolomite	calcium-magnesium carbonate, $\text{CaMg}(\text{CO}_3)_2$	dolomite <sup>1</sup>
gypsum	hydrous calcium sulfate, $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$	gypsum <sup>2</sup>
anhydrite	anhydrous calcium sulfate, $\text{CaSO}_4$	anhydrite
halite	sodium chloride, $\text{NaCl}$	salt
silica (quartz)	silicon dioxide, $\text{SiO}_2$	chert, flint
various iron minerals		ironstone

<sup>1</sup>Limestones and dolomites commonly are referred to as carbonate rocks or carbonates. Most dolomites are the result of chemical alteration of limestones. Some geologists prefer to use the term “dolostone” for a rock composed of the mineral dolomite.

<sup>2</sup>Gypsum, anhydrite, and salt commonly are referred to as evaporite rocks or evaporites.

## OTHER FEATURES OF SEDIMENTARY ROCKS

Some features of sedimentary rocks result from water-current flow, burrowing, and biologic growth. These features, called sedimentary structures, may resemble traces of biological activity. Various sedimentary structures such as ripple marks or drag marks are indicative of sea-bottom or river-bed conditions and generally are observed on bedding planes.

Current-flow bedding is common in river, delta, shoreline beach and bar, and shallow sea deposits that were affected by wind, waves, or currents. Beds or laminae may be at an angle to the lower or upper bed surface. This angled bedding within a larger, more or less flat bed is called cross-bedding. Angles may be up to 35° from the horizontal and dip in the direction of the ancient flow. Cross-bedding is common in sand-size rocks such as sandstones and some carbonates. Mississippian-age sandstones and Devonian-age limestones contain many such cross-beds, which are easily observed on weathered surfaces. Ripple marks are the usual expression of small cross-laminations on the exposed surface of a bed.

Many rocks lack current cross-beds and appear homogeneous or massive throughout. Sandstones and siltstones may show churned and mixed grain sizes that are highlighted by a mottled color pattern. Churned bedding typically is the result of burrowing by animals (bioturbation), although there generally is no clear trace of fossils present. Churned bedding may also result from nonbiological deformation of soft, wet sediments in shallow lagoons or close to the seashore.

## SEDIMENTARY-ROCK CONCEPTS

A few sedimentary-rock concepts and terms are helpful in understanding the occurrence of fossils. The topics discussed here are superposition and original horizontality, stratigraphic terminology, unconformities, sedimentary facies and environments, faunal succession, and plate tectonics.

### Superposition and original horizontality

Centuries of observation of sedimentary processes show that sediments are deposited mainly one bed at a time, one on top of the other. Sediments deposited on gently sloping sea bottoms are the most likely to be preserved because they are less likely to be disturbed or eroded. Allowing for the small differences in slope of the sea floor and in the current flow that produces cross-bedding, sedimentary beds are so arranged that three conclusions can be drawn:

1. Older beds were deposited first and lie below younger beds, so that beds are successively younger upward.
2. Beds that tilt at high angles from the horizontal were moved by tectonic forces after the beds were lithified.
3. Beds that cut across, or cut out, other beds are younger than the beds they cut.

### Stratigraphic terminology

Sedimentary rocks are categorized using different kinds of features, such as rock type, age, and fossil content. These categories are (1) rock-stratigraphic, or lithostratigraphic, units, (2) time-stratigraphic, or chronostratigraphic, units, (3) geologic-time units, and (4) biostratigraphic units.

A lithostratigraphic unit is based on rock type, or lithology, and is defined at a specific locality, called a type area. The fundamental lithostratigraphic unit is the formation. It is based on designated beds of rocks of a specific lithology (such

as shale or sandstone) that are thick enough to be shown on a geologic map. Formations are named for a place (such as Columbus) and a rock type (such as limestone) to make the formal formation name: the Columbus Limestone. If the rock unit contains more than one rock type, the word "formation" is used with the place name, as, for example, the Dayton Formation, which is limestone and shale. Formations may be combined into larger units called groups (example: Detroit River Group) or subdivided into smaller units called members and beds (example: Cleveland Shale Member of the Ohio Shale). Descriptions of fossil-collecting localities generally refer to the group, formation, member, or bed that contains the fossils. These lithostratigraphic units are used in the following chapters to describe the occurrence of fossils.

A chronostratigraphic (time-stratigraphic) unit is a body of rock deposited during a defined unit of geologic time, such as a period. Chronostratigraphic units are closely related to geologic-time units. The primary chronostratigraphic unit is the system. The correspondence between chronostratigraphic and geologic-time units is shown below.

Geologic-time unit	Chronostratigraphic unit	Example
Era	Erathem	Paleozoic Era/Erathem
Period	System	Ordovician Period/System
Epoch	Series	Cincinnatian Series
Age	Stage	Edenian Stage
Chron	Zone	

For some units, the terms "upper" and "lower" or "late" and "early" are used. "Upper" and "lower" are used with lithostratigraphic terms (example: Upper Ordovician Waynesville Formation); "late" and "early" are used with time terms (example: Late Ordovician time). The term "middle" applies to both lithostratigraphic and time units.

A biostratigraphic unit is defined on the basis of its fossil content. The primary biostratigraphic unit is the zone or biozone, which encompasses a series of beds defined by the presence of a particular fossil or group of fossils. The boundaries of a biostratigraphic unit may or may not coincide with the boundary of a lithostratigraphic unit; there is no inherent relationship between them. An interval zone encompasses all rocks deposited and preserved during the time span of the existence of the particular genus or species on which it is based. An example of an interval zone is the *Foerstia (Protosalvinia)* Zone in the Devonian-age Ohio Shale; this zone is named for a fossil plant. An assemblage zone is a zone based on the unique and joint occurrence of three or more species or genera and is named for one of them. An example is the *Rhynchotrema* Assemblage Zone, an assemblage of bottom-dwelling marine organisms in Upper Ordovician strata that is named for a brachiopod.

### Unconformities

Unconformity surfaces represent periods of erosion or nondeposition. They may be nearly smooth or have high relief, and they may be local or widespread. Unconformities commonly are represented by wavy lines on stratigraphic charts (fig. 3-1) and cross sections (fig. 3-5). There are three main types of unconformities: angular unconformity, disconformity, and paraconformity (fig. 3-6).

In an angular unconformity (fig. 3-6, top) the bedding planes between two groups of rocks are not parallel; gen-

erally, older (lower) rocks lie at an angle to the overlying (younger) rocks. The creation and preservation of an angular unconformity requires major deformation such as substantial uplift or mountain building, erosion of the deformed strata, resubmergence, and subsequent deposition. Angular unconformities in Ohio are generally very subtle (shallow angle) and can be recognized only by geologic mapping over large areas. The time required to form an angular unconformity is generally in excess of several million years.

A disconformity (fig. 3-6, middle) characterizes surfaces between parallel or nearly parallel beds in which the underlying beds have been eroded. A disconformity indicates a significant interruption in the sedimentary sequence. The disconformable rock surface is commonly visibly irregular or uneven.

A paraconformity (fig. 3-6, bottom) characterizes surfaces between parallel beds in which the surface generally is not discernible without careful study, especially of the faunal changes across the boundary. Paraconformities are common, even within formations.

#### Sedimentary facies and environments

All sediments are deposited in specific environments. Early Paleozoic environments were characterized by tropical and subtropical, shallow to moderately deep seas where mud banks, sand bars, and reefs abounded (fig. 3-7). Limestones and calcareous shales were the dominant deposits. A comparable modern-day environment is the Caribbean Sea. Later Paleozoic environments were characterized by streams, deltas, coal swamps, and nearshore seas (fig. 3-8). Sandstones, siltstones, and shales were the dominant deposits. A comparable modern-day environment is the Mississippi delta. These environments differed extremely from the environments of the Ice Age glaciers or even today's rivers and lakes in our temperate, continental environment. Overall, sedimentary environments vary with climatic change, which in turn reflects shifting continental plates and proximity to mountain building and erosion (see sections on plate tectonics and geologic history of Ohio).

Sedimentary environments may differ from place to place even at the same time. The deposits of different lithologies and sedimentary environments laid down at the same time in different places are different aspects—called facies—of the overall sedimentary unit (fig. 3-9). Lithofacies are based mainly on differences in rock type. Biofacies are based mainly on differences in fauna. Environmental or sedimentary facies are based on differences in depositional environments. Knowledge of facies and environments helps to understand how fossil organisms lived and died, as well as how the fossils are distributed in a rock unit.

#### Faunal succession

By collecting fossils from strata that were in known, regular, stratigraphic order, geologists more than a century and a half ago established conclusively that fossil faunas do not repeat themselves and do not occur out of order, unless the rocks containing them have been deformed and rearranged. However, a specific fauna may be missing from a certain series of beds because of lack of preservation, erosion of the beds, or for paleoecologic reasons. This principle of faunal succession explains why different fossils are found in different rock units. For example, a particular assemblage of species of brachiopods, bryozoans, corals, and clams is unique

