DEPARTMENT OF NATURAL RESOURCES
DIVISION OF GEOLOGICAL SURVEY
Lawrence H. Wickstrom, Chief

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Central Ohio's Geology in Core and Outcrop Workshop II

Hosted by
Ohio Department of Natural Resources
Division of Geological Survey

Sponsored by
Ohio Geological Society

Horace R. Collins Laboratory
Delaware, Ohio
April 20, 2011

Ohio Department of Natural Resources
Division of Geological Survey
2045 Morse Road, Bldg. C-1
Columbus, Ohio 43229-6693
2011

Agenda

9:00–9:05 A.M.	Welcome
9:05–9:30 A.M.	Geological Survey's geohazards and geologic mapping programs
9:30–10:00 A.M.	Central Ohio geology
10:00–10:15 A.M.	Break
10:15–11:00 A.M.	**Group A exercise:** The utility of Geological Survey map products **Group B exercise:** Core description 101; anatomy of a fact sheet
11:00–11:45 A.M.	**Group A exercise:** Core description 101; anatomy of a fact sheet **Group B exercise:** The utility of Geological Survey map products
11:45–12:30 P.M.	**Lunch provided**
12:30–2:00 P.M.	**Group A exercise:** Soil Classifications—Unified, AASHTO, USDA, ODOT's version of AASHTO, and Rock Mass Classification ASTM **Group B exercise:** Utility of fact sheets in field-like settings; group discussion
2:00–2:15 P.M.	Break
2:15–3:45 P.M.	**Group A exercise:** Utility of fact sheets in field-like settings; group discussion **Group B exercise:** Soil Classifications—Unified, AASHTO, USDA, ODOT's version of AASHTO, and Rock Mass Classification ASTM
3:45–4:00 P.M.	Questions; workshop evaluation

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Cover image: Berea Sandstone-Sunbury Shale unconformable contact with sulfide mineralization.

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Speakers

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Introduction to Central Ohio Geology

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Contents

Maps

Ohio Department of Transportation Soil and Rock Classification*

QUICK REFERENCE FOR VISUAL DESCRIPTION OF SOILS

(1) STRENGTH OF SOIL
Noncohesive (granular) soils—Compactness

Description	Blows per ft.
Very loose	≤4
Loose	5–10
Medium dense	11–30
Dense	31–50
Very dense	>50

Strength of soil: Cohesive (fine-grained) soils—Consistency

Description	Qu (TSF)	Blows per ft.	Hand manipulation
Very soft	<0.25	<2	Easily penetrates 2 in. by fist
Soft	0.25–0.5	2–4	Easily penetrates 2 in. by thumb
Medium stiff	0.5–1.0	5–8	Penetrates by thumb with moderate effort
Stiff	1.0–2.0	9–15	Readily indents by thumb, but does not penetrate
Very stiff	2.0–4.0	16–30	Readily indents by thumbnail
Hard	>4.0	>30	Indents with difficulty by thumbnail

(2) COLOR

If a color is a uniform color throughout, the term is *single*, modified by an adjective such as *light* or *dark*. If the predominate color is shaded by a secondary color, the secondary color precedes the primary color. If two major and distinct colors are swirled throughout the soil, the colors are modified by the term *mottled*.

(3) PRIMARY COMPONENT

Use description from Classification of Soils chart on p. 2.

(4) COMPONENT MODIFIERS

Description	Percentage by weight
Trace	0–10
Little	10–20
Some	20–35
"And"	35–50

(5) SOIL ORGANIC CONTENT

Description	Percentage by weight
Slightly organic	2–4
Moderately organic	4–10
Highly organic	>10

(6) RELATIVE VISUAL MOISTURE

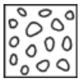
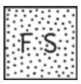
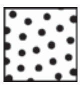
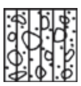
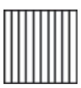
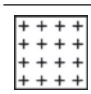
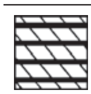
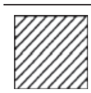
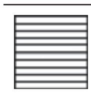
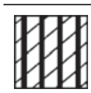
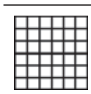
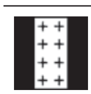
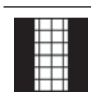
Description	Criteria	
	Cohesive soil	Noncohesive soil
Dry	Powdery; cannot be rolled; water content well below the plastic limit	No moisture present
Damp	Leaves very little moisture when pressed between fingers; crumbles at or before rolled to $^{1}/_{8}$ in.; water content below plastic limit	Internal moisture, but no to little surface moisture
Moist	Leaves small amounts of moisture when pressed between fingers; rolled to $^{1}/_{8}$ in. or smaller before crumbling; water content above plastic limit to –3% of the liquid limit	Free water on surface, moist (shiny) apperance
Wet	Very mushy; rolled multiple times to $^{1}/_{8}$ in. or smaller before crumbles; near or above the liquid limit	Voids filled with free water; can be poured from split spoon

*Pages 1–9 of this booklet modified from Specifications for Geotechnical Explorations, Appendix A—Soil and Bedrock Classification (p. 109–122), published by the Ohio Department of Transportation (2008).

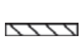
CLASSIFICATION OF SOILS

Ohio Department of Transportation

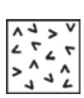
(The classification of a soil is found by proceeding from top to bottom of the chart. The first classification that the test data fits is the correct classification.)

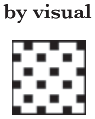
Symbol	Description	Classification: AASHTO	Classification: OHIO	LL_O/LL x 100*	Percent pass #40	Percent pass #200	Liquid Limit (LL)	Plastic Index (PI)	Group index max.	Remarks
	Gravel and/or stone fragments	A-1-a			30 max.	15 max.		6 max	0	Min. of 50% combined gravel, cobble, and boulder sizes
	Gravel and/or stone fragments with sand	A-1-b			50 max.	25 max.		6 max.	0	
	Fine sand	A-3			51 min.	10 max.	Nonplastic		0	
	Coarse and fine sand		A-3a			35 max.		6 max.	0	Min. of 50% combined coarse and fine sand sizes
	Gravel and/or stone fragments with sand and silt	A-2-4				35 max.	40 max.	10 max.	0	
		A-2-5					41 min.			
	Gravel and/or stone fragments with sand, silt, and clay	A-2-6				35 max.	40 max.	11 min.	4	
		A-2-7					41 min.			
	Sandy silt	A-4	A-4a	76 min.		36 min.	40 max.	10 max.	8	Less than 50% silt sizes
	Silt	A-4	A-4b	76 min.		50 min.	40 max.	10 max.	8	50% or more silt sizes
	Elastic silt and clay	A-5		76 min.		36 min.	41 min.	10 max.	12	
	Silt and clay	A-6	A-6a	76 min.		36 min.	40 max.	11–15	10	
	Silty clay	A-6	A-6b	76 min.		36 min.	40 max.	16 min.	16	
	Elastic clay	A-7-5		76 min.		36 min.	41 min.	≤LL–30	20	
	Clay	A-7-6		76 min.		36 min.	41 min.	>LL–30	20	
	Organic silt	A-8	A-8a	75 max.		36 min.				Without organics would classify as A-4a or A-4b
	Organic clay	A-8	A-8b	75 max.		36 min.				Without organics would classify as A-5, A-6a, A-6b, A-7-5, or A-7-6

Material classified by visual inspection

 Sod and topsoil

 Pavement or base

 Uncontrolled fill (describe)

 Bouldery zone

 Peat: S–sedimentary; W–woody; F–fibrous; L–loamy; etc.

*Only perform the oven-dried liquid limit test and this calculation if organic material is present in the sample.

QUICK REFERENCE GUIDE FOR ROCK DESCRIPTION

(1) ROCK TYPE

Common rock types are: claystone, coal, dolomite, limestone, sandstone, siltstone, and shale.

(2) COLOR

To be determined when rock is wet. When using the GSA color charts, use only name, not code.

(3) WEATHERING

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 to 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.

(4) RELATIVE STRENGTH

Description	Field parameter
Very weak	Core can be carved with a knife and scratched by fingernail. Can be excavated readily with a point of a pick. Pieces 1 inch or more in thickness can be broken by finger pressure.
Weak	Core can be grooved or gouged readily by a knife or pick. Can be excavated in small fragments by moderate blows of a pick point. Small, thin pieces can be broken by finger pressure.
Slightly strong	Core can be grooved or gouged 0.05 inch deep by firm pressure of a knife or pick point. Can be excavated in small chips to pieces about 1 inch maximum size by hard blows of the point of a geologist'a pick.
Moderately strong	Core can be scratched with a knife or pick. Grooves or gouges to 1/4 inch deep can be excavated by hand blows of a geologist's pick. Requires moderate hammer blows to detach hand specimen.
Strong	Core can be scratched with a knife or pick only with difficulty. Requires hard hammer blows to detach hand specimen. Sharp and resistant edges are present on hand specimen.
Very strong	Core cannot be scratched by a knife or sharp pick. Breaking of hand specimens requires hard repeated blows of a geologist's hammer.
Extremely strong	Core cannot be scratched by a knife or sharp pick. Chipping of hand specimens requires hard repeated blows of a geologist's hammer.

(5) TEXTURE

Component		Grain diameter (in.)
Boulder		>12
Cobble		3–12
Gravel		0.08–3
Sand	Coarse	0.02–0.08
	Medium	0.01–0.02
	Fine	0.005–0.01
	Very fine	0.003–0.005

(6) BEDDING

Description	Thickness (in.)
Very thick	>36
Thick	18–36
Medium	10–18
Thin	2–10
Very thin	0.4–2
Laminated	0.1–0.4
Thinly laminated	<0.1

(7) DESCRIPTORS

Arenaceous—sandy	**Conglomeritic**—contains rounded to subrounded gravel	**Friable**—easily broken down
Argillaceous—clayey	**Crystalline**—contains crystalline structure	**Micaceous**—contains mica
Brecciated—contains angular to subangular gravel	**Dolomitic**—contains calcium/magnesium carbonate	**Pyritic**—contains pyrite
Calcareous—contains calcium carbonate	**Ferriferous**—contains iron	**Siliceous**—contains silica
Carbonaceous—contains carbon	**Fissile**—thin planar partings	**Stylolitic**—contains stylotites (suture-like structure)
Cherty—contains chert fragments	**Fossiliferous**—contains fossils	**Vuggy**—contains openings

(8) DISCONTINUITIES

Discontinuity Types

Type	Parameters
Fault	Fracture which expresses displacement parallel to the surface and does not result in a polished surface.
Joint	Planar fracture that does not express displacement. Generally occurs at regularly spaced intervals.
Shear	Fracture which expresses displacement parallel to the surface and results in polished surfaces or slickensides.
Bedding	A surface produced along a bedding plane.
Contact	A surface produced along a contact plane. Generally not seen in Ohio.

Degree of Fracturing

Description	Spacing
Unfractured	>10 ft.
Intact	3–10 ft.
Slightly fractured	1–3 ft.
Moderately fractured	4–12 in.
Fractured	2–4 in.
Highly fractured	<2 in.

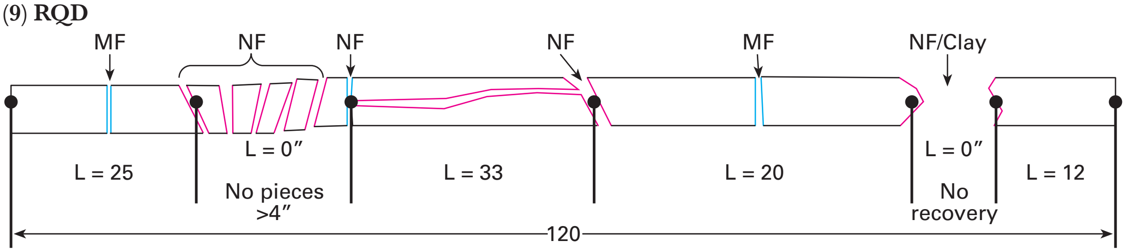
Aperture Width

Description	Spacing (in.)
Open	>0.2
Narrow	0.05–0.2
Tight	<0.05

Surface Roughness

Description	Criteria
Very rough	Near vertical steps and ridges occur on the discontinuity surface.
Slightly rough	Asperities on the discontinuity surface are distinguishable and can be felt.
Slickensided	Surface has a smooth, glassy finish with visual evidence of striation.

