Information Circular 63

# Ohio's Geology in Core and Outcrop

## A Field Guide for Citizens and Environmental and Geotechnical Investigators

by
Gregory A. Schumacher, Brian E. Mott, and Michael P. Angle

STATE OF OHIO
DEPARTMENT OF NATURAL RESOURCES
DIVISION OF GEOLOGICAL SURVEY
Thomas J. Serenko, Chief

Columbus 2013

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O.D.N.R GEOLOGICAL SURVEY

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**Editing:** Charles R. Salmons
**Graphic design and layout:** Lisa Van Doren

**Front cover:** Umbrella Rock, Tuscarawas County, Ohio. Pennsylvanian Allegheny and Pottsville Groups undivided.

**Back cover:** Core of multicolored mudstone or red bed from the Conemaugh Group, Gallia County, Ohio. Red beds are weak clay-rich beds that are highly susceptible to weathering. Rapid weathering produces landslide-prone, thick colluvium deposits and also undercuts overlying resistant geologic units, such as sandstone beds, creating rock falls. Landslides are major environmental hazards associated with the Conemaugh Group that damage structures and roadways in southeastern Ohio nearly every year. Black and red reference lines are drawn to help determine the top of each core piece. When the red line is to the right, the core is oriented from top to bottom with the page.

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## PREFACE

One afternoon while drawing a bedrock geologic map, a citizen called with an apparently simple yet very complex request: "Tell me about the geology of Ohio." This request immediately brought to mind many questions. Was the caller interested in the geologic or environmental features of Ohio's bedrock or did he want information about the characteristics of the glacial deposits covering his land? Was he interested in information about potential mineral resources? Did he want to learn about the engineering or hydrogeologic properties of the rocks or glacial deposits occurring in his area? Maybe he was interested in learning about how the rocks or glacial sediments were deposited? After asking the caller some of these questions, I determined that he wanted to learn more about the potential mineral resources underlying his farm. Upon consulting Ohio Geological Survey geologic maps and other publications, I was able to answer the citizen's request during a return phone call.

It has been years since that phone call, but I continue to think about the best way to respond to the caller's request: "Tell me about the geology of Ohio."

With the help of my coauthors, this field guide is an attempt to succinctly summarize the near-surface geology of Ohio in a publication written for citizens, students, teachers, geologists, environmental scientists, and engineers. With such a diverse audience in mind, we provide an introduction to Ohio's geology, including discussion of the components of the 65 fact sheets describing the state's surficial deposits and near-surface bedrock geologic units as mapped by the Ohio Geological Survey. We also define and explain the limited geologic terminology used in the guide and include on each fact sheet a "Further reading" section for readers interested in learning more about each geologic unit. In addition, we provide photographs illustrating Ohio's near-surface geologic units in natural and man-made exposures. We also provide photographs of core taken from these geologic units. Informative geologic maps, stratigraphic columns, figures, and tables are also included throughout the field guide to aid the reader in understanding Ohio's complex geology.

We are honored to dedicate this guidebook to the many Ohio Geological Survey employees who over the years have contributed to the statewide mapping program. Some may have worked for only a few hours and others for a career, but without everyone's collective efforts this mammoth project would not have been successful. Thank you and congratulations to all for a job well done!

Gregory A. Schumacher
June 14, 2013

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# ABBREVIATIONS USED IN THIS INFORMATION CIRCULAR

| | |
|---|---|
| *Units of Measure* | |
| British thermal unit | Btu |
| centimeter(s) | cm |
| foot/feet | ft |
| gallons per minute | gpm |
| gallons per day | gpd |
| inch(es) | in |
| kilometer(s) | km |
| mega-annum | Ma |
| meter(s) | m |
| micron(s) | μ |
| mile(s) | mi |
| millimeter(s) | mm |
| pound(s) | lb(s) |
| pounds per square inch | psi |
| second(s) | sec |
| tons per square foot | TSF |
| years before present | YBP |
| | |
| *Lithologic & Stratigraphic Units** | |
| Conglomerate | Cong/cong |
| Dolomite | Dol/dol |
| Formation | Fm/fm |
| Group | Gp/gp |
| Limestone | Ls/ls |
| Member | Mbr/mbr |
| Sandstone | Ss/ss |
| Shale | Sh/sh |
| | |
| *Other Abbreviations* | |
| National Park | NP |
| Railroad | RR |
| State Memorial | SM |
| State Natural Area | SNA |
| State Nature Preserve | SNP |
| State Park | SP |
| State Route | S.R. |
| State Scenic River | SSR |
| Wildlife Area | WA |

*Lowercase lithologic and stratigraphic names and abbreviations indicate informal status of a unit.

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## INTRODUCTION

What is the geology beneath your feet? The Ohio Department of Natural Resources (ODNR), Division of Geological Survey (the Survey) posed this question to nearly 500 Ohio citizens, students, faculty members, environmental scientists, geologists, and government decision makers between January 1, 2007, and December 31, 2009. The results showed that less than 10 percent could correctly identify the bedrock-geologic unit they were standing on. The survey results are very surprising because most visitors to the Survey's Horace R. Collins Laboratory or those attending a presentation about Ohio's geology have a better understanding of, or at least a higher level of interest in, Ohio's geology. Survey respondents also were asked: What can the Survey do to help educate Ohio's citizens on the geology of Ohio? A common suggestion was to produce a concise field guide that describes the characteristic features of Ohio's mapped geologic units, provides photographs illustrating the diagnostic features of these units in outcrop and core, and uses the wide variety of map products available from the Survey to help citizens locate the geologic units beneath their feet at any location in the state.

In response to these suggestions, the Survey has developed this Information Circular, a field guide containing 65 fact sheets that describe 111 geologic units that are recognized as part of the Survey's surficial or near-surface bedrock mapping programs conducted from 1981 to present (fig. 1). Included in this field guide are the major geologic units mapped on the *Bedrock Geologic Map of Ohio* (Slucher and others, 2006) and selected units from *Descriptions of Geologic Map Units* (Shrake and others, 1998). In addition, we have included fact sheets for the Utica shale and Pottsville Group-Sharon sandstone/conglomerate because both of these units contain important economic resources and because the latter exhibits spectacular scenic features created by weathering.

A *near-surface geologic unit* is defined as a unit mapped within a few hundred feet of the modern land surface. In the case of the deeply buried valleys of the Teays River System of Ohio (see Hansen, 1995), the near-surface geologic units may extend up to 800 to 1,000 ft (244–305 m) below the modern land surface. This field guide does not include fact sheets for the deeper subsurface geologic units present in Ohio.

The field guide is intended to complement the thousands of geologic maps produced by the Survey's surficial and bedrock-geologic mapping programs by providing a concise summary of the many environmental and geologic features that separates one geologic unit from another. So, we encourage you to acquire the appropriate geologic maps for the area of interest. For example, you may be interested in learning about the general geology for central Ohio and the page-sized bedrock geology or glacial geology maps available on the Survey's website, **OhioGeology.com**, will meet your needs. On the other hand, you may be working for an engineering firm designing a major construction project that requires extensive core drilling to define the detailed geology of the future construction site. In this case you will want to collect all the geologic information available for the site, including surficial-geology, bedrock-geology, bedrock-topography, and structure-contour maps.

Bedrock-geology maps, bedrock-topography maps, surficial-geology maps, and many other types of geologic maps are available for purchase or public inspection at the Survey's Geologic Records Center located at 2045 Morse Road, Building C-1, Columbus, Ohio 43229. In addition, Survey geologists will gladly respond to phone-in requests for brief descriptions of the geology for any area of the state. For assistance, call (614) 265-6576 and request to be transferred to a geologist in the Geologic Mapping and Industrial Minerals Group.

## OHIO GEOLOGICAL SURVEY MAP PRODUCTS

One of the primary functions of the Survey is to publish maps and reports that illustrate and explain Ohio's geology. The *Bedrock Geologic Map of Ohio* (Slucher and others, 2006) represents the completion of a statewide mapping effort by the Survey to replace the 1920 *Geologic Map of Ohio* (Bownocker, 1920). This effort began in 1981 and 788 Mylar open-file bedrock-geology maps (scale 1:24,000) were completed and compiled to produce the new *Bedrock Geologic Map of Ohio.* To produce the 788

**NEAR-SURFACE GEOLOGIC UNITS IN OHIO**

| Geologic Time (million years before present) NOT TO SCALE | System/ Period | WEST | EAST |
|---|---|---|---|
| 2.6 | **Quaternary and Neogene(?)** | | **organic deposits**<br>**clay**<br>**silt**<br>**sand**<br>**sand and gravel**<br>**till**<br>**lacustrine** |
| 299 | **Permian? Pennsylvanian** | | **Dunkard Group**<br>Washington coal<br>Hockingport sandstone |
| 318 | **Pennsylvanian** | | **Monongahela Group**<br>Waynesburg coal<br>Pittsburgh coal<br>**Conemaugh Group**<br>Ames limestone<br>**Allegheny and Pottsville Groups undivided**<br>Upper Freeport coal<br>Lower Kittanning coal<br>Lower Mercer limestone<br>**Pottsville Group**<br>**Sharon sandstone/conglomerate** |
| 359 | **Mississippian** | **Coldwater Shale**<br>**Sunbury Shale** | **Maxville Limestone**<br>Rushville Formation<br>**Logan Formation**<br>Vinton Member<br>Allensville Member<br>Byer Member<br>Berne Member<br>**Cuyahoga Formation-Black Hand Member**<br>**Cuyahoga Formation**<br>Southern Ohio: Henley Shale, Portsmouth Shale, and Buena Vista Sandstone Members<br>Central Ohio: Raccoon, Fairfield, and Wooster Shale Members<br>Northeastern Ohio: Shenango sandstone and shale, Orangeville Shale, Sharpsville Sandstone, and Meadville Shale Members<br>**Sunbury Shale** |

— CONTINUED —

**FIGURE 1. Major surficial and near-surface geologic units mapped in the surficial and near-surface-bedrock mapping programs conducted by the ODNR Division of Geological Survey between 1981 and present. Also included are select geologic units that contain important economic resources or scenic features. Stratigraphic correlation between units is approximate and units are presented from west to east across the outcrop belt of each System/Period. Geologic units in bold type represent one of the 65 fact sheets included in this field guide. Units in normal text represent a formation, member, or bed subdivided from the corresponding group or formation featured in a fact sheet. Geologic time scale modified from USGS (2010).**

open-file bedrock-geology maps, another 3,062 bedrock-topography and structure-contour maps were required. So, each of the 788 topographic quadrangles within the State of Ohio have an open-file bedrock-geology, bedrock-topography, and one or more structure-contour maps at the scale of 1:24,000 (Swinford, 1997; McDonald, 2002; McDonald and others, 2003). All of these maps are available at the Survey's Geologic Records Center.

What are bedrock-geology, bedrock-topography, structure-contour, and surficial-geology maps? *Bedrock-geology maps* show the regional distribution of the hard, layered sedimentary rocks that may be exposed at the land surface or more commonly, buried beneath a blanket of soil and surficial materials overlying the bedrock. Ohio's bedrock units consist of primarily shale, sandstone, conglomerate, limestone, dolomite, clay, and coal; less common are gypsum, flint, and ironstone. These rock types occur in individual beds that are stacked one on top of another like the layers of a cake. The icing capping the cake is represented by the surficial deposits that cover much of Ohio's bedrock.

— CONTINUED —

| Geologic Time (million years before present) NOT TO SCALE | System/ Period | WEST | | | EAST |
|---|---|---|---|---|---|
| 359 | Devonian | | **Berea Sandstone**<br>**Bedford Shale**<br>Cussewago Sandstone | | |
| | | **Antrim Shale** | | **Ohio Shale**<br>Cleveland Shale Member<br>Chagrin Shale Member<br>Three Lick Bed<br>Huron Shale Member<br>**Olentangy Shale** | |
| | | Traverse Group: **Ten Mile Creek Dolomite** | **Prout Limestone** | | |
| | | Traverse Group: **Silica Formation** | **Plum Brook Shale** | | |
| | | **Dundee Limestone** | | **Delaware Limestone**<br>**Columbus Limestone**<br>Central Ohio: Delhi and Bellepointe Members<br>Northern Ohio: Venice and Marblehead Members | |
| | | **Detroit River Group**<br>Lucas Dolomite<br>Amherstburg Dolomite<br>Sylvania Sandstone<br>Holland Quarry Shale | | | |
| 416 | Silurian | **Salina Group**<br>**Tymochtee Dolomite**<br>**Greenfield Dolomite** | **Bass Islands Dolomite**<br>**Salina Group**<br>**Tymochtee Dolomite**<br>**Greenfield Dolomite** | | **Salina Group**<br>**Tymochtee Dolomite**<br>**Greenfield Dolomite** |
| | | **Lockport Dolomite** | **Cedarville Dolomite**<br>**Springfield Dolomite**<br>**Euphemia Dolomite**<br>**Massie Shale**<br>**Laurel Dolomite**<br>**Osgood Shale** | | **Peebles Dolomite**<br>**Lilley Formation**<br>**Bisher Formation**<br>**Estill Shale** |
| | | **Cataract Group and Clinton Group undifferentiated** | **Dayton Limestone**<br>**Brassfield Formation** | | **Drowning Creek Formation**<br>Dayton Member<br>undifferentiated rocks<br>Brassfield Member<br>Belfast Member |
| 443 | Ordovician | Cincinnati group:<br>**Drakes Formation**<br>Preachersville Member<br>**Whitewater Formation**<br>**Saluda Formation**<br>**Liberty Formation**<br>**Waynesville Formation**<br>**Arnheim formation**<br>**Grant Lake Formation**<br>Mount Auburn Member<br>Corryville Member<br>Bellevue Member<br>**Miamitown Shale**<br>**Fairview Formation**<br>**Kope Formation**<br>Grand Avenue Member<br>Fulton beds<br>**Utica shale**<br>**Point Pleasant Formation** | | **Drakes Formation**<br>Preachersville Member<br>**Waynesville Formation**<br>**Arnheim formation**<br>**Grant Lake Limestone**<br>Straight Creek Member<br>Corryville Member<br>Bellevue Member<br>**Fairview Formation**<br>**Kope Formation**<br>**Point Pleasant Formation** | |

**NEAR-SURFACE GEOLOGIC UNITS IN OHIO**

The contact between the bedrock and the overlying surficial deposits is called the *bedrock-topographic surface*. Maps that depict the irregular bedrock surface are termed *bedrock-topography maps*. For each open-file bedrock-geology map there is a corresponding open-file bedrock-topography map. The contours drawn on a bedrock-topography map represent points of equal elevation (relative to sea level) present on the buried bedrock surface in the same manner that topographic maps use contours to depict elevations on Ohio's land surface.

*Structure-contour maps* are drawn to show the dip or tilt of the tops of bedrock geologic units mapped in Ohio. Ohio's bedrock has been slightly to strongly deformed by compression from continental collision and the formation of the Appalachian Mountains, faulting and earthquakes, ice loading by continental glaciers, thermal expansion and contraction of the interior of Earth, and meteorite or comet impacts over geologic time. In some places, the beds that comprise a mapped bedrock unit are flat-lying just as they were when they were deposited. However, most of Ohio's bedrock units are slightly deformed and generally dip to the east at such a slight angle that it is difficult to see on individual exposures. However, the rocks within the Serpent Mound Impact Structure located in Adams, Highland, and Pike Counties have been deformed by the impact of a comet or meteorite sometime between 256 and 330 million years ago (Watts, 2004). These rocks dip in a wide variety of orientations ranging from vertical to only slightly dipping.

A geologist uses structure maps to draw the contacts of bedrock units on a map, generally a topographic quadrangle. If bedrock is exposed at the land surface, the contacts between bedrock units will follow the topographic contours published on topographic maps. On the other hand, if the bedrock units are buried under a blanket of glacial drift, the contacts between bedrock units will not follow and often cut across topographic contours.

*Surficial-geology maps* delineate the composition and distribution of unconsolidated sediments deposited by rivers, streams, and Ice Age continental glaciers upon the bedrock surface. These maps depict in three dimensions the composition of the surficial deposits (e.g., sand and gravel, till, clay); the thickness of each deposit; and the lateral extent(s) and vertical sequence(s) of these deposits for a given map area.

## How to use geologic maps and fact sheets

So how are bedrock-geology, bedrock-topography, structure-contour, and surficial-geology maps helpful in answering geologic questions for any location in Ohio? Perhaps a good way to answer this question is to discuss a common request submitted to Survey geologists. Imagine a citizen is planning to purchase land to build a dream home in the Ohio countryside. In this example, the potential buyer is interested in buying some property located on a broad, level stretch of ground overlooking a picturesque stream in central Ohio. A fundamental question is: Is there enough fresh, clean water available for domestic use? Other questions may include:

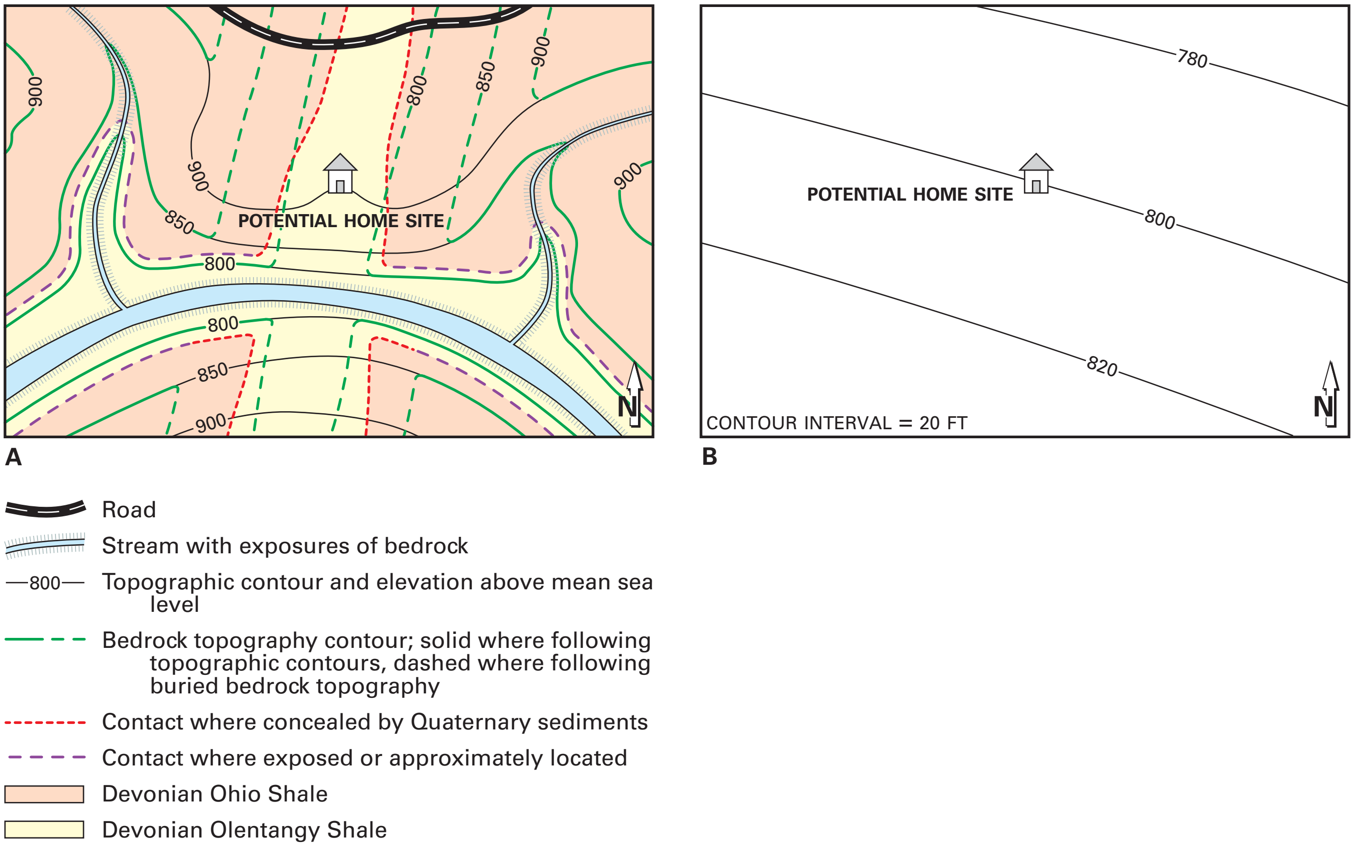
- What are the physical characteristics of the geologic units at the site?
- Are there potential engineering properties that require costly blasting instead of excavation of surficial deposits?
- Are there potential geologically related hazards?
- What is the potential economic value of the geologic units of the site?

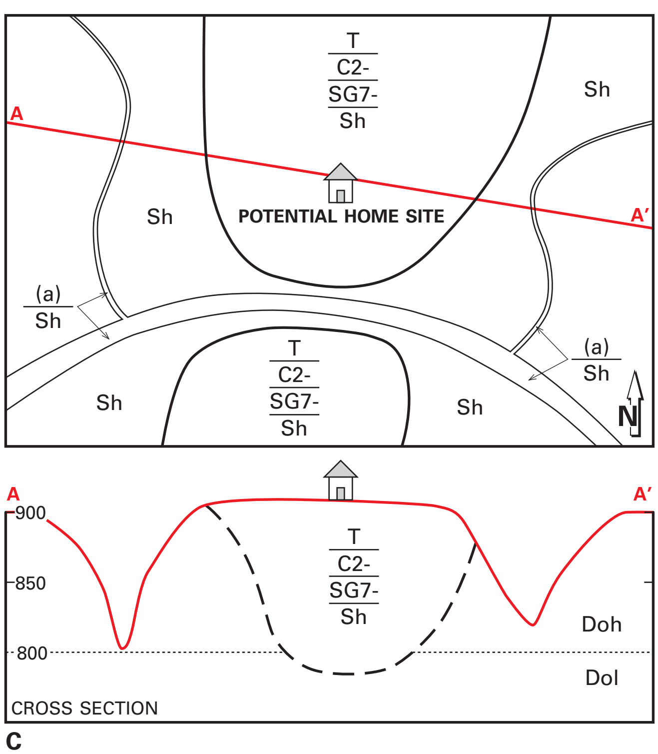
The first step is to determine the location of the potential home site. A cell phone, personal GPS device, and web-based mapping programs can assist in providing information such as the latitude and longitude of the site and other useful information in locating the site on a road map or topographic base map. Another option to determine on which topographic map the site is located is to visit the Survey website at **OhioGeology.com** and download Educational Leaflet 16, *Ohio Topographic Maps* (Hansen, 2011). The index to 7.5-minute (1:24,000-scale) topographic maps provides the names of all 788 topographic quadrangles that occur in Ohio and geographical information such as county names, major highways, cities and towns, and major waterways. Using this map, the name of the individual topographic map or maps can be determined. Knowing the name(s) of the topographic map(s) where the potential home site is located makes ordering open-file geologic maps easy when contacting the Survey's Geologic Records Center.

Open-file bedrock-geology and bedrock-topography maps are drawn on a topographic base map because of the wealth of information portrayed on a topographic map and the relationship of topography to geology. Topographic quadrangle maps show the locations of cultural features, such as schools, homes, barns, places of worship, fence lines, roads, rail lines, and pipelines; political boundaries, such as county, township, section boundaries, and boundaries of cities and towns; and natural features, such as lakes, ponds, rivers, and forested areas—all of which are very helpful for finding the location of the potential home site on the map. Once the home site is located, the elevation of the land surface is read from the topographic contours shown on the bedrock-geologic map. In the dream home example, the home is located on the 900 ft topographic contour above mean sea level (fig. 2a). The near-surface bedrock unit is read from the map and is the Devonian Olentangy Shale, as explained in the map legend.

The bedrock-topography contours indicate that the contact between the Olentangy Shale and the overlying surficial deposits is slightly below 800 ft (244 m) above mean sea level. The elevation is read from the bedrock-topographic surface contours just as land surface elevation is read from the topographic contours. The thickness of the site's surficial deposits is over 100 ft (30 m) and is calculated by subtracting the land surface elevation from the elevation of the bedrock-topographic surface. Also, the site is situated in an ancient stream valley, now buried by surficial deposits, which once flowed nearly perpendicular to the modern stream valley.

If the potential land owner is interested in the tilt or dip of the rocks, this information is available from the open-file structure-contour maps drawn for the bedrock-geologic units mapped on the bedrock-geologic quadrangle. The top of the Olentangy Shale structure-contour map shows that the dream home is located on the 800-ft contour (fig. 2b). Also, the structure map shows that the top of the Olentangy




| | |
|---|---|
| —— | Boundary between map units having different uppermost lithologies; underlying lithologies may or may not differ |
| T | Till, average thickness is 10 ft (3 m), but thickness may vary from 5 to 15 ft (1.5–4.5 m) |
| C2- | Clay with maximum thickness of 20 ft (6 m) in a thinning trough- or wedge-shaped deposit |
| SG7- | Sand and gravel with maximum thickness of 70 ft (21 m) in a thinning trough- or wedge-shaped deposit |
| (a) | Stream deposits (alluvium) in discontinuous deposits ranging from 0 to 10 ft (0–3 m) thick |
| Sh | Shale |
| Doh | Devonian Ohio Shale |
| Dol | Devonian Olentangy Shale |

**FIGURE 2. (A) Bedrock-geology and bedrock-topography map of a hypothetical home site overlooking a picturesque stream in central Ohio. (B) Structure-contour map on the top of the Olentangy Shale. (C) Surficial-geologic map and cross section of the hypothetical home site.**

is dipping or tilted from the southwest to the northeast across the map area.

Consulting the surficial-geology map (fig. 2c), the potential buyer can learn about what materials make up the 100+ ft (30+ m) of surficial materials that underlie the dream home site. A surficial-geology map, sometimes called a *stack map*, defines the major sediment type(s) and thickness of each sediment type in a vertical stack of units. The stack of materials underlying the potential home site is represented by the letter *T* over *C2-* over *SG7-* over Olentangy Shale. The letter *T* represents glacial till averaging 10 ft (3 m) thick, but may vary in thickness from 5 to 15 ft (1.5–4.5 m) thick. The letter *C and 2-* equal clay that may range in thickness from 0 to 20 ft (0–6 m) in a trough or wedge-shaped deposit. The letters *SG* and 7- are sand and gravel that varies in thickness from 0 to 70 ft (0–21 m) in the basal part of the ancient buried stream valley cut into the Ohio and Olentangy Shales.

Now that the geology of the potential home site has been identified, the buyer can address the question of whether the site has enough fresh, clean ground water for domestic use. Consulting the fact sheet for the Olentangy Shale, the hydrogeologic properties section indicates that the Olentangy is a poor aquifer or water-bearing unit that commonly produces minimal yields. It is suitable for limited household use. However, the buyer has a second option concerning the ground water at the site. The sand-and-gravel fact sheet indicates that aquifers in this unit can range from poor to some of the best in the state. So, the thick sequence of sand and gravel has the potential to yield large quantities of high-quality ground water. The buyer may want to visit the ODNR Division of Soil and Water website at **ohiodnr.gov/soilandwater** to examine the logs and yields of nearby water wells to determine the potential ground-water yields from the sand-and-gravel unit.

Also, the potential buyer is interested in learning about the engineering properties of the underlying surficial deposits to determine if the unit can be easily excavated for a basement. The till fact sheet indicates that till can be highly variable in composition and hardness. Also, the presence of a high water table determines numerous building constraints on basements, foundations, septic systems, and leach fields. So, the thin layer of till blanketing the site may be a potential engineering problem.

The till and underlying clay deposit have the potential to slump along steep slopes during times of high water table conditions. This may be a factor that requires additional drainage systems to assist in the removal of ground water during the wet times of the year.

The underlying sand-and-gravel deposits may be of economic benefit as a source of aggregates for use by the construction industry. Additional research is required to determine if this sand-and-gravel deposit would be of high quality and meet the engineering standards for aggregate.

The buyer now has the geologic information to make an informed decision whether to purchase the property and whether the site may have the necessary ground water for domestic use. The available data suggests that the potential site will be good property to build the dream home in the country. However, geology is not an exact science. There is always the chance that even with large quantities of data the geologic interpretation for a given site is not correct. So, only when a water well driller is hired and the well is completed will the question be answered about the amount and quality of the ground water at the site.

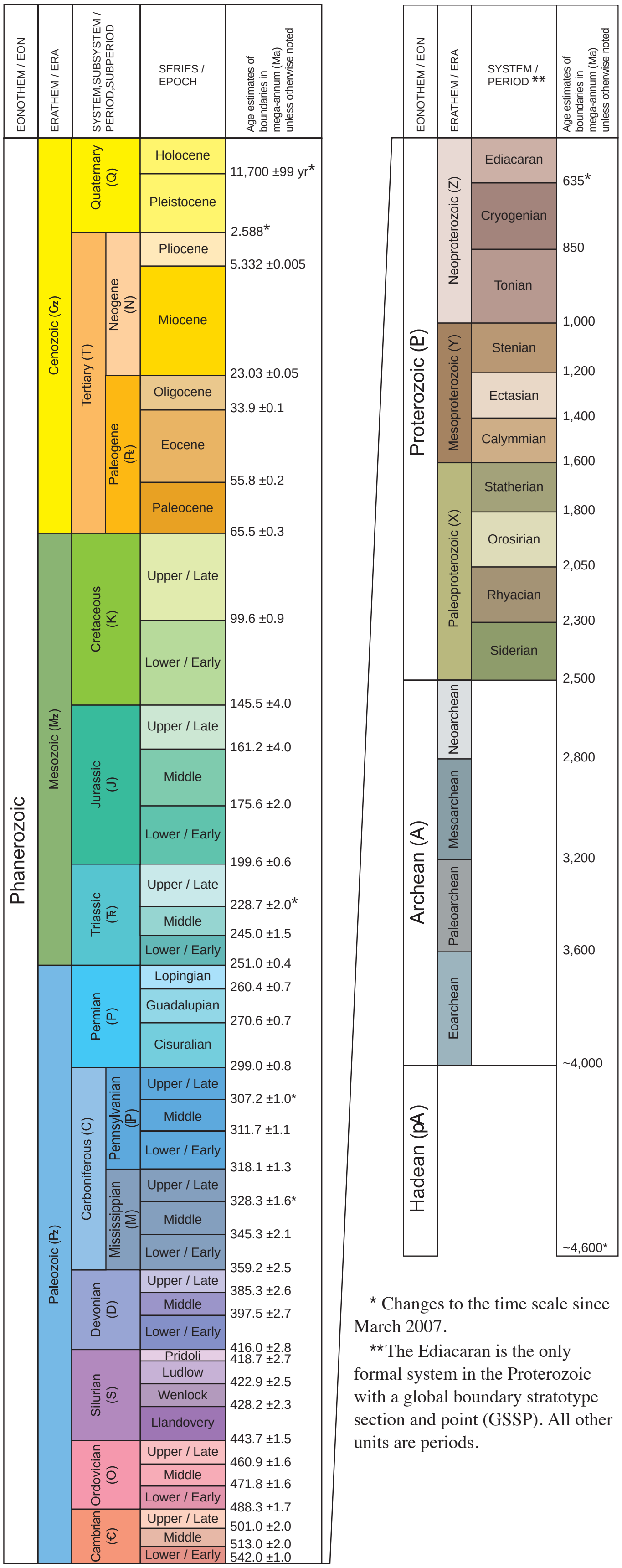
For the interested reader, additional examples of the value of geologic maps to Ohio homeowners are available. Please see the *Ohio Geology* article, "The Value of Geologic Maps to Ohio Homeowners," by Schumacher and Hull (2006).

## GEOLOGIC TIME UNITS

The age of Earth is 4.54 ± 0.05 billion years. Geologic time is subdivided into large time units called *eons* that are in turn subdivided into *eras* and the fundamental geologic time unit, the *period*. Periods can be subdivided into *epochs, ages,* and *chrons*. For example, Ohio's most recent Ice Age occurred during the Pleistocene Epoch of the Quaternary Period (0.01–2.6 million years ago). The Quaternary, Neogene, and Paleogene Periods comprise the Cenozoic Era of the Phanerozoic Eon (fig. 3). A second classification is used when geologists talk about the time that a sequence of rocks was deposited. The time-rock or *chronostratigraphic* units are stratigraphic units with time boundaries that define a specific interval of time. The basic chronostratigraphic unit is the *system*, so the rocks of the Ordovician System of Ohio were deposited during the Ordovician Period of geologic time. An *erathem* contains two or more systems, and systems can be subdivided into two or more *series*. Series are subdivided into stages that contain the smallest time-rock subdivision, the *zone*.

Chronostratigraphic units are used by geologists to correlate rock sequences from one area to another. At any time during Earth history, sediments are being deposited in a wide variety of depositional environments, being eroded from other environments, and may be in transit between the two. So, if we think of Earth today, all the sediments being deposited in rivers and streams, deltas, nearshore environments, and offshore to the deep ocean floor are being deposited at the same time. As we will see in the "History of Ohio's Near-Surface Bedrock Geology" (p. 12), this explains why geologic units with different diagnostic features are deposited in the same geologic system.

Figure 3 illustrates the chronostratigraphic framework for Earth's rocks according to USGS (2010). Just as geologic groups, formations, members, and beds change as new information is learned about the rocks, so too is the chronostratigraphic framework revised on a regular basis. Thus when talking about the age of this formation or that member, always keep in mind that recent changes in the chronostratigraphic framework may render a previously established date obsolete.




* Changes to the time scale since March 2007.

**The Ediacaran is the only formal system in the Proterozoic with a global boundary stratotype section and point (GSSP). All other units are periods.

**FIGURE 3. Divisions of geologic time approved by the U.S. Geological Survey Geologic Names Committee, 2010. The chart shows major chronostratigraphic and geochronologic units. It reflects ratified unit names and boundary estimates from the International Commission on Stratigraphy (Ogg, 2009). From USGS (2010).**

## OHIO'S NEAR-SURFACE GEOLOGY

### Surficial Deposits

During the Pleistocene Epoch (11,700–2.6 million years before present [YBP]), several episodes of ice advance occurred in Ohio. The latest or Wisconsinan ice advance (roughly 11,700–25,000 YBP) represents the uppermost surficial deposits for the vast majority of glaciated Ohio (fig. 4). The older Illinoian-age deposits (roughly 130,000–300,000 YBP) typically underlie the Wisconsinan deposits, often at great depths (fig. 4). In some areas, the Wisconsinan ice has eroded away all of the previous Illinoian deposits. It is often difficult determining the age of the deposits at depth when they are not exposed at the land surface. The Illinoian ice typically did extend beyond the boundary of the later Wisconsinan ice and represents the uppermost glacial unit where it does so. Examples of Illinoian deposits are found all along the ice margin, particularly in areas east of Cincinnati but also in portions of Ross, Fairfield, Licking, Richland, Stark, and Columbiana Counties. Deposits predating the Illinoian (typically considered to be greater than 700,000 YBP) are not believed to be found at the surface in Ohio and are most likely limited to some of the deeper glacial valleys. These units previously were referred to as Kansan in age but are now collectively referred to as pre-Illinoian. Glacial-related deposits compose the surficial materials for roughly two thirds of Ohio.

The surficial materials and near-surface bedrock of Ohio are defined as the earth materials that typically occur within a few hundred feet of the modern land surface or bedrock-topographic surface, except for limited areas of thick surficial deposits, such as deeply incised ancient stream valleys. Surficial materials are composed of: (1) soil; (2) materials deposited by glaciers, flowing water, or the wind or in lakes; (3) organic matter; or (4) a mixture of soils and near-surface, weathered bedrock fragments created by downslope mass wasting.

*Soils* are defined as being the uppermost layer of material weathered from underlying parent material, which may be bedrock, alluvium, lake deposits, glacial drift, or in rare cases, ancient soils. The soils contain accumulated organic material and distinct layers or *horizons* that form by the weathering of underlying parent material.

The reader may wonder why there is not a category in this report specifically for soils. For example, one might have heard of engineers or contractors conducting soil borings or studying soil mechanics.

Soil scientists define *soil* as the upper 5–6 ft (1.5–1.8 m) of material that has weathered through a variety of chemical, biological, and physical processes to create distinct layers or horizons that form a collective profile. The base of the soil is formed by the parent material, which may be bedrock, weathered bedrock (or *regolith*), glacial/surficial materials, or alluvium. A great deal of information on local soil conditions can be obtained from a county soil survey. Information includes details on suitability for building; drainage characteristics; suitability for foundations and septic systems; and compatibility with crops, lawns, and trees.

Geologists view soils much the same as soil scientists, hence they would typically refer to only the top 5–6 ft (1.5–1.8 m) as soil in most instances. Geologists also have an interest in buried, ancient soils that they refer to as *paleosols*. A geologist would only log this topmost interval as soil and then would continue logging the remaining surficial materials and ultimately the underlying bedrock.

By contrast, engineers refer to all unconsolidated or nonlithified materials as soil. At depths beyond five feet, their usage of *soil* is mostly analogous to the geologists' term *drift*. For example, a driller would drill into 70 ft (21 m) of glacial till, while an engineer would log 70 ft (21 m) of soil; the soil scientist would identify only the top 5–6 ft (1.5–1.8 m) and consider the rest of the till as the parent material; and the geologist would describe all of the surficial material below the top 5 ft (1.5 m).

*Alluvium* deposits are mainly gravel, sand, and silt associated with the floodplains of modern streams and rivers or outwash plains produced by meltwater originating from melting glaciers.

*Lacustrine* deposits consist of sands, silts, and clays deposited within ancient and modern lakes. These deposits tend to contain alternating laminations that are clay-rich and silt-rich. *Varves* are thin, alternating layers of sand- or silt-rich sediment overlain by clay-rich sediment that represent an annual or one-year cycle of sedimentation in a lake or other body of water. The coarse sand and silt layers represent "summer" time deposits resulting from sediment-laden meltwater draining into the lake during warmer months; these "summer" time deposits transition upward into clay-rich sediments deposited from the fine particles suspended in the lake during the "winter" when lakes and streams are frozen.

Lacustrine deposits reflect a low-energy environment. Examples of areas of lacustrine deposition would include deeper portions of larger lakes that are removed from the higher-energy, coarser shoreline deposits. Inland, lacustrine deposits are associated with partially blocked, sluggishly flowing streams. Such streams usually are the result of a stream being blocked by advancing ice or deposits associated with ice that tend to dam or block the stream, causing the stream to pond. This ponding leads to a quiet-water environment containing lacustrine deposits. Thin layers of sand may reflect flood or storm events that transported and deposited coarser sediments into the lake. Thicker deposits of sand and silt occur in deltas, beach ridges, bars, spits, and wind-blown dunes of shoreline or beach environments. Beaches, deltas, sand bars, and other shoreline deposits reflect active deposition by a higher-energy shoreline environment. These are commonly associated with ancestors of Lake Erie, such as

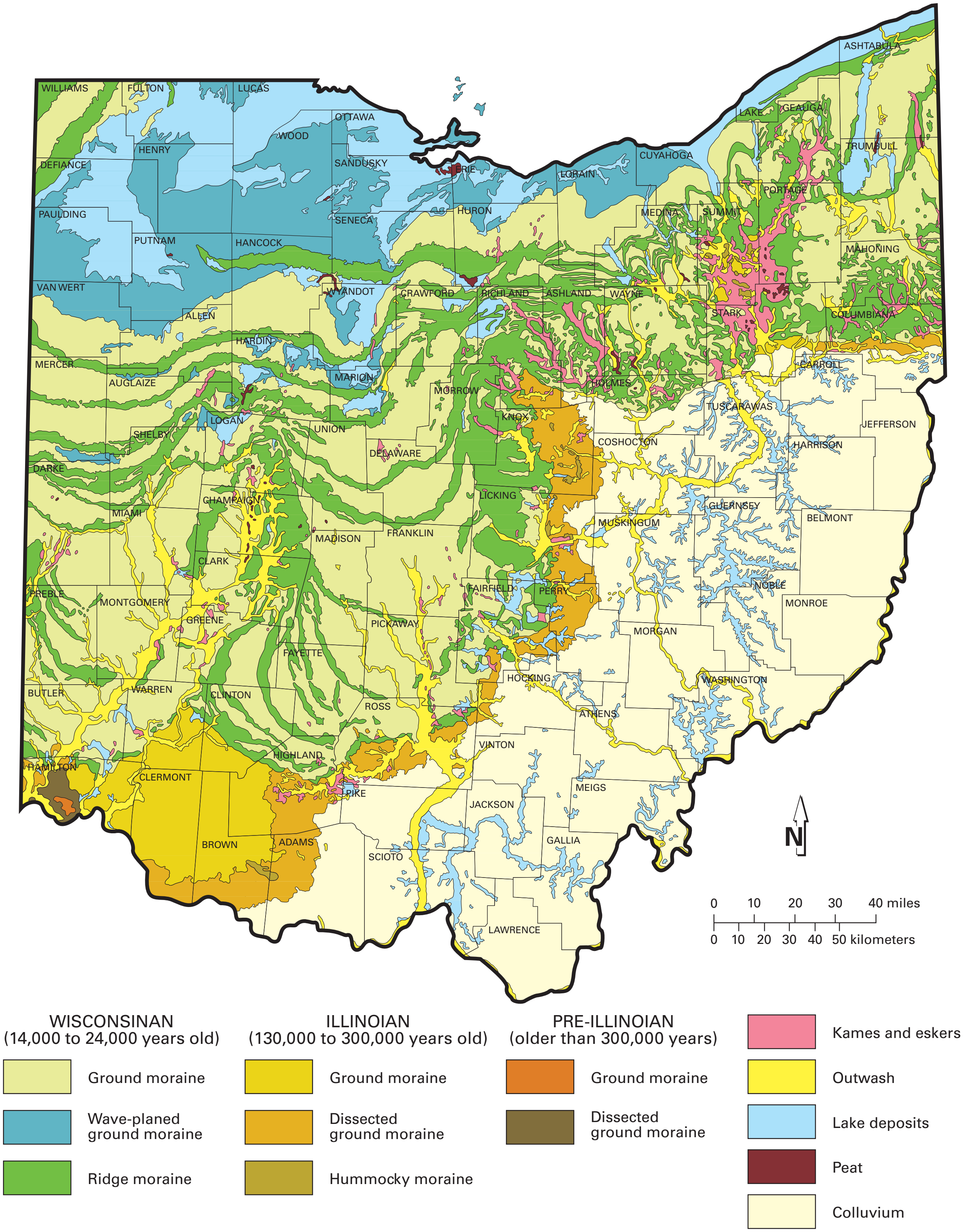



**FIGURE 4. Glacial map of Ohio.**

Lake Maumee, but also occur along the margins of some of the larger, interior, glacially related lakes. The wind may rework the uppermost, finest-grained beach ridges, creating sand dunes.

*Glacial drift* is a general term that applies to all clay, silt, sand, gravel, pebble, cobbles, and boulders transported by glaciers or deposited by or from glacial ice or from meltwater derived from glacial ice. Drift typically falls into one of four categories:

- Coarser-grained, sorted, sandy, layered deposits commonly referred to as *sandur*, which are deposited in outwash and valley train deposits.
- Finer-grained, layered and sorted deposits, including lacustrine units.
- Highly variable, layered and sorted deposits referred to as *ice-contact deposits*.
- Non-layered mixtures of clay, silt, sand and gravel, pebbles, cobbles, and boulders termed *till*.

*Outwash deposits* are created by active deposition from meltwater streams. The nature of these deposits depends upon their proximity to the melting ice sheet and the overall energy level of the flowing meltwater.

Ice-contact deposits include *kames* and *eskers*. They are composed of masses of generally poorly sorted sand and gravel with minor till, deposited in depressions, holes, tunnels, or other cavities in the ice. As the surrounding ice melts, a mound of sediment remains behind. Typically, these deposits may collapse or flow as the surrounding ice melts and may display steep, high-angle, distorted or tilted beds, faults, and folds. Kames are comprised of isolated or small groups of rounded mounds of dirty sand and gravel with minor till. Eskers are comprised of elongate, narrow, sinuous ridges of sand and gravel.

Till is both non-layered and unsorted and was directly deposited by the ice sheet. There are two main types of glacial till, *lodgment* and *ablation* till. Lodgment till is “plastered down” or “bulldozed” at the base of an actively moving ice sheet. Lodgment till tends to be relatively dense and compacted and pebbles typically are angular, broken, and have a preferred direction or orientation. “Hardpan” and “boulder clay” are two common terms used for lodgment till. Ablation or “melt-out” till occurs as the ice sheet melts or stagnates away. Ablation till tends to be less dense, less compacted, and slightly coarser as meltwater commonly washes away some of the fine silt and clay. At the land surface, till accounts for two primary landforms: *ground moraine* and *end moraine*. Ground moraine (till plain) is relatively flat to gently rolling. End moraines are ridge like, with terrain that is steeper and more rolling or *hummocky*.

*Organic deposits* include: (1) peat and muck that consist of coarse- to fine-grained, decayed or decomposing vegetation; (2) peat moss or *sphagnum*, a form of moss growing on top of or within peat; and (3) marl, which is a mixture of organic material and limestone resulting from the deposition of limestone in bogs or wetlands.

*Colluvium* is a loose mixture of soils and bedrock fragments that forms on hillsides and moves downslope to form thicker deposits at the bases of hills. Landslides commonly occur in colluvium deposits.

## Near-Surface Bedrock

Ohio’s near-surface bedrock consists of sedimentary rocks that range in age from the Upper Ordovician to Lower Permian Periods (~450 to ~290 million YBP). Sedimentary rocks are formed by the accumulation, layer by layer, of sand, silt, clay, lime mud, or organic matter over long periods of time. Sediments are deposited in ancient oceans, lagoons, lakes, river deltas, river systems; along coastline beaches; or on the land surface by wind or the melting of glacial ice. These rocks are primarily limestone, dolomite, clay, shale, siltstone, sandstone, and conglomerate with minor amounts of coal, gypsum, chert, and iron ore. Ohio’s sedimentary rocks range in thickness from a few thousand feet in western Ohio to over 13,000 ft (3,962 m) thick in eastern Ohio.

In western and northern Ohio, the near-surface bedrock is largely buried under a blanket of glacial drift and modern sediments. Exposures are generally restricted to stream or river valleys and man-made excavations. In the hilly terrain of southeastern Ohio, bedrock is commonly concealed by a veneer of soil and colluvium except in those areas subject to extensive strip mining where the bedrock is buried under thin to thick blankets of mine spoil. Exposures are common in streams, on hillsides, and along strip mine highwalls.

Ohio’s bedrock varies from flat-lying to slightly tilted, except for the highly deformed rocks within the Serpent Mound Impact Structure and several high-angle normal faults and other structures that displace rocks locally. In northwest Ohio, the rocks tilt, or *dip* in geologic terminology, to the north and northwest into a thick sequence of sedimentary rocks that form the Michigan Basin. The Michigan Basin, like the Appalachian Basin of eastern Ohio, formed in areas where Earth’s crust subsided and were infilled with thick sequences of sedimentary rocks that dip inward toward the center of the basin. Surrounding basins are areas of Earth’s crust that were uplifted, forming areas of relatively thin sequences of generally flat-lying sedimentary rocks commonly referred to as *arches*. The Findlay Arch of northwest Ohio separates the Michigan Basin from the Appalachian Basin of eastern Ohio, and the Cincinnati Arch separates the Appalachian Basin from the Illinois Basin of Indiana and Illinois. The Indiana-Ohio Platform is an area of generally flat-lying rocks where the Findlay, Cincinnati, and Kankakee Arches join in western Ohio (fig. 5).

Many excellent accounts have been written describing the geologic history of Ohio. Interested readers are encouraged to read Allan Coogan’s “Ohio’s Surface Rocks and Sediments,” chapter 3 of *Fossils of Ohio* (Feldmann

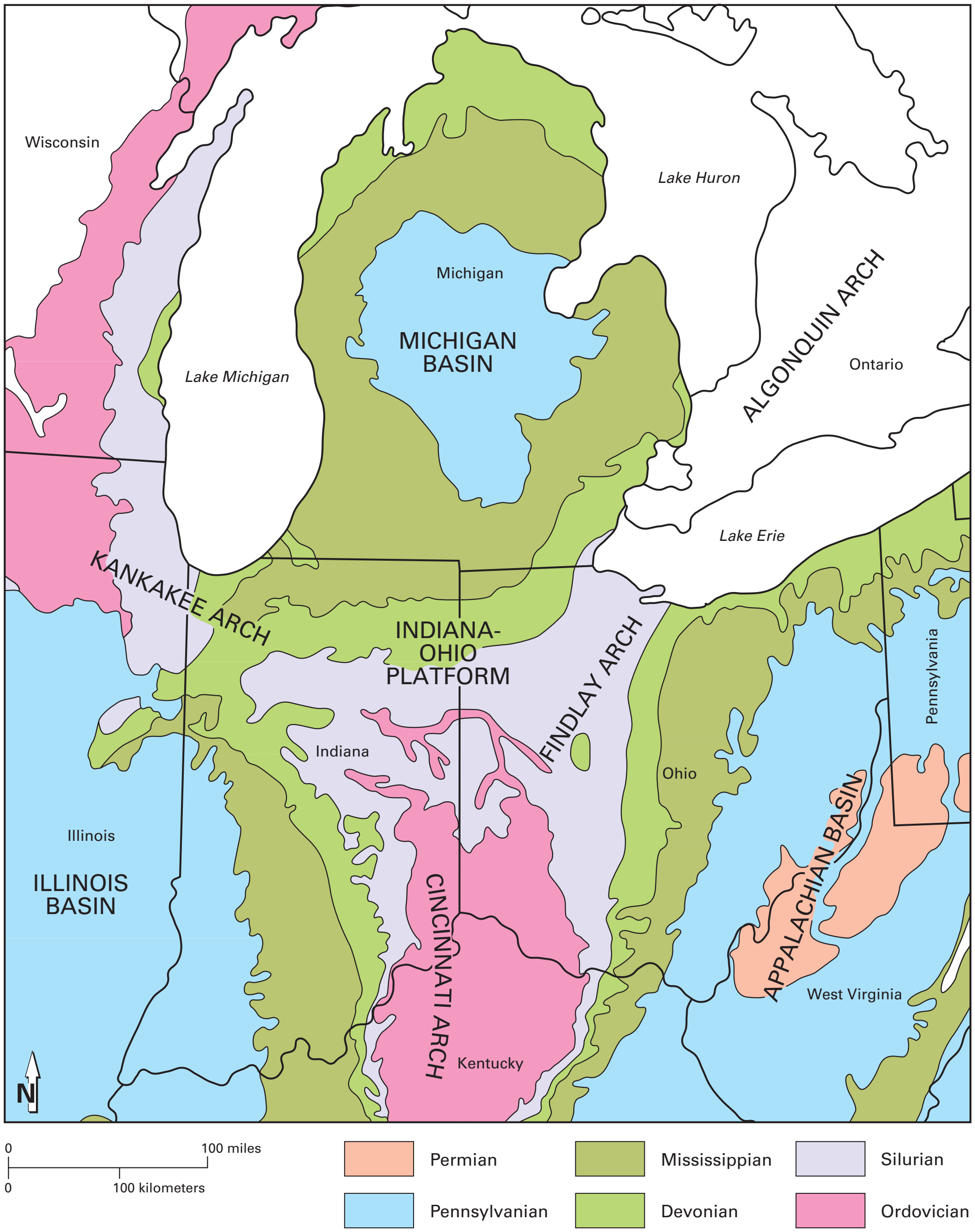



**FIGURE 5. Structural features and generalized distribution of Ordovician through Permian rocks in Ohio and adjacent states (modified from Botoman and Stieglitz, 1978, fig. 2).**

and Hackathorn, 1996); or the "Introduction to Ohio's Geology" chapter in Mark Camp's *Roadside Geology of Ohio* (2006); or the "Geology of Ohio" series, written by Michael Hansen from 1996 to 2001, from the Survey's *Ohio Geology* newsletter (see "References Cited" beginning on p. 187 for complete citations). Our goal in this section is to present a brief overview of the geologic history of the near-surface bedrock units mapped in Ohio.

The distribution of Ohio's near-surface bedrock geology, as illustrated on the *Bedrock Geologic Map of Ohio* (Slucher and others, 2006; fig. 6), was created by the formation of the basins and arches, the changes in depositional environments of the geologic units, and the forces of erosion through geologic time. The older Ordovician and Silurian rocks of western Ohio define the location of the Cincinnati Arch of southwestern Ohio, the Indiana-Ohio Platform of west-central Ohio, and the Findlay Arch of northwestern Ohio. The succession of progressively younger rocks observed in northwestern Ohio and eastern Ohio define the Ohio portions of the Michigan and Appalachian Basins, respectively.

As mapped by Slucher and others (2006), Ordovician rocks in western Ohio clearly define the ancient, dendritic drainage pattern of the Teays River System and other ancient drainage systems (fig. 6). The Teays River and its tributaries cut into the western Ohio bedrock beginning some 2 to 3 million years ago, removing the Silurian bedrock units over time and exposing the underlying Ordovician rocks. Today, the Teays and its tributaries are largely buried by thick deposits of glacial drift deposited by repeated advances of continental glaciers during the recent Ice Age (Hansen, 1995).

Ohio's geologic history has exhibited many changes in depositional environments and the variety of rocks deposited in each environment. What is interesting about this process is that mountain building (or *orogenies*), large-scale glaciations, changes in sea level, and changes in climate have recurred throughout geologic time. So as the processes causing certain depositional environments are repeated throughout geologic time, so are the rocks deposited in each environment. Thus Ohio's stratigraphic column contains many geologic units that have the same or similar diagnostic characteristics and that recur throughout the column of rocks. For example, the Ordovician Utica shale, Devonian Ohio and Antrim Shales, and Mississippian Sunbury Shale are characterized by organic-rich, brown or black shale. To highlight geologic units that recur in Ohio's stratigraphic column, we list these units in the "Stratigraphic context" section of each fact sheet.

Geologists organize the progression of Ohio's near-surface bedrock into a *stratigraphic column*, a graphic representation of the sequence of sedimentary rock layers mapped in Ohio (fig 1). The column is organized with the oldest rocks at the bottom overlain by successively younger rocks until the entire column is capped by the youngest rocks of Ohio. Thus the Point Pleasant Formation exposed along the Ohio River in southwest Ohio comprises the oldest rocks exposed in the state, and the Dunkard Group exposed along the Ohio River in southeast Ohio comprises the youngest rocks. The youngest sediments in Ohio are unconsolidated, wind-blown, alluvial and lacustrine deposits being deposited today on Ohio's land surface or in Ohio's rivers and lakes.

The stratigraphic column is subdivided into groups, formations, members, and beds (fig 1). Each of these stratigraphic units is characterized by rocks of a specific lithology, such as limestone or sandstone, or by the interbedding rock types. Each unit contains characteristics that differentiate it from the overlying and underlying units. The units are commonly named for geographical features, such as a city, town, river, stream, lake, or mountain. Each fact sheet in this field guide features a brief description of how the unit was named. The *formation* is the fundamental unit of stratigraphic classification and two or more formations comprise a *group*. *Members* are subdivisions of formations and *beds* are building blocks of all stratigraphic units.

Formal stratigraphic units are identified by an uppercase lithologic or stratigraphic name (e.g. Sunbury Shale, Bisher Formation) and informal stratigraphic units by a lowercase lithologic or stratigraphic name (e.g., Utica shale, Cincinnati group). To formalize a stratigraphic unit, a geologist must write a scientific paper that is published in a peer-reviewed scientific publication. Such a paper formalizes the stratigraphic unit; explains the unit's stratigraphic rank (e.g., formation, member) and why the name was selected; designates the stratigraphic section or sections that display the diagnostic features of the unit; identifies the geologic features of the unit; explains the nature of the upper and lower boundaries; identifies the unit dimensions and geologic age; and describes how the unit was deposited.

Informal stratigraphic units, such as the Upper Freeport coal, Fulton beds, or glacial till, are commonly used by geologists to name important economic units, to discuss differences in the lithologies within a formal unit (e.g., the brown Fulton shale beds of the Kope Formation), to describe units too thin to map at the usual map scales, or for units in the process of becoming formal units.

The groups, formations, members, or beds mentioned in the stratigraphic column and in the description of mapped units on the *Bedrock Geologic Map of Ohio* may change in the future as geologists develop new techniques to study Ohio's rocks and acquire new data from coring projects and as new outcrops are exposed by stream erosion and man-made excavations. Some of the names of the near-surface geologic units may change over time. For example, recent studies have documented that the Laurel Dolomite, as traditionally used in Ohio, does not correlate to the Laurel Dolomite originally named and mapped in Indiana. The Laurel Dolomite as traditionally used in Ohio is indeed a new formation, the Lewisburg Formation (see Brett and others, 2012). In situations such as the Laurel of Ohio, we will use the stratigraphic nomenclature presented on the *Bedrock Geologic Map of Ohio* and as mapped on individual 7.5-minute bedrock-geologic maps.

## History of Ohio's Near-Surface Bedrock Geology

The story of Ohio's near-surface geology begins some 440 million years ago during the Ordovician Period, one of the warmest periods in Earth history. Ohio was located somewhere between 15° and 20° south of the equator (fig. 7). During the Ordovician, two episodes of mountain building occurred along the edge of ancient North America. A broad, shallow, tropical sea teeming with abundant and diverse marine life covered much of ancestral North America, including Ohio. Hurricanes and other tropical storms regularly swept across Ohio.

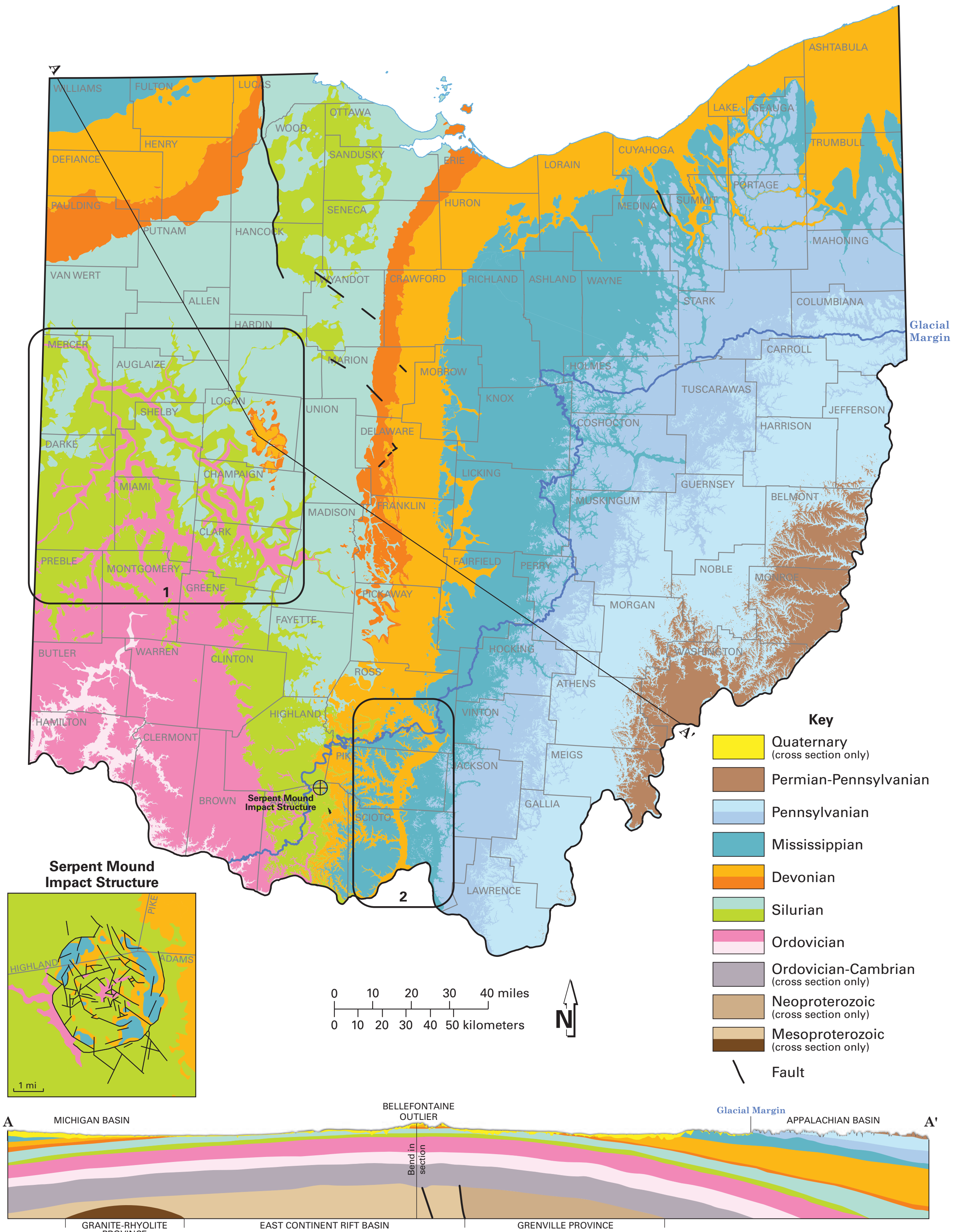



**FIGURE 6. Generalized bedrock geologic map of Ohio. (1) The Ordovician rocks mapped in west-central Ohio define the ancient, dendritic drainage pattern of the Teays River System. (2) A second segment of the Teays River System is well illustrated by the Devonian rocks mapped in central Scioto and Pike Counties and eastern Ross County located in southern Ohio.**

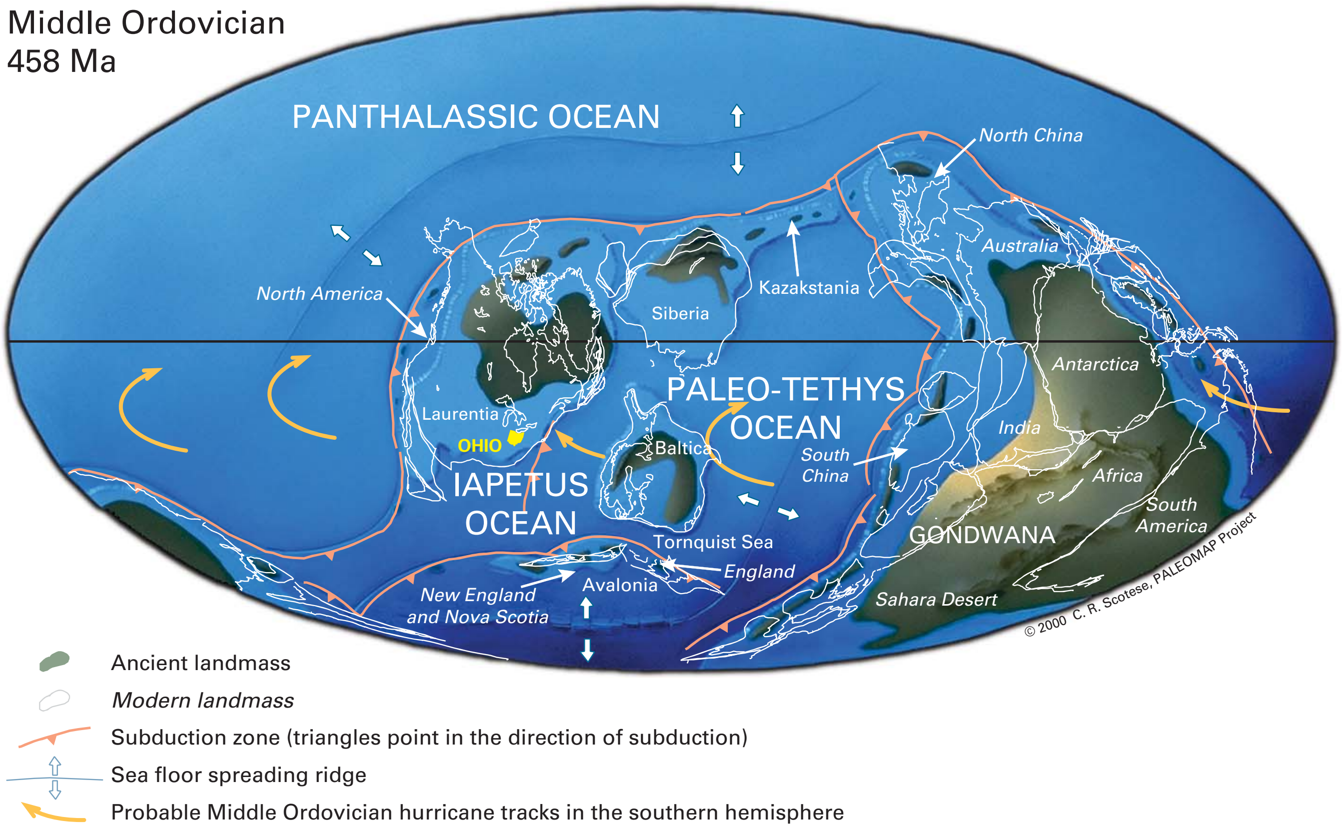



**FIGURE 7. Paleogeographic map showing the position of the Middle Ordovician continents and oceans about 458 million years ago or about 5.5 million years before the deposition of the basal Kope Formation. Modified from Scotese (2013).**

The hurricanes and tropical storms and the rapid proliferation of organisms inhabiting the Ordovician seas combined to produce the characteristic interbedded limestone and shale of the Upper Ordovician geologic units of southwest Ohio. Hurricane and storm waves propagated through the water column and scoured the bottom sediments, eroding and transporting sediments and prolific, diverse burrowing and bottom-dwelling organisms. The unearthed, dislodged, and toppled organisms were dragged across the sea floor in a layer of sediment-laden water near the sea floor. As a hurricane moved away, wave energy waned and the sediments and organisms would be deposited as a new limestone bed; the coarse sediments and organisms settled at the bed bottom and particle size decreased upward through the graded bed. The upper part of the sequence consisted of clay-sized particles that formed the base of the overlying shale bed. Fine-grained sediments continued to be deposited and new organisms colonized the post-storm sea bed, producing abundant skeletal material. When the next hurricane or major storm swept across Ohio, the whole process—fine-grained sedimentation, organisms colonizing the sea floor and producing abundant skeletal fragments, hurricane waves scouring and eroding the sea bottom, and deposition of a new limestone and shale beds—started over again and occurred thousands of times during the Ordovician Period.