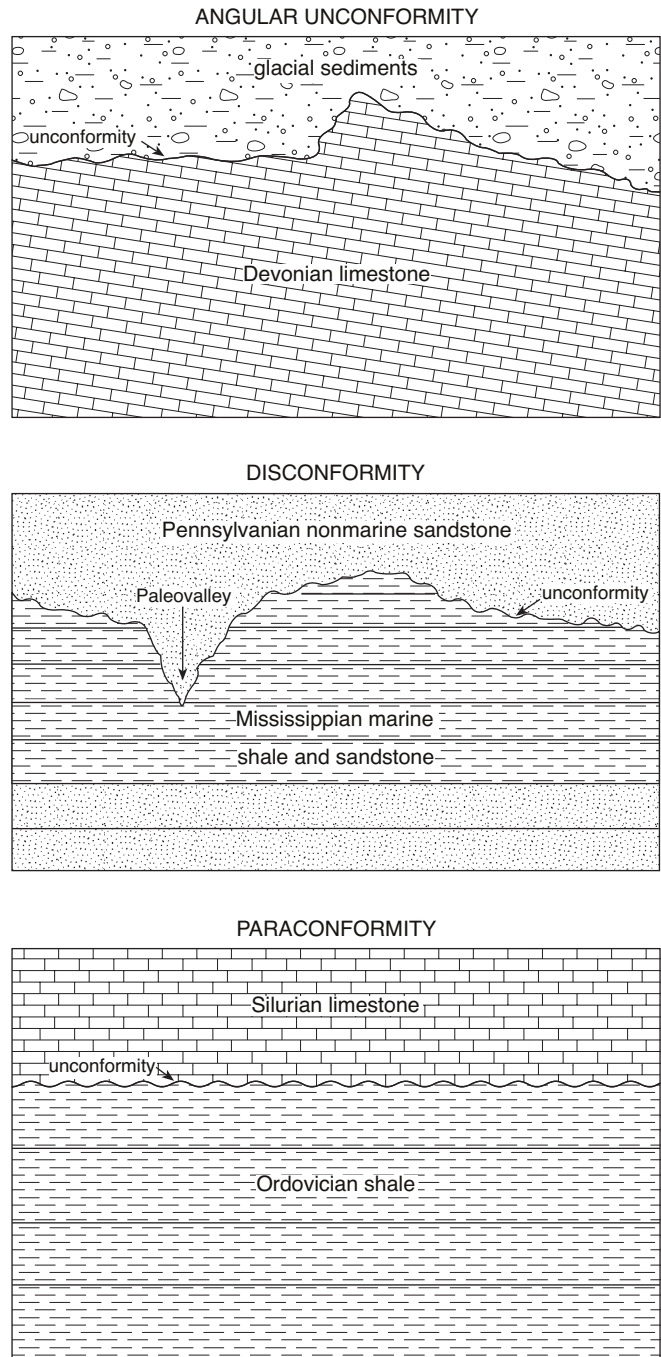


FIGURE 3-6.—Types of unconformities. In the illustration of an angular unconformity, flat-lying glacial sediments overlie dipping, eroded Devonian limestone. In the illustration of a disconformity, nearly flat-lying Pennsylvanian nonmarine sandstone overlies eroded hills and valleys of Mississippiian marine shale and sandstone. In the illustration of a paraconformity, nearly flat-lying, shallow-water Silurian limestone overlies nearly flat-lying deeper water Ordovician marine shale; units are separated by an unconformable surface of nondeposition.

to a period of time and place because of the prior evolutionary history of the individual species, local environmental conditions, and subsequent geologic events such as mass extinctions and changes in relative sea level. So, even though Ordovician, Silurian, and Devonian fossil assemblages may contain brachiopods, bryozoans, corals, and clams, the



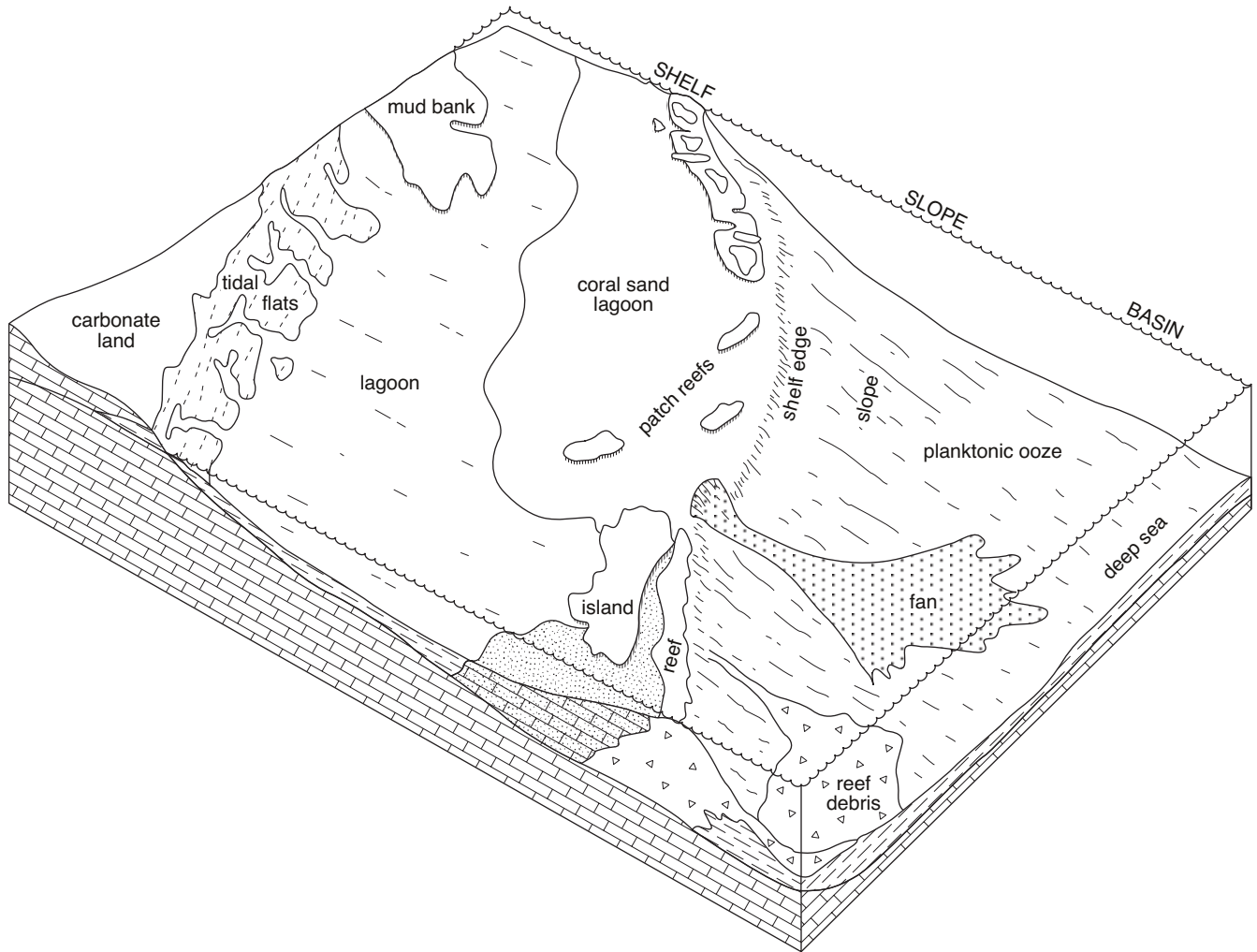


FIGURE 3-7.—Generalized block diagram showing typical carbonate sedimentary environments. These environments were common in earlier Paleozoic time (Ordovician, Silurian, and Devonian Periods).

species and genera are distinctly different, making each assemblage unique from older and younger ones. The change in faunal assemblages over time is the result of extinction of species and organic evolution. The rate of evolutionary change in marine environments is sufficiently fast that new faunal assemblages are recognizable at intervals of about 5 to 20 million years. For some marine organisms, evolutionary rates are so fast that faunal changes can be measured in an interval of thousands of years or less.

A fossil genus (or rarely a species) that is relatively common, occurs over a large geographic area, and has a narrow stratigraphic range is called an index or guide fossil. The index fossil is a key to identifying the whole faunal assemblage and establishing its age.

#### Plate tectonics

The rock record in Ohio is the result of local geological and climatological conditions throughout geologic time, the changing geographic position of Ohio through time, and tectonic forces that result in folding, faulting, and vertical movement of the rocks and the surfaces upon which they were deposited. Tectonism is a general term for the move-

ment or deformation of the rocks that form the crust of the Earth. Folding is the bending of rock layers due to stress. Faulting is the fracturing and displacement of rock layers due to stress.

The forces that have physically changed Ohio's geographic position as well as deformed its surface are closely related to the movement of pieces of the Earth's crust, a process called plate tectonics. Plate-tectonic activity is driven by the flow of plastic mantle material within the Earth. Although detailed treatment of plate tectonics is not possible here, it is useful to understand the basic process. Excellent, more detailed treatments of the subject can be found in many modern geology textbooks.

The outer portion of the Earth is called the lithosphere. It can be thought of as a thin, rigid skin floating on a very hot, plastic interior, called the asthenosphere (fig. 3-10). The asthenosphere is in constant motion, much as water moves as it is heated on a stove. As the asthenosphere slowly moves, the lithosphere is dragged along. In this process, large, rigid sections of the lithosphere, called plates, move relative to one another. The modern Earth consists of six major plates and several smaller plates.