(9) RQD



$$RQD = \left(\frac{\sum \textit{Length of pieces} > 4 \textit{ inches}}{\textit{Total length of core}} \right) * 100 \qquad RQD = \left(\frac{25 + 33 + 20 + 12}{120} \right) * 100 = 75\%$$

(10) LOSS

$$\textit{Run loss} = \left(\frac{L_R - R_R}{L_R} \right) * 100 \qquad \textit{Unit loss} = \left(\frac{L_U - R_U}{L_U} \right) * 100$$

Where L_R = Run length, R_R = Run recovery, L_U = Rock unit length, and R_U = Rock unit recovery.

ROCK TYPE

GENERAL AND GLOSSARY

The following terms are used in describing the rock types found within Ohio. The following listing is presented in alphabetical order.

Term	Definition
Amorphous	Does not contain crystalline structure with shapeless appearance.
Anhydrous	Does not contain water within the crystalline structure.
Bioturbated	Evidence of past organisms, such as filled burrows, within the rock mass.
Conchoidal fracture	A curved fracture plane with a rock mass.
Concretion	A solidified mass of concentrated material, usually of a single or multiple mineral composition.
Dilute HCl	A liquid composed of a 10% hydrochloric acid solution.
Hydrous	Contains water within the crystalline structure.
Hardness	When describing rock and minerals, the hardness of the material is commonly referred to. The hardness is the ability of the material to resist scratching. The easier the material is scratched, the lower the hardness; and the more resistant the material is to scratching, the higher the hardness. The following table lists hardness of common items to aid in field determinations: (see table below)
Indurated	Partially lithified (hardened) sediment.
Lithified	Process during which unconsolidated sediments are formed into sedimentary rock.
Luster	The ability of the material to reflect light resulting in a surface appearance.
Vitreous	Description referring to a glassy luster.

Object	Hardness
Fingernail	2.5
Copper penny (pre-1982)	3.5
Knife blade/nail	5.5
Window glass	5.5
Hardened steel (file)	6.5

ROCK TYPES

The following are descriptions of the basic rock types found within Ohio. It should be noted that when referencing a percentage of composition the percentage is based on volume not weight.

Rock type	Description
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 inter-grain 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 semi-vitreous 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.

Rock type (cont.)	**Description (cont.)**
Coal	A combustible substance containing more than 50%, by weight, and more than 70%, by volume, of carbonaceous material; formed from the compaction and lithification of plant remains. Colors of coals range from brown to black. It is generally lightweight with a shiny appearance on fresh surfaces.
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 inter-grain 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	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 ($CaSO_4 \bullet 2H_2O$). 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. 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 (FeCO3 , 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 upon 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. Descriptions based on Folk or Dunham Carbonate Classification systems are not needed.
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). Shale has a laminated structure, which gives it fissility along which the rock splits readily. Shale is commonly interbedded with sandstone or limestone. Carbonaceous shale often grades into coal. Typical colors may be red, brown, black, green or gray.
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 carbonaceous 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.

ROCK DESCRIPTORS

The following listing of descriptors is for rock types found within Ohio. The following descriptors should be applied when the condition comprises 10% or more of the observed sample by volume. If the condition comprises less than 10% use "contains . . ." For example if the core contains more than 10% mica, then the rock is "micaceous"; but if the rock is composed of 5% mica, then the rock "contains mica." The following listing is presented in alphabetical order.

Percentage composition		**Description**
>10	**≤10**	
Arenaceous	NA	Contains sand-sized particles. Should not be used to describe sandstone, conglomerate, or breccia.
Argillaceous	NA	Contains clay and/or silt-sized particles that result in the appearance having a slightly clayey texture. Should not be used to describe shale, claystone, or mudstone.
Brecciated	NA	Contains less than 25% angular to subangular gravel, cobbles, and boulders. Typically used to describe sandstone, limestone, or dolomite.
Calcareous	NA	Contains calcium carbonate indicated by reaction with HCl. Should not be used for describing limestone or dolomite.
Carbonaceous	NA	Contains a significant amount of carbon but is not combustible. Should not be used to describe coal.
Cherty	Contains chert fragments	Contains chert fragments.
Conglomeritic	NA	Contains less than 25% rounded to subrounded gravel, cobbles, and boulders. Typically used to describe sandstone, limestone, or dolomite.
Crystalline	NA	Contains crystalline structure visible with the unaided eye or a 10-power hand lens. Generally referred to by the crystal size based upon texture chart, i.e., fine grained.
Dolomitic	NA	Contains calcium/magnesium carbonate. Reacts slightly with dilute HCl on a fresh surface and slightly to moderately on a powdered surface. Should only be used with limestone.
Ferriferous/ferric	Slightly ferric	Contains iron-based minerals that are either visible or result in an increased density.
Fissile	NA	Partings along closely spaced planes parallel or nearly parallel to bedding.
Fossiliferous	Contains fossils	Contains remains of plant and animals, including carbonized fossils, silica, pyrite, or other mineral-replaced organisms and sand-, silt-, and/or clay-filled casts or burrows of organisms in most sedimentary rocks.
Friable	NA	Can be easily broken down with hand pressure.
Lithic	Contains lithic fragments	Contains less than 25% rounded to angular rock fragments. Typically used to describe claystone.
Marine	NA	Reference made to limestone and dolomites that were deposited in a salt-water marine environment.
Micaceous	Contains mica	Rock mass contains mica fragments.
Non-marine	NA	Reference made to limestone and dolomites that were deposited in a fresh-water environment. Commonly also referred to as "impure."
Petroliferous	NA	Contains free petroleum or petroleum staining, including natural asphalt.
Pyritic	Contains pyrite	Rock mass contains pyrite crystals or nodules.
Siliceous	Contains silica	Rock mass contains very fine to fine silica material.
Stylolitic	NA	Contains stylotites (cranial suture-like structures) within the rock mass.
Vuggy	NA	Contains solution cavities that may or may not contain mineral crystals. Typically used to describe carbonate rocks.

ROCK CORE PHOTO EXAMPLES

FIGURE 1.—Correct method of core photo.

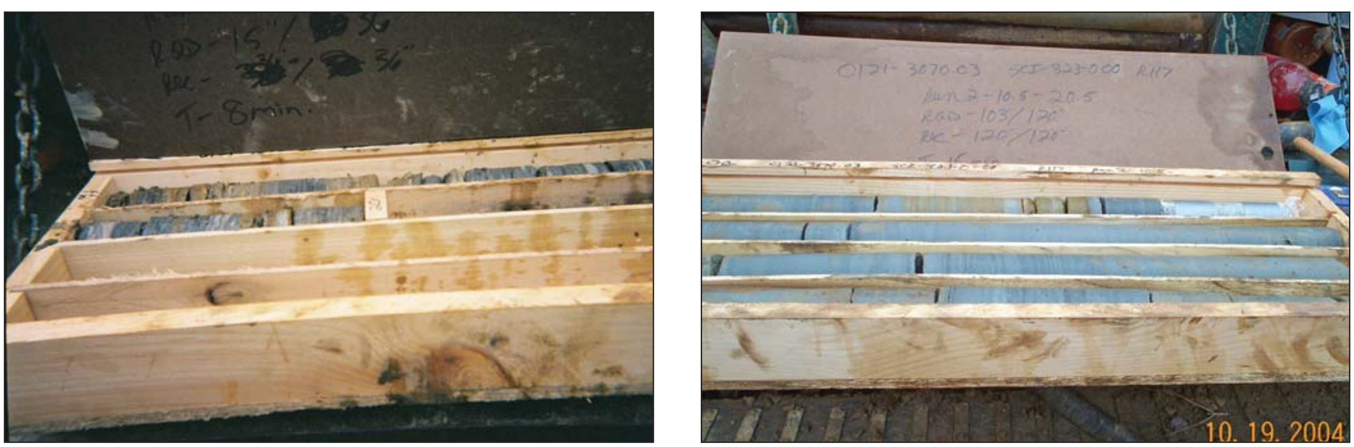


FIGURE 2.—Incorrect method of core photo (obtuse angle). Photos taken at bad angles resulting in the inability to see details in the core and entire lengths of the core samples are not visible.

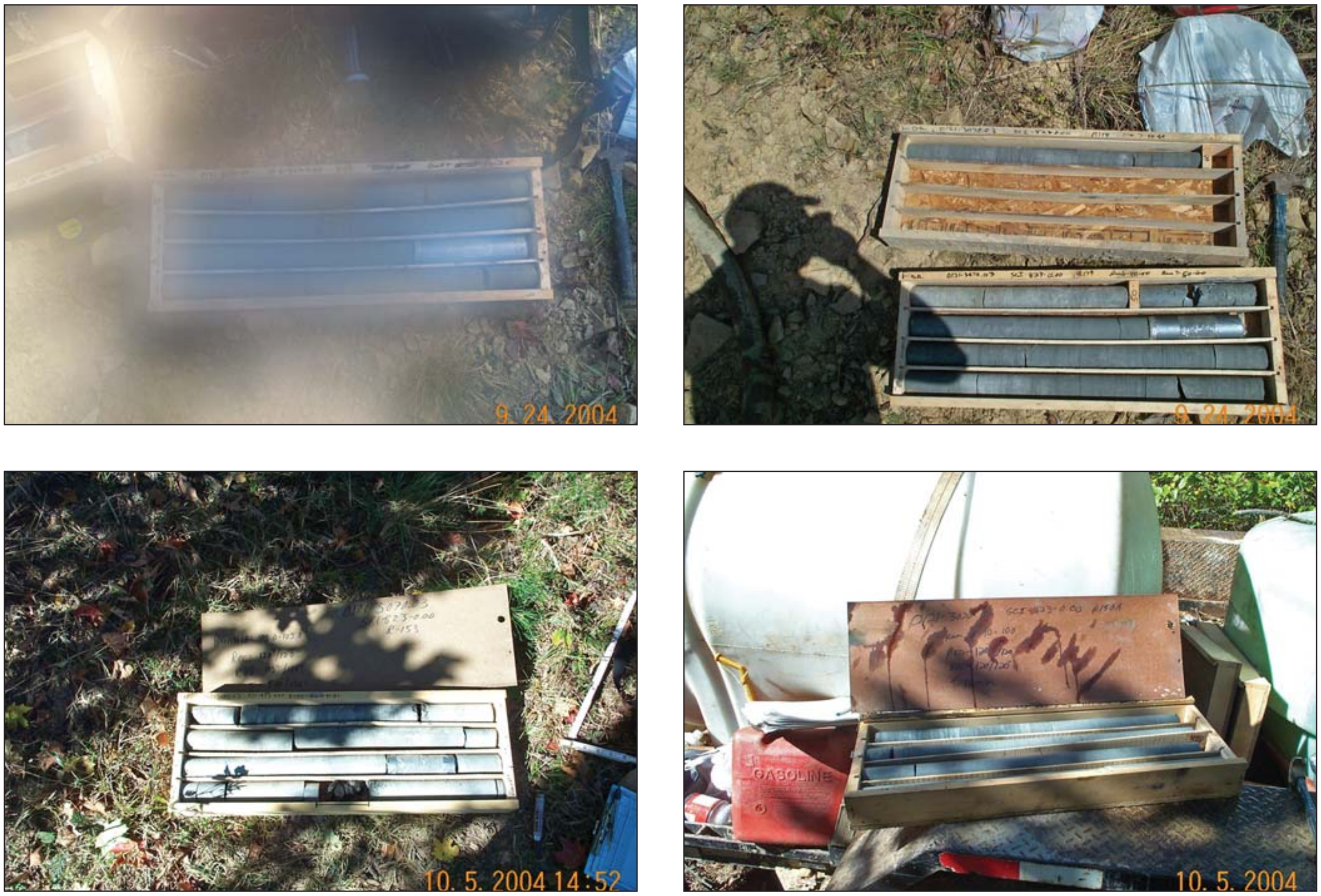


FIGURE 3.—Incorrect method of core photo (shading). Photos taken with shading over the cores result in the inability to distinguish the entire characteristics of the core samples.

FACT SHEET SOURCE MATERIAL

Unpublished Sources

1. Mapping geologist's field observations.
2. Field notes.
3. Bedrock and surficial geology field maps.
4. Measured sections.
5. Brief core descriptions.
6. Geophysical logs.
7. Geotechnical and engineering firm reports and core descriptions.
8. Ohio Department of Transportation boring logs.

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2. Core descriptions.
3. Measured sections.
4. Bedrock geology maps, scale 1:24,000.
5. Bedrock topography maps, scale 1:24,000.
6. Surficial geology maps, scale 1:100,000.