However, the action of hurricanes and tropical storms is just part of the story concerning the diagnostic features of Ordovician rocks in Ohio. The relative abundance of limestone compared to shale was also affected by changes in sea level. Sea level dropped during widespread glaciation, caused when Earth's climate cooled, and/or uplift or sinking of the seafloor related to the mountain building occurring along the margins of ancestral North America. The interaction of these factors produced a slightly tilted sea bottom and a gradient of water depths. Water depth ranged from nearshore "shallower" water environments through a transition zone to offshore "deeper" water environments. Geologists estimate that the water depth of the "deeper" water environments ranged from about 60 ft to over 160 ft (18–49 m). We do not know for sure, but "shallower" water environments were probably between 0 and 20 ft (0–6 m) deep. In reality, Ordovician water depths in Ohio were very shallow when compared to the typical range of water depths occurring in the oceans of the Ordovician or today. However, the water depth of the "deeper" environments is significant because hurricane waves generally will affect only the upper few hundred feet of the ocean water column. Thus only the strongest hurricanes generate waves that affect the "deeper" water environments, but nearly all hurricanes and tropical storms affected "shallower" parts of the water column.

The sediments deposited in the "shallower" water environments were subject to higher amounts of bottom erosion because nearly every hurricane or tropical storm affected the bottom sediments. Coarser-grained sediments and larger skeletal fragments were concentrated in limestone beds and much of the finer-grained sediments and smaller skeletal fragments were transported into "deeper" water environments. The resulting rocks formed in the "shallower" water environments are characterized by limestone-dominant; highly fossiliferous; and wavy-, irregular-, or nodular-bedded geologic units. The Whitewater Formation; Saluda Formation; portions of the Arnheim formation; the Straight Creek and Bellevue Members of the Grant Lake Limestone; and Bellevue and Mount Auburn Members of the Grant Lake Formation were all deposited in "shallower water" environments. In the case of the shale-dominate Drakes Formation, some of the unit was deposited in very shallow water and other portions in mudflats along an ancient Ordovician shoreline.

The abundance of shale and fossiliferous to sparsely fossiliferous, planar-bedded units characterize the "deeper" water environments. Occasional limestone beds created by the strongest hurricanes punctuate the shale-dominant sequence. Weaker hurricanes possibly produced thin, rhythmic sequences of silty shale that grade into clayey shale, which in turn is capped by the sharp erosional base of the next rhythmic sequence. Further evidence for rapid sedimentation and burial by hurricane-generated waves includes the abundant preservation of complete skeletons of easily disarticulated fossils, such as crinoids and trilobites, near the bases of these rhythmic sequences. The Utica shale, Kope Formation, Miamitown Shale, and Waynesville Formation were deposited in the "deeper" water environments.

A transition environment occurs between the "shallower" and "deeper" environments in which the geologic units deposited contain roughly equal amounts of planar-bedded limestone and shale. The Liberty Formation, portions of the Arnheim formation, the Corryville Member of the Grant Lake Limestone or Grant Lake Formation, the Fairview Formation, and the Point Pleasant Formation represent the units deposited in this type of environment.

During the Ordovician, the repeated interaction between mountain building along the edge of the ancient North American continent and changes in climate resulted in times of uplift and subsidence of the seafloor combined with rising and lowering of sea level. This produced very gentle slopes in the seafloor and different water depths along these gradients. So, the environmental gradient of "shallower" to "deeper" water occurred more than once during the Ordovician, thus explaining why geologic units with the same diagnostic features recur in the Ordovician geologic column (fig. 8).

Near the end of the Ordovician Period, Earth's climate cooled to the point that the polar region expanded considerably into the southern and northern hemispheres. Vast continental glaciers, many hundreds of feet thick, formed during this Late Ordovician Ice Age. Huge quantities of water were frozen in these vast glaciers, causing sea level to fall around the world. In Ohio, the falling sea level caused the seas to drain away and the former sea bed to become dry land. The worldwide drop in sea level resulted in the widespread loss of shallow marine habitats all over the planet and one of the major extinctions of plants and animals in Earth history.

The retreat of the sea causes sediment deposition to cease and subjects the former sea bottom to erosion. The break in sedimentation creates a gap in the rock record known as an *unconformity*. One can think of the rock record as the pages of a book. Each bed of rock records the geologic information for that time in Earth history. Each page of the book also records information about the story that the author is telling and unconformities represent the pages missing from the book. The amount of history missing can be a short time and restricted to a localized area or can span millions of years and the unconformity can be widespread.

In southwestern Ohio, sedimentation ceased at the top of the Drakes Formation as sea level dropped and land emerged. The reddish-gray to maroon shale beds near the top of the Drakes formed as the iron minerals within the sediments were oxidized or rusted when exposed to oxygen from the atmosphere. The break in sedimentation resulted in a period of erosion on Ohio's Ordovician landscape and produced the Ordovician-Silurian worldwide unconformity that is present at the top of the Drakes.

During the early Silurian Period, Earth experienced times of warming and cooling, causing continental glaciers to melt back in the warmer periods and then advance in the cooler periods. Glacier melting released vast quantities of water, causing sea level to rise and flooding of the coastal lowlands of western Ohio. During cooler periods, the accumulation of ice caused sea level to fall and expose vast areas of the former sea bed. Climate variations and possibly mountain building caused repeated fluctuations of sea level that flooded and retreated from the coastal lowlands present in what is today western Ohio.

The tidal flat to intertidal environments of the Belfast Member of the Brassfield Formation or Drowning Creek Formation represents the initial slow migration of the advancing sea across the Ordovician landscape. The remainder of the Brassfield was deposited in nearshore to offshore environments as water depths increased. At the top of the Brassfield, water depths decreased and retreated from western Ohio. The limestone and dolomite of the Dayton Limestone represent the next rise of sea level, as

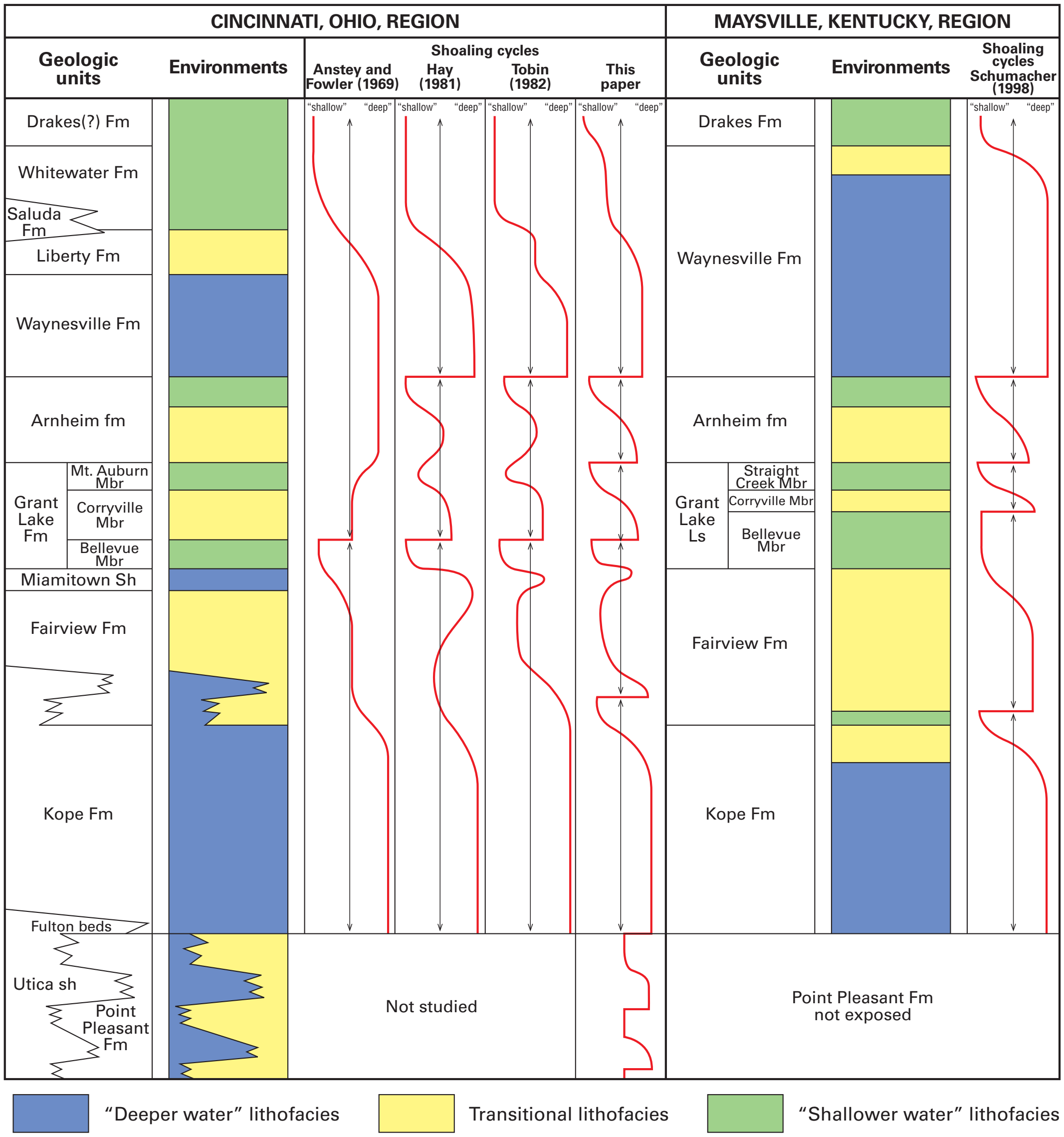



**FIGURE 8. Schematic diagram comparing geologic units, depositional environments, and repeating "deeper" to "shallower" water or shoaling cycles in the Ordovician rocks mapped in southwestern Ohio and Maysville, Kentucky, regions. The Utica shale generally is not exposed in southwestern Ohio. The brown shales, named Fulton beds of the Kope Formation, represent a tongue of the Utica shale that occurs in scattered exposures along the Ohio River in Hamilton and Clermont Counties (modified from Schumacher, 1998, fig. 16-4).**

tidal flat to offshore environments once again developed in western Ohio.

Multiple sea level advances and retreats throughout the Silurian caused geologic units with very similar diagnostic features to recur through the stratigraphic column. For example, the Osgood Shale is gray, calcareous, sparsely fossiliferous shale and the Massie Shale is gray, calcareous, fossiliferous shale. Another example is illustrated by the Euphemia, Cedarville, Peebles, and Lockport Dolomites, which were all deposited in offshore environments originally as fossiliferous limestone. As sea level fell, the shallow-water, nearshore environments subjected the limestone to magnesium-rich, high-salinity waters, which converted the limestone to vuggy (porous) dolomite.

Beginning in the Late Silurian and continuing into the Early Devonian, a major unconformity developed as regional uplift associated with renewed mountain building along the east coast of ancestral North America caused the sea to drain away. The Silurian rocks of western Ohio were subjected to a long period of erosion. Extensive karst features, such as sinkholes, caves, and underground drainage systems, developed on and within the Silurian and Devonian landscape. Many of these features can be observed in the Bass Islands Dolomite and upper Salina Group along with the presence of extensive fractured and angular pieces of dolomite cemented together to form the characteristic *brecciated* dolomite beds of these units.

During the Middle Devonian, tropical seas once again inundated the Silurian land surface as Ohio began to subside into the ancestral Appalachian Basin. Rivers and streams transported sediments to vast deltas building into the shallow Devonian seas. In Ohio, the return of clear tropical seas containing abundant marine life resulted in the deposition of limestone units, such as the Columbus, Dundee, and Delaware Limestones; or dolomite units, such as the Lucas and Amherstburg Dolomites of the Detroit River Group or the Ten Mile Creek Dolomite; or the Sylvania Sandstone.

With time, the Appalachian Mountains continued to be thrust upward and eroded, producing large quantities of mud, sand, and gravel that were transported to the sea. The large amounts of sediments deposited in the Appalachian Basin caused additional subsidence of the sea floor in Ohio. Slowly from east to west, limestone deposition was replaced by the deposition of shale as the muddy sediments were deposited in central and western Ohio. The Olentangy and Plum Brook Shales, Prout Limestone, Silica Formation, and Ten Mile Creek Dolomite represent the transitional units from underlying limestone, dolomite, and sandstone units to overlying geologic units comprised primarily of shale, mudstone, siltstone, sandstone, and conglomerate in Ohio.

Capping the Olentangy Shale, Prout Limestone, and Ten Mile Creek Dolomite are the organic-rich black shales of the Antrim Shale and Huron Shale Member of the Ohio Shale. These units were deposited in subsiding basins where bottom sediments, and at times the water column, became oxygen starved or *anoxic*. Anoxic environments are deadly for marine organisms because without oxygen these creatures quickly suffocate. The exclusion of living marine organisms from anoxic environments allowed the organic-rich shale to accumulate because in oxygen-rich environments these organisms would otherwise consume and digest much of the organic matter in the sediment. The Cleveland Shale Member and Sunbury Shale are other near-surface, organic-rich geologic units that accumulated in the subsiding Appalachian and Michigan Basins.

Periodically during the Devonian and Mississippian Periods, oxygen would return to the lower water column and bottom sediments, producing individual beds of gray shale or sandstone in the otherwise organic-rich shale sequence. Usually, the change back to anoxic bottom conditions occurred quickly, but in a few situations the oxygen-rich bottom conditions persisted for longer time periods, producing thicker sequences of gray shale or sandstone represented by the Chagrin Shale Member of the Ohio Shale, Three Lick Bed, Bedford Shale, Cussewago Sandstone, and Berea Sandstone.

By the end of Sunbury Shale deposition (about 358 million YBP), the leading edges of vast deltas building into Ohio from the east had reached central and western Ohio. The Cuyahoga Formation and associated members reflect the wide variety of rocks that are deposited in marginal marine, deltaic, or fluvial environments. Geologists have recognized seven different combinations of the shale, sandstone, and conglomerate along the 260-mi (416-km)-long outcrop of the Cuyahoga Formation from the Ohio River northward to the Ohio/Pennsylvania border. For example, the reddish-gray shale of the Henley Member of southern Ohio was deposited at the leading edge of the advancing delta in deeper marine settings. Abundant oxygen in the water column and bottom sediments allowed organisms to burrow into or live atop the sediments and for the shale to be oxidized, creating the reddish color. The Black Hand Member is comprised of coarse-grained sandstone and localized conglomerates of quartz pebbles that were deposited in delta or river channels as the seas retreated from much of Ohio.

During Mississippian time, deltas continued to build across much of Ohio, depositing the sandstone-dominant Logan Formation. Over time, sandstone deposition slowed as erosion rates of the ancestral Appalachian Mountains decreased and as continued basin subsidence allowed the sea to flood over parts of the Logan Formation in east-central and southern Ohio. The localized Rushville Formation and more widespread Maxville Limestone were deposited during these advances of the sea. Maxville deposition ceased when the sea once again drained away from Ohio.

The advance and retreat of the sea across eastern Ohio occurred many times from the base of the Pottsville Group through most of the Conemaugh Group of Ohio. The rocks deposited during advances of the seas were limestone, sandstone, and fossiliferous shales. Rocks deposited when the swampy coastal lowlands appeared include coal, clay, mudstone, shale, sandstone, conglomerate, and limestone deposited in freshwater lakes. The Pennsylvanian Period produced over 120 named beds of coal, limestone, sandstone, and iron ore, including more than 60 separate coal beds. Only 14 of these coal beds have sufficient thickness and regional distribution to be economically mined, whether in the past or today.

The sea retreated for the last time during deposition of the upper part of the Conemaugh Group. Continental sediments consisting of shale, sandstone, freshwater limestone, and mudstone occur in the upper part of the Conemaugh and in the Monongahela and Dunkard Groups. Mudstones or more commonly red beds weather rapidly, forming landslide-prone thick colluvium. When water saturated, the clay-rich unconsolidated colluvium may lose cohesive strength, fail, and readily slide down slope. Landslides in the Conemaugh, Monongahela, and Dunkard Groups damage structures and roadways nearly every year, costing millions of dollars to repair.

Ohio's bedrock geologic record ends at the top of the Dunkard Group because there are no rocks younger than Permian age known in Ohio. Rocks that contained dinosaurs or marine rocks containing some the world's largest sharks may have been deposited in Ohio, but because of the long period of erosion, these rocks were eroded and all record of them is gone. So, the top of the Dunkard marks a major unconformity (or gap) in geologic time where over 260 million years of Earth history is missing.

## FACT SHEET ANATOMY

This field guide contains a total of 65 fact sheets that describe the characteristics of 111 near-surface bedrock and surficial geologic units mapped on the *Bedrock Geologic Map of Ohio* (Slucher and others, 2006), open-file bedrock-geologic maps, or surficial-geology maps. The fact sheets (fig. 9) are designed to provide the reader with a concise summary of the diagnostic features that distinguish one geologic unit from the underlying and overlying units. After the fact sheet title, an introductory paragraph details the characteristic rock or rocks of the unit, the environment(s) in which the unit was deposited, the mapped distribution of the unit throughout the State of Ohio, how the unit was named and for what nearby geographic feature, and the unit thickness.

The body of each fact sheet consists of twelve major categories providing information about the geologic unit:

- Diagnostic features
- General features
- Lithologic variations or how the rocks vary from one part of Ohio to another
- Fossil content
- Weathering characteristics
- Contacts with the overlying and underlying geologic units
- Overlying and underlying units and similarities to other geologic units mapped in Ohio
- Engineering properties
- Hydrogeologic properties

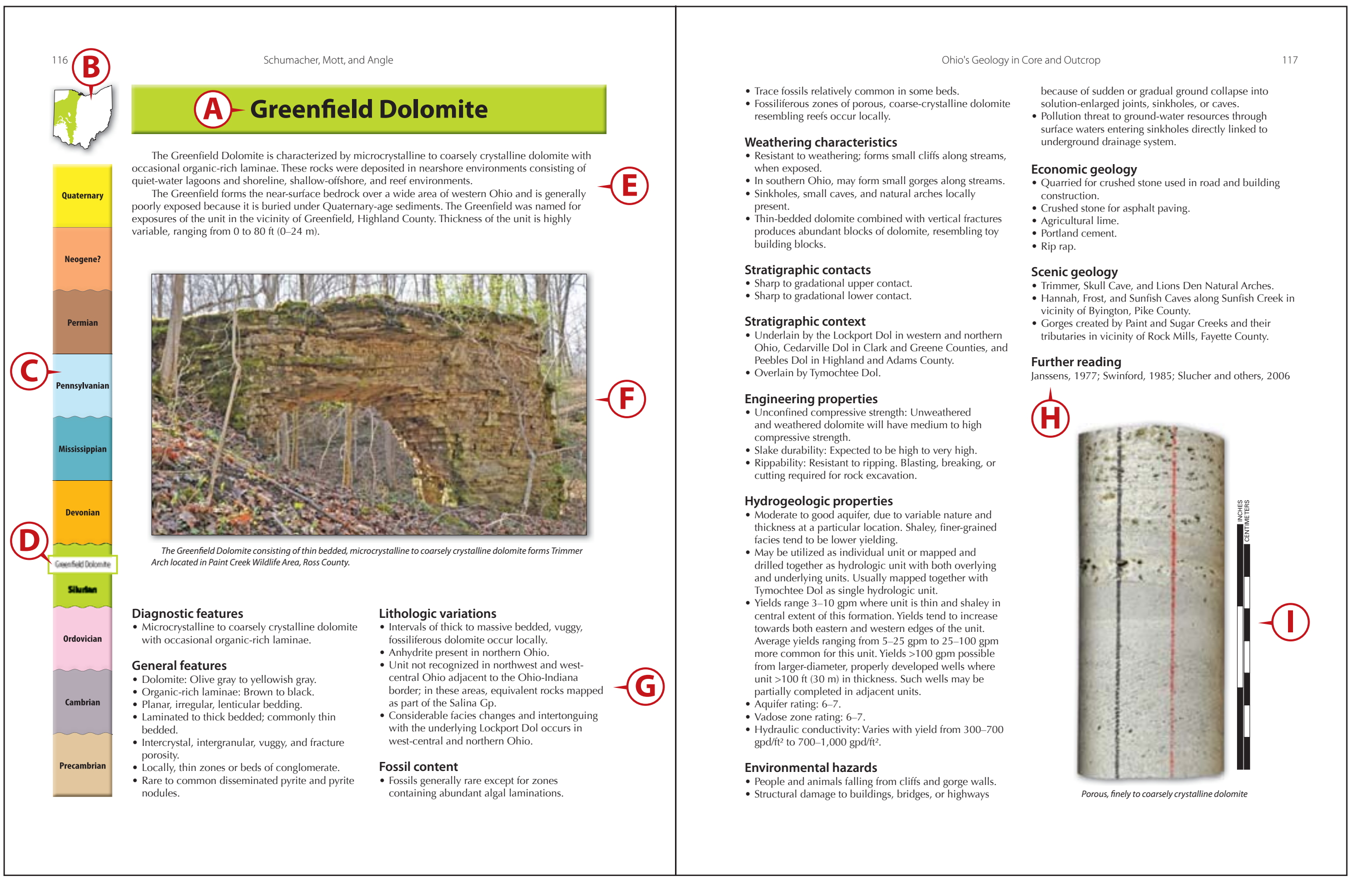



**Figure 9. The anatomy of a fact sheet. (A) Geologic unit name. (B) Mapped distribution of rocks in the unit's geologic system. (C) Time-rock column of Ohio. A wavy line between geologic periods indicates a major unconformity. (D) Chronostratigraphic position of the geologic unit. (E) Introductory paragraph. (F) Photo of outcrop or natural setting diplaying diagnostic features of the geologic unit. (G) Fact sheet text describing the geology of the unit. (H) Further reading provides references to learn more about the unit. (I) Photo and scale of rock core with diagnostic features of the geologic unit. Black and red reference lines are drawn to help determine the top of each core piece. When the red line is to the right, the core is oriented from top to bottom with the page.**

- Environmentally related hazards
- Economic geology
- Scenic geology

A "Further reading" section provides interested readers with references detailing more information about each unit.

The chronostratigraphic position of each unit is illustrated on the time-rock column for Ohio (fig. 9, C). The thumbnail bedrock geologic map showing the mapped distribution of each system of Ohio's rocks is located in the left hand corner of each fact sheet (fig. 9, B). For example, if the reader examines the fact sheet for the Greenfield Dolomite, the thumbnail map illustrates the distribution of the Silurian System and **not** the mapped distribution of the Greenfield Dolomite. For those interested in the mapped distribution of the Greenfield, see the *Bedrock Geologic Map of Ohio* (Slucher and others, 2006) and open-file bedrock geologic quadrangles for southern Ohio. On some fact sheets, figures are included to highlight important geologic information.

The final components are photographs showing the diagnostic features of each geologic unit in a natural setting (or outcrop) or man-made exposure, such as a road cut (fig. 9, F), and in a section of core (fig. 9, I). Captions for each natural or man-made exposure emphasize the geologic unit's diagnostic features and general location.

## TERMINOLOGY

The authors have targeted the content of the field guide to a wide audience, which includes Ohio citizens, students, teachers, and professionals in the fields of geology, engineering, and environmental science. Thus we have limited the amount of geologic terminology used throughout the field guide and used as much as possible more common terminology that would be recognized by a diverse audience. However, a certain amount of geologic terminology is necessary to adequately describe the characteristics of the near-surface geologic units of Ohio. When describing Ohio's near-surface rocks, we used the following criteria:

- Lithology
- Color
- Grain or crystal size
- Bedding
- Induration (hardness)
- Sedimentary structures
- Porosity
- Amount of burrowing by organisms
- Weathering characteristics
- Accessory minerals, if abundant

Table 1 summarizes the common and not-so-common rock types of Ohio, and the Mohs scale of hardness for these rock types is given in table 2. Ohio's near-surface bedrock is composed predominantly of sedimentary rocks; table 3 summarizes the common descriptors used to describe the characteristics of sedimentary rocks.

### Describing the Geologic Properties of Ohio's Rocks

To describe the colors of Ohio's rocks, we used white, gray, black, and other colors of the spectrum. In some cases, we may have added a descriptive term, such as *light* or *dark*, before a rock's basic color.

To describe grain size, we used the scale of Wentworth (1922) that defines fine grains as those with sizes between 0.0625 and 0.25 mm (0.0025–0.01 in), medium grains as between 0.25 and 0.50 mm (0.01–0.02 in), and coarse grains as between 0.50 and 2.0 mm (0.02–0.08 in). We use the same size breakdown when describing the sizes of crystals present in a crystalline rock. *Microcrystalline* refers to the texture of a rock consisting of crystals that can be seen only under the microscope. *Micrite* refers to a limestone lithified from lime mud, with crystals less than 0.004 mm (4 μ) in size. Micritic limestone consists of over 90 percent micrite.

The thickness of Ohio's near-surface geologic units is divided into laminations that range from 0.1 to 0.4 in (0.3–1.0 cm) or beds that may be thin, medium, thick, or massive bedded. Thin beds range in thickness from 0.1 to 4 in (0.3–10 cm), medium beds from 4 to 12 in (10–30 cm), and thick beds from 12 to 36 in (30–100 cm). Massive beds are greater than 36 in (100 cm) thick.

Bedding types consist of planar, lenticular, nodular, irregular, wavy, and massive (fig. 10). *Planar bedding* is used when the bed top and bed bottom, commonly called *bedding planes*, are flat or smooth and more or less parallel to one another. *Lenticular bedding* occurs when the bedding planes resemble a double convex lens in cross-section. *Nodular bedding* consists of scattered small, irregularly rounded lumps or masses called *nodules* that usually are encased in sedimentary rocks of a different composition. *Irregular bedding* is characterized by bedding planes that are rough and irregular with many elevations and depressions. *Wavy bedding* features undulatory bedding planes that resemble wave crests and troughs. *Massive bedding* consists of very thick, homogeneous beds where it is often difficult to determine bed tops and bottoms. *Cross bedding* refers to beds inclined at an angle to horizontal bedding. Examples of cross bedding occur in the middle and upper parts of Umbrella Rock illustrated on the cover of this report.

*Intertonguing* of sedimentary rocks commonly occurs when the transition from one depositional environment to another occurs over a longer period of geologic time. In a vertical or lateral stratigraphic sequence this produces beds or groups of beds that alternate in increasing or decreasing abundance until the transition from one rock type to another occurs. *Intergrading* of sedimentary rocks occurs when the transition between two different sedimentary rocks occurs gradually over a vertical or lateral stratigraphic sequence.

**TABLE 1. *Ohio's basic rock types*[1]**

| Rock type | Description[2] |
|---|---|
| Anhydrite | A rock or mineral consisting of anhydrous calcium sulfate ($CaSO_4$), which is common to massive evaporite beds and readily alters to gypsum. Anhydrite is white, has a vitreous or pearly luster, and a hardness of 3.5. |
| Breccia | A coarse-grained sedimentary rock comprised of more than 25% subangular to angular gravel, cobbles, and/or boulders. These grains are supported by either intergrain contact or a matrix of sands, silt and/or clay and cemented by calcite, dolomite, hematite, silica or hardened clay. Color depends on the cementing agent with white, gray, yellow, orange, brown, and red colors common. |
| Chert | A hard, dense sedimentary rock consisting of very fine quartz crystals and may contain amorphous silica or silica-replaced fossils. Chert varies in color, but commonly is white or ranges from brown to black, has a semivitreous to dull luster, and a hardness of 7. When broken it commonly produces conchoidal fractures. These fractures are smooth with sharp edges. Chert forms as oval or irregular nodular or concretionary segregations or as layered deposits in limestone and dolomite. Also referred to as *flint*. |
| Claystone | A fine-grained rock formed of at least 75% clay-sized particles. Claystone is comprised of lithified clay having the texture and composition of shale, but lacking the laminations and fissility of a shale. Generally has a blocky, thick to massive appearance. Claystone may range in color from red, gray, olive, yellow, or brown with multiple colors typical. Slickensides are commonly found within claystone. |
| Coal | A combustible substance containing more than 50%, by weight, and more than 70%, by volume, of organic-rich material; formed from the compaction and lithification of plant remains. Coal is ranked into four categories based on moisture, carbon, and caloric content. *Lignite* contains the highest moisture content and lowest amount of carbon and a caloric content less than 8,300 Btu/lb. *Subbituminous* coal occurs between lignite and bituminous coal and contains less moisture, more carbon, and a caloric content ranging between 8,300 to 10,500 Btu/lb. *Bituminous* coal is the most abundant rank of coal and occurs in great abundance in Pennsylvanian- and Permian-age rocks. The caloric content is more than 10,500 Btu/lb. Anthracite is 92–98 percent carbon and has a caloric content ranging from 10,500 to 12,500 Btu/lb. *Cannel* coal is a special type of coal consisting of mostly spores and pollen and is characterized by compact, thick beds that break with a conchoidal fracture. Coals may contain bands of varying lusters. Banded coals contain alternating bright and dull lusters. |
| Conglomerate | A coarse-grained sedimentary rock comprised of more than 25% rounded to subrounded gravel, cobbles, and/or boulders. These grains are supported by either intergrain contact or a matrix of sands, silt and/or clay and cemented by calcite, hematite, silica or hardened clay. Color depends on the matrix and cementing agent with white, gray, yellow, orange, brown, and red colors common. |
| Dolomite | A sedimentary rock of which more than 50% consists of the mineral dolomite (calcium magnesium carbonate—$CaMg(CO_3)_2$) and less than 10% is comprised of the mineral calcite. It is commonly interbedded with limestone, and the magnesium can be replaced with ferrous iron. Dolomite typically has a hardness of 3.5 to 4, colors ranging from white to light gray, and will weakly react with cold dilute HCl on fresh or powdered surfaces. |
| Fireclay/Flint clay | See *underclay* for description. The preferred use is *underclay*. |
| Flint | A common name for chert, generally used by archaeologists. See *chert* for a description. |
| Gypsum | A rock or mineral consisting of hydrous calcium sulfate ($CaSO_4 \cdot 2H_2O$). It forms thick, extensive beds in Silurian-aged rock commonly associated with halite and anhydrite in evaporative deposits. Gypsum may be white, translucent, or transparent with a vitreous to pearly luster and a hardness of 2.0. Does not react with dilute HCl. |
| Halite | A rock or mineral occurring in massive, granular compact or cubic-crystalline forms associated with evaporite beds. It is comprised of sodium chloride (NaCl) and is commonly known as *salt*. Halite is colorless to white with a hardness of 2.0 to 2.5. Fresh samples will have a salty flavor. |
| Ironstone | A sedimentary rock that is heavy and compact, containing primary components of iron oxides, carbonates, clay, and/or sand. Fresh surfaces generally are gray and weather (oxidize) to yellowish brown (limonite) to deep red (hematite), depending on the type and amount of oxide/hydroxide formed. It is very distinct in that its density is greater than a typical sedimentary rock.<br>Purer forms of ironstone occur as concretionary forms within shale, sandstone, and limestone or dolomite layers or at bedding contacts. Generally these concretionary forms are composed of goethite (Fe(OH), hardness 5.0–5.5), limonite (FeX(OH), hardness 4.0–5.5), or siderite ($FeCO_3$ , hardness 3.5–4.5) and can be called "kidney ores" for their kidney shapes. Colors of these concretions vary between gray, yellowish brown, brown, brownish red, or black, depending on the composition and degree of weathering. |
| Limestone | A sedimentary rock consisting of the mineral calcite (calcium carbonate—$CaCO_3$). Impurities may include chert, clay, and minor mineral crystals. It may be crystalline (hard, pure, fine to coarse texture) with very fine grains not visible to the naked eye and/or fossiliferous (contains remains of organisms). Limestone is typically white to dark gray in color with a hardness of 3.5 to 4.0 and reacts vigorously with cold, dilute HCl. |
| Mudstone | A fine-grained sedimentary rock comprised of mud (silt and clay)-sized particles. *Mudstone* can be used as a generic term incorporating the rock classes of siltstone, claystone, and shale within Ohio. Although this term was widely used on past projects, the three previous descriptions are preferred for current projects. For a detailed description, see *claystone*. |
| Sandstone | A sedimentary rock comprised of grains of angular or rounded sand in a matrix of silt and/or clay cemented together by silica, iron oxides, or calcium carbonate. Sandstones may be composed of up to 25% of particles of gravel, cobble, and/or boulder sizes. Color depends on the cementing agent with white, gray, yellow, orange, brown, and red colors common. |
| Shale | A fine-grained sedimentary rock formed by the lithification of clay, silt, or mud (predominate particle size is less than 0.002 mm [2 µ]). Shale has a laminated structure, which gives it fissility along which the rock splits readily. Shale is commonly interbedded with sandstone or limestone. Organic-rich shale often grades into coal. Typical colors may be red, brown, black, green or gray. |

**TABLE 1.** ***Ohio's basic rock types (cont.)***[1]

| Rock type | Description[2] |
|---|---|
| Siltstone | A fine-grained sedimentary rock formed from particles finer than sand but coarser than clay. Siltstone is comprised of lithified silt and lacks lamination or fissility. Typical colors may be gray, olive, or brown. Generally, siltstone has a fine-grit feeling when rubbed against teeth. |
| Underclay | A layer of clay laying immediately beneath a coal bed or organic-rich shale. This layer may be bioturbated and indurated or lithified. It is chiefly comprised of siliceous or aluminous clay capable of withstanding high temperatures without deformation and may have a high shrink/swell potential. |

[1]Modified from Ohio Department of Transportation (2008). It should be noted that when referencing a percentage of composition the percentage is based on volume and not weight.
[2]See Table 2 for Mohs hardness scale.

**TABLE 2.** ***Mohs scale of hardness***

| Hardness | Mineral | Hardness of common materials | |
|---|---|---|---|
| 1 | talc | | |
| 2 | gypsum | 2 | fingernail |
| 3 | calcite | 3 | copper penny |
| 4 | fluorite | | |
| 5 | apatite | 5 | steel knife blade or window glass |
| 6 | orthoclase | | |
| 7 | quartz | | |
| 8 | topaz | | |
| 9 | corundum | | |
| 10 | diamond | | |

**TABLE 3.** ***Common descriptors used when describing sedimentary rocks***

| | | |
|---|---|---|
| **Arenaceous**—sandy | **Crystalline**—contains crystalline structure | **Micaceous**—contains mica |
| **Argillaceous**—clayey | **Dolomitic**—contains calcium/magnesium carbonate | **Petroliferous**—contains oil and/or natural gas |
| **Brecciated**—contains angular to subangular gravel | **Ferriferous**—contains iron | **Pyritic**—contains pyrite |
| **Calcareous**—contains calcium carbonate | **Fissile**—exhibits thin planar partings | **Siliceous**—contains silica |
| **Cherty**—contains chert fragments | **Fossiliferous**—contains fossils | **Stylolitic**—contains stylolites (suture-like structure) |
| **Conglomeratic**—contains rounded to subrounded gravel | **Friable**—easily broken down | **Vuggy**—contains openings |

Upon weathering, shales break along planes of natural weakness called *partings*. As opposed to fractures, which cut across bedding, partings occur parallel to bedding and are classified by Potter and others (1980) into five categories based on thickness. *Papery* partings have a thickness less than 0.5 mm (0.02 in). *Fissile* partings range in thickness from 0.5 to 1.0 mm (0.02–0.04 in) and *platy* partings range from 1.0 to 5 mm (0.04–0.2 in). The thicker partings include *flaggy* partings, which range from 5 mm to 10 mm (0.2–0.4 in), and *slabby* partings, which have thicknesses between 10 mm and 300 mm (0.4–12 in).

Sedimentary structures consist of structures that form during the deposition of sediments and include laminations, ripple marks, or graded bedding.

*Soft-sediment deformation* occurs as thin intervals of deformed bedding in an otherwise undeformed stratigraphic succession. Geologists use terms such as *concretionary beds, contorted bedding, convolute lamination, flow rolls* or *flow roll horizons, ball-and-pillow structures, gnarly bedding,* or *saucer structures* to describe soft-sediment deformation. These beds or structures occur when sediment grains of sandstone or limestone lose cohesion, causing the bed to liquefy and founder into the underlying beds. Submarine slumping or sediment flows are caused by gravitational slope failure and seismic activity. Examples of soft-sediment deformation are found on pages 77, 150, and 176.

*Porosity* is any opening in a rock that, if connected to other pores, may allow the transfer of fluids and gases through the rock. Common types of porosity include

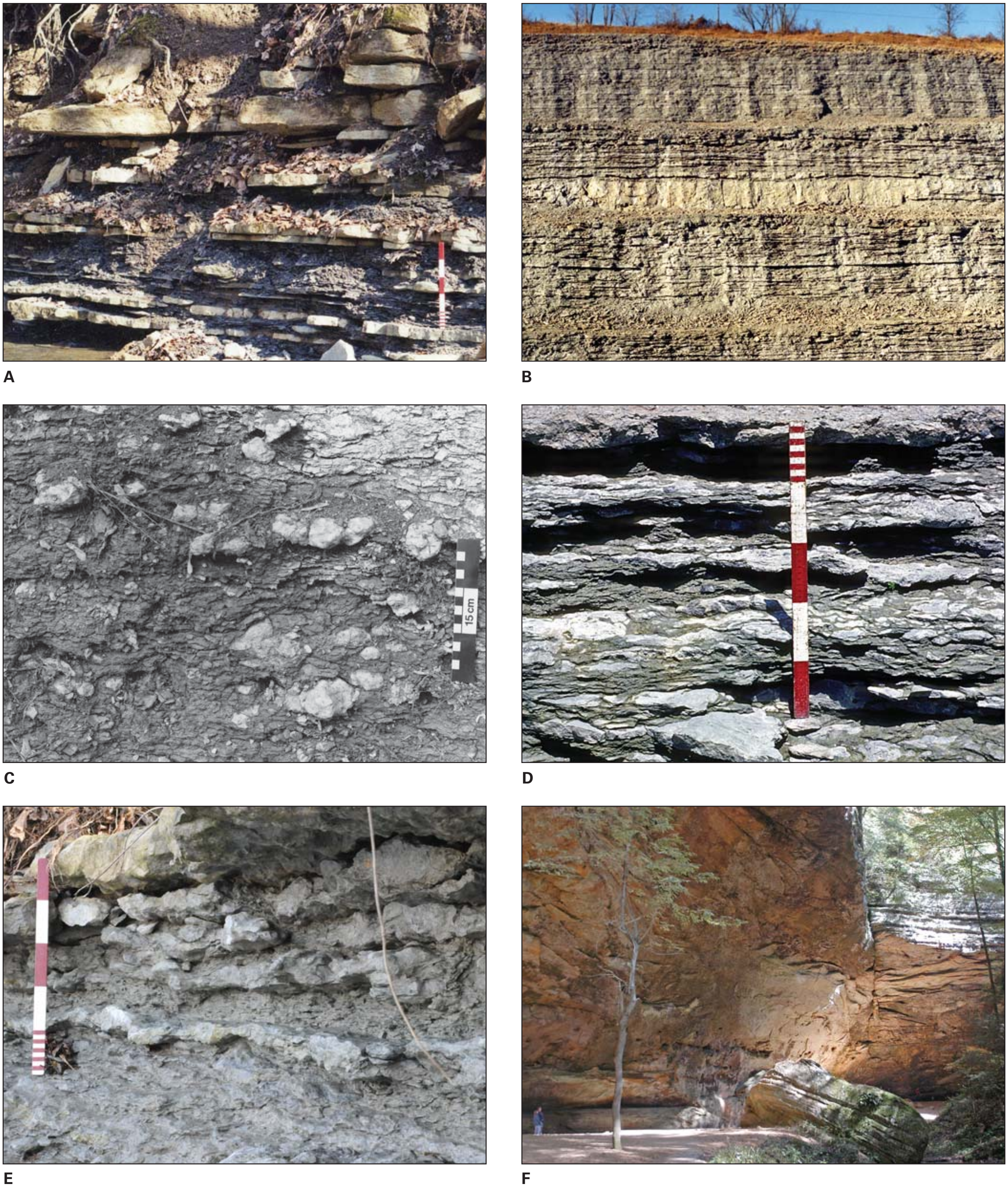



**FIGURE 10. Common bedding types of Ohio's rocks. (A) Planar beds of Ordovician limestone and shale. (B) Single lenticular bed in a sequence of limestone and shale. (C) Nodular limestone beds and irregular shale beds. (D) Irregular beds of limestone and shale. (E) Wavy beds of limestone and shale. (F) Massive sandstone beds. Scale is 50 cm (1.6 ft).**

open space along fractures in the rock; intercrystalline or intergranular, or open spaces at the contacts between crystals or grains in a rock; and vuggy, or small cavities often lined with crystals that formed by dissolution of the encasing rock.

Each fact sheet also describes the fossil content of each unit. For the interested reader, additional information about Ohio's fossils is available in *Fossils of Ohio* (Feldmann and Hackathorn, 1996), *A Sea Without Fish: Life in the Ordovician Sea of the Cincinnati Region* (Meyer and Davis, 2009), and *Strata and Megafossils of the Middle Devonian Silica Formation* (Kesling and Chilman, 1975).

Sedimentary rocks are commonly home for burrowing organisms that build their homes in or may eat the sediment in order to digest the accumulated organic matter. Also, many organisms walk or move along the surface of the sediment leaving behind tracks and trails. Trace fossils are the preserved tracks, trails, burrows, and borings resulting from the life activities of organisms as they interact with sediments. Collectively, the reworking of the sediment by organisms is termed *bioturbation*. Slight bioturbation is just a scattered burrow or track that only slightly disturbs the original fabric of the rock. Heavy bioturbation occurs when the original fabric of the rock is completely disrupted and a secondary fabric develops. *Burrow mottling* consists of differences in grain size or color that highlight the burrows in heavily bioturbated rocks.

Any rocks at or near the modern land surface are subject to weathering. The characteristics of how rocks weather is summarized in Table 4.

Most sedimentary rocks contain small amounts of accessory minerals. There may be a wide variety or just a few. Common accessory minerals in Ohio's near-surface rocks include: anhydrite, barite, calcite, celestite, chert (flint), fluorite, galena, glauconite, gypsum, halite, hematite, marcasite, pyrite, quartz, siderite, and sphalerite (see Carlson, 1991).

## Describing the Engineering Properties of Ohio's Rocks

To the engineer, rock hardness and how well the rock is cemented together are critical properties that must be determined before any construction project can proceed. The hardness or *induration* of Ohio's near-surface rocks ranges from soft or friable rocks that are easily broken with hand pressure to hard rocks that break only with considerable effort. Three primary engineering tests are used to determine rock strength, how quickly the rock weathers, and how easily the rock can be mechanically excavated.

*Unconfined compressive strength* (also known as uniaxial compressive strength) is one of the most basic parameters of rock strength and measures the capacity of the rock to withstand compressive forces along the vertical axis (long axis) of a core sample. *Slake durability* is a test to determine the resistance of rock to breakdown or disintegration through abrasion, wetting, and drying. The test is typically conducted on weak rocks, including shale, claystone, siltstone, mudstone, and some sandstones. *Rippability* is the ease with which soil or rock can be mechanically excavated with conventional earth-moving equipment, such as an excavator, backhoe, bulldozer, or grader. Rippability of rock is assessed by numerous parameters including uniaxial strength, degree of weathering, abrasiveness, and spacing of discontinuities. Sedimentary rocks are generally the most rippable.

## Describing the Hydrogeologic Properties of Ohio's Rocks

Beginning in 1988, the ODNR Division of Soil & Water Resources initiated a series of county-based Ground Water Pollution Potential (GWPP) maps. The purpose of these maps is to depict the relative vulnerability of aquifers to contamination from the ground surface. Currently,

**TABLE 4.** ***Rock weathering characteristics***

| Description | Field parameter |
|---|---|
| Unweathered | No evidence of any chemical or mechanical alteration of the rock mass. Mineral crystals have a bright appearance with no discoloration. Fractures show little or no staining on surfaces. |
| Slightly weathered | Slight discoloration of the rock surface with minor alterations along discontinuities. Less than 10% of the rock volume presents alteration. |
| Moderately weathered | Portions of the rock mass are discolored as evident by a dull appearance. Surfaces may have a pitted appearance with weathering "halos" evident. Isolated zones of varying rock strengths due to alteration may be present; 10–15% of the rock volume presents alterations. |
| Highly weathered | Entire rock mass appears discolored and dull. Some pockets of slightly to moderately weathered rock may be present and some areas of severely weathered materials may be present. |
| Severely weathered | Majority of the rock mass reduced to a soil-like state with relic rock structure discernable. Zones of more resistant rock may be present, but the material can generally be molded and crumbled by hand pressures. |

GWPP maps and associated reports are available for 74 of Ohio's 88 counties.[1]

This process is based upon a national system referred to by the acronym DRASTIC, which stands for the seven primary criteria utilized by this system: depth to water, net recharge, aquifer media, soil media, topography (% slope), impact of vadose zone media, and hydraulic conductivity (permeability). The system consists of determining both a hydrogeologic setting and deriving a ranked index value based upon these seven criteria for every map unit.

Of the seven parameters, the three discussed in the following paragraphs and referred to throughout this publication are derived primarily from the basic geology.

Aquifer media represent consolidated or unconsolidated rock material capable of yielding sufficient quantities of water for use. Aquifer media accounts for the various physical characteristics of the rock that provide mechanisms of attenuation, retardation, and flow pathways that affect a contaminant reaching and moving through an aquifer. *Aquifer ratings* range from 1 to 10; fine-grained units, such as shale and glacial till, have low values and karst limestone, massive sandstones, and sand and gravel deposits have the highest values. Very low-yielding units may be viewed as restricting or impeding ground-water flow and therefore may be considered an *aquiclude*. An *aquitard* is a unit that totally restricts ground-water flow.

The impact of the vadose zone media refers to the attenuation and retardation processes that can occur as a contaminant moves through the unsaturated zone above the aquifer. The vadose zone represents that area below the soil horizon and above the aquifer that is unsaturated or discontinuously saturated. Various attenuation, travel time, and distance mechanisms related to the types of geologic materials present can affect the movement of contaminants in the vadose zone. Where an aquifer is unconfined, the vadose zone media represents the materials below the soil horizon and above the water table. Under confined aquifer conditions, the vadose zone is simply referred to as a confining layer. The presence of the confining layer in the unsaturated zone has a significant impact on the pollution potential of the ground water in an area. *Vadose zone ratings* range from 1 to 10; fine-grained units, such as shale and glacial till, have low values and karst limestone, massive sandstones, and sand and gravel deposits have the highest values.

*Hydraulic conductivity* of an aquifer is a measure of the ability of the aquifer to transmit water and is also related to ground-water velocity and gradient. Hydraulic conductivity is dependent upon the amount and interconnectivity of void spaces and fractures within a consolidated or unconsolidated rock unit. Hydraulic conductivity considers the capability for a contaminant that reaches an aquifer to be transported throughout that aquifer over time. Higher hydraulic conductivity typically corresponds to higher vulnerability to contamination. Ranges of hydraulic conductivity values are used to determine the final rating, which varies from 1 to 10 with higher ratings denoting greater values of hydraulic conductivity. Typically finer-grained units, such as shale and glacial till, have lower values and karst limestone, massive sandstones, and sand and gravel deposits have the higher ratings.

[1]Information on this program and the county maps can be obtained from the ODNR Division of Soil and Water Resources website at **ohiodnr.gov/soilandwater**.

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# Organic deposits
**(includes peat, sphagnum, muck, and marl)**


*Peat* is a material composed primarily of decayed or decomposing vegetation. Peat is commonly brown in color and contains visible plant material (e.g., branches, wood, bark). Peat moss or *sphagnum* is a type of moss that frequently grows on top of or within a peat deposit. As this material decays and is buried, it may blend with other decaying peat materials. *Muck* is a related deposit that is composed predominately of *humus*, a very fine, decayed organic material. The material composing muck is commonly too finely grained to identify plant remains. Muck is typically dark gray to black and tends to have a gritty feel. Muck may contain small silt-sized or fine-sand-sized particles that reflect sunlight and provide a mineral component that accompanies the dominant organic component. *Marl* is a lightweight carbonate deposit, somewhat similar to the tufa or travertine deposited in caverns. It is deposited by carbonate-rich ground water that discharges in bogs or wetlands from springs and seeps. Marl varies from light gray to light brown in color. Marl also is lightweight and porous, somewhat resembling pumice.


*Fragments of peat (woody material) overlying fine-grained, dark muck deposit in a sand-and-gravel pit near Lodi, Wayne County.*

## Diagnostic features
- Variety of deposits may exist separately, be variably mixed together, or repeat cyclically.
- Visible plant (or *sapric*) material indicates peat, while muck has fine-grained organics.
- Marl distinguished by lighter color, crusty porous appearance, and carbonate composition; fizzes readily with dilute acid.
- Proximity to kettles, current ponds, prior lakebeds (lacustrine deposits), and modern floodplains important.
- Acidic wetlands referred to as *bogs*; acidity due to decaying plant materials and humus.
- Alkaline wetlands referred to as *fens;* alkaline nature typically due to high carbonate/sulfate in springs or seeps.

## General features
- Topographic position, wetland conditions, and saturated nature diagnostically important.

## Lithologic variations
- Deposits may be relatively uniform or gradational with each other. Size of plant

material in peat may vary from small twigs, leaves, and needles to larger branches, logs, and tree trunks.
- Muck may be composed of almost entirely organic materials or contain appreciable amounts of clay, silt, and very fine-grained sand particles.
- Marl deposits may have small leafs and twigs cemented in place in carbonate matrix.
- See county soil surveys for information on differentiating various surficial organic deposits.

### Fossil content
- Excellent sources of plant fossils, including limbs, leaves, pine cones, and especially pollen.
- Excellent potential source of invertebrate fossils, such as mollusks and beetles, and vertebrates, ranging from rodents to the largest mammals. Most of Ohio's largest vertebrate finds, including mammoths, mastodons, beaver, and elk, have been found in peat bogs.
- Zones of calcareous mollusks, particularly snails, may be common where organic and lacustrine deposits interfinger or interbed.

### Weathering characteristics
- Due to high proportion of organic matter, peat deposits commonly decay or decompose. As plant material decomposes, the remaining mineral content may increase, making it more difficult to differentiate between peat and muck. If water table drops and peat is exposed at ground surface, the peat is prone to desiccation and wind can severely erode the deposit.
- Degree of weathering important in determining hydrogeologic properties of material, including permeability.
- Organic deposits typically indicate very low-energy depositional environment.

### Stratigraphic contacts
- May be sharp or gradational depending on type of adjacent materials. Contacts between various organic deposits may be gradational.
- Contacts with inorganic deposits, such as silt, clay, or sand, typically sharper.

### Stratigraphic context
- May represent uppermost surficial unit in low-lying areas.
- Peat is commonly encountered at the land surface, in low-lying wetlands and kettles.
- Peat may be encountered in the subsurface, where it is usually found underlying lacustrine deposits or less commonly, till.
- See soil surveys and ODNR Division of Geological Survey maps for information.

### Engineering properties
- Organic deposits rate a special engineering classification. Low strength and high saturation make them highly unsuitable for most engineering and construction purposes at land surface and in shallow subsurface. Thicker accumulations in subsurface may constitute engineering or foundation problems.
- Engineers and soil scientists refer to peat and related deposits as *histosols*.

*Dried muck*

### Hydrogeologic properties

- At or near surface, deposits typically too close to surface to comprise an aquifer for drilled wells. Water quality may be objectionable.
- Deposits at depth may yield water, but organic, decaying nature makes it difficult or objectionable to complete a well in them.
- Peat typically very permeable, especially for deposits with coarser, larger plant fibers.
- Muck, when dry, becomes quite hard and can behave as an aquitard. Permeability commonly low when deposits are wet.
- Recharge may be moderately high or very low depending on amount of coarser, peaty materials or finer-grained muck present.
- Lab tests record permeability ranging $10^{-4}$–$10^{-9}$ cm/sec$^2$.
- *In-situ* slug tests/long-term pumping tests reveal permeabilities ranging $10^{-5}$–$10^{-8}$cm/sec$^2$.

### Environmental hazards

- Many areas associated with organic deposits include or are adjacent to ecologically sensitive areas, including wetlands, nature preserves, and wildlife refuges.
- Presence of high water table determines numerous building constraints on basements, foundations, septic systems, and leach fields.
- During drought conditions, deposits may become combustible.
- See soils surveys and ODNR Division of Geological Survey maps for information regarding characteristics of organic deposits locally.

### Economic geology

- Peat and peat moss, and to lesser extent muck, are valued for gardening and nursery purposes. Many historic peat deposits have been mined out; remaining deposits now preserved or actively used for truck farms and vegetable crops.
- Marl had historical limited use as a source of carbonate or lime and limited use as a decorative rock or building stone along Sandusky Bay.

### Scenic geology

- Many remaining peat and muck deposits occupy kettles, wetlands, bogs, and other scenic areas that now serve as nature preserves, wildlife refuges, and parks frequently visited by birders, hikers, and fishermen.
- Triangle Lake Bog SNP, Stage's Pond SNP, and Jackson Bog SNP.

### Further reading

Dachnowski, 1912; Stout, 1940; White, 1982; Hansen, 1997a; Weatherington-Rice and Christy, 2000


# Glacial clay deposits

**(see also "Glacial lacustrine deposits")**

*Clay* is a term geologists use for fine-grained particles with a particle size less than 0.0039 mm (3.9 µ). Engineers consider the size distinction between clay and silt particles as being 0.005 mm (5 µ), whereas soil scientists put the distinction at 0.002 mm (2 µ).

Clay and silt very commonly occur together and may be difficult to differentiate in outcrop and in water well log reports. Grain-size analysis may be necessary to help determine the correct proportion of particle sizes in a particular sample. Clay deposits require very low-energy environments for these fine particles to settle out. They are most commonly associated with glacial lacustrine environments. Slow-moving, impeded rivers also can deposit clay in features referred to as *oxbow lakes*. Also, slow-moving runoff can selectively carry clay particles to sluggish streams resulting in a very clay-rich alluvium.

Clay deposits have inherently poor drainage. Surface water readily collects or ponds on clay deposits.

The nature of various lacustrine deposits is discussed in the section "Glacial lacustrine deposits." Clay deposits typically were deposited in the quietest, deepest parts of lakes or ponds, furthest from any stream inputs.

*Thick, lacustrine-related clay deposit located in a clay pit southeast of Alliance, Columbiana County.*

## Diagnostic features

- Typically require grain-size analysis to separate from silt; separating may not be practical, depending on degree of study. Deposits appear massive and uniform and lack bedding; may contain *varves*. May also contain fine sand and silt, with sand on the bottom followed by silt then progressively finer clay particles. Individual intervals typically uniform and well sorted.
- Lab analysis required to differentiate *fat* and *lean* clays (see "Engineering properties").
- A common field test for clay is the "ribbon test." A handful of material is thoroughly wetted and rubbed vigorously between the palms of the hands. An elongated "ribbon" or "worm" is formed if clay content is relatively high. Numerous cracks or breaks in the ribbon indicate higher proportion of silt and lower proportion of clay.
- Typically less compacted and less dense than

till. Relatively soft, plastic, and sticky. Lack gravel, cobble, and coarse-sand content of till. Silt coarser to the touch and not as sticky or plastic as clay.
- Primary porosity typically horizontal. Secondary porosity may add to the vertical component.
- Important to note moisture content (e.g., damp, moist, sticky, plastic, saturated).

### General features
- Depending on degree of saturation, may be soft, sticky, or plastic.
- Gray where unoxidized; brown where weathered; mottled colors may represent variable water table conditions.

### Lithologic variations
- Typically uniform deposits; may be gradational with silt deposits. Differentiating between clay and silt in typical lacustrine deposit may be difficult or impractical. Care must be taken to differentiate between clay deposits related to glacial, lacustrine, and fluvial processes and clay resulting from weathered bedrock (see "Surficial deposits" [p. 8–10] for discussion on soils).
- See county soil surveys and ODNR Division of Geological Survey glacial geologic maps for information on differentiating surficial clay from silt deposits.

### Weathering characteristics
- Degree of oxidation; mottling of colors; presence of fractures and joints; presence of secondary carbonate or gypsum.
- Degree of weathering important in determining hydrogeologic properties of material, including permeability.

### Stratigraphic contacts
- May be sharp or gradational, depending on type of adjacent materials. Contact with silt, especially in lacustrine deposits, may be difficult to determine.
- Contact with till may be very gradational; contact with sand and gravel typically more distinct.
- Rare to sit directly upon bedrock; however, contact typically sharp where this occurs.

### Stratigraphic context
- May represent uppermost surficial unit in low-lying areas.
- Subsurface deposits interbedded with till may indicate former intermorainal lakes or blockage of drainage by advancing ice. (For deposits in subsurface, refer to soil surveys and ODNR Division of Geological Survey maps for information.)
- Deposits interbedded with coarser, water-laid sands and gravels indicate substantial change in water energy and local change in drainage.

### Engineering properties
- Unconfined compressive strength: Variable; ranges 0 to >4.5 TSF (63 psi), which is very good for a soil.
- Soil strength dependent upon degree of saturation and grain-size distribution.
- Clays referred to as *fat* or *lean*.
- A *fat clay* has a Liquid Limit >50 and mineralogy that causes clay to swell when wetted. Fat clays feel greasy to the touch when wetted.
- A *lean clay* has a Liquid Limit <50 and mineralogy that causes the clay not to swell when wetted. Lean clays do not feel greasy to the touch when wetted.


*Oxidized clay*

### Hydrogeologic properties
- Generally considered an aquitard or aquiclude, not an aquifer.
- Historically, dug wells have produced minimal yields and monitor wells in saturated zone may maintain water levels.
- Recharge low.
- Lab tests record permeability ranging $10^{-7}$–$10^{-9}$ cm/sec$^2$.
- *In-situ* slug tests/long-term pumping tests reveal permeabilities ranging $10^{-6}$–$10^{-7}$ cm/sec$^2$ for weathered, fractured clay.
- Primary flow and permeability is preferentially horizontal, along laminations, bedding planes, and varves, as opposed to vertical.
- Secondary permeability and flow may be vertical due to joints and fractures.
- Shallow ground-water flow in these deposits typically is toward nearest shallow stream or drainage ditch.

### Environmental hazards
- Slumping may occur along steep slopes and under saturated, high water table conditions. Higher bluffs are particularly unstable.
- Presence of high water table determines numerous building constraints on basements, foundations, septic systems, and leach fields.
- See soils surveys and ODNR Division of Geological Survey maps for information regarding characteristics of clay locally.

### Economic geology
- May be suitable as important fill for earthen structures, such as highway embankments, earthen dams, and levees.
- Due to low permeabilities, may be suitable as liner for ponds, landfills, manure containment, and reservoirs when compacted adequately.
- May be suitable as cover for landfill operations.
- Valuable for ceramics, tile, and pottery industries.
- Valuable for products such as pigments, coloring, and cosmetics.

### Scenic geology
- Notorious for slumping and covering an outcrop.
- On occasion, can produce scenic, steep bluffs commonly found along margins of downcutting streams in areas of thick glacial drift.
- Steep clay bluffs common along Lake Erie shoreline.
- Rare to see truly pure clay deposit at surface. Typical lacustrine and fluvial deposits contain some silt.

### Further reading
White, 1982; Hansen, 1997a; Weatherington-Rice and Christy, 2000

# Glacial silt deposits

**(includes loess; see also "Glacial lacustrine deposits")**


*Silt* is a term that geologists use for fine-grained particles with a particle size greater than 0.0039 mm (3.9 μ) and less than 0.0625 mm (62.5 μ). Engineers consider the size distinction between clay and silt particles as being 0.005 mm (5 μ) and the distinction between silt and sand at 0.075 mm (75 μ or #200 sieve). Soil scientists put the distinction at 0.002 mm (2 μ) for clay and silt and at 0.05 mm (50 μ) for silt and sand.

Clay and silt very commonly occur together and may be difficult to differentiate in outcrop and in water well log reports. Grain-size analysis may be necessary to help determine the correct proportion of particle sizes in a particular sample. Silt deposits require low- to moderate-energy environments for these fine particles to settle out; the required energy level is between that of a true clay and sand. Silt deposits are most commonly associated with glacial lacustrine environments. Silt also is a common particle size for most fluvial/alluvial deposits. Typically, alluvium that is predominantly clay or predominantly sand requires much lower velocities or finer parent materials for the clay or higher velocities and coarser parent materials for the sand.

Silt deposits also are transitional with sand deposits, particularly in a deltaic environment. Much like the break between clay and silt, the break between sand and silt may also require grain-size analysis to determine the grain size.

*Loess* deposits are windblown and are typically composed of silt particles that tend to be more angular and less rounded in nature.