There are three types of plate movement. At convergent

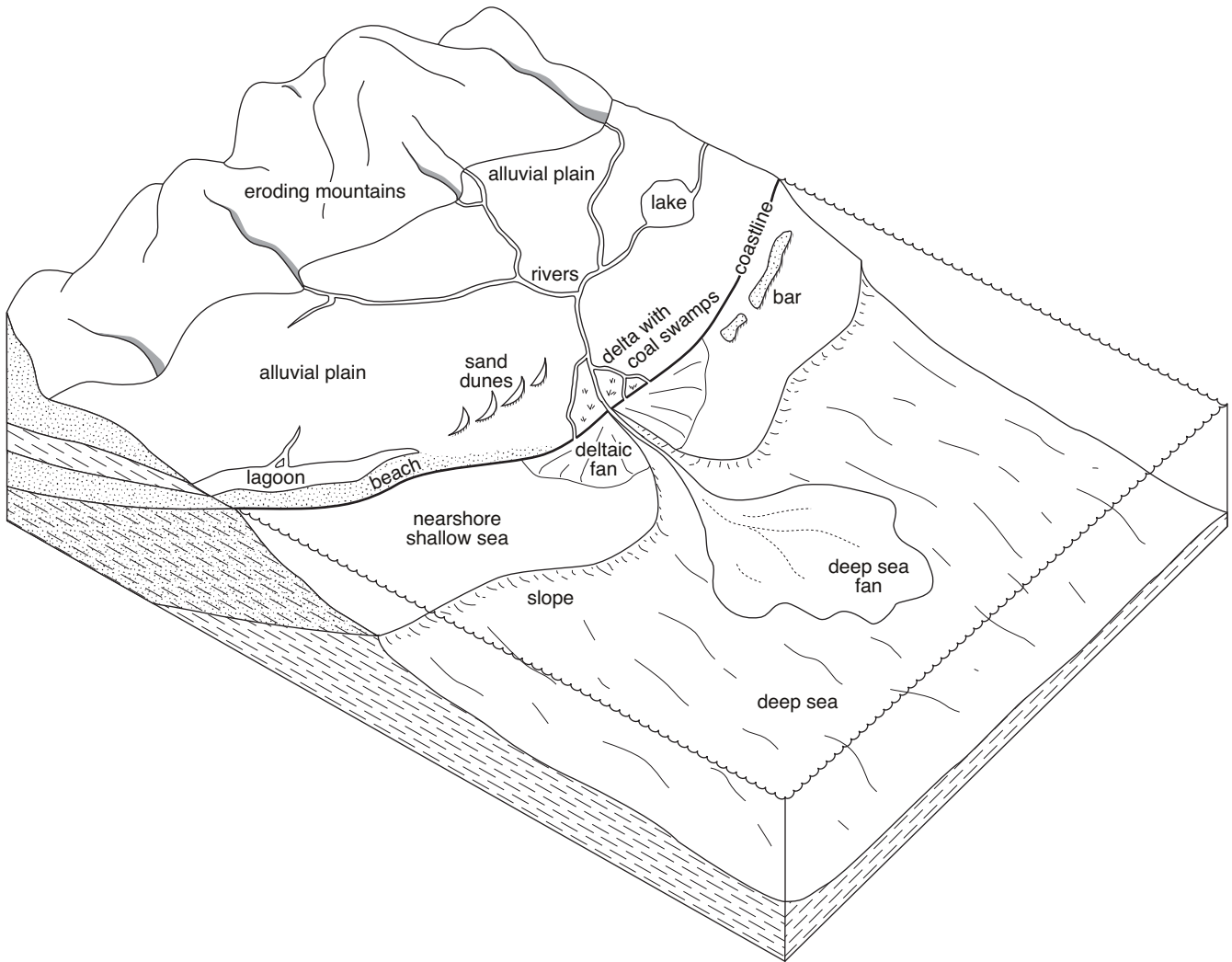


FIGURE 3-8.—Generalized block diagram showing typical siliciclastic sedimentary environments. Environments range from terrestrial alluvial plains to marginal-marine lagoons, to relatively deep, marine seas. These environments were common in later Paleozoic time (Mississippian, Pennsylvanian, and Permian Periods).

W	Lithofacies	E	Formation and member names
	buff cross-bedded sandstone facies		Berea Sandstone
	red shale facies		Red Bedford
	blue siltstone facies		Euclid Member
	gray shale facies		Gray Bedford
	black shale facies		Cleveland Member
	gray shale facies		Chagrin Member
	black shale facies		Huron Member

FIGURE 3-9.—Facies diagram showing relationship of Devonian-Mississippian rocks in northeastern Ohio.

boundaries, plates collide to form major folded mountain chains and fault zones. The Appalachian Mountains are examples of the effects of plate collisions. At divergent or spreading boundaries, plates move away from one another. The great Mid-Atlantic ocean ridge system is a spreading center. At transform fault boundaries, plates slide past one another. The San Andreas fault in California is an example of a transform fault boundary. Much of the earthquake and volcanic activity on the Earth occurs at the margins of plates and can be attributed to plate-tectonic motion.

Within plate boundaries, where Ohio is located, folding and faulting tend to be less severe. In many areas, tectonism is confined to subtle warping and minor ruptures or fractures, called joints, in the rocks. Over long periods of geological time, flexing within plates may cause the plate surface to rise and fall. This motion, coupled with the rise and fall of sea level, due in part to changes in the amount of ice stored on continents, helps explain the accumulation of sediments during part of geological history (when the surface is lower) and erosion of sediments at other times (when the surface is higher).

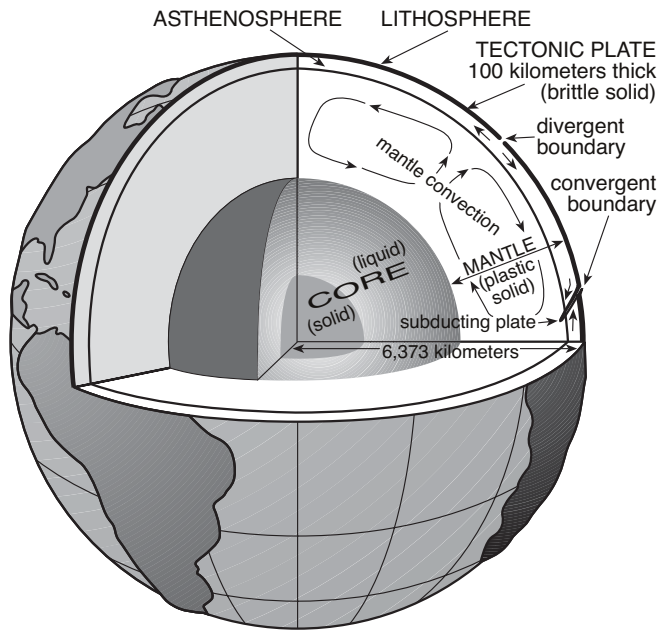


FIGURE 3-10.—Cross section of the Earth showing tectonic plates and convergent and divergent boundaries (modified from Washington Division of Geology and Earth Resources Information Circular 85, 1988).

Ohio has been situated within the bounds of the North American Plate (see figs. 3-14, 3-15) from Precambrian time to the Recent. Thus, since the end of the Precambrian, there has been no major deformation of the area that is Ohio other than fracturing at the close of the Paleozoic Era. Nonetheless, global plate-tectonic motions have been responsible for movement of Ohio and the North American continent from a tropical location 15-20° south of the Equator during the Paleozoic to its present temperate location between 38° and 42° north of the Equator. Furthermore, the surface of this area was depressed during most of the Paleozoic to the extent that much of the time it was beneath the sea and fossiliferous sedimentary rocks formed. Since the Late Paleozoic, the region has been elevated, apparently above sea level, and the sedimentary rocks have largely been weathered and eroded. The historical sequence outlined below provides more detail about the changes that occurred in Ohio.

### GEOLOGIC HISTORY OF OHIO

The earliest record of the geologic history of Ohio is preserved in the igneous and metamorphic Precambrian rocks of the deep subsurface. These rocks, which geologists commonly call the basement, are known only from deep well drilling and have been dated at more than 1 billion years old. Central and eastern Ohio are underlain by metamorphic rocks of the Grenville Province, the remains of a Precambrian plate that collided with the older portion of the North American continent, the Superior Province, 1 to 2 billion years ago to form the Grenville Mountains. The western edge of the Grenville Province is delineated by the Grenville Front, which is several tens of kilometers wide. The Grenville Front parallels and partly underlies the Cincinnati and Findlay Arches. West of this front, buried deep in the subsurface, is a rift or series of rifts in the basement, similar to the Red Sea rift of modern times. A rift is an area where

a continental plate began to split apart. But, in the case of the western Ohio rifts, separation during the Precambrian was incomplete. The western Ohio rift, known as the East Continent Rift Zone, is quite deep and is filled with up to 6 km of undeformed sandstones and other siliciclastic rocks. West of the rift zone are older igneous and metamorphic rocks of the Superior Province. The ancient Grenville Mountains were eroded to an undulating plain bounded on the west by rift valleys (see fig. 3-11) by the time of onset of the early Paleozoic deposition in Ohio.

By Late Cambrian time, shallow seas covered Ohio and sediments were deposited and preserved, beginning a record of mainly marine and deltaic deposition, interrupted by periods of erosion (resulting in unconformities), which lasted until Early Permian time. Nonmarine deposition was intermittently common in the Pennsylvanian and Permian Periods. From what we can surmise from deposits and fossils found elsewhere, the area that is now Ohio has been an exposed continental area since the close of the Permian. In the Late Paleozoic, North America was part of a northern landmass called Laurasia, which collided with a southern landmass called Gondwana to form the supercontinent of Pangea (see fig. 3-15). Laurasia and Gondwana broke up in the Mesozoic, and the plates separated to create the Atlantic Ocean and the Gulf of Mexico. The area of Ohio remained high and dry, undergoing erosion for most of the past 245 million years of Earth history. The next substantial record is preserved as glacial deposits (see fig. 3-1).

### PALEOZOIC HISTORY

#### Cambrian through Early Ordovician time

During the Cambrian Period, which began about 570 million years ago, Ohio was part of a broad coastal plain, comparable to the modern Gulf Coast of the U.S. In Middle to Late Cambrian time, the sea slowly spread across and eventually covered the area, overlapping the underlying, faulted Precambrian igneous and metamorphic rocks (figs. 3-11, 3-12A). Initially, sand and mud were deposited, then carbonate sediments accumulated. These sediments were lithified into sandstone, shale, limestone, and dolomite; these rocks (Mount Simon Sandstone, Eau Claire and Rome Formations, Knox Dolomite) are encountered only by drilling into the subsurface. Accumulation of several hundred meters of these rocks ended with withdrawal of the sea, followed by erosion (fig. 3-13) in Early Ordovician time, about 500 million years ago. The sea receded owing to uplift resulting from collision between the North American Plate and part of another plate to the east of Ohio. The related mountain-building event was the beginning of the Taconic Orogeny.

#### Middle Ordovician through Early Devonian time

In Middle Ordovician time, about 475 million years ago, the center of the North American continent lay astride the Equator, and Ohio lay south of the Equator (fig. 3-14). The sea again overlapped the continent, resubmerging the eroded land surface. Limestones were deposited widely as carbonate banks, reefs, and lagoonal and bar deposits (see fig. 3-7) during a time of only slight tectonic activity. These Middle Ordovician rocks in Ohio are known only from subsurface drilling.

The oldest exposed rock unit in Ohio, the Point Pleasant

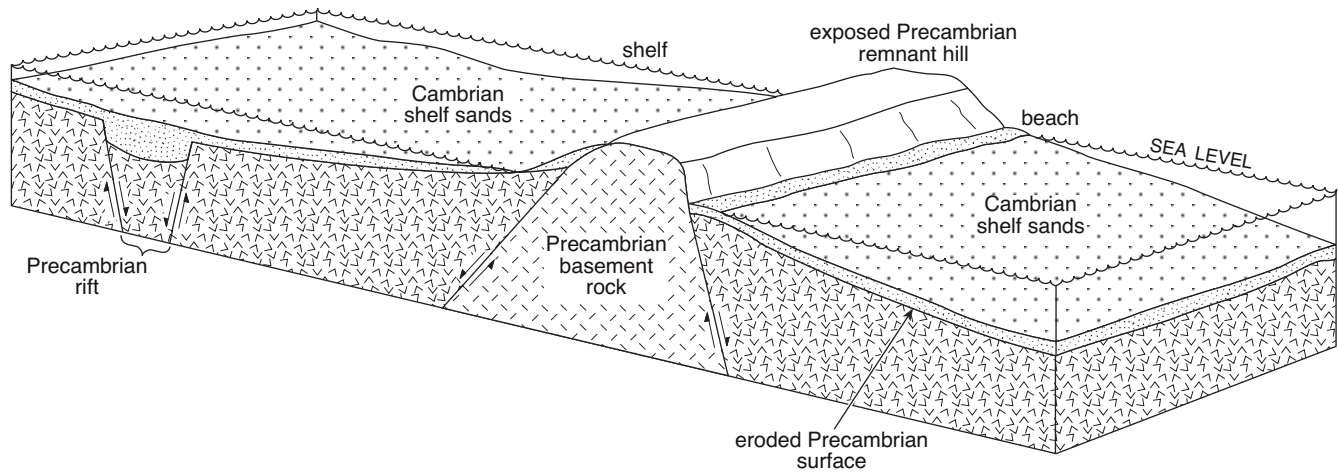


FIGURE 3-11.—Block diagram showing the onlap of the Precambrian basement rock by the Late Cambrian seas, deposition of basal Cambrian shelf sands over the faulted and eroded basement, and the Precambrian rift zone in western Ohio.