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GEOLOGIC TIME SCALE

Eon	Era	System/Period (Subsystem)		Age at base (millions of years)
Phanerozoic	Cenozoic	Quaternary		1.8
		Tertiary	(Neogene)	23.0
			(Paleogene)	65.5
	Mesozoic	Cretaceous		145.5
		Jurassic		199.6
		Triassic		251.0
	Paleozoic	Permian		299.0
		Carboniferous	(Pennsylvanian)	318.1
			(Mississippian)	359.2
		Devonian		416.0
		Silurian		443.7
		Ordovician		488.3
		Cambrian		542.0
Proterozoic	Precambrian	Neoproterozoic		2,500
		Mesoproterozoic		
		Paleoproterozoic		
Archean		Neoarchean		3,600
		Mesoarchean		
		Paleoarchean		
		Eoarchean		base not defined
		origin of earth		≈ 4,550

(modified from Gradstein, F.M., Ogg, J.G., Smith, A.G., and others, 2004 [2005], A geologic time scale 2004: Cambridge University Press, 589 p.)

Glacial Sand-and-Gravel Deposits

During the Pleistocene Epoch (2 million–10,000 years before present), several episodes of ice advance occurred in central Ohio. The last advance, the Late Wisconsinan Ice Sheet, deposited surficial materials in central Ohio. The majority of the glacial deposits in central Ohio are of three main types: (glacial) till; lacustrine deposits; and sand-and-gravel deposits, which range from disconnected lenses within glacial till to outwash sand-and-gravel (valley train) deposits and ice-contact sand-and-gravel (kames, eskers) deposits. *Drift* is an older term that collectively refers to the entire sequence of glacial deposits.

Sand-and-gravel lenses interbedded in glacial till can vary considerably, ranging from a few inches thick and a few feet in lateral extent to over 20 ft in thickness and extending over a mile laterally. Lenses can vary from stratified and bedded to relatively uniform to almost chaotic in nature.

Outwash deposits are created by active deposition of sediments by meltwater streams and are generally bedded, or stratified, and sorted. Sorting and degree of coarseness depend on the nature and proximity of the melting ice sheet. Deposition of outwash may precede an advancing ice sheet or be associated with a melting ice sheet.

Kames and *eskers* are ice-contact features. 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. These deposits may display 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 elongated, narrow, sinuous ridges of sand and gravel.

Diagnostic features:

- Sand, gravel, or a combination of the two are dominant.
- Deposits vary from relatively loose and friable to very dense and cohesive. Moisture conditions and presence of minor fines greatly increases stickiness and cohesiveness.
- Can vary from well to poorly sorted to chaotic. Deposits may be relatively uniform or highly variable and viewed as being "clean" or "dirty." Bedding can be highly variable and massive, parallel, cross-bedded, gradational, or otherwise.

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

- Important to note moisture content (e.g., damp, moist, sticky, plastic, saturated). Oxidized or unoxidized colors might help indicate position of the water table.

General features:

- Surficial geomorphology and setting are important in helping determine the nature and origin of a sand-and-gravel deposit.

Stratigraphic context:

- Surficial deposits typically occupy distinctive geomorphic settings (e.g., outwash plains, terraces, kame fields, eskers).
- In the subsurface, the nature of sand and gravel has to be inferred; determining the origin or setting becomes more difficult.
- Extreme care should be taken to separate "washed" or disturbed sand and gravel and fines in the upper portion of the split-spoon from undisturbed, natural materials; this artificial washing may misrepresent the degree of sorting, bedding, proportion of fines, etc. in the sample interval.

Lithologic variations:

- In central Ohio, outwash deposits are usually associated with broad valleys and wide modern floodplains and adjacent terraces. Kame and ice-contact features are likely found along the margins of valleys and upland areas.

Weathering characteristics:

- Weathering and predominant coloration of sand-and-gravel bodies is key to determining position of the water table.

Geologic hazards:

- Typically, deposits at the surface or in the subsurface represent relatively few hazards as far as building or construction.
- The high permeability and porosity of sand-and-gravel deposits make them very vulnerable to ground-water contamination.

Hydrogeologic properties:

- Can vary from relatively poor aquifers to some of the best aquifers in the state.
- Wells in the seams, lenses, or bodies of sand interbedded in glacial till or glacio-lacustrine units produce highly variable yields. Yields for these bodies can vary from 3 gpm to over 500 gpm.
- In general, yields for sand-and-gravel wells are dependent upon the diameter, construction, and 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 upon the proportion of till to sand and gravel and the nature of the deposits. 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 Ohio. Aquifer ratings vary from 7 to 10 and ranges of hydraulic conductivity vary from 700–100 gpd/ft^2 to greater than 2,000 gpd/ft^2.

Glacial Lacustrine Deposits

During the Pleistocene Epoch (2 million–10,000 years before present), several episodes of ice advance occurred in central Ohio. The last advance, the Late Wisconsinan Ice Sheet, deposited surficial materials in central Ohio, the majority of which are of three main types: (glacial) till, lacustrine deposits, and sand-and-gravel deposits. *Drift,* an older term, collectively refers to the entire sequence of glacial deposits.

Lacustrine deposits tend to be laminated (or varved) and contain various proportions of silts and clays. Thin layers of fine sand interbedded with the clayey to silty lacustrine deposits may reflect storm or flood events. The net produces a "wafer-like" appearance. Permeability is preferentially horizontal due to the laminations. The inherent vertical permeability is low, but may be increased by secondary porosity features, such as fractures, joints, root channels, etc. Intermorainal lakes are a major source of thin, near-surface lacustrine deposits in central Ohio. The lakes were created during the recession of the ice sheets when meltwater was trapped between the ice and end moraines. In some areas meltwater may have been trapped between two end moraines, forming a lake.

Slack-water ponds and lakes are the other major type of lacustrine deposits in central Ohio. These deposits were formed as ice advanced into a valley setting and blocked drainageways. They were also caused by tributary streams that overflowed as their base stream migrated away or became choked with coarse sediments.

Diagnostic features:

- Usually defined texturally or grain-sized as a silty clay or clayey silt. May display thin bedding, laminations, or varves. Deposits might appear massive and uniform and lack bedding. Individual intervals tend to be uniform and well-sorted.
- Deposits tend to be less compacted and dense than till and are relatively soft, plastic, and sticky. They lack the gravel, cobbles, and coarse sand content of till. Sand typically appears in discrete bands or laminae as opposed to being disseminated throughout the matrix.
- Important to note moisture content (e.g., damp, moist, saturated).

General features:

- Typically silty to clayey. Laminations, beds, varves may be common. Individual layers tend to be well sorted and uniform.

Thin-bedded and laminated lacustrine deposits (Sandusky County).

- Gray where unoxidized; brown where weathered; mottled colors may represent variable water table conditions.

Stratigraphic context:
- May represent the uppermost surficial unit in low-lying areas.
- Deposits in the subsurface interbedded with till may indicate former intermorainal lakes or blockage of drainage by advancing ice.
- Deposits interbedded with coarser, water-laid sands and gravels indicate a substantial change in water energy and a local change in drainage.

Lithologic variations:
- In central Ohio, intermorainal lakes may be silty or clayey, depending upon the nature of surrounding till and adjacent materials supplying sediments to the lakes.

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

Geologic hazards:
- Lacustrine bluffs or steeper slopes with a higher water table may be especially unstable and prone to slumping. A number of building constraints based upon such conditions include suitability for basements, foundations, septic systems, leach fields, etc.

Hydrogeologic properties:
- Monitor wells installed in the saturated zone typically will maintain water.
- Recharge and water movement is variable. These deposits are generally viewed as impermeable and comprising an aquitard. Research shows that recharge and water movement occurs in these deposits, particularly when weathered and fractured. Lab tests show permeability ranging from 10^{-7} to 10^{-9} cm/sec^2, whereas *in situ* tests based upon slug tests; long-term, low-yield pumping tests; and others may reveal permeabilities in the range of 10^{-6}cm/sec^2. Permeability and flow are preferentially horizontal, especially when deposits are highly laminated or bedded. Shallow ground-water flow in these deposits will typically flow towards the nearest shallow stream or drainage ditch.

Glacial Till

During the Pleistocene Epoch (2 million–10,000 years before present), several episodes of ice advance occurred in central Ohio. The last advance, the Late Wisconsinan Ice Sheet, deposited surficial materials in central Ohio, the majority of which are of three main types: (glacial) till, lacustrine deposits, and sand-and-gravel deposits. *Drift,* an older term, collectively refers to the entire sequence of glacial deposits.

Till is an unsorted, non-stratified (non-bedded) mixture of sand, gravel, silt, and clay deposited directly by the ice sheet. Till also may be referred to as a *diamict*, which has the same definition as far as the nature of the material but lacks the genetic implication of glacial deposition. There are two main types or facies of glacial till: *lodgment till* and *ablation till*. Lodgment till, which is "plastered-down" or "bulldozed" at the base of an actively moving ice sheet, tends to be relatively dense and compacted, and pebbles typically are angular or 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. Debris bands are laid down or stacked as the ice between the bands melts. Ablation till tends to be less dense, less compacted, and slightly coarser as meltwater commonly washes away some of the fine silt and clay.

Till has relatively low inherent permeability. Permeability in till is in part dependent upon the primary porosity of the till, which reflects how finely textured the particular till is. Vertical permeability in till is controlled largely by factors influencing secondary porosity, such as fractures (joints), root channels, sand seams, etc. Fractures may also interconnect the sand-and-gravel lenses.

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.

Diagnostic features:

- Usually defined texturally or grain-sized as a silty clay or clayey silt. May have significant proportion of fine to coarse sand and gravel, pebbles, or cobbles surrounded by a matrix of finer-grained materials.
- Typically lacks bedding, sorting, and laminations.
- Highly compacted, massive, and dense (lodgment till), ranging to more loosely compacted, friable, and disaggregates relatively easily (ablation or highly-weathered till).
- Important to note structure (e.g., massive, blocky, prismatic).
- Important to note moisture content (e.g., damp, moist, sticky, plastic, saturated).

Weathered exposure of clay-rich glacial till containing occasional pebbles, cobbles, and boulders (Hamilton County).

General features:
- Typically silty to clayey, containing sand in matrix and pebbles or cobbles.
- Gray where unoxidized; brown where weathered; mottled colors may represent variable water table conditions.

Stratigraphic context:
- Typically the uppermost surficial unit.
- Encountered in buried valleys to depth up to 400 ft in central Ohio.

Lithologic variations:
- In central Ohio, uppermost till is more loamy (silty to sandy) mix south of the Powell end moraine. North of Powell Moraine, uppermost till is more clayey and sand content lower.
- Generally more compacted and pebbly with depth. Proportions of carbonate materials within the matrix and pebble content of the till change sharply across the middle of central Ohio as bedrock changes from sandstone, shale, and siltstone to limestone and dolomite.

Weathering characteristics:
- Important to note weathering characteristics, degree of oxidation, mottling of colors, presence of fractures and joints, rotting of pebbles, presence of secondary carbonate or gypsum. Degree of weathering is important in determining hydrogeologic properties of the material, including permeability. Look for ghosts or "rotting" pebbles as these can skew results of a textural analysis.

Geologic hazards:
- Slumping may occur in saturated tills with high water tables; building constraints based upon such conditions include suitability for basements, foundations, septic systems, leach fields, etc.

Hydrogeologic properties:
- Typically not considered to be an aquifer. Historically, farms used wells excavated into weathered till as a seasonal source of water. Monitor wells installed in the saturated zone typically will maintain water.
- Most wells in till tap various interbedded lenses, seams, or bodies of sand. Size, nature, and geometry of these sand bodies can vary significantly, as does corresponding yield. Yields for sand bodies vary from 3 gpm to over 500 gpm.
- Recharge and water movement though till varies. Till is generally viewed as impermeable and comprising an aquitard. Research shows recharge and water movement occurs particularly in weathered, fractured till. Lab tests show permeability of 10^{-7}–10^{-9} cm/sec^2, whereas *in situ* tests based on slug tests; long-term, low-yield pumping tests; etc. may reveal permeabilities of 10^{-5}cm/sec^2.

Cuyahoga Formation

Rocks forming the Mississippian Cuyahoga Formation were deposited in marginal marine, deltaic, or fluvial depositional environments producing a complex relationship of intertonguing and intergradational conglomerates, sandstones, siltstones, and shales. These sediments were eroded from the Devonian-age highlands and the Catskill and Pocono deltas to the east. Rivers and streams transported the eroded sediments into the marginal marine and newly forming deltas of Ohio during the Mississippian Period.