The natures of various lacustrine deposits are discussed under the description for "Glacial lacustrine deposits."

*Massive bedded silt deposit found in a gravel pit near Lodi, Wayne County.*

## Diagnostic features

- Typically require lab analysis to separate fine silt from clay.
- May require laboratory analysis to separate coarse silt from very fine sand.
- Typically less compacted and dense than till. May not be as plastic or sticky as clay. Silt lacks grainy, gritty feel of sand on fingertips; however, may feel somewhat gritty against teeth.
- Important to note moisture content (e.g., damp, moist, sticky, plastic, saturated).
- Does not create ribbons or worms (when rolled between hands) as well as clay. Cracks or breaks in ribbon or worm tend to suggest silt-sized particles mixed with clay-sized particles.

## General features

- Typically soft to moderately firm, depending on saturation. Somewhat "runny" or "soupy" when wet.
- Exhibits *dilatancy,* a property that distinguishes it from clay. Dilatancy refers to when a sample containing a high proportion of silt is shaken, the sample tends to expand and water tends to separate and flow out of the sample. When shaking stops and the sample is pressed or squeezed, the material becomes more cohesive and water tends to re-enter the sample.
- Gray where unoxidized; brown where weathered; mottled colors may represent variable water table conditions.

## Lithologic variations

- Typically uniform deposits; may be gradational with clay deposits. Differentiating clay from silt in typical lacustrine deposit may be difficult or impractical. Differentiating very fine sand from silt in a typical deltaic deposit also may be difficult or impractical.
- See county soil surveys and ODNR Division of Geological Survey glacial geologic maps for information on differentiating surficial silt from clay deposits.

## Fossil content

- Fossils typically uncommon.
- In rare instances, discrete layer may contain abundant gastropods and related mollusks.

## Weathering characteristics

- Degree of oxidation; mottling of colors; presence of fractures and joints; presence of secondary carbonate or gypsum.
- Degree of weathering important in determining hydrogeologic properties of material, including permeability.

## Stratigraphic contacts

- Contacts may be sharp or gradational depending on type of adjacent materials.
- Contact with clay, especially in lacustrine deposits, may be difficult to determine, especially for finer-grained silts.
- Contact with fine-sand deposits, such as in some deltaic environments, might be difficult for coarser-grained silts.
- Contact with till may be very gradational; contact with sand and gravel typically more distinct.
- Rare to sit directly upon bedrock; however, contact typically sharp where this occurs.

## Stratigraphic context

- May represent uppermost surficial unit in low-lying areas.
- Deposits in subsurface interbedded with till may indicate former intermorainal lakes or blockage of drainage by advancing ice. (For deposits in subsurface, refer to soil surveys and ODNR Division of Geological Survey maps for information.)
- Deposits interbedded with coarser, water-laid sands and gravels indicate substantial change in water energy and local change in drainage.


*Oxidized silt*

### Engineering properties
- Unconfined compressive strength: Variable.
- Soil strength dependent upon degree of saturation and grain-size distribution.
- High silt soils lack stability and strength when wetted and are considered unsuitable material for engineering purposes.
- Subject to liquefaction and fluidization.
- Differential ground-water pressure causes ground (silt) boils.

### Hydrogeologic properties
- Generally considered an aquitard or aquiclude, not an aquifer.
- Historically, dug wells have produced minor yields and monitor wells in saturated zone will maintain water levels.
- Recharge low to variable.
- Lab tests record permeability ranging $10^{-6}$–$10^{-8}$ cm/sec$^2$.
- *In-situ* slug texts/long-term pumping tests reveal permeabilities ranging $10^{-5}$–$10^{-7}$ cm/sec$^2$.
- Primary flow and permeability is preferentially horizontal, along laminations, bedding planes, and varves, as opposed to vertical, except for loess. Shallow ground-water flow in these deposits typically is toward nearest shallow stream or drainage ditch.
- Secondary permeability and flow may be vertical due to joints and fractures.

### Environmental hazards
- Slumping may occur along steep slopes and under saturated, high water table conditions. Higher bluffs particularly unstable.
- Presence of high water table determines numerous building constraints on basements, foundations, septic systems, and leach fields.
- See soils surveys and ODNR Division of Geological Survey maps for information regarding characteristics of silt locally.

### Economic geology
- No previous economic uses or values known.
- Typically not as useful for the ceramic, pottery, and pigment industries.

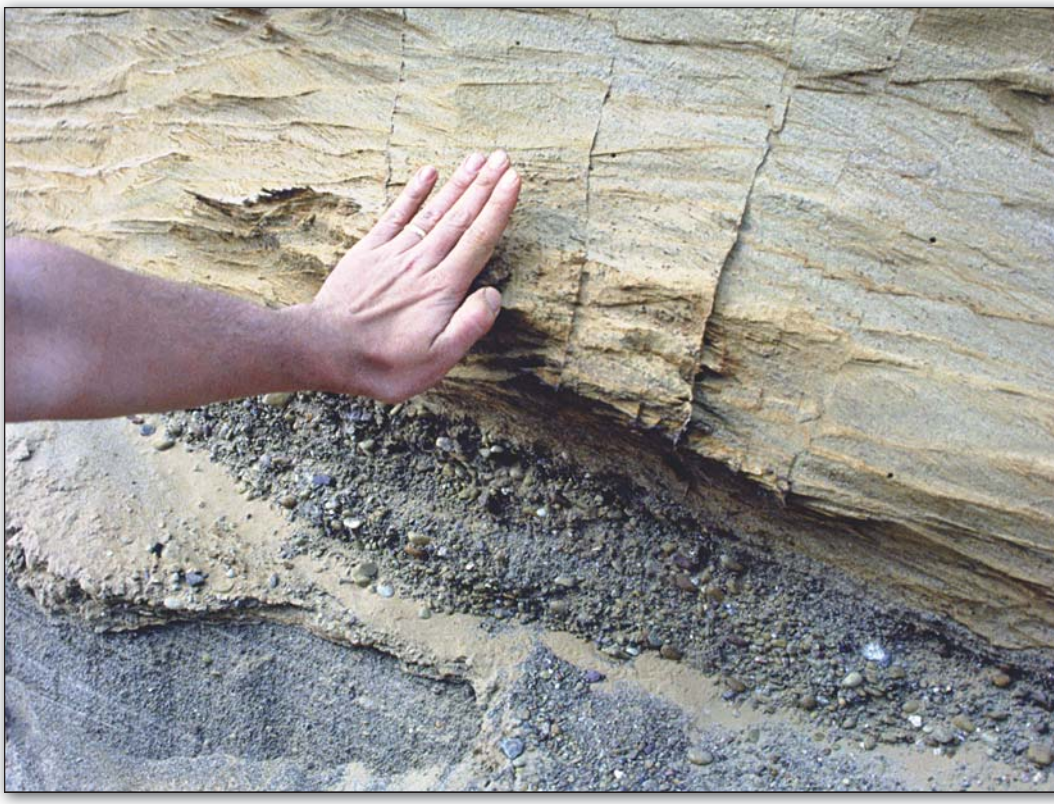
### Scenic geology
- Notorious for slumping and covering an outcrop.
- On occasion, can produce scenic, steep bluffs commonly found along margins of downcutting streams in areas of thick glacial drift. In areas of loess, may give steep bluffs or high hilltops a more rounded appearance; such bluffs typically downwind (usually to the east, based upon prevailing wind direction) from a major valley source.
- Steep silt bluffs common along Lake Erie shoreline.
- Truly pure silt deposits rare at the surface. Typically, lacustrine deposits also contain clay; deltaic/fluvial and fluvial deposits also contain some sand.

### Further reading
White, 1982; Hansen, 1997a; Weatherington-Rice and Christy, 2000


# Glacial sand deposits

*Sand* is a particle ranging in size from 0.0625 mm (62.5 µ) to 2 mm (0.08 in). It is subdivided by categories ranging from very fine grained to medium grained to very coarse grained. *Gravel* is coarser and ranges from 2 mm to 64 mm. *Silt* is finer grained, less than 0.025 mm (25.0 µ). *Clay* is even finer grained, with particles less than 0.0039 mm (3.9 µ). True sand deposits typically lack gravel and pebbles on the coarse end and lack silt and clay on the fine end. Such deposits show an intermediate energy level between the lower energy levels associated with the deposition of silt and clay and the higher energy level associated with deposition of sand and gravel.

Examples of sand deposits in Ohio include deltas, alluvial fans, and most beach ridges found in northern Ohio. The shoreline or beach environment includes beach ridges; bars; spits; and wind-blown sand, which creates dunes.



*Fine-grained, cross-bedded sand overlying coarse sand and thin gravel beds in a gravel pit near Lodi, Wayne County.*

## Diagnostic features

- Sand particle size distinctively coarser than finer-grained materials, such as till; lacustrine; or modern, finer-grained alluvium.
- Sand particle size distinctively finer than coarser-grained materials, such as gravel, pebbles, and cobbles.
- May vary from relatively loose and friable to very dense and cohesive.
- Deposits can vary from well to poorly sorted; grain sizes may be relatively uniform or highly variable. Deposits may be viewed as "clean" or "dirty."
  - *Clean* refers to well-sorted deposits containing predominantly sand-sized particles and lacking finer-grained materials, such as silt and clay.
  - *Dirty* refers to more poorly sorted deposits containing abundant fine-grained particles, such as silt and clay.

- Bedding can be highly variable and massive, parallel, cross-bedded, gradational, or otherwise.

### General features
- Surficial geomorphology and setting are important in helping determine nature and origin of sand deposit.
- Examples include beach ridges and dunes. Sandy deltaic deposits commonly lay landward of finer-grained lacustrine deposits.

### Lithologic variations
- Sandy deltaic deposits usually associated with margins of lake plains or broad valleys.
- Sandy beach ridges and dunes typically lie along edges of paleolakes and help mark ancient shorelines.
- Deposits in both surface and subsurface reflect changes in water energy and bedload.
- Change from coarse to very fine-grained sediments can vary from sharp to gradual in both surface and subsurface.

### Fossil content
- Fossils typically uncommon due to high-energy environment and turbid nature of water.

### Weathering characteristics
- Weathering and predominant coloration of sand bodies important in determining position of water table, areas within the zone of recharge, and maximum extent of atmospheric oxygen in the profile.
- Sand weathers olive to gray in low-oxygen environments and brown to orange in high-oxygen environments.
- Degree of weathering important in determining the hydrogeologic properties of the material, including permeability and porosity.
- Highly weathered units will develop a fine-grained, argillic weathering zone at top surface; may show bright orange, red or yellow iron or blackish manganese stains.

### Stratigraphic contacts
- Contacts may be sharp or gradational and vary with water energy. In rare instances, various deltaic beds (e.g., topsets, foresets) may be visible in outcrop.
- Sand bodies interbedded within glacial till will have very irregular boundaries that may be difficult to discern.
- Grain size, sorting, and bedding make better indicators of contacts than coloration changes.

### Stratigraphic context
- Surficial sand deposits typically occupy distinctive geomorphic settings, such as deltas, alluvial fans, beach ridges, and dunes. (See soils surveys and ODNR Division of Geological Survey maps for information on determining geomorphic setting.)
- In subsurface, nature of deposit has to be inferred from its characteristics, and determining origin or setting becomes more difficult. How thick or laterally continuous a particular unit is usually requires information from additional nearby borings or well records or by other methods, such as geophysics.
- Extreme care should be taken to separate "washed" or disturbed sand and associated minor fines in upper portion of split-spoon sampler from undisturbed, natural materials. This artificial washing may misrepresent the degree of sorting, bedding, and proportion of fines in sample interval.


*Sand, becoming coarser grained near the bottom of photo*

### Engineering properties
- Unconfined compressive strength: Variable.
- Soil strength dependent upon degree of saturation and grain-size distribution. Saturated deposits may have tendency to flow.
- Sorting, cohesiveness, and nature of bedding have impact on properties.
- Typically, coarser materials have more favorable engineering properties.
- Angle of repose may be important for very coarse, steep-sided deposits.
- Subject to liquefaction and fluidization.
- Inherently good drainage, favorable for home sites, except where water table is shallow.

### Hydrogeologic properties
- Can vary from relatively poor aquifers to good aquifers.
- Moisture conditions and presence of minor fines can greatly increase stickiness and cohesiveness.
- Important to note moisture content (e.g., damp, moist, sticky, plastic, saturated). Oxidized or unoxidized colors might help indicate position of water table and extent of potential atmospheric influence; this may have implications for recharge and ground-water flow.
- Wells completed in various seams, lenses, or bodies interbedded in glacial till or glacio-lacustrine units produce highly variable yields. Size, nature, and geometry of these sand bodies can vary significantly as can corresponding yields. Yields for such bodies vary from 3 gpm to >100 gpm.
- Yields from wells completed in sand deposits, such as deltas, beaches, and fans, vary considerably based upon the coarseness and degree of sorting. Finer-grained sands perform much poorer as aquifers than coarser-grained sands.
- Yields for sand wells in general also are dependent upon well diameter; proper well construction techniques, particularly the use of properly sized well screens and gravel filter packs; and thorough development of the well. Use of screens and filter packs is particularly essential for finer-grained sands.
- Aquifer ratings for sand interbedded in till vary from 4 to 7; ranges of hydraulic conductivity vary from 100–300 gpd/ft$^2$ to 700–1,000 gpd/ft$^2$.
- Saturated, fine-grained sands or silty-sand mixes can become problematic when drilled. Wells penetrating such units are subject to sand rising or flowing back up the well casing, causing problems in advancing the well.

### Environmental hazards
- Sand deposits at surface or in subsurface represent relatively few hazards for building or construction, with exception of a very high water table.
- At depth, presence of very fine-grained, saturated sand to silty sand may prove difficult for drilling. Fine-grained deposits have been referred to as “heaving,” “shooting,” or “quicksand.”
- Along slopes, similar fine-grained, saturated sand units may create unstable conditions and be prone to slumping or flowing. Small areas of organic deposits and kettles may be associated with sand deposits.
- Perhaps the most significant hazard from sand deposits is that high permeability and porosity make them conduits for ground-water contamination.
- Consult soils surveys or ODNR Division of Geological Survey maps for building purposes.

### Economic geology
- Important sources of aggregates.
- Important as aquifers for water supply.
- Provide excellent recharge for underlying aquifers.

### Scenic geology
- Sand deposits often provide scenic areas favorable for home sites.

### Further reading
White, 1982; Hansen, 1997a

# Glacial sand and gravel deposits
**(includes cobbles and boulders)**


*Sand* is a particle that ranges in size from 0.0625 mm (62.5 μ) to 2 mm (0.08 in). It is subdivided into categories ranging from very fine grained to medium grained to very coarse grained. *Gravel* ranges in size from 2 mm to 64 mm (0.08–2.5 in). Very fine gravel is referred to as *granules;* larger gravel sizes are referred to as *pebbles*. *Cobbles* range in size from 64 mm to 256 mm (2.5–10.1 in), and *boulders* are considered to be greater than 256 mm (10.1 in). Cobbles and boulders are commonly disseminated throughout glacial till deposits. Cobbles and boulders within a sand-and-gravel deposit indicate a very high-energy environment and typically rapid deposition. Abundant cobbles and boulders may indicate an outwash deposit very close to the energy source (melting glacier) or more likely an ice-contact deposit, such as a kame or esker.


*Sand-and-gravel pit illustrating thick, cross-bedded sand beds underlying an extensive sand-and-gravel deposit, Hamilton County.*

## Diagnostic features

- Sand, gravel, or a combination of the two are dominant over fine-grained materials, such as till; lacustrine; or modern, finer-grained alluvium.
- Deposits vary from relatively loose and friable to very dense and cohesive.
- Sand and gravel can vary from well to poorly sorted to chaotic. Deposits may be relatively uniform or highly variable. Deposits may be viewed as being "clean" or "dirty."
  - *Clean* refers to well-sorted deposits containing predominantly sand- to gravel-sized particles and lacking finer-grained materials, such as fine-grained sand, silt, and clay.
  - *Dirty* refers to more poorly sorted deposits containing abundant fine-grained particles, such as fine-grained sand, silt, and clay.
- Bedding can be highly variable and massive, parallel, cross-bedded, gradational, or otherwise.

## General features

- Surficial geomorphology and setting are important in helping determine nature and origin of a deposit. Typically, outwash deposits are more highly influenced by fluvial processes

than by processes associated with ice wastage (melting).
- Examples include outwash terraces, kames, and eskers.

### Lithologic variations
- Outwash deposits usually associated with broad valleys and underlie wide, modern floodplains and adjacent terraces.
- Kame and ice contact features more likely found along the margins of valleys; adjacent to end moraines; marking outflow areas associated with former intermorainal lakes; or in regions of obvious ice-marginal, ablational (ice-wastage) terrain.
- Deposits in both surface and subsurface reflect changes in water energy and bedload.
- Change from coarse to very fine-grained sediments can vary from sharp to gradual in both surface and subsurface.

### Fossil content
- Fossils typically uncommon due to high-energy environment and turbid nature of water.

### Weathering characteristics
- Weathering and predominant coloration of sand and gravel bodies important in determining position of water table, areas within the zone of recharge, and maximum extent of atmospheric oxygen in the profile.
- Degree of weathering important in determining hydrogeologic properties of material, including permeability and porosity.
- Highly weathered units will develop fine-grained weathering zone at top surface.
- Highly weathered materials may show bright yellow, orange or red iron or blackish manganese stains; may contain some rotting pebbles.

### Stratigraphic contacts
- Contacts may be sharp or gradational and vary with water energy. Contacts with outwash-type deposits likely sharper than ice-contact deposits.
- Sand-and-gravel bodies interbedded within glacial till will have very irregular boundaries that may be difficult to discern.
- Grain size, sorting, and bedding make better indicators of contacts than coloration changes.

### Stratigraphic context
- Surficial sand-and-gravel deposits typically occupy distinctive geomorphic settings, such as outwash plains, terraces, kame fields, and eskers. (See soils surveys and ODNR Division of Geological Survey maps for information on determining geomorphic setting.)
- In subsurface, nature of sand and gravel has to be inferred from its characteristics; determining origin or setting becomes more difficult. How thick or laterally continuous a particular unit is requires information from additional nearby borings or well records or by other methods, such as geophysics.
- Extreme care should be taken to separate "washed" or disturbed sand and gravel and fines in the upper portion of the split-spoon sampler from undisturbed, natural materials. This artificial washing may misrepresent degree of sorting, bedding, and proportion of fines in sample interval.

### Engineering properties
- Unconfined compressive strength: Variable.
- Soil strength dependent upon degree of saturation and grain-size distribution.
- Sorting, cohesiveness, and nature of bedding have large


*Poorly sorted sand and gravel*

impact on properties. Typically, coarser materials have more favorable engineering properties.
- Angle of repose may be important for very coarse, steep-sided deposits.
- High percentage of boulders and cobbles may be an obstacle to excavation.
- Subject to liquefaction and fluidization.

### Hydrogeologic properties
- Vary from relatively poor aquifers to some of the best aquifers in the state.
- Important to note moisture content (e.g., damp, moist, sticky, plastic, saturated). Oxidized or unoxidized colors might help indicate the position of the water table and the extent of potential atmospheric influence; this may have implications on recharge and ground-water flow.
- Wells completed in various seams, lenses, or bodies of sand interbedded in glacial till or glacio-lacustrine units produce highly variable yields. Size, nature, and geometry of such sand bodies can vary significantly as can corresponding yields. Yields for these bodies can vary from 3 gpm to over 500 gpm.
- Yields for sand-and-gravel wells in general also dependent upon well diameter; proper well construction techniques, particularly use of properly-sized well screens and gravel filter packs; and thorough development of the well. Aquifer ratings for sand and gravel interbedded in till vary from 4 to 7; ranges of hydraulic conductivity vary from 100–300 gpd/ft$^2$ to 700–1,000 gpd/ft$^2$.
- Wells completed in sand-and-gravel units within ice-contact features also vary considerably depending on proportion of till to sand and gravel and sorting, relative coarseness, and nature of the deposits. Another important factor is that kames and other ice-contact features may locally occupy topographically higher positions in the landscape and be located above the water table. In such situations, deposits represent a relatively permeable vadose zone more so than an aquifer. Aquifer ratings for ice-contact deposits typically range from 6 to 7; ranges of hydraulic conductivity vary from 300–700 gpd/ft$^2$ to 700–1,000 gpd/ft$^2$.
- Wells completed in sand-and-gravel units within thick, well-sorted, coarse outwash deposits represent some of the highest-yielding aquifers in the state. Aquifer ratings vary from 7 to 10; ranges of hydraulic conductivity vary from 700–100 gpd/ft$^2$ to >2,000 gpd/ft$^2$.

### Environmental hazards
- Typically, deposits at surface or in subsurface represent relatively few hazards for building or construction, with exception of a very high water table.
- At depth, presence of very fine-grained, saturated sand to silty sand may prove difficult for drilling. These fine-grained deposits are referred to as "heaving," "shooting," or "quicksand."
- Along slopes, similar fine-grained, saturated sand units may create unstable conditions and be prone to slumping or flowing. Small areas of organic deposits and kettles may be associated with sand-and-gravel deposits, particularly ice-contact deposits.
- Perhaps the most significant hazard from sand-and-gravel deposits is that high permeability and porosity make them conduits for ground-water contamination.
- Consult soils surveys or ODNR Division of Geological Survey maps for building purposes.

### Economic geology
- Very important sources of aggregates.
- Very important as aquifers for water supply.
- Provide excellent recharge for underlying aquifers.

### Scenic geology
- Sand-and-gravel deposits, particularly kames, eskers, and outwash terraces, often provide scenic areas favorable for home sites.
- Inherently good drainage also favorable for home sites.
- On occasion, can produce scenic, steep bluffs commonly found along the margins of downcutting streams in areas of thick glacial drift.

### Further reading
White, 1982; Hansen, 1997a


# Glacial till

*Till* is an unsorted, non-stratified (non-bedded) mixture of sand, gravel, silt, and clay deposited directly by the ice sheet. At the land surface, till accounts for two primary landforms: ground moraine and end moraine. *Ground moraine* (till plain) is relatively flat to gently rolling. *End moraines* are ridge-like, with terrain that is steeper and more rolling or hummocky. Typically, till is thinner in areas of ground moraine and thicker in end moraines.


*Loamy glacial till underlying clayey till in outcrop along the Auglaize River, Defiance County.*

## Diagnostic features

- Typically defined texturally or according to grain-size as a silty clay, sandy clay, or clayey silt.
- May have significant proportion of fine to coarse sand and gravel, pebbles, or cobbles surrounded by matrix of finer-grained materials.
- Typically lacks bedding, sorting, or laminations.
- May be highly compacted, massive, dense (lodgment till) and range to more loosely compacted, friable, and disaggregating relatively easily (ablation till, "melt-out" till, or highly-weathered till).

## General features

- Gray where unoxidized; brown where weathered; mottled colors may represent variable water table conditions.
- Important to note the structure (e.g., massive, blocky, prismatic).
- Important to note moisture content (e.g., damp, moist, sticky, plastic, saturated).
- Examples include end moraines and ground moraines.

## Lithologic variations

- Uppermost unit typically more clayey in northern Ohio.
- Uppermost unit typically more loamy (i.e., relatively higher proportions of silt and sand) in southwestern Ohio.
- Typically more compacted and pebbly with depth.
- Carbonate content of matrix and pebbles increases in western Ohio, based on underlying bedrock units.

## Fossil content

- Fossils not inherent.
- May contain wood, tree trunks, and stumps

overridden and eroded by advancing ice sheet.
- May contain durable fossils eroded from underlying bedrock (e.g., horn corals).

## Weathering characteristics
- Note degree of oxidation, mottling of colors, presence of fractures/jointing, rotting of pebbles, presence of secondary carbonate or gypsum coatings/crystals.
- Weathering affects hydrogeologic properties, mainly secondary permeability and porosity.
- Highly-weathered pebbles tend to physically disintegrate into sand-sized grains and are referred to as "rotting" pebbles or "ghosts." Rotting pebbles may skew results of grain-size analysis.

## Stratigraphic contacts
- Contacts vary from very sharp to gradational. Sharp contacts may feature a "stone line" of cobbles.
- Till may incorporate or scoop up materials from underlying units, making contacts appear more transitional.
- Do not base contacts only on color changes.

## Stratigraphic context
- Typically uppermost surficial unit. (See soils surveys and ODNR Division of Geological Survey maps for information on this topic.)
- May be encountered in buried valleys to depths up to 400 ft in central Ohio.
- Multiple till units may be encountered. Non-till lithologies may/may not occur between till units.

## Engineering properties
- Unconfined compressive strength: Variable.
- Soil strength dependent upon degree of saturation and grain-size distribution.
- Dependent upon nature of till (e.g., lodgment vs. ablation).

## Hydrogeologic properties
- Generally considered an aquitard or aquiclude, not an aquifer.
- Historically, dug wells have produced low yields and monitor wells in saturated zone will maintain water levels.
- Recharge variable.
- Lab tests record permeability ranging $10^{-7}$–$10^{-9}$ cm/sec$^2$.
- *In-situ* slug texts/long-term pumping tests reveal permeabilities ranging $10^{-5}$–$10^{-7}$ cm/sec$^2$ for weathered, fractured tills.
- Wells completed in till utilize small bodies, seams, or lenses of interbedded sand and gravel; size, nature, and geometry of these lenses, plus interconnection between lenses, determines corresponding yield.

## Environmental hazards
- Slumping may occur along steep slopes and under saturated, high water table conditions.
- Presence of high water table determines numerous building constraints on basements, foundations, septic systems, and leach fields.
- See soils surveys and ODNR Division of Geological Survey maps for information regarding characteristics of till locally.

## Economic geology
- Important fill material for highway embankments, earthen dams, levees, and other infrastructure.
- Fine-grained material, may be suitable liner for ponds, landfills, manure containment, and reservoirs when compacted adequately.
- May be suitable as cover for landfill operations.

## Scenic geology
- Indurated, erosion-resistant tills can produce scenic, steep bluffs commonly found along margins of downcutting streams in areas of thick glacial drift. Examples include outcrops in Defiance, Geauga, Franklin, Licking, and Preble Counties.

## Further reading
White, 1982; Hansen, 1997a; Weatherington-Rice and Christy, 2000; Weatherington-Rice and others, 2006


*Clayey glacial till with angular clasts (pebbles)*


# Glacial lacustrine deposits

*Lacustrine* deposits tend to be laminated (or *varved*) and contain various proportions of silts and clays. Thin layers of fine sand interbedded with clayey to silty lacustrine deposits may reflect storm or flood events, the net effect being a wafer-like appearance. Permeability is preferentially horizontal due to the laminations and water-laid nature of these sediments. The inherent vertical permeability is slow; however, secondary porosity features (e.g., fractures, joints, root channels) help increase the vertical permeability.

*Thin bedded and laminated lacustrine deposits, Sandusky County.*

## Diagnostic features

- Typically defined texturally or according to grain size as silty clay or clayey silt.
- Typically display thin bedding, laminations, or varves.
- May appear massive and uniform and lack bedding.
- Typically less compacted and less dense than till.
- Relatively soft, plastic, and sticky.
- Generally lack gravel, cobble, and coarse-sand content of till.
- Sand typically appears in discrete bands or laminae as opposed to disseminated throughout the matrix.

## General features

- Individual layers tend to be well-sorted and uniform.
- Gray where unoxidized; brown where weathered; mottled colors may represent variable water table conditions.

## Lithologic variations

- Intermorainal lakes predominantly silty or clayey, depending on nature of surrounding till and other adjacent materials supplying sediment to the lakes.
- Subsurface deposits demonstrate similar variability, especially if interbedded with sand-and-gravel deposits that represent rapid shifts in water energy.
- See county soils surveys and ODNR Division of Geological Survey glacial geologic maps for information on differentiating surficial lacustrine deposits.

## Fossil content
- Fossils typically uncommon.
- In rare instances, a discrete layer may contain abundant gastropods and related mollusks.

## Weathering characteristics
- Important to note degree of oxidation, mottling of colors, presence of fractures and joints, presence of secondary carbonate or gypsum.
- Degree of weathering important in determining hydrogeologic properties of material, including permeability.

## Stratigraphic contacts
- Contacts may be sharp or gradational depending on type of adjacent materials.
- Contact with till may be very gradational; contact with sand and gravel typically more distinct.
- Rare to sit directly upon bedrock; however, contact typically sharp where this occurs.

## Stratigraphic context
- May represent uppermost surficial unit in low-lying areas.
- Subsurface deposits interbedded with till may indicate former intermorainal lakes or blockage of drainage by advancing ice. (For deposits in the subsurface, refer to soils surveys and ODNR Division of Geological Survey maps for information.)
- Deposits interbedded with coarser, water-laid sands and gravels indicate a substantial change in water energy and a local change in drainage.

## Engineering properties
- Unconfined compressive strength: Variable; ranges 0 to >4.5 TSF (63 psi).
- Soil strength dependent upon degree of saturation and grain-size distribution.

## Hydrogeologic properties
- Generally considered an aquitard or aquiclude, not an aquifer.
- Historically, dug wells have produced minor yields and monitor wells in saturated zone will maintain water levels.
- Recharge variable.
- Permeability ranges $10^{-7}$–$10^{-9}$ cm/sec$^2$.
- *In-situ* slug tests/long-term pumping tests reveal permeabilities ranging $10^{-6}$–$10^{-7}$ cm/sec$^2$.
- Primary flow and permeability is preferentially horizontal, along laminations, bedding planes, and varves, as opposed to vertical.
- Secondary permeability and flow may be vertical due to joints and fractures.
- Shallow ground-water flow in these deposits typically is toward nearest shallow stream or drainage ditch.
- Primary porosity typically horizontal.
- Secondary porosity may add to the vertical component.

## Environmental hazards
- Slumping may occur along steep slopes and under saturated, high water table conditions. Higher bluffs particularly unstable.
- Presence of high water table determines numerous building constraints on basements, foundations, septic systems, and leach fields.
- See soils surveys and ODNR Division of Geological Survey maps for information regarding characteristics of till locally.

## Economic geology
- May be suitable as fill for earthen structures, such as highway embankments, earthen dams, and levees.
- Where fine-grained clay content is high, materials may be suitable as liner for ponds, landfills, manure containment, and reservoirs when compacted adequately.
- May be suitable as cover for landfill operations.

## Scenic geology
- Notorious for slumping and covering the rest of an outcrop.
- On occasion, can produce scenic, steep bluffs commonly found along margins of downcutting streams in areas of thick glacial drift.
- Steep lacustrine bluffs common along Lake Erie shoreline.

## Further reading
White, 1982; Hansen, 1997a; Weatherington-Rice and Christy, 2000


*Fine-grained lacustrine*


# Dunkard Group

The Dunkard Group is characterized by an abundance of mudstone, shale, siltstone, and sandstone; a lack of mineable coals; and rapid horizontal and vertical changes between these rock types. In Ohio, the Washington and Greene Formations are recognized by some geologists but these units were not mapped on the *Bedrock Geologic Map of Ohio* (Slucher and others, 2006) because there is little difference between the rocks comprising both units. Also, over 25 beds have been named, of which the Washington coal and top of the Waynesburg coal or base of the Hockingport sandstone were mapped on open-file 1:24,000-scale bedrock-geologic quadrangles. Traditionally, the Dunkard Group was assigned to the Permian System. More recent studies of the flora of the lower Dunkard rocks have documented a transition vertically through these rocks from mainly plant fossils of the Pennsylvanian System to primarily plant fossils of the Permian System above the Washington coal. Thus the lower Dunkard rocks below the Washington coal are considered to be Pennsylvanian and/or Permian in age. These rocks were deposited in vast deltas, in large rivers flowing across coastal lowlands, or in numerous lakes and wetlands that were present in the coastal lowlands.

The Dunkard is exposed along a 5- to 30-mi (8–48-km)-wide belt in southeastern Ohio, mainly adjacent to the Ohio River from Lawrence to Jefferson Counties. In Morgan, Muskingum, and Noble Counties, the group occurs along the Cambridge Monocline. The Dunkard Group was named and first described along Dunkard Creek, Greene County, Pennsylvania. The unit ranges in thickness from 0 to more than 600 ft (0 to >180 m) thick.

*Dunkard Group red beds, gray shale and clay beds, and thin sandstone beds in road cut for S.R. 68 just north of Sherman, West Virginia, and east of Buffington Island, Meigs County, Ohio.*

## Diagnostic features

- Abundant mudstone, shale, siltstone, and sandstone.
- Lack of mineable coals.
- Rapid horizontal and vertical change and gradation between rock types.

## General features

- Shades of red, yellow, olive, green, brown, or black.
- Lenticular, planar, nodular, irregular, and cross bedding.
- Mudstone, shale, and siltstone: Argillaceous to sandy, non-bedded to thin bedded, locally calcareous.

- Sandstone: Fine grained to conglomeratic, thin to massive to cross bedded, and micaceous.
- Limestone: Argillaceous to micrite rich, thin to medium bedded.
- Coal: Impure, banded, thin bedded, discontinuous.

### Lithologic variations
- Limestone and coal beds best developed in lower 200 ft (61 m) of unit.
- Limestone beds commonly lenticular to planar bedded in northern part of outcrop belt, nodular bedded in the south.
- Red mudstone and shale restricted to upper parts of unit in north and throughout unit in south.
- Hockingport ss restricted to eastern portions of Athens and Meigs Counties and western Washington County.

### Fossil content
- Plant fossils range from sparse to common.
- Brackish-water brachiopods.
- Rare to common non-marine bivalves, ostracodes, fish, amphibians, reptiles, and insects.
- Trace fossils relatively common in some beds.

### Weathering characteristics
- Sandstone- and limestone-dominant units resistant to weathering and form cliffs, ledges, and gorges in stream valleys.
- Clay- and shale-dominant units less resistant to weathering and form thin to thick colluvium deposits on slopes.
- Coals generally not resistant to weathering.

### Stratigraphic contacts
- Upper contact not present in Ohio.
- Sharp lower contact placed at top of Waynesburg (No. 11) coal.

### Stratigraphic context
- Underlain by the Monongahela Gp.
- Overlain by Cenozoic-age clay- to sand-sized sediments deposited by wind and water or modern soils.
- Similar unit: Conemaugh Gp.

### Engineering properties
- Interbedded unit featuring weak and strong beds. Dominant rocks are weaker shales and mudstones, with lesser amounts of siltstones, and coals. Stronger rocks include less prevalent sandstones and limestones. The shales and mudstones should be considered as the controlling rock types in this formation due to their tendency to weather rapidly after exposure.
- Unconfined compressive strength: Unweathered shales, mudstones, coals, and siltstones have very low to high compressive strength. Weathered shales, coals, and siltstones have extremely low to medium compressive strength. Resistant limestone and sandstones anticipated to have medium to high compressive strength.
- Slake durability: Slake durability of dominant shales, mudstones, and lesser coal units can range from very low to high. Sandstone and limestone would have high to extremely high slake durability.
- Rippability: Weathered shales, mudstones, and coal beds, particularly near the surface, can be ripped by conventional earth-moving equipment. Sandstones,


*Red and gray shale*

limestones, siltstones, and shales that are not significantly weathered are resistant to ripping. Blasting, breaking, or cutting required for rock excavation.
- Shales and mudstones of the Dunkard Gp, specifically the red Creston shales, are highly susceptible to weathering and can be very soft even when unweathered.

### Hydrogeologic properties
- Typically poor aquifer with minimal yields; suitable for limited household and small farm usage.
- Average yield: <5 gpm.


*Hockingport ss*

- Topographic position important; stream valleys yield better than adjacent ridge tops and slopes.
- Shallower, perched aquifers may be present. Perched aquifers may be depleted during prolonged dry periods.
- Yields may be derived from a number of units and horizons with dry intervals between the water-contributing units.
- Regional aquifers typically associated below the stream base elevation for the area. Individual upland areas and ridges typically function as independent aquifer units.
- Yields vary with primary porosity, including permeability, sorting, and bedding planes, and with secondary porosity related to joints and fractures.
- Intervals containing sandstone may yield marginally better than those with finer-grained units.
- Somewhat high yields possible in weathered portion of the unit.
- Aquifer rating: 3.
- Vadose zone rating: 3.
- Hydraulic conductivity: 1–100 gpd/ft$^2$.

### Environmental hazards
- Structural damage to buildings or highways caused by sudden rock falls of resistant sandstone and limestone units that have been undermined by rapid erosion of less-resistant clay and shale units.
- Abundant landslides associated with colluvium weathered from clay- and shale-dominant units.
- People and animals falling from cliffs and gorge walls formed in sandstone-dominant units.

### Economic geology
- Historically, Dunkard sandstones were used to produce high-quality grindstone, building stone, bridge abutments, and tombstones. Shale was quarried to produce bricks, and limestone was mined locally for agricultural lime and use on county and township roads.
- In 2011, the Waynesburg "A" or Washington (No. 12) coals were not mined commercially in Ohio.
- Historically, coals of the Dunkard have been mined for mainly local use because they occur near the surface, are poor quality, and weathered.

### Scenic geology
- The Hockingport ss and other thick Dunkard sandstones form spectacular scenic gorges, cliffs, natural arches, waterfalls, and rock-shelter caves.
- In Washington County, Ladd and Irish Run Natural Arches. Please note that an access permit is required before visiting Ladd SNP.
- Boord SNP features a scenic gorge, waterfalls, and high sandstone cliffs.

### Further reading
Berryhill, 1963; Collins and Smith, 1977; Collins, 1979; Martin, 1998; Camp, 2006

# Monongahela Group


The Monongahela Group is characterized by an abundance of shale, siltstone, and mudstone with lateral and vertical changes between rock types. Within the Monongahela, over 25 beds have been named, of which the widespread Pittsburgh (No. 8) coal was mapped on individual 1:24,000-scale bedrock geologic maps. These rocks were deposited in vast deltas, in large rivers flowing across coastal lowlands, or in numerous lakes and wetlands that occurred in the coastal lowlands.

The group is exposed along a 5- to 50-mi (8–80-km)-wide belt extending southwestward from Jefferson County to Lawrence County. The Monongahela was named for exposures along the Monongahela River in Pennsylvania. The Native American word *Monongahela* means "river of the falling or caving bank." The Monongahela ranges in thickness from 230 to 350 ft (70–107 m).

*Typical exposure of the shale and limestone beds of the Monongahela Group at a railroad cut for the Baltimore & Ohio RR at Stewartsville, Belmont County.*

## Diagnostic features

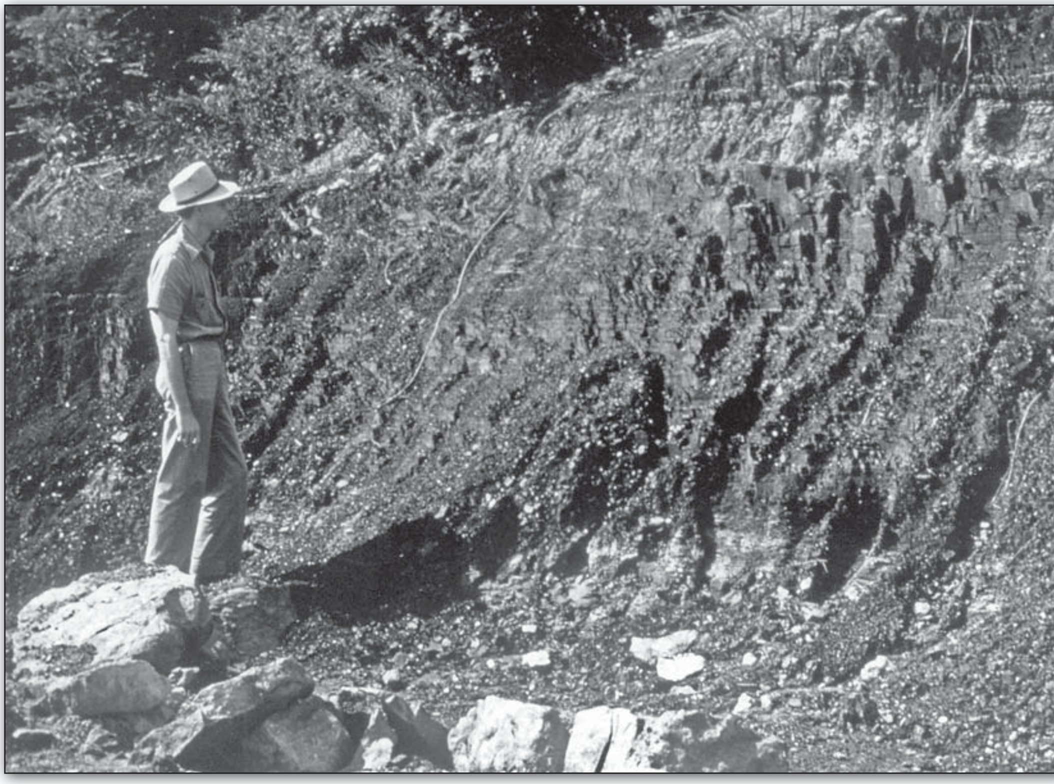
- Abundant shale, siltstone, and mudstone.
- Lateral and vertical changes between rock types.

## General features

- Shades of black, red, gray, and green to variegated red and yellow.
- Lenticular, planar, nodular, irregular, and cross bedding.
- Thin to massive bedded.
- Mudstone, shale, and siltstone: Argillaceous to sandy, non-bedded to thin bedded, locally calcareous.
- Sandstone: Fine to coarse grained, locally calcareous and conglomeratic, thin to massive to cross bedded, and micaceous.
- Limestone: Micritic to coarse grained, thin to medium bedded, nodular to irregular bedding.
- Coal: Banded, bituminous, thin to thick bedded, local to regional distribution. Economic coals are Pittsburgh (No. 8), Pomeroy (No. 8a, Redstone), Meigs Creek (No. 9), and Waynesburg (No. 11).

## Lithologic variations

- Interbedded, gray, non-marine shale and limestone units common in central and northern portions of outcrop belt.



*Approximately 6 ft (2 m) of Pittsburgh coal exposed along U.S. 22 near Wintersville, Jefferson County. In the foreground are blocks of the underlying Pittsburgh limestone. Photo courtesy of W. H. Smith.*

- Non-marine limestone units more common in basal half of unit.
- Red and variegated red and yellow mudstone and shale units ("red beds") and thick sandstones occur in southern portion of outcrop belt.
- Thicker-bedded, mineable coals common in central and northern portions of outcrop belt. In southern Ohio, coals tend to be thinner or absent.

### Fossil content
- Plant fossils range from sparse to common.
- Non-marine units may contain bivalves, ostracodes, fish, amphibians, reptiles, and insects.
- Trace fossils relatively common in some beds.

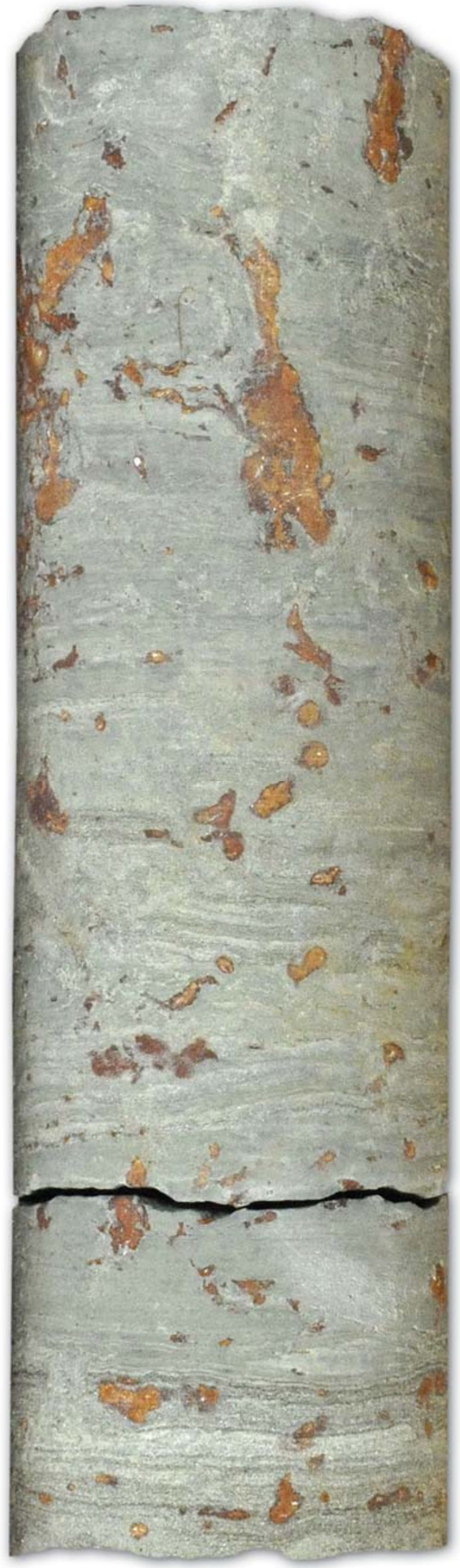
### Weathering characteristics
- Sandstone and limestone units resistant to weathering; in thick deposits, form cliffs along hillsides and streams.
- Mudstone, siltstone, and shale units less resistant to weathering and form thin to thick colluvium deposits on slopes.
- Coals generally not resistant to weathering.

### Stratigraphic contacts
- Sharp upper contact at top of Waynesburg (No. 11) coal.
- Sharp lower contact at base of Pittsburgh (No. 8) coal.

### Stratigraphic context
- Underlain by Conemaugh Gp.
- Overlain by Dunkard Gp.

### Engineering properties
- Interbedded formation dominated by weaker beds and less prevalent strong beds. The dominant weaker shales, mudstones, siltstones, and coals should be considered the controlling rock types where present. These weaker rock types are anticipated to weather rapidly after exposure.
- Unconfined compressive strength: Unweathered shales, mudstones, and coals will have a low to high compressive strength. Weathered shales, mudstones, and coals will have poor to medium compressive strength. Limestones, sandstones, and siltstones will have medium to high compressive strength.
- Slake durability: Slake durability of dominant shales, mudstones, and coal units can range from low to high. Limestones, sandstones, and siltstones would have medium to extremely high slake durability.
- Rippability: Shales, mudstones, and coal units, particularly near the surface, can be ripped with some difficulty by conventional earth-moving equipment. Limestones, sandstones, siltstones, and shales that are not significantly weathered are resistant to ripping. Blasting, breaking, or cutting required for rock excavation.

*Nodular limestone and shale*

*Sandstone with iron nodules*

- Shales and mudstones of the Monongahela Group, specifically the upper Uniontown shale and Tyler shale, are highly susceptible to weathering and can be very soft even when unweathered.

## Hydrogeologic properties

- Typically poor aquifer with minimal yields; suitable for limited household and small farm usage.
- Average yield: <5 gpm.
- Yields may be derived from coal beds; however, water quality may be objectionable. In cases where water from coal is contributing high sulfur and iron, coal beds may need to be cased off by the driller.
- Topographic position important; stream valleys yield better than adjacent ridgetops and slopes.
- Shallower, perched aquifers may be present. Perched aquifers may be depleted during prolonged dry periods.
- Yields may be derived from a number of units and horizons with dry intervals between the water-contributing units.
- Regional aquifers typically associated below the stream base elevation for the area. Individual upland areas and ridges typically function as independent aquifer units.
- Yields vary with primary porosity, including permeability, sorting, and bedding planes, and with secondary porosity related to joints and fractures.
- Intervals containing sandstone may yield marginally better than those with finer-grained units.
- Somewhat high yields possible in weathered portion of the unit.
- Aquifer rating: 3.
- Vadose zone rating: 3
- Hydraulic conductivity: 1–100 gpd/$ft^2$.

## Environmental hazards

- Structural damage to buildings and highways caused by sudden rock falls of resistant sandstone and limestone units that have been undermined by rapid erosion of less-resistant clay and shale units.
- Structural damage to buildings, highways, pipelines, sewer systems, and water wells caused by slow to sudden sinkhole development resulting from the collapse of overlying rock and unconsolidated material into voids left from underground mining of coal and other industrial minerals.
- Abundant landslides associated with colluvium weathered from mudstone and shale units.
- People and animals falling from cliffs formed in sandstone units or into sinkholes.

## Economic geology

- In 2011, nearly 20 million tons of Pittsburgh (No. 8), Pomeroy (No. 8a, Redstone), and Meigs Creek (No. 9) coals were mined in Belmont, Guernsey, Harrison, Jefferson, Meigs, Monroe, and Noble Counties. The Fishpot ls was mined in Monroe and Noble Counties for crushed stone, rip rap, and building and road construction.
- Historically, Monongahela sandstones were quarried for building foundations and heavy building stone.
- In the shallow subsurface, some Monongahela sandstone units have produced economic quantities of oil, gas, and brine.

## Scenic geology

- Appalachian Plateau consisting of picturesque forest- and farm field-covered hills between 300 and 600 ft (91–182 m) high.
- In areas of extensive strip mining, large areas of pasture land and small wooded areas.

## Further reading

Brant and DeLong, 1960; Collins, 1979; DeLong, 1996; Crowell, 1998; Crowell and others, 2008; Gordon, 2009

# Conemaugh Group


The Conemaugh Group is characterized by an abundance of siltstone, shale, and mudstone with horizontal and vertical changes between rock types. In Ohio, the Glenshaw and Casselman Formations of Pennsylvania and West Virginia are not formally recognized or mapped by most geologists. Within the Conemaugh, over 40 beds have been named, of which the widespread Ames limestone was mapped on individual 1:24,000-scale bedrock geologic maps. The group was deposited in nearshore marine environments, deltas, marine and brackish-water bays and lagoons, and coastal lowlands.

The Conemaugh is exposed along a 20- to 50-mi (32–80-km)-wide belt extending southwestward from Mahoning and Columbiana Counties to Lawrence County. The Conemaugh was named for exposures along the Conemaugh River in Pennsylvania. The unit ranges in thickness from 350 to 500 ft (106–152 m).

*On March 20, 2012, a number of large sandstone blocks became dislodged from an exposure of the Conemaugh Group and fell or rolled downslope. One of the blocks crushed an Athens County resident's car. Photo courtesy of Dr. Greg Springer.*

## Diagnostic features

- Abundant siltstone, shale, and mudstone.
- Rapid to gradational horizontal and vertical changes between rock types.

## General features

- Shades of red, yellow, olive, green, brown, or black.
- Lenticular, planar, nodular, irregular, and cross bedding.
- Mudstone, shale, and siltstone: Argillaceous to sandy, non-bedded to thin bedded, locally calcareous; may contain marine fossils in lower half of unit.
- Sandstone: Fine to medium grained, locally conglomeratic, thin to massive to cross bedded, and micaceous.
- Limestone: Micritic to coarse grained, thin to medium bedded; marine fossils common in lower part of unit.
- Coal: Impure, bituminous, thin bedded, discontinuous.

*The multicolored shale, sandstone, mudstone, and clay of the Conemaugh Group exposed along S.R. 7 at East Liverpool, Columbiana County. Notice the rapid pinching out of the light gray sandstone located near the top of the cut.*

### Lithologic variations

- Marine shale and limestone units occur in lower half of unit; rare in upper half.
- Non-marine limestone units common in upper half of unit.
- Red mudstone and shale units ("red beds") first occur in upper half of Conemaugh.
- Lack of mineable coals, except in very local seams thick enough for economic development.

### Fossil content

- Plant fossils range from sparse to common.
- In rare examples, stumps from entire forests have been preserved in place.
- Brackish-water brachiopods.
- Marine units highly fossiliferous with brachiopods, bivalves, gastropods, and echinoderms most common (e.g., Brush Creek, Cambridge, and Ames limestone beds).
- Non-marine units may contain bivalves, ostracodes, fish, amphibians, reptiles, and insects.
- Trace fossils relatively common in some beds.

### Weathering characteristics

- Sandstone and limestone units resistant to weathering and in thicker deposits, form cliffs along hillsides and streams.
- Mudstone, siltstone, and shale units less resistant to weathering and form thin to thick colluvium deposits on slopes.
- Coals generally not resistant to weathering.

### Stratigraphic contacts

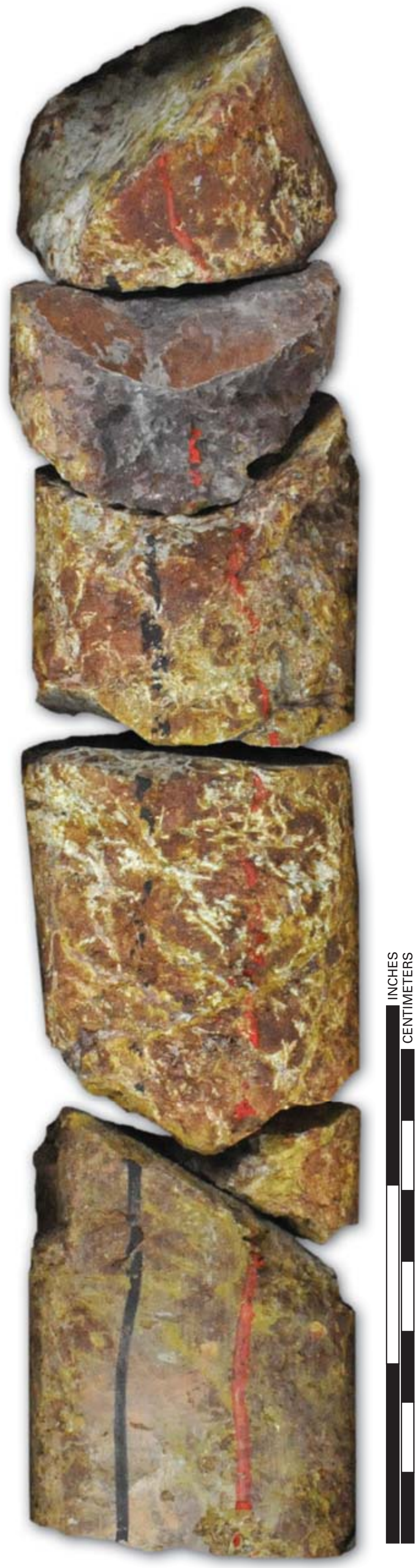
- Sharp upper contact at base of Pittsburgh (No. 8) coal.
- Sharp lower contact at top of Upper Freeport (No. 7) coal.

### Stratigraphic context

- Underlain by Pottsville and Allegheny Gps undivided.
- Overlain by Monongahela Gp.
- Similar unit: Dunkard Gp.

### Engineering properties

- Interbedded formation with weak and strong beds. Dominant weaker shales and mudstones with lesser amounts of siltstones, and coals. Shales, mudstones, coal, and siltstones should be considered the controlling rock types due to their tendency to weather rapidly after exposure.
- Unconfined compressive strength: Unweathered shales, mudstones, coals, and siltstones will have very low to high compressive strength. Weathered shales, coals, and siltstones will have extremely low to medium compressive strength. Resistant limestones and sandstones anticipated to have medium to high compressive strength.




*Red bed*


*Nodular limestone and shale*

- Slake durability: Slake durability of dominant shales, mudstones, and lesser coal units range from very low to high. Sandstones and limestones would have high to extremely high slake durability.
- Rippability: Weathered shale, mudstones, and coal beds, particularly near the surface, can be ripped by conventional earth-moving equipment. Sandstones, limestones, siltstones, and shales that are not significantly weathered are resistant to ripping; blasting, breaking, or cutting would be required for rock excavation.
- Shales and mudstones of the Conemaugh Gp, specifically the red beds—Round Knob shale (below the Ames limestone) and red Clarksburg shale (below the Connellsville sandstone)—are highly susceptible to weathering and can be very soft even when unweathered.

### Hydrogeologic properties

- Typically poor aquifer with minimal yields; suitable for limited household and small farm usage.
- Average yield: <5 gpm.
- Yields may be derived from coal beds; however, water quality may be objectionable. In cases where water from coal is contributing high sulfur and iron, coal beds may need to be cased off by the driller.
- Topographic position important; stream valleys yield better than adjacent ridgetops and slopes.
- Shallower, perched aquifers may be present. Perched aquifers may be depleted during prolonged dry periods.
- Yields may be derived from a number of units and horizons with dry intervals between the water-contributing units.
- Regional aquifers typically associated below the stream base elevation for the area. Individual upland areas and ridges typically function as independent aquifer units.
- Yields vary with primary porosity, including permeability, sorting, and bedding planes, and secondary porosity related to joints and fractures.
- Intervals containing sandstone may yield marginally better than those with finer-grained units.
- Somewhat high yields possible in weathered portions of the unit.
- Aquifer rating: 3.
- Vadose zone rating: 3.
- Hydraulic conductivity: 1–100 gpd/$ft^2$.

### Environmental hazards

- Structural damage to buildings or highways caused by sudden rock falls of resistant sandstone and limestone units that have been undermined by rapid erosion of less-resistant clay and shale units.
- Abundant landslides associated with colluvium weathered from mudstone and shale units.
- People and animals falling from cliffs formed in sandstone units.

### Economic geology

- In 2011, the Mahoning (No. 7a) coal was mined commercially in Columbiana and Jefferson Counties. Conemaugh clay and shale were mined for the manufacture of construction fill material and other common clay products.
- Historically, Conemaugh sandstones were quarried for dimension stone, building foundations, heavy building stone, canal locks, bridge piers and abutments, and retaining walls. Some limestone units were mined locally for agricultural lime and for use on county and township roads.
- In the shallow subsurface, some Conemaugh sandstone units have produced economic quantities of oil, gas, and brine.

### Scenic geology

- Appalachian Plateau consisting of picturesque forest- and farm field-covered hills between 300 and 600 ft (91–182 m) high and incised, broad valleys of the ancient Teays-age drainage system.
- Thicker sandstone units form cliffs, gorges, and small rock shelters. E.g., Buffalo sandstone forming Cradle in the Rocks at Fox Lake WA, Hosak's Cave in Salt Fork SP, and Table Rock and rock shelters at Burr Oak SP.

### Further reading

Condit, 1912; Stout, 1944a; Collins, 1979; Hook and Miller, 1996; Wolfe, 2009

# Allegheny and Pottsville Groups undivided

The Allegheny and Pottsville Groups undivided is characterized by an abundance of shale, sandstone, and conglomerate and subordinate amounts of limestone, clay, flint, and coal. Rapid lateral and vertical changes between these rock types is common. The great abundance of mineral resources within the Allegheny and Pottsville Groups historically has, and continues to be, of major economic importance to Ohio. For more than 200 years, many of the 58 named beds of coal, clay, shale, limestone, iron ore, sandstone, and conglomerate have been mined and used as fuel or to manufacture a variety of products. The Lower Mercer limestone, Lower Kittanning (No. 5) coal, and Upper Freeport (No. 7) coal have been mapped on individual 1:24,000-scale bedrock geologic maps. These rocks were deposited in a wide variety of environments beginning with deposition in deep valleys cut into Mississippian rocks and continuing in shallow marine environments, shorelines, deltas, large rivers flowing across coastal lowlands, and in numerous bays and lagoons that occurred in the coastal lowlands.

The Allegheny and Pottsville Groups undivided were mapped as a combined unit on the individual 1:24,000-scale, reconnaissance bedrock-geology quadrangles throughout eastern Ohio, while Allegheny and Pottsville Groups undifferentiated is mapped on the *Bedrock Geologic Map of Ohio* (Slucher and others, 2006). For this fact sheet, we selected the Allegheny and Pottsville Groups undivided because for field studies, the reconnaissance bedrock-geology quadrangles are most likely going to be used. By definition, the lower contact of the Allegheny Group is placed at the base of the Newland (No. 4, Brookville). The base of the Allegheny Group cannot be mapped in many areas of Ohio because the Newland (No. 4, Brookville) coal was either not deposited or later eroded. Thus the two groups were combined to expedite reconnaissance bedrock mapping.

The groups are exposed along a 20–60-mi (32–96-km)-wide belt extending southwestward from the Ohio-Pennsylvania border in Trumbull, Mahoning, and Columbiana Counties to Scioto and Lawrence Counties. The Allegheny was named for exposures along the Allegheny River in western Pennsylvania, and the Pottsville for the City of Pottsville, Pennsylvania. The unit ranges in thickness from 450 to 620 ft (137–189 m).



*The Upper Freeport coal exposed along the east side of Interstate 77 just north of the interchange with Interstate 70, Guernsey County. The Upper Freeport is one of eight economically important coals that occur in the Allegheny and Pottsville Groups.*

## Diagnostic features

- Shale, sandstone, conglomerate, and subordinate amounts of limestone, clay, flint, and coal.
- Rapid lateral and vertical changes between rock types.

## General features

- Shades of black, gray, and brown.
- Lenticular, planar, nodular, irregular, and cross bedding.
- Thin to massive bedded.
- Shale: Clayey to sandy, thin to medium bedded, locally calcareous; may contain marine fossils.
- Clay: Clayey to silty, varies from plastic to flint clay; underlies coal beds; non-bedded; commonly contains abundant plant fossils and root traces; generally <3 ft (<0.9 m) thick.
- Sandstone: Very fine to coarse grained, locally quartz rich and conglomeratic; thin to massive to cross bedded, locally calcareous.
- Limestone: Micritic to medium grained, thin to medium bedded, nodular to irregular bedding; may grade into flint.
- Coal: Banded, bituminous, locally channel, thin to thick bedded. Economic coals are Lower Mercer (No. 3), Upper Mercer (No. 3a), Newland (No. 4, Brookville), Clarion (No. 4a), Lower Kittanning (No. 5), Middle Kittanning (No. 6), Lower Freeport (No. 6a), and Upper Freeport (No. 7).

## Lithologic variations

- Sandstone and conglomerate common in lower portions of Pottsville Gp.
- Some non-marine limestone units occur in upper portion of Allegheny Gp.
- Micritic limestone common beneath coal beds of Allegheny Gp.
- Mineable coals abundant but generally restricted to localized areas.

## Fossil content

- Plant fossils range from sparse to common.
- Marine units contain bivalves, brachiopods, bryozoans, cephalopods, corals, echinoderms, gastropods, and trilobites.
- Non-marine or brackish units may contain bivalves, ostracodes, fish, amphibians, reptiles, and insects.
- Trace fossils relatively common in some beds.
- Famous Linton fossil location occurs within Upper Freeport coal zone at Yellow Creek, Jefferson County.

## Weathering characteristics

- Sandstone and conglomerate resistant to weathering and thicker deposits form cliffs and gorges along hillsides and streams.
- Shale, clay, coal, and limestone units less resistant to weathering and form thin to thick colluvium deposits on slopes.

## Stratigraphic contacts

- Sharp upper contact at top of Upper Freeport (No. 7) coal.
- Sharp lower contact.

## Stratigraphic context

- Underlain by Logan Fm, Maxville Ls, or Rushville Fm in southeastern Ohio.
- Underlain by Cuyahoga Fm in northeastern Ohio.
- Overlain by Conemaugh Gp.

## Engineering properties

- Interbedded formation with weak and strong beds.

*Mine subsidence pit measuring 35 ft across and 25 ft deep has opened in a residential area in North Canton, Stark County. These pits occur as the overlying strata collapses into the mined voids of abandoned or active underground mines. Mine subsidence is a major geologic hazard in areas with underground mining. See the Survey website, **OhioGeology.com,** for more information.*

*Buckeye Furnace is a restored example of the charcoal-fired blast furnaces that dotted the landscape of the Hanging Rock Iron Region of Hocking, Vinton, Jackson, Gallia, Scioto, and Lawrence Counties. Locally mined iron ore was processed through charcoal-fired blast furnaces to produce pig iron from 1818 to 1916.*

Dominant weaker shales, coals, and siltstones should be considered the controlling rock types in this formation. Shales, coals, and siltstones anticipated to weather rapidly after exposure.