Formation of Middle to earliest Late Ordovician age, crops out along the Ohio River near Cincinnati. This rock unit represents the transition between shallow-water carbonate-bank limestones of the Middle Ordovician and the overlying, deeper water shales and limestones of the Late Ordovician (about 445 million years ago). These shales and limestones of the Late Ordovician Cincinnati Series were deposited offshore (fig. 3-12B) in an epicontinental sea that was receiving sediment input from the mountains that formed in the early part of the Taconic Orogeny. The tropical environment and warm seas produced beds that are richly fossiliferous. These Upper Ordovician strata are exposed in numerous outcrops throughout a broad area in southwestern Ohio. Exposures on the hillsides and in stream and road cuts around Cincinnati are the best of Ohio's fossil-hunting areas. The State Invertebrate Fossil—the trilobite *Isotelus*—and many other well-preserved fossils can be found in the shales and limestones of the Cincinnati Series. In latest Ordovician time, at the culmination of the Taconic Orogeny, the area that is Ohio was part of a rapidly subsiding (sinking) basin. The record of Ordovician deposition ends with a paraconformable break at the top of the Drakes Formation, toward the end of the Ordovician, about 438 million years ago. This break is widely attributed to a fall in sea level owing to glaciation in the Southern Hemisphere.

Silurian deposition began about 438 million years ago when sea level rose and flooded the exposed Ordovician surface. In their outcrop area on the east and west flanks of the Cincinnati Arch and on the crest of the Findlay Arch, the Silurian rocks consist of shallow-water, subtropical, carbonate-bank deposits (fig. 3-12C). Part of the bank had reefs, as in the Lower Silurian Lockport Dolomite. There are evaporite deposits (gypsum, anhydrite, and halite) between the reefs and overlying them. The Silurian carbonate rocks are moderately fossiliferous, but preservation is commonly poor.

The final stages of Silurian deposition reflect a subsiding but otherwise stable, shallow, marine environment that periodically experienced lowered sea level and evaporation of the sea water to form the thick salt beds of the Salina Group in eastern Ohio. These salt beds are mined more than 500 meters beneath Lake Erie at Cleveland (Cuyahoga County) and Fairport Harbor (Lake County).

In Early Devonian time, another plate collision along the

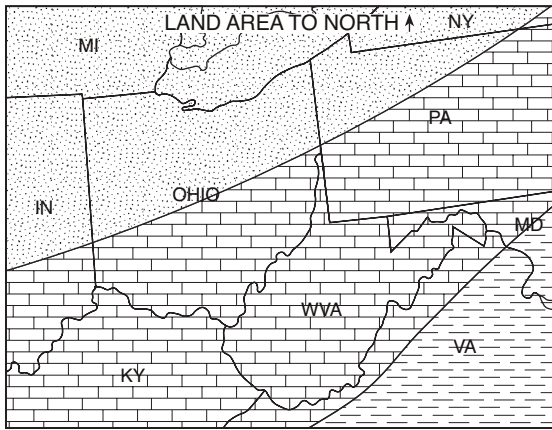
northeastern margin of North America resulted in uplift and erosion. Deposition of sediments was essentially continuous in the Appalachian Basin in eastern Ohio. Lower Devonian rocks (Helderberg Limestone and Oriskany Sandstone, about 408 million years old) occur in the subsurface in eastern Ohio (Dow, 1962). A very limited deposit of Lower Devonian rocks (Holland Quarry Shale) was exposed in a quarry in Lucas County in northwestern Ohio, but this quarry has been long abandoned and is now reclaimed. Elsewhere, particularly along the present-day Devonian outcrop from southern Ohio to Lake Erie, a major unconformity separates Upper Silurian rocks from Middle Devonian dolomites and limestones. The uplift and related mountain-building activity that ended Middle Ordovician to Early Devonian deposition are referred to as the Acadian Orogeny.

#### Middle Devonian through Mississippian time

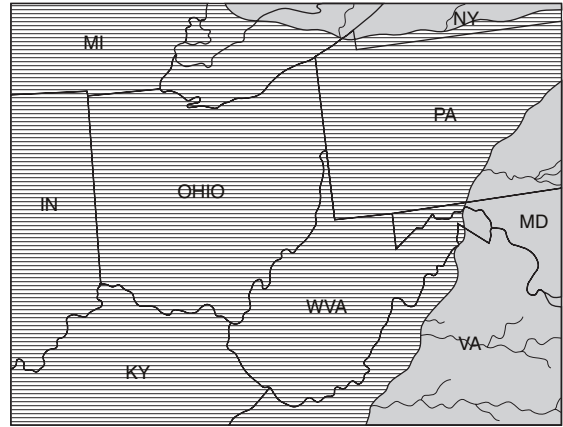
Middle Devonian sedimentation began in clear seas about 386 million years ago with deposition of the sediments that would become the richly fossiliferous Columbus Limestone east of the Findlay Arch and its approximate equivalents on the western side of the Findlay Arch, including the carbonates of the Detroit River Group (see fig. 3-19). These strata overlie the eroded Upper Silurian beds in a slight angular unconformity; the surface is characterized at some outcrops by phosphate-rich bone beds containing fish scales and teeth. The Columbus Limestone and the overlying Delaware Limestone crop out in a north-south band from south of Columbus (Franklin County) to Sandusky County and on Kelleys Island in Lake Erie. The best exposures of these fossiliferous units are in quarries along this belt. The quarries provide limestone for road construction, cement, and other building materials.

Toward the end of Middle Devonian time, carbonate deposition gave way to deposition of clay and organic matter that would become dark-brown to black marine shales (Olentangy Shale and Ohio Shale). These sediments began to fill a more rapidly subsiding, relatively stagnant offshore marine basin. The Olentangy Shale and the Ohio Shale (Huron, Chagrin, and Cleveland Shale Members) overall are poorly fossiliferous, but locally contain brachiopod and arthropod faunas and spectacular fish remains, especially shark and arthrodire fossils, such as the *Dunkleosteus* armor featured on the cover

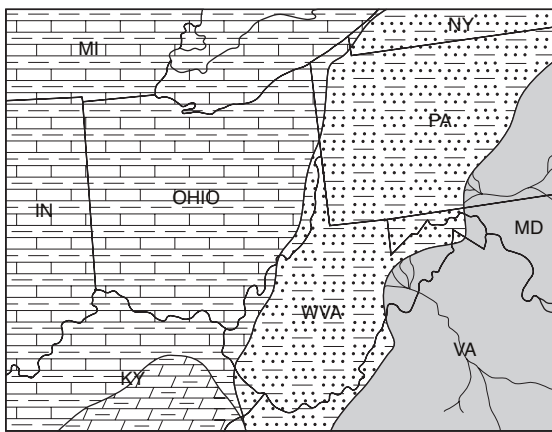




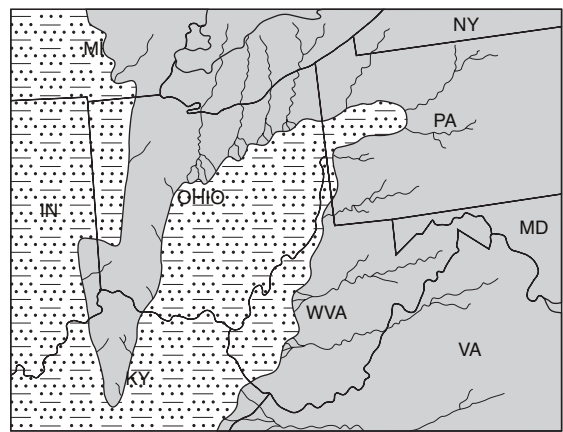
A. LATE CAMBRIAN



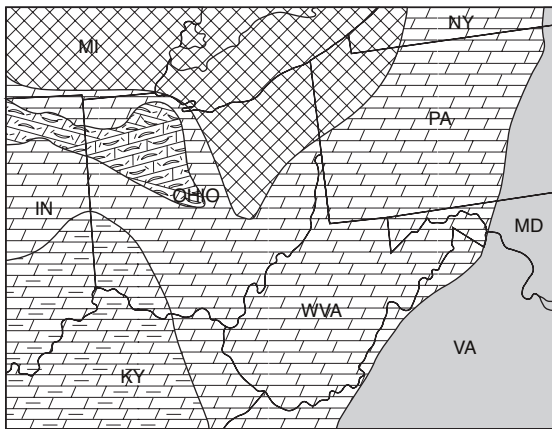
D. LATE DEVONIAN



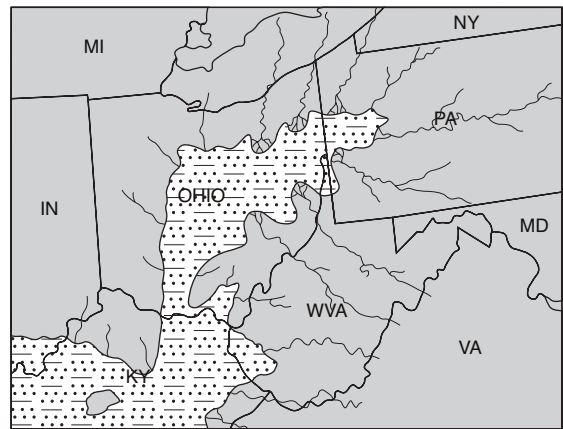
B. LATE ORDOVICIAN



E. EARLY MISSISSIPPIAN



C. MIDDLE SILURIAN



F. MIDDLE PENNSYLVANIAN

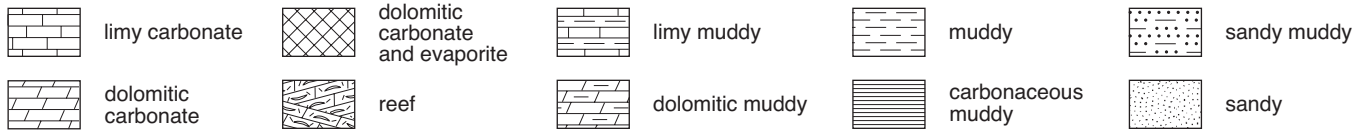


FIGURE 3-12.—Generalized paleogeographic maps of Ohio and surrounding areas during various Paleozoic periods. Land areas are shown by screen pattern. **A** modified by Ronald A. Riley from Dott and Batten (1976) and Palmer (1974). **B** modified by E. Mac Swinford from Weir and others (1984). **C** modified by E. Mac Swinford from Dott and Batten (1976) and Droste and Shaver (1983). **D-F** modified from Hansen (no date).