The Cuyahoga Formation, and overlying Logan Formation, occur along a 1- to 50-mile (1.6- to 80-km) wide, southwest-to-northeast oriented, outcrop belt that extends from Portsmouth, through Newark, Mansfield, Wooster, Akron, Warren, and into northwestern Pennsylvania. The Cuyahoga ranges in thickness from 50- to 650-feet (15- to 198-m) and was first named for exposures along the Cuyahoga River between Akron and Cleveland in 1870. Historically, Cuyahoga Formation shale was mined for the manufacture of drain tile and paving, face, and hollow bricks, and sandstone from the formation was quarried for high-quality dimension stone.

Diagnostic features:
- 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.
- Sparsely fossiliferous with local intervals of highly fossiliferous rocks.

Stratigraphic context:
- Underlain by Sunbury Shale.

Weathered and heavily gullied exposure of the shale-rich Cuyahoga Formation along U.S. Route 23 in Scioto County.

- Overlain by Logan Formation.
- Similar unit: Bedford Shale.

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

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

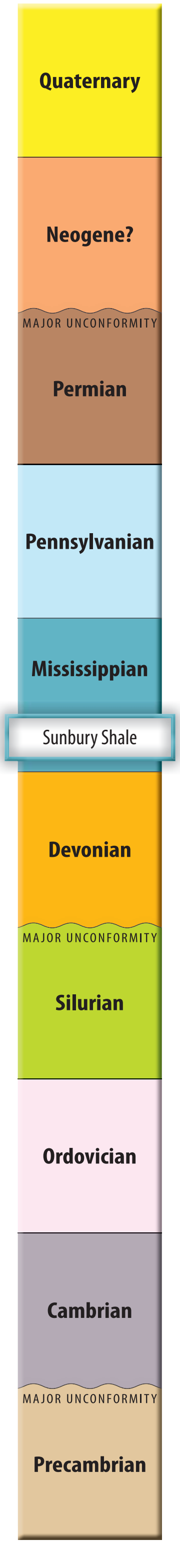
Economic geology:
- Cuyahoga shale deposits are mined for production of bricks and other clay products.
- Sandstone quarried for dimension stone, crushed or broken stone, glass sand, and other industrial uses.

Lithologic variations:
- Along the outcrop belt of the Cuyahoga, some of the distinctive stratigraphic intervals have been recognized as members, including: in southern Ohio, the Henley Shale, Portsmouth Shale, and Buena Vista Sandstone Members; in central Ohio, the Black Hand Member; and in northeastern Ohio, the Shenango Sandstone and Shale Member.

Scenic geology:
- The Black Hand Member of the Cuyahoga Formation is the best-known unit for forming waterfalls, cliff-lined gorges, and rock-shelter caves.
- Exposures of the Black Hand Member 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.

Hydrogeologic properties:
- Poor to moderate aquifer capable of supplying the needs of households and small farms.
- Average yield for shale and siltstone units is 3 to 10 gpm with a maximum yield of about 15 gpm.
- Average yield for the sandstone is 10–15 gpm with a maximum yield of about 25 gpm.
- Yield varies considerably along outcrop belt depending upon the relative proportion of shale, siltstone, and sandstone and the abundance of fractures and joints intersecting bedding planes.
- Aquifer rating ranges from 3 to 5 depending upon the proportion of shale and siltstone to sandstone.
- Hydraulic conductivity ranges from 1–100 gpd/ft^2 to 100–300 gpd/ft^2.

Sunbury Shale



The Mississippian Sunbury Shale is the uppermost of three major tongues of organic-rich, black shale deposited in central Ohio. Like the Ohio Shale, the Sunbury was deposited in a shallow to moderately deep tropical sea with limited oxygen in the water column and sea floor sediments lacking oxygen. Thick stratigraphic sequences of organic-rich, black shale accumulate in oxygen-poor environments because bacteria and burrowing and bottom dwelling organisms that normally decompose or consume any accumulating organic matter cannot live in anoxic conditions.

The Sunbury is mainly buried under Quaternary sediments along a 1- to 5-mile, north–south outcrop belt through central and northern Ohio. In southern Huron County, the Sunbury intertongues and intergrades into the basal Cuyahoga Formation. 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 feet (9 to 27 m) and was named for Sunbury, Ohio, where the unit was first described in 1878.

Diagnostic features:
- Brownish black.
- Carbonaceous.
- Petroliferous odor.

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

Stratigraphic context:
- Underlain by Berea Sandstone.
- Overlain by Cuyahoga Formation.
- Similar units: Cleveland Shale Member of the Ohio Shale; Huron Shale Member of the Ohio Shale.

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

Lithologic variations:
- Brownish-black, laminated, carbonaceous shales characterizing the Sunbury are remarkably uniform in character along the outcrop belt.

Weathering characteristics:
- The Sunbury weathers from dark brown and black to a gray brown to gray.
- High iron content in some beds result in rust-colored groundwater and staining on the Sunbury Shale and underlying Berea Sandstone.
- Repeated cycles of wetting/drying and freeze/thaw result in rapid breakdown.
- In rock cuts, weathered shale forms loose talus slopes.

Economic geology:
- Natural gas source rock and reservoir in the subsurface of northeastern and eastern Ohio.
- Potential source of petroleum.

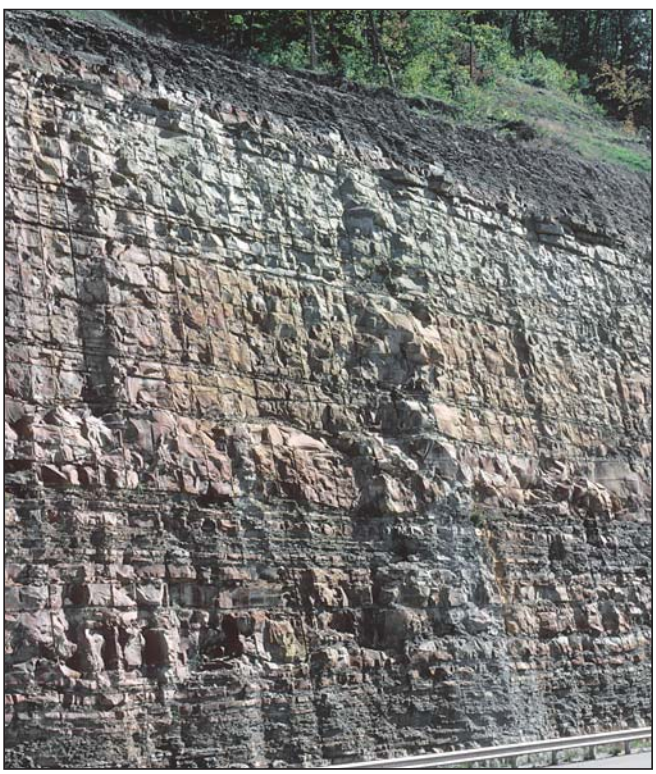
Geologic Hazards:
- Organic-rich Sunbury Shale is combustible; open burning near exposures of this unit is discouraged.
- The Sunbury contains small amounts of uranium and is a source of radon, a naturally occurring, radioactive gas that migrates into buildings from uranium-rich rocks; glacial sediments containing pieces of uranium-rich rocks; and soils derived from uranium-rich rocks. Radon is a known cancer-causing agent.

Hydrogeologic properties:

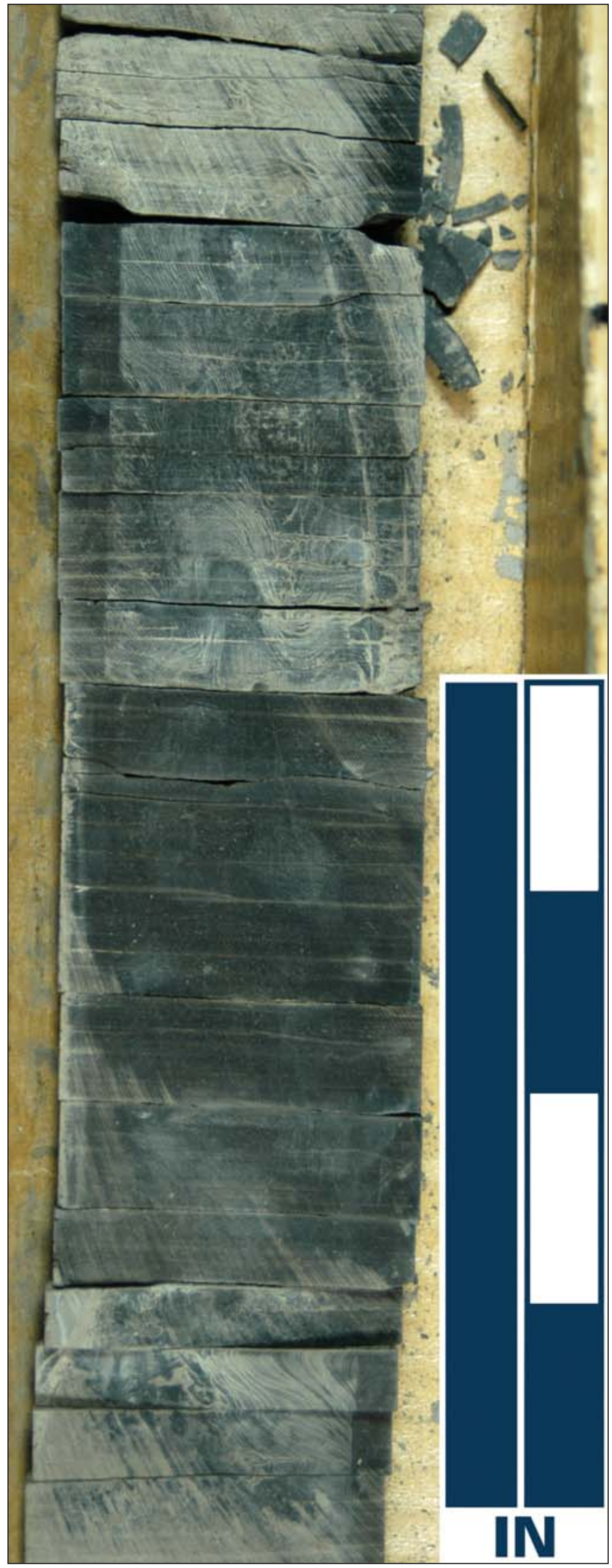
- Typically poor aquifer; generally suitable for limited household or small farm use.
- Average yield 3 to 5 gpm, with a maximum of roughly 10 gpm.
- Yield predominantly comes from a combination of joints and fractures as they intersect bedding planes.
- Best yields develop from the uppermost, weathered portion of the 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 and completed in the underlying Berea Sandstone. This allows the Sunbury Shale to be cased-off, if the water quality is objectionable.
- Wells drilled into the overlying Cuyahoga Formation may be extended into the Sunbury if extra well-bore storage is needed, as long as water quality is not objectionable.
- Aquifer rating ranges from 2 to 3.
- Hydraulic conductivity in the range of 1–100 gpd/ft^2.

Engineering Properties:

- Unconfined Compressive Strength—Slightly strong to strong.
- Slake Durability—Good to very good.
- Rippability—Non-rippable.



Contact between the thick sandstone beds of the Berea and the overlying black, organic-rich shales of the Sunbury. Note small landslide in the shale-rich Cuyahoga Formation exposed near the top of the road cut.



Berea Sandstone

The Berea Sandstone was deposited in deltas that built into the shallow tropical seas that covered Ohio in the Late Devonian and Early Mississippian. Like the sediments that formed the Bedford Shale, the sand comprising the Berea was transported by rivers and streams originating in the Acadian Highlands and Devonian-age Catskill and Pocono deltas to the east.

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-feet (15- to 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-feet (0.3- to 47-m) thick. Historically, the Berea was the principal source of grindstones and was used as dimension stone in many historic buildings throughout Ohio.

Diagnostic features:

- Dominance of sandstone over sandy shale.
- Fine to medium grain size.

General features:

- Bluish gray, gray, light brown.
- Thin to thick bedded.
- Prominent, widespread zone of soft-sediment deformation occurs in basal part of unit.

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

Stratigraphic context:
- Underlain by Bedford Shale.
- Overlain by Sunbury Shale.
- Similar units: upper part of Bedford Shale in southern Ohio.

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

Lithologic variations:
- Highly variable in thickness.
- Grain size decreases from north to south along the outcrop belt.
- The amount of interbedded shale increases in southern Ohio.

Weathering characteristics:
- Weathers to medium to dark brown.
- In road cuts, the Berea generally forms stable cliffs. The unit will produce rock falls if less resistant Bedford Shale is allowed to erode and undercut the overlying Berea.

Economic geology:
- Quarried for use as dimension stone, flagstone, aggregate, and riprap.
- In the subsurface of Ohio, Berea Sandstone reservoirs produce oil and natural gas.