- Unconfined compressive strength: Unweathered clay, shales, coals, and siltstones will have low to high compressive strength. Weathered shales, coals, and siltstones will have poor to medium compressive strength; limestones and sandstones will have a high compressive strength.
- Slake durability: Slake durability of the dominant shale and lesser coal units range from low to very high. Sandstone and limestone would have high to extremely high slake durability.
- Rippability: Weathered shale and coals beds, particularly near the surface, can be ripped with some difficulty by conventional earth-moving equipment. Sandstones, limestones, siltstones, and shales that are not significantly weathered are resistant to ripping; blasting, breaking, or cutting would be required for rock excavation.


*Coal*


*Pottsville shaley sandstone*

## Hydrogeologic properties

- A poor to moderate aquifer, typically capable of meeting water needs for households and small to moderate-sized farms.
- Average yield: Varies from 0–5 to 5–10 gpm for shale, limestone, and siltstone-dominant portions of the Allegheny and Pottsville Gps. Yields of 5–15 gpm encountered in areas with interbedded shale, limestone, siltstone, and sandstone. Yields up to 20 gpm reported for sandstone-dominant portions near the base of Allegheny and Pottsville Gps.
- Yields may be derived from the coal beds; however, water quality may be objectionable. In cases where water from coal is contributing high sulfur and iron, coal beds may need to be cased off by the driller.
- Topographic position important; stream valleys yield better than adjacent ridgetops and slopes.
- Shallower, perched aquifers may be present. Yields may be derived from a number of units and horizons with dry intervals between the water-contributing units.
- Regional aquifers typically associated below the stream base elevation for the area. Individual upland areas and ridges typically function as independent aquifer units.
- Yields vary with primary porosity, including permeability, sorting, and bedding planes, and secondary porosity related to joints and fractures.
- Somewhat high yields possible in weathered portions of the unit.
- Aquifer rating: 3 for shale-rich intervals; 4 for interbedded intervals; 4–5 for sandstone-rich intervals.
- Vadose zone rating: 3 for shale-rich intervals; 4 for interbedded intervals; 5 for weathered portions of sandstone-rich intervals.
- Hydraulic conductivity: 1–100 gpd/ft$^2$ for shale and siltstone to 100–300 gpd/ft$^2$ for sandstone-rich intervals.

## Environmental hazards

- Structural damage to buildings and highways because of sudden rock falls of resistant sandstone that have been undermined by the rapid erosion of less-resistant clay and shale units.
- Structural damage to buildings, highways, pipelines, sewer systems, and water wells because of slow to sudden sinkhole development resulting from the collapse of overlying rock and unconsolidated material into the voids left from underground mining of coal and other industrial minerals.
- People and animals falling from cliffs and gorges formed in sandstone units.

## Economic geology

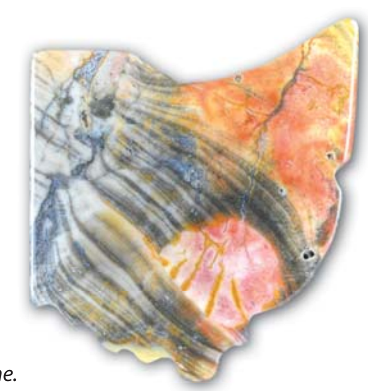
- In 2011, over 8 million tons of coal was mined from Upper Mercer (No. 3a), Newland (No. 4, Brookville), Clarion (No. 4a), Lower Kittanning (No. 5), Middle Kittanning (No. 6), Lower Freeport (No. 6a), and Upper Freeport (No. 7). Limestone was mined from the Vanport and Putnam Hill limestones for crushed stone, rip rap, and building and road construction. Clay and shale was mined from the Brookville, Tionesta, and Lower Kittanning clays or shales for the production of pottery, bricks, lining for landfills, cement manufacture, and other construction activities. Sandstone and conglomerate were mined for glass sand, foundry sand, crushed stone and aggregate, and polishing and grinding sand.
- Historically, Ohio's official gemstone, flint, was extensively quarried by Native Americans along Flint Ridge located in eastern Licking County. Iron ore from the Hanging Rock Iron Region of Hocking, Vinton, Jackson, Gallia, Scioto, and Lawrence Counties was mined and processed through charcoal-fired blast furnaces to produce pig iron from 1818 to 1916. Clay and shale were mined by Native Americans for the production of pottery and many types of ceremonial artifacts. European settlers first produced bricks in 1788 and Ohio's ceramic industry has been an important part of the economy in southeastern Ohio ever since. Sandstone was quarried for use as dimension and building stone, foundations, construction of charcoal blast furnaces, canal locks, and pulp stones.
- In the shallow subsurface, some Allegheny and Pottsville Gp undivided sandstone units produce economic quantities of oil, gas, and brine.

## Scenic geology

- Appalachian Plateau consisting of picturesque forested ridges and hills dissected by broad, flat-bottomed valleys. Relief ranges from 200 to 500 ft (61–152 m) high.
- Thick sandstone and conglomerate units form cliffs, gorges, waterfalls, and scenic ridges and hills. E.g., Newton Falls, Lanterman's Falls in Mill Creek MetroParks; prominent cliffs at Beaver Creek SP and along the Muskingum River Valley at Duncan Falls and Philo, Muskingum County. Also, see Sharon sandstone/conglomerate fact sheet.

## Further reading

Stout, 1916; Stout, 1944b; Brant and DeLong, 1960; Hansen, 1984; Collins, 1986; Crowell, 1996; Wolfe and Blankenbeker, 2005; Getz, 2011; Wolfe, 2012

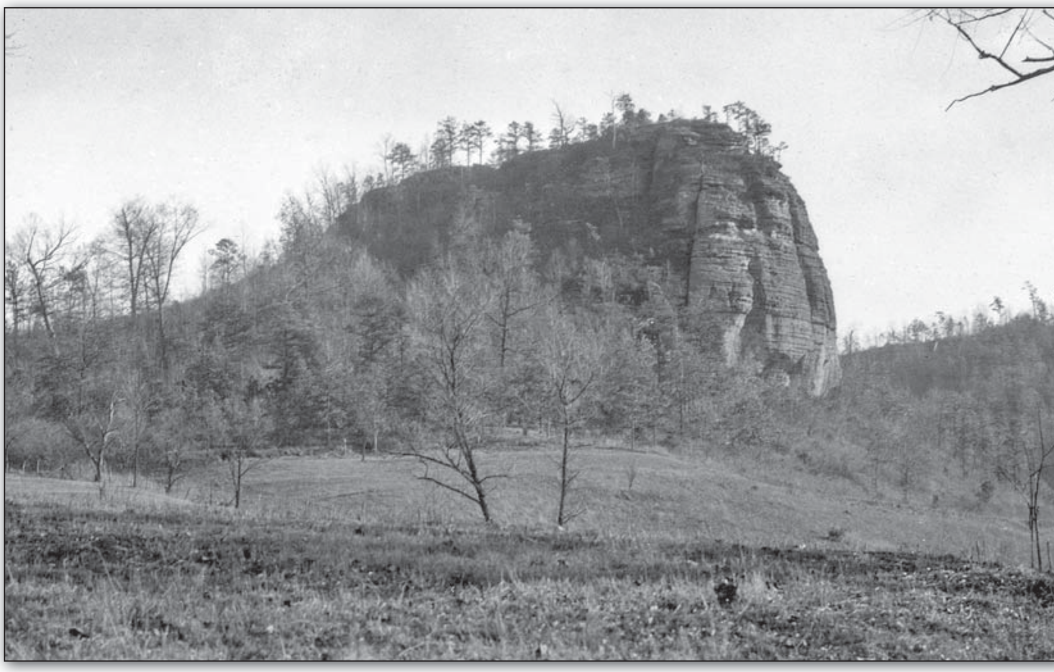


*Flint—Ohio's official gemstone.*

# Pottsville Group
# Sharon sandstone/conglomerate


The Pottsville Group-Sharon sandstone/conglomerate is characterized by sandstone, consisting of medium-grained, well-rounded quartz grains that comprise over 96 percent of the unit, interbedded with conglomeratic sandstone and conglomerate. Rapid lateral and vertical changes between these rock types are common. While not mapped on individual 1:24,000-scale bedrock-geologic maps or on the *Bedrock Geologic Map of Ohio* (Slucher and others, 2006), the Sharon is included as a fact sheet because of the spectacular scenic features and economic importance. This unit was deposited in deep valleys that were eroded into the underlying Mississippian rocks by braided and meandering rivers.

The Sharon is limited to relatively small geographic areas in Ohio. The best exposures are in Geauga, Mahoning, Portage, Stark, and Summit Counties of northeastern Ohio and Jackson, Pike, and Scioto Counties in southern Ohio. The Sharon was named for exposures in the vicinity of Sharon, Pennsylvania. The unit ranges in thickness from 0 to 250 ft (0–76 m).



*Side view of over 200 ft of Sharon conglomerate forming Big Rock, located in Liberty Township, Jackson County. Many scenic gorges, cliff exposures, and outliers like Big Rock are common in Jackson County.*

## Diagnostic features
- Interbedded, medium- to coarse-grained, well-rounded, high-silica (over 96%), quartz-rich sandstone; conglomeratic sandstone; and conglomerate.
- Rapid lateral and vertical changes between rock types.

## General features
- Shades of white, gray, and tan.
- Lenticular, planar, irregular, and cross bedding.
- Thin to massive bedded.
- Conglomerates consist of well-rounded quartz and quartzite granules to pebbles.

## Lithologic variations
- Conglomerate beds occur as narrow, linear beds that grade into conglomeratic sandstone or rapidly pinch out into adjacent sandstone beds.
- Sandstone beds contain a variety of cross-bedding types that vary both laterally and vertically throughout the unit.
- Minor amounts of horizontal bedding also present.

**Fossil content**
- Sparsely fossiliferous to non-fossiliferous.
- Devonian-age corals and other reworked fossils derived from older geologic units have been found in northeastern Ohio.

**Weathering characteristics**
- Sandstone and conglomerate are resistant to weathering, forming spectacular cliffs, gorges, rounded prominent hills, rock shelters, and waterfalls.

**Stratigraphic contacts**
- Sharp to gradational upper contact.
- Sharp lower contact.

**Stratigraphic context**
- Underlain by Logan Fm, Maxville Ls, or Rushville Fm in southern Ohio.
- Underlain by Cuyahoga Fm in northeastern Ohio.
- Overlain by Sharon (No. 1) coal or Sharon shale.

**Engineering properties**
- Unconfined compressive strength: Unweathered Sharon ss/cong will have a high compressive strength. Weathered portions will have a low to high compressive strength, depending on degree of weathering.
- Slake durability: Expected to have high slake durability.
- Rippability: Resistant to ripping except where highly weathered. Typically requires breaking; blasting is required for rock excavation.

**Hydrogeologic properties**
- A moderate to good aquifer capable of supplying the water needs for households and moderate- to large-sized farms.
- Average yield: 10–25 gpm in areas where unit is thinner; 15–25 gpm in areas with thicker sequences of the Sharon ss/cong. Maximum yields exceeding 100 gpm reported for larger diameter wells developed in thicker, highly fractured sections in northeastern Ohio.
- Yields vary with primary porosity, including permeability, sorting, and bedding planes, and secondary porosity related to joints and fractures.
- Somewhat high yields possible in weathered portions of the unit.
- Aquifer rating: 4–5, with limited areas having a rating of 6 in vicinity of Geauga, Summit, and Portage Counties.
- Yields and aquifer ratings for the Sharon in southeastern Ohio typically lower than in northeastern Ohio.
- Vadose zone rating: 5, with 6 reported for weathered regions in southeastern Ohio.
- Hydraulic conductivity: 1–100 gpd/ft$^2$ to 100–300 gpd/ft$^2$; limited areas may see a range of 300–700 gpd/ft$^2$.

*Cascade Falls is one of the many scenic features preserved in Nelson Kennedy Ledges State Park. The Sharon sandstone/conglomerate forms abundant vertical cliffs, gorges, and scenic waterfalls in the northeastern Ohio counties of Medina, Summit, and Portage.*

**Environmental hazards**
- People and animals falling from cliffs and gorge walls.
- Falling rocks from cliff and gorge walls, especially during winter and spring freeze/thaw cycles.

**Economic geology**
- In 2011, the Sharon was mined in Geauga and Mahoning counties for glass, foundry, and polishing and grinding sand; crushed or broken stone; construction material; and concrete work.
- In the subsurface, the Sharon is the Maxton sand of drillers and is a producer of oil, gas, and brine.
- Excellent source of ground water.

## Scenic geology

- Unit forms broad, flat to gently rolling ridges separated by picturesque, narrow gorges and cliff-lined valleys. Relief ranges from 200 to 400 ft (61–122 m) high.
- Thick sandstone and conglomerate units form spectacular cliffs, gorges, rounded prominent hills, and rock shelters, including:
  - In southern Ohio: Sharon scenery may be observed at Boone, Big, and Buzzard Rocks; Canter's Cave; Lake Katherine SNP; Rock Run; and Leo Petroglyph SM.
  - In northeastern Ohio: Nelson-Kennedy Ledges SP; Virginia Kendall Ledges Park in the Cuyahoga Valley NP; Worden's and Whipps Ledges in Cleveland Metroparks, Hinckley Reservation; Gorge Metro Park in Akron; Cuyahoga Falls; and City of Kent, Franklin Mills River Edge Park.

## Further reading

Stout, 1916; Stout, 1944a; Fuller, 1955; Coogan and others, 1974; Foos, 2003


*Sandstone with rounded quartz pebbles*


# Maxville Limestone

The Maxville Limestone can be subdivided into a basal, argillaceous to arenaceous, dolomitic limestone and an upper, high-calcium, microcrystalline to coarse-grained, fossiliferous limestone with occasional shale partings or thin beds. These rocks were deposited in mudflat, shoreline, nearshore, and offshore environments. The Maxville Limestone occurs in discrete deposits of limited extent from central Muskingum County southward to the Ohio River in Lawrence County. Post-Mississippian erosion has completely removed the unit in southern Hocking and Vinton Counties. The unit was named for exposures located in Little Monday Creek near Maxville in Perry County. The Maxville ranges in thickness from 0 to 42 ft (0–13 m), where exposed.

*The characteristic high-calcium, microcrystalline limestone beds comprising the upper part of the Maxville Limestone from Licking County, outside of Newark, Ohio.*

## Diagnostic features

- Upper portion: High-calcium, microcrystalline to coarse-grained, fossiliferous limestone with occasional shale beds or partings.
- Lower portion: Argillaceous to arenaceous, dolomitic limestone.

## General features

- Gray, blue gray, green, and brown.
- Thin to thick bedding.
- Planar, irregular, and lenticular bedding.
- Locally, nodular chert is white or light brown.
- Brecciated limestone common in some beds.

## Lithologic variations

- Grain size can vary considerably within a single exposure and between exposures.
- Amount of shale and shale partings is highly variable between exposures.
- Upper portion generally eroded and often not present in exposures.
- Thickness highly variable within and between exposures.

## Fossil content

- Upper portion highly to sparsely fossiliferous with bivalves, brachiopods, bryozoans, and gastropods being most common and blastoids, cephalopods, crinoids, and trilobites being less common.
- Lower portion sparsely fossiliferous with occasional trace fossils.

## Weathering characteristics

- Upper portion resistant to weathering, forming small cliffs along streams, and in streams can form small waterfalls and riffles.

## Stratigraphic contacts

- Sharp upper contact.
- Sharp lower contact.

## Stratigraphic context

- Underlain by Logan Fm.
- Underlain by Rushville Fm in a localized area of eastern Fairfield County.
- Overlain by Pottsville Gp.
- Similar units: Dundee Ls.

## Engineering properties

- Unconfined compressive strength: Unweathered Maxville Ls will have high to very high compressive strength. Weathered Maxville Ls will vary due to presence of shaley layers within the limestone that compromise rock strength. Generally, will have medium to high compressive strength.
- Slake durability: Expected to have high to very high slake durability; can be diminished where high siltstone and shale content present.
- Rippability: Should be considered resistant to ripping. Blasting, breaking, or cutting required for rock excavation.

## Hydrogeologic properties

- Poor to moderate aquifer capable of supplying water needs for households and moderate- to large-sized farms.
- In many areas is too thin and too near the surface to be a stand-alone aquifer. Wells drilled into this unit typically include rocks from the overlying Pottsville Gp or underlying Logan Fm.
- Average yield: 5–10 gpm in areas where unit is thick enough to be identified in water well log drilling reports.
- Aquifer rating: 3–4.
- Vadose zone rating: 3–4.
- Hydraulic conductivity: 1–100 gpd/$ft^2$.

## Environmental hazards

- No environmental hazards associated with this unit.


*Micritic limestone*


*Fossiliferous limestone*

## Economic geology
- Quarried for crushed stone used in road and building construction.
- Crushed stone for asphalt paving.
- Portland cement.

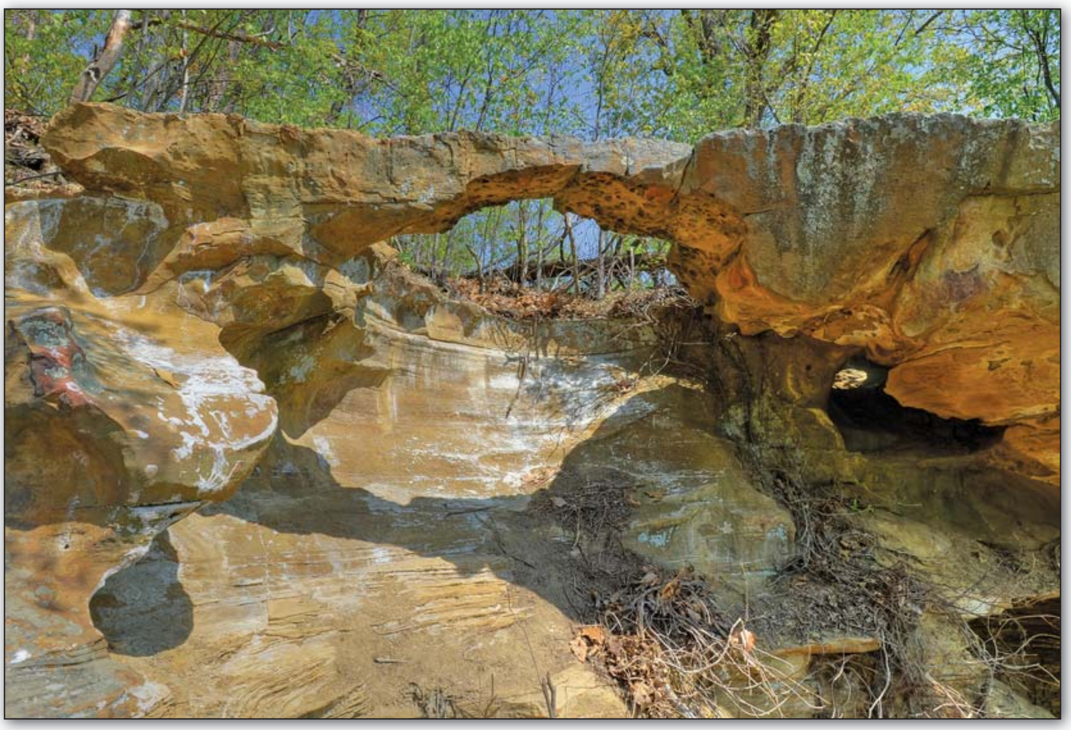
## Scenic geology
- Small waterfalls and riffles where exposed in streams.

## Further reading
Morse, 1910; Lamborn, 1951; Hoare, 2003

# Logan Formation

The sandstone-dominant Logan Formation was deposited in offshore and marginal marine environments that produced relatively widespread regional stratigraphic units in Ohio. The regional distribution of the Berne, Byer, Allensville, and Vinton Members is in sharp contrast to the localized distribution of members and beds recognized in the underlying Cuyahoga Formation and the overlying Pottsville Group. The conglomerates, sandstones, siltstones, and minor shales of the Logan were derived from sediments eroded from the Devonian-age highlands, the Catskill and Pocono deltas, and older Mississippian-age sediments. Rivers and streams transported and deposited pebble-, sand-, silt-, and clay-sized particles in the shallow sea that covered much of Ohio during Mississippian time.

The Logan and Cuyahoga Formations were mapped as a combined unit on the *Bedrock Geologic Map of Ohio* (Slucher and others, 2006) and individual 1:24,000-scale, reconnaissance bedrock-geology quadrangles. Detailed mapping of these units is left for future mappers to complete. The Logan and Cuyahoga Formations occur along a 1–50-mi (2–80-km)-wide, southwest-to-northeast-oriented outcrop belt that extends from Portsmouth, through Newark and Mansfield, to the area of Wooster. The Logan is absent north and northeast of Wooster. The Logan ranges in thickness from 0 to 400 ft (0–122 m) and was first named for exposures near the town of Logan in Hocking County.



*Raven Rock Arch, formed in the thin to massive bedded, fine-grained Logan Formation. Raven Rock State Nature Preserve, Scioto County.*

## Diagnostic features

- Dominance of sandstone.
- Regional vertical and lateral continuity of Berne, Byer, Allensville, and Vinton Mbrs.

## General features

- Sandstone interbedded with siltstone, shale, and conglomerate.
- Gray, brown, and yellow.
- Thin to massive bedding.
- Fine- to coarse-grained sandstone.
- Conglomerate comprised mainly of quartz granules and pebbles.

## Lithologic variations

- Berne and Allensville Mbrs characterized by

- coarse-grained sandstone and conglomerate, but locally may contain fine-grained sandstone, siltstone, and shale beds.
- Byer and Vinton Mbrs contain fine- to medium-grained sandstone, siltstone, and shale in thin to massive beds.

**Fossil content**
- Fossiliferous with local intervals containing abundant fossils.
- Bivalves and brachiopods common.
- Bryozoans, corals, cephalopods, echinoderms, gastropods, and ostracodes less common.
- Trace fossils range from rare to common.

**Weathering characteristics**
- Resistant, gorge- and cliff-forming unit.
- Abundant slump blocks of sandstone occur on slopes comprised of the Cuyahoga Fm.

**Stratigraphic contacts**
- Sharp upper contact.
- Gradational to sharp lower contact.

**Stratigraphic context**
- Underlain by Cuyahoga Fm.
- Overlain by Maxville Ls, where present, or Rushville Fm in a small localized area of eastern Fairfield County.
- Overlain by Pottsville Gp where Maxville Ls and/or Rushville Fm has been eroded away.

**Engineering properties**
- Unconfined compressive strength: Unweathered sandstones will have a medium to high compressive strength that diminishes with presence of siltstone and shale; weathered portions will have a low to high compressive strength, depending on degree of weathering.
- Slake durability: Generally expected to have high slake durability in sandstone units. Siltstone and less common shales more susceptible to slaking.
- Rippability: Resistant to ripping. Blasting, breaking or cutting required for rock excavation.

**Hydrogeologic properties**
- Moderate aquifer typically capable of supplying water needs for households and small- to moderate-sized farms.
- Average yield: 5–10 gpm for shale and siltstone-dominant portions and relatively thin sandstone-dominant zones; 10–25 gpm in areas with thicker sequences of sandstone-rich intervals.
- Yields vary with primary porosity, including permeability, sorting, and bedding planes, and secondary porosity related to joints and fractures.
- Somewhat high yields possible in weathered portion of unit.
- Aquifer rating: Typically 4 for interbedded intervals; 4–5 for sandstone-rich intervals.
- Vadose zone rating: Typically 4 for interbedded intervals, with 5 reported for weathered portions of sandstone-rich intervals.
- Hydraulic conductivity: 1–100 gpd/ft$^2$ for shale- and siltstone-rich intervals; 100–300 gpd/ft$^2$ for sandstone-rich intervals.

**Environmental hazards**
- Rock falls from cliffs and gorge walls.
- People and animals falling from cliffs.

**Economic geology**
- Historically, sandstone quarried for dimension stone, crushed or broken stone, and other industrial uses.
- Currently, not quarried for industrial or commercial purposes.

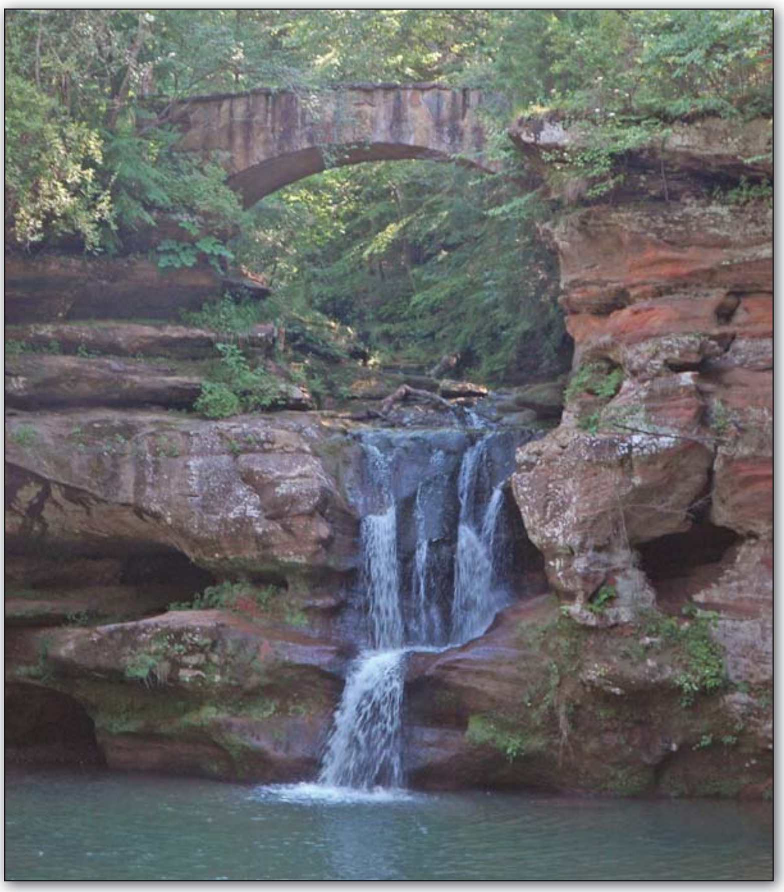
**Scenic geology**
- Erosion-resistant character produces very hilly topography with occasional cliffs and gorges along streams cutting through the unit.
- Raven Rock, Rockgrin, and Slide Arches in Scioto County.

**Further reading**
Hyde, 1953; Coogan and others, 1981


*Sandstone and minor shale*

# Cuyahoga Formation Black Hand Member

The Black Hand Member of the Cuyahoga Formation occurs in the upper part of the formation and is characterized by thick to massive beds of cross-bedded sandstone that form prominent cliffs. It is best known for the formation of spectacular scenic gorges, natural arches, waterfalls, and rock-shelter caves. The unit was deposited in large deltas and river channels that built into shallow tropical seas covering Ohio during the Mississippian Period. The Black Hand Member is exposed in three 15- to 20-mi (24–32-km)-wide, elongate, northward- or northwestward-oriented deposits. The first deposit occurs primarily in Fairfield and Hocking Counties, the second in Licking and Knox Counties, and the third in Ashland, Knox, and Richland Counties. In the subsurface of eastern Ohio, similar elongate sandstone deposits, commonly named the "Big Injun" by well drillers, are correlative to the Black Hand Member. These elongate sandstones commonly thin and grade laterally into shale-dominant units on outcrop and in the subsurface. The thickness of the Black Hand ranges from 0 to 330 ft (0–100 m) and was named for the large, dark, hand-shaped Native American petroglyph carved in the sandstone wall of the Black Hand Gorge of the Licking River in Licking County. In 1828, the petroglyph was blasted away during the construction of the towpath for the Ohio & Erie Canal.

*Cliff-forming, thick to massive bedded sandstone of the Black Hand Member of the Cuyahoga Formation exposed at the Upper Falls of Old Man's Creek in Hocking Hills State Park, Hocking County.*

### Diagnostic features
- Cross-bedded sandstone.
- Thick to massive bedding.
- Cliff forming.

### General features
- White, gray, brown, and yellow.
- Quartz-rich sandstone and conglomerate.
- Fine- to very coarse-grained sandstone.
- Planar, irregular, and lenticular bedded.

- Conglomerate comprised of mainly quartz granules and pebbles.
- Conglomerate beds occur as thin lenticular beds with a sandy matrix.

### Lithologic variations
- The Black Hand Mbr thins and grades laterally into the Fairfield Shale Mbr in Fairfield and Hocking Counties, the Raccoon Shale Mbr in Licking and Knox Counties, and the Wooster Shale Mbr in Ashland, Knox, and Richland Counties.

### Fossil content
- Sparsely fossiliferous with local intervals of fossiliferous rocks.
- Bivalves, brachiopods, gastropods, and cephalopods common.
- Trace fossils rare.

### Weathering characteristics
- Resistant, cliff-forming unit.
- Weathered surfaces often pitted and corroded, creating a honey comb effect.
- Large, abundant slump blocks of sandstone.

### Stratigraphic contacts
- Sharp upper contact.
- Sharp lower contact.

### Stratigraphic context
- Underlain by Fairfield, Raccoon, and Wooster Shale Mbrs of the Cuyahoga Fm.
- Overlain by Logan Fm.

Similar unit: Sharon sandstone/conglomerate.

### Engineering properties
- Unconfined compressive strength: Unweathered sandstone will have medium to high compressive strength; weathered portions of the formation will have low to high compressive strength, depending on degree of weathering.
- Slake durability: Expected to have high slake durability.
- Rippability: Resistant to ripping except where highly weathered. Typically requires breaking; blasting is required for rock excavation.

### Hydrogeologic properties
- Moderate to good aquifer capable of supplying water needs for households and moderate- to large-sized farms.
- Average yield: 10–25 gpm in areas where unit is thinner; 15–25 gpm in areas with thicker sequences. Max. yields exceeding 50 gpm reported for larger diameter wells developed in thicker, highly-fractured sections in south-central Ohio.
- Yields vary with primary porosity, including permeability, sorting, and bedding planes, and secondary porosity related to joints and fractures.
- Somewhat high yields possible in weathered portion of the unit.
- Aquifer rating: Typically 4 or 5, with limited areas of 6 in vicinity of Hocking and Fairfield Counties.
- Vadose zone rating: Typically 4, with 5 reported for weathered regions in southeastern Ohio.
- Hydraulic conductivity: 1–100 gpd/ft$^2$ to 100–300 gpd/ft$^2$. Limited areas may range 300–700 gpd/ft$^2$.

### Environmental hazards
- Falling rocks from cliff and gorge walls, especially during winter and spring freeze/thaw cycles.

*High cliffs, massive bedded sandstone, and Black Hand Rock along the Licking River east of Newark, Licking County.*

• People and animals falling from cliffs and gorge walls.

### Economic geology

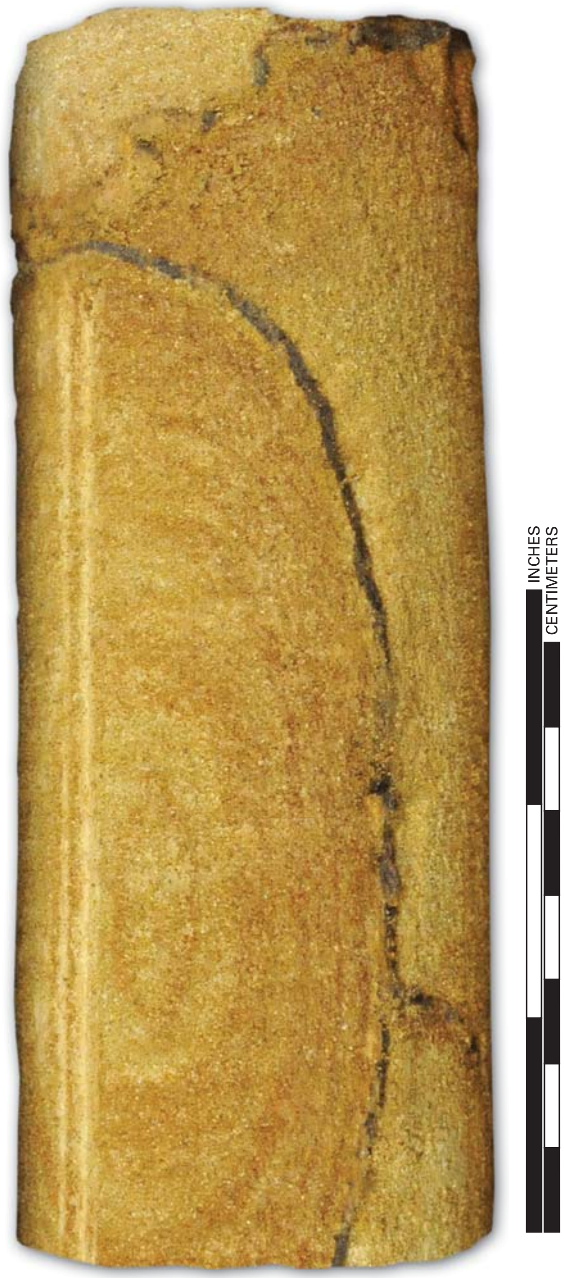
• Historically, the Black Hand Mbr was quarried for use as building stone, dimension stone for bridge abutments and retaining walls, and a source of sand for the production of glass. In the subsurface during the 1800s, salt was produced from brine pumped from the Black Hand and other sandstones from the Cuyahoga Fm.
• Today, the Black Hand is used on an intermittent basis for glass sand, depending on market conditions.

### Scenic geology

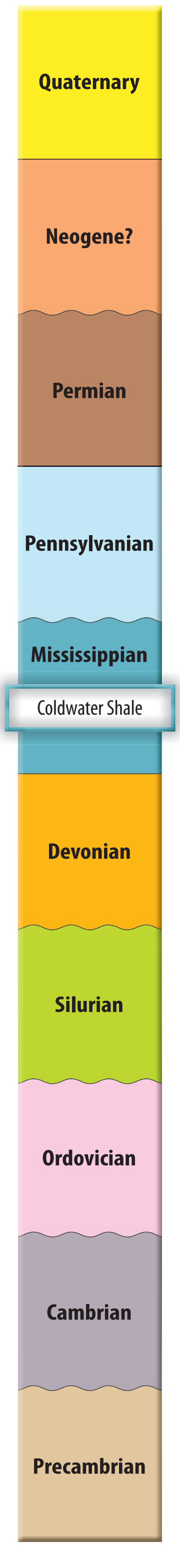
• The Black Hand Mbr is best known for forming spectacular scenic gorges, cliffs, natural arches, waterfalls, and rock-shelter caves, including:
• Hocking County: Ash Cave, Cedar Falls, Conkle's Hollow, Old Man's Cave and Gorge, and Rock House.
• Fairfield and Licking Counties: Rising Sun Park, Shallenberger SNP, Wahkeena SNP, and Rock Mill Bridge Falls (in the Lancaster area) and Black Hand Gorge SNP (east of Newark).
• Ashland, Knox, and Richland Counties: Clearfork Gorge in Mohican SP.
• Natural arches located in Hocking County include Rockbridge, Balcony Natural Bridge, Unger Hollow Arch, Old Man's Pantry, Rock House, Saltpetre Cave, Surprise Arch, Three-Hole Arch, and Annex Arch.

### Further reading

Hansen, 1975; Malcuit and Bork, 1987; Snyder, 2010

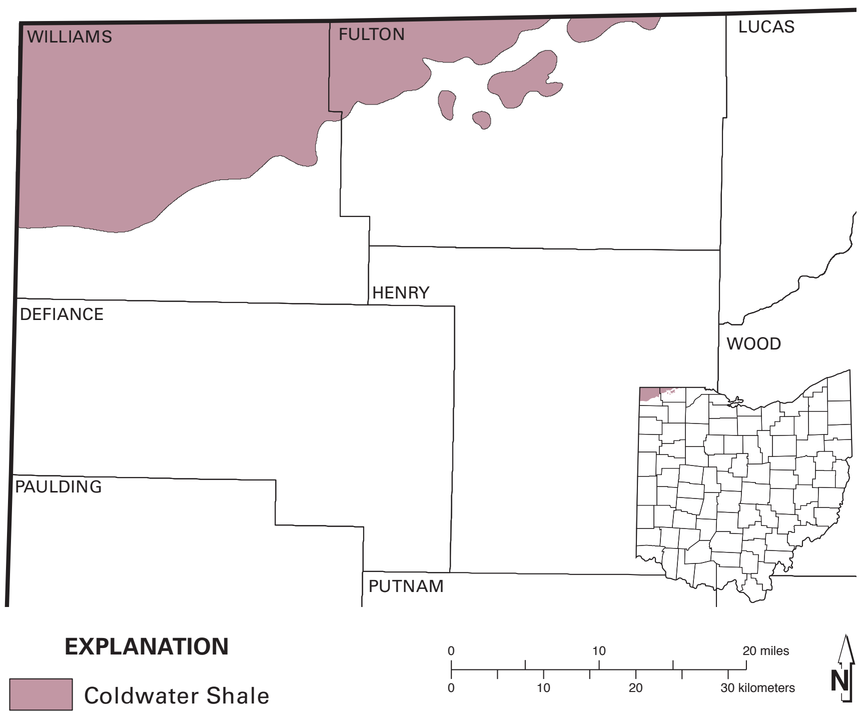



*Weathered sandstone displaying Liesegang rings (or banding), which are caused by precipitation of accessory minerals during evaporation of ground water.*




# Coldwater Shale

The Coldwater Shale is characterized by light- to dark-gray, calcareous shale with light-gray to reddish-brown carbonate nodules. These rocks were deposited in a vast tropical sea adjacent to distant shorelines containing marginal marine and deltaic environments. The muds and silts of the Coldwater were eroded from the Devonian highlands and coastal landscape to the east and transported by rivers, streams, and ocean currents to be deposited in northwest Ohio during the Mississippian Period. The Coldwater is buried under a thick blanket of Quaternary-age sediments and is rarely exposed at the surface. The unit forms the near-surface bedrock in extreme northwest Ohio and is mapped in Williams and Fulton Counties. The unit ranges in thickness from 0 to 150 ft (0–46 m) and was first named for exposures along the Coldwater River in south-central Michigan.




*The outcrop belt of the Coldwater Shale as mapped in northwestern Ohio. Exposures of the Coldwater are rare because it is largely buried under extensive Quaternary deposits.*

## Diagnostic features
- Light- to dark-gray, calcareous shale with light-gray to reddish-brown carbonate nodules.

## General features
- Thin to thick bedded.
- Planar bedding.
- Occasional laminations or thin beds of siltstone or fine-grained sandstone.
- Fissile to platy partings in shale beds.

## Lithologic variations
- Laminations and thin beds of siltstone and sandstone increase in abundance in the basal part of unit.
- Upper part of the Coldwater is mainly shale.

## Fossil content
- Sparsely fossiliferous.
- Pyrite-filled burrows common.

## Weathering characteristics
- Not resistant to weathering and would likely form abundant colluvium in stream and river valleys.

## Stratigraphic contacts
- Upper contact not present in Ohio.
- Sharp lower contact.

## Stratigraphic context
- Underlain by Sunbury Sh.
- Overlain by Marshall Ss in Michigan. No overlying rock unit present in Ohio.

## Engineering properties
- Composed mainly of weaker shale beds. Shales of this formation anticipated to weather after exposure.
- Unconfined compressive strength: Unweathered shale will have medium to high compressive strength; weathered shale anticipated to have extremely low to medium compressive strength.
- Slake durability: Shales subject to degradation after exposure. Shale slake durability ranges low to high, based on amount of weathering present.
- Rippability: Weathered shale beds, particularly near the surface, may be ripped by conventional earth-moving equipment. Deeper and less-weathered beds anticipated to be resistant to ripping and require blasting, breaking, or cutting.

## Hydrogeologic properties
- Typically poor aquifer; marginally suitable for limited household or small farm use.
- Average yield: 3–5 gpm. Max. yield: 10 gpm.
- Yields provided by combination of joints and fractures as they intersect bedding planes.
- High sulfide and iron content may represent a water quality problem.
- For best results, wells should be completed and screened in overlying thick sequences of glacial drift or along the weathered drift/bedrock contact.
- Aquifer rating: 2–3.
- Vadose zone rating: 2–3.
- Hydraulic conductivity: 1–100 gpd/ft$^2$.

## Environmental geology
- No known environmental hazards associated with this unit.

## Economic geology
- Raw material for manufacture of Portland cement.
- Mined to produce bricks and drain tiles.

## Scenic geology
- None.

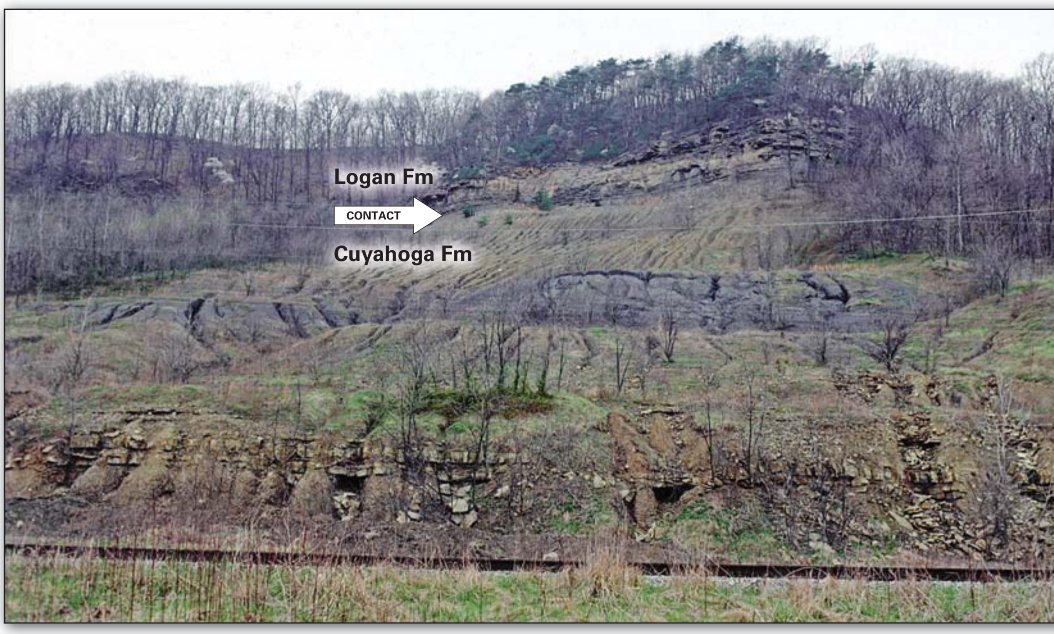
## Further reading
Ells, 1979

*Shale with reddish-brown carbonate nodule*


# Cuyahoga Formation

The localized changes in rock types, both vertically and horizontally, within the shale-dominant Cuyahoga Formation are diagnostic. Geologists have recognized at least seven different combinations of the shale, sandstone, and conglomerate along the 260-mi (416-km) outcrop of the Cuyahoga, from the Ohio River in Scioto County northward to Cuyahoga County then east to the Ohio-Pennsylvania border. The rapid change between different rock types is common in marginal marine, deltaic, or fluvial depositional environments. The sediment source for the Cuyahoga was the erosion of the Devonian-age highlands and the Catskill and Pocono deltas to the east. Rivers and streams transported the eroded sediments into Ohio during the Mississippian Period.

The Cuyahoga and Logan Formations were mapped as a combined unit on the *Bedrock Geologic Map of Ohio* (Slucher and others, 2006) and individual 1:24,000-scale, reconnaissance bedrock-geology quadrangles. The detailed mapping is left for future mappers to complete. The Cuyahoga Formation and overlying Logan Formation occur along a 1–50-mi (1.6–80-km)-wide, southwest-to-northeast-oriented outcrop belt that extends from Portsmouth through Newark, Mansfield, Wooster, Akron, and Warren into northwestern Pennsylvania. The Cuyahoga ranges in thickness from 50 to 650 ft (15–198 m) and was first named in 1870 for exposures along the Cuyahoga River between Akron and Cleveland.




*Weathered and heavily gullied exposure of the shale-rich Cuyahoga Formation along U.S. 23 in Scioto County. The contact with the overlying sandstone-rich and cliff-forming Logan Formation is present near the top of the hill.*

## Diagnostic features

- Localized vertical and horizontal variability of shale, siltstone, sandstone, and conglomerate lithologies.
- Abundance of shale.

## General features

- Shale interbedded with sandstone, siltstone, and conglomerate.
- Gray, olive, brown, and yellow.
- Thin to massive bedding.
- Planar, irregular, and lenticular bedded.

## Lithologic variations

- Along the outcrop belt, some distinctive stratigraphic intervals have been recognized as members, including:
    - Southern Ohio: Henley Sh, Portsmouth Sh, and Buena Vista Ss Mbrs

- Central Ohio: Black Hand Ss and Raccoon, Fairfield, and Wooster Sh Mbrs
- Northeastern Ohio: Orangeville Sh, Sharpsville Ss, and Meadville Sh Mbrs

- In Trumbull County, the Shenango sandstone and shale occur in the lower part of the Cuyahoga Fm and both units pinch out a short distance west of the Ohio-Pennsylvania line. The Shenango ss is gray, brown, or white; thin to massive bedded; fine to coarse grained; and quartz rich. The Shenango sh is gray to brown, clay rich, thin to thick bedded and interbedded with siltstone and sandstones. The Shenango is not mapped separately but is included in the Cuyahoga and Logan undivided on the *Bedrock Geologic Map of Ohio*.

### Fossil content

- Sparsely fossiliferous with local intervals of highly fossiliferous rocks.
- Bivalves, brachiopods, gastropods, and cephalopods common.
- Bryozoans, corals, echinoderms, sponges, trilobites, and fossil vertebrates less common.
- Trace fossils common.

### Weathering characteristics

- Shale weathers to light-gray to light-brown, clay-rich colluvium on natural slopes and at bases of road cuts.
- Landslides may form in colluvium deposits subject to over-steepening by stream erosion or undercutting natural slopes.
- Sandstone and conglomerate intervals resistant to erosion and form abundant cliffs, waterfalls, gorges, rock-shelters, and natural bridges.

### Stratigraphic contacts

- Sharp upper contact.
- Sharp lower contact.

### Stratigraphic context

- Underlain by Sunbury Sh.
- Overlain by Logan Fm.
- Similar unit: Bedford Sh.

### Engineering properties

- Interbedded formation dominated by weaker shale and less prevalent strong beds, with the exception of the massive Black Hand Ss. Dominant weaker shales considered the controlling rock types in this formation where present. Shales anticipated to weather rapidly after exposure.
- Unconfined compressive strength: Unweathered shales will have low to high compressive strength; weathered shales will have low to medium compressive strength; limestone, sandstones/conglomerates, and siltstones will have medium to high compressive strength.

*Sandstone and shale*

- Slake durability: Slake durability of dominant shales ranges low to high. Limestone, sandstones/conglomerates, siltstones would have high to extremely high slake durability.
- Rippability: Weathered shale, particularly near the surface, can be ripped with some difficulty by conventional earth-moving equipment. Limestone, sandstones/conglomerates, siltstones, and shales that are not significantly weathered are resistant to ripping; blasting, breaking, or cutting would be required for rock excavation.

## Hydrogeologic properties

- A poor to moderate aquifer, typically capable of supplying water needs for households and small- to moderate-sized farms.
- Average yield: Ranges 0–5 to 5–10 gpm for shale- and siltstone-dominant portions. Yields of 5–15 gpm in areas with interbedded shale, siltstone, and sandstone. Yields range ≤20 gpm for sandstone-dominant portions.
- Yields vary with primary porosity, including permeability, sorting, and bedding planes, and secondary porosity related to joints and fractures.
- Somewhat high yields possible in weathered portion of unit.
- Aquifer rating: Typically 3 for shale-rich intervals; 4 for interbedded intervals; 4–5 for sandstone-rich intervals.
- Vadose zone rating: Typically 3 for shale-rich intervals and 4 for interbedded intervals, with 5 reported for weathered portions of sandstone-rich intervals.
- Hydraulic conductivity: 1–100 gpd/ft$^2$ for shale and siltstone; 100–300 gpd/ft$^2$ for sandstone-rich intervals.

## Environmental hazards

- Landslides occur in colluvium deposits accumulating on hillsides.
- Rockfalls from cliffs formed in sandstone and conglomerate intervals.
- People and animals falling from cliffs.

## Economic geology

- Historically, Cuyahoga Fm shale was mined for manufacture of drain tile and paving, face, and hollow bricks; sandstone was quarried for high-quality dimension stone.
- Today, Cuyahoga shale mined for production of bricks and other clay products; sandstone quarried for dimension stone, crushed or broken stone, glass sand, and other industrial uses.

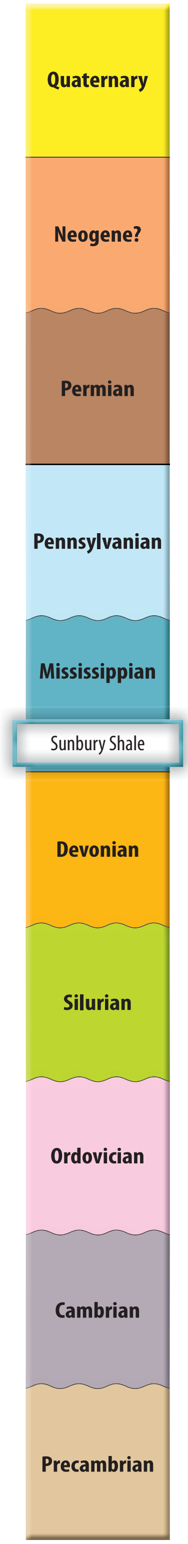
## Scenic geology

- The Black Hand Mbr of the Cuyahoga Fm is the best-known unit for forming waterfalls, cliff-lined gorges, and rock-shelter caves.
- Exposures of the Black Hand Mbr in Hocking County are well known for such spectacular scenic features as Ash Cave, Cedar Falls, Conkle's Hollow, Old Man's Cave, and Rock House.
- In Fairfield and Licking Counties, Rising Sun Park and Rock Mill Bridge Falls (in the Lancaster area) and Black Hand Gorge (east of Newark) are formed in the Black Hand Ss.

## Further reading

Hyde, 1953; Bork and Malcuit, 1979

# Sunbury Shale




The Mississippian-age Sunbury Shale is the uppermost of three major intervals of organic-rich, black shale deposited in central Ohio. Like the Ohio Shale-Huron and Cleveland Members, the Sunbury was deposited in a shallow to moderately deep tropical sea with low oxygen. Thick stratigraphic sequences of organic-rich, black shale accumulate in oxygen-poor environments because bottom-dwelling organisms that normally decompose organic matter cannot live in oxygen-starved or anoxic conditions.

The Sunbury is mainly buried under Quaternary-age sediments along a 1- to 5-mi (1.6–8.0-km)-wide, north–south outcrop belt through central and northern Ohio. The Sunbury intertongues and intergrades into the basal Cuyahoga Formation from southern Huron County to northern Franklin County. In northwest Ohio, the Sunbury lies under thick deposits of unconsolidated sediments and is not exposed. From central Ohio southward to the Ohio River, the Sunbury Shale, Berea Sandstone, and Bedford Shale are grouped together in a single undivided map unit. The Sunbury ranges in thickness from 30 to 90 ft (9–27 m) and was named for the town of Sunbury (eastern Delaware County), where the unit was first described in 1878.


*The sharp contact between the thick sandstone beds of the Berea Sandstone and the overlying black, organic-rich shales of the Sunbury Shale. Road cut for S.R. 32 on Tener Mountain in Pike County. Scale is 50 cm (1.6 ft).*

## Diagnostic features
- Brownish-black shale.
- Organic rich.
- Petroliferous odor.

## General features
- Laminated to thin bedded.
- Fissile partings.
- Iron-stained shale chips common in soils and colluvium weathered from the Sunbury.

## Lithologic variations
- Brownish-black, laminated, organic-rich shales characterizing the Sunbury Sh are remarkably uniform in character along the outcrop belt.

**Fossil content**
- Sparsely fossiliferous.
- Rare fish remains, plant fossils, and brachiopods occur locally.

**Weathering characteristics**
- Somewhat resistant to weathering.
- Weathers from dark brown and black to gray.
- High iron content in some beds results in rust-colored ground water and staining on the Sunbury Sh and underlying Berea Ss.
- In rock cuts, weathered shale forms loose talus slopes.

**Stratigraphic contacts**
- Sharp upper contact.
- Sharp lower contact.

**Stratigraphic context**
- Underlain by Berea Ss, except in northwestern Ohio where underlain by the Bedford Sh.
- Overlain by Cuyahoga Fm, except in northwestern Ohio where overlain by the Coldwater Sh.
- Similar units: Cleveland and Huron Shale Mbrs of the Ohio Shale.

**Engineering properties**
- Unconfined compressive strength: Unweathered shale will have medium to high compressive strength; weathered shale will have low to medium compressive strength.
- Slake durability: Shale beds subject to degradation after exposure; slake durability ranges low to high.
- Rippability: Shale beds resistant to ripping and may require cutting, breaking, or blasting for rock excavation.

**Hydrogeologic properties**
- Typically poor aquifer; generally suitable for limited household or small farm use.
- Average yield: 3–5 gpm. Max. yield: 10 gpm.
- Yield predominantly comes from combination of joints and fractures as they intersect bedding planes.
- Best yields develop from uppermost, weathered portion of formation.
- Wells may be drilled deeper in the formation to obtain additional borehole storage.
- High sulfide and iron contents may represent a water quality problem.
- For best results, wells should be drilled through the Sunbury Sh and completed in the underlying Berea Ss. This allows the Sunbury Sh to be cased off, if water quality is objectionable.
- Wells drilled into overlying Cuyahoga Fm may be extended into the Sunbury if extra well-bore storage is needed, as long as water quality is not objectionable.
- Aquifer rating: 2–3.
- Vadose zone rating: 2–3.
- Hydraulic conductivity: 1–100 gpd/ft$^2$.

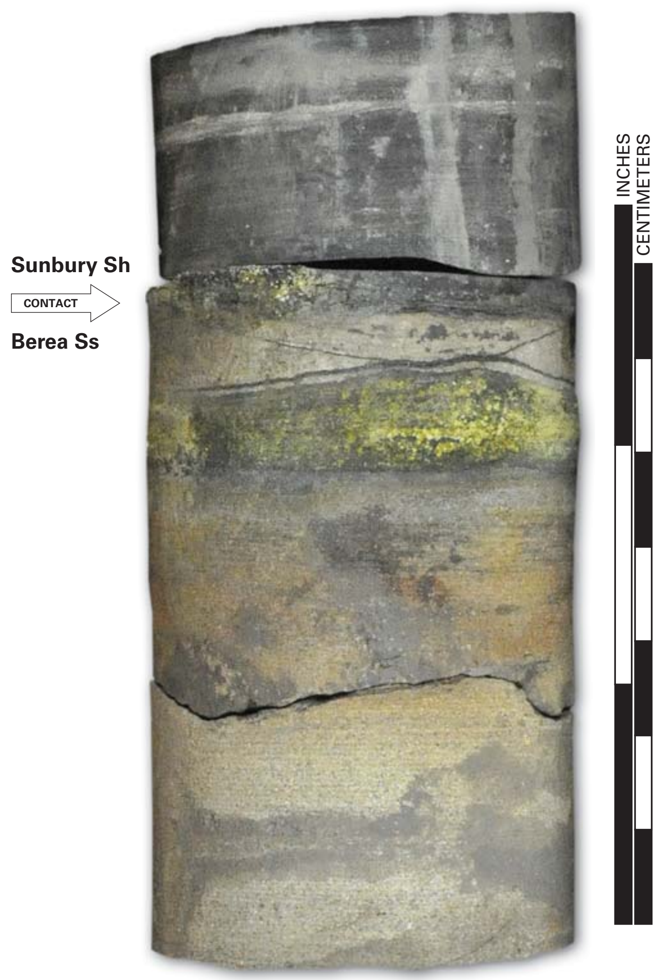
**Environmental hazards**
- Organic-rich Sunbury Sh is combustible; open burning near exposures of this unit is discouraged.
- Contains small amounts of uranium and is a source of radon, a naturally occurring, radioactive gas that migrates into buildings. Radon is a known cancer-causing agent.

**Economic geology**
- Source of petroleum and natural gas.

**Scenic geology**
- None.

**Further reading**

Hoover, 1960




*Sunbury Sh-Berea Ss contact*

# Berea Sandstone

The Berea Sandstone is characterized by fine- to medium-grained sandstone deposited in deltas that formed along the margins of the shallow tropical seas that covered Ohio during the Late Devonian. The sand comprising the Berea was eroded from older sandstones and transported by rivers and streams from the Acadian Highlands into Ohio.

The erosion-resistant Berea Sandstone, historically known as the "cliff stone" in southern Ohio, commonly forms low ridges or ridge tops, small gorges, and waterfalls. In southern Ohio, the Berea caps many of the narrow, sinuous ridges forming the Allegheny Escarpment and is exposed in the Scioto River valley. The Berea Escarpment is a north–south-oriented set of ridges rising 50 to 100 ft (15–30 m) above the adjacent lowlands of central and northern Ohio. East of Cleveland, the Berea and younger Mississippian and Pennsylvanian rocks form the Portage Escarpment. The Berea Sandstone, named for exposures near the City of Berea in Cuyahoga County, ranges in thickness from 1 to 155 ft (0.3–47 m).


*Contact between the thin bedded sandstone and shale of the Bedford Shale with the overlying, thick sandstone beds of the Berea Sandstone. The Berea in this exposure contains the prominent widespread interval of soft-sediment deformation characterizing the base of the unit.*

## Diagnostic features

- Dominance of sandstone over sandy shale.
- Fine to medium grain size.
- Prominent, widespread zone of soft-sediment deformation occurs in basal part of unit.

## General features

- Bluish gray, gray, light brown.
- Thin to thick bedded.
- Planar to lenticular bedding.

## Lithologic variations

- Highly variable in thickness.
- Grain size decreases north to south along outcrop belt.
- Amount of interbedded shale increases in southern Ohio.

### Fossil content
- Non-fossiliferous to sparsely fossiliferous.
- Fish teeth and skeletal remains, plant fossils, and brachiopods occur locally.

### Weathering characteristics
- Weathers from gray to medium brown to dark brown.
- Resistant to weathering.

### Stratigraphic contacts
- Sharp upper contact.
- Sharp lower contact.

### Stratigraphic context
- Underlain by Bedford Sh.
- Overlain by Sunbury Sh.

### Engineering properties
- Unconfined compressive strength: Unweathered sandstones will have medium to high compressive strength that diminishes with presence of siltstone and shale; weathered portions will have low to high compressive strength, depending on degree of weathering.
- Slake durability: Expected to have high slake durability in sandstone units. Siltstone and less-common shales more susceptible to slaking.
- Rippability: Resistant to ripping except where highly weathered. Typically requires breaking; blasting is required for rock excavation.

### Hydrogeologic properties
- Moderate aquifer capable of supplying water needs for households and small- to moderate-sized farms.
- Average yield: 5–15 gpm in central Ohio. Max. yields: 25–35 gpm.
- Max. yields exceeding 50 gpm reported for thicker, highly-fractured sections in northeastern Ohio.
- Yields vary with primary porosity, including permeability, sorting, and bedding planes, and secondary porosity related to joints and fractures.
- Somewhat high yields possible in weathered portion of unit.
- Sulfide may be a water quality factor.
- In eastern Ohio, Berea encountered at greater depths and may contain brine or petroleum.
- Aquifer rating: 4, with 5 reported for limited areas in northeastern Ohio.
- Vadose zone rating: Typically 4, with 5 reported for weathered regions in northeastern Ohio.
- Hydraulic conductivity: 1–100 gpd/ft$^2$ to 100–300 gpd/ft$^2$.

### Environmental hazards
- Generally forms stable cliffs but will produce rock falls if less-resistant Bedford Sh erodes and undercuts overlying Berea.
- People and animals falling from cliffs and gorge walls.

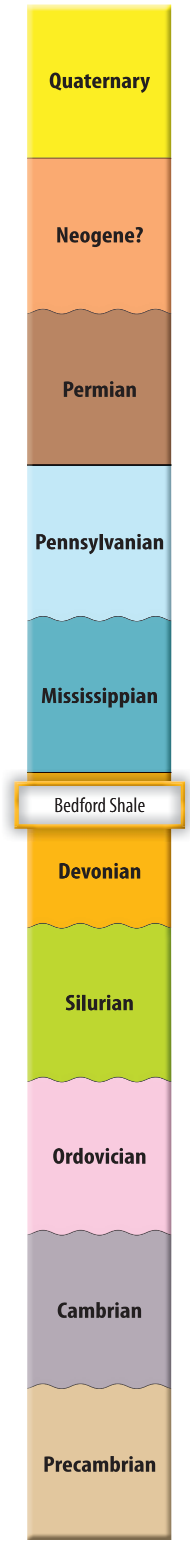
### Economic geology
- Historically, the Berea was the principal source of grindstones and was used as dimension stone in many historic buildings throughout Ohio.
- Quarried for use as dimension stone, flagstone, aggregate, and riprap.
- In the subsurface of Ohio, Berea reservoirs produce oil and natural gas.

### Scenic geology
- Erosion-resistant character produces many waterfalls and stream gorges statewide. In the Cleveland area, the more scenic features include Brandywine Falls, Buttermilk Falls, Berea Falls, and Chagrin Falls.
- Excellent exposures are present within Deep Lock Quarry Metro Park of Summit County and many other streams located in the Cuyahoga Valley NP and Cascade and Elywood Parks in Elyria.
- Allegheny Escarpment of southern Ohio.