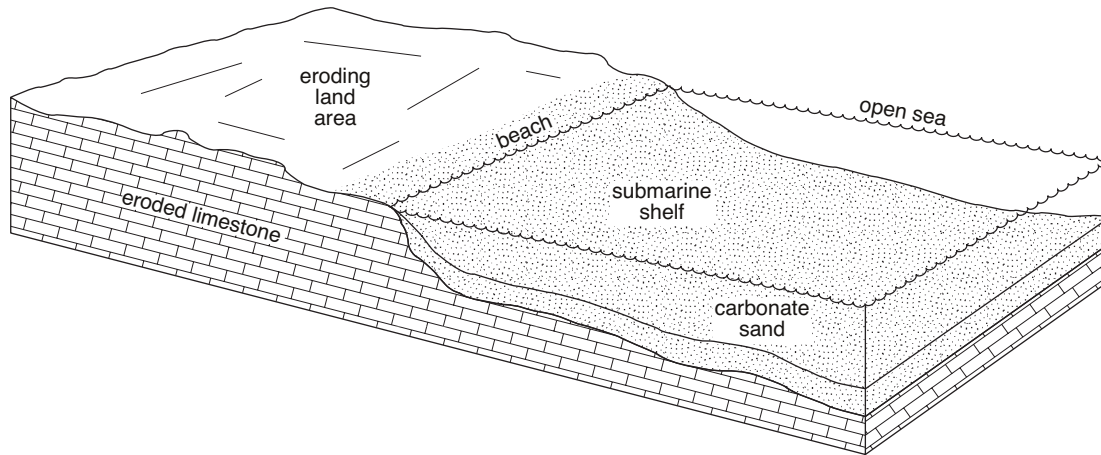


FIGURE 3-13.—Block diagram of erosion at low stand of sea level. As the sea recedes from left to right, the rocks are exposed and eroded.

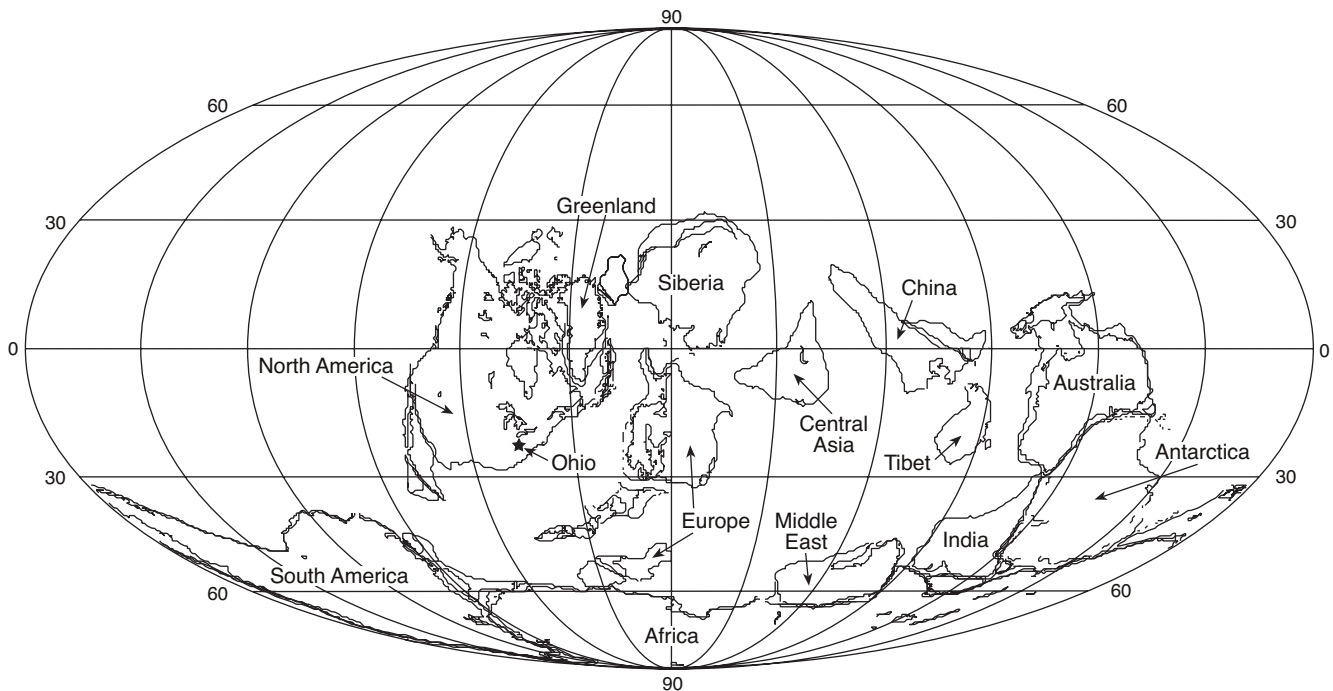


FIGURE 3-14.—Postulated position of the continents in the Early Paleozoic (Late Ordovician) (modified from Scotese and Denham, 1988).

of this book. These shales crop out in a north-south band from Scioto County on the Ohio River through central Ohio to Erie County on the Lake Erie shore and then east to Pennsylvania and beyond to New York. The shoreline of this basin was in central Pennsylvania (fig. 3-12D).

By the end of the Devonian and beginning of the Mississippian, about 340 million years ago, the offshore marine basin was partly filled. The dark marine shales of the Late Devonian were covered by fluvial, deltaic and marginal-marine clastic sediments deposited in basin and shelf tectonic settings (fig. 3-12E) (see Pashin and Ettensohn, 1995). The Bedford Shale, the Berea Sandstone, the Cuyahoga Formation, and the Logan Formation (see fig. 3-20) were deposited in these environments. The black Sunbury Shale represents a brief return to stagnant basin conditions between the Berea Sandstone and the Cuyahoga Formation.

The western edge of the Mississippian outcrop belt paral-

lels the north-south Devonian shale outcrop belt through central Ohio and then eastward parallel to the Lake Erie shore. Mississippian strata form a band of hills 5-10 km south of the present Lake Erie shoreline. The Mississippian rocks display various characteristics of deltaic and near-shore marine deposition (see fig. 3-8). The Cuyahoga and Logan Formations are moderately fossiliferous, containing brachiopod- and mollusk-rich faunas. Some excellent crinoid assemblages have been found in localized pockets in the Cuyahoga Formation.

Another major erosional event ended Mississippian deposition in Ohio and removed younger Mississippian strata, except for remnants of the Rushville and Maxville Formations in eastern Ohio. Valleys were carved by Mississippian and Early Pennsylvanian streams into the underlying Mississippian rocks. Pennsylvanian rocks were deposited on this irregular erosional surface.

## Pennsylvanian and Permian time

The first record of renewed uplift to the east and/or subsidence (relative lowering of the Earth's surface) at the western edge of the Appalachian Basin is the sediments of the Early to Middle Pennsylvanian Sharon sandstone of the Pottsville Group (see fig. 3-21). Pennsylvanian and Permian rocks are primarily siliciclastic, consisting of nonmarine shales, sandstones, underclays, coals, ironstones, and limestones, as well as marine shales, limestones, ironstones, and flints. Moreover, unlike the deltas of earlier times, those of Pennsylvanian time were covered with lush vegetation. Although land plants were common in the Devonian and Mississippian, they did not overwhelm the landscape until the Pennsylvanian. Grand tree ferns, early conifers, reeds, and rushes grew in profusion in and around the swamps of the Pennsylvanian deltas. As the vegetation died, it accumulated in the water as peat, which was later compressed and heated deep underground to form Ohio's extensive coal deposits.

Rivers, lakes, deltas with peat (coal) swamps, open marine embayments, lagoons, beaches, and barrier bars characterized the final episodes of Paleozoic deposition in the Pennsylvanian and Early Permian. The four main subdivisions of the Pennsylvanian, the Pottsville, Allegheny, Conemaugh, and Monongahela Groups, as well as the Upper Pennsylvanian-Lower Permian Dunkard Group, display progressively more terrestrial environments of deposition consistent with the ongoing development of the supercontinent of Pangea (fig. 3-15).

Fossils in these upper Paleozoic strata are indicative of marginal-marine and terrestrial environments (fig. 3-12F). The climate was warm and tropical because the area that is now Ohio was near the Late Paleozoic Equator. Pennsylvanian strata are exposed in spectacular road cuts along Interstate Route 77 from Canton (Stark County) south to Marietta (Washington County) and along Interstate Route 70 from Cambridge (Guernsey County) to Bridgeport (Bel-

mont County). There are equally impressive exposures of Pennsylvanian and Permian rocks in the cliffs along the Ohio River from Marietta north to East Liverpool (Columbiana County). The Pennsylvanian marine zones, mostly limestones and calcareous shales, generally are the most fossiliferous. Plant fossils are more common in freshwater shales. Permian (Dunkard Group) strata are present only in southeastern Ohio and are mainly continental fluvial- deltaic and lacustrine deposits which contain fossil vertebrates such as reptile and amphibian bones, fossil plants, and some fossil freshwater invertebrates.

## MESOZOIC AND CENOZOIC HISTORY

During the Mesozoic Era and the Tertiary Period of the Cenozoic Era, an interval of about 245 million years, uplift, erosion, and weathering removed all traces of any deposits of these ages (if indeed there were any). Extensive systems of stream valleys dissected the entire surface of Ohio before the Pleistocene glaciations and may have removed several hundred meters of rock. The most recent chapter in Ohio's geologic history began about 2 million years ago when, in response to the cooling of the Earth's climate, continental glaciers moved south from Canada to cover about two-thirds of Ohio at their maximum extent (see fig. 3-3). Except for the continental deposits of the Pleistocene Ice Age and the sediments of the postglacial Recent, there is no observable record of Mesozoic and Cenozoic deposition in Ohio. Fossils in Pleistocene and Recent sediments consist of plant fragments, bones of land animals, and remains of lake and river dwellers such as clams, snails, and fish. Although they are comparatively rare, these fossils can be spectacular, as in the case of mastodon bones.