Scenic geology:
- Erosion-resistant character produces many waterfalls and stream gorges statewide. In the Cleveland area, some of the more scenic include Brandywine Falls, Buttermilk Falls, Berea Falls, and Chagrin Falls.
- Allegheny Escarpment of southern Ohio.

Hydrogeologic properties:
- A moderate aquifer capable of supplying the water needs for households and small- to moderate-sized farms.
- Average yield is 5 to15 gpm in central Ohio with maximum yields ranging from 25 to 35 gpm.
- Maximum yields exceeding 50 gpm have been 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 are possible in the weathered portion of the unit.
- Sulfide may be a water quality factor.
- In eastern Ohio, the Berea is encountered at greater depths and may contain brine or petroleum.
- Aquifer rating is typically 4 with 5 reported for limited areas in northeastern Ohio.
- Hydraulic conductivity is in the range of 1–100 gpd/ft^2 to 100–300 gpd/ft^2.

Engineering Properties:
- Unconfined Compressive Strength—Strong.
- Slake Durability—Good to very good.
- Rippability—Non-rippable.

Bedford Shale

Deposited in a shallow tropical sea that covered much of Ohio in the Late Devonian and Early Mississippian, 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 increase in siltstone and sandstone beds in the upper part of the Bedford is the change from offshore marine deposition to the beginning of deltaic sedimentation.

The Bedford Shale is frequently concealed under undifferentiated Cenozoic-age deposits along much of the north–south outcrop belt that extends from the Ohio River, northward through the eastern Columbus suburbs, to 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 Bedford in Cuyahoga County. The Bedford ranges in thickness from 60 to 155 feet (18.3 to 47.2 m). Historically, bricks and drain tiles were manufactured from shale mined from the Bedford. In 2008 the Bedford was mined by two companies for the manufacture of bricks and other common clay products and construction materials.

Diagnostic features:

- Clayey shale.
- Intervals of red and brown shale in central and northern Ohio.
- Siltstone and sandstone beds increasing in abundance upward.

General features:

- Laminated to medium bedded.
- Gray, bluish gray, green, red, or brown.
- Ripple marks common in siltstone and sandstone beds.

Stratigraphic context:

- Underlain by Ohio Shale.
- Overlain by Berea Sandstone.
- Similar units: Olentangy Shale, some intervals of Chagrin Member of Ohio Shale, and Cuyahoga Formation.

Red Bedford Shale along Rocky Fork Creek. North side Havens Corners Rd., Gahanna, Franklin County.

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

Lithologic variations:
- In southern Ohio, the Bedford is 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 occur and the presence of siltstone and sandstone beds is restricted to the very top of the Bedford. A widespread zone of contorted and deformed bedding is present in the upper part of the Bedford and basal Berea Sandstone.

Weathering characteristics:
- The Bedford Shale rapidly weathers to light-gray or brown clay because of repeated wetting/drying and freeze/thaw cycles.
- The unit forms thick colluvial deposits on the steep hill slopes of southern Ohio.
- In northern Ohio, the Bedford is somewhat resistant to erosion and may form steep cliffs along the Lake Erie shoreline and some streams of the region.

Geologic hazards:
- Landslides commonly occur within the thick colluvial deposits that form from weathering of the Bedford Shale.
- Slabs and blocks of sandstone and siltstone commonly occur randomly oriented within Bedford colluvial deposits.

Hydrogeologic properties:
- Typically a very poor aquifer with minimal yields; rarely suitable for even domestic use.
- Average yields are typically less than 3 gpm and maximum yield under 5 gpm.
- Yields most likely obtained from fracture zones and the upper, weathered portion of this unit.
- For groundwater modeling purposes, this unit may be considered a lower confining unit or boundary unit when compared to overlying, sandstone-rich units.
- Aquifer rating ranges from 1 to 2.
- Hydraulic conductivity is in the range of 1–100 gpd ft^2

Engineering Properties:
- Unconfined Compressive Strength—Slightly strong to strong.
- Slake Durability—Poor to very good.
- Rippability—Non-rippable.

Ohio Shale

The Upper Devonian Ohio Shale was deposited in a shallow to moderately deep tropical sea with limited oxygen in both the water column and sea floor sediments. Thick stratigraphic sequences of organic-rich black shale accumulate in oxygen-poor environments because burrowing and bottom-dwelling organisms that normally decompose or consume any accumulating organic matter cannot live in anoxic conditions. The Ohio Shale contains two of the three major tongues of organic-rich black shale deposited in central Ohio.

The Ohio Shale forms the bedrock underlying Columbus and Cleveland. Mapped along a 5- to 20-mile (8- to 32-km) wide band, it 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 feet (76- to 152-m) and thickens to over 4,000 feet along the Ohio River in eastern Ohio. The unit was named after the hills adjacent to the Ohio River in southern Ohio. Historically, the Chagrin Shale Member of the Ohio Shale was used in the manufacture of face and paving bricks in northeast Ohio, and in central Ohio various intervals in the Ohio Shale were mined and mixed with the Olentangy Shale to make hollow drain tile and bricks.

Diagnostic features:
- Brownish black.
- Carbonaceous.
- Petroliferous odor.

General features:
- Laminated to thin bedded.
- Fissile partings.
- Iron-stained shale chips common in soils and colluvium weathered from the Ohio Shale.
- Sparsely fossiliferous but contains abundant organic material.

Stratigraphic context:
- Underlain by Olentangy Shale.
- Overlain by Bedford Shale.
- Similar units: Sunbury Shale.

Stratigraphic contacts:
- Sharp upper contact.
- Sharp to gradational lower contact intertonguing with Olentangy Shale.

Lithologic variations (in ascending stratigraphic order):
- Huron Shale Member—brownish-black, laminated, organic-rich shale with carbonate/siderite concretions.
- Chagrin Shale Member—dark- to medium-gray shale with interbedded siltstone and sandstone beds. The Three Lick Bed of the Chagrin Shale Member is a widespread marker horizon consisting of three distinct, gray shale beds separated by thin, brownish-black shale beds.
- Cleveland Shale Member—brownish-black, laminated, organic-rich shale; resembles the Huron Shale Member (without the carbonate/siderite concretions) and Sunbury Shale.

Weathering characteristics:
- The Ohio Shale weathers from dark brown and black to a gray-brown to gray.

Cleveland Shale Member

- High iron content in some beds result in rust colored groundwater and staining of household fixtures.
- Repeated cycles of wetting/drying and freeze/thaw result in rapid break down of the shale.
- In rock cuts, weathered shale forms loose talus slopes.

Economic geology:
- Natural gas source rock and reservoir in southeastern Ohio and in the subsurface adjacent to the outcrop belt of central and northeastern Ohio.
- Potential source of petroleum.

Geologic hazards:
- Organic-rich members of the Ohio Shale are combustible; open burning near exposures of these members is discouraged.
- The Ohio Shale is uranium-rich in Ohio and is a source of radon. Radon is a naturally occurring, radioactive gas that migrates into buildings from uranium-rich rocks, glacial sediments containing abundant pieces of uranium-rich rocks, and soils. Radon is a known cancer-causing agent.

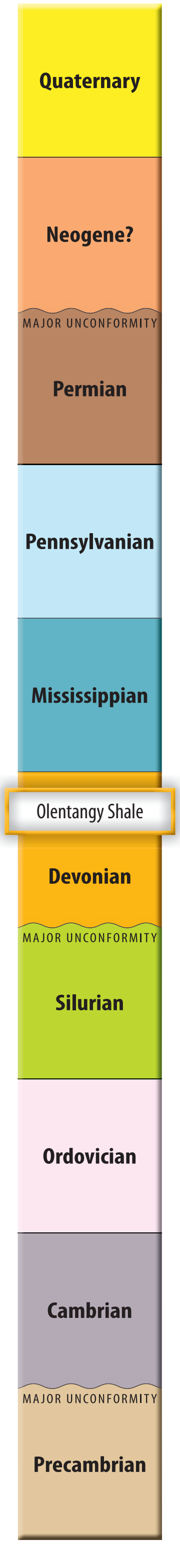
Hydrogeologic properties:
- Typically a poor aquifer; generally suitable for limited household or small farm use.
- Average yield is 3 to 5 gpm with a maximum yield of roughly 10 gpm.
- Yield predominantly comes from a combination of joints and fractures as they intersect bedding planes.
- Best yields are developed from the uppermost weathered portion of the 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 groundwater modeling purposes, this unit may be considered a lower confining unit or boundary unit when compared to overlying sandstone and shale units.
- Aquifer rating ranges from 2 to 3.
- Hydraulic conductivity is in the range of 1–100 gpd/ft^2.

Engineering Properties:
- Unconfined Compressive Strength—Slightly strong to strong.
- Slake Durability—Good to very good.
- Rippability—Non-rippable.

Historic exposures of the Ohio Shale along the banks of Alum Creek near the present-day bridge for U.S. Route 36 over Alum Creek Lake.

Chagrin Shale Member

Olentangy Shale



In the Olentangy Shale, the gradual change from shale interbedded with fossiliferous limestone to shale interbedded with brownish-black, organic-rich shales 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 is largely 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 feet (6 to 16.7 m). Historically, clay from the Olentangy was mined for use in manufacturing drainage tile and hollow bricks.

Diagnostic features:

- Gray to greenish-gray clay.
- Discontinuous beds and limestone nodules (lower portion).
- Thin beds of brownish-gray to brown shale (upper portion).

Type locality of the Olentangy Shale along the banks of the Olentangy River, south of Delaware, Ohio. 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.

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

Stratigraphic context:
- Underlain by Delaware Limestone.
- Overlain by Ohio Shale.
- Similar units: Bedford Shale.

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

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

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

Hydrogeologic properties:
- Typically poor aquifer with minimal yields; suitable for limited household and small farm usage.
- Average yield is 3 to 5 gpm, with a maximum of roughly 10 gpm.
- Yields provided by a 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 and Ohio shales have similar hydrogeologic properties and may be mapped together.
- Aquifer rating ranges from 2 to 3.
- Hydraulic conductivity in the range of 1–100 gpd/ft^2.

Engineering Properties:
- Unconfined Compressive Strength—Weak to slightly strong.
- Slake Durability—Very poor to poor.
- Rippability—Moderately rippable to non-rippable.

Delaware Limestone

The Delaware Limestone was deposited in tropical shallow seas, teeming with abundant marine life, during the Middle Devonian. Rocks of the Delaware are found in stream exposures and quarries in a 1- to 5-mile (1.6- to 8-km) wide band that extends from Columbus, Ohio, northward to Sandusky, Ohio. The Delaware is not present south of Columbus. The unit ranges in thickness from 0 to 45 feet (0 to 13 m) and is named for the exposures in the vicinity of Delaware, Ohio. Olentangy Indian Caverns occurs within the Delaware.

Diagnostic features:
- Shaley (argillaceous) limestone.
- Bluish gray to black chert nodules and layers.
- Petroliferous odor when broken.

General features:
- Gray to brown.
- Thin to thick bedded with shale partings.
- Fossiliferous.

Stratigraphic context:
- Underlain by Columbus Limestone.
- Overlain by Olentangy Shale.

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

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

Weathering characteristics:
- Weathers brown.
- Produces blocks, slabs, or pebbles of limestone, common in streams and glacial sediments.
- Solution enlargement along joints.

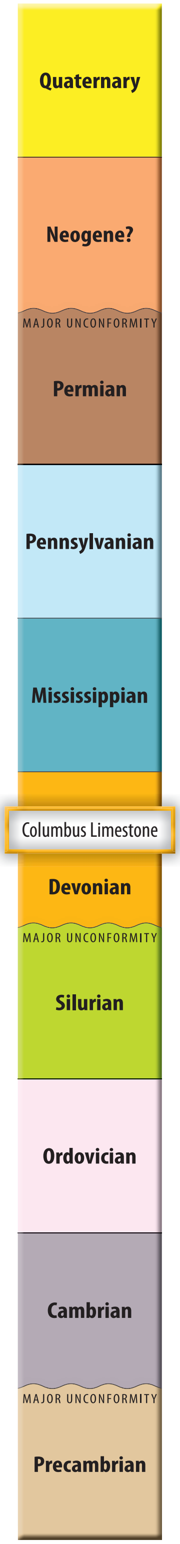
Economic geology:
- Quarried for over 100 years for dimension stone, crushed stone, agricultural lime, Portland and asphaltic cements, and use in construction and road resurfacing.