### Further reading
Bownocker, 1915; Pepper and others, 1954

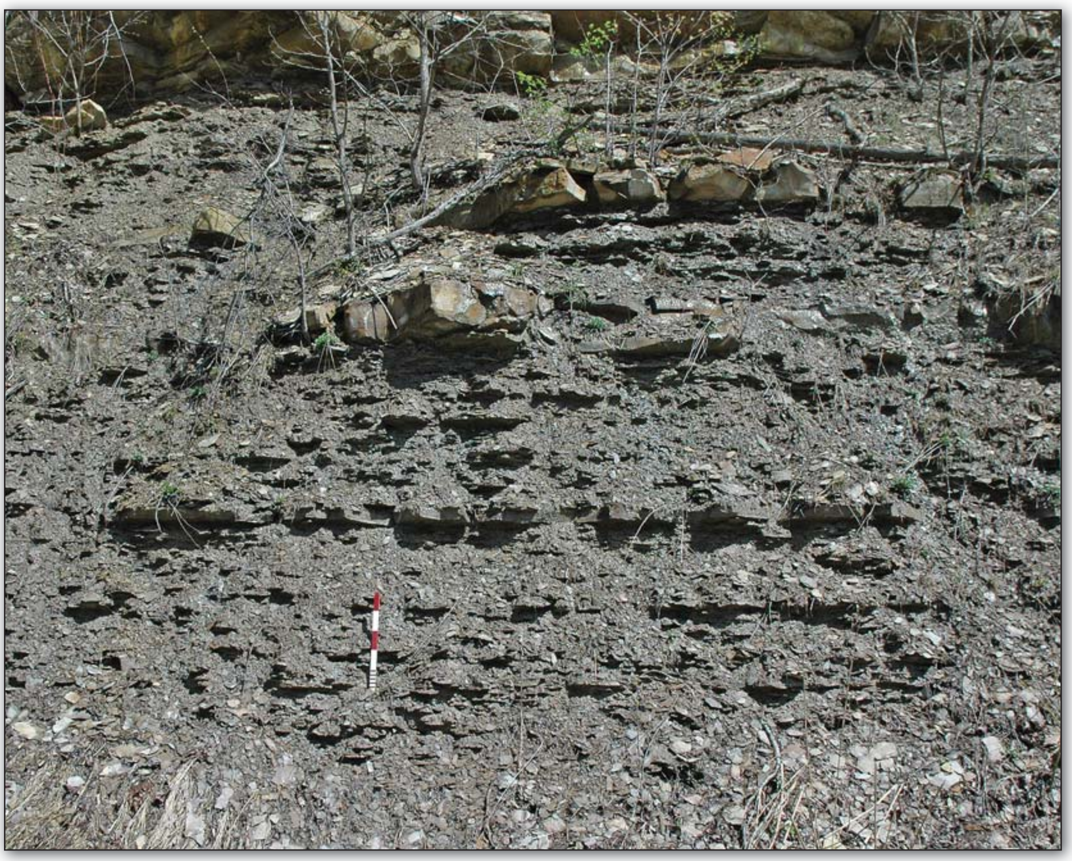

*Sandstone and shale; note soft-sediment deformation at base of upper sandstone bed*

# Bedford Shale




The Bedford Shale is distinguished by interbedded shale, siltstone, and sandstone. Deposited in a shallow tropical sea that covered much of Ohio during the Late Devonian, the mud, silt, and sand that formed the Bedford Shale was transported by rivers and streams originating in the Acadian Highlands and Devonian-age Catskill and Pocono deltas to the east. The predominance of siltstone and sandstone beds in the upper part of the Bedford represents the change from offshore marine deposition to the beginning of deltaic sedimentation.

The Bedford Shale is frequently concealed under undifferentiated Quaternary-age deposits along much of the north–south outcrop belt that extends from the Ohio River, northward through the eastern Columbus suburbs, into Huron and Erie Counties. East of Huron and Erie Counties, the unit parallels Lake Erie to the Ohio-Pennsylvania border. Exposures of the Bedford are largely restricted to stream exposures in areas of thin glacial deposits. The unit was named for exposures on Tinkers Creek near the town of Bedford in Cuyahoga County. The Bedford Shale ranges in thickness from 60 to 155 ft (18–47 m).



*Interbedded shale and sandstone beds in the upper part of the Bedford Shale exposed in a road cut for U.S. 23 north of Waverly, Pike County. Scale is 50 cm (1.6 ft).*

## Diagnostic features

- Gray shale interbedded with siltstone and sandstone in southern Ohio.
- Gray shale and intervals of red and brown shale interbedded with siltstone and sandstone in central and northern Ohio.
- Siltstone and sandstone beds increasing in abundance upward through the unit.

## General features

- Laminated to medium bedded.
- Gray, bluish gray, green, red, or brown.

- Ripple marks and cross-laminations common in siltstone and sandstone beds.

## Lithologic variations
- In southern Ohio: Generally gray to bluish gray and contains abundant siltstone and sandstone beds in the upper half of the unit.
- In central and northern Ohio: Red and green shale beds, presence of siltstone and sandstone beds restricted to very top of unit. Widespread zone of contorted and deformed bedding present in upper part of the Bedford Sh and basal Berea Ss.
- In Ashtabula and Trumbull Counties: Cussewago Ss underlies the Bedford Sh and overlies the Ohio Sh. Cussewago best developed in northwestern Pennsylvania and is a quartz-rich, yellow to brown, massive to cross-bedded, pebbly sandstone averaging about 30 ft (9 m) thick. Cussewago was included as part of Berea Ss and Bedford Sh undivided unit mapped in this region.

## Fossil content
- Sparsely fossiliferous.
- Basal Bedford contains a low-diversity fauna of brachiopods, bivalves, and gastropods in some regions.
- Pyrite-filled burrows rare to common.

## Weathering characteristics
- Weathers rapidly to light-gray or brown clay because of repeated wetting/drying and freeze/thaw cycles.
- Forms thick colluvium on the steep hill slopes of southern Ohio.

## Stratigraphic contacts
- Sharp upper contact.
- Sharp lower contact.

## Stratigraphic context
- Underlain by Ohio Sh or Cussewago Ss in Ashtabula and Trumbull Counties.
- Overlain by Berea Ss.
- Similar units: Olentangy Sh, some intervals of Chagrin Mbr of Ohio Sh, and Cuyahoga Fm.

## Engineering properties
- Unconfined compressive strength: Unweathered shale will have medium to high compressive strength; weathered shale will have low to medium compressive strength. Presence of sandstone and other resistant beds will locally increase unconfined compressive strength of the rock.
- Slake durability: Shale beds subject to degradation after exposure and slake durability ranges low to medium.
- Rippability: Unweathered shale is resistant to ripping and requires blasting, breaking, or cutting for rock excavation. Weathered shale can be excavated with earth-moving equipment.

## Hydrogeologic properties
- Typically very poor aquifer with minimal yields; rarely suitable for even domestic use.
- Average yields: <3 gpm. Max. yield: <5 gpm.
- Yields most likely obtained from fracture zones and upper, weathered portion of this unit.
- For ground-water modeling purposes, may be considered a lower-confining unit or boundary unit when compared to overlying, sandstone-rich units.
- Aquifer rating: 1–2.
- Vadose zone rating: 1–2.
- Hydraulic conductivity: 1–100 gpd $ft^2$.

## Environmental hazards
- Landslides common in thick colluvium formed from weathering of the Bedford Sh.
- Rock falls of overlying Berea Ss as the less-resistant Bedford is eroded from under the more-resistant Berea.

## Economic geology
- Bedford Sh formerly used to manufacture bricks and drain tiles.
- In 2011, the Bedford was mined for manufacture of bricks and other common clay products and construction materials.

## Scenic geology
- Allegheny Escarpment of southern Ohio.
- In northern Ohio, the Bedford is somewhat resistant to erosion and may form steep cliffs along some streams of the region.

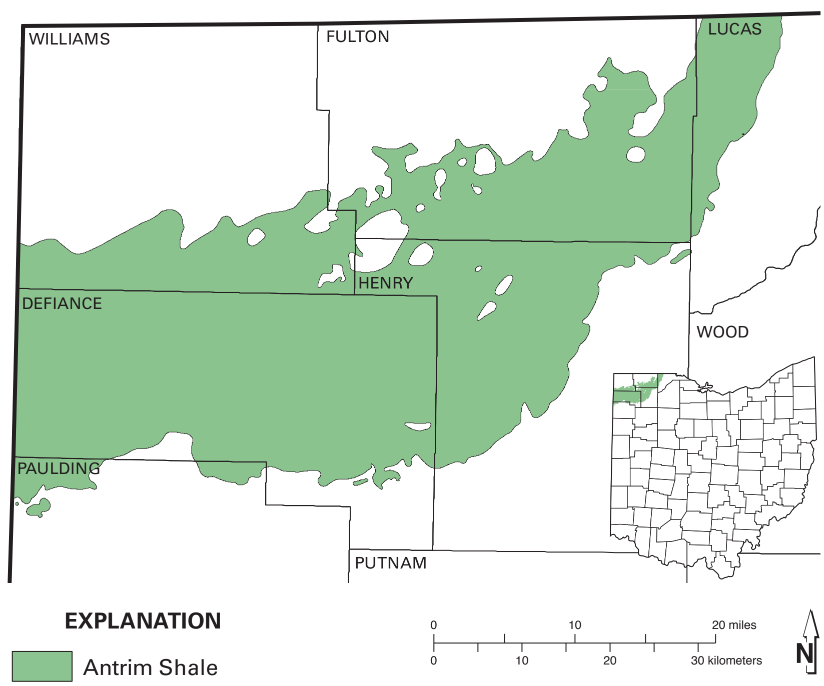
## Further reading
Hansen, 2001; Pashin and Ettensohn, 1995


*Shale with sandstone laminations*

# Antrim Shale


The Antrim Shale is dominated by organic-rich, brown to black shale with subordinate amounts of gray shale. The unit was deposited in a shallow to moderately deep tropical sea with limited oxygen in both the water column and sea floor sediments. For long time periods, the sea and bottom sediments lacked oxygen, so no oxygen-breathing organisms could survive in this anoxic environment. Thus thick sequences of organic-rich, brown to black shale accumulated because burrowing and bottom-dwelling organisms that normally consumed any accumulating organic matter in the sediments could not live in this environment.

The Antrim is mapped in northwestern Ohio along a crescent-shaped belt ranging from 5 to 20 mi (8–32 km) in width that extends from the Ohio-Michigan border through Lucas, Fulton, Henry, Defiance, and Paulding Counties to the Ohio-Indiana border. Along the outcrop belt, the Antrim is buried under extensive deposits of Quaternary materials except for a few exposures in the river beds and low valley walls of the Maumee and Auglaize Rivers. The name Antrim Shale was introduced in 1901 to describe type-section exposures located in Antrim County, Michigan. The unit ranges in thickness from 0 to 230 ft (0–70 m). Historically, some of the basal gray shale was used in the manufacture of Portland cement.




*The outcrop belt of the Antrim Shale as mapped in northwestern Ohio. Extensive Quaternary deposits cover much of the outcrop belt and limit exposure of the Antrim Shale to the river beds and low valley walls of the Maumee and Auglaize Rivers.*

## Diagnostic features

- Brown to black shale.
- Organic rich.
- Petroliferous odor.
- Occasional pyrite and gypsum laminations, crystals, and nodules.
- Fissile partings.

## General features

- Laminated to thin bedded.
- Rare to occasional interbeds with calcareous, gray shale.

## Lithologic variations

- Gray shale laminations and beds vary in abundance throughout the unit.
- Amount of pyrite and gypsum is highly variable throughout the unit.

## Fossil content
- Abundant organic matter derived from microscopic plants and animals.
- Rare skeletal remains of plants and animals.

## Weathering characteristics
- Weathers from brown and black to gray-brown to gray.
- In rock cuts, weathered shale forms loose talus slopes.
- High iron content in some beds results in rust colored ground water and staining of household fixtures.

## Stratigraphic contacts
- Sharp upper contact.
- Sharp lower contact.

## Stratigraphic context
- Underlain by Traverse Gp.
- Overlain by Bedford Sh.
- Similar units: Ohio Sh, Sunbury Sh.

## Engineering properties
- Unconfined compressive strength: Unweathered shale will have medium to high compressive strength; weathered shale will have extremely low to medium compressive strength.
- Slake durability: Shales subject to degradation after exposure, with the gray shales being more susceptible than the black-brown shales. Slake durability of the shale of this formation can range from medium to high in unweathered rock.
- Rippability: Weathered shaley beds, particularly near the surface, can be ripped by conventional earth-moving equipment. Unweathered shales of the formation would require blasting, breaking, or cutting for rock excavation.

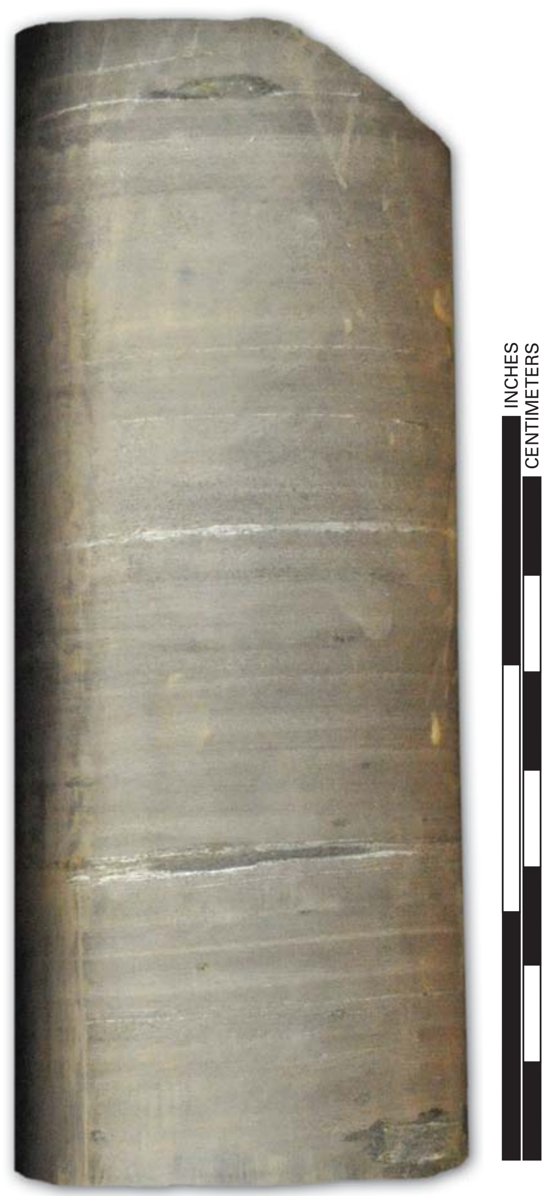
## Hydrogeologic properties
- Typically a poor aquifer; generally suitable for limited household or small farm use.
- Average yield: 3–5 gpm. Max. yield: 10 gpm.
- Yield predominantly comes from combination of joints and fractures as they intersect bedding planes.
- Best yields developed from uppermost weathered portion of formation.
- Wells may be drilled deeper in the formation to obtain additional borehole storage.
- High sulfide and iron content may represent a water quality problem.
- For ground-water modeling, may be considered a lower-confining unit or boundary unit when compared to overlying sandstone and shale units.
- Aquifer rating: 2–3.
- Vadose zone rating: 2–3.
- Hydraulic conductivity: 1–100 gpd/$ft^2$.

## Environmental hazards
- Organic-rich Antrim Sh is combustible; open burning near exposures of this unit is discouraged.
- Antrim Sh is a uranium-bearing rock and a source of radioactive radon gas. Long-term exposure to radon may cause cancer in humans.

## Economic geology
- Natural gas source rock and reservoir.
- Potential source of petroleum.

## Scenic geology
- None.

## Further reading
Hoover, 1960; Harrell and others, 1993; Hansen, 1999



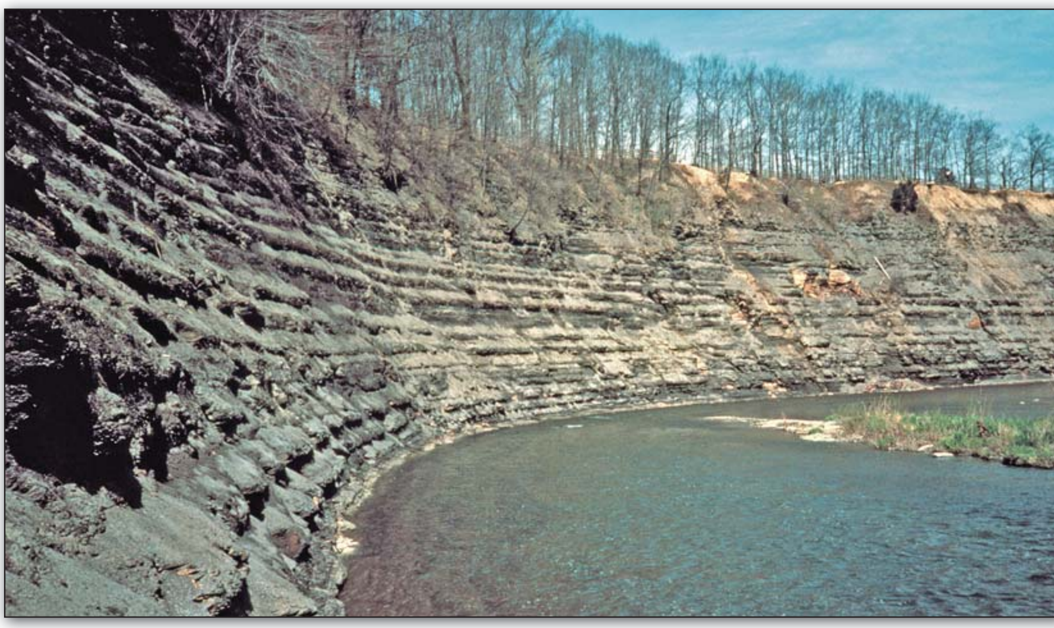

*Organic-rich shale*

# Ohio Shale

The Ohio Shale is dominated by organic-rich, brown to black shale with subordinate amounts of gray shale. The unit was deposited in a shallow to moderately deep tropical sea with limited oxygen in the water column and sea floor sediments. Thick stratigraphic sequences of organic-rich, brown to black shale accumulated in oxygen-poor environments because burrowing and bottom-dwelling organisms that normally consumed any accumulating organic matter could not live in oxygen-starved conditions.

The Ohio Shale contains two major intervals of organic-rich shale, the Huron and Cleveland Members, separated by the Chagrin Member. The Chagrin Member is characterized by gray shale containing limited organic matter that was deposited during periods when oxygen-rich waters returned to the sea bottom. The Chagrin may also contain brown or black shale beds.

The Ohio Shale forms the bedrock underlying the cities of Columbus and Cleveland. The unit was named after the hills adjacent to the Ohio River in southern Ohio. Mapped along a 5- to 20-mi (8–32-km)-wide band, the unit bisects the state and parallels the Lake Erie shoreline in northeastern Ohio. Along the outcrop belt, the Ohio Shale ranges in thickness from 250 to over 500 ft (76–152 m) and thickens to over 4,000 ft (1,219 m) in the deep subsurface along the Ohio River in eastern Ohio.



*Cleveland Shale Member exposed at Fort Hill along the Rocky River in Cuyahoga County.*


### Diagnostic features

- Brown to black shale.
- Organic rich.
- Petroliferous odor.

### General features

- Laminated to thin bedded.
- Fissile partings.
- Rare limestone beds with cone-in-cone structures.

### Lithologic variations

- Huron Shale Mbr: Brown to black, laminated, organic-rich shale with carbonate/siderite concretions.
- Chagrin Shale Mbr: Dark- to medium-gray shale with interbedded siltstone and sandstone beds. The Chagrin thins southward and becomes the Three Lick Bed of the Ohio Sh, a widespread marker horizon consisting of three distinct, gray shale beds separated by thin, brownish-black shale beds.

*Concretions from the Huron Shale Member forming the stream bed of Deer Creek in Pickaway County.*

- Cleveland Shale Mbr: Brown to black, laminated, organic-rich shale; resembles Huron Shale Mbr (without abundant carbonate/siderite concretions) and Sunbury Sh.

## Fossil content

- Abundant organic matter derived from microscopic fossil animals and plants.
- Rare skeletal remains of plants and animals, except for the Huron Mbr *Foerstia* algal spore zone, correctly known as *Protosalvinia,* and the relatively common fish fossils found in the Cleveland Mbr.
- Occasional plant and animal fossils occur inside concretions from the Huron Mbr and Cleveland Mbr.

## Weathering characteristics

- Weathers from brown and black to gray-brown to gray.
- Rusty red iron-stained shale chips common in soils and colluvium weathered from the Ohio Sh.
- High iron content in some beds results in rust-colored ground water and staining of household fixtures.
- Repeated cycles of wetting/drying and freeze/thaw result in rapid breakdown.
- In rock cuts, weathered shale forms loose talus slopes.

## Stratigraphic contacts

- Sharp upper contact.
- Sharp to gradational lower contact, intertongues with Olentangy Sh.

## Stratigraphic context

- Underlain by Olentangy Sh.
- Overlain by Bedford Sh.
- Similar units: Antrim Sh, Sunbury Sh.


*Cleveland Shale Mbr*

## Engineering properties

- Unconfined compressive strength: Unweathered shale will have medium to high compressive strength; weathered shale will have low to medium compressive strength.
- Slake durability: Shale beds subject to degradation after exposure; slake durability ranges low to high.
- Rippability: Weathered shale beds, particularly near the surface, can be ripped with conventional earth-moving equipment. Unweathered shale beds more resistant to ripping and require blasting, breaking, or cutting for rock excavation.

## Hydrogeologic properties

- Typically poor aquifer; generally suitable for limited household or small farm use.
- Average yield: 3–5 gpm. Max. yield: 10 gpm.
- Yield predominantly comes from combination of joints and fractures as they intersect bedding planes.
- Best yields developed from uppermost weathered portion of formation.
- Wells may be drilled deeper in the formation to obtain additional borehole storage.
- High sulfide and iron content may represent a water quality problem.
- For ground-water modeling, may be considered a lower-confining unit or boundary unit when compared to overlying sandstone and shale units.
- Aquifer rating: 2–3.
- Vadose zone rating: 2–3.
- Hydraulic conductivity: 1–100 gpd/ft$^2$.

## Environmental hazards

- Organic-rich Huron Mbr and Cleveland Mbr are combustible; open burning near exposures of these members is discouraged.
- Uranium-rich in Ohio and a source of radioactive radon gas. Radon is a known cancer-causing agent.

## Economic geology

- Natural gas source rock and reservoir in eastern Ohio and in the subsurface adjacent to outcrop belt of central and northeastern Ohio.
- Potential source of petroleum.
- Historically, the Chagrin Mbr was mined to manufacture face and paving bricks in northeast Ohio.
- In central Ohio, shale mined from the Ohio Sh was mixed with the Olentangy Sh to produce drain tiles and bricks.

## Scenic geology

- Erosion-resistant character produces numerous steep exposures and gorges statewide.
- In southern Ohio, forms slopes of the Allegheny Escarpment in Ross, Pike, Highland, and Adams Counties.


*Black, organic-rich shale of the Cleveland Shale Mbr in contact with the gray shale of the Chagrin Shale Mbr*


*Deformed, inclined bedding in the Huron Shale Mbr resulting from soft-sediment deformation and compaction around the base of a light-brown concretion*

- Well exposed along the southern valley wall of Paint Creek in Ross County near Seip Mound at Copperas Mountain.
- In northeastern Ohio, present in the scenic gorges of Conneaut Creek and the Ashtabula, Grand, and Huron Rivers. Good exposures in Hidden Valley, Hogback Ridge, Indian Point, and Paine Falls Parks; Penitentiary Glen Reservation; Hach-Otis SNP; and Hell Hollow Wilderness Area.
- In north-central Ohio, Lorain County Metro Parks: Black River, French Creek, Schoepfle, and Vermilion River Reservations.

### Further reading

Hoover, 1960; Schopf and Schwietering, 1970; Hansen, 1999; Hellstrom and Babcock, 2000

# Olentangy Shale


Beginning at its base, the Olentangy Shale exhibits a gradual change from shale interbedded with nodular limestone to gray shale interbedded with brownish-black, organic-rich shale. This change illustrates a major transition in depositional environments—from carbonate deposition in tropical seas teeming with carbonate-shelled organisms to siliciclastic deposition in tropical seas, favoring the accumulation of organic-rich sediments because of low oxygen levels in the water column and bottom sediments.

The Olentangy commonly is buried under Quaternary-age sediments along a narrow, north–south-oriented outcrop belt extending from the Lake Erie shoreline in Erie County, through central Ohio, southward to the Ohio River. River and stream exposures are the best places to examine the Olentangy, which was named for a large exposure along the Olentangy River just south of Delaware, Ohio. The Olentangy ranges in thickness from 20 to 55 ft (6–17 m). Historically, clay from the Olentangy was mined for use in manufacturing drainage tile and hollow bricks.


*Type locality of the Olentangy Shale exposed along the banks of the Olentangy River, south of Delaware, Delaware County. The low hydraulic conductivity of the Olentangy is well illustrated by the line of springs and associated mineral deposits occurring along the contact with the overlying Ohio Shale.*

## Diagnostic features

- Gray to greenish-gray shale interbedded with discontinuous beds and limestone nodules (lower portion).
- Thin beds of gray shale interbedded with brownish-black to brown shale (upper portion).

## General features

- Thin bedded.
- Clayey shale.
- Platy to fissile partings.
- Disseminated pyrite.
- Sparsely fossiliferous.

## Lithologic variations
- Characteristic limestone beds and nodules of lower portion are absent south of Delaware County.

## Fossil content
- Fossils generally rare; fossils common locally and consist of brachiopods, crinoids, cephalopods, ostracodes, and tentaculitids.
- Trace fossils range from rare to common.

## Weathering characteristics
- Rapidly weathers to light-gray clay because of wetting/drying and freeze/thaw cycles.
- Forms relatively thick colluvium.

## Stratigraphic contacts
- Sharp to gradational upper contact.
- Sharp lower contact.

## Stratigraphic context
- Underlain by Delaware Ls.
- Overlain by Ohio Sh.
- Similar units: Bedford Sh.

## Engineering properties
- Unconfined compressive strength: Unweathered shale will have low to medium compressive strength; weathered shale will have low to medium compressive strength.
- Slake durability: Shales subject to degradation after exposure and slake durability ranges medium to high.
- Rippability: Weathered shale beds, particularly near the surface, can be ripped by conventional earth-moving equipment. Unweathered shale beds more resistant to ripping and require blasting, breaking, or cutting for rock excavation.

## Hydrogeologic properties
- Typically poor aquifer with minimal yields; suitable for limited household and small farm usage.
- Average yield: 3–5 gpm. Max. yield: 10 gpm.
- Yields provided by combination of joints and fractures as they intersect bedding planes.
- Due to soft, clayey nature, the weathered portion may or may not be higher yielding than unweathered portions.
- For ground-water modeling, may be considered a lower confining unit or boundary unit.
- Olentangy Sh and Ohio Sh have similar hydrogeologic properties and may be mapped together.
- Aquifer rating: 2–3.
- Vadose zone rating: 2–3.
- Hydraulic conductivity: 1–100 gpd/ft$^2$.

## Environmental hazards
- Small landslides may occur in thick colluvium derived from the Olentangy Sh.

## Economic geology
- Currently, not used as a raw material for manufacturing or other commercial activities.
- Historically, unit was mined for manufacture of drain tile and bricks.

## Scenic geology
- None.

## Further reading
Hoover, 1960

*Gray shale*

# Prout Limestone

The Prout Limestone is characterized by microcrystalline to fine-crystalline limestone that may be locally dolomitic. These rocks were deposited in nearshore environments consisting of shoreline and shallow-offshore environments with occasional coral reefs. The Prout is mapped along a narrow (0.1- to 1-mi [0.2–1.6-km]-wide) band beginning in the northeastern corner of Seneca County, continuing northeastward through the northwestern corner of Huron County, and through western Erie County to the Lake Erie shoreline. The unit is poorly exposed because it is largely buried under Quaternary-age sediments. The Prout was named for exposures in the vicinity of the historic village of Prout, located in Erie County. Thickness is highly variable, ranging from 0 to 9 ft (0–3 m).

*The Prout Limestone exposed in thin to medium beds of microcrystalline to fine-crystalline limestone along Pipe Creek, Erie County. Scale is 50 cm (1.6 ft).*

## Diagnostic features
- Microcrystalline to fine-crystalline limestone, locally dolomitic.

## General features
- Gray to brownish-gray and brown to black organic-rich laminae.
- Argillaceous, in part.
- Lenticular and irregular bedding.
- Thin to thick bedded.
- Intercrystalline, intergranular, vuggy, and fracture porosity, primarily in dolomitic beds.
- Pyrite occurs throughout the unit.

## Lithologic variations
- Locally, chert occurs just below the upper contact with the Ohio Sh.

## Fossil content
- Silicified fossils range from rare to very abundant.
- Brachiopods, corals, and crinoids common.
- Trace fossils relatively common in argillaceous beds.

**Weathering characteristics**
- Resistant to weathering and forms small riffles and low cliffs along streams.

**Stratigraphic contacts**
- Sharp upper contact.
- Sharp lower contact.

**Stratigraphic context**
- Underlain by the Plum Brook Sh.
- Overlain by Ohio Sh.

**Engineering properties**
- Unconfined compressive strength: Unweathered will have a medium to high compressive strength.
- Slake durability: Expected to have high to very high durability.
- Rippability: Should be considered resistant to ripping. Blasting, breaking, or cutting is required for rock excavation.

**Hydrogeologic properties**
- Due to both limited areal extent and thickness, it is typically not considered an aquifer.
- Wells would typically pass though this unit and the underlying Plum Brook Sh to be completed in the deeper underlying limestone.
- Aquifer rating: 2–3.
- Vadose zone rating: 2–3.
- Hydraulic conductivity: 1–100 gpd/$ft^2$.

**Environmental hazards**
- No associated environmental hazards.

**Economic geology**
- Currently, not used as a raw material for manufacturing or other commercial activities.
- Historically, the abundant chert/flint occurring in the upper part of the Prout was used by prehistoric Native Americans as tools and weapon points.

**Scenic geology**
- None.

**Further reading**
Hatfield, 1988; Slucher and others, 2006

*Fossiliferous, finely crystalline limestone*

# Plum Brook Shale

The Plum Brook Shale is characterized by blue-gray to gray, calcareous shale interbedded with fine-grained limestone and dolomitic limestone. These rocks were deposited in the offshore region of a shallow tropical sea with abundant fauna of sea creatures that either burrowed into the sea floor or lived on the sea floor or in the overlying sea. The Plum Brook is mapped along a narrow (1- to 2-mi [1.6–3.2-km]-wide) band beginning in the northeastern corner of Seneca County, continuing northeastward through the northwestern corner of Huron County, and through western Erie County to the Lake Erie shoreline. The unit was named for exposures along Plum Brook (Erie County) and ranges in thickness from 20 to 60 ft (6–18 m).

*Plum Brook Shale displaying the characteristic gray, calcareous shale interbedded with fine-grained limestone and dolomitic limestone along Plum Brook, Erie County. Scale is 20 cm (0.66 ft).*

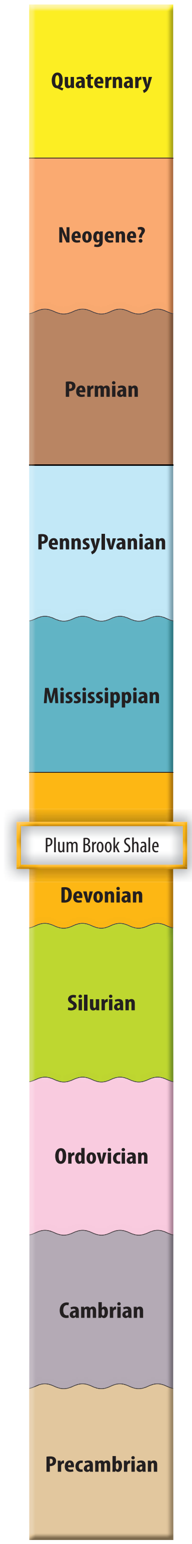
## Diagnostic features
- Blue-gray to gray, calcareous shale.
- Fine-grained limestone and dolomitic limestone.
- Pyrite nodules and individual crystals occur throughout unit but are more common in lower portions.

## General features
- Thin to thick bedded.
- Planar, irregular, and rare nodular bedding.
- Platy to flaggy partings in shale beds.

## Lithologic variations
- Fossiliferous shale beds common in upper part of unit.

## Fossil content
- Abundant fauna of brachiopods, bryozoans, crinoids, corals, and trilobites.
- Trace fossils vary from rare to common.

## Weathering characteristics
- Not resistant to weathering.
- Produces abundant colluvium that results in poor exposure of the unit.



## Stratigraphic contacts
- Sharp upper contact.
- Sharp lower contact.

## Stratigraphic context
- Underlain by Delaware Ls.
- Overlain by Prout Ls.

## Engineering properties
- Unconfined compressive strength: Unweathered shale will have low to high compressive strength; weathered shale will have extremely low to medium compressive strength; limestone will have a high compressive strength.
- Slake durability: Shales subject to rapid degradation after exposure. Slake durability of the shale of this formation can range from medium to high in unweathered rock. Weathered portions of unit range from extremely low to medium.
- Rippability: Weathered shale beds, particularly near the surface, can be ripped by conventional earth-moving equipment. Unweathered shale beds more resistant to ripping and require blasting, breaking, or cutting for rock excavation.

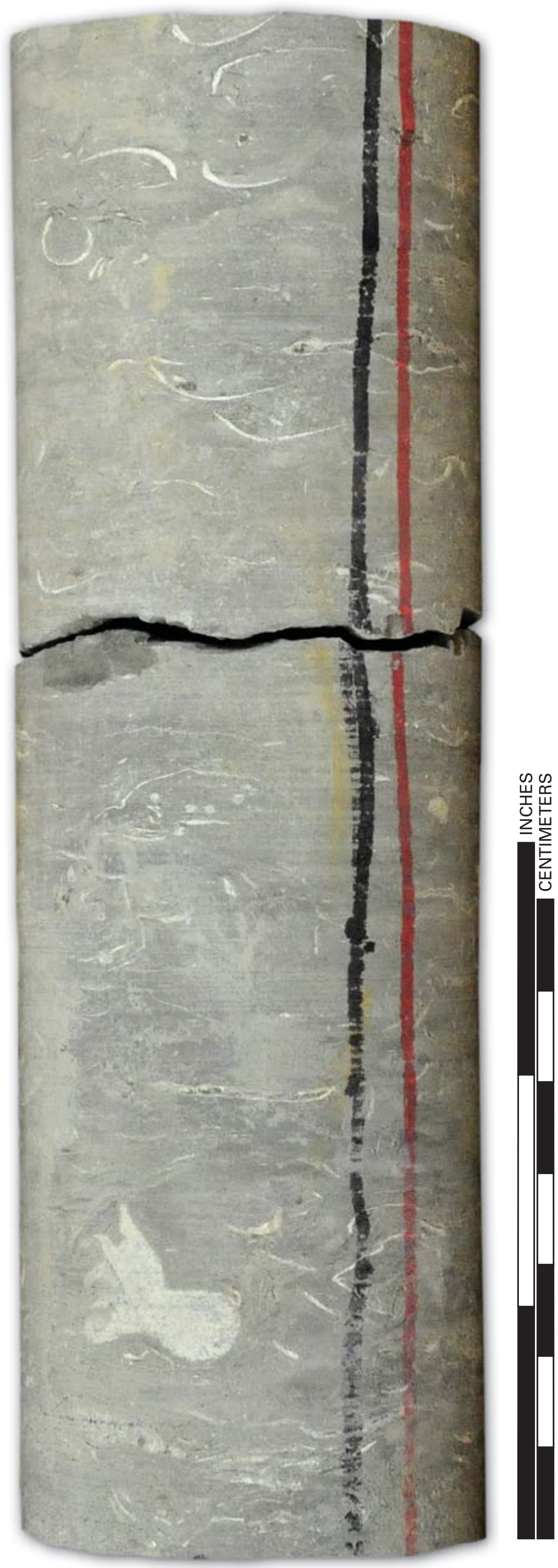
## Hydrogeologic properties
- Typically poor aquifer with minimal yields; suitable for limited household and small farm usage.
- Average yield: 3–5 gpm. Max. yield: 10 gpm.
- Yields provided by a combination of joints and fractures as they intersect bedding planes.
- Unit is typically too thin and too low-yielding to be a good aquifer; wells will typically be extended into underlying limestone units.
- Aquifer rating: 2–3.
- Vadose zone rating: 2–3.
- Hydraulic conductivity: 1–100 gpd/ft$^2$.

## Environmental hazards
- Potential landslide development in thick colluvium derived from the Plum Brook.

## Economic geology
- Currently, not used as raw material for manufacturing or other commercial activities.
- Historically, fine-grained limestone from this unit may have been used by prehistoric Native Americans as pipestone to carve ceremonial pipes.

## Scenic geology
- None.

## Further reading
Sparling, 1988; Herdendorf and others, 2006




*Gray brachiopod-rich shale*

# Traverse Group

The Traverse Group is characterized by cherty dolomite; fossiliferous, argillaceous limestone; and calcareous, fossiliferous shale. The group is subdivided into the upper Ten Mile Creek Dolomite and the lower Silica Formation in northwest Ohio. On the *Bedrock Geologic Map of Ohio* (Slucher and others, 2006), the Ten Mile Creek Dolomite and Silica Formation were mapped together as an undivided unit that is equivalent to the Traverse Group. In the subsurface of Williams and Defiance Counties, the Silica Formation loses the characteristic interbedding of shale and limestone and the Ten Mile Creek Dolomite contains increased amounts of limestone similar to the Silica Formation. Thus the two units cannot be recognized with confidence and are included in the Traverse Group undivided.

These rocks were deposited in nearshore environments and in deeper waters offshore in a vast, tropical sea that covered northwestern Ohio during the Devonian Period. The group is poorly exposed throughout northwestern Ohio because it is buried under a thin to moderately thick covering of Quaternary-age sediments. The best exposures are in quarries. The Traverse Group was named for rocks exposed near Little Traverse Bay and Grand Traverse Bay of Lake Michigan. The unit ranges in thickness from 0 to 170 ft (0–52 m).

*The Silica Formation of the Traverse Group characterized by planar bedded, fossiliferous, argillaceous limestone and calcareous, fossiliferous shale exposed by quarrying in the Medusa South Quarry of France Stone Company.*

## Diagnostic features

- Upper part: Dolomite with rare to abundant chert nodules.
- Lower part: Fossiliferous shale interbedded with argillaceous, fossiliferous limestone.

## General features

- Yellowish gray, bluish gray, dark gray, or brownish gray.
- Planar, irregular, and lenticular bedding.
- Thin to thick bedded.
- Chert, marcasite, and pyrite present.

## Lithologic variations
- Silica Fm: Amount of shale decreases westward from Lucas County and is nearly absent in some wells located in Williams and Defiance Counties.
- Ten Mile Creek Dol: Amount of limestone increases westward.
- Silica thins to west.
- Ten Mile Creek thickens to northwest.

## Fossil content
- Silica Fm is world renowned for abundance and preservation of fossils.
- Brachiopods, bivalves, bryozoans, cephalopods, corals, crinoids, gastropods, trace fossils, and trilobites common.
- Ten Mile Creek is sparsely fossiliferous.

## Weathering characteristics
- Resistant to weathering.
- Exposures limited to river and stream beds and valley walls.

## Stratigraphic contacts
- Sharp upper contact.
- Sharp lower contact.

## Stratigraphic context
- Underlain by Dundee Ls.
- Overlain by Antrim Sh.

## Engineering properties
- See the Ten Mile Creek Dol and Silica Fm fact sheets.

## Hydrogeologic properties
- See the Ten Mile Creek Dol and Silica Fm fact sheets.

## Environmental hazards
- In quarries, rock falls especially during the freeze/thaw cycles of late winter and early spring.
- Potential of people and equipment falling from cliffs.

## Economic geology
- Quarried for crushed stone used in road and building construction.
- Agricultural lime.
- Portland cement.
- Rip rap.

## Scenic geology
- Olander Park System's Fossil Park, Sylvania, Lucas County.

## Further reading
Janssens, 1970; Kesling and Chilman, 1975; Slucher and others, 2006


*Porous oil-stained dolomite from Ten Mile Creek Dol*


*Gray, fossiliferous shale from Silica Fm*

# Ten Mile Creek Dolomite

The Ten Mile Creek Dolomite is characterized by dolomite with chert. These rocks were deposited in nearshore environments consisting of quiet-water lagoons, shoreline, and nearshore environments. The Ten Mile Creek forms the near-surface bedrock along a 0.5- to 5.0-mi (0.8–8.0-km)-wide area that arcs across Lucas, Henry, Defiance and Paulding Counties and is generally poorly exposed because it is largely buried under Quaternary-age sediments. The unit was named for exposures along Ten Mile Creek just south of Sylvania, Lucas County. Thickness of the Ten Mile Creek ranges from 10 to 54 ft (3–16 m).

*The Fossil Park at Sylvania in Lucas County displaying the thick, planar bedded dolomite with chert of the Ten Mile Creek Dolomite. Visitors are collecting fossils from shale of the underlying Silica Formation quarried and trucked to the park from the nearby Hanson Aggregates active quarry.*

## Diagnostic features

- Microcrystalline to medium-crystalline dolomite with lenticular and nodular chert.

## General features

- Dolomite: Yellowish gray to brownish gray.
- Chert: White to gray.
- Planar, nodular, lenticular bedding.
- Thin to thick bedded.
- Minor argillaceous dolomite and shale beds.
- Intercrystal, intergranular, vuggy, and fracture porosity.

## Lithologic variations

- Amount of limestone increases in lower part of the formation westward from Lucas County into Williams and Defiance Counties.
- Unit thickens northwestward from Henry, Paulding, and Lucas Counties into Williams and Defiance Counties.

## Fossil content

- Fossils vary from rare to common.
- Corals, echinoderms, bryozoans, and brachiopods comprise common fossils.

- Trace fossils relatively common in some beds.

## Weathering characteristics
- Resistant to weathering and forms small cliffs along streams, when exposed.

## Stratigraphic contacts
- Sharp upper contact.
- Sharp lower contact.

## Stratigraphic context
- Underlain by Silica Fm.
- Overlain by Antrim Sh.

## Engineering properties
- Unconfined compressive strength: Unweathered will have a medium to high compressive strength. Generally, the dolomite and cherty dolomite will have retained medium to high compressive strength.
- Slake durability: Expected to have high to very high durability.
- Rippability: Should be considered resistant to ripping. Blasting, breaking, or cutting required for rock excavation.

## Hydrogeologic properties
- Poor to moderate aquifer capable of supplying domestic, most farm, and small business needs.
- Average yield for domestic wells in this aquifer range from <5 gpm to 5–10 gpm.
- Aquifer yield depends upon the abundance of fractures and joints within a particular area.
- Yields vary with the thickness of the unit. Where the unit is thinner, wells may be completed in underlying carbonate units.
- Aquifer rating: 4–5.
- Vadose zone rating: 4–5.
- Hydraulic conductivity: <100 gpd/ft$^2$ to 100–300 gpd/ft$^2$, depending on fracturing.

## Environmental hazards
- No associated environmental hazards.

## Economic geology
- Historically, used in the manufacture of Portland cement.

## Scenic geology
- None.

## Further reading
Janssens, 1970; Slucher and others, 2006


*Porous, fossiliferous, oil-stained dolomite*

# Silica Formation

The Silica Formation consists of interbedded, fossiliferous, argillaceous limestone and calcareous, fossiliferous shale. These rocks were deposited in tropical seas in deeper offshore waters that covered northwestern Ohio during the Devonian Period. The Silica is largely buried under a mantle of Quaternary-age sediments that blanket northwestern Ohio. Quarries represent the best exposures. The Silica is mapped along a 0.5- to 5.0-mi (0.8–8.0-km)-wide band that arcs across Lucas, Henry, Defiance, and Paulding Counties. The unit was named for the quarry exposures owned by Medusa Portland Cement near Silica, Lucas County. Thickness of the Silica ranges from 10 to 54 ft (3–16 m).

*The Silica Formation exposed in the Hanson Aggregates Quarry, Sylvania, Lucas County, displaying interbedded fossiliferous shale and argillaceous, fossiliferous limestone beds.*

## Diagnostic features
- Fossiliferous, argillaceous limestone.
- Calcareous, fossiliferous shale.

## General features
- Bluish gray, gray, or brownish gray.
- Thin to thick bedded.
- Planar to irregular bedding.
- Pyrite and marcasite crystals and nodules common.
- Fine- to coarse-grained limestone.

## Lithologic variations
- Shale content decreases northwestward into the subsurface.
- Unit thins to the west.

## Fossil content
- Fossils from the Silica Fm are world famous for their abundance and excellent preservation.
- Diverse fauna of primarily bivalves, brachiopods, bryozoans, cephalopods, corals, crinoids, gastropods, trace fossils, and trilobites.


*An assemblage of complete specimens and moulted fragments of the trilobite* Eldredgeops, *traditionally named* Phacops. *The plaster cast is from a slab collected from the Silica Formation.*

- Vertebrate fossils present and include remains from armored and bony fishes.

## Weathering characteristics
- Not resistant to weathering due to high shale content.
- Rarely exposed in rivers or streams.

## Stratigraphic contacts
- Sharp upper contact.
- Sharp lower contact.

## Stratigraphic context
- Underlain by Dundee Fm.
- Overlain by Ten Mile Creek Dol.

## Engineering properties
- Unconfined compressive strength: Unweathered Silica Sh will have medium to high compressive strength. Weathered shale from the formation will have extremely low to medium compressive strength. Presence of limestone and other resistant beds will locally increase the unconfined compressive strength of the rock.
- Slake durability: The Silica Sh is subject to rapid degradation after exposure. Slake durability of the shale of this formation can range from medium to high in unweathered rock. Weathered portions can range from extremely low to medium.
- Rippability: Weathered shale beds, particularly near the surface, can be ripped by conventional earth-moving equipment. Limestone beds and unweathered shales of the formation would require blasting, breaking, or cutting for rock excavation.

## Hydrogeologic properties
- Typically poor aquifer with minimal yields; suitable for limited household and small farm usage.
- Average yield: 3–5 gpm. Max. yield: 10 gpm.
- Unit is typically too thin and too low-yielding to be a good aquifer; wells will typically be extended into underlying limestone units.
- Aquifer rating: 2–3.
- Vadose zone rating: 2–3.
- Hydraulic conductivity: 1–100 gpd/ft$^2$.

## Environmental hazards
- No associated environmental hazards.

## Economic geology
- Quarried for crushed stone used in road and building construction.
- Agricultural lime.
- Crushed stone for asphalt paving.
- Portland cement.
- Rip rap.

## Scenic geology
- The Olander Park System's Fossil Park at Sylvania, Lucas County.

## Further reading
Kesling and Chilman, 1975; Feldmann and Hackathorn, 1996


*Fossil-rich shale*

# Delaware Limestone

The Delaware Limestone is characterized by argillaceous limestone containing gray to black chert nodules or beds. Petroliferous odor indicates that hydrocarbons have migrated through the Delaware and residual amounts are present. The unit was deposited in tropical, shallow seas teeming with abundant marine life during the Middle Devonian. Rocks of the Delaware are typically buried under Quaternary-age sediments, except in quarries, larger streams, and rivers. The unit is exposed along a 1- to 5-mi (1.6–8-km)-wide band that extends from Columbus northward to Sandusky, Erie County. The Delaware is not present south of Columbus. The unit ranges in thickness from 0 to 45 ft (0–13 m) and is named for exposures in the vicinity of Delaware, Delaware County.

*Thin to thick beds of Delaware Limestone forming small waterfall within Camp Lazarus Boy Scout Camp, Delaware County.*

## Diagnostic features
- Argillaceous limestone.
- Bluish gray to black chert nodules and beds.
- Petroliferous odor when broken.

## General features
- Gray to brown.
- Thin to thick bedded with shale partings.
- Fine to coarse grained.
- Planar, lenticular, and nodular bedded.

## Lithologic variations
- Bed thickness and type of bedding is variable from exposure to exposure.
- Amount of chert present also is variable.

## Fossil content
- Diverse fauna of primarily brachiopods, bivalves, corals, cephalopods, crinoids, gastropods, phosphatic fish remains, tentaculitids, and trilobites.
- Trace fossils vary from rare to common.

### Weathering characteristics
- Resistant to weathering.
- Produces blocks, slabs, or pebbles of limestone, common in streams and glacial sediments.
- Solution enlargement along joints.
- Sinkhole development.

### Stratigraphic contacts
- Sharp upper contact.
- Sharp to gradational lower contact.

### Stratigraphic context
- Underlain by Columbus Ls.
- Overlain by Olentangy Sh.

### Engineering properties
- Unconfined compressive strength: Medium to high; weathered limestone will have medium to high compressive strength.
- Slake durability: Very high.
- Rippability: Resistant to ripping. Blasting, breaking, or cutting is required for rock excavation.

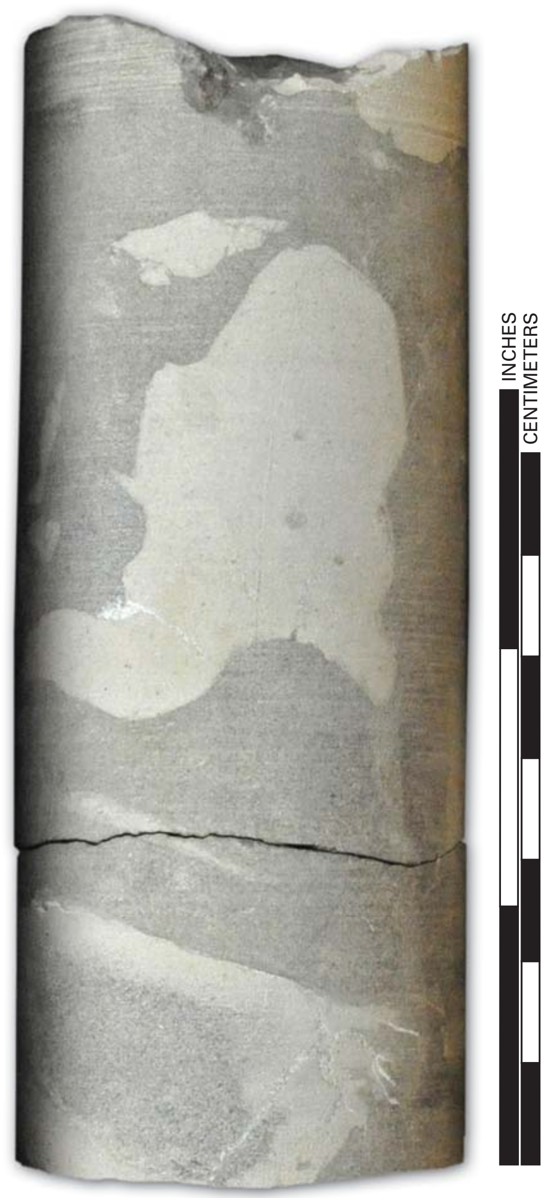
### Hydrogeologic properties
- Moderate aquifer capable of supplying domestic, most farm, and small business needs.
- Average yield: 10–25 gpm for domestic wells in this aquifer.
- Yields as high as 100 gpm from larger diameter wells intersecting fracture zones.
- Aquifer yield depends upon abundance of fractures and joints within a particular area.
- In areas adjacent to modern streams and rivers, the Delaware tends to have higher yields because the unit is highly fractured and receives higher recharge.
- Yields tend to decrease where unit is covered by thick, overlying shale or glacial till, perhaps due to decreased recharge.
- Evaluated as a massive limestone; aquifer rating: 6–7.
- Vadose zone rating: 6–7.
- Hydraulic conductivity: Ranges from 100–300 gpd/ft$^2$ to 300–700 gpd/ft$^2$, depending on fracturing.

### Environmental hazards
- Dissolution of the Delaware can cause sinkholes or sudden collapse of caves, resulting in land surface subsidence. If buildings, roads, or bridges are built over these features, foundation failure may result in damage or destruction of such structures.
- Sinkholes provide a conduit for rapid movement of surface water, potentially carrying sewage, animal wastes, and agricultural and industrial chemicals directly into the ground-water system. Rapid movement of pollutants into the ground-water system severely threatens potable water supplies.

### Economic geology
- Quarried for over 100 years for dimension stone.
- Crushed stone for road and building construction, Portland cement, and asphalt paving.
- Agricultural lime for soil improvement.

### Scenic geology
- Olentangy Indian Caverns in Delaware County.
- Small cliffs, gorges, waterfalls, and riffles in streams and rivers.

### Further reading
Stauffer, 1909; Westgate, 1926




*Gray chert nodules in dark-gray limestone*

# Dundee Limestone


The Dundee Limestone is characterized by cherty dolomitic limestone or dolomite in the lower portion and fossiliferous or micritic limestone in the upper portion. These rocks were deposited in mudflat, shoreline, nearshore, and offshore environments. The near-surface rocks of the Dundee Limestone typically are buried under Quaternary-age sediments and occur in a 0.1- to 5.0-mi (0.2–8.0-km)-wide band that arcs from Lucas County westward through Wood, Henry, and Paulding Counties. Natural exposures of the unit are restricted to larger streams and rivers of northwest Ohio, such as the banks and river bed of the Maumee River at Grand Rapids, Wood County. The unit was named for exposures located at Dundee, Michigan. The unit ranges in thickness from 0 to 105 ft (0–32 m).


*Medium to thick bedded, fossiliferous limestone beds of the upper part of the Dundee Limestone underlying the fossiliferous shale and limestone of the Silica Formation in the highwall of the Hanson Aggregates Quarry, Sylvania, Lucas County.*

## Diagnostic features

- Upper portion: Fossiliferous or micritic limestone.
- Lower portion: Cherty dolomitic limestone or dolomite.

## General features

- Gray to brown.
- Thin to thick bedding.
- Planar, irregular, and lenticular bedding.
- Microcrystalline to coarsely crystalline.
- Dolomite beds often have a sandy appearance and may contain quartz sand grains.
- Nodular chert is white or light brown.

## Lithologic variations

- Fossiliferous limestone overlays and grades laterally into micritic limestone.
- Cherty dolomitic limestone or dolomite underlays the micritic limestone.
- The micritic limestone reaches its maximum thickness of between 40 and 60 ft (12–18 m) along a north–south line centered in eastern Fulton and Henry Counties and western Defiance County and ends in the northeastern corner of Paulding County.
- The micritic limestone thins to zero in eastern Fulton and central Henry and Paulding Counties and into northeastern Indiana.

### Fossil content
- Upper portion is fossiliferous with brachiopods, bryozoans, and corals most common.
- Lower portion, including micritic limestone, is sparsely fossiliferous.
- Trace fossils common in the micritic limestone.

### Weathering characteristics
- Resistant to weathering.
- In rivers and large streams, unit forms a zone of rapids and riffles.

### Stratigraphic contacts
- Sharp upper contact.
- Sharp lower contact.

### Stratigraphic context
- Underlain by Detroit River Gp.
- Overlain by Silica Fm of the Traverse Gp.
- Similar unit: Maxville Ls.

### Engineering properties
- Unconfined compressive strength: Unweathered will have a medium to high compressive strength. Weathered will have a medium to high compressive strength.
- Slake durability: Expected to have high to very high durability.
- Rippability: Resistant to ripping. Blasting, breaking, or cutting is required for rock excavation.

### Hydrogeologic properties
- Moderate aquifer capable of supplying domestic, most farm, and small business needs.
- Average yield: 10–25 gpm for domestic wells in this aquifer.
- Yields as high as 500 gpm from larger diameter wells intersecting fracture zones.
- Aquifer yield depends upon abundance of fractures and joints within a particular area.
- In areas adjacent to modern streams and rivers, the Dundee tends to have higher yields because the unit is highly fractured and receives higher recharge.
- Where unit is thin, wells are completed in underlying Detroit River Gp carbonate units.
- Evaluated as a massive limestone; aquifer rating: 6–7.
- Vadose zone rating: 6–7.
- Hydraulic conductivity: Ranges from 100–300 gpd/$ft^2$ to 300–700 gpd/$ft^2$, depending on fracturing.

### Environmental hazards
- No associated environmental hazards.

### Economic geology
- Quarried for crushed stone used in road and building construction and asphalt paving.
- Portland cement.
- Rip rap.

### Scenic geology
- Small waterfalls and riffles where exposed in streams.

### Further reading
Janssens, 1970


*Fossiliferous limestone* *Micritic limestone*

# Columbus Limestone


The diagnostic features of the Columbus Limestone are gray, fossiliferous limestone underlain by brown, finely crystalline dolomite. The unit was deposited in tropical, shallow seas, teeming with abundant marine life, which inundated Ohio during the Middle Devonian. The Columbus is exposed in stream exposures and quarries in a 1- to 5-mi (1.6–8-km)-wide band extending from southern Pickaway County northward along the Scioto River valley through the city of Columbus to Sandusky and Kelley's Island, Erie County. In western Ohio, the Columbus is mapped in the Bellefontaine outlier located in Logan and Champaign Counties. The unit ranges in thickness from 0 to 105 ft (0–32 m) and is named for the exposures in the vicinity of Columbus, Franklin County.


*The contact between the lighter, thicker beds of the Columbus Limestone and the overlying darker, thinner beds of the Delaware Limestone is well illustrated in the high walls of Penry Quarry, Delaware County.*

## Diagnostic features

- Gray, fossiliferous limestone in upper 2/3 of unit.
- Brown, finely crystalline dolomite in lower 1/3 of unit.
- Petroliferous, in some zones.

## General features

- Fossiliferous limestone and dolomite.
- Gray to brown.
- Thick to massive bedding.
- Fine- to coarse-crystalline dolomite.
- Fine- to coarse-grained limestone.
- Occasional white to gray chert nodules.

## Lithologic variations

- Delhi Mbr and Bellepoint Mbr, central Ohio: Delhi consists of gray, fossiliferous limestone with some chert comprising the upper 2/3. Bellepoint consists of brown, finely crystalline dolomite in thick to massive beds.
- Venice Mbr and Marblehead Mbr, northern Ohio: Venice is bluish-gray, argillaceous, fossiliferous, thick to massive bedded limestone; locally cherty. Marblehead is gray to light-brown, fossiliferous limestone.
- In central Ohio, base of Bellepoint Mbr may contain a pebble conglomerate bed or locally developed quartz-rich sandstone.

## Fossil content

- Delhi, Marblehead, and Venice Mbs highly fossiliferous; Bellepoint less fossiliferous.

- Diverse fauna of primarily brachiopods, bivalves, corals, cephalopods, crinoids, gastropods, phosphatic fish remains, stromatoporoids, and trilobites.
- Abundant trace fossils; locally forms zones of burrow mottling within the unit.

## Weathering characteristics
- Weathers light gray or brown.
- In natural exposures and road cuts, unit forms cliffs and rocky, steep slopes in areas of higher relief.
- Abundant sinkholes present in upland areas with thin drift cover.
- Subterranean caves and solution-enlarged joints occur locally.

## Stratigraphic contacts
- Sharp to gradational upper contact.
- Sharp lower contact.

## Stratigraphic context
- Underlain by Salina Gp.
- Overlain by Delaware Ls.

## Engineering properties
***Delhi Mbr***
- Unconfined compressive strength: Medium to high; weathered limestone will have a medium to high compressive strength.
- Slake durability: High to very high.
- Rippability: Resistant to ripping. Blasting, breaking, or cutting required for rock excavation.

***Bellepoint Mbr***
- Unconfined compressive strength: Medium to high; weathered dolomite will have medium to high compressive strength.
- Slake durability: High to very high.
- Rippability: Resistant to ripping. Blasting, breaking, or cutting required for rock excavation.

## Hydrogeologic properties
- Moderate to excellent aquifer capable of supplying domestic and farm needs.
- Average yield: 15–35 gpm for domestic wells completed in this aquifer.
- Deeper, larger-diameter wells produce yields that average from 100 to 500 gpm, making them suitable for industrial, municipal, school, and major agricultural needs.
- Yields >1,000 gpm have been reported from wells that intersect major solution-enlarged joint sets.
- Recharge increases significantly in vuggy intervals of the Columbus and areas with secondary solution along fractures and joints, which also contributes to higher yields.

*A sampling of the wide variety of cave formations present in one of Ohio's scenic wonders, Ohio Caverns in Champaign County. Stalactites hanging from the ceiling and stalagmites growing upward from the cave floor or columns formed when the two meet are precipitated from calcium carbonate-rich ground water. Dissolution of the Columbus Limestone by slightly acidic rainwater is the source of the ground water.*

- Usually defined as a solution limestone; aquifer rating: 7–8.
- Unit evaluated as a karst limestone in northern Ohio; aquifer rating: 9–10.
- Vadose zone rating: Varies 7–10, depending on development of solution and karst features.
- Hydraulic conductivity: Ranges from 700–1,000 gpd/ft$^2$ to 1,000–2,000 gpd/ft$^2$, depending on degree of solutioning and karst development.

## Environmental hazards
- Dissolution of the Columbus can cause sinkholes to open or sudden collapse of caves, resulting in land surface subsidence. If buildings, roads, or bridges are built above these features, foundation failure may result in damage or destruction of such structures.
- Sinkholes provide a conduit for rapid movement of surface water, potentially carrying sewage, animal waste, and agricultural and industrial chemicals directly into the ground-water system. Rapid movement of these pollutants into the ground-water system poses a severe threat to potable water supplies.

## Economic geology
- Quarried for over 200 years for dimension stone, crushed stone, agricultural lime, Portland cement, asphaltic cement, and for use in construction and road resurfacing.

- The Ohio Statehouse in downtown Columbus and portions of many other buildings are constructed of limestone from the Delhi Mbr.

## Scenic geology

- Glacial Grooves, Kelleys Island.
- Ohio Caverns, Champaign County.
- Zane Cavern, Logan County.
- Seneca Caverns, Seneca County.
- Olentangy Indian Caverns, Delaware County.
- Hayden Falls along Scioto River, Columbus.

## Further reading

Wolfe, 2011

*Kelleys Island glacial grooves formed in the Columbus Limestone.*


*Brown, finely crystalline dolomite of the Bellepointe Mbr*


*Gray, fossiliferous limestone of the Delhi Mbr*

# Detroit River Group

Quaternary
Neogene?
Permian
Pennsylvanian
Mississippian
Devonian
Detroit River Group
Silurian
Ordovician
Cambrian
Precambrian

The Detroit River Group is characterized by dolomite, sandy dolomite, sandstone, and limited shale. Four formations, listed in ascending order, are recognized in northwestern Ohio: Holland Quarry Shale, Sylvania Sandstone, Amherstburg Dolomite, and Lucas Dolomite. No attempt has been made by the ODNR Division of Geological Survey to map the individual formations of the Detroit River Group because of rapid speed of reconnaissance mapping, lack of good exposures, extensive burial under Quaternary-age sediments, and limited subsurface data. These rocks were deposited in shallow-offshore, shoreline, and lagoon environments as the tropical Devonian coastal regions met the shallow sea in northwestern Ohio. The rocks of the Detroit River Group typically are buried under Quaternary-age sediments except in quarries, larger streams, and rivers of northwestern Ohio. One of the better natural exposures of the group is located in the Maumee River adjacent to Otsego Park in Wood County. These rocks occur in a 0.1- to 5.0-mi (0.2–8.0-km)-wide band that arcs from Lucas County westward through Wood, Henry, Putnam, and Paulding Counties. Also this unit is mapped in the Bellefontaine outlier in Logan and Champaign Counties. The Detroit River Group was named for exposures along the Detroit River in Michigan. The thickness of the group ranges from 0 to 170 ft (0–52 m).


*Thin to medium bedded, brown dolomite of the Detroit River Group underlying the thick bedded, gray Columbus Limestone capping the quarry highwall at Marblehead quarry located just south of Marblehead, Ottawa County.*

## Diagnostic features

- Dolomite, sandy dolomite, sandstone, and limited shale.
- Lucas and Amherstburg Dols: Gray to brown dolomite.
- Sylvania Ss: White, fine- to medium-grained sandstone with frosted, well-rounded quartz sand grains.
- Holland Quarry Sh: Gray to black, fossiliferous, sandy shale.

## General features

- Color varies from white, gray, and brown to black.
- Microcrystalline to finely crystalline.
- Planar, irregular, and lenticular bedding.

- Some intervals laminated.
- Organic-rich laminae.
- Thin to thick bedded.
- Gypsum and anhydrite rare to common; chert generally rare.
- Fracture, moldic, vuggy, and intercrystalline porosity.
- Intervals of brecciated dolomite common.

### Lithologic variations

- Holland Quarry Sh, known only from Lucas County, occurs in a depression fill located upon the paleokarst that developed in the pre-Devonian terrain of northwestern Ohio.
- Thickness of the Sylvania Ss is highly variable and ranges from 0 to an estimated 50 ft (0–15 m) with the greatest thickness located in western Lucas County and central Fulton County.
- Amount of sand grains increase in the basal portion of the Amherstburg Dol; where underlain by the Sylvania Ss, contact between these units is gradational.
- In those areas where Sylvania Ss and Holland Quarry Sh missing, the basal Amherstburg may or may not be sandy.