## REGIONAL STRATIGRAPHY

The present pattern of rock outcrops (see fig. 3-2) is the

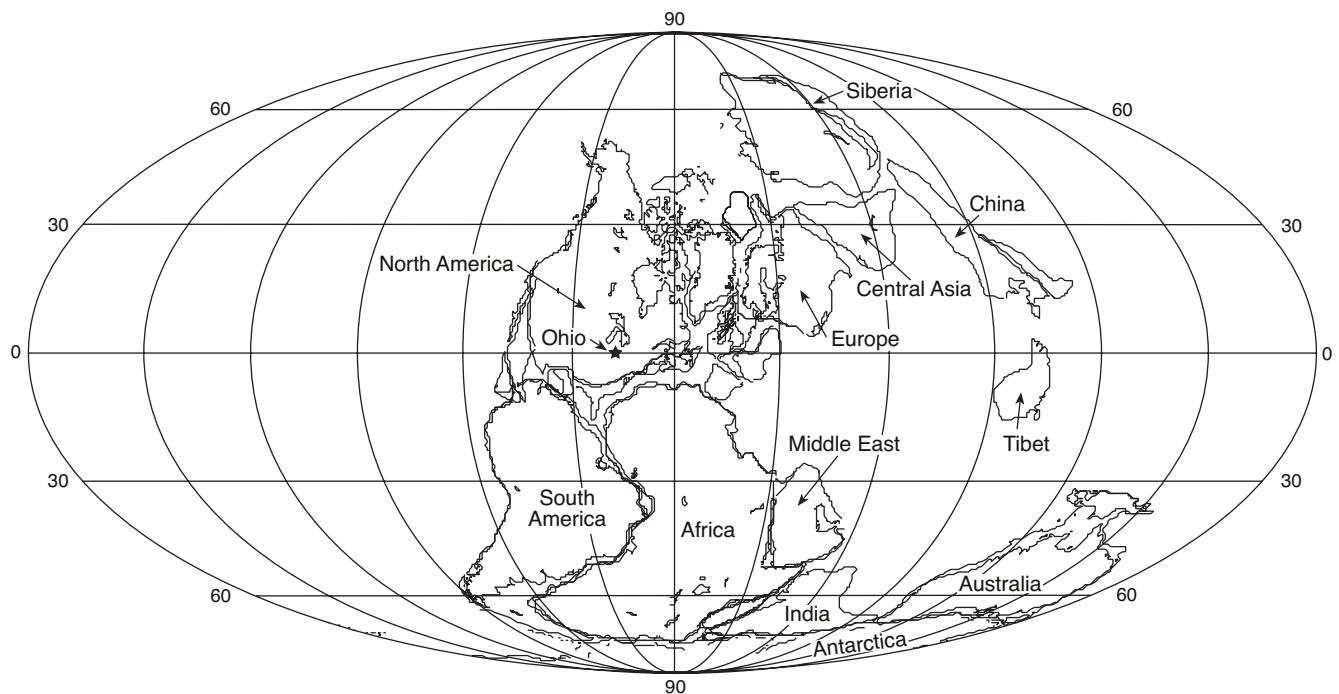


FIGURE 3-15.—Postulated position of the continents in the Late Paleozoic (Middle Pennsylvanian) (modified from Scotese and Denham, 1988).

result of the position of rock units in relation to geologic structures, the various erosional regimes, and the distribution of glacial deposits. On one hillside or in one stream or road cut, only a hundred meters or so of rock are typically exposed, that is, generally just one or two formations can be seen at one locality. A few kilometers away, another set of formations may be exposed. Unfortunately, not all the formations of Ohio can be described in this volume. The following paragraphs describe and illustrate composite sections of Paleozoic formations, many fossiliferous, for five general areas of Ohio shown in figure 3-16.

**SOUTHWESTERN OHIO**

This area is characterized by abundant outcrops of Upper Ordovician shales and limestones (fig. 3-17) in the hills of Cincinnati and surrounding areas. All of the units are highly fossiliferous. Fossil collecting is permitted at Caesar

Creek State Park (see Shrake, 1992) in Warren County and Hueston Woods State Park (see Ohio Division of Parks and Recreation, no date) in Butler and Preble Counties.

**CENTRAL OHIO**

In eastern Adams, Highland, and Clinton Counties, relatively fossiliferous Silurian-age rocks of the Brassfield, Bisher, and Lilley Formations are exposed (fig. 3-18). Around Dayton (Montgomery County) and Springfield (Clark County), Silurian formations exposed in quarries and river valleys include the moderately fossiliferous Dayton Formation. The Silurian formations are not as fossiliferous as the Ordovician formations. Farther east, in south-central Ohio, Devonian and Mississippian shales and sandstones (Ohio, Bedford, and Sunbury Shales and Berea Sandstone) crop out. Plant and fish fossils are locally abundant in the Ohio Shale. In central Ohio, the Ohio and Olentangy Shales



FIGURE 3-16.—The five areas of Ohio that are discussed in the text and represented in the regional stratigraphic columns in figures 3-17 through 3-21. The boundaries of the geologic systems from figure 3-2 also are shown.



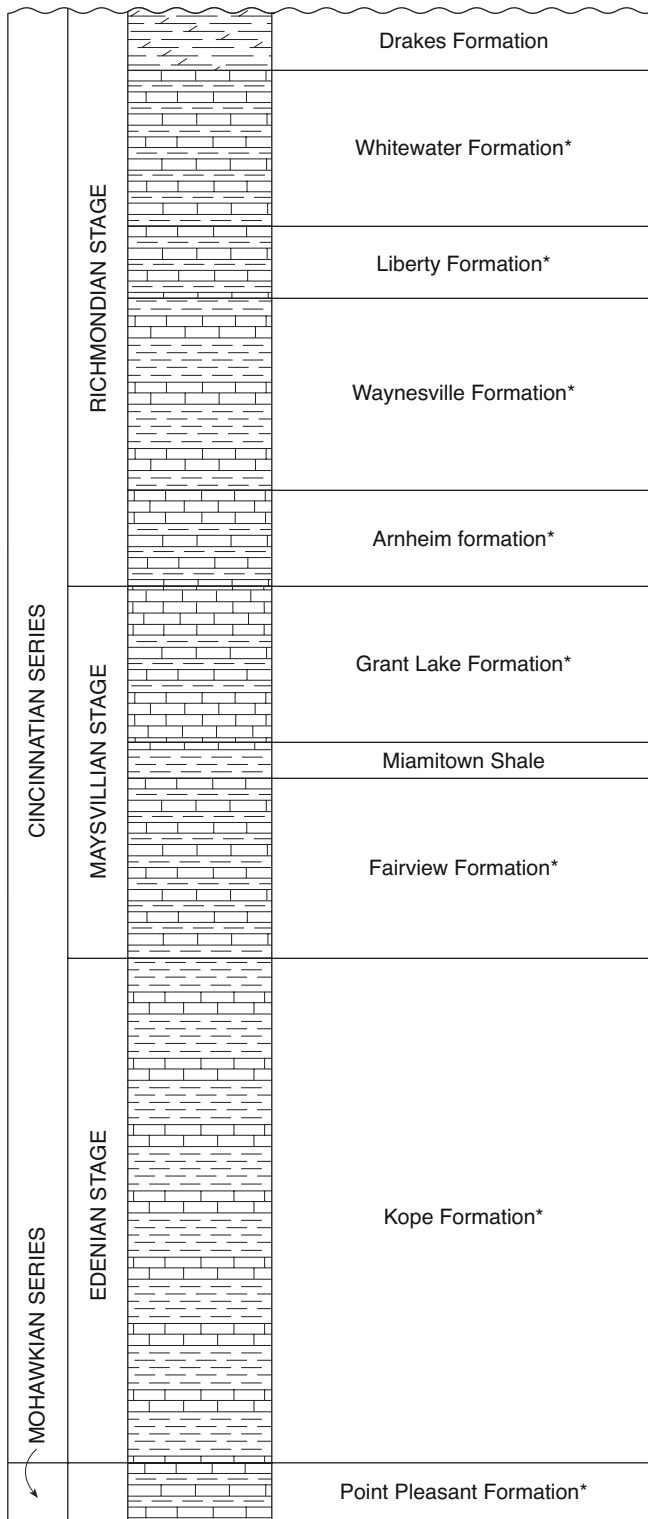


FIGURE 3-17.—Generalized section of Middle and Upper Ordovician formations in southwestern Ohio. Asterisks indicate units that are fossiliferous. This composite section represents about 225 meters of rock exposed across the area. The section is not to scale, but the thicknesses indicated are proportional. The term Cincinnati Group is used in much of the geologic literature for southwestern Ohio for rocks of the Kope Formation through the Drakes Formation. Other nomenclature also has been used for these rocks. See figure 3-18 for explanation of rock types.

and the Columbus and Delaware Limestones crop out. The Columbus Limestone is very fossiliferous. The Ohio State House in Columbus is built of Columbus Limestone, and many fossils can be seen in the steps, pillars, and walls (see Melvin and McKenzie, 1992).

#### NORTHWESTERN OHIO

On the crest and flanks of the Findlay Arch, Lower and Upper Silurian and Middle and Upper Devonian formations are the surface rocks (fig. 3-19). Except for the island area of Lake Erie and some deeper river valleys, these rocks are exposed only in quarries. Some of these units are moderately fossiliferous and some are very fossiliferous, such as the world-famous Silica Formation at Sylvania (Lucas County) (see Stewart, 1927) and the Columbus Limestone at Marblehead (Ottawa County) and on Kelleys Island. Ancient reefs dominated by stromatoporoids, corals, and bryozoans are common in the Lockport Dolomite.

#### NORTHEASTERN OHIO

Siliciclastic rocks of Late Devonian through Early Pennsylvanian age crop out in the deeper valleys and in quarries and road cuts in northeastern Ohio. Exposures of Devonian and Mississippian rocks are common in the Cuyahoga Valley and along the Lake Erie shore from Erie County to the Pennsylvania line (fig. 3-20). Farther south, other Mississippian formations and Lower Pennsylvanian rocks are exposed. Spectacular fish remains have been found in the Cleveland Shale Member of the Ohio Shale in the Cleveland area. The Chagrin Shale Member has produced some excellent arthropod fossils. The Cuyahoga Formation also is fossiliferous in places and is particularly noted for its crinoid fossils.