Geologic 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 the conduit for the rapid movement of surface water, potentially carrying sewage, animal wastes, and agricultural and industrial chemicals directly into the groundwater system. Rapid movement of pollutants into the groundwater system severely threatens potable water supplies.

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 Delaware tends to have higher yields because the unit is highly fractured and receives higher recharge.
- Yields tend to decrease where the unit is covered by thick overlying shale or glacial till, perhaps due to decreased recharge.
- The Delaware was evaluated as a massive limestone; aquifer ratings typically range 6–7.
- Hydraulic conductivity ranges from 100–300 gpd/ft^2 to 300–700 gpd/ft^2, depending upon fracturing.

Engineering Properties:
- Unconfined Compressive Strength—Very strong.
- Slake Durability—Very good.
- Rippability—Non-rippable.

Columbus Limestone



The Columbus Limestone 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-mile (1.6- to 8-km) wide band extending from southern Pickaway County, along the Scioto River valley in the Columbus region, northward to Sandusky, Ohio. The unit ranges in thickness from 0 to 105 feet (0 to 32 m) and is named for the exposures in the Columbus region.

Diagnostic features:
- Gray, fossiliferous limestone, upper $^{2}/_{3}$ of unit.
- Brown, finely crystalline dolomite, lower $^{1}/_{3}$ of unit.

General features:
- Fossiliferous limestone and dolomite.
- Gray to brown.
- Thick to massive bedding.
- Finely to coarsely crystalline.
- Occasional white to gray chert nodules.

Stratigraphic context:
- Underlain by Salina Group.
- Overlain by Delaware Limestone.

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

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

Weathering characteristics:
- The Columbus weathers to light gray or brown.
- In natural exposures and road cuts, the Columbus 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.

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 Statehouse in downtown Columbus and portions of many other buildings are constructed of the Delhi Member.

Scenic geology:
- Ohio Caverns, Champaign County.

Delhi Member

- Zane Cavern, Logan County.
- Seneca Caverns, Seneca County.
- Hayden Falls along Scioto River, Columbus.

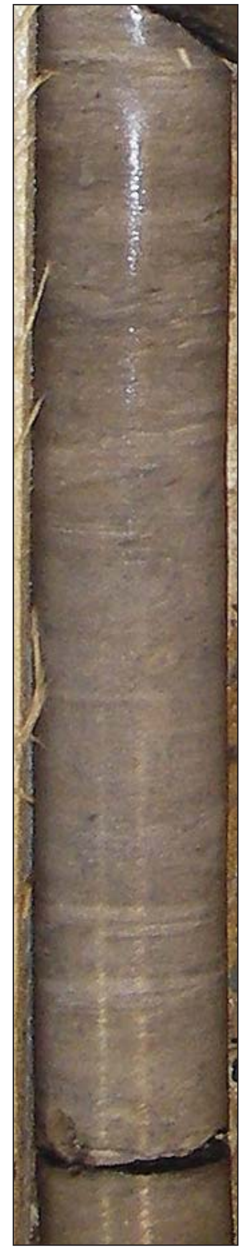
Geologic hazards:
- Dissolution of the Columbus can result in sinkholes opening or sudden collapse of caves resulting in land surface subsidence. If buildings, roads, or bridges are built over these features, foundation failure may result in damage or destruction of these structures.
- Sinkholes provide 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 these pollutants into the ground-water system poses a severe threat to potable water supplies.

Hydrogeologic properties:
- Moderate to excellent aquifer capable of supplying domestic and farm needs.
- Average yield for domestic wells completed in this aquifer range from 15 to 35 gpm.
- 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 exceeding 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.
- The Columbus is usually defined as a solution limestone and aquifer ratings range from 7 to 8.
- The Columbus was evaluated as a karst limestone in northern Ohio, and aquifer ratings range from 9 to 10.
- Hydraulic conductivity ranges from 700–1,000 gpd/ft^2 to 1,000–2,000 gpd/ft^2, depending upon degree of solutioning and karst development.

Engineering Properties:

Delhi Member
- Unconfined Compressive Strength—strong to very strong.
- Slake Durability—Very good.
- Rippability—Non-rippable.

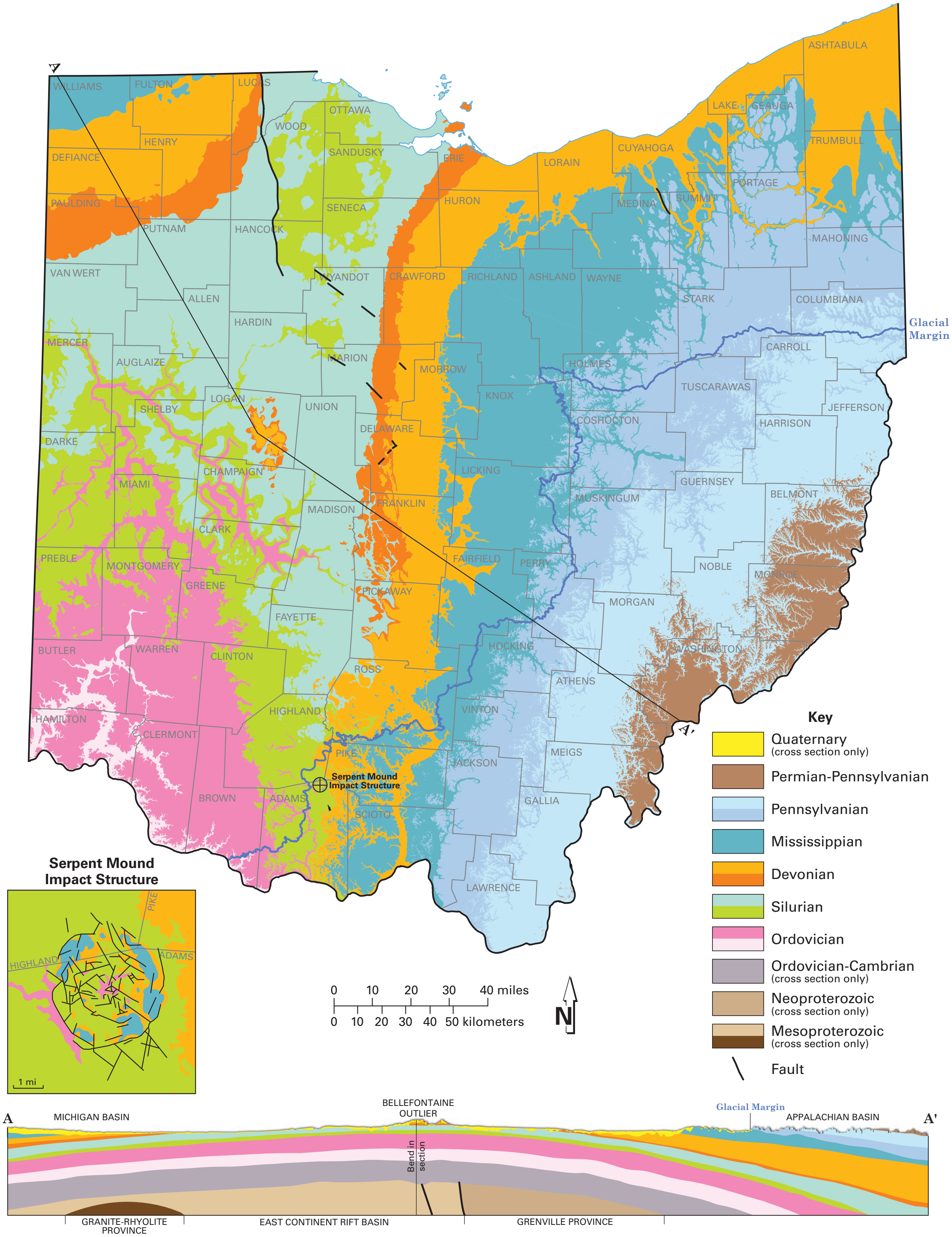
Bellepoint Member
- Unconfined Compressive Strength—Moderately strong to very strong.
- Slake Durability—Very good.
- Rippability—Non-rippable.



Bellepoint Member

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

Bedrock Geologic Map of Ohio



This map is a generalization of the Bedrock Geologic Map of Ohio (Slucher and others, 2006)—the first statewide 1:500,000-scale bedrock-geology map compiled by the Ohio Division of Geological Survey since 1920 and the first to properly portray the bedrock geology that exists beneath the extensive deposits of Quaternary sediments that cover much of the bedrock in the state. Overall, the bedrock geology of Ohio consists of flat lying to gently dipping carbonate, siliciclastic, evaporite, and organoclastic strata of sedimentary origin that range in age from Upper Ordovician to Upper Carboniferous-Lower Permian. At depth, as illustrated in the cross section, older sedimentary, igneous, and metamorphic rocks that range from Lower Ordovician to Mesoproterozoic in age occur. At the surface, an irregular veneer of mainly unconsolidated Quaternary sediments conceal most bedrock units occurring northward and westward of the glacial margin.

Strata of the Ordovician System are the oldest exposed rocks in Ohio and consist mainly of alternating shale and limestone sequences. Silurian System strata are mostly dolomites with lesser amounts of shale. Rocks of the Devonian System consist of two contrasting types. Lower and Middle Devonian-age strata are mainly carbonate rocks whereas Upper Devonian-age rocks consist mostly of clastic rocks. In Champaign and Logan Counties, Devonian rocks occur on a small erosional remnant referred to as the Bellefontaine Outlier by geologists. Coincidentally, the highest topographic point in Ohio (Campbell Hill–1,549 feet above sea level) occurs also in this area.

The Carboniferous System is divided into two Subsystems, the Mississippian and Pennsylvanian. Mississippian strata are mostly shales and sandstones that occur locally in various proportions. Pennsylvanian strata consist mainly of a diverse array of alternating sandstones, siltstones, shales, mudstones, limestones, and underclays; economic coal beds occur also in portions of this sequence. The youngest interval of sedimentary rocks in Ohio, the Dunkard Group, occurs only in southeastern Ohio and consists of strata similar in composition to the underlying Upper Pennsylvanian-age rocks; however, the age of the Dunkard Group has been debated since the late 1800s. Dunkard strata contain a well-studied late Pennsylvanian-age assemblage of plant fossils with infrequent early Permian-age forms. Yet, fossil plant spores found in coal beds in the interval only support a late, but not latest Pennsylvanian age. Thus, until more definitive fossils are found, geologist are unable to determine the exact age of the Dunkard Group beyond a combined Permian-Pennsylvanian age assignment.

In west-central Ohio, the ancient Teays River system extended across much of Ohio during the late Neogene to early Quaternary Periods and sculptured an extensive network of deeply dissected valleys into the bedrock surface. The spatial configuration of many geologic units on this map clearly reflects the major channel networks of these former drainage systems. Also, four major regional structural geology elements affect the spatial distribution of rocks in Ohio: the Appalachian and Michigan basins, and the Cincinnati and Findlay arches which occur between the two basins. Locally, several high-angle normal faults displace rocks in the state.

The Serpent Mound Impact Structure in southern Ohio is a circular area of deformed and broken rocks that is approximately four and one-half miles in diameter. Recent investigations indicate the feature is the result of a meteorite impact believed to have occurred between 256 and 330 million years ago.

Cross section A-A' traverses Ohio from the northwest to the southeast and intersects the southern portion of the Michigan Basin, the area between the Cincinnati and Findlay arches, and the western Appalachian Basin, respectively. The stratigraphic units shown in this profile illustrate the broad, arching geometric distortion to the bedrock in Ohio created mainly by periods of tectonic subsidence within these regional structural basins. For specific details on the various rock units, economic commodities, and geologic hazards within Ohio, see either the printed or digital version of the Bedrock Geologic Map of Ohio (Slucher and others, 2006).

Quaternary (about 1.8 million years ago to present)—Unconsolidated sediments: till, gravel, sand, silt, clay, and organic debris. Continental origin. (Shown in cross section only)

Period of widespread erosion

Permian and Pennsylvanian (about 298 to 302 million years ago)—Sedimentary rocks: mainly shale, sandstone, siltstone, mudstone, and minor coal. Continental origin.

Pennsylvanian (about 302 to 307 million years ago) Sedimentary rocks: mainly shale, sandstone, siltstone, mudstone, limestone, and some coal. Continental and marine origin.

Pennsylvanian (about 307 to 318 million years ago)—Sedimentary rocks: mainly sandstone, siltstone, shale, and conglomerate, with some coal and limestone. Deltaic and marine origin.

Period of widespread erosion

Mississippian (about 322 to 359 million years ago)—Sedimentary rocks: sandstone, shale, siltstone, conglomerate, and minor limestone. Marine to marginal marine origin.