### Fossil content

- Sparsely fossiliferous to fossiliferous.
- Algal laminations common.
- Brachiopods, gastropods, bivalves, and corals less common.

### Weathering characteristics

- Resistant to weathering.
- Where exposed forms small cliffs, riffles, and rapids in rivers and streams.

### Stratigraphic contacts

- Sharp upper contact.
- Sharp lower contact.

### Stratigraphic context

- Underlain by Salina Gp.
- Overlain by Dundee Ls.

### Engineering properties

- Unconfined compressive strength: Unweathered limestones, dolomites, and sandstone of the Detroit River Gp will have a medium to high compressive strength; weathered portions of the theses units will have a medium to high compressive strength, depending on the degree of weathering. Holland Quarry Sh is rare and anticipated to behave similarly to the Antrim Sh.
- Slake durability: Generally, the carbonate and sandstone units of the Detroit River Gp are anticipated to have high to very high slake durability except where higher shale content is present.
- Rippability: Detroit River Gp resistant to ripping. Blasting, breaking or cutting is required for rock excavation.


*Brown, finely crystalline dolomite*

### Hydrogeologic properties

- Moderate aquifer capable of supplying domestic, most farm, and small business needs.
- Average yield for domestic wells in this aquifer range 10–25 gpm.
- Yields from larger-diameter wells intersecting fracture zones are as high as 100 gpm.
- Aquifer yield depends upon the abundance of fractures and joints within a particular area.
- In areas adjacent to modern streams and rivers, the Detroit River Gp tends to have higher yields because the unit is highly fractured and receives higher recharge.
- Where the Detroit River Gp is thin, wells are completed in underlying carbonate units.
- Evaluated as a massive limestone; aquifer rating: 6–7.
- Vadose zone rating: 6–7.

### Environmental hazards

- In the Bellefontaine outlier region, potential for solution-enlarged joints and sinkhole development in areas of thin to absent glacial drift.

### Economic geology

- Detroit River dolomites are quarried for crushed stone used in road and building construction.
- Agricultural lime.
- Crushed stone for asphalt paving.
- Portland cement.
- Rip rap.
- Sylvania Ss is a source of silica sand that historically has been used as glass sand.

### Scenic geology

- None.

### Further reading

Janssens, 1970; Swinford and Slucher, 1995; Slucher and others, 2006

# Salina Group

The Salina Group is characterized by microcrystalline to finely crystalline dolomite interbedded with shale, anhydrite, and gypsum. These rocks were deposited in nearshore environments consisting of quiet-water lagoons and shoreline, shallow-offshore, and reef environments surrounding a large evaporite basin. The Salina Group forms much of the near-surface bedrock in west-central and north-central Ohio. Throughout this area, the Salina is poorly exposed because it is buried under Quaternary-age sediments. Exposures are restricted to stream cuts, Lake Erie shore cliffs, and quarries.

The Salina Group is divided, in ascending order, into the Greenfield Dolomite, Tymochtee Dolomite, and Salina undifferentiated. Some geologists recognize the Bass Islands Dolomite or Group for rocks mapped as the uppermost Salina Group on the *Bedrock Geologic Map of Ohio* (Slucher and others, 2006). We include a fact sheet for the Bass Islands Dolomite (p. 112) because this unit was mapped on seven 1:24,000-scale, bedrock-geologic quadrangles in Erie, Ottawa, Sandusky, and Seneca Counties. The Salina undifferentiated is distinguished from the underlying Tymochtee Dolomite because it does not contain shale laminations or beds nor argillaceous dolomite. The Salina was introduced to name the rocks exposed in the vicinity of Syracuse, New York. In Ohio, the thickness of the Salina Group is quite variable, ranging from zero to over 700 ft (213 m) in north-central Ohio.

*Thin to medium bedded, microcrystalline to finely crystalline dolomite of the Salina Group exposed along the Scioto River in Delaware County. The combination of vertical fractures and thin bedding produces abundant blocks of dolomite, resembling toy building blocks. Scale is 50 cm (1.6 ft).*


## Diagnostic features

- Microcrystalline to finely crystalline dolomite interbedded or interlaminated with shale, anhydrite, and gypsum.

## General features

- Dolomite: Gray to brown.
- Shale: Brown to black.
- Anhydrite, gypsum, and salt: Clear, white, gray, orange, and red.

- Planar, irregular, nodular, and wavy bedding.
- Laminated to thick bedded, commonly thin bedded.
- Argillaceous to silty dolomite.
- Burrow mottling.
- Intercrystal, intergranular, vuggy, and fracture porosity.
- Thin zones or beds of conglomerate.

### Lithologic variations
- Greenfield and Tymochtee Dols not recognized in northwestern and west-central Ohio adjacent to the Ohio-Indiana border because their diagnostic shale interbeds and interlaminations are absent.
- Salt beds restricted to subsurface of northeastern Ohio.

### Fossil content
- Fossils generally rare, except for zones containing abundant algal laminations.
- Trace fossils relatively common in some beds.
- Fossiliferous zones of porous, coarse-crystalline dolomite, resembling reefs, occur locally in west-central Ohio adjacent to Ohio-Indiana border.

### Weathering characteristics
- Resistant to weathering and forms small cliffs along streams, when exposed.
- In southern Ohio, Greenfield and Tymochtee Dols form small gorges along streams.
- Thin bedding combined with vertical fractures produces abundant blocks of dolomite, resembling toy building blocks.

### Stratigraphic contacts
- Sharp upper contact.
- Sharp to gradational lower contact.

### Stratigraphic context
- Underlain by Lockport Dol in western and northern Ohio, Cedarville Dol in Clark and Greene Counties, and Peebles Dol in Highland and Adams Counties.
- Overlain by Detroit River Gp in northwest Ohio, Columbus Ls from Lake Erie southward through Columbus to Pickaway County, and Olentangy Sh in Ross County southward to Ohio River.

### Engineering properties
- Unconfined compressive strength: Unweathered dolomites and limestones will have medium to high compressive strength. Generally, dolomite and cherty dolomite will have retained medium to high compressive strength. Anhydrite and gypsum within the formation typically will be weak and have low to medium compressive strength.
- Slake durability: Dolomite and limestone expected to have high to very high durability. Shale, anhydrite, and gypsum expected each to have very low to medium slake durability.

*Finely crystalline, burrowed, porous dolomite*

- Rippability: Resistant to ripping. Blasting, breaking, or cutting is required for rock excavation.

### Hydrogeologic properties

- Moderate to excellent aquifer, due to variable nature and thickness at a particular location.
- May be utilized as individual unit or mapped and drilled together as hydrologic unit with both overlying and underlying units.
- Yields range 3–10 gpm where unit very thin and more to southern and western edges of the formation. Average yields ranging from 5–25 gpm to 25–100 gpm more common. Yields exceeding 100 gpm possible from larger-diameter, properly developed wells where unit >100 ft (30 m) in thickness in northern and central Ohio. A high-yielding, vuggy zone near the base of this unit has historically been referred to as the "Newburg zone" by drillers.
- Aquifer rating: 6–8.
- Vadose zone rating: 6–8.
- Hydraulic conductivity: Varies with yield from 300–700 gpd/ft$^2$ to 700–1,000 gpd/ft$^2$.

### Environmental hazards

- In southern Ohio, people and animals falling from cliffs and gorge walls.
- Structural damage to buildings, bridges, or highways because of sudden or gradual ground collapse into solution-enlarged joints, sinkholes, or caves.
- Pollution threat to ground-water resources through surface waters entering sinkholes directly linked to underground drainage system.

### Economic geology

- Quarried for crushed stone used in road and building construction.
- Crushed stone for asphalt paving.
- Agricultural lime.
- Portland cement.
- Rip rap.
- Subsurface salt deposits mined beneath Lake Erie offshore from Cleveland and Fairport Harbor.
- Historically, gypsum was mined between 1822 and 2004 from quarries and underground mines located near the town of Gypsum, Ottawa County and between 1912 and 1918 near Castalia, Erie County.

### Scenic geology

- Cliffs and rocky shorelines of the Bass Islands in Lake Erie.
- Trimmer, Skull Cave, and Lions Den Natural Arches.
- Put-in Bay, Crystal Rock, and Brewery Caves in Ottawa and Erie Counties.
- Hannah, Frost, and Sunfish Caves along Sunfish Creek in vicinity of Byington, Pike County.
- Gorges created by Paint and Sugar Creeks and their tributaries in vicinity of Rock Mills, Fayette County.

### Further reading

White, 1926; Janssens, 1977; Slucher and others, 2006; Snyder, 2010


# Bass Islands Dolomite

The Bass Islands Dolomite is characterized by microcrystalline to finely crystalline dolomite that has been fractured into angular pieces and later cemented to form massive beds of brecciated dolomite. These rocks were deposited in nearshore environments consisting of quiet-water lagoons and shoreline, shallow-offshore, and reef environments surrounding a large evaporate basin. Near the end of the Silurian Period, sea level dropped, exposing these rocks to weathering and karst-forming processes. Abundant sinkholes, breccia-filled caves, and breccia-filled fractures formed in the uppermost Salina Group of northern Ohio.

Some geologists have named and mapped the breccia-dominated top of the Salina as the Bass Islands Dolomite. Other geologists have not differentiated the Bass Islands Dolomite from the upper Salina Group because the dolomite characterizing both units is the same, except that it is brecciated in the Bass Islands. We include a fact sheet for this unit because it has been mapped on seven bedrock-geology quadrangles (scale 1:24,000) in Ottawa, Erie, Sandusky, and Seneca Counties. Throughout these counties, the Bass Islands Dolomite is poorly exposed because it is largely buried under Quaternary-age sediments except for excellent cliff exposures along the shorelines of the Bass Islands and Catawba Island in Ottawa County. The Bass Islands ranges in thickness from 0 to 100 ft (0–30 m) and was named for the cliff exposures of these islands.

*Bass Islands Dolomite located on the west side of Catawba Island, Ottawa County, consisting of thin beds of microcrystalline to finely crystalline dolomite. Some beds consist of angular pieces of dolomite cemented together to form beds of brecciated dolomite.*

## Diagnostic features

- Fractured, microcrystalline to finely crystalline dolomite.

## General features

- Gray to yellow-gray dolomite.
- Irregular, nodular, and wavy bedding.
- Laminated to massive bedded; commonly thin bedded.

- Intercrystal and fracture porosity.

## Lithologic variations
- Degree of fracturing varies, from intervals that contain very few fractures that grade vertically and laterally to zones that are highly fractured.

## Fossil content
- Fossils generally rare except for zones containing algal laminations.
- Large ostracodes locally present.
- Trace fossils relatively common in some beds.

## Weathering characteristics
- Resistant to weathering.
- Forms small cliffs along Lake Erie shoreline of the Bass and Catawba Islands.
- Subject to karst-forming processes, producing caves and sinkholes.

## Stratigraphic contacts
- Sharp upper contact.
- Sharp to gradational lower contact.

## Stratigraphic context
- Underlain by undifferentiated rocks of the Salina Gp.
- Overlain by Columbus Ls.

## Engineering properties
- Unconfined compressive strength: Unweathered dolomite will have medium to high compressive strength. Generally, weathered dolomite and cherty dolomite will retain medium to high compressive strength depending on degree of weathering.
- Slake durability: Expected to be high to very high.
- Rippability: Resistant to ripping. Blasting, breaking, or cutting required for rock excavation.

## Hydrogeologic properties
- Moderate to good aquifer, depending on thickness and nature at a particular location.
- May be utilized as individual unit or mapped and drilled together as hydrologic unit with underlying units.
- Average yield: 5–25 gpm to 25–100 gpm more common. Yields >100 gpm possible from larger-diameter, properly developed wells where unit is thicker. Such wells typically penetrate underlying units as well.
- Aquifer rating: 6–8.
- Vadose zone rating: 6–8.
- Hydraulic conductivity: Varies with yield from 300–700 gpd/ft² to 700–1,000 gpd/ft².

## Environmental hazards
- People and animals falling from cliffs.
- Structural damage to buildings, bridges, or highways because of sudden or gradual ground collapse into solution-enlarged joints, sinkholes, or caves.
- Pollution threat to ground-water resources through surface waters entering sinkholes directly linked to underground drainage systems.

## Economic geology
- Historically, mined for crushed stone.

## Scenic geology
- Needle's Eye Arch.
- Put-in Bay, Crystal Rock, and Brewery Caves in Ottawa and Erie Counties.

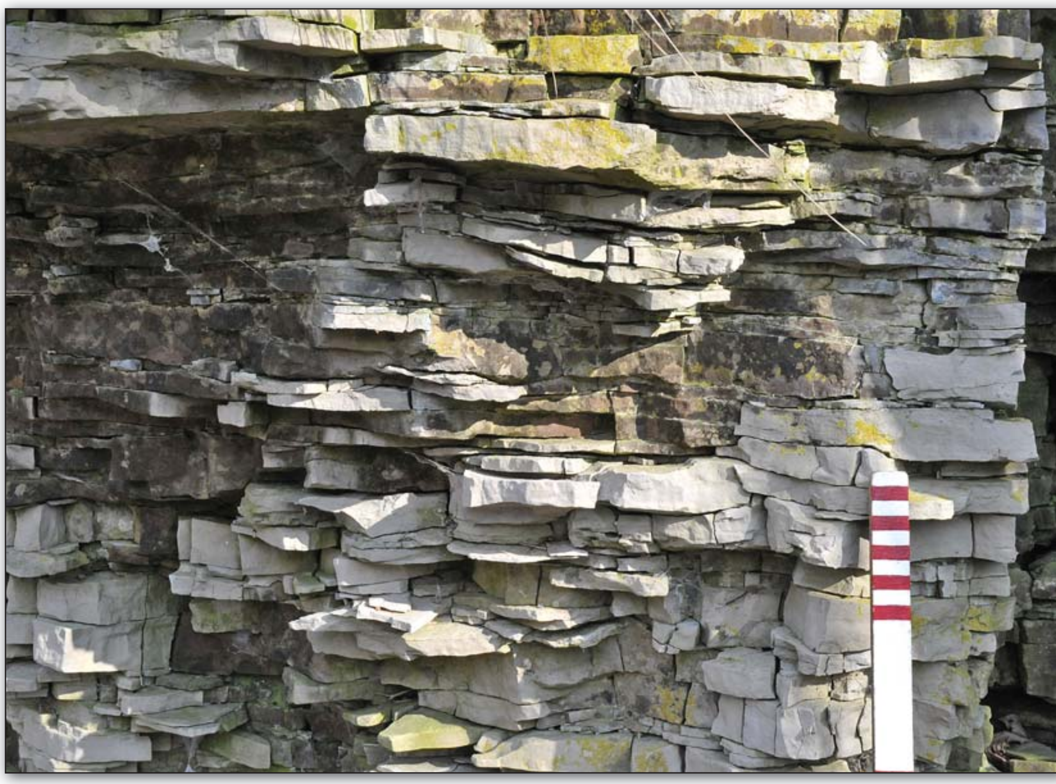
## Further reading
Carman, 1946; Sparling, 1970


*Fractured, angular, microcrystalline dolomite cemented with white calcite cement*


# Tymochtee Dolomite

The Tymochtee Dolomite is characterized by interbedded, microcrystalline to coarsely crystalline dolomite and shale laminations and beds. These rocks were deposited in nearshore ocean environments consisting of quiet-water lagoons and shoreline, shallow-offshore, and reef environments.

The Tymochtee forms the near-surface bedrock over a wide area of western Ohio and is generally poorly exposed because it largely is buried under Quaternary-age sediments. The Tymochtee was named for the exposures along Tymochtee Creek at Crawford, Wyandot County. Thickness of the unit is variable, ranging from 0 to 140 ft (0–42 m).



*Microcrystalline to coarsely crystalline, argillaceous dolomite with minimal shale interbeds characterizes the type section of the Tymochtee Dolomite located along Tymochtee Creek at Crawford in Wyandot County. Scale is 20 cm (0.66 ft).*

## Diagnostic features

- Microcrystalline to coarsely crystalline, argillaceous dolomite interbedded with gray, brown, or black organic-rich shale laminations and beds.

## General features

- Dolomite: Dark gray to yellowish gray.
- Organic-rich laminae: Brown to black.
- Planar, irregular, lenticular bedding.
- Laminated to massive bedded, commonly thin bedded.
- Intercrystalline and fracture porosity.
- Locally, thin zones or beds of conglomerate.
- Rare to common disseminated pyrite, anhydrite, and gypsum.
- Rare to common pyrite and gypsum nodules.

## Lithologic variations

- Unit not recognized in northwestern and west-central Ohio adjacent to the Ohio-Indiana border; in these areas, equivalent rocks are mapped as part of the Salina Gp.
- Considerable facies changes and intertonguing with the Salina Gp undifferentiated dolomites, which lack shale beds and laminations.

## Fossil content
- Fossils generally rare except for zones containing abundant algal laminations.
- Trace fossils relatively common in some beds.

## Weathering characteristics
- Resistant to weathering; forms small cliffs along streams, when exposed.
- In southern Ohio, may form small gorges along streams.
- Sinkholes, small caves, and natural arches locally present.

## Stratigraphic contacts
- Sharp to gradational upper contact.
- Sharp lower contact.

## Stratigraphic context
- Underlain by the Greenville Dol.
- Overlain by Salina Gp undifferentiated rocks and, locally in southern Ohio, the Olentangy Sh.

## Engineering properties
- Unconfined compressive strength: Unweathered and weathered dolomite will have medium to high compressive strength.
- Slake durability: Expected to be high to very high.
- Rippability: Resistant to ripping. Blasting, breaking, or cutting required for rock excavation.

## Hydrogeologic properties
- Moderate to good aquifer, due to variable nature and thickness at a particular location. Shaley, finer-grained facies tend to be lower yielding.
- May be utilized as individual unit or mapped and drilled together as hydrologic unit with both overlying and underlying units.Usually mapped together with the Greenfield Dol as single hydrologic unit.
- Yields range 3–10 gpm where unit thin and shaley in central extent of this formation. Yields tend to increase towards both eastern and western edges of unit. Average yields ranging from 5–25 gpm to 25–100 gpm more common. Yields >100 gpm possible from larger-diameter, properly developed wells where unit >100 ft (30 m) in thickness. Such wells may be partially completed in adjacent units.
- Aquifer rating: 6–7.
- Vadose zone rating : 6–7.
- Hydraulic conductivity: Varies with yield from 300–700 gpd/ft² to 700–1,000 gpd/ft².

## Environmental hazards
- People and animals falling from cliffs and gorge walls.
- Structural damage to buildings, bridges, or highways because of sudden or gradual ground collapse into solution-enlarged joints, sinkholes, or caves.
- Pollution threat to ground-water resources through surface waters entering sinkholes directly linked to underground drainage system.

## Economic geology
- Quarried for crushed stone used in road and building construction.
- Crushed stone for asphalt paving.
- Portland cement.
- Rip rap.

## Scenic geology
- Lions Den Natural Arch in Pike County.
- Hannah, Frost, and Sunfish Caves along Sunfish Creek in the vicinity of Byington, Pike County.
- Gorges created by Paint and Sugar Creeks and their tributaries in the vicinity of Rock Mills, Fayette County.

## Further reading
Janssens, 1977


*Finely crystalline dolomite with laminated and thin bedded shale*

# Greenfield Dolomite


The Greenfield Dolomite is characterized by microcrystalline to coarsely crystalline dolomite with occasional organic-rich laminae. These rocks were deposited in nearshore environments consisting of quiet-water lagoons and shoreline, shallow-offshore, and reef environments.

The Greenfield forms the near-surface bedrock over a wide area of western Ohio and is generally poorly exposed because it is buried under Quaternary-age sediments. The Greenfield was named for exposures of the unit in the vicinity of Greenfield, Highland County. Thickness of the unit is highly variable, ranging from 0 to 80 ft (0–24 m).

*The Greenfield Dolomite consisting of thin bedded, microcrystalline to coarsely crystalline dolomite forms Trimmer Arch located in Paint Creek Wildlife Area, Ross County.*

## Diagnostic features

- Microcrystalline to coarsely crystalline dolomite with occasional organic-rich laminae.

## General features

- Dolomite: Olive gray to yellowish gray.
- Organic-rich laminae: Brown to black.
- Planar, irregular, lenticular bedding.
- Laminated to thick bedded; commonly thin bedded.
- Intercrystal, intergranular, vuggy, and fracture porosity.
- Locally, thin zones or beds of conglomerate.
- Rare to common disseminated pyrite and pyrite nodules.

## Lithologic variations

- Intervals of thick to massive bedded, vuggy, fossiliferous dolomite occur locally.
- Anhydrite present in northern Ohio.
- Unit not recognized in northwestern and west-central Ohio adjacent to the Ohio-Indiana border; in these areas, equivalent rocks mapped as part of the Salina Gp.
- Considerable facies changes and intertonguing with the underlying Lockport Dol occurs in west-central and northern Ohio.

## Fossil content

- Fossils generally rare except for zones containing abundant algal laminations.

- Trace fossils relatively common in some beds.
- Fossiliferous zones of porous, coarse-crystalline dolomite resembling reefs occur locally.

### Weathering characteristics
- Resistant to weathering; forms small cliffs along streams, when exposed.
- In southern Ohio, may form small gorges along streams.
- Sinkholes, small caves, and natural arches locally present.
- Thin-bedded dolomite combined with vertical fractures produces abundant blocks of dolomite, resembling toy building blocks.

### Stratigraphic contacts
- Sharp to gradational upper contact.
- Sharp to gradational lower contact.

### Stratigraphic context
- Underlain by the Lockport Dol in western and northern Ohio, Cedarville Dol in Clark and Greene Counties, and Peebles Dol in Highland and Adams County.
- Overlain by Tymochtee Dol.

### Engineering properties
- Unconfined compressive strength: Unweathered and weathered dolomite will have medium to high compressive strength.
- Slake durability: Expected to be high to very high.
- Rippability: Resistant to ripping. Blasting, breaking, or cutting required for rock excavation.

### Hydrogeologic properties
- Moderate to good aquifer, due to variable nature and thickness at a particular location. Shaley, finer-grained facies tend to be lower yielding.
- May be utilized as individual unit or mapped and drilled together as hydrologic unit with both overlying and underlying units. Usually mapped together with Tymochtee Dol as single hydrologic unit.
- Yields range 3–10 gpm where unit is thin and shaley in central extent of this formation. Yields tend to increase towards both eastern and western edges of the unit. Average yields ranging from 5–25 gpm to 25–100 gpm more common for this unit. Yields >100 gpm possible from larger-diameter, properly developed wells where unit >100 ft (30 m) in thickness. Such wells may be partially completed in adjacent units.
- Aquifer rating: 6–7.
- Vadose zone rating: 6–7.
- Hydraulic conductivity: Varies with yield from 300–700 gpd/ft$^2$ to 700–1,000 gpd/ft$^2$.

### Environmental hazards
- People and animals falling from cliffs and gorge walls.
- Structural damage to buildings, bridges, or highways because of sudden or gradual ground collapse into solution-enlarged joints, sinkholes, or caves.
- Pollution threat to ground-water resources through surface waters entering sinkholes directly linked to underground drainage system.

### Economic geology
- Quarried for crushed stone used in road and building construction.
- Crushed stone for asphalt paving.
- Agricultural lime.
- Portland cement.
- Rip rap.

### Scenic geology
- Trimmer, Skull Cave, and Lions Den Natural Arches.
- Hannah, Frost, and Sunfish Caves along Sunfish Creek in vicinity of Byington, Pike County.
- Gorges created by Paint and Sugar Creeks and their tributaries in vicinity of Rock Mills, Fayette County.

### Further reading
Janssens, 1977; Swinford, 1985; Slucher and others, 2006


*Porous, finely to coarsely crystalline dolomite*


# Lockport Dolomite

The Lockport Dolomite is characterized by white to gray, porous dolomite occurring in thick to massive beds that weather to a pitted and corroded surface. These rocks were deposited in a shallow tropical sea containing abundant marine plants and animals. Their skeletons and skeletal fragments accumulated into thick beds of limestone that were later changed into dolomite as magnesium-rich, high-salinity waters were circulated through these sediments.

In most of western Ohio, the Lockport is buried under glacial drift and lake silt and clay deposits. The Lockport occurs in the buried valley of the Teays River in west-central Ohio and in the upland areas between buried Teays River tributaries in west-central Ohio. In north-central Ohio, the Lockport occurs in a 20–30-mi (32–48-km)-wide band bounded by the Bowling Green Fault System to the west and rocks of the underlying Greenfield and Tymochtee Dolomites to the east. Where exposed, the Lockport occurs along streams and in natural low ridges with elevations of 10–50 ft (3–15 m) above the surrounding countryside. Commonly, the low ridges are sites of active and abandoned stone quarries. The Lockport Dolomite was introduced in 1839 to name the exposures of dolomite in Lockport Township of Niagara County, New York. In Ohio, the Lockport ranges in thickness from 30 to 450 ft (9–137 m).

*Medium to massive beds of the Lockport Dolomite quarried in Rockford Quarry located in Mercer County. Massive beds correspond to fossil reefs common in the quarry and the tilted medium beds represent reef flank beds.*

## Diagnostic features

- White to medium-gray dolomite.
- Thick to massive bedding.
- Abundant porosity and vugs ranging in size from pinpoint to small caves.

## General features

- Fine- to coarse-crystalline dolomite.
- Abundant fossil molds and casts.
- Some zones contain burrow mottling.

## Lithologic variations
- Locally, basal portion contains bedded chert and chert nodules.
- Grades laterally into the Euphemia, Springfield, and Cedarville Dols of west-central Ohio.

## Fossil content
- Diverse marine fauna with crinoids, cystoids, and brachiopods dominating.
- Coral, bryozoans, bivalves, cephalopods, gastropods, and trilobites common.

## Weathering characteristics
- Resistant to weathering.
- Weathered surfaces often pitted and corroded creating a honeycomb effect.
- Forms cliffs, waterfalls, and gorges in quarries, streams, and road cuts.

## Stratigraphic contacts
- Sharp to gradational upper contact.
- Sharp to gradational lower contact.

## Stratigraphic context
- Underlain by Clinton and Cataract Gps undifferentiated.
- Overlain by Greenfield Dol in north-central and northern Ohio or Salina Gp in northwestern Ohio adjacent to the border with Indiana.
- Similar units: Euphemia, Peebles, and Cedarville Dols.

## Engineering properties
- Unconfined compressive strength: Unweathered dolomite will have medium to high compressive strength. Weathered dolomite will have medium to high compressive strength.
- Slake durability: Expected to be high to very high.
- Rippability: Resistant to ripping. Blasting, breaking, or cutting required for rock excavation.

## Hydrogeologic properties
- Moderate to excellent aquifer.
- May be utilized independently or mapped and drilled together as hydrologic unit with overlying units. Typically higher yielding than underlying units.
- Average yield: 10–25 gpm for domestic wells completed in this aquifer range. Yields ranging from 5–25 gpm to 25–100 gpm common for this unit. Yields >100 gpm possible from larger-diameter, properly developed wells where unit >100 ft (30 m) in thickness, in northern and western Ohio. A high-yielding, vuggy zone near the top of this unit has historically been referred to as the "Newburg zone" by drillers.
- Aquifer rating: 6–8.
- Vadose zone rating: 6–8.
- Hydraulic conductivity: Varies with yields from 300–700 gpd/ft$^2$ to 700–1,000 gpd/ft$^2$.

## Environmental hazards
- Falling rocks from cliff and gorge walls, especially during winter and spring freeze/thaw cycles.
- People and animals falling from cliffs and gorge walls.
- Potential for solution-enlarged joints and sinkhole development in areas of thin to absent glacial drift.
- Caves and sinkholes common in western Sandusky and Seneca Counties.

## Economic geology
- Quarried for nearly 150 years for use in road and building construction, Portland cement, agricultural lime, crushed stone for asphalt paving, and rip rap.
- Source of abundant, hard ground water, particularly the "Newburg zone."

## Scenic geology
- Forms gorge walls and waterfall for Greenville Creek SSR at Greenville Falls SNA.
- Greenville Falls Natural Arch and other rock arches in west-central Ohio were formed by weathering of Lockport Dol.

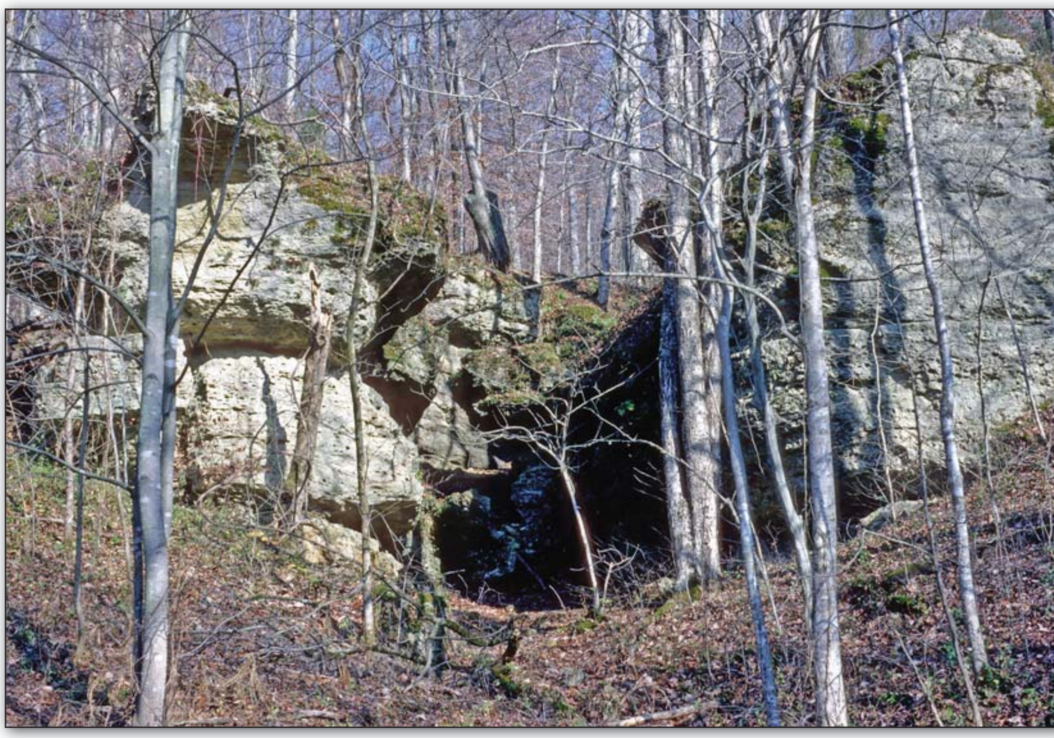
## Further reading
Janssens, 1977; Strobel and Bugliosi, 1991


*Porous dolomite*


# Peebles Dolomite

The Peebles Dolomite is characterized by gray to blue-gray, porous dolomite occurring in thick to massive beds that weather to a pitted and corroded surface. These rocks were deposited in a shallow tropical sea containing abundant marine plants and animals. Their skeletons and skeletal fragments accumulated into thick beds of limestone that were later changed into dolomite as magnesium-rich, high-salinity waters circulated through these sediments.

The Peebles occurs in a 1–10-mi (1.6–16-km)-wide band extending southeastward from northern Highland County to the Ohio River in Adams County. The Peebles Dolomite was introduced in 1929 to describe the rocks exposed in the vicinity of Peebles, Adams County. The Peebles ranges in thickness from 0 to 120 ft (0–36 m). Locally, the pores and vugs in the Peebles may contain abundant deposits of asphalt.



*Weathered, pitted, and corroded surface of the thick to massive beds of the porous Peebles Dolomite along Long Lick Road in Adams County.*

## Diagnostic features
- Gray to blue-gray dolomite.
- Thick to massive bedding.
- Abundant porosity and large vugs.

## General features
- Abundant fine to coarse dolomite crystals.
- Abundant fossil molds and casts.

## Lithologic variations
- Rare medium to thin bedding in some exposures.
- Grades laterally into the Cedarville Dol of west-central Ohio.

## Fossil content
- Diverse marine fauna with crinoids, cystoids, and brachiopods dominating.
- Coral, bryozoans, bivalves, cephalopods, gastropods, and trilobites common.
- The diagnostic brachiopod *Pentamerus* (see p. 129) abundant in lower part of unit.

### Weathering characteristics
- Resistant to weathering.
- Weathered vertical surfaces often pitted and corroded creating a honeycomb effect.
- Forms cliffs, waterfalls, and gorges in streams and road cuts.
- Along outcrop belt of the Peebles, weathered upper surface forms wide, gently rolling plains often containing numerous sinkholes.

### Stratigraphic contacts
- Sharp upper contact.
- Gradational lower contact.

### Stratigraphic context
- Underlain by Lilley Fm.
- Overlain by Greenfield Dol.
- Similar units: Euphemia Dol, Cedarville Dol, and Lockport Dol.

### Engineering properties
- Unconfined compressive strength: Unweathered dolomite will have medium to high compressive strength. Weathered dolomite will have medium to high compressive strength.
- Slake durability: Expected to be high to extremely high.
- Rippability: Resistant to ripping. Blasting, breaking, or cutting required for rock excavation.

### Hydrogeologic properties
- Moderate to poor aquifer.
- In areas where unit is thin, it is most likely mapped and drilled together as hydrologic unit with overlying/underlying units.
- Average yield: 3–10 gpm for domestic wells completed in this aquifer.
- Aquifer rating: 3–4.
- Vadose zone rating: 3–4.
- Hydraulic conductivity: Varies from 1–100 gpd/ft$^2$ to 100–300 gpd/ft$^2$.

### Environmental hazards
- Falling rocks from cliff and gorge walls, especially during winter and spring freeze/thaw cycles.
- People and animals falling from cliffs and gorge walls.
- Structural damage to buildings, bridges, or highways because of sudden or gradual ground collapse into solution-enlarged joints, sinkholes, or caves.
- Pollution threat to ground-water resources through surface waters entering sinkholes directly linked to underground drainage system.

### Economic geology
- Quarried for crushed stone used in road and building construction.
- Agricultural lime.
- Crushed stone for asphalt paving.
- Rip rap.

### Scenic geology
- Peebles Dol and underlying Lilley Fm form the walls of Rocky Fork Gorge in eastern Highland County, Baker's Fork Gorge near Fort Hill, and Paint Creek Gorge at the dam site for Paint Creek SP.
- Peebles Dol and overlying Greenfield Dol form gorge walls at Shoemaker SNP and Davis Memorial SNP, east of Peebles, Adams County.
- Cedar Fork, Mattress, Crawl, Blocked, Natural Y, Keyhole, Spring Creek, Miller, and Miller Natural Arches.

### Further reading
Rexroad and others, 1965; Pavey and others, 2007; McLaughlin and others, 2008b; Snyder, 2010


*Porous to vuggy dolomite*

# Lilley Formation


The Lilley Formation consists of two types of dolomite that occur in planar to irregular beds: (1) silty to shaley, fine-grained, fossiliferous dolomite and (2) medium- to coarse-grained, fossiliferous dolomite. These rocks were deposited in a vast, shallow sea near the shoreline. The warm, tropical waters provided excellent habitat for a wide variety of plants and animals.

The Lilley is exposed in Highland and Adams Counties along a 1–5-mi (1.6–8.0-km)-wide band. The Lilley was named for Lilley Hill in Hillsboro, Highland County, where quarries and an abandoned railroad cut exposed these rocks. The unit ranges in thickness from 20 to 80 ft (6–24 m). Locally, the Lilley may contain asphalt.

*Medium to thick bedded, medium- to coarse-grained, fossiliferous dolomite of the Lilley Formation in abandoned quarry four miles (6 km) east of West Union, Adams County.*

## Diagnostic features

- Fine- to coarse-grained dolomite.
- Fossiliferous.
- Planar to irregular bedding.

## General features

- Gray to blue gray.
- Thin to thick bedding.
- Occasional beds of dolomitic shale.
- Minor shale and limestone beds.

## Lithologic variations

- In Adams County, fine-grained, fossiliferous, shaley dolomite more common than medium- to coarse-grained, fossiliferous dolomite.
- In Highland County, medium- to coarse-grained, fossiliferous dolomite more common than fine-grained, fossiliferous, shaley dolomite.
- Middle portion of the Lilley Fm contains dolomitic shale beds.

## Fossil content

- Marine fauna with crinoids dominating.
- Crinoids, coral, brachiopods, and stromatoporoids common.
- Local coral and stromatoporoid bioherms.

### Weathering characteristics
- Resistant to weathering.
- Forms cliffs, waterfalls, and gorges in streams and road cuts.

### Stratigraphic contacts
- Upper contact gradational.
- Lower contact sharp.

### Stratigraphic context
- Underlain by Bisher Fm.
- Overlain by Peebles Dol.

### Engineering properties
- Unconfined compressive strength: Unweathered will have medium to high compressive strength. Weathered portions will have low to high compressive strength, depending on degree of weathering. Shaley facies within the formation will lower unconfined compressive strength for weathered portions.
- Slake durability: Expected to be high except where higher shale content present.
- Rippability: Resistant to ripping. Blasting, breaking, or cutting required for rock excavation.

### Hydrogeologic properties
- Moderate to poor aquifer.
- Might be mapped and drilled together as hydrologic unit with overlying/underlying units.
- Average yield: 3–10 gpm for domestic wells completed in this aquifer.
- Aquifer rating: 4–5.
- Vadose zone rating: 4–5.
- Hydraulic conductivity: Varies from 1–100 gpd/ft$^2$ to 100–300 gpd/ft$^2$.

### Environmental hazards
- Falling rocks from cliff and gorge walls, especially during winter and spring freeze/thaw cycles.
- People and animals falling from cliffs and gorge walls.
- Sinkhole development common.

### Economic geology
- Crushed stone for road and building construction.
- Crushed stone for asphalt paving.
- Agricultural lime for soil improvement.

### Scenic geology
- Lilley Fm and overlying Peebles Dol form walls of Rocky Fork Gorge in eastern Highland County, Baker's Fork Gorge near Fort Hill SM, and Paint Creek Gorge at the dam site for Paint Creek SP.
- Lilley Fm and underlying Bisher Fm are exposed in gorge walls and form the waterfall in Fallsville WA in northern Highland County, the gorge for Lees Creek at Leesburg, and the gorge and waterfalls for Rattlesnake Creek at East Monroe.

### Further reading
Rodgers, 1936; Swinford, 1985


*Fine-grained, fossiliferous, porous, shaley dolomite*


# Bisher Formation

The Bisher Formation is characterized by predominantly silty to shaley, fine-grained, fossiliferous dolomite and medium- to coarse-grained, fossiliferous dolomite. Minor beds of fossiliferous chert nodules and geodes occur locally. These rocks were deposited in a vast, shallow tropical sea near or at the shoreline and possibly in tidal flats adjacent to the shoreline. Offshore, the warm, tropical waters provided excellent habitat for a wide variety of plants and animals.

The Bisher is exposed in Highland and Adams Counties along a 1–5-mi (1.6–8.0-km)-wide band. The Bisher was named for Bisher Dam located 1 mi (1.6 km) south of Hillsboro, Highland County. The unit ranges in thickness from 20 to 90 ft (6–27 m).

*Cross-bedded and cross-laminated, fine-crystalline, fossiliferous dolomite of the Bisher Formation exposed in a road cut for S.R. 41 south of Peebles, Adams County. This cut contains prominent oxidized, solution-enlarged, vertical cracks. Scale is 50 cm (1.6 ft) and is pointing to shale rip-up clasts.*

## Diagnostic features
- Fine- to coarse-grained dolomite.
- Silty to shaley dolomite.
- Minor chert nodules and geodes.

## General features
- Gray to blue gray.
- Minor dolomitic shale interbeds.
- Abundant cross bedding and cross lamination.
- Planar, lenticular, and wavy bedding.

## Lithologic variations
- Rocks for the Bisher Fm vary from exposure to exposure in the portion of fine-grained, silty to shaley dolomite and medium- to coarse-grained, fossiliferous dolomite.
- Amount of interbedded dolomitic shale varies between exposures.

## Fossil content
- Open to restricted marine fauna with brachiopods and crinoids dominating.

- Fossils less abundant in upper part of unit.
- Some beds contain abundant trace fossils.
- Basal part of Bisher contains a highly fossiliferous zone dominated by brachiopod *Cryptothyrella* (formally known as the *Whitfieldella* bed), occurring throughout southern Ohio and northeastern Kentucky.

## Weathering characteristics
- Resistant to weathering.
- Forms cliffs, waterfalls, and gorges in streams and road cuts.
- Weathers to distinctive brownish orange color.

## Stratigraphic contacts
- Upper contact gradational.
- Lower contact sharp.

## Stratigraphic context
- Underlain by Estill Sh.
- Overlain by Lilley Fm.

## Engineering properties
- Unconfined compressive strength: Unweathered will have medium to high compressive strength. Weathered portions will have low to high compressive strength, depending on degree of weathering. Shaley facies within the formation will lower unconfined compressive strength of weathered portions.
- Slake durability: Expected to be high except where higher shale content present.
- Rippability: Resistant to ripping. Blasting, breaking, or cutting required for rock excavation.

## Hydrogeologic properties
- Moderate to poor aquifer.
- In areas where unit is thin, it is most likely mapped and drilled together as a hydrologic unit with overlying/underlying units.
- Average yield: 3–10 gpm for domestic wells completed in this aquifer.
- Aquifer rating: 3–4.
- Vadose zone rating: 3–4.
- Hydraulic conductivity: Varies from 1–100 gpd/ft$^2$ to 100–300 gpd/ft$^2$.

## Environmental hazards
- Falling rocks from cliff and gorge walls, especially during winter and spring freeze/thaw cycles.
- People and animals falling from cliffs.
- Some sinkhole development and solution enlargement of joints.

## Economic geology
- Crushed stone for road and building construction.
- Crushed stone for asphalt paving.
- Agricultural lime for soil improvement.

## Scenic geology
- Bisher Fm and overlying Lilley Fm are exposed in gorge walls and form the waterfall in Fallsville WA in northern Highland County, the gorge for Lees Creek at Leesburg, and the gorge and waterfalls for Rattlesnake Creek at East Monroe.

## Further reading
Rodgers, 1936; McLaughlin and others, 2008b


*Fossiliferous, fine-grained, silty dolomite*

# Estill Shale


The Estill Shale is characterized by greenish-gray to reddish-gray, dolomitic shale interbedded with burrowed calcareous dolomite or dolomite. These rocks were deposited in nearshore areas of a shallow tropical sea with a reduced fauna of sea creatures. These creatures primarily burrowed into the sea floor. Sea creatures that produced shells that were later fossilized were rare in this environment.

The Estill Shale is exposed in a 5–10-mi (8–16-km)-wide band in Clinton, Highland, and Adams Counties. The Estill was named for the exposures occurring near Estill Springs in Estill County, Kentucky. The unit ranges in thickness from 30 to 180 ft (9–55 m).


*Landslide damage occurring to Poplar Ridge Road in Adams County below the contact of the Estill Shale and the Bisher Formation. Estill Shale clay-rich colluvium is exposed in road cut on left and a cliff of the Bisher Formation occurs in the road cut at the top of the hill.*

## Diagnostic features

- Greenish-gray to reddish-gray, dolomitic shale.
- Interbedded with calcareous dolomite and dolomite.

## General features

- Lenticular, planar, or nodular bedding.
- Shale commonly medium to thick bedded.
- Fissile to platy partings in shale beds
- Dolomite occurs as laminations or thin beds.

## Lithologic variations

- Abundant glauconite occurs in basal 1–2 ft (0.3–0.6 m) of unit.
- Dolomite beds increase in upper 10 ft (3.3 m) of unit.

## Fossil content

- Sparse fauna of ostracodes, mollusks, and rare brachiopods.
- Abundant trace fossils in calcareous siltstones and dolomitic siltstones.

- Occasional horizontal and vertical pyrite-filled burrows in shale beds.

### Weathering characteristics
- Not resistant to weathering; rapidly forms abundant colluvium.
- Forms gentle slopes underlying the cliff-forming Bisher and Lilley Fms.

### Stratigraphic contacts
- Sharp, undulating upper contact.
- Upper contact forms a conspicuous change in slope from near-vertical cliffs of the Bisher to gentle slopes of the Estill.
- Sharp lower contact.

### Stratigraphic context
- Underlain by Dayton Fm.
- Underlain by Drowning Creek Fm in southern Highland and Adams Counties.
- Overlain by Bisher Fm.
- Overlain by Laurel Dol in Clinton County.

### Engineering properties
- Unconfined compressive strength: Unweathered shale will have low to high compressive strength. Weathered shale will have extremely low to medium compressive strength.
- Slake durability: Shale beds subject to degradation after exposure; slake durability ranges from very low to medium.
- Rippability: Unweathered shale beds resistant to ripping and may require blasting, breaking, or cutting for rock excavation. Weathered shaley beds, particularly near the surface, can be ripped by conventional earth-moving equipment.

### Hydrogeologic properties
- Numerous springs occur at top of the unit.
- Due to shaley nature, the Estill Sh is a relatively poor aquifer on its own.
- In areas where the Estill Sh is thin, it is most likely mapped and drilled together as a hydrologic unit with overlying/underlying units.
- Average yield: 3–5 gpm. Extending a well deeper for extra storage, use of larger pressure/storage tanks, or other low-yielding aquifer measures may be necessary to provide adequate yields for domestic and small farm needs. Drilling into underlying or overlying units may help increase yield.
- Aquifer rating: 3–4 for hydrologic interval including the Estill Sh.
- Vadose zone rating: 3–4 for hydrologic interval including the Estill Sh.
- Hydraulic conductivity: 1–100 gpd/ft$^2$.

### Environmental hazards
- Frequent landslide development in thick colluvium, particularly in southern Highland and Adams Counties.
- Rock falls where stream erosion undercuts resistant dolomite cliffs.

### Scenic geology
- Huge boulders of dolomite littering the gentle slopes of Estill Sh.

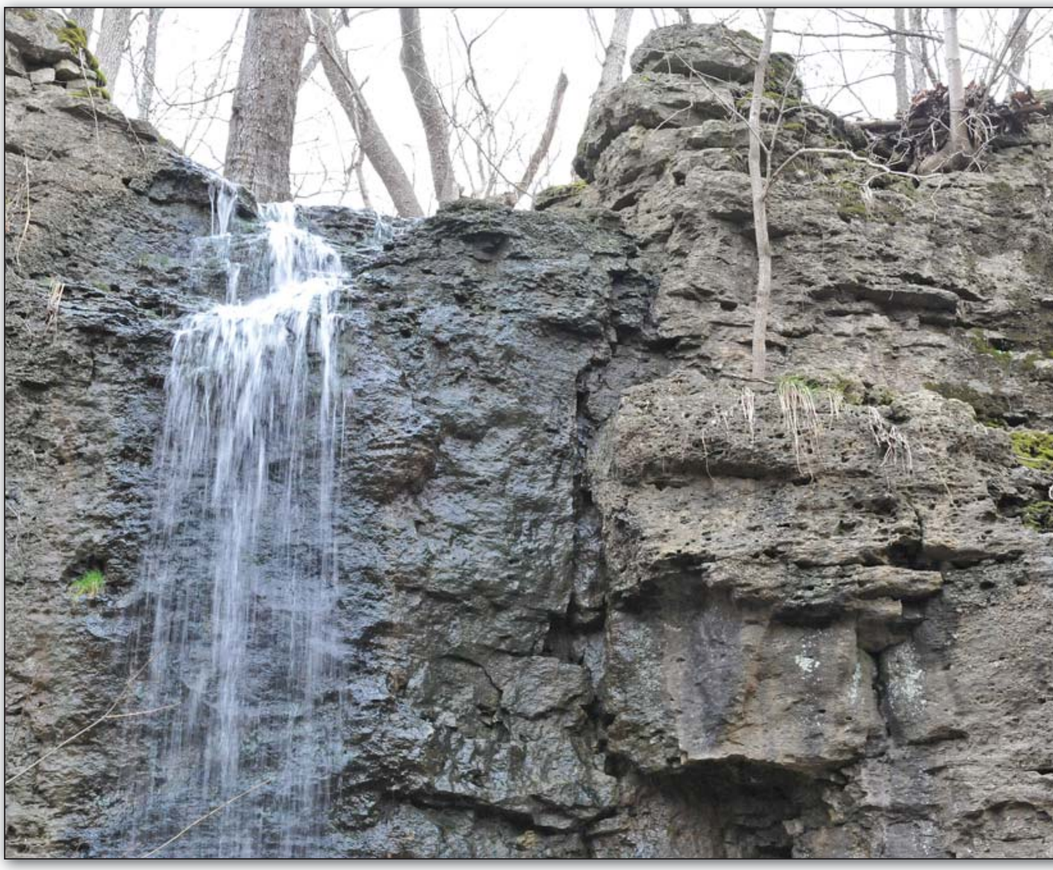
### Further reading
Rexroad and others, 1965; Swinford, 1985


*Greenish-gray, dolomitic shale interbedded with thin dolomite*


# Cedarville Dolomite

The Cedarville Dolomite is characterized by white to light-gray, porous dolomite occurring in thick to massive beds that weather to a pitted and corroded surface. These rocks were deposited in a shallow tropical sea containing abundant marine plants and animals. Their skeletons and skeletal fragments accumulated into thick beds of limestone that were later changed into dolomite as magnesium-rich, high-salinity waters were circulated through these sediments.

The Cedarville occurs in a 1–15-mi (1.6–24-km)-wide band extending southeastward from the Clark-Champaign County line to the Clinton-Highland County line. The Cedarville Dolomite was introduced in the 1870s to replace the local term of *Pentamerus* limestone for the rocks being quarried in the vicinity of Cedarville, Greene County. The Cedarville ranges in thickness from 0 to 100 ft (0–30 m).



*The thick to massive bedded Cedarville Dolomite as exposed in the western gorge wall at Amphitheater Falls in Clifton Gorge State Nature Preserve.*

## Diagnostic features

- White to gray dolomite.
- Thick to massive bedding.
- Abundant porosity and large vugs.

## General features

- Abundant fine to coarse dolomite crystals.
- Abundant fossil molds and casts.

## Lithologic variations

- Rare medium to thin bedding in some exposures.
- Grades laterally into the Lockport Dol of western and northern Ohio and Peebles Dol of southern Ohio.

## Fossil content

- Diverse marine fauna with crinoids, cystoids, and brachiopods dominating.

Pentamerus *brachiopods are commonly found in the Cedarville Dolomite.*

- Coral, bryozoans, bivalves, cephalopods, gastropods, and trilobites common.
- Diagnostic brachiopod *Pentamerus* abundant throughout.

## Weathering characteristics
- Resistant to weathering.
- Weathered surfaces often pitted and corroded, creating a honeycomb effect.
- Forms cliffs, waterfalls, and gorges in streams and road cuts.
- Abundant large slump blocks of dolomite produced as cliff faces and gorge walls are undercut by rapid erosion of less resistant Massie Sh, Laurel Dol, and Osgood Sh.

## Stratigraphic contacts
- Sharp to gradational upper contact.
- Sharp lower contact.

## Stratigraphic context
- Underlain by Springfield Dol.
- Overlain by Salina Gp.
- Similar units: Euphemia Dol, Peebles Dol, and Lockport Dol.

## Engineering properties
- Unconfined compressive strength: Unweathered dolomite will have medium to high compressive strength. Weathered dolomite will have a medium to high compressive strength.
- Slake durability: Expected to be high to extremely high.
- Rippability: Resistant to ripping. Blasting, breaking, or cutting required for rock excavation.

## Hydrogeologic properties
- Moderate to relatively good aquifer.
- May be utilized independently or mapped and drilled together as hydrologic unit with overlying units.
- Average yield: 10–25 gpm for domestic wells completed in this aquifer Max. yield: 25–100 gpm for deeper, larger-diameter wells in this formation.
- Aquifer rating: 5–7.
- Vadose zone rating: 5–7.
- Hydraulic conductivity: Varies from 1–100 gpd/ft$^2$ to 100–300 gpd/ft$^2$. Areas in northern extent of this aquifer may reach 300–700 gpd/ft$^2$ especially when combined in an interval with other higher-producing aquifers.

## Environmental hazards
- Falling rocks from cliff and gorge walls, especially during winter and spring freeze/thaw cycles.
- People and animals falling from cliffs and gorge walls.
- Potential for solution-enlarged joints and sinkhole development in areas of thin to absent glacial drift.

## Economic geology
- Quarried for nearly 200 years for road and building construction, Portland cement, agricultural lime, asphaltic cement, and rip rap.
- Source of abundant, hard ground water.

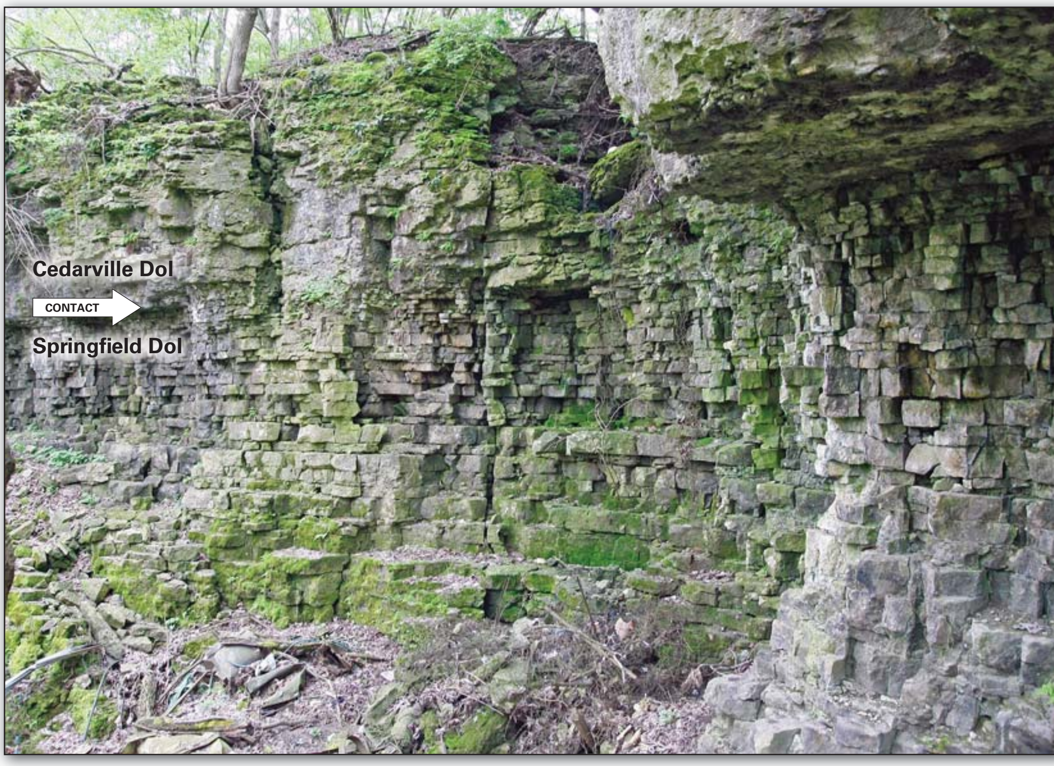
## Scenic geology
- Forms gorge walls of Clifton Gorge SNP, Glen Helen Nature Preserve, Clark Run Gorge, and Massie's Creek Gorge and upper gorge walls of John Bryan SP.
- Main unit forming abundant massive slump blocks, such as Streamboat Rock in Clifton Gorge and the top of Pompey's Pillar at Glen Helen Nature Preserve.
- Forms resistant lip of Ludlow Falls at Ludlow Falls, Miami County; Amphitheater Falls in Clifton Gorge SNP; and many other waterfalls.

## Further reading
Horvath and Sparling, 1967; Sandy, 2012a


*Porous, vuggy dolomite*


# Springfield Dolomite

The diagnostic features of the Springfield Dolomite include medium to thick-bedded, fine crystalline dolomite that weathers to a distinctive brick-like pattern. These rocks were deposited in a shallow tropical sea containing marine plants and animals. The Springfield was originally deposited as a limestone that was later changed into dolomite as magnesium-rich, high-salinity waters were circulated through the limestone. The Springfield occurs in a narrow (less than 1 mi wide) band extending southeastward from the Clark-Champaign County line to the Clinton-Highland County line. The Springfield stone was introduced in 1871 as a name for the building stone being quarried in the Springfield (Clark County) region. The Springfield ranges in thickness from 5 to 15 ft (1.5–4.6 m).




*Cliff exposure located in Clark County illustrating the medium to thick bedded, brick-like weathering Springfield Dolomite and overlying thick to massive bedded, vuggy Cedarville Dolomite.*

## Diagnostic features
- Fine crystalline dolomite.
- Medium to thick bedding.
- Weathers to brick-like appearance.

## General features
- Some burrow mottling.
- Fossil molds and casts.
- Rare to moderate amount of quartz silt.

## Lithologic variations
- Highly variable in thickness from outcrop to outcrop.
- Some sections contain minor amounts of chert.
- Grades laterally into the Lockport Dol of western and northern Ohio and Peebles Dol of southern Ohio.

## Fossil content
- Marine fauna with brachiopods dominating.
- Coral, echinoderms, bryozoans, bivalves, cephalopods, gastropods, and trilobites also present.
- Diagnostic brachiopod *Pentamerus* (see p. 129) occurs scattered throughout the unit.

## Weathering characteristics
- Less resistant to weathering than Euphemia Dol and Cedarville Dol.
- Forms a shallow reentrant in cliff exposures.
- Weathers to brick-like appearance pattern.

## Stratigraphic contacts
- Sharp to gradational upper contact.
- Sharp lower contact.

## Stratigraphic context
- Underlain by Euphemia Dol.
- Overlain by Cedarville Dol.

## Engineering properties
- Unconfined compressive strength: Unweathered dolomite will have medium to high compressive strength. Weathered dolomite will have medium to high compressive strength.
- Slake durability: Expected to be high to very high.
- Rippability: Resistant to ripping. Blasting, breaking, or cutting required for rock excavation.

## Hydrogeologic properties
- Moderate to relatively good aquifer.
- Due to thin nature of unit, it is most likely mapped and drilled together as hydrologic unit with overlying/underlying units.
- Average yield: 10–25 gpm for domestic wells completed in this aquifer. Max. yield: 25–100 gpm for deeper, larger-diameter wells in this formation.
- Aquifer rating: 5–7.
- Vadose zone rating: 5–7.
- Hydraulic conductivity: Varies from 1–100 gpd/ft$^2$ to 100–300 gpd/ft$^2$. Areas in the northern extent of this aquifer may reach 300–700 gpd/ft$^2$ especially when combined in an interval with other higher-producing aquifers.

## Environmental hazards
- Falling rocks from cliff and gorge walls, especially during winter and spring freeze/thaw cycles.
- People and animals falling from cliffs and gorge walls.
- Potential for solution-enlarged joints and sinkhole development in areas of thin to absent glacial drift.

## Economic geology
- Historically, quarried for dimension stone.
- Agricultural lime, asphaltic cement, crushed stone, and rip rap.

## Scenic geology
- Euphemia, Springfield, and Cedarville Dols form gorge walls of Clifton Gorge SNP, Glen Helen Nature Preserve, Clark Run Gorge, and Massie's Creek Gorge and upper gorge walls of John Bryan SP.

## Further reading
Bownocker, 1915; Sandy, 2012a


*Finely crystalline, porous dolomite*


# Euphemia Dolomite

The Euphemia Dolomite is distinguished from the overlying Springfield Dolomite by thin to massive bedding, light-gray, porous dolomite with some mottling and from the underlying Massie Shale by the lack of shale. When exposed, the Euphemia weathers to a pitted and corroded surface with large vugs. These rocks were deposited in a shallow tropical sea containing abundant marine plants and animals. Their skeletons and skeletal fragments accumulated into thick beds of limestone that were later changed into dolomite as magnesium-rich, high-salinity waters were circulated through the limey sediments.

The thin Euphemia is exposed in a narrow band, generally less than 1 mi (1.6 km) wide, extending southeastward from the Clark-Champaign County line to the Clinton-Highland County line. The Euphemia Dolomite, named after the village of Euphemia, Preble County, was introduced in 1917 to separate these rocks from the overlying well-bedded Springfield Dolomite. The Euphemia ranges in thickness from 5 to 15 ft (1.5–4.5 m).


*The Euphemia-Springfield contact is well exposed along the road to the lower picnic area in John Bryan State Park, Greene County. The sharp contact between these units separates the thick to massive bedding of the Euphemia Dolomite from the medium to thick bedding and brick-like weathering of the Springfield Dolomite.*

## Diagnostic features

- Gray dolomite.
- Thin to massive bedding.
- Abundant porosity and large vugs.
- Some mottling.

## General features

- Abundant fine to coarse fossil grains.
- Fossil molds and casts.

## Lithologic variations
- Mixture of lenticular, irregular, and rare planar beds that vary in abundance from exposure to exposure.

## Fossil content
- Diverse marine fauna with crinoids, corals, and brachiopods dominating.
- Bryozoans and trilobites less common.
- Brachiopod *Pentamerus* (see p. 129) occurs throughout and is more common near top of unit.

## Weathering characteristics
- Resistant and forms prominent salient under the less-resistant Springfield.
- Weathered surfaces often pitted and corroded, creating a honeycomb effect.
- Forms resistant base of high gorge walls and small cliffs, waterfalls, and riffles in streams.
- Small slump blocks may occur on colluvium-rich slopes weathered from Massie Sh, Laurel Dol, and Osgood Sh.

## Stratigraphic contacts
- Sharp to gradational upper contact.
- Sharp lower contact.

## Stratigraphic context
- Underlain by Massie Sh.
- Overlain by Springfield Dol.
- Similar units: Cedarville Dol, Peebles Dol, and Lockport Dol.

## Engineering properties
- Unconfined compressive strength: Unweathered dolomite will have medium to high compressive strength. Weathered dolomite will have medium to high compressive strength.
- Slake durability: Expected to be high to very high.
- Rippability: Resistant to ripping. Blasting, breaking, or cutting is required for rock excavation.

## Hydrogeologic properties
- Moderate to relatively good aquifer.
- Due to overall thin nature of unit, the Euphemia may be mapped and drilled together as hydrologic unit with overlying units.
- Average yield: 10–25 gpm for domestic wells completed in this aquifer. Max. yield: 25–100 gpm for deeper, larger-diameter wells completed in this formation.
- Aquifer rating: 5–6.
- Vadose zone rating: 5–6.
- Hydraulic conductivity: Varies from 1–100 gpd/ft$^2$ to 100–300 gpd/ft$^2$.

## Environmental hazards
- Falling rocks from cliffs and gorge walls, especially during winter and spring freeze/thaw cycles.

## Economic geology
- Historically, used sparingly as a building stone.
- May be quarried with overlying Springfield Dol and Cedarville Dol for aggregate used for road and building construction and railroad ballast.

## Scenic geology
- Euphemia forms basal portion of gorge walls of Clifton Gorge SNP and Glen Helen Nature Preserve, Clark Run Gorge, and Massie's Creek Gorge and upper gorge walls of John Bryan SP.
- Forms small slump blocks.