#### EASTERN OHIO

The surface rocks in eastern Ohio are primarily of Pennsylvanian and Permian age; Mississippian rocks are present in the western part of this area. The area is largely unglaciated south and east of Canton (Stark County). Stream and road cuts expose Pennsylvanian-age interbedded sandstones, shales, coals, and thin limestones (fig. 3-21). The marine limestones and shales are moderately fossiliferous, especially the Lower Mercer, Putnam Hill, Vanport, Brush Creek, Cambridge, and Ames units. Plant fossils are abundant in the shales and sandstones. Permian rocks are limited to southeasternmost Ohio.

#### ACKNOWLEDGMENTS

Reviewers for this chapter included Thomas M. Berg, Merrienne Hackathorn, Michael C. Hansen, Dennis N. Hull, Gregory A. Schumacher, David A. Stith, and E. Mac Swinford (Ohio Division of Geological Survey) and Loren E. Babcock (The Ohio State University).

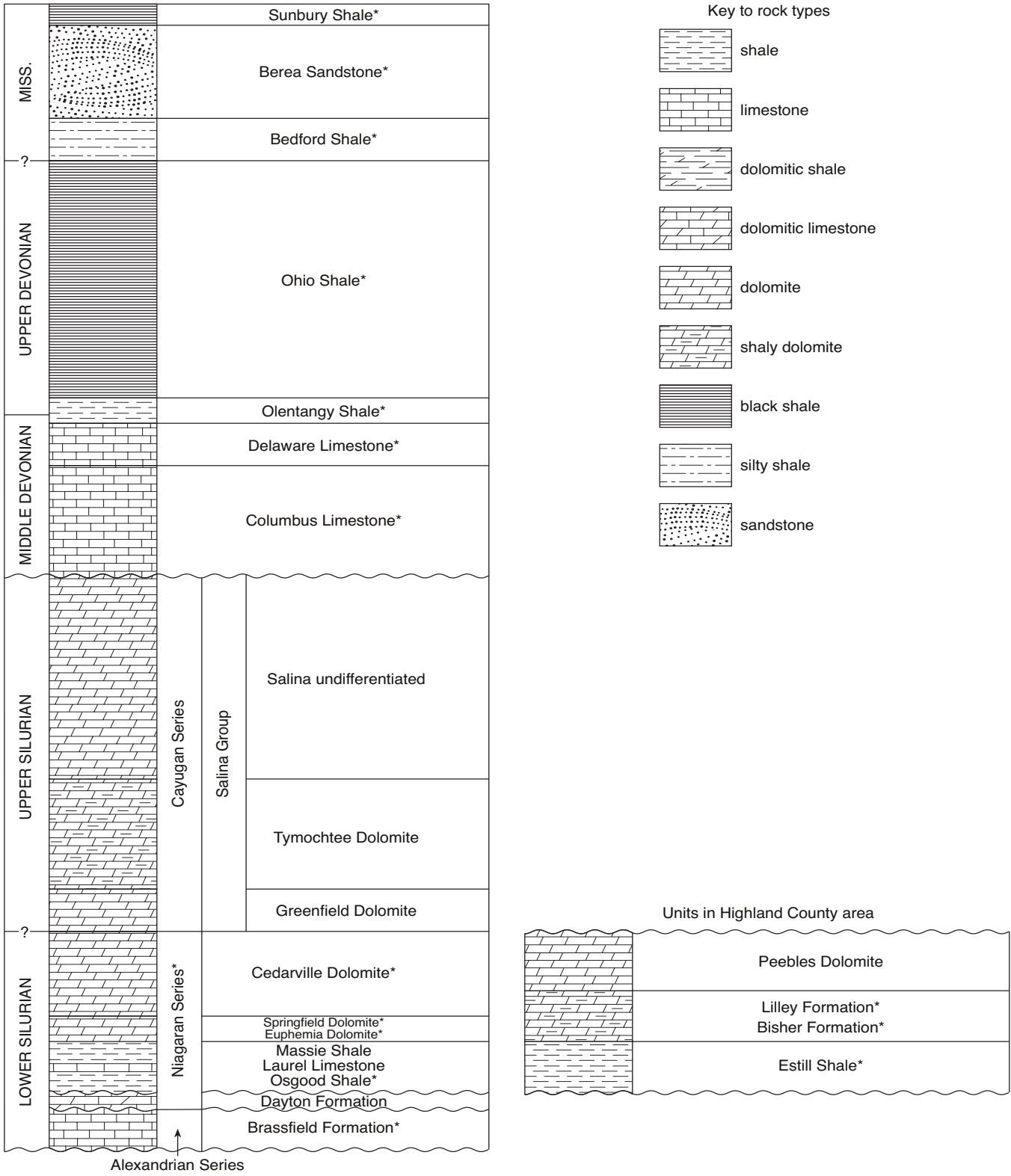


FIGURE 3-18.—Generalized section of Silurian, Devonian, and Mississippian formations in west-central and south-central Ohio. Asterisks indicate units that are fossiliferous. This composite section represents about 330 meters of rock exposed across the area. The section is not to scale, but the thicknesses indicated are proportional.

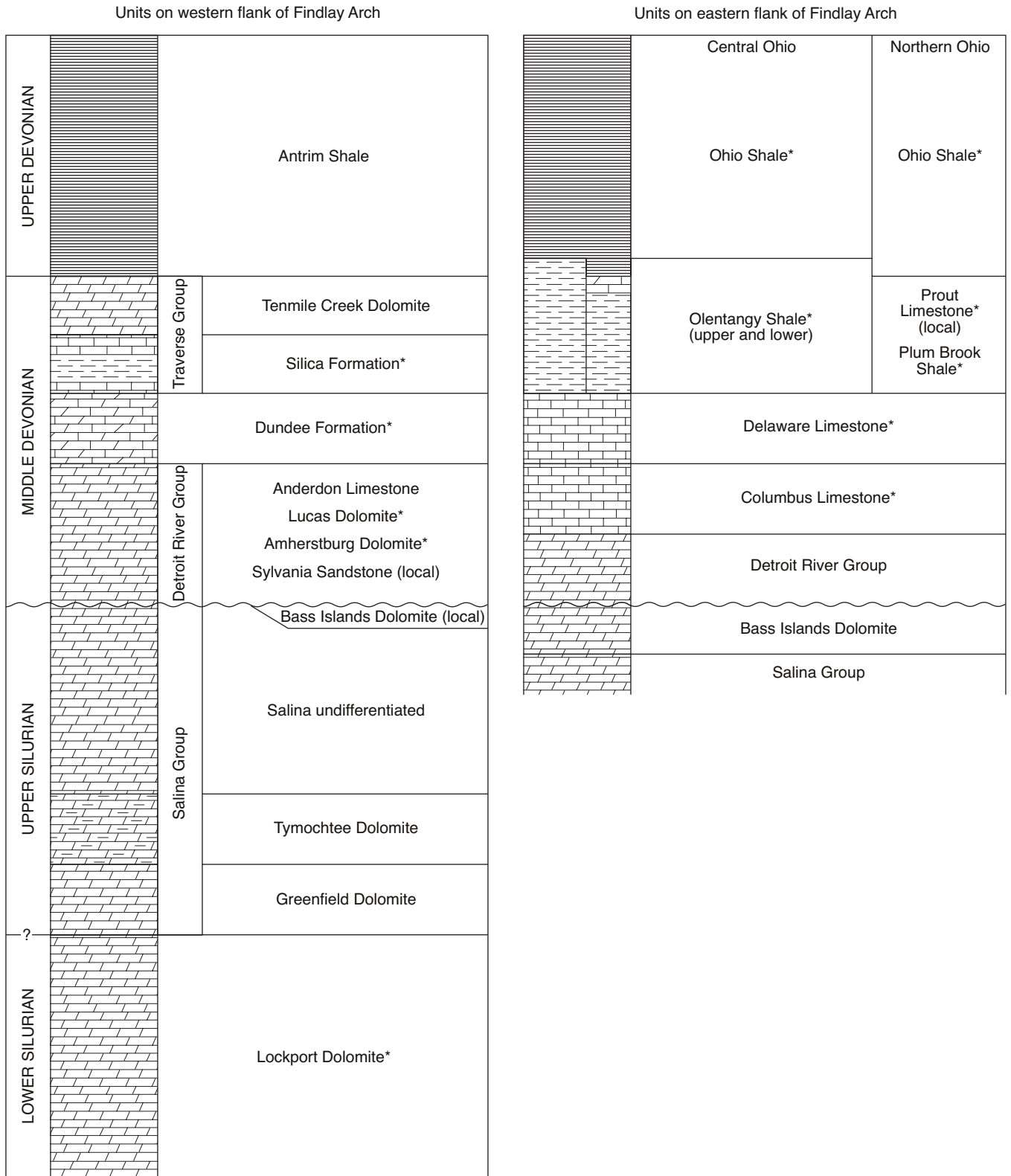


FIGURE 3-19.—Generalized section of Silurian and Devonian formations in northwestern Ohio. Asterisks indicate units that are fossiliferous. This composite section represents more than 300 meters of rock exposed across the area. The section is not to scale, but the thicknesses indicated are proportional. See figure 3-18 for key to rock types.