Devonian (about 359 to 385 million years ago)—Sedimentary rocks: mainly shale and siltstone with some sandstone. Marine to marginal marine origin.

Devonian (about 385 to 407 million years ago)—Sedimentary rocks: mainly limestone and dolomite with some shale, and minor sandstone. Marine and eolian origin.

Period of widespread erosion

Silurian (about 416 to 423 million years ago)—Sedimentary rocks: dolomite, anhydrite, gypsum, salt, and shale. Marine and restricted marine origin.

Silurian (about 423 to 435 million years ago)—Sedimentary rocks: dolomite and shale with some limestone. Marine origin.

Period of widespread erosion

Ordovician (about 446 to 450 million years ago)—Sedimentary rocks: shale and limestone. Marine origin.

Ordovician (about 450 to 460 million years ago)—Sedimentary rocks: limestone and shale. Marine origin.

Period of widespread erosion

Ordovician and Cambrian (about 486 to 510 million years ago)—Sedimentary rocks: mainly dolomite, sandstone, shale, with minor limestone. Marine origin. (Shown in cross section only)

Period of widespread erosion

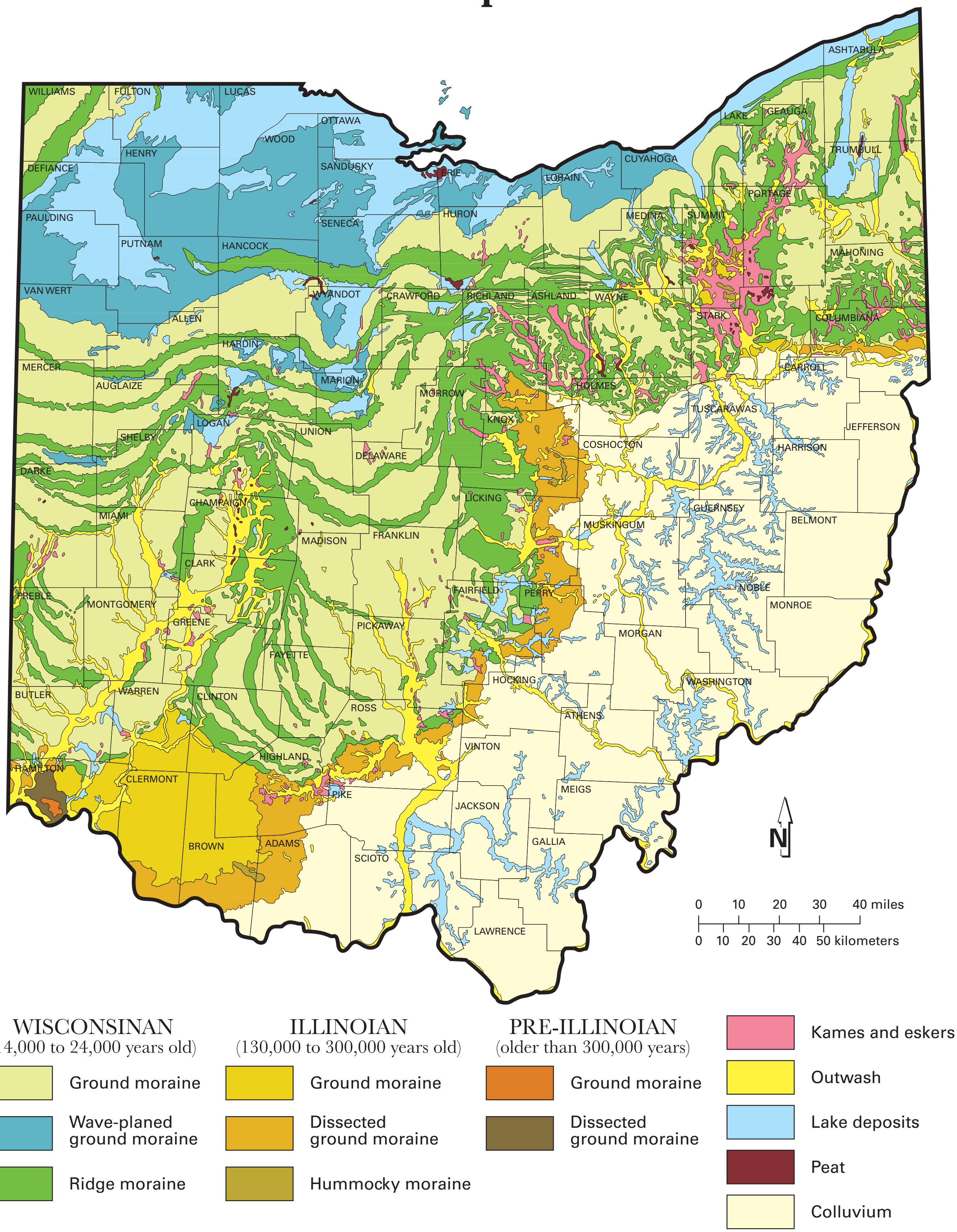
Neoproterozoic (between 900 million and 1 billion years ago)—Metamorphic rocks: gneiss, schist, amphibolite, and marble; and igneous rocks: granite. Form during collision of tectonic plates. (Shown in cross section only)

Mesoproterozoic (between 1.0 and 1.2 billion years ago)—Sedimentary rocks: sandstone and siltstone; and igneous rocks: basalt and rhyolite. Form during rifting of continental landmass. (Shown in cross section only)

Period of widespread erosion

Mesoproterozoic (between 1.45 and 1.52 billion years ago)—Igneous rocks: granite and rhyolite. Formed during crustal evolution and differentiation. (Shown in cross section only)

Glacial Map of Ohio



Although difficult to imagine, Ohio has at various times in the recent geologic past (within the last 1.6 million years) had three-quarters of its surface covered by vast sheets of ice perhaps as much as 1 mile thick. This period of geologic history is referred to as the Pleistocene Epoch or, more commonly, the Ice Age, although there is abundant evidence that Earth has experienced numerous other "ice ages" throughout its 4.6 billion years of existence.

Ice Age glaciers invading Ohio formed in central Canada in response to climatic conditions that allowed massive buildups of ice. Because of their great thickness, these ice masses flowed under their own weight and ultimately moved south as far as northern Kentucky. Oxygen-isotope analysis of deep-sea sediments indicates that more than a dozen glaciations occurred during the Pleistocene. Portions of Ohio were covered by the last two glaciations, known as the Wisconsinan (the most recent) and the Illinoian (older), and by an undetermined number of pre-Illinoian glaciations.

Because each major advance covered deposits left by the previous ice sheets, pre-Illinoian deposits are exposed only in extreme southwestern Ohio in the vicinity of Cincinnati. Although the Illinoian ice sheet covered the largest area of Ohio, its deposits are at the surface only in a narrow band from Cincinnati northeast to the Ohio-Pennsylvania border. Most features shown on the map of glacial deposits of Ohio are the result of the most recent or Wisconsinan-age glaciers.

The material left by the ice sheets consists of mixtures of clay, sand, gravel, and boulders in various types of deposits of different modes of origin. Rock debris carried along by the glacier was deposited in two principal fashions, either directly by the ice or by meltwater from the glacier. Some material reaching the ice front was carried away by streams of meltwater to form outwash deposits. Material deposited by water on and under the surface of the glacier itself formed features called kames and eskers, which are recognized by characteristic shapes and composition. A distinctive characteristic of glacial sediments that have been deposited by water is that the material was sorted by the water that carried it. Thus, outwash, kame, and esker deposits normally consist of sand and gravel. The large boulder-size particles were left behind and the smaller clay-size particles were carried far away, leaving the intermediate gravel- and sand-size material along the stream courses.

Material deposited directly from the ice was not sorted and ranges from clay to boulders. Some of the debris was deposited as ridges parallel to the edge of the glacier, forming terminal or end moraines, which mark the position of the ice when it paused for a period of time, possibly a few hundred years. When the entire ice sheet receded because of melting, much of the ground-up rock material still held in the ice was deposited on the surface as ground moraine. The oldest morainic deposits in Ohio are of Illinoian and pre-Illinoian age. Erosion has significantly reduced these deposits along the glacial boundary, leaving only isolated remnants that have been mapped as dissected ground moraine and hummocky moraine.

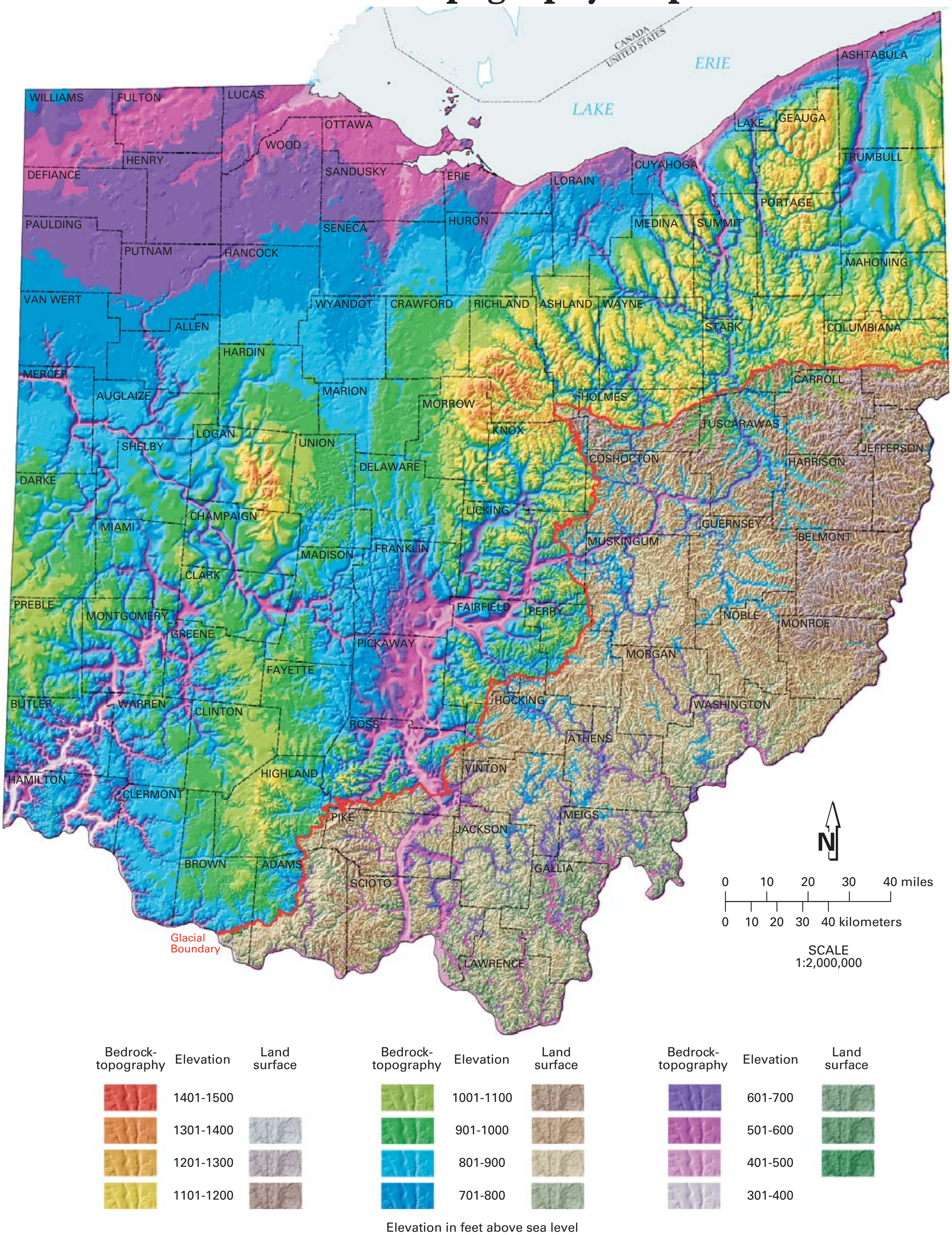
Many glacial lakes were formed in Ohio during the Ice Age. Lake deposits are primarily fine-grained clay- and silt-size sediments. The most extensive area of lake deposits is in northern Ohio bordering Lake Erie. These deposits, and adjacent areas of wave-planed ground moraine, are the result of sedimentation and erosion by large lakes that occupied the Erie basin as Wisconsinan-age ice retreated into Canada. Other lake deposits accumulated in stream valleys whose outlets were temporarily dammed by ice or outwash. Many outwash-dammed lake deposits are present in southeastern Ohio far beyond the glacial boundary. Peat deposits are associated with many lake deposits and formed through the accumulation of partially decayed aquatic vegetation in oxygen-depleted, stagnant water.

The term glacial drift commonly is used to refer to any material deposited directly (e.g., ground moraine) or indirectly (e.g., outwash) by a glacier. Because the ice that invaded Ohio came from Canada, it carried in many rock types not found in Ohio. Pebbles, cobbles, and boulders of these foreign rock types are called erratics. Rock collecting in areas of glacial drift may yield granite, gneiss, trace quantities of gold, and very rarely, diamonds. Most rocks found in glacial deposits, however, are types native to Ohio.

Certain deposits left behind by the ice are of economic importance, particularly sand and gravel, clay, and peat. Sand and gravel that have been sorted by meltwater generally occur as kames or eskers or as outwash along major drainageways. Sand and gravel are vital to Ohio's construction industry. Futhermore, outwash deposits are among the state's most productive sources of ground water.

Glacial clay is used in cement and for common clay products (particularly brick). The minor quantities of peat produced in the state are used mainly for mulch and soil conditioning.

Shaded Bedrock-Topography Map of Ohio



The shaded bedrock-topography map of Ohio depicts the configuration and elevation of the bedrock surface. In southeastern Ohio, the bedrock surface coincides with present-day land-surface topography and is depicted by earth-tone hues to represent elevation intervals. In glaciated western and northern Ohio, the bedrock surface is buried under mainly glacial sediments that can be several-hundred-feet thick. The land surface in this region was smoothed by glaciation (figure 1) and masks a complexly dissected, underlying bedrock surface. This dissected bedrock surface is the result of erosion before, during, and after glaciation. Spectral hues depict elevation intervals on the buried-bedrock surface and show the bedrock surface as if the overlying glacial sediment were removed.

Prior to and during glaciation, the north-flowing Teays River system dominated surface-water drainage patterns in western and southern Ohio (figure 2). Water flow direction in the main Teays valley was north from Wheelersburg (Scioto County) to Circleville (Pickaway County) and then northwest to Mercer County where the Teays Valley exited the state. Remnants of the Teays Valley are distinct on the present land surface in southern Ohio and form a continuous valley on the buried-bedrock surface across western Ohio. Modern rivers and streams still occupy portions of this valley system. Water flow in the Teays River system was disrupted by early glaciations as southward-advancing glaciers blocked outlets of the north-flowing river system. Drainageways, both large and small, were abandoned or filled with sediment as ice advanced and retreated.

In northwestern Ohio, the generally smooth buried-bedrock surface is the result of repeated scouring by glacial ice advancing westward out of the Lake Erie basin. Another distinctly scoured bedrock surface is in the Grand River Lobe (figure 2) in northeastern Ohio where smooth north-south trending valleys mirror ice-flow direction. South of the scour-dominated surface of northern Ohio, the bedrock surface has been sculpted by water to create a distinct drainage pattern (figure 2). Large volumes of glacial meltwater eroded the bedrock surface, widening and deepening existing valleys of the Teays system and creating new valleys. Some modern rivers and creeks flow in unusually wide valleys; evidence that far greater volumes of water generated from melting glaciers once flowed in these valleys. Flow direction in other valleys has been reversed as glacial ice or glacial sediments blocked formerly northward and westward flowing streams.

Southeastern Ohio is unglaciated and devoid of ice-deposited sediment (glacial till). However, many river valleys in southeast Ohio did carry glacial meltwater away from the ice front and toward the Ohio River. In the process, many of these valleys were at times made deeper by the erosive force of fast-flowing meltwater streams, and at other times partially filled with sediment. Some valleys in unglaciated Ohio contain thick deposits of clay and silt that accumulated on the bottoms of lakes that formed when glacial ice blocked the flow of rivers or when rapidly accumulating meltwater sediments blocked the mouths of rivers.

This map is one of the results of a 7-year effort by the ODNR, Division of Geological Survey to map the bedrock geology of Ohio. Bedrock-topography maps are essential to producing accurate bedrock-geology maps of glaciated Ohio and of partially buried valleys beyond the glacial limit. Bedrock-topography maps were created for all 788 7.5-minute topographic quadrangles in the state and are available from the Division's Geologic Records Center. Some pre-existing county bedrock-topography maps (1:62,500 scale) and data were photographically enlarged to 1:24,000 scale, revised, and utilized in the compilation of 1:24,000-scale, bedrock-topography maps. Data concentration and contour intervals on the original maps vary widely across the state in response to changing geologic and topographic conditions. Data consists mainly of water-well logs on file at the ODNR, Division of Water, supplemented by outcrop data, Ohio Department of Transportation bridge-boring data, and oil-and-gas-well data.

Elevation contours and over 158,000 data points from the 788 bedrock-topography maps were digitized and compiled for the glaciated portions of the state and for the major valleys beyond the glacial boundary containing significant accumulations of sediment deposited during and after glaciation. The bedrock-topography contours were digitally converted in the ARC GIS environment into a continuous grid model (60 meter grid spacing). This surface was shaded from the northwest slightly above the horizon to produce the appearance of a three-dimensional surface.

The land surface represents the topography of the bedrock surface in southeastern Ohio (excluding valleys beyond the glacial boundary) and in some glaciated areas near the glacial limit where meltwater sediments are thin or absent. Land-surface topography is based largely on data derived from the U.S. Geological Survey's National Elevation Dataset (30 meter grid spacing).

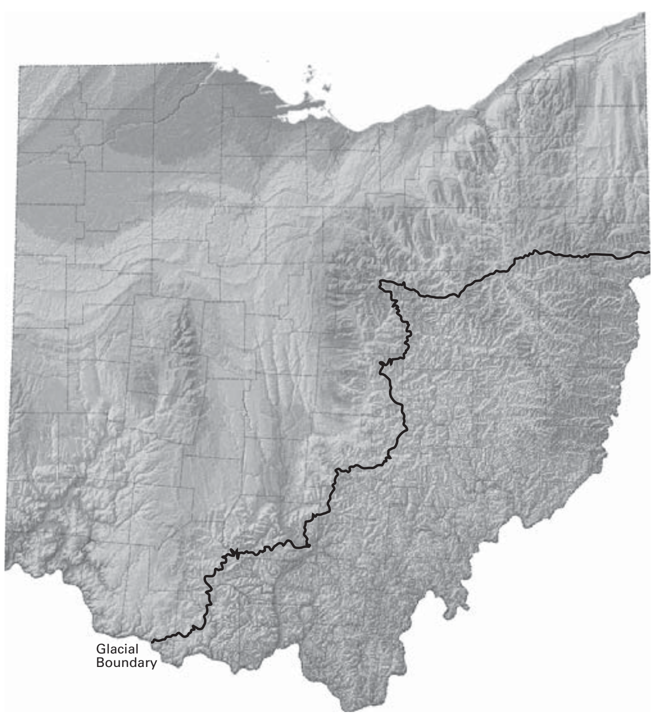


FIGURE 1.—Shaded elevation map of Ohio with the glacial boundary. Note the smooth landscape of glaciated northern and western Ohio compared to the high-relief landscape of unglaciated southeastern Ohio.

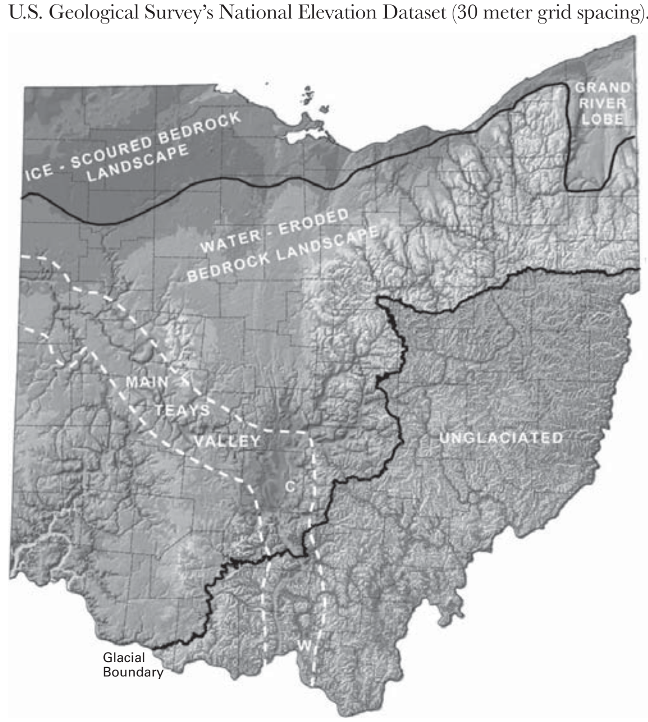
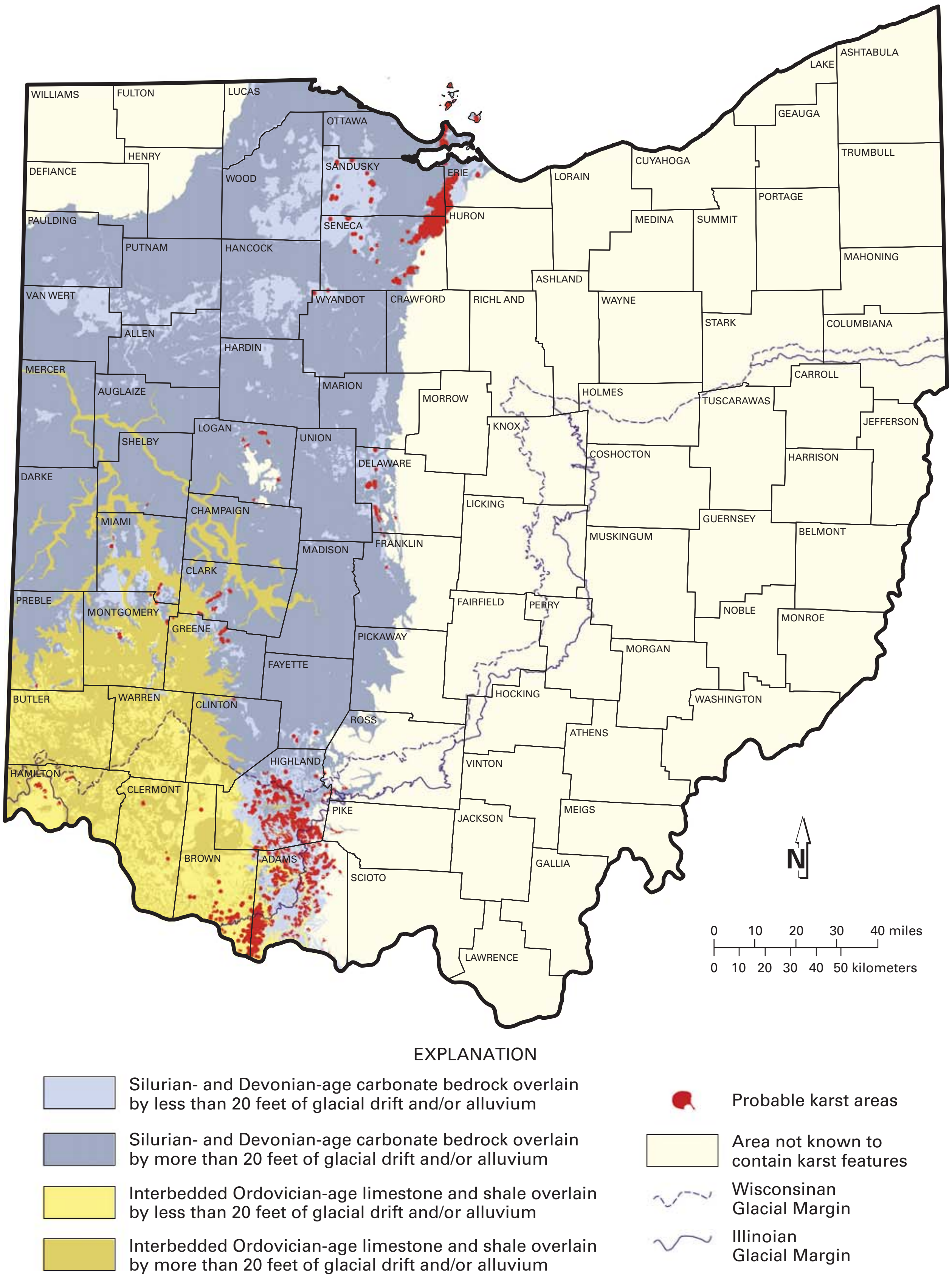


FIGURE 2.—Bedrock-topography map of Ohio showing the extent of the main Teays