## Further reading
Hansen, 1998; Sandy, 2012a


*Porous, vuggy dolomite*


# Clinton and Cataract Groups

The Clinton and Cataract Groups are characterized by limestone, dolomite, and rare shale. In western Ohio, the Clinton Group includes lateral equivalents of the traditional Brassfield and Dayton Formations, and the Cataract Group contains lateral equivalents of the traditional Osgood Shale and Laurel Dolomite. The Clinton and Cataract Groups formal stratigraphic nomenclature were utilized on the *Bedrock Geologic Map of Ohio* (Slucher and others, 2006) to replace the informal sub-Lockport undifferentiated, as mapped on the individual 1:24,000-scale reconnaissance bedrock-geology quadrangles for western Ohio.

Reconnaissance bedrock mapping documented the thinning of the Osgood Shale to just a few feet and the pinching out of the Massie Shale. Likewise, many of the limestone and dolomite units mapped in Greene and Clark Counties also thinned, some changed rock type, and in places, some are absent. Reconnaissance geologic mapping quickly maps large areas in a very limited timeframe. When the rocks change from one area to another, as in this situation, time was not available for geologic mappers to conduct a detailed study of the stratigraphy of the sub-Lockport interval in western Ohio.

These rocks were deposited in nearshore environments consisting of shallow-offshore and reef environments in the tropical sea that covered western Ohio during the Early Silurian. The rocks of the Clinton and Cataract Groups are relatively well exposed in the Great Miami and Stillwater River valleys in Montgomery and Miami Counties. In the remainder of western Ohio, the units are commonly buried under Quaternary-age sediments. The Clinton Group was named for the rocks exposed in the vicinity of Clinton, New York. The Cataract Group is well exposed at Cataract, Ontario. In Ohio, the combined thickness of both groups ranges from 15 to 175 ft (5–53 m).

*The cliffs associated with Charleston Falls are thin to medium bedded, fine- to coarse-grained limestone of the traditional Brassfield Formation or lower part of the Clinton Group as mapped on the* Bedrock Geologic Map of Ohio *(Slucher and others, 2006). Charleston Falls Preserve is the most visited park in the Miami County Park District.*

### Diagnostic features
- Limestone, dolomite, and rare shale.

### General features
- Color varies from white to light gray through darker shades of gray, tan, pink, red, and brown.
- Planar, irregular, and lenticular bedding.
- Thin to thick bedded.
- Glauconite, chert, and pyrite present.

### Lithologic variations
- Shale beds rare in both groups.
- Nodular- to irregular-bedded chert occurs in some limestone or dolomite units.
- Units thicken from west to east.
- Some limestone and dolomite units may be absent in some locations.

### Fossil content
- Fossiliferous to sparsely fossiliferous.
- Common fossils are crinoids, brachiopods, and bryozoans and trace fossils; less common are bivalves, cephalopods, corals, gastropods, stromatoporoids, and trilobites.
- Some intervals contain abundant burrows, forming a mottled appearance when exposed in outcrop.

### Weathering characteristics
- Resistant to weathering.
- Where exposed form cliffs, waterfalls, and small gorges in rivers and streams.
- May form small sinkholes and caves along solution-enlarged joints.

### Stratigraphic contacts
- Sharp to gradational upper contact.
- Sharp to gradational lower contact.

### Stratigraphic context
- Underlain by Drakes Fm or Cincinnati gp.
- Overlain by Lockport Dol.

### Engineering properties
- Unconfined compressive strength: Unweathered portions will have medium to high compressive strength. Weathered portions will have medium to high compressive strength, depending on degree of weathering. Rare shaley strata within the groups will lower weathered unconfined compressive strength.
- Slake durability: Expected to be high except where shale content present.
- Rippability: Resistant to ripping. Blasting, breaking, or cutting required for rock excavation.


*Oil-stained core from lower Clinton Gp from Preble County*


*Dayton Ls*

### Hydrogeologic properties

- Clinton Gp is a moderate aquifer and the Cataract Gp represents a relatively poor aquifer.
- Where units are thin, they are most likely mapped and drilled together as a hydrologic unit with overlying/underlying units.
- Average yield: 5–25 gpm for domestic wells completed in this aquifer for the Clinton. Yields tend to decrease in the Cataract.
- Aquifer rating: 4–5.
- Vadose zone rating: 4–5.
- Hydraulic conductivity: Varies from 1–100 gpd/ft$^2$ for the Cataract to a range of 1–100 gpd/ft$^2$ to 100–300 gpd/ft$^2$ for the Clinton.

### Environmental hazards

- In Preble County, basal Brassfield may contain petroleum, asphalt, and natural gas, thus downgrading ground-water quality.
- Rock falls especially during the freeze/thaw cycles of late winter and early spring.
- Potential of people and livestock falling from cliffs.
- Potential for solution-enlarged joints and sinkhole development in areas of thin to absent glacial drift.
- Small caves.

### Economic geology

- Quarried for crushed stone used in road and building construction.
- Agricultural lime.
- Crushed stone for asphalt paving.
- Portland cement.
- Rip rap.

### Scenic geology

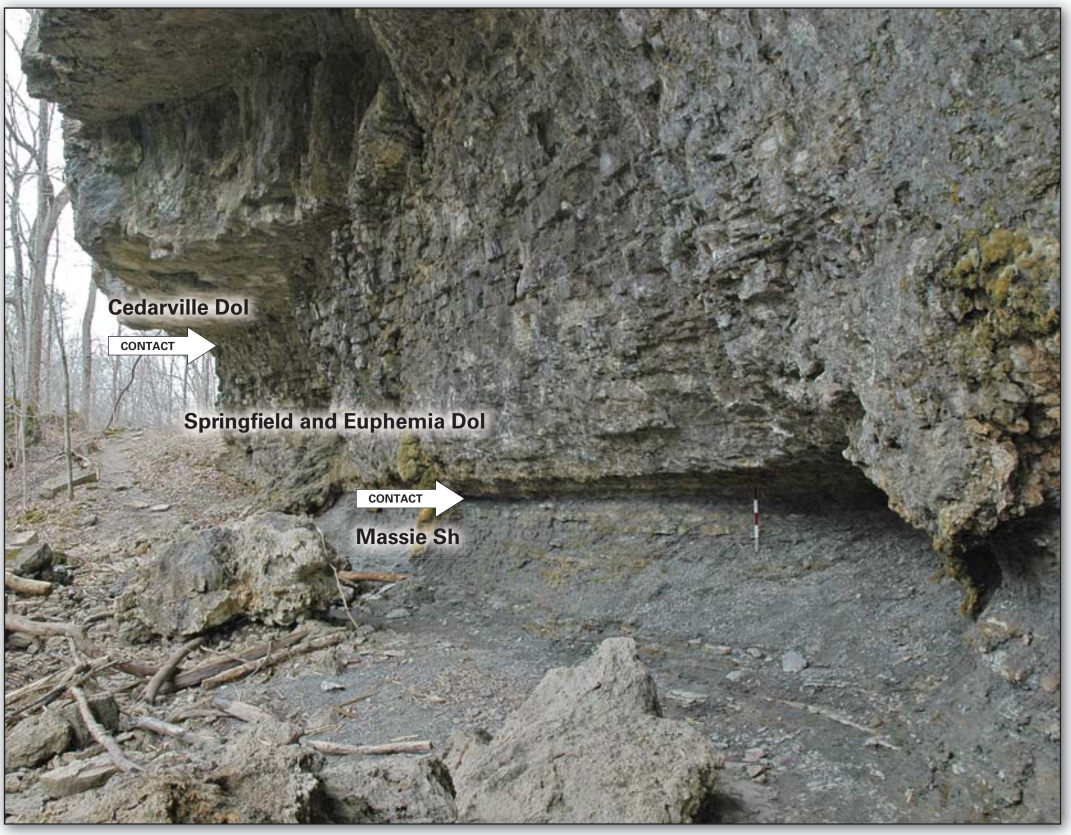
- Spectacular waterfalls and cascades; many available for public viewing in state, county, and municipal park districts. Examples include: Martindale and Patty Falls, Englewood Metro Park; Charleston Falls, Miami Park District; Ludlow Falls, Miami County.
- Forms abundant cliff exposures along rivers and streams.
- Small rock shelters under the base of the Clinton Gp as the less-resistant, underlying Drakes Fm is removed by rapid erosion.

### Further reading

Schumacher, 1993; Larsen, 1994; Swinford and Slucher, 1995; Slucher and others, 2006

# Massie Shale

The Massie Shale is characterized by gray, calcareous, fossiliferous shale interbedded with rare fossiliferous limestone and silty limestone. These rocks were deposited in a vast, shallow tropical sea with an abundant fauna of sea creatures. These creatures burrowed into the sea floor, lived on the sea floor, or lived above the seafloor in the tropical sea. The Massie Shale occurs in Clark, Clinton, and Greene Counties. Generally, it is poorly exposed except in the Little Miami River and Massie Creek gorges. The Massie was named for the excellent exposures located in the Massie Creek Gorge, about 0.5 mi (0.8 km) west of Cedarville, Greene County. The Massie ranges in thickness from 0 to 10 ft (0–3 m).




*Gray, thick bedded, fossiliferous Massie Shale and rare thin, dolomitic limestone beds exposed along the gorge walls of Massies Creek Gorge in Greene County Parks District, Indian Mound Reserve Park located west of Cedarville, Greene County. The Euphemia and Springfield Dolomites are exposed in the reentrant underlying the protruding massive beds of the Cedarville Dolomite. The low permeability of the Massie stops the downward flow of ground water through vertical cracks in the overlying dolomite. The springs that form along the contact of the Massie and the Euphemia provide moisture for algal growth and travertine precipitation. Scale is 50 cm (1.6 ft).*

## Diagnostic features

- Gray, calcareous, fossiliferous shale.
- Rare fossiliferous dolomitic limestone and silty dolomitic limestone.

## General features

- Shale beds medium to thick bedded.
- Limestone beds laminated to thin bedded.
- Fissile to platy partings in shale beds.

## Lithologic variations

- Contains increasing amounts of dolomitic limestone and dolomite beds in the western part of Clark and Greene Counties and central Clinton County.

## Fossil content
- Brachiopods, bryozoans, crinoids, and snails common.
- Trilobites less common.

## Weathering characteristics
- Not resistant; unit weathers rapidly, forming abundant colluvium.
- Forms prominent reentrants under overlying resistant dolomite units.

## Stratigraphic contacts
- Sharp upper contact.
- Sharp lower contact.

## Stratigraphic context
- Underlain by Laurel Dol.
- Overlain by Euphemia Dol.

## Engineering properties
- Unconfined compressive strength: Unweathered shale will have low to high compressive strength. Weathered shale will have extremely low to medium compressive strength.
- Slake durability: Shale beds subject to degradation after exposure; slake durability ranges from very low to medium.
- Rippability: Unweathered shale beds are resistant to ripping and require blasting, breaking, or cutting for rock excavation. Weathered shaley beds, particularly near the surface, can be ripped by conventional earth-moving equipment.

## Hydrogeologic properties
- Springs occur along contact with Euphemia Dol.
- Relatively poor aquifer.
- Due to thin nature (<10 ft [3 m]), unit typically not considered an individual hydrologic unit and is mapped and drilled together with underlying and overlying units, which feature better aquifer characteristics.
- Average yield: 10–25 gpm for the hydrologic interval, which includes the Massie Sh; suitable for most domestic and small farm needs.
- Aquifer rating: 3–4.
- Vadose zone rating: 3–4.
- Hydraulic conductivity: 1–100 gpd/ft$^2$.

## Environmental hazards
- Danger of falling rocks as unit is eroded from under overlying cliff-forming dolomite.

## Economic geology
- Not used as raw material for manufacturing or other commercial activities.

## Scenic geology
- Spectacular overhanging cliffs.
- Small rock shelters under overhanging dolomite cliffs.
- Boulder fields of huge dolomite blocks that have toppled into the gorge, resulting from rapid lateral and vertical stream erosion of the less-resistant Massie Sh, Laurel Dol, and Osgood Sh.

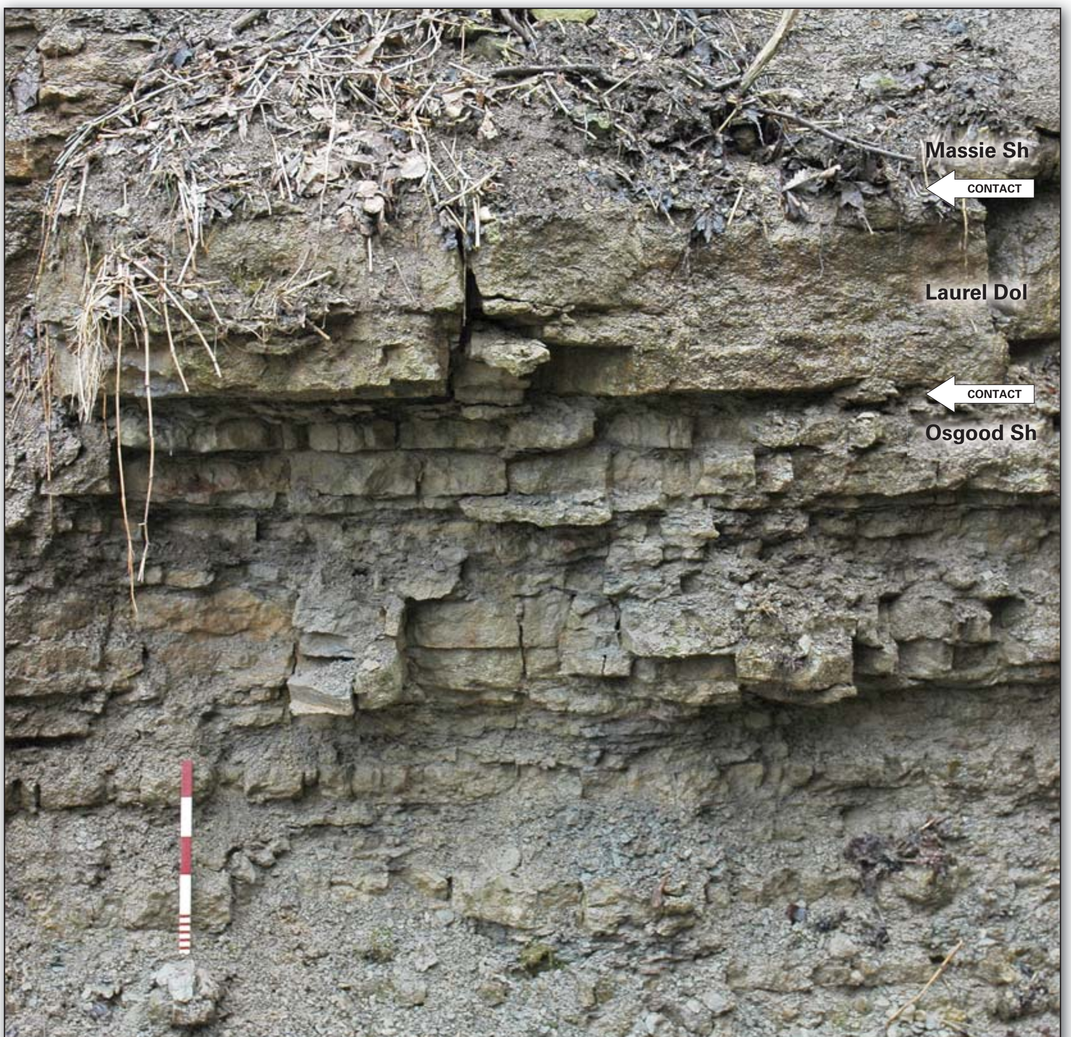
## Further reading
Stout, 1941; Ausich, 1987


*Fossiliferous shale and fossiliferous, shaley limestone*


# Laurel Dolomite

The Laurel Dolomite is characterized by finely crystalline, fossiliferous, dolomitic limestone and dolomite with rare shale beds. These rocks were deposited in a shallow sea with a variety of plants and animals. The Laurel is a very thin unit that is exposed in a very thin band only a few feet to a few hundred feet wide in Greene, Clark, Miami, Montgomery, and Preble Counties.

Recent stratigraphic investigations of the Lower Silurian rocks of western Ohio have demonstrated that the Laurel Dolomite of Indiana correlates to the Euphemia Dolomite, whereas the Laurel Dolomite of Ohio occurs below the Massie Shale. Thus the Lewisburg Formation is proposed by McLaughlin and others (2008b) and Cramer (2009) to replace the Laurel Dolomite of Ohio. The Laurel Dolomite is mapped throughout west-central Ohio and to avoid confusion we used this term for this fact sheet. Readers should consider these recent changes in stratigraphic nomenclature when investigating the Lower Silurian rocks of Ohio and Indiana. The Laurel Dolomite was named for the exposures near Laurel, Indiana. In Ohio, the Laurel ranges in thickness from 3 to 6 ft (0.9–1.8 m).




*Thin bedded, fossiliferous, dolomitic limestone and dolomite beds of the Laurel Dolomite exposed in an unnamed tributary of the Little Miami River termed the "south section" of Ausich (1987), located in John Bryan State Park, Greene County. The upper Osgood Shale underlies the Laurel and the slumped Massie occurs above. Scale is 50 cm (1.6 ft).*

## Diagnostic features
- Finely crystalline, fossiliferous, dolomitic limestone and dolomite with rare shale beds.

## General features
- Gray to dark gray.
- Thin to medium bedded.
- Dense, hard, well-cemented unit.
- Irregular to planar bedding.

## Lithologic variations
- Contains minor amounts of pyrite and chert at some exposures.

## Fossil content
- Crinoids, brachiopods, and corals common.
- Burrow mottling present in some limestone beds.

## Weathering characteristics
- Resistant to weathering.
- Forms a persistent ledge when exposed in stream cuts.

## Stratigraphic contacts
- Sharp lower contact.
- Sharp upper contact.

## Stratigraphic context
- Underlain by Osgood Sh.
- Overlain by Massie Sh in Greene, Clark, Montgomery and Miami Counties.

## Engineering properties
- Unconfined compressive strength: Unweathered portions will have medium to high compressive strength. Weathered portions will have medium to high compressive strength, depending on degree of weathering. Shaley facies within the formation will have lower unconfined compressive strength.
- Slake durability: Expected to be high except where higher shale content present.
- Rippability: Resistant to ripping. Blasting, breaking, or cutting required for rock excavation.

## Hydrogeologic properties
- Due to its thin nature (<10 ft [3 m]), unit is typically not considered an individual hydrologic unit and is mapped and drilled together with underlying and overlying units, which feature better aquifer characteristics.
- Average yield: 3–10 gpm for the hydrologic interval, which includes the Laurel Dol; suitable for most domestic and small farm needs.
- Aquifer rating: 4–5 for the hydrologic interval including the Laurel Dol.
- Vadose zone rating: 3–4 for the hydrologic interval including the Laurel Dol.
- Hydraulic conductivity: 1–100 gpd/ft$^2$.

## Scenic geology
- Forms the floors of many rock shelters created by the rapid weathering of the Massie Sh from under the cliff-forming Euphemia Dol, Springfield Dol, and Cedarville Dol.

## Further reading
Ausich, 1987; McLaughlin and others, 2008b; Cramer, 2009

*Finely crystalline, fossiliferous dolomite*

# Osgood Shale

The Osgood Shale is characterized by blue-gray to gray, calcareous shale interbedded with sparsely fossiliferous, fine-grained limestone and dolomitic limestone. These rocks were deposited in nearshore areas of a shallow tropical sea with a reduced fauna of sea creatures. These creatures primarily burrowed into the sea floor, although some lived on the sea floor or in the overlying sea.

The Osgood Shale occurs in a narrow band generally less than 1 mi (1.6 km) wide in Clark, Clinton, and Greene Counties. The Osgood was named for the exposures occurring near Osgood, Indiana. The unit ranges in thickness from 3 to 25 ft (0.9–7.6 m).

*The upper part of the Osgood Shale characterized by blue-gray, thin to thick bedded shale with interbedded thin bedded limestone. This exposure occurs in an unnamed tributary of the Little Miami River termed the "south section" of Ausich (1987) located in John Bryan State Park, Greene County. Scale is 50 cm (1.6 ft).*


## Diagnostic features
- Blue-gray to gray, calcareous shale.
- Sparsely fossiliferous, fine-grained limestone and dolomitic limestone.

## General features
- Thin to medium bedded.
- Lenticular to planar bedding.
- Burrow mottling.
- Fissile to platy partings in shale beds.

## Lithologic variations
- Limestone beds increase in upper part of unit.
- Shale dominates in lower part of unit.

## Fossil content
- Sparse fauna of brachiopods, bryozoans, crinoids, corals, and trilobites.

## Weathering characteristics
- Not resistant to weathering, rapidly forming abundant colluvium.
- Forms gentle slopes separating the cliff-forming Euphemia Dol and Springfield Dol and the underlying cliff-forming Brassfield Fm and Dayton Fm.

- Rapid stream erosion of the Osgood undercuts overlying resistant dolomite units, causing gorge wall collapse and formation of abundant slump blocks.

## Stratigraphic contacts
- Sharp upper contact.
- Sharp lower contact.

## Stratigraphic context
- Underlain by Dayton Ls.
- Overlain by Laurel Dol.

## Engineering properties
- Unconfined compressive strength: Unweathered shale will have low to high compressive strength. Weathered shale will have extremely low to medium compressive strength.
- Slake durability: Shale beds subject to degradation after exposure; slake durability ranges from very low to medium.
- Rippability: Unweathered shale beds resistant to ripping and require blasting, breaking, or cutting for rock excavation. Weathered shaley beds, particularly near the surface, can be ripped by conventional earth-moving equipment.

## Hydrogeologic properties
- Relatively poor aquifer.
- Typically not considered an individual hydrologic unit due to thin nature (<25 ft [7.6 m]).
- Mapped and drilled together with underlying and overlying units, which feature better aquifer characteristics.
- Average yield: Varies from 3–10 gpm to 10–25 gpm for the hydrologic interval, which includes the Osgood Sh; suitable for most domestic and small farm needs.
- Aquifer rating: 4–5.
- Vadose zone rating: 3–4.
- Hydraulic conductivity: 1–100 gpd/ft$^2$.

## Environmental hazards
- Landslide development in thick colluvium derived from the Osgood Sh.
- Rock falls in areas with overhanging resistant dolomite cliffs.

## Economic geology
- Not used as raw material for manufacturing or other commercial activities.

## Scenic geology
- Huge boulders of dolomite littering the gentle slopes of Osgood Sh.

## Further reading
Ausich, 1987


*Gray shale*

# Dayton Limestone

The Dayton Limestone is characterized by fine to microcrystalline limestone and dolomitic limestone occuring in planar to irregular beds that are laterally continuous. These rocks were deposited in offshore to nearshore environments associated with the vast, shallow sea that covered Ohio during the Silurian. In Ohio, the Dayton Limestone outcrops along a very narrow band of less than 0.25 mi (0.4 km) wide, extending from the Dayton region southeastward to the Ohio River in Adams County. In southern Highland and Adams Counties, the Dayton Limestone is reduced in stratigraphic rank to a member of the Drowning Creek Formation on the *Bedrock Geologic Map of Ohio* (Slucher and others, 2006). Glacial deposits and soil cover much of the outcrop belt of the Dayton northwestward from the Highland-Clinton County line. Recent stratigraphic studies of the Dayton have demonstrated that in western Ohio, the unit is absent in some areas. The Dayton was first used to describe the limestone extensively quarried in the vicinity of Dayton, Montgomery County. Where present in Ohio, the Dayton ranges in thickness from 2 to 15 ft (0.6–4.6 m).

*Small waterfalls formed by the resistant, finely crystalline to microcrystalline, planar bedded Dayton Limestone. Tributary to Lick Fork located in Adams County. Scale is 50 cm (1.6 ft).*


## Diagnostic features

- Finely crystalline to microcrystalline limestone or dolomitic limestone.
- Planar to irregular bedding.

## General features

- Light gray to yellowish gray.
- Thin to thick bedded.
- Beds laterally continuous.
- Burrow mottling common.

- Unit may include beds or laminations of shale or argillaceous material.
- Glauconite and pyrite present.

### Lithologic variations
- Unit changes from limestone in the Dayton region to a dolomitic limestone in southern Ohio.
- Amount of shale or argillaceous material increases in southern Ohio.

### Fossil content
- Sparsely fossiliferous with rare crinoids and corals.
- Abundant burrows forming mottled appearance in many exposures.

### Weathering characteristics
- Resistant to weathering.
- Forms a laterally persistent ledge that is well exposed in streams.

### Stratigraphic contacts
- Sharp upper contact.
- Sharp lower contact.

### Stratigraphic context
- Underlain by Brassfield Fm in west-central Ohio and undifferentiated rocks of the Drowning Creek Fm in Adams County.
- Overlain by Osgood Sh in west-central Ohio and Estill Sh in southern Ohio.

### Engineering properties
- Unconfined compressive strength: Unweathered limestone will have medium to high compressive strength. Weathered limestone will have medium to high compressive strength.
- Slake durability: Expected to be high to very high.
- Rippability: Resistant to ripping. Blasting, breaking, or cutting required for rock excavation.

### Hydrogeologic properties
- Moderate aquifer.
- Due to thin nature of unit, it is most likely mapped and drilled together as a hydrologic unit with overlying/underlying units.
- Average yield: 5–25 gpm for domestic wells completed in this aquifer; yields tend to decrease towards southeastern extent of unit.
- Aquifer rating: 4–5.
- Vadose zone rating: 4–5.
- Hydraulic conductivity: Varies from 1–100 gpd/ft$^2$ to 100–300 gpd/ft$^2$.

### Economic geology
- Historically, quarried as major building stone in the Dayton region.
- Source of crushed stone.

### Scenic geology
- Unit forms a small picturesque waterfall or series of riffles in most streams.

### Further reading
McDowell, 1983; Kleffner and others, 2012; Sandy, 2012b


*Microcrystalline limestone*

# Brassfield Formation

The Brassfield Formation is characterized by fossiliferous limestone, dolomite, cherty limestone, and minor iron-rich limestone interbedded with rare to abundant, sparsely fossiliferous to fossiliferous shale. The basal Belfast Member is characterized by silty, granular dolomite and dolomitic limestone with locally abundant burrows. These rocks were deposited in a vast, shallow sea that teemed with abundant plants and animals.

In Ohio, the Brassfield occurs along a narrow (0.5–2-mi [0.8–3.2 km]-wide) band extending in an arc from the Ohio-Indiana line in Butler and Preble Counties through the Dayton region then extending southeastward to the Ohio River in Adams County. Several small "islands" of Brassfield occur overlying the Ordovician rocks in Preble, Montgomery, Warren, and Brown Counties in Ohio. In the Dayton region, occasional reefs and shoals developed, producing well-sorted, calcium-rich limestone beds containing little, if any, shale. In southern Ohio, the limestone beds contain more dolomite and clay and are interbedded with abundant, sparsely fossiliferous to fossiliferous shale beds. The Brassfield Formation is reduced in stratigraphic rank to a member of the Drowning Creek Formation in southern Highland and Adams Counties

The Brassfield was first used to describe the limestone and dolomite rocks exposed in the Louisville & Atlantic Railroad cuts near the town of Brassfield in Madison County, Kentucky. In Ohio, the Brassfield ranges in thickness from 12 to 50 ft (3.7–15 m).

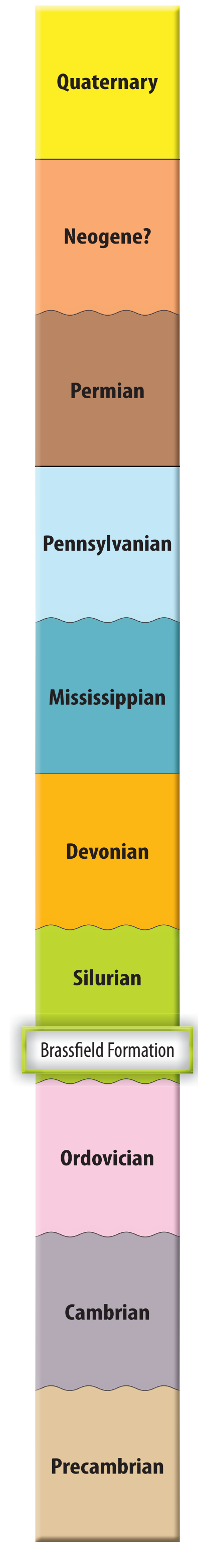
*The eastern highwall of the Fairborn Parks and Recreation Department, Oakes Quarry Park, Greene County, displaying the characteristic thin to thick bedded, fossiliferous, high-calcium limestone of the Brassfield Formation with prominent joints.*

## Diagnostic features

- Fine- to coarse-crystalline limestone.
- High-calcium limestone in Dayton region.
- Limestone interbedded with dolomite, chert, and shale in Adams and Highland Counties.

## General features

- Planar, irregular, lenticular, and nodular bedding.
- Thin to thick bedded.
- Color varies from white to light gray through darker shades of gray, tan, pink, red, and brown.



### Lithologic variations
- Nodular- to irregular-bedded chert is abundant in the lower portion of the unit in Adams and Highland Counties.
- Near the top of the Brassfield, iron-rich limestone beds form a distinctive stratigraphic marker that is mapped throughout Adams and Highland Counties.
- Large distinctive crinoid columns, resembling beads, occur in great abundance in the uppermost Brassfield in southern Ohio.

### Fossil content
- Abundant fossils are crinoids, corals, stromatoporoids, brachiopods, and bryozoans and trace fossils.
- Trilobites, gastropods, bivalves, and cephalopods less common.
- In the Fairborn region, the Brassfield contains over 26 genera and 29 species of criniods representing one of the world's most diverse Early Silurian crinoid faunas.

### Weathering characteristics
- Resistant to weathering.
- Forms cliffs, waterfalls, and gorges in streams and road cuts.
- Commonly weathers reddish gray to light gray.

### Stratigraphic contacts
- Sharp to gradational lower contact.
- Sharp upper contact.

### Stratigraphic context
- Underlain by Drakes Fm.
- Overlain by Dayton Ls in west-central Ohio or undifferentiated rocks of the Drowning Creek Fm in southern Ohio.

### Engineering properties
- Unconfined compressive strength: Unweathered portions will have medium to high compressive strength. Weathered portions will have medium to high compressive strength.
- Slake durability: Expected to be high to very high. Porosity makes unit susceptible to freeze/thaw breakdown.
- Rippability: Resistant to ripping. Blasting, breaking, or cutting required for rock excavation.


*Brassfield Fm south core; interbedded limestone and shale*


*Brassfield Fm north core; fossiliferous, high-calcium limestone with minor shale*

## Hydrogeologic properties

- A moderate to relatively poor aquifer, due to its variable nature.
- May be utilized singularly or mapped and drilled together as a hydrologic unit with overlying units.
- Better aquifer than underlying Ordovician units.
- Average yield: Typically 3–10 gpm, in limited areas where formation is thicker and more vuggy. Max. yield: 25 gpm.
- Suitable for most domestic and small farm needs.
- Aquifer rating: 4–5.
- Vadose zone rating: 3–4.
- Hydraulic conductivity: 1–100 gpd/ft$^2$.

## Environmental hazards

- Rocks falls, especially during freeze/thaw cycles of late winter and early spring.
- Falls from cliff tops by people and livestock.
- Potential for solution-enlarged joints and sinkhole development in areas of thin to absent glacial drift.
- Small caves.

## Economic geology

- Major source of high-calcium limestone (>95% calcium carbonate) in the Fairborn region.
- High-calcium limestone is used to manufacture Portland cement.
- Source of crushed stone.

## Scenic geology

- Abundant, spectacular, waterfalls and cascades; many available for public viewing in state, county, and municipal park districts. Some examples include: inner gorge at John Bryan SP; Martindale and Patty Falls, Englewood Metro Park; Charleston Falls, Miami Park District.
- Forms abundant cliff exposures along streams especially in southern Ohio beyond the limit of glaciation.
- Small rock shelters under the base of the unit as the less-resistant Drakes Fm is removed by rapid erosion.

## Further reading

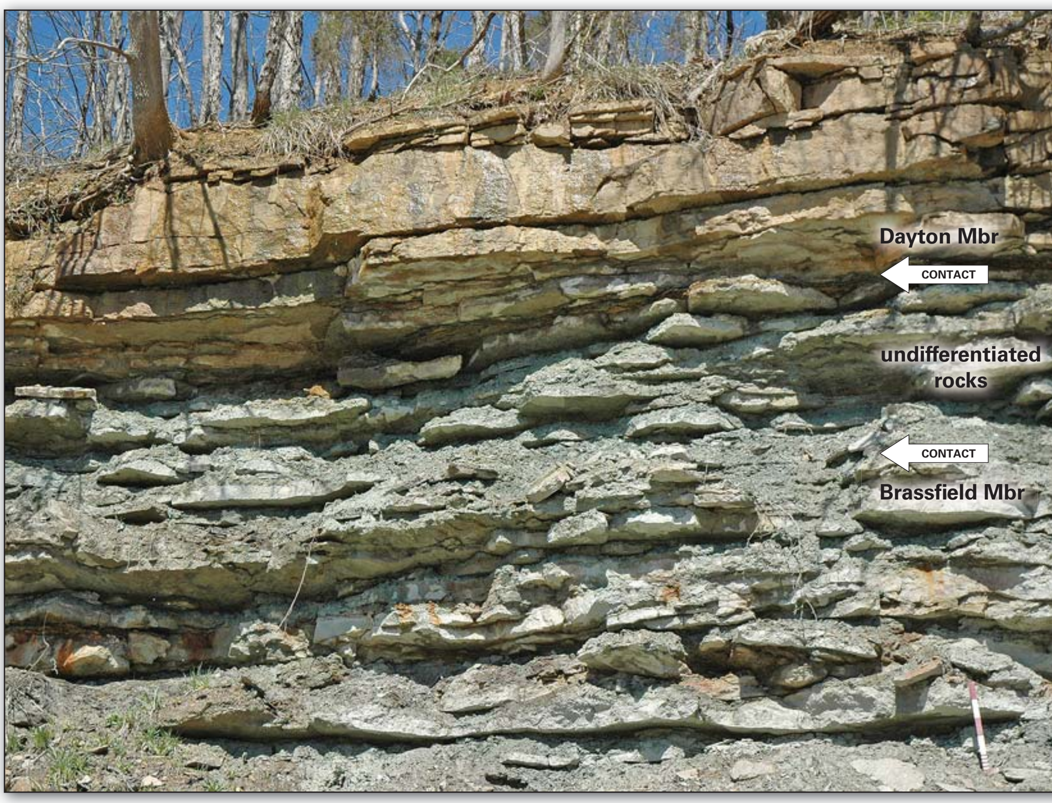
Swinford, 1985; Wolfe 2008; Ausich 2009

# Drowning Creek Formation


The Drowning Creek Formation is characterized by interbedded fossiliferous limestone, dolomitic limestone, dolomite, chert, and sparsely fossiliferous to fossiliferous shale. The Drowning Creek Formation is subdivided, in ascending order, into the Brassfield Member, the middle undifferentiated rocks, and the Dayton Member. These rocks were deposited in a vast, shallow sea, offshore and along the ancient shoreline.

In Ohio, the Drowning Creek occurs along a narrow band from 0.5 to 2 mi (0.8–3.2-km) wide. An outlier of the Drowning Creek is present in the northeast corner of Brown County.

The Drowning Creek was introduced to redefine the existing Lower Silurian stratigraphic nomenclature of eastern Kentucky to better match the geology mapped by U.S. Geological Survey and Kentucky Geological Survey geologists. In Ohio, the formation is mapped in southern Highland and Adams Counties on the *Bedrock Geologic Map of Ohio* (Slucher and others, 2006) and replaces the Brassfield Formation, Noland Formation, and Dayton Limestone undivided rocks that are mapped on the 1:24,000-scale bedrock-geologic quadrangles in this area. The name *Belfast* is retained to describe the basal silty, granular dolomite and dolomitic limestone of the Brassfield Member, but a formal stratigraphic rank has not been assigned. The Drowning Creek ranges in thickness from 45 to 70 ft (14–21 m).




*Fossiliferous limestone, dolomitic limestone, and dolomite interbedded with sparsely fossiliferous and fossiliferous shale of the Drowning Creek Formation exposed in a road cut for S.R. 41 in Adams County. Scale is 50 cm (1.6 ft).*

## Diagnostic features

- Dayton Mbr: Finely crystalline to microcrystalline limestone or dolomitic limestone.
- Undifferentiated rocks: Planar-bedded, sparsely fossiliferous, dolomitic shale interbedded with fine- to coarse-grained dolomitic limestone and dolomite.
- Brassfield Mbr: Fine- to coarse-crystalline limestone interbedded with dolomite, chert, and shale.

## General features

- Color varies from white to light gray through darker shades of gray, tan, pink, red, and brown.
- Planar, irregular, and lenticular bedding.
- Thin to thick bedded.
- Burrow mottling common.
- Glauconite and pyrite present.

## Lithologic variations

- Basal Belfast characterized by silty, granular dolomite and dolomitic limestone with locally abundant burrows.
- Nodular- to irregular-bedded chert abundant in lower portion of the Brassfield Mbr.
- Near the top of the Brassfield Mbr, iron-rich limestone beds form a distinctive stratigraphic marker that has been mapped throughout Adams and Highland Counties.
- Dayton Mbr contains increased amount of shale or argillaceous material when compared to Dayton Ls of west-central Ohio.

## Fossil content

- Brassfield Mbr and undifferentiated rocks: Common fossils are crinoids, brachiopods, and bryozoans and trace fossils; less common are bivalves, cephalopods, corals, gastropods, stromatoporoids, and trilobites. Large distinctive crinoid columns, resembling beads, occur in great abundance in the uppermost Brassfield Mbr in southern Ohio.
- Dayton Mbr: Sparsely fossiliferous with rare crinoids and corals and abundant burrows, forming a mottled appearance in many exposures.

## Weathering characteristics

- Brassfield Mbr and Dayton Mbr resistant to weathering.
- Undifferentiated rocks weather quickly, often forming a small reentrant under the cliff-forming Dayton Mbr.
- Brassfield Mbr and Dayton Mbr form cliffs, waterfalls, and gorges in streams and road cuts.
- Dayton Mbr forms a laterally persistent ledge that is well exposed in streams.

## Stratigraphic contacts

- Sharp upper contact.
- Sharp lower contact.

## Stratigraphic context

- Underlain by Drakes Fm.
- Overlain by Estill Sh.

## Engineering properties

- See the fact sheets for the Dayton Ls and Brassfield Fm.

## Hydrogeologic properties

- Moderate to poor aquifer, varies with lithology of units. Dayton Mbr might produce higher yields, depending on amount of argillaceous zones.
- May be utilized as an individual unit; most likely mapped and drilled together as a hydrologic unit with overlying units.
- Average yield: 3–10 gpm, suitable for most domestic and small farm needs.
- Aquifer rating: 3–4.
- Vadose zone rating: 3–4.
- Hydraulic conductivity: 1–100 gpd/ft$^2$.

## Environmental hazards

- Brassfield Mbr and Dayton Mbr: Rock falls especially during the freeze/thaw cycles of late winter and early spring and the potential of people and livestock falling from cliffs.

## Economic geology

- Brassfield Mbr and Dayton Mbr are a source of crushed stone.

## Scenic geology

- Forms abundant cliff exposures along streams.
- Waterfalls and riffles common.
- Small rock shelters under the base of the Drowning Creek as the less-resistant Drakes Fm is removed by rapid erosion.

## Further reading

McDowell, 1983; Swinford, 1985; Slucher and others, 2006


*Interbedded fossiliferous limestone and sparsely fossiliferous shale*


# Cincinnati group

The Cincinnati group is characterized by interbedded fossiliferous limestone and shale and the ratio of shale to limestone in each formation, member, or bed. As mapped in southwestern Ohio, the group contains thirteen formations and seven members or beds (fig. 1). The characteristic ratio of shale to limestone that defines the mapped formations, members, or beds of southwestern Ohio cannot be recognized in northern and eastern Ohio because of the major increase in the amount of shale and reduction in limestone throughout the group.

These rocks were deposited in a vast tropical sea that contained a gently sloping sea floor. A gradient of water depths occurred along the sloping sea floor, ranging from nearshore shallow-water environments to offshore deeper-water environments. The rocks deposited in shallow-water environments were fossiliferous, limestone-rich units containing beds characterized by wavy, irregular, or nodular bedding (e.g., Whitewater Formation). Fossiliferous, shale-dominant rocks containing planar, lenticular, and irregular bedding formed in deeper-water environments (e.g., Waynesville Formation); rocks with about 50% fossiliferous limestone and shale exhibiting planar, lenticular, irregular bedding were deposited in the transitional environments between shallow and deeper water (e.g., Liberty Formation). During the Late Ordovician, sea level rise and fall combined with regional uplift and subsidence associated with distant mountain building, causing the sea to advance and retreat over the gentle slope multiple times. Thus as water depth increased or decreased, the series of environments would move up and down the gentle slope, creating a series of formations, members, or beds that recur vertically through the Cincinnati group. For example, the recurrence of the deeper-water environment through the Cincinnati group explains why the Kope Formation, Miamitown Shale, and Waynesville Formation are all characterized by similar diagnostic features.

The Cincinnati group is well exposed in stream cuts along the Ohio, Great Miami, and Little Miami River valleys and their tributaries. The unit is generally poorly exposed on the upland areas between stream valleys and is covered by a thin to moderately thick covering of Quaternary-age sediments. The Cincinnati group was introduced to name the rocks in the vicinity of Cincinnati, Ohio. The unit ranges in thickness from 700 to 1,000 ft (213–305 m).

*Interbedded planar to irregular bedded limestone and shale beds of the Cincinnati group exposed along U.S. 62 just south of the Ohio River in Mason County, Kentucky. In the center of the road cut is a prominent zone of soft-sediment deformation mapped in upper part of the Fairview Formation of southern Brown and Adams Counties, Ohio, and Mason County, Kentucky. The lens-shaped, thick bedded, fine-grained limestone contains ball-and-pillow structures, convolute lamination, and shale diapirs.*

## Diagnostic features
- Interbedded, fossiliferous limestone and shale.
- Amount of shale is a diagnostic feature used to define the mapped formations/members of southwestern Ohio.

## General features
- Limestone: Light to dark gray.
- Shale: Gray to brown.
- Planar, irregular, nodular, and wavy bedding.
- Laminated to thick bedded.
- Rare to occasional burrows with pyrite filling.
- Cross-laminations, crude-graded bedding, and shale clasts.

## Lithologic variations
- Point Pleasant Fm and basal Kope Fm intertongue and grade into the Utica sh present in the subsurface of western and northern Ohio.
- Generally, amount of shale increases and amount of limestone decreases as the formations and members are traced from surface exposures into the subsurface in eastern, central, and northern Ohio.

## Fossil content
- Limestone beds highly fossiliferous.
- Shale beds sparsely fossiliferous to fossiliferous.
- Excellent preservation of fossils.
- Common fossils include bryozoans, brachiopods, echinoderms, trilobites, and molluscs.
- Trace fossils relatively common in some beds.

## Weathering characteristics
- Limestone-dominant formations and members resistant to weathering, forming cliff-lined stream valleys and gorges and small waterfalls and riffles in stream beds.
- Shale-dominant formations and members less resistant to weathering, forming thin to thick colluvium deposits on slopes.

## Stratigraphic contacts
- Sharp upper contact.
- Sharp to gradational lower contact.

## Stratigraphic context
- Underlain by Lexington Ls in southwestern, central, and eastern Ohio and Trenton Ls of northwestern Ohio.
- Overlain by Clinton and Cataract Gps in west-central Ohio; Brassfield Fm in Clark, Greene, Clinton, Montgomery, Warren, and Highland Counties; and Brassfield Mbr of the Drowning Creek Fm in southern Highland and Adams Counties.

## Engineering properties
- Please turn to the fact sheets for each formation of the Cincinnati gp.

*Interbedded fossiliferous limestone and shale*

## Hydrogeologic properties

- Please turn to the fact sheets for each formation of the Cincinnati gp.

## Environmental hazards

- Limestone-dominant formations and members: People and animals falling from cliffs and gorge walls.
- Structural damage to buildings, bridges, or highways because of sudden or gradual ground collapse into solution-enlarged joints, sinkholes, or caves.
- Landslides associated with colluvium weathered from shale-dominant formations or members.

## Economic geology

- Historically, shale of Kope Fm quarried for brick manufacture.
- Historically, limestone was used to build stone walls and foundations for structures and as a building stone.

## Scenic geology

- Liberty and Whitewater Fms combine to form scenic gorges and waterfalls in Hueston Woods SP; Woodland Trails WA; Camden, Ohio, region; and Caesar Creek Gorge NP.
- Grant Lake Ls and underlying Fairview Fm form excellent cliff exposures, small gorges, and small waterfalls in White Oak, Red Oak, Straight, and Eagle Creeks and their tributaries.
- Grant Lake Fm and underlying Fairview Fm form excellent cliff exposures and abundant small waterfalls in main channel and tributaries of Ohio, Great Miami, and Little Miami Rivers.
- Stream erosion of the less-resistant Waynesville and Kope Fms forms broad picturesque valleys containing wide flood plains often backfilled with alluvium and glacial sediments.

## Further reading

Fenneman, 1916; Potter, 1996; Hansen, 1997b; Davis and Cuffey, 1998; McLaughlin and others, 2008a; Meyer and Davis, 2009

# Drakes Formation


The Drakes Formation is dominated by dolomitic shale with minor interbedded fossiliferous limestone or dolomitic limestone, and it caps the Late Ordovician rocks preserved in Ohio. The unit was deposited during a time of mountain building along the present-day Appalachian Mountains and widespread continental glaciation that covered much of a supercontinent, known as *Gondwana,* located in the Southern Hemisphere. The Drakes was deposited in very shallow seas or on adjacent mud flats. Finally, the former sea bed and mud flats became dry land as the sea retreated from Ohio. Fossil evidence indicates that a major gap in the rock record, or unconformity, occurs at the top of the Drakes Formation, where rocks of the latest Ordovician and earliest Silurian ages were either never deposited or eroded away in southwestern Ohio.

Soil and glacial sediments frequently cover the Drakes Formation along much of its narrow outcrop, extending northwestward from the Ohio River in central Adams County to the Dayton Region, then extending southwestward through Montgomery and Preble Counties. In Adams County, the Drakes is well exposed in stream cuts and road cuts because of the overlying, cliff-forming Brassfield Member of the Drowning Creek Formation. The Drakes was named for a dirt road exposure near Drakes Creek in south-central Kentucky. The Drakes Formation is divided into the Rowland Member and overlying Preachersville Member; only the Preachersville extends into Ohio. In Ohio, the thickness of the Drakes ranges from 20 to 30 ft (6–9 m).


*The upper part of the greenish-gray to reddish shale of the Drakes Formation and overlying Brassfield Member of the Drowning Creek Formation exposed in a road cut for S.R. 41, approximately 0.4 mi (0.6 km) south of the intersection with Logan Lane, Adams County. The contact of the Drakes and Brassfield occurs at the top of the uppermost greenish shale. The geologist avoids the prominent reentrant which is created by rapid erosion of the nonresistant Drakes and leads to the potential hazard of falling rocks from the overlying Brassfield.*

## Diagnostic features
- Greenish-gray to reddish, dolomitic shale.
- Shale comprises 80–90% of unit.

## General features
- Thin to thick bedded.
- Platy to fissile partings.
- Disseminated pyrite.
- Interbedded, fossiliferous limestone and dolomitic limestone with sparsely fossiliferous shale.

## Lithologic variations
- Fossiliferous limestone beds decrease vertically through unit.
- Dolomitic limestone beds increase vertically through unit.

## Fossil content
- Brachiopods, bryozoans, trilobites, molluscs, and echinoderms in fossiliferous limestone beds.
- Fossil content decreases in upper part of unit.

## Weathering characteristics
- Rapidly weathers to light yellowish-gray clay because of wetting/drying and freeze/thaw cycles.
- Forms thin to thick colluvium when not extensively covered with glacial sediments.

## Stratigraphic contacts
- Sharp upper contact.
- Gradational lower contact.

## Stratigraphic context
- Underlain by Whitewater Fm in western Ohio.
- Underlain by Waynesville Fm in southern Ohio.
- Overlain by Clinton and Cataract Gps in west-central Ohio; Brassfield Fm in Clark, Greene, Clinton, Montgomery, Warren, and Highland Counties; and Brassfield Mbr of the Drowning Creek Fm in Adams and southern Highland Counties.
- Similar units: Kope Fm and Miamitown Sh.

## Engineering properties
- Interbedded formation with very weak and strong beds. Weaker shales should be considered the controlling rocks in the Drakes.
- Unconfined compressive strength: Unweathered shale will have a medium compressive strength; weathered shale will have a poor compressive strength. Limestone will have a high compressive strength.
- Slake durability: Shale beds from the Drakes subject to rapid degradation after exposure. Shale slake durability ranges low to high. Limestone would have an extremely high slake durability.
- Rippability: Unweathered shale beds resistant to ripping and may require blasting, breaking, or cutting for rock excavation. Weathered shale beds commonly can be ripped by conventional earth-moving equipment. Limestone beds may require additional effort to excavate.

## Hydrogeologic properties
- Typically poor aquifer with minimal yields; suitable for limited household and small farm usage.
- Average yield: 3–5 gpm. Max. yield: 10 gpm.
- Yields provided by a combination of joints and fractures as they intersect bedding planes.
- Due to soft, clayey nature, weathered portion may or may not be higher yielding than unweathered portions.
- Wells may be drilled deeper into underlying units to increase well bore storage.
- For ground-water modeling purposes, may be considered a lower-confining or boundary unit.
- Similar hydrogeologic properties to underlying Ordovician units and typically mapped together. Individual Ordovician units commonly too thin to constitute an individual hydrogeologic unit.
- Aquifer rating: 2–3.
- Vadose zone rating: 2–3.
- Hydraulic conductivity: 1–100 gpd/ft$^2$.

## Environmental hazards
- Rapid weathering and stream erosion of softer, shale-rich Drakes produces undermining of resistant cliff-forming Brassfield Fm or Brassfield Mbr of Drowning Creek Fm, causing large rock falls particularly in stream valleys and road cuts.
- Small landslides possible in colluvium derived from this unit.

## Scenic geology
- Colorful reddish-gray and maroon shale beds, where exposed.

## Further reading
Weir and others, 1965


*Green shale*

# Whitewater Formation


The Whitewater Formation is characterized by highly fossiliferous, wavy- to irregular-bedded limestone interbedded with fossiliferous shale. These rocks were deposited in a vast, shallow sea that teemed with abundant marine life. Occasional shoals developed, producing well-sorted limestone beds containing minimal amounts of shale. The Whitewater is best developed in the vicinity of Richmond, Indiana, and is named for the abundant exposures found in the gorge of the Whitewater River at Richmond.

In Ohio, the Whitewater outcrops in a 10–20-mi (16–32-km)-wide band extending in an arc from the Ohio-Indiana line in Butler and Preble Counties through the Dayton region; it then extends southeastward to the Clinton-Highland County line, where the unit thins and grades laterally into the Liberty and Waynesville Formations. The Whitewater ranges in thickness from 0 to 80 ft (0–24 m).

*The cliff-forming; highly fossiliferous; wavy-, nodular-, and irregular-bedded limestone and shale beds of the Whitewater Formation exposed in Beasley Run, Preble County. The small gorge is located along Camden Road about 500 ft (152 m) south of the intersection with Gasper Somers Road. Scale is 50 cm (1.6 ft).*

## Diagnostic features

- Wavy-, nodular-, or irregular-bedded limestone.
- Wavy- to irregular-bedded shale.
- Limestone comprises 60–70% of unit.
- Highly fossiliferous limestone and shale beds.

## General features

- Light gray to dark gray.
- Thin bedded.
- Discontinuous limestone and shale beds.
- Fissile partings in shale beds.
- Thin zones containing abundant colonial corals.

## Lithologic variations

- The percentage of shale increases southeastward from Dayton region to Clinton-Highland County line.
- The number of continuous, irregular- to planar-bedded limestone beds increases from Dayton region to Clinton-Highland County line.

## Fossil content

- Brachiopods, bryozoans, and horn corals very abundant.

- Trilobites, bivalves, cephalopods, gastropods, and echinoderms less common.
- Abundance and variety of fossils declines near top of unit.
- Fossil collecting allowed at Hueston Woods SP, Caesar Creek SP, and Cowen Lake SP. **Please check with park officials prior to collecting fossils.**

### Weathering characteristics
- Resistant to weathering.
- Forms cliffs, riffles, and gorges in streams and road cuts.

### Stratigraphic contacts
- Sharp to gradational upper contact.
- Sharp lower contact.

### Stratigraphic context
- Underlain by Liberty Fm.
- Overlain by Drakes Fm.
- Similar units: Grant Lake Ls Bellevue and Straight Creek Mbrs; Grant Lake Fm, Bellevue Mbr.

### Engineering properties
- Interbedded formation composed mostly of strong and limited weak beds. Shales considered the controlling rocks in this formation.
- Unconfined compressive strength: Unweathered shale will have a medium compressive strength; weathered shale will have a very low to medium compressive strength. Where present in the formation, resistant limestone will increase the unconfined compressive strength of the rock.
- Slake durability: Shales of the Whitewater subject to rapid degradation after exposure. Shale slake durability of this formation ranges from medium to high. Limestone slake durability is extremely high.
- Rippability: Resistant to ripping.

### Hydrogeologic properties
- Typically poor aquifer with minimal yields; suitable for limited household and small farm usage.
- Average yield: 3–5 gpm. Max. yield: 10 gpm.
- Yields provided by a combination of joints and fractures as they intersect bedding planes.
- Wells may be drilled deeper into underlying units to increase well bore storage.
- For ground-water modeling purposes, may be considered a lower-confining or boundary unit.
- Similar hydrogeologic properties to overlying and underlying Ordovician units and typically mapped together. Individual Ordovician units commonly too thin to constitute an individual hydrogeologic unit.
- Aquifer rating: 2–3.
- Vadose zone rating: 2–3.
- Hydraulic conductivity: 1–100 gpd/ft$^2$.

### Environmental hazards
- Danger of falling rocks from cliff and gorge exposures, especially in spring.
- Potential for solution enlargement of joints and minor sinkhole development in areas of thin to absent glacial drift.

### Economic geology
- Currently, not quarried for industrial or commercial purposes.
- Historically, limestone was used in road building or agricultural lime.

### Scenic geology
- Whitewater Fm and underlying Liberty Fm form gorges of Whitewater River and tributaries at Richmond, Indiana; streams in the Hueston Woods SP and Camden, Ohio, regions; Caesar Creek; and Cowan Creek below dam for Cowan Lake.

### Additional reading
Coogan, 1996; Hansen, 1997b


*Wavy-, nodular-, irregular-bedded fossiliferous limestone and shale*

# Saluda Formation

The Late Ordovician Saluda Formation in southwestern Ohio contains abundant micritic limestone. These rocks were deposited in an environment similar to modern atolls consisting of quiet-water lagoons, nearshore marine environments, and coral bioherms or reef-like environments. The Saluda is best developed in southeastern Indiana near Madison and progressively thins northward. In Ohio, the Saluda is present only in Butler and Preble Counties, where it pinches out into the Liberty and Whitewater Formations.

The Saluda is largely buried under Quaternary-age sediments in western Ohio but may be well exposed in stream cuts. The unit was named for exposures along Saluda Creek in Jefferson County, Indiana. In Ohio, the Saluda ranges in thickness from 0 to 11 ft (0–3.4 m).

*Nodular-bedded, micritic limestone and irregular-bedded shale characterizing the Saluda Formation in southwestern Ohio. Scale is 50 cm (1.6 ft).*

## Diagnostic features
- Micritic limestone.
- Dominant medium to thick bedded limestone.

## General features
- Light gray to dark gray.
- Nodular, irregular, and wavy bedding.
- Dolomitic shale beds.
- Local fossiliferous limestone beds.
- Burrow mottling.
- Limestone beds average 55% and shale beds average 45% of the unit.

## Lithologic variations
- Increase in number of fossiliferous limestone and fossiliferous shale beds near pinch out of the Saluda.
- Micritic limestone beds grade laterally into dolomite beds in Indiana.
- Dolomitic shale beds thin and pinch-out into dolomite beds in Indiana.

## Fossil content
- Fossils generally rare except for discontinuous zones containing abundant colonial corals near top and bottom of unit.
- Trace fossils relatively common in many beds.
- Lower diversity of fossils compared to Liberty Fm and Whitewater Fm.
- Rare bryozoans, brachiopods, and gastropods occur in most beds.

## Weathering characteristics
- Resistant to weathering and produces abundant slabs of micritic limestone on slopes.
- In streams, unit forms a thin zone of riffles or waterfalls.

## Stratigraphic contacts
- Sharp upper contact.
- Sharp lower contact.

## Stratigraphic context
- Underlain primarily by Liberty Fm but locally by the Whitewater Fm.
- Overlain by Whitewater Fm.

## Engineering properties
- Interbedded formation with weak and strong beds. Weaker shales should be considered as controlling rocks in this formation.
- Unconfined compressive strength: Unweathered shale will have medium compressive strength; weathered shale will have very low to medium compressive strength. Limestone will have a medium to high compressive strength.
- Slake durability: Shales of this formation subject to more rapid degradation after exposure. However, abundance of limestone increases resistance of this formation.


*Nodular- to irregular-bedded, micritic limestone and shale*

Shale slake durability ranges medium to extremely high. Limestone would have an extremely high slake durability.
- Rippability: Weathered shale beds can be ripped with some difficulty by conventional earth-moving equipment. Limestone and shale not significantly weathered are resistant to ripping.

## Hydrogeologic properties

- Typically poor aquifer with minimal yields; suitable for limited household and small farm usage.
- Average yield: 3–5 gpm. Max. yield: 10 gpm.
- Yields provided by a combination of joints and fractures as they intersect bedding planes.
- Due to soft, clayey nature, weathered portion may or may not be higher yielding than unweathered portions.
- For ground-water modeling purposes, may be considered a lower-confining or boundary unit.
- Similar hydrogeologic properties to overlying and underlying Ordovician units and typically mapped together. Individual Ordovician units commonly too thin to constitute an individual hydrogeologic unit.
- Aquifer rating: 2–3.
- Vadose zone rating: 2–3.
- Hydraulic conductivity: 1–100 gpd/ft².

## Environmental hazards

- None.

## Economic geology

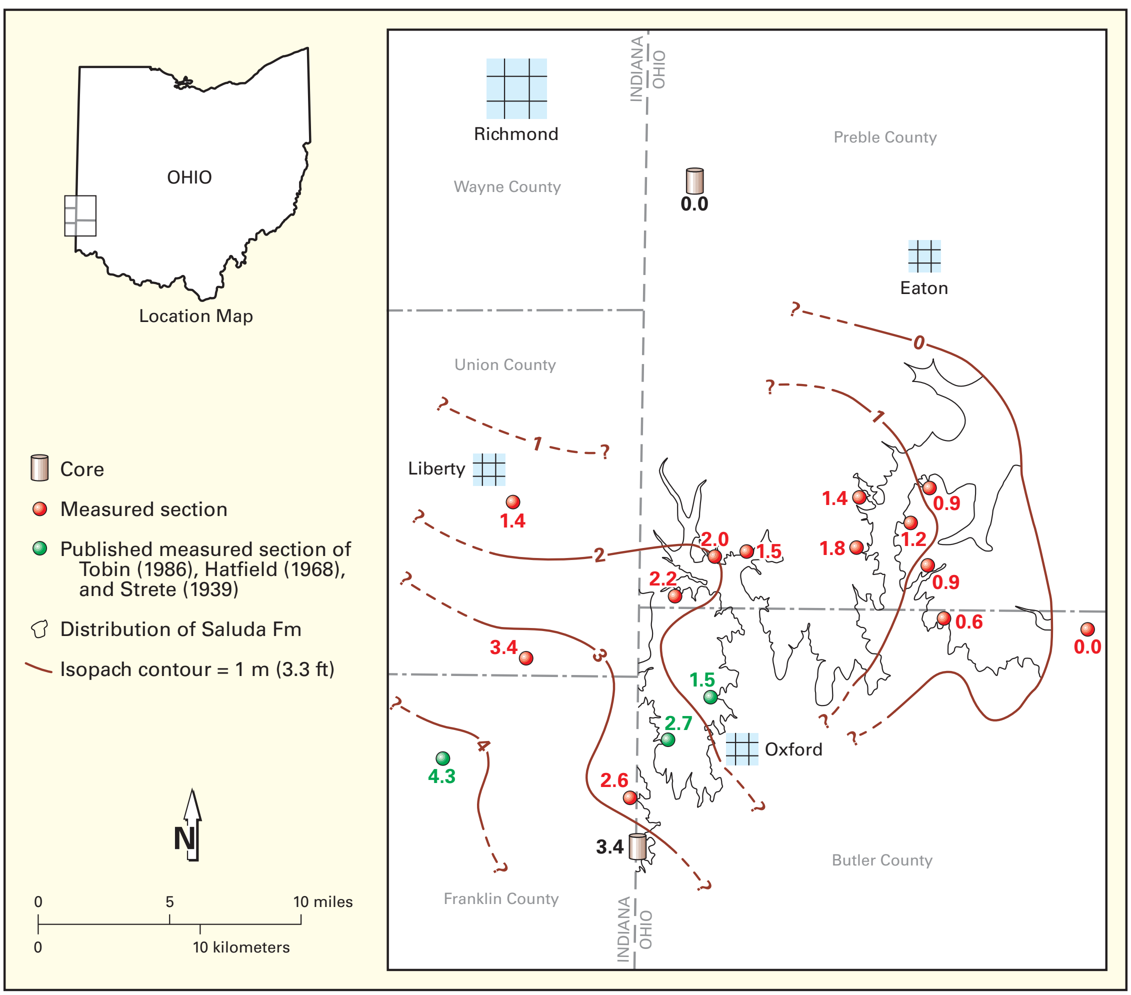
- In Ohio, the Saluda currently is not quarried for industrial/commercial purposes.

## Scenic geology

- Small waterfalls and riffles where exposed in streams.

## Further reading

Hatfield, 1968; Butler and Cuffey, 1996; Strete, 1939




*Isopach map showing the thickness of the Saluda Formation in western Ohio and eastern Indiana. The mapped distribution of the Saluda is shown for Ohio only.*


# Liberty Formation

The Liberty Formation consists of interbedded planar- to irregular-bedded, fossiliferous limestone and sparsely fossiliferous shale. The unit was deposited in the transitional environment between the shallow-water environment of the Whitewater Formation and the offshore, deeper-water environment of the Waynesville Formation. Major hurricanes frequently swept across southwestern Ohio during the Late Ordovician, creating many of the characteristic interbedded limestone and shale beds and the excellent preservation of fossils characterizing the Liberty.

The Liberty generally is buried under Quaternary-age sediments along a narrow, arching outcrop belt extending from Butler and Preble Counties through the southern Dayton region, then southeastward into central Highland County, where the unit pinches out. River and stream exposures are the best places to examine the Liberty Formation; here it forms steep slopes and cliffs along stream valleys and a series of small waterfalls in streams. The unit was named for excellent exposures in the vicinity of Liberty, Indiana, and it ranges in thickness from 20 to 40 ft (6–12 m).

*Small waterfalls formed by the nearly equal amounts of planar- to irregular-bedded limestone and shale beds of the Liberty Formation. This section is exposed in an unnamed tributary of Paint Creek, 0.75 mi (1.2 km) west of Camden, Preble County, along old S.R. 725. Scale is 50 cm (1.6 ft).*

## Diagnostic features

- Planar- to irregular-bedded limestone and shale.
- Sparsely fossiliferous shale.
- Limestone and shale beds average 50% of unit.