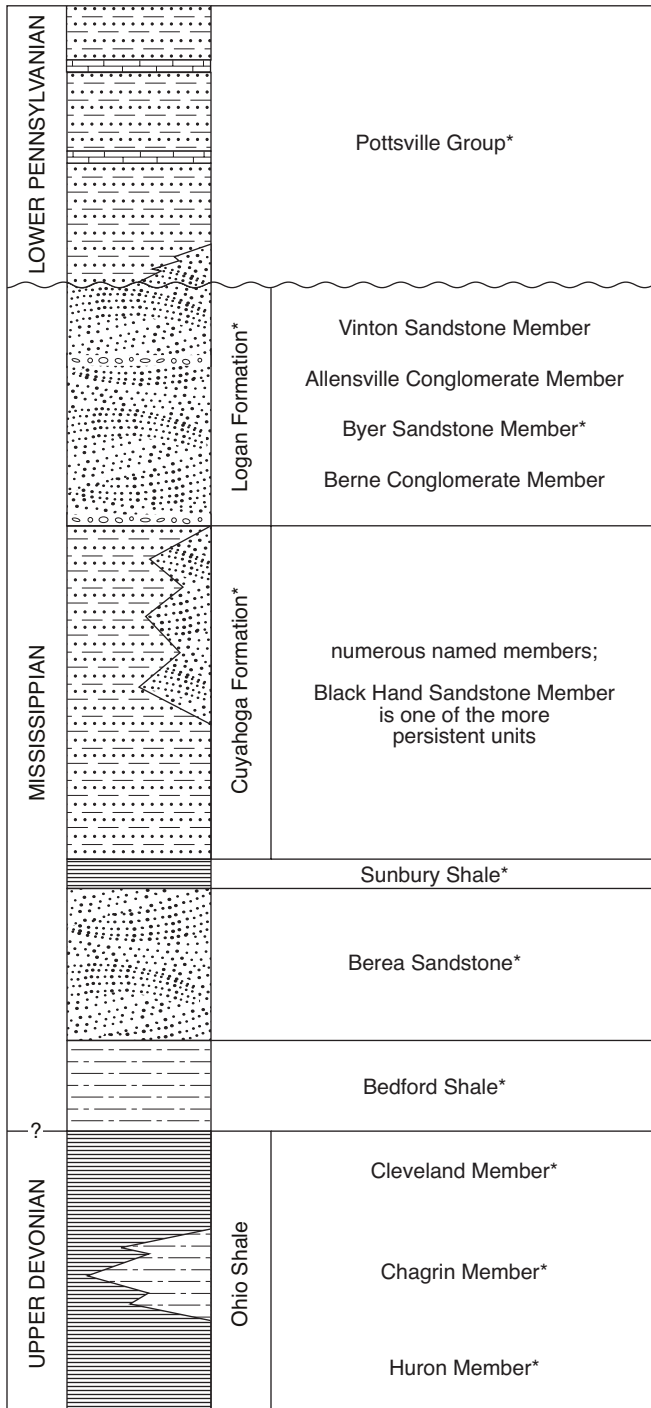


FIGURE 3-20.—Generalized section of Upper Devonian, Mississippian, and Lower Pennsylvanian formations in northeastern Ohio. Asterisks indicate units that are fossiliferous. This composite section represents about 400 meters of rock exposed across the area. The section is not to scale, but the thicknesses indicated are proportional. The term “Waverly” is used in the older literature to refer to Mississippian rocks in Ohio. Some geologists use the European term “Carboniferous,” which encompasses the Mississippian and Pennsylvanian Periods of the U.S. Many units have been named within the Cuyahoga Formation, but most units are local and cannot be traced over great distances. The Black Hand Member is a spectacular massive sandstone that is fairly widespread but discontinuous. See Hyde (1953), Hoover (1960), and Collins (1979) for more information on Mississippian rocks in Ohio. See figure 3-18 for explanation of rock types.

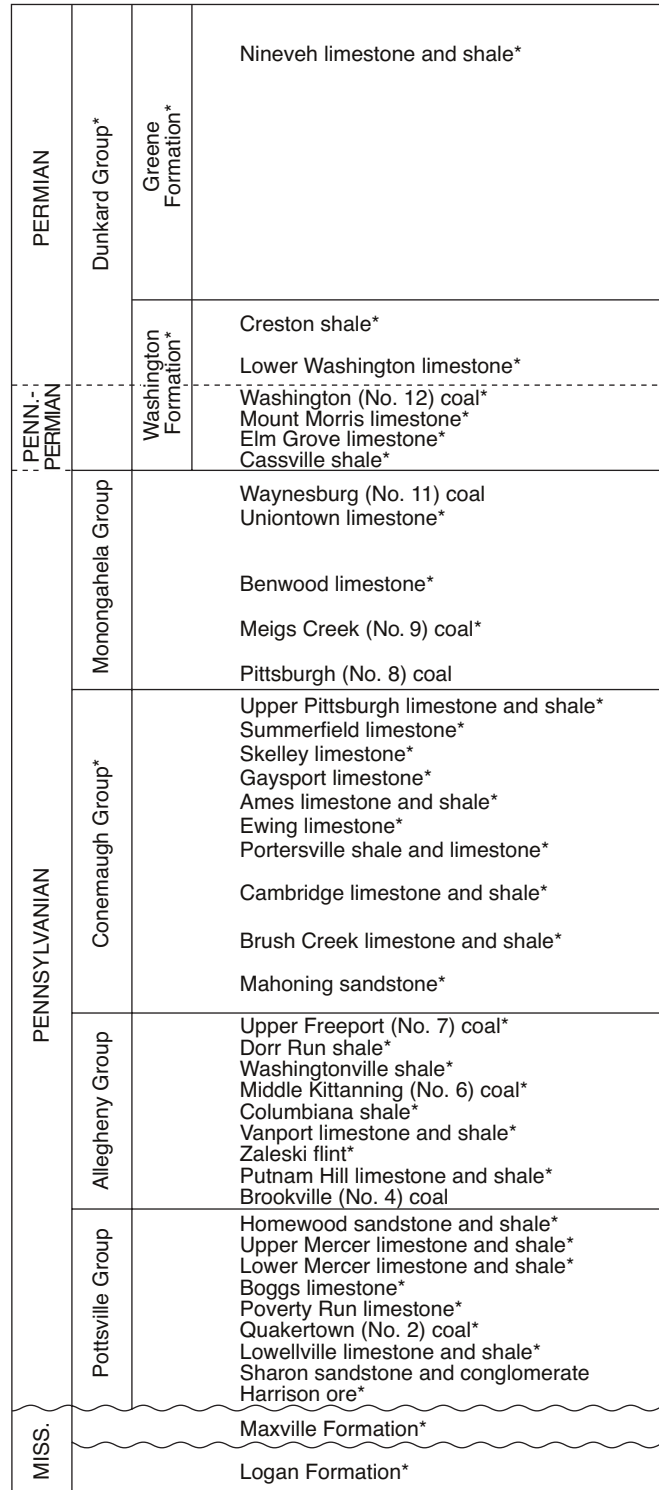


FIGURE 3-21.—Uppermost Mississippian, Pennsylvanian, and Permian units in eastern and southeastern Ohio. Asterisks indicate units that are fossiliferous. This composite section represents more than 500 meters of rock exposed across the area. The section is not to scale, but the thicknesses indicated are proportional. The only formally defined units in the Pennsylvanian of Ohio are the groups. There are more than 100 named beds, but many of them are local and cannot be traced over great distances. Only the bounding units of the groups and the fossiliferous units are shown. See Stout (1943) and Collins (1979) for more information on Pennsylvanian rocks in Ohio.



# References

- Carlson, E. H., 1991, Minerals of Ohio: Ohio Division of Geological Survey Bulletin 69, 155 p.
- Collins, H. R., 1979, The Mississippian and Pennsylvanian (Carboniferous) Systems in the United States—Ohio: U.S. Geological Survey Professional Paper 1110-E, 26 p.
- Coogan, A. H., Heimlich, R. A., Malcuit, R. J., Bork K. B., and Lewis, T. L., 1981, Early Mississippian deltaic sedimentation in central and northeastern Ohio, *in* Roberts, T. G., ed., GSA Cincinnati '81 Field Trip Guidebooks: American Geological Institute, v. 1, p. 113-152.
- Dott, R. H., and Batten, R. L., 1976, Evolution of the Earth: New York, McGraw-Hill Book Co., 504 p.
- Dow, J. W., 1962, Lower and Middle Devonian limestones in northeastern Ohio and adjacent areas: Ohio Division of Geological Survey Report of Investigations 42, 67 p.
- Droste, J. B., and Shaver, R. H., 1983, Atlas of Early and Middle Paleozoic paleogeography of the southern Great Lakes area: Indiana Geological Survey Special Report 32, 32 p.
- Hansen, M. C., no date, Guide to the geology along Interstate 77 between Marietta and Cleveland: Ohio Division of Geological Survey Educational Leaflet 15, folded brochure.
- Hoover, K. V., 1960, Devonian-Mississippian shale sequence in Ohio: Ohio Division of Geological Survey Information Circular 27, 154 p.
- Hyde, J. E. (M. F. Marple, ed.), 1953, Mississippian formations of central and southern Ohio: Ohio Division of Geological Survey Bulletin 51, 355 p.
- Larsen, G. E., 1994, Regional bedrock geology of the Ohio portion of the Lima, Ohio-Indiana 30 x 60 minute quadrangle: Ohio Division of Geological Survey Map 7.
- Melvin, R. W., and McKenzie, G. D., 1992, Guide to the building stones of downtown Columbus: a walking tour: Ohio Division of Geological Survey Guidebook 6, 33 p.
- Ohio Division of Parks and Recreation, no date, The fossils of Hueston Woods: Ohio Department of Natural Resources, 15 p.
- Palmer, A. R., 1974, Search for the Cambrian world: American Scientist, v. 62, p. 216-224.
- \_\_\_\_\_ 1983, compiler, The Decade of North American Geology 1983 geologic time scale: Geology, v. 11, p. 503-504.
- Pashin, J. C., and Eddensohn, F. R., 1995, Reevaluation of the Bedford-Berea sequence in Ohio and adjacent states: forced regression in a foreland basin: Geological Society of America Special Paper 298, 74 p.
- Schumacher, G. A., 1993, Regional bedrock geology of the Ohio portion of the Piqua, Ohio-Indiana 30 x 60 minute quadrangle: Ohio Division of Geological Survey Map 6.
- Scotese, C. R., and Denham, C. R., 1988, Terra Mobilis: plate tectonics for the Macintosh: published by the authors.
- Shrake, D. L., 1992, Excursion to Caesar Creek State Park in Warren County, Ohio: a classic Upper Ordovician fossil-collecting locality: Ohio Division of Geological Survey Guidebook 12, 18 p.
- Stewart, G. A., 1927, Fauna of the Silica Shale of Lucas County: Ohio Division of Geological Survey Bulletin 32, 76 p.
- Stout, Wilber, 1943, Generalized section of coal bearing rocks of Ohio: Ohio Division of Geological Survey Information Circular 4, chart.
- Swinford, E. M., and Slucher, E. R., 1995, Regional bedrock geology of the Bellefontaine, Ohio, 30 x 60 minute quadrangle: Ohio Division of Geological Survey Map 8.
- Weir, G. W., Peterson, W. L., and Swadley, W C, 1984, Lithostratigraphy of Upper Ordovician strata exposed in Kentucky: U.S. Geological Survey Professional Paper 1151-E, 121 p.