## General features

- Gray to bluish gray.
- Thin to medium bedded.
- Platy to flaggy partings in shale beds.
- Disseminated pyrite.
- Graded bedding and ripple marks common in limestone beds.

## Lithologic variations

- Average amount of shale increases from approximately 50% in Butler and Preble Counties to over 60% in Highland County.
- Average amount of limestone decreases from 50% in Butler and Preble Counties to less than 40% in Highland County.

## Fossil content
- Highly fossiliferous.
- Diverse fauna of primarily brachiopods, bryozoans, bivalves, corals, crinoids, trilobites, cephalopods, gastropods, and abundant trace fossils.
- Excellent fossil preservation.

## Weathering characteristics
- Fairly resistant to weathering, forming cliffs and steep slopes in stream valleys.
- Forms thin colluvium with abundant slabs of limestone.

## Stratigraphic contacts
- Sharp to gradational upper contact.
- Sharp lower contact.

## Stratigraphic context
- Underlain by Waynesville Fm.
- Overlain by Whitewater Fm.
- Similar units: Fairview Fm; Grant Lake Fm, Corryville Mbr.

## Engineering properties
- Interbedded formation with weak and strong beds. Weaker shales should be considered the controlling rocks in this formation.
- Unconfined compressive strength: Unweathered shale will have medium compressive strength; weathered shale will have low to medium compressive strength. Limestone will have medium to high compressive strength.
- Slake durability: Shales of this formation subject to more rapid degradation after exposure. However, abundance of limestone increases resistance of this formation. Shale slake durability ranges low to high. Limestone would have an extremely high slake durability.
- Rippability: Weathered shale beds can be ripped with some difficulty by conventional earth-moving equipment. Limestone and shale not significantly weathered are resistant to ripping.

## Hydrogeologic properties
- Typically poor aquifer with minimal yields; suitable for limited household and small farm usage.
- Average yield: 3–5 gpm. Max. yield: 10 gpm.
- Yields provided by a combination of joints and fractures as they intersect bedding planes.
- Due to soft, clayey nature, weathered portion may or may not be higher yielding than unweathered portions.
- For ground-water modeling purposes, may be considered a lower-confining or boundary unit.
- Similar hydrogeologic properties to overlying and underlying Ordovician units and typically mapped together. Individual Ordovician units commonly too thin to constitute an individual hydrogeologic unit.
- Aquifer rating: 2–3.
- Vadose zone rating: 2–3.
- Hydraulic conductivity: 1–100 gpd/ft$^2$.

## Environmental hazards
- None.

## Economic geology
- Limestone beds used as building stone in decorative retaining walls and for stepping stones.
- Historically, limestone from the Liberty used for structure foundations, stone walls, and occasionally as building stone for structures.

## Scenic geology
- The resistant Liberty Fm and Whitewater Fm combine to form scenic gorges in Hueston Woods SP; Woodland Trails WA; Camden, Ohio, region; and Caesar Creek Gorge SNP.
- Limestone beds form series of small waterfalls as streams cut through the Liberty.

## Further reading
Tobin, 1986; Feldmann and Hackathorn, 1996

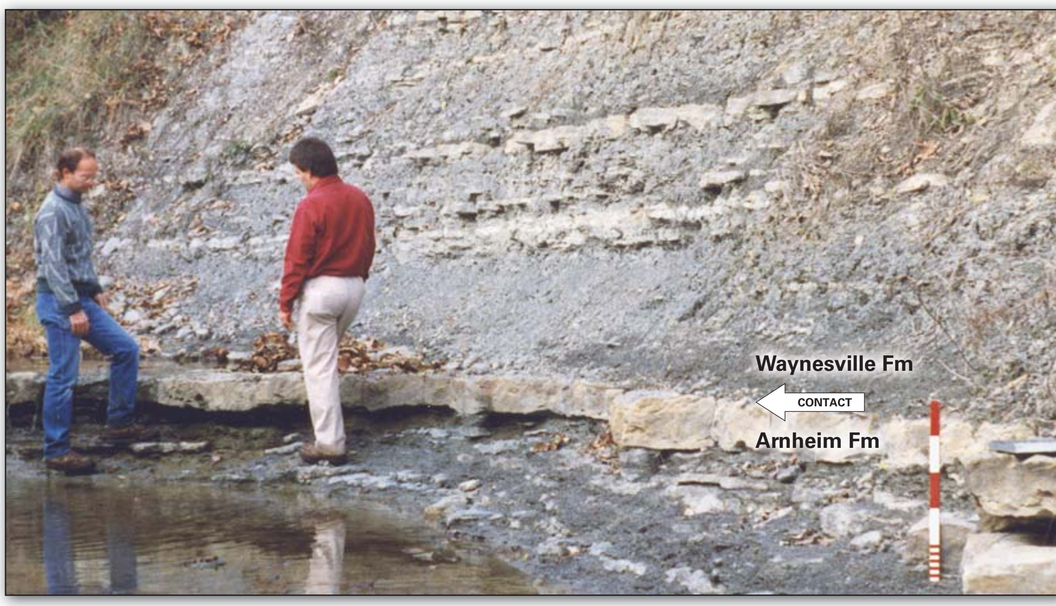

*Planar-bedded limestone and shale*

# Waynesville Formation


Characteristic features of the Waynesville Formation include the dominance of shale that occurs in medium to thick beds. Shale averages over 70% of the unit and limestone averages 30%.

The deeper-water, offshore, tropical environment of the Waynesville was home to abundant and diverse marine life. Frequent hurricanes passed over this environment, creating ideal conditions for the preservation of fossils. Each hurricane would erode, suspend, transport, and rapidly deposit sea floor sediment and marine life into a new deposit that buried many plants and animals. Many of the animals and none of the plants were able to burrow out of the storm deposit and were fossilized as the sediment solidified. This process recurred hundreds of times, creating a vast graveyard of plants and animals that lived during the deposition of the Waynesville.

The Waynesville was first described and named for the stream exposures found in the Waynesville, Warren County, region. The unit is exposed in a 2–15-mi (3.2–24-km)-wide band along the valley walls of the tributaries of the Great Miami River and Little Miami River and the uplands of central Hamilton, Clinton, Highland, Clermont, Brown, and Adams Counties. The Waynesville ranges in thickness from 90 to 120 ft (27–37 m) in thickness and is commonly buried under glacial sediments where it occurs in the upland areas.




*The shale-rich Waynesville Formation and Arnheim formation are well exposed in a small stream located at Waynesville, Warren County. The medium to thick bedded shale and thin to medium bedded limestone of the basal Waynesville Formation are well exposed overlying the two prominent limestone beds present at the top of the Arnheim formation. Scale is 50 cm (1.6 ft).*

## Diagnostic features

- Ratio of 70% shale to 30% limestone.
- Medium to thick bedded shale beds.
- Calcareous shale beds with minor pyrite nodules or irregular blobs.
- Dominance of thin-bedded limestone.

## General features

- Gray to bluish gray.
- Planar to irregular bedding with occasional nodular-bedded limestone.
- Sparsely fossiliferous shale and highly fossiliferous limestone.

## Lithologic variations

- Many repeating, well-developed sedimentary cycles consisting of a thicker, shale-dominant interval capped by a thinner interval containing abundant limestone beds.
- Rare intervals of nodular- to wavy-bedded limestone.

### Fossil content
- Spectacular preservation of fossils, especially trilobites and echinoderms.
- World renowned for abundance of brachiopods, bryozoans, corals, bivalves, gastropods, cephalopods, trilobites, echinoderms, and trace fossils.
- Fragments and rare complete specimens of Ohio's state fossil, the trilobite *Isotelus,* commonly found.
- Two narrow, widespread, shale-rich zones containing abundant complete specimens of trilobites *Flexicalymene* and *Isotelus* and well-preserved cephalopods can be traced throughout much of southwestern Ohio and into Indiana.

### Weathering characteristics
- Weathers rapidly to light-gray clay with abundant limestone slabs because of repeated wetting/drying and freeze/thaw cycles.
- Forms relatively thick colluvium on steeper slopes.

### Stratigraphic contacts
- Sharp to gradational upper contact.
- Sharp lower contact.

### Stratigraphic context
- Underlain by Arnheim fm.
- Overlain by Liberty Fm or Drakes Fm.
- Similar unit: Kope Fm.

### Engineering properties
- Interbedded formation composed mostly of weak and limited strong beds. Shales considered the controlling rocks in this formation.
- Unconfined compressive strength: Unweathered shale will have low to medium compressive strength; weathered shale will have very low compressive strength. Where present in the formation, resistant limestone beds will increase unconfined compressive strength of the rock.
- Slake durability: Shales of this formation subject to rapid degradation after exposure. Shale slake durability ranges low to high.
- Rippability: Weathered shale beds can be ripped by conventional earth-moving equipment. Limestone and shale not significantly weathered are more resistant to ripping.

### Hydrogeologic properties
- Typically poor aquifer with minimal yields; suitable for limited household and small farm usage.
- Average yield: 3–5 gpm. Max. yield: 10 gpm.
- Yields provided by a combination of joints and fractures as they intersect bedding planes.
- Due to soft, clayey nature, weathered portion may or may not be higher yielding than unweathered portions.
- For ground-water modeling purposes, may be considered a lower-confining or boundary unit.
- Similar hydrogeologic properties to overlying and underlying Ordovician units and typically mapped together. Individual Ordovician units commonly too thin to constitute an individual hydrogeologic unit.
- Aquifer rating: 2–3.
- Vadose zone rating: 2–3.
- Hydraulic conductivity: 1–100 gpd/ft$^2$.

### Environmental hazards
- Landslides occur in thicker colluvial deposits accumulating on steeper hillsides.

### Scenic geology
- Stream erosion of the less-resistant Waynesville forms broad picturesque valleys containing wide flood plains of alluvium and glacial sediments.

### Further reading
Frey, 1987; Shrake, 1995; Schumacher and Shrake, 1997; Meyer and Davis, 2009


*Fossiliferous, medium bedded shale and fossiliferous, thin bedded limestone of the Waynesville Fm*

# Arnheim formation


The Arnheim formation is characterized by the alternation of nodular- to wavy-bedded limestone and irregularly bedded, fossiliferous shale with nearly equal amounts of planar-bedded, fossiliferous limestone and sparsely fossiliferous shale. These sequences form repetitive sedimentary cycles that occur throughout the formation. The rocks were deposited in a vast, shallow sea that teemed with abundant marine life.

The Arnheim occurs along a 1–5-mi (1.6–8-km)-wide band extending in an arc from the Ohio-Indiana state line in Butler and Preble Counties through the Dayton region, then extending southeastward to the Ohio River in Brown and Adams Counties. Much of the outcrop area of the Arnheim is buried under thin to extensive deposits of glacial drift and modern sediments. The unit was named for the excellent exposures along Straight Creek near the village of Arnheim, Brown County. The Arnheim ranges in thickness from 50 to 100 ft (15–30 m).

*The Arnheim formation exposed in an unnamed tributary of the West Fork of Eagle Creek near Russellville, Brown County, illustrating the characteristic alternation of planar-bedded, fossiliferous limestone and sparsely fossiliferous shale with nearly equal amounts of nodular- to wavy-bedded limestone and irregularly bedded, fossiliferous shale. Scale is 50 cm (1.6 ft).*

## Diagnostic features

- Repetitive sedimentary cycles.
- Shale comprises 50–60% of the formation.
- Highly fossiliferous limestone beds.
- Fossiliferous to sparsely fossiliferous shale beds.

## General features

- Gray to olive gray.
- Thin to medium bedded.
- Discontinuous limestone and shale beds.
- Fissile to platy partings in shale beds.
- Rare to common pyrite in shale beds and burrow fillings.
- Abundant phosphate minerals filling fossil gastropod molds and casts in upper part of unit.

## Lithologic variations

- Repetitive sedimentary cycles range in thickness from <3 ft to >20 ft (<1 m to >6 m).
- Top of unit contains a series of thick-bedded, nodular limestone beds that are laterally persistent along outcrop belt.

**Fossil content**
- Brachiopods, bryozoans, bivalves, gastropods, and trilobites common.
- Echinoderms and cephalopods less common.
- Brachiopod index fossils *Retrorsirostra carleyi* and *Leptaena richmondensis* common in thin zones in the middle of the Arnheim that can be traced throughout southwestern Ohio.
- Trilobites *Flexicalymene* and the Ohio state fossil *Isotelus* commonly found in middle part of the unit.

**Weathering characteristics**
- Generally not resistant to weathering except in youthful streams actively cutting deep valleys.
- In these valleys, unit forms small cliffs, riffles, and waterfalls in streams.

**Stratigraphic contacts**
- Sharp upper contact.
- Sharp lower contact.

**Stratigraphic context**
- Underlain by Grant Lake Fm in Butler, western Clermont, Clinton, Hamilton, Montgomery, Preble, and Warren Counties.
- Underlain by Grant Lake Ls in Adams, Brown, and central and eastern Clermont Counties.
- Overlain by Waynesville Fm.

**Engineering properties**
- Interbedded formation composed of varying amounts of weak shale and strong limestone beds through the formation. Weaker shales considered the controlling rocks in this formation; this is specifically true of the more shale-rich portions of the unit. Shale beds anticipated to weather rapidly after exposure.
- Unconfined compressive strength: Unweathered shale will have low to medium compressive strength; weathered shale will have a very low compressive strength. Where present in the formation, resistant limestone beds will increase unconfined compressive strength of the rock.
- Slake durability: Shale slake durability ranges low to high. Limestone beds will have high slake durability.
- Rippability: Weathered shale beds, particularly near the surface, may be ripped by conventional earth-moving equipment. Unweathered strong limestone beds result in the formation being resistant to ripping and requiring blasting, breaking, or cutting.

**Hydrogeologic properties**
- Typically poor aquifer with minimal yields; suitable for limited household and small farm usage.
- Average yield: 3–5 gpm.
- Yields provided by combination of joints and fractures as they intersect bedding planes.
- For ground-water modeling purposes, may be considered a lower-confining or boundary unit.
- Similar hydrogeologic properties to overlying and underlying Ordovician units and typically mapped together. Individual Ordovician units commonly too thin to constitute an individual hydrogeologic unit.
- Aquifer rating: 2–3.
- Vadose zone rating: 2–3.
- Hydraulic conductivity: 1–100 gpd/ft$^2$.

**Environmental hazards**
- None.

**Economic geology**
- Currently not quarried for industrial/commercial purposes.
- Historically, locally used in road building.

**Scenic geology**
- Arnheim fm and Waynesville, Liberty, and Whitewater Fms form scenic valleys of the Little Miami River and the gorge walls at Caesar Creek Gorge SNP in Warren County.

**Further reading**
Foerste, 1912

Isotelus, *Ohio's official state fossil, is commonly found in the Arnheim formation.*


*Two core intervals illustrating the characteristic alternation between nearly equal amounts of (**A**) nodular- to wavy-bedded limestone and irregularly bedded, fossiliferous shale and (**B**) planar-bedded, fossiliferous limestone and sparsely fossiliferous shale*

# Grant Lake Limestone

The Grant Lake Limestone is characterized by interbedded wavy-, irregular-, lenticular-, or planar-bedded, fossiliferous limestone and shale. Limestone constitutes 50–90% of the unit.

The Grant Lake Limestone is subdivided, in ascending order, into the Bellevue, Corryville, and Straight Creek Members. These rocks were deposited in a vast, shallow sea that teemed with abundant marine life. The sea was quite shallow during the time that the Bellevue and Straight Creek Members were deposited, allowing waves to wash away much of the shaley material and concentrate skeletal fragments that later formed the abundant limestone beds of these units. The Corryville Member was deposited in more offshore, deeper water. As major hurricanes swept across southwestern Ohio during the Late Ordovician (fig. 7), large waves eroded and redeposited the sea bottom sediments, creating the planar- to lenticular-bedded limestone and shale beds characterizing the Corryville.

In Ohio, the Grant Lake Limestone is mapped in a 15–20-mi (24–32-km)-wide area, commonly buried beneath a thin deposit of Quaternary-age sediments in Adams, Brown, and Clermont Counties. The unit was named for Grant Lake located in Mason County, Kentucky, and has been mapped across much of northeastern and central Kentucky. In Ohio, the Grant Lake ranges in thickness from 80 to 120 ft (24–37 m).

*Wavy- to irregular-bedded, fossiliferous limestone and shale exposed at the type section of the Straight Creek Member of the Grant Lake Limestone. The stream cut is located along the West Fork of Straight Creek in Brown County. Scale is 50 cm (1.6 ft).*

## Diagnostic features

- Grant Lake Ls: Interbedded wavy-, irregular-, lenticular-, or planar-bedded, fossiliferous limestone and shale. Limestone averages 70–90%.
- Bellevue Mbr: Interbedded wavy- to irregular-bedded, fossiliferous limestone and shale. Limestone averages 50–70%.
- Corryville Mbr: Interbedded planar- to lenticular-bedded, fossiliferous limestone and planar-bedded, sparsely fossiliferous shale. Shale averages 35–75%.
- Straight Creek Mbr: Interbedded wavy- to irregular-bedded, fossiliferous limestone and shale. Limestone averages 50–90%.

## General features

- Light to dark gray, bluish gray.
- Thin to thick bedded.
- Discontinuous to continuous limestone and shale beds.
- Fissile to flaggy partings in shale beds.

### Lithologic variations

- Average amount of shale increases from 20% in Adams and Brown Counties to 50% in the gradational zone between the Grant Lake Ls and the Grant Lake Fm located in Clermont County.
- Percentage of shale increases in the Bellevue, Corryville, and Straight Creek Mbrs from Adams and Brown Counties northwestward to Clermont County.
- Corryville thins from 60 ft (18 m) in Clermont County to <20 ft (<6 m) in Adams and Brown Counties.
- Bellevue thickens from <20 ft (<6 m) to nearly 70 ft (21 m) in Adams and Brown Counties.
- Straight Creek thickness averages 20 ft (6 m) and varies little across the exposed area of the Grant Lake Ls.

### Fossil content

- Brachiopods and bryozoans very abundant.
- Trilobites, bivalves, cephalopods, gastropods, and echinoderms less common.
- Corryville Mbr is world famous for abundance and excellent preservation of fossils.
- Large, thick-shelled brachiopod *Vinlandostrophia ponderosa*, traditionally named *Platystrophia ponderosa,* common in Bellevue and Straight Creek Mbrs.

### Weathering characteristics

- Resistant to weathering.
- Forms cliffs, riffles, and small gorges in streams and road cuts.

### Stratigraphic contacts

- Sharp upper contact.
- Sharp lower contact.

### Stratigraphic context

- Underlain by Fairview Fm.
- Overlain by Arnheim fm.
- Similar units: Bellevue and Corryville Mbrs of the Grant Lake Fm.

### Engineering properties

- Interbedded formation composed of varying amounts of weak shale and strong limestone beds through the formation. Weaker shales considered the controlling rocks in this formation; this is specifically true of the more shale-rich portions of the Corryville Mbr. Shales of this formation anticipated to weather after exposure.
- Unconfined compressive strength: Unweathered shale will have low to medium compressive strength; weathered shale will have very low compressive strength. Where present in the formation, resistant limestone beds will increase unconfined compressive strength of the rock.
- Slake durability: Shale slake durability ranges low to high. Limestone beds will have high slake durability.
- Rippability: Weathered shale beds, particularly near the surface, may be ripped by conventional earth-moving equipment. Unweathered strong limestone beds result in the formation being resistant to ripping; blasting, breaking, or cutting required.

*Small cave in the limestone-rich Bellevue Member of the Grant Lake Limestone exposed in a stream cut along Straight Creek, 3 mi (5 km) east of Georgetown, Brown County.*

## Hydrogeologic properties

- Typically poor aquifer with minimal yields; suitable for limited household and small farm usage.
- Average yield: 3–5 gpm.
- Yields provided by combination of joints and fractures as they intersect bedding planes.
- For ground-water modeling purposes, may be considered a lower-confining or boundary unit.
- Similar hydrogeologic properties to overlying and underlying Ordovician units and typically mapped together. Individual Ordovician units commonly too thin to constitute an individual hydrogeologic unit.
- Aquifer rating: 2–3.
- Vadose zone rating: 2–3.
- Hydraulic conductivity: 1–100 gpd/ft$^2$.

## Environmental hazards

- Falling rocks from cliff and gorge walls, especially during winter and spring freeze/thaw cycles.
- People and animals falling from cliffs and gorge walls.
- Structural damage to buildings, bridges, or highways because of sudden or gradual ground collapse into solution-enlarged joints, sinkholes, or small caves.
- Pollution threat to ground-water resources through surface waters entering sinkholes directly linked to underground drainage system.

## Economic geology

- Currently not quarried for industrial/commercial purposes
- Historically, limestone was used in road building or agricultural lime.

## Scenic geology

- Grant Lake Ls and underlying Fairview Fm form excellent cliff exposures and small gorges in main channel and tributaries of White Oak, Red Oak, Straight, and Eagle Creeks.

## Further reading

Peck, 1966; Schumacher and others, 1991


*Straight Creek Mbr*

*Corryville Mbr*

# Grant Lake Formation


The Grant Lake Formation is characterized by interbedded wavy-, irregular-, nodular-, or planar-bedded, fossiliferous shale and limestone. Shale constitutes 50–60% of the unit and represents a shale-rich equivalent of the Grant Lake Limestone.

The Grant Lake Formation is subdivided, in ascending order, into the Bellevue, Corryville, and Mount Auburn Members. These highly fossiliferous rocks were deposited in a vast, shallow sea. The Bellevue Member was deposited in shallow water where wave action washed away much of the shaley material and concentrated skeletal fragments that later formed the abundant limestone beds of this unit. The Corryville Member was deposited in deeper, offshore water in which the bottom sediments were disturbed only by large waves produced by major hurricanes. Late Ordovician hurricanes swept across southwestern Ohio and eroded, transported, and deposited Corryville bottom sediments, creating the characteristic planar- to lenticular-bedded limestone and shale beds (fig. 7). The Mount Auburn Member was deposited in a shallow-water environment similar to the Bellevue, but wave action was diminished and removed only a limited amount of shaley material.

The Grant Lake Formation is mapped in a 15–20-mi (24–32-km)-wide area in western Clermont and Hamilton Counties and in the valleys of the Great Miami River, Little Miami River, and their tributaries in Butler, Montgomery, and Warren Counties. The unit was buried beneath Quaternary-age sediments filling the ancestral valleys of these rivers in Montgomery and Warren Counties. The unit was named for Grant Lake located in Mason County, Kentucky. In Ohio, the Grant Lake Formation ranges in thickness from 60 to 130 ft (18–40m).

*Nodular- to irregular-bedded limestone and fossiliferous irregular-bedded shale of the Mount Auburn Member of the Grant Lake Formation exposed along Dick Creek, Warren County. Scale is 50 cm (1.6 ft).*

## Diagnostic features

- Grant Lake Fm: Interbedded wavy-, irregular-, nodular-, or planar-bedded, fossiliferous shale and limestone.
- Bellevue Mbr: Interbedded wavy- to irregular-bedded, fossiliferous limestone and shale. Limestone varies 50–70%.
- Corryville Mbr: Interbedded planar- to lenticular-bedded, fossiliferous limestone and planar-bedded, sparsely fossiliferous shale. Shale content varies 50–75%.
- Mount Auburn Mbr: Interbedded nodular- to irregular-bedded, fossiliferous shale and limestone. Shale content varies 50–80%.

## General features

- Light to dark gray, bluish gray.
- Thin to thick bedded.
- Discontinuous to continuous limestone and shale beds.
- Fissile to flaggy partings in shale beds.

## Lithologic variations

- Average amount of shale increases from 50% within the gradational zone of the Grant Lake Ls in Clermont County to over 60% in Butler and Warren Counties.
- Percentage of shale increases in the Bellevue, Corryville, and Mount Auburn Mbrs northward from Hamilton County to Butler, Montgomery, and Warren Counties.
- Corryville thins from 60 ft (18 m) in Clermont County to <30 ft (<9 m) in Butler County.
- Bellevue thickens and thins between <20 ft (<6 m) to >30 ft (>9 m) throughout Butler, Hamilton, Montgomery, and Warren Counties.
- Mount Auburn thickness averages 20 ft (6 m) and varies little across exposed area of the Grant Lake.

## Fossil content

- Brachiopods and bryozoans very abundant.
- Trilobites, bivalves, cephalopods, gastropods, and echinoderms less common.
- Corryville Mbr is world famous for abundance and excellent preservation of fossils.
- Large, thick-shelled brachiopod *Vinlandostrophia ponderosa*, traditionally named *Platystrophia ponderosa,* common in Bellevue and Mount Auburn Mbrs.

## Weathering characteristics

- Resistant to weathering.
- Forms cliffs, riffles, and small waterfalls in streams and road cuts.

## Stratigraphic contacts

- Sharp upper contact.
- Sharp lower contact.

## Stratigraphic context

- Underlain by Miamitown Sh.
- Overlain by Arnheim fm.
- Similar units: Bellevue and Corryville Mbrs of the Grant Lake Ls.

## Engineering properties

- Interbedded formation composed of varying amounts of weak shale and strong limestone beds through the formation. Weaker shales considered the controlling rocks in this formation; this is specifically true of the more shale-rich portions of the Corryville and Mount Auburn Mbrs. Shales of this formation anticipated to weather after exposure.
- Unconfined compressive strength: Unweathered shale will have low to medium compressive strength;


*The wavy- to irregular-bedded, fossiliferous limestone and shale beds of the Bellevue Member of the Grant Lake Formation overlain by the planar-bedded, sparsely fossiliferous shale beds and planar, fossiliferous limestone beds of the Corryville Member. Scale is 50 cm (1.6 ft).*

weathered shale will have very low compressive strength. Where present in the formation, resistant limestone beds will increase unconfined compressive strength of the rock.
- Slake durability: Shale slake durability ranges low to high. Limestone beds will have high slake durability.
- Rippability: Weathered shale beds, particularly near the surface, may be ripped by conventional earth-moving equipment. Unweathered strong limestone beds result in the formation being resistant to ripping and requiring blasting, breaking, or cutting.

## Hydrogeologic properties
- Typically poor aquifer with minimal yields; suitable for limited household and small farm usage.
- Average yield: 3–5 gpm.
- Yields provided by combination of joints and fractures as they intersect bedding planes.
- For ground-water modeling purposes, may be considered a lower-confining or boundary unit.
- Similar hydrogeologic properties to overlying and underlying Ordovician units and typically mapped together. Individual Ordovician units commonly too thin to constitute an individual hydrogeologic unit.
- Aquifer rating: 2–3.
- Vadose zone rating: 2–3.
- Hydraulic conductivity: 1–100 gpd/ft$^2$.

## Environmental hazards
- Falling rocks from cliff and gorge walls, especially during winter and spring freeze/thaw cycles.
- Structural damage to buildings, bridges, or highways because of sudden or gradual ground collapse into solution-enlarged joints, sinkholes, or small caves.
- Pollution threat to ground-water resources through surface waters entering sinkholes directly linked to underground drainage system.

## Economic geology
- Currently not quarried for industrial/commercial purposes.
- Historically, limestone was used in road building and stone wall construction.

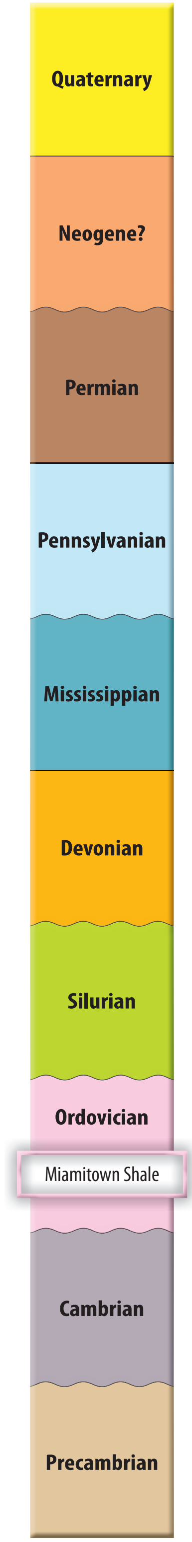
## Scenic geology
- Grant Lake and underlying Fairview Fms form excellent cliff exposures and abundant small waterfalls in main channel and tributaries of East Fork of the Little Miami River and Little Miami River, Stonelick, O'Bannon, and Indian Creeks and Todds Fork.
- City of Sharonville, Trammel Fossil Park: Visitors learn about Ordovician geology of Hamilton County through interpretative displays and limited fossil collecting of small specimens.

## Further reading
Schumacher and others, 1991


*Mount Auburn Mbr*


*Bellevue Mbr*

# Miamitown Shale




The diagnostic features of the Miamitown Shale are the dominance of shale that occurs in medium to thick beds; shale averages over 90% of the unit. The Miamitown was deposited in a vast, shallow sea containing a somewhat restricted fauna of marine life.

The unit was first described and named for the excellent exposures created by the construction of Interstate 74 near Miamitown, in western Hamilton County. The Miamitown is best exposed in a narrow (less than one mile wide) band within the valleys of the Great Miami and Little Miami Rivers and their tributaries in Butler, Hamilton, and northwestern Clermont Counties. The unit was buried by Quaternary-age sediments filling the ancestral valleys of these rivers in northern Butler and Warren Counties and Montgomery County. The Miamitown ranges in thickness from 0 to 35 ft (0–11 m).


*Miamitown Shale and Bellevue Member of the Grant Lake Formation contact exposed in West Fork of Mill Creek, Hamilton County. Note the thick bedded shale interbedded with planar- to nodular-bedded limestone of the Miamitown Shale. Scale is 50 cm (1.6 ft).*

## Diagnostic features

- Ratio of 90% shale to 10% limestone.
- Medium to thick bedded shale.

## General features

- Gray to bluish gray.
- Shale: Planar to irregular bedding.
- Limestone: Nodular, planar, and irregular bedding.
- Sparsely fossiliferous shale and highly fossiliferous limestone.

## Lithologic variations

- Nodular-bedded limestone common in Hamilton and Butler Counties.
- Nodular-bedded limestone less common and replaced with planar- to irregular-bedded limestone in northwestern Clermont and southwestern Warren Counties.

## Fossil content

- Diagnostic fauna dominated by gastropods and bivalves.
- Brachiopods, bryozoans, cephalopods, trilobites, echinoderms, and trace fossils less common.

## Weathering characteristics

- Weathers rapidly to light-gray clay colluvium with abundant limestone nodules or slabs because of repeated wetting/drying and freeze/thaw cycles.
- Forms relatively thick colluvium in areas where unit is >20 ft (>6 m) thick.

## Stratigraphic contacts

- Sharp upper contact.
- Sharp lower contact.

## Stratigraphic context

- Underlain by Fairview Fm.
- Overlain by Grant Lake Fm.
- Similar unit: Kope Fm.

## Engineering properties

- Contains weak, rapidly weathered shale with few strong limestone beds. Weaker shales considered the controlling rocks in this formation and anticipated to weather rapidly after exposure.
- Unconfined compressive strength: Unweathered shale will have low to high compressive strength; weathered shale will have very low compressive strength. Where present in the formation, resistant limestone beds will increase unconfined compressive strength of the rock.
- Slake durability: Shale slake durability ranges low to high. Limestone will have extremely high slake durability.
- Rippability: Weathered shale beds, particularly near the surface, can be ripped with some difficulty by conventional earth-moving equipment. Unweathered

*Medium bedded shale and irregular-bedded, fossiliferous limestone* portions of formation likely to require blasting, breaking, or cutting for rock excavation.

### Hydrogeologic properties

- Typically very poor aquifer with minimal yields; suitable for limited household and small farm usage.
- Average yield: <3 gpm.
- Yields provided by combination of joints and fractures as they intersect bedding planes.
- For ground-water modeling purposes, may be considered a lower-confining or boundary unit.
- Similar hydrogeologic properties to overlying and underlying Ordovician units and typically mapped together. Individual Ordovician units commonly too thin to constitute an individual hydrogeologic unit.
- Aquifer rating: 2–3.
- Vadose zone rating: 2–3.
- Hydraulic conductivity: 1–100 gpd/ft$^2$.

### Environmental hazards

- Small landslides may occur in colluvium deposits accumulating on steeper hillsides.

### Scenic geology

- Stream erosion of the less-resistant Miamitown underlying the cliff-forming Bellevue Mbr of the Grant Lake Fm results in natural reentrants and cliff-lined stream valleys.

### Further reading

Ford, 1967; Dattilo, 1996

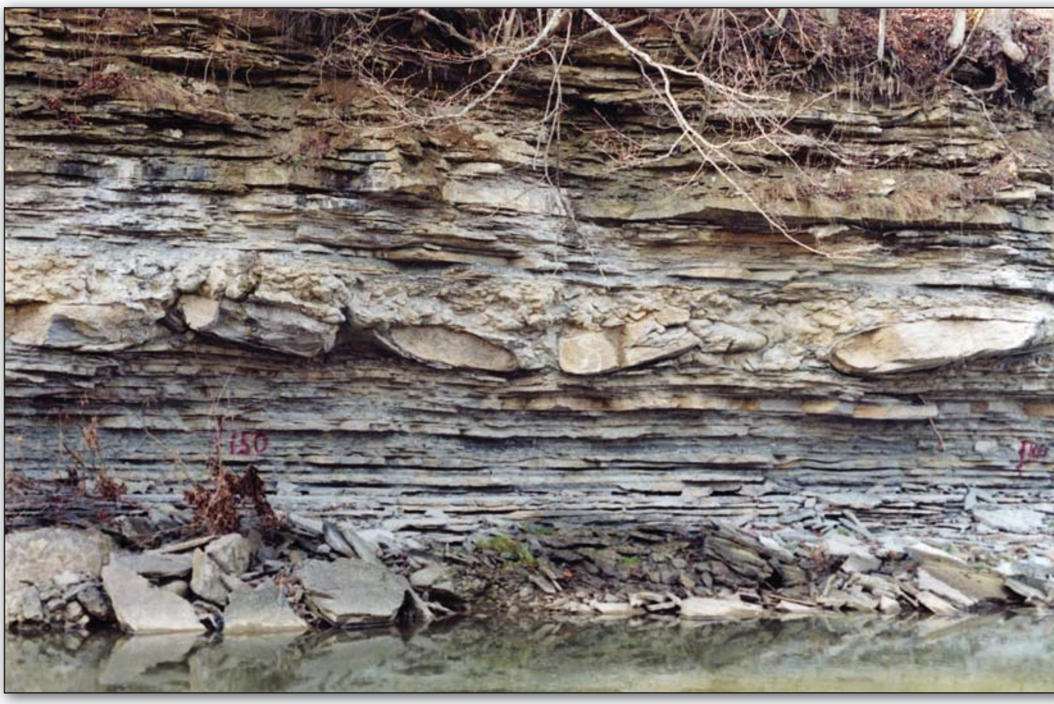

*Limestone slab from the Miamitown Shale illustrating* (**A**) *gastropod and* (**B**) *bivalve dominant fauna.*

# Fairview Formation

- Quaternary
- Neogene?
- Permian
- Pennsylvanian
- Mississippian
- Devonian
- Silurian
- Ordovician
- Fairview Formation
- Cambrian
- Precambrian

The Fairview Formation is characterized by interbedded planar- to irregular-bedded, fossiliferous limestone and sparsely fossiliferous shale. The unit was deposited in the transitional environment between the shallow-water environments of the Bellevue Member of the Grant Lake Formation or Grant Lake Limestone and the offshore, deeper-water environments of the Kope Formation. Major hurricanes frequently swept across southwestern Ohio during the Late Ordovician (fig. 7), creating many of the characteristic interbedded limestone and shale beds and the excellent preservation of fossils characterizing the Fairview.

The Fairview is well exposed in stream exposures associated with the tributaries and river valleys of the Ohio, Great Miami, and Little Miami Rivers throughout southwestern Ohio. In Butler, Montgomery, and Warren counties, the unit is buried by Quaternary-age sediments partially filling the ancestral valleys of these rivers. The unit was named for the excellent exposures in the vicinity of Fairview Heights, Cincinnati, and ranges in thickness from 50 to 120 ft (15–37 m).



*Cliff-forming character of the planar-bedded limestone and shale beds of the Fairview Formation along West Fork of Eagle Creek, Brown County. The widespread zone of soft-sediment deformation mapped in the upper part of the Fairview in southern Brown and western Adams County occurs midway through this exposure.*

## Diagnostic features
- Planar- to irregular-bedded limestone and shale.
- Sparsely fossiliferous shale.
- Limestone and shale beds each average 50% of the unit.

## General features
- Gray to blue gray.
- Thin to medium bedded.
- Platy to flaggy partings in shale beds.
- Disseminated pyrite.
- Graded bedding and ripple marks common in some limestone beds.

## Lithologic variations
- In Hamilton County, basal portion of the Fairview is termed the North Bend Tongue, which intertongues with the Wesselman Tongue of the upper part of the Kope Fm.
- In Clermont, Brown, and Adams Counties,

basal part of the Fairview contains a widespread, ledge-forming zone of thin, irregular- to wavy-bedded limestone and shale containing abundant specimens of the brachiopod *Strophomena*. The zone ranges in thickness from 3 to 6 ft (1–2 m).
- In Brown and Adams Counties, a widespread zone of soft-sediment deformation characterized by ball-and-pillow structures and convolute laminations is mapped in the upper part of the Fairview.

### Fossil content
- Abundant, diverse fauna of primarily brachiopods, bryozoans, bivalves, corals, crinoids, trilobites, cephalopods, and gastropods and abundant trace fossils.
- Excellent preservation of fossils.

### Weathering characteristics
- Resistant to weathering, forming cliffs and steep slopes in river and stream valleys.
- On slopes, forms thin colluvium with abundant slabs of limestone.
- Forms small waterfalls and riffles in river and stream beds.

### Stratigraphic contacts
- Sharp upper contact.
- Sharp lower contact.

### Stratigraphic context
- Underlain by Kope Fm.
- Overlain by Miamitown Sh in Butler, western Clermont, Clinton, Hamilton, Montgomery, Preble, and Warren Counties.
- Overlain by the Bellevue Mbr of the Grant Lake Ls in Adams, Brown, and central and eastern Clermont Counties.
- Similar units: Liberty Fm; Corryville Mbr of the Grant Lake Fm.

### Engineering properties
- Interbedded formation composed of nearly equal amounts of weak and strong beds through the formation. Weaker shales considered the controlling rocks in this formation and anticipated to weather rapidly after exposure.
- Unconfined compressive strength: Unweathered shale will have low to high compressive strength; weathered shale will have very low compressive strength. Where present in the formation, resistant limestone beds will increase unconfined compressive strength of the rock.
- Slake durability: Shale slake durability ranges low to high. Limestone will have high slake durability.
- Rippability: Weathered limestone and shale beds, particularly near the surface, may be ripped by conventional earth-moving equipment. However, unweathered strong limestone beds and well-cemented shale beds combine to make formation resistant to


*Planar- to irregular-bedded, fossiliferous limestone and sparsely fossiliferous shale* ripping. Therefore, excavation of Fairview Fm generally requires blasting, breaking, or cutting.

### Hydrogeologic properties

- Typically poor aquifer with minimal yields; suitable for limited household and small farm usage.
- Average yield: 3–5 gpm.
- Yields provided by combination of joints and fractures as they intersect bedding planes.
- For ground-water modeling purposes, may be considered a lower-confining or boundary unit.
- Similar hydrogeologic properties to overlying and underlying Ordovician units and typically mapped together. Individual Ordovician units commonly too thin or low yielding to constitute an individual hydrogeologic unit.
- Aquifer rating: 2–3.
- Vadose zone rating: 2–3.
- Hydraulic conductivity: 1–100 gpd/$ft^2$.

### Environmental hazards

- Small landslides may occur in weathered colluvium.
- Danger of falling rocks from cliff exposures, especially in spring.
- Falls from cliff tops by people and livestock.

### Economic geology

- Limestone beds used as building stone in decorative retaining walls and for stepping stones.
- Historically, limestone from the Fairview or Hill Quarry beds was used to build foundations for structures and stone walls and as building stone for the Covenant-First Presbyterian Church, Cincinnati Art Museum, Art Academy of Cincinnati (Art Institute), and other buildings.

### Scenic geology

- The resistant Fairview and the Bellevue Mbr of the Grant Lake Fm or Bellevue Mbr of Grant Lake Ls combine to form scenic cliff lines, streams, or gorges along streams and rivers.
- Limestone beds form series of small waterfalls as streams cut through the unit.

### Further reading

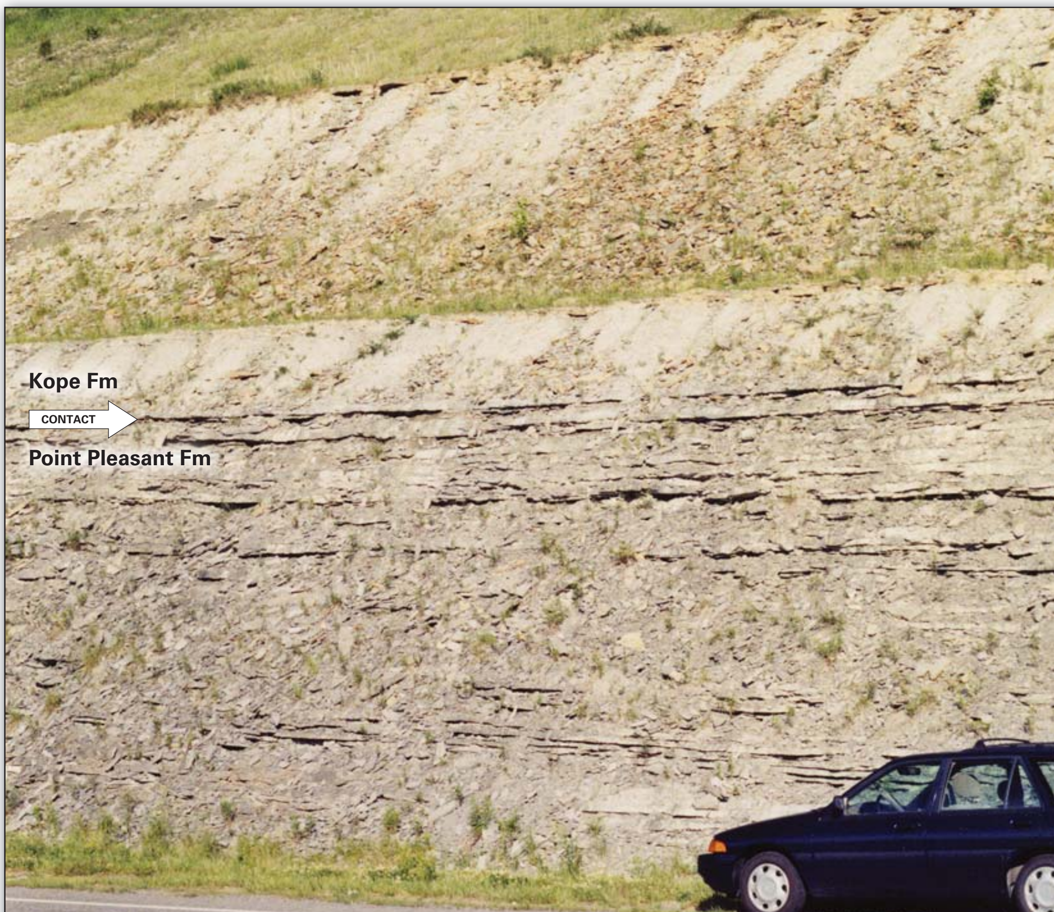
Potter and others, 1991; Hannibal and Davis, 1992; Agnello, 2005

# Kope Formation

The diagnostic features of the Kope Formation include the dominance of shale that occurs in medium to thick beds. Shale averages 75% of the unit, and the Kope is subdivided into the Grand Avenue Member and basal Fulton beds.

The Kope Formation was deposited in a vast, shallow sea containing abundant and diverse marine life. Major hurricane waves frequently eroded, transported, and redeposited the bottom sediments, creating the interbedding of limestone and shale. The offshore environment of the Kope featured water depths deeper than the underlying portions of the Point Pleasant Formation and overlying Fairview Formation.

The Kope was named for the stream exposures along Kope Hollow located in southern Brown County. The unit is exposed along the valley walls of the Ohio, Great Miami, and Little Miami Rivers; Mill Creek; and the tributaries of these streams. The unit was buried by Quaternary-age sediments filling the ancestral valleys of the Great Miami and Ohio Rivers in Montgomery, Warren, and Adams Counties. The Kope ranges in thickness from 200 to 260 ft (60–79 m).




*Point Pleasant-Kope Formation contact in road cut for Kentucky S.R. 1159 just south of the intersection with the Alexandria to Ashland (AA) Highway (Kentucky S.R. 9).*

Quaternary
Neogene?
Permian
Pennsylvanian
Mississippian
Devonian
Silurian
Ordovician
Kope Formation
Cambrian
Precambrian

## Diagnostic features

- Ratio of 75% shale to 25% limestone.
- Medium to thick bedded shale.

## General features

- Gray to bluish gray.
- Planar to irregular bedding.
- Sparsely fossiliferous shale and highly fossiliferous limestone.
- Calcareous shale with minor pyrite.
- Platy to flaggy partings in shale.

## Lithologic variations

- Many repeating, well-developed sedimentary cycles consisting of a thicker shale-dominant interval capped by a thinner interval containing abundant limestone beds.
- In Hamilton County, upper part of the Kope Fm is termed the Wesselman Tongue, which intertongues with the North Bend Tongue of the Fairview Fm.
- Grand Avenue Mbr, characterized by lithologies similar to the overlying Fairview Fm, occurs 30–40 ft (9–12 m) below the Kope-Fairview contact.
- The Fulton beds occur in the basal portion of the Kope Fm in Hamilton and Clermont Counties and represent a tongue of Utica sh.

## Fossil content

- Spectacular preservation of fossils, especially trilobites and echinoderms.
- Brachiopods, bryozoans, gastropods, cephalopods, trilobites, echinoderms, and trace fossils common.

## Weathering characteristics

- Weathers rapidly to light-gray clay with limestone slabs because of repeated wetting/drying and freeze/thaw cycles.
- Forms thick colluvium on steeper slopes.

## Stratigraphic contacts

- Sharp upper contact.
- Sharp lower contact.

## Stratigraphic context

- Underlain by Point Pleasant Fm.
- Underlain by Utica sh in western and northern Ohio.
- Overlain by Fairview Fm.
- Similar unit: Miamitown Sh.

## Engineering properties

- Contains weak, rapidly weathering shale with few strong limestone beds. Weaker shale beds should be considered the controlling rocks in this formation and are anticipated to weather rapidly after exposure.
- Unconfined compressive strength: Unweathered shale will have low to high compressive strength; weathered shale


*Thick bedded, sparsely fossiliferous shale and thin, planar, fossiliferous limestone*

will have very low compressive strength. Where present in the formation, resistant limestone beds will increase unconfined compressive strength of the rock.
- Slake durability: Shale slake durability ranges low to high. Limestone would have extremely high slake durability.
- Rippability: Weathered shale beds, particularly near the surface, can be ripped with some difficulty by conventional earth-moving equipment. Unweathered portions of the formation likely to require blasting, breaking, or cutting for rock excavation.

## Hydrogeologic properties

- Typically poor aquifer with minimal yields; suitable for limited household and small farm usage.
- Shaley nature makes it an exceptionally poor aquifer with yields <3 gpm.
- Yields provided by combination of joints and fractures as they intersect bedding planes.
- For ground-water modeling purposes, may be considered a lower-confining or boundary unit.
- Similar hydrogeologic properties to overlying and underlying Ordovician units and typically mapped together. Individual Ordovician units commonly too thin to constitute an individual hydrogeologic unit.
- Aquifer rating: 2–3.
- Vadose zone rating: 2–3.
- Hydraulic conductivity: 1–100 gpd/ft$^2$.

## Environmental hazards

- Major landslides occur in colluvium deposits accumulating on hillsides.

## Economic geology

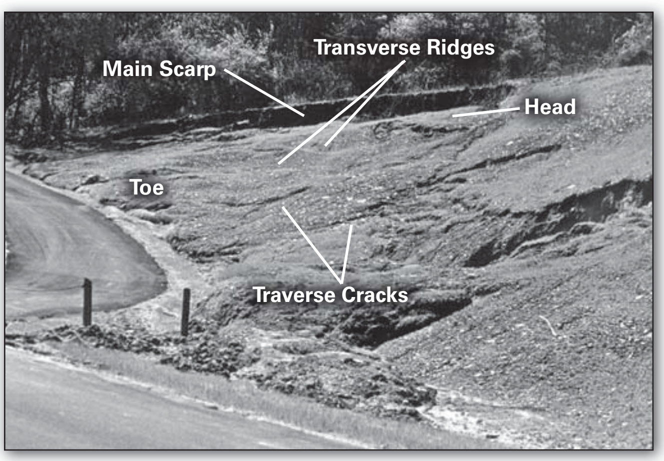
- Historically, shale quarried to produce high-quality red bricks.

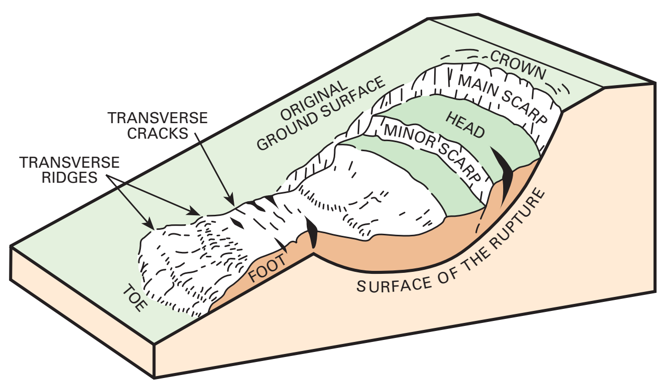
## Scenic geology

- Stream erosion of the less-resistant Kope forms broad picturesque valleys containing wide flood plains that are often backfilled with alluvium and glacial sediments.

## Further reading

Ford, 1967




*Rotational landslide in weathered colluvium derived from the Kope Formation. Such landslides are characterized top to bottom by a semi-circular main scarp formed when the surface of rupture intersects the land surface. The landslide head is the upper surface of colluvium that is rotating downslope adjacent to the main scarp. As the colluvium moves/flows downslope, transverse ridges and cracks develop in the main body of the landslide. The lower part of the landslide is the toe, which is flowing on the surface of separation or in this image, down the drainage ditch in the foreground or over the ground adjacent to the road. The accompanying block diagram provides a three dimensional illustration of rotational landslide components and cross section through a typical rotational landslide. Diagram not to scale.*


# Utica shale

The diagnostic feature of the Utica shale is the dominance of brown to black shale, which averages 95% of the unit. The Utica is a widespread unit that is buried under younger rocks throughout much of Ohio and reaches its maximum thickness within the Sebree Trough. The Utica intertongues with the Kope Formation, Point Pleasant Formation, and the Lexington Limestone in the Point Pleasant Basin of southern and eastern Ohio. One of these tongues is exposed in limited exposures along the Ohio River and its tributaries in Hamilton and Clermont Counties and is named the Fulton beds of the basal Kope Formation. The Fulton is characterized by thick bedded, dark-gray to brown shale interbedded with thin or medium bedded, fine- to coarse-grained limestone. Shale averages 80% of the unit.

The Utica shale was deposited in offshore, deeper-water environments containing little to no oxygen in the bottom sediments and overlying water column, allowing the preservation of varying amounts of organic matter. The Utica shale was named in 1842 for exposures at Utica in Oneida County, New York. In Ohio, it ranges in thickness from 0 to 340 ft (0–104 m).

*Exposure of the shale-dominant, dark-gray to brown, thin to thick bedded Fulton beds along 12 Mile Creek near New Richmond, Clermont County.*

## Diagnostic features
- Brown to black shale beds.

## General features
- Shale bedding ranges laminated to thick.
- Limestone bedding ranges laminated to thin.
- Shale and limestone: Planar to irregular bedding.
- Limestone: Parallel to cross-laminated, fine-grained beds.
- Minor amounts of pyrite.

## Lithologic variations
- Rhythmically laminated limestone and shale common in some intervals.
- In upper Utica, amounts of brown to black shale and fine-grained, laminated limestone decrease in abundance as gray shale and coarser-grained limestone increase over a transition interval of approximately 100 ft (30 m).

## Fossil content
- Sparsely fossiliferous shale.
- Sparsely to highly fossiliferous limestone.
- Diagnostic fauna dominated by floating or swimming organisms, such as graptolites and trilobites.
- Bottom-dwelling organisms generally rare.

**Weathering characteristics**
- Weathers rapidly to light-gray clay colluvium with some limestone slabs because of repeated wetting/drying and freeze/thaw cycles.
- Forms relatively thick colluvium.

**Stratigraphic contacts**
- Gradational upper contact.
- Sharp lower contact.

**Stratigraphic context**
- Underlain by Trenton Ls in northwest Ohio.
- Underlain by Point Pleasant Fm or Lexington Ls, depending on stratigraphic position of the various tongues of Utica sh, in the subsurface of southwestern, south-central, and southeastern Ohio.
- Overlain by Kope Fm.

**Engineering properties**
- Interbedded formation composed mainly of weaker shale with few strong limestone beds. Dominant weaker shales considered the controlling rocks in this formation and anticipated to weather after exposure.
- Unconfined compressive strength: Unweathered shale will have medium to high compressive strength; weathered shale will have low to medium compressive strength. Where present in the formation, resistant limestone beds will increase unconfined compressive strength of the rock.
- Slake durability: Shale slake durability ranges low to high based on amount of weathering present. Limestone will have high slake durability.
- Rippability: Weathered shale beds, particularly near the surface, may be ripped by conventional earth-moving equipment. Less-weathered beds anticipated to be resistant to ripping and require blasting, breaking, or cutting.

**Hydrogeologic properties**
- Typically poor aquifer with minimal yields; suitable for limited household and small farm usage.
- Water quality may be objectionable due to sulfur and hydrocarbons found in this unit.
- Average yield: 3–5 gpm.
- Yields provided by combination of joints and fractures as they intersect bedding planes.
- For ground-water modeling purposes, may be considered a lower-confining or boundary unit.
- Similar hydrogeologic properties to overlying and underlying Ordovician units and typically mapped together. Individual Ordovician units commonly too thin to constitute an individual hydrogeologic unit.
- Aquifer rating: 2–3.
- Vadose zone rating: 2–3.
- Hydraulic conductivity: 1–100 gpd/ft$^2$.

*Brown shale with limestone laminations*

## Environmental hazards

- Small landslides may occur in colluvium deposits accumulating on steeper hillsides.

## Economic geology

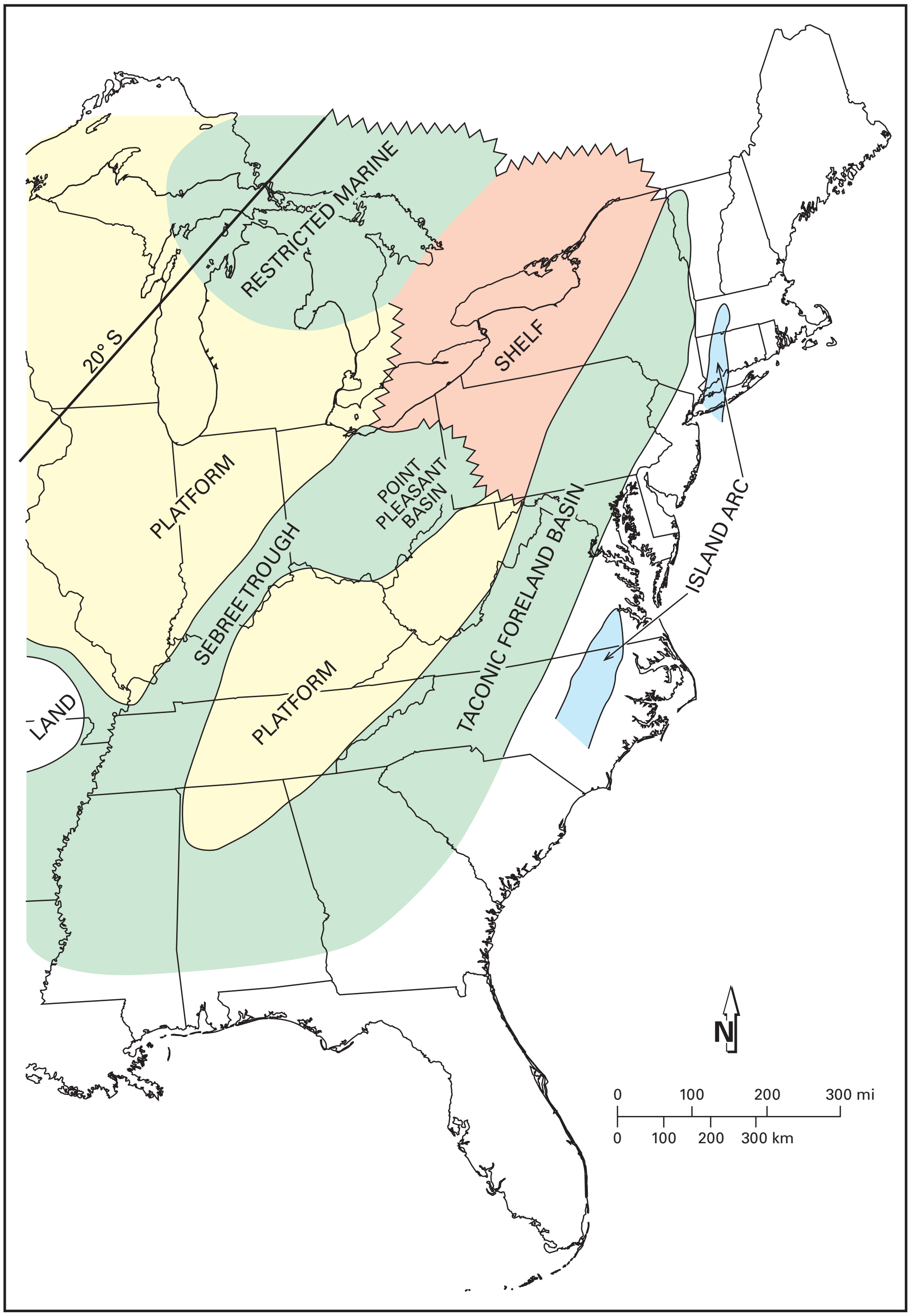
- Natural gas source rock and reservoir.
- In some regions, petroleum source.

## Scenic geology

- None.

## Further reading

Fenneman, 1916; McFarlan and Freeman, 1935; Lattman, 1954; McLaughlin and others, 2008a




*Paleogeographic reconstruction of major depositional and tectonic features present during the deposition of the Utica shale during the Late Ordovician Period. The Utica shale was deposited in the Sebree Trough and portions of the Point Pleasant Basin (modified from Wickstrom and others, 1992).*

# Point Pleasant Formation

The Point Pleasant Formation is characterized by interbedded planar- to irregular-bedded, fossiliferous, coarse-grained limestone and sparsely fossiliferous shale. In the subsurface of Ohio, Point Pleasant rocks become finer grained and thinner bedded and change to rhythmically laminated fine-grained limestone and brown to black shale.

The unit was deposited in the transitional environments between the shallow-water environments in northern and central Kentucky and deeper-water environments of the Sebree Trough of western Ohio. The Point Pleasant is well exposed along the valley walls and within the tributary streams of the Ohio River in southwestern Ohio. The unit was named for the excellent exposures in the vicinity of Point Pleasant, Clermont County, and ranges in thickness from 50 to 120 ft (15–37 m).

*Planar- to irregular-bedded limestone and shale of the Point Pleasant Formation as exposed along Big Run in Clermont County. Permission required prior to entering private property to visit this exposure. Scale is 50 cm (1.6 ft).*

## Diagnostic features

- Planar- to irregular-bedded limestone and shale.
- Medium to coarse grained.
- Sparsely fossiliferous shale.
- Limestone averages 60% of the unit.

## General features

- Gray to bluish gray.
- Thin to medium bedded.
- Platy to flaggy partings in shale beds.
- Graded bedding and ripple marks common in some limestone beds.

## Lithologic variations

- Amount of limestone and size of fossil fragments decrease northward from exposures in the Ohio River valleys into the subsurface.
- Limestone bed thickness decreases northward from medium bedded to thin bedded or laminated into the Sebree Trough.
- Amount of shale increases and changes color from primarily gray to brownish gray to brown northward in the subsurface as the unit grades into and intertongues with the Utica sh.

**Fossil content**
- Abundant, diverse fauna of primarily brachiopods, bryozoans, crinoids, and trilobites.
- Bivalves, cephalopods, gastropods, and trace fossils less common.
- Some beds display excellent preservation of fossils.

**Weathering characteristics**
- Resistant to weathering, forming cliffs and steep slopes in river and stream valleys.
- On gentle slopes, forms thin colluvium with abundant slabs of limestone.
- Forms small waterfalls and riffles in river and stream beds.

**Stratigraphic contacts**
- Sharp upper contact.
- Sharp lower contact.

**Stratigraphic context**
- Underlain by Lexington Ls.
- Overlain by Kope Fm.
- Similar units: Fairview Fm, Corryville Mbr of the Grant Lake Ls or Grant Lake Fm, and Liberty Fm.

**Engineering properties**
- Interbedded formation composed of varying amounts of weak shale and strong limestone beds through the formation. Weaker shales considered the controlling rocks in this formation. Shales of this formation anticipated to weather after exposure.
- Unconfined compressive strength: Unweathered shale will have medium to high compressive strength; weathered shale will have extremely low to low compressive strength. Limestone is anticipated to have medium to high compressive strength.
- Slake durability: Shale slake durability ranges low to high. Limestone will have high slake durability.
- Rippability: Abundance of strong limestone beds results in the formation being resistant to ripping. Therefore, excavation generally requires blasting, breaking, or cutting.

**Hydrogeologic properties**
- Typically poor aquifer with minimal yields; suitable for limited household and small farm usage.
- Average yield: 3–5 gpm.
- Yields provided by combination of joints and fractures as they intersect bedding planes.
- For ground-water modeling purposes, may be considered a lower-confining or boundary unit.
- Similar hydrogeologic properties to overlying and underlying Ordovician units and typically mapped together. Individual Ordovician units commonly too thin to constitute an individual hydrogeologic unit.
- Aquifer rating: 2–3.
- Vadose zone rating: 2–3.
- Hydraulic conductivity: 1–100 gpd/ft$^2$.

**Environmental hazards**
- Danger of falling rocks from cliff exposures, especially in spring.
- Falls from cliff tops by people and livestock.

**Economic geology**
- Historically, limestone from the Point Pleasant or River Quarry beds was used to build stone walls and foundations for structures and as a building stone for building and bridge foundations, agricultural lime, and Portland cement.
- Limestone beds used as building stone in decorative retaining walls and for stepping stones.
- In subsurface of eastern Ohio, unit is a major producer of oil and gas when hydraulically fractured.

**Scenic geology**
- The resistant Point Pleasant forms scenic cliffs in stream valleys.
- Limestone beds form a series of small waterfalls as streams cut through the unit.

**Further reading**

Stith, 1986; Wickstrom and others, 1992; McLaughlin and others, 2008a


*Irregular-bedded, fossiliferous limestone and shale*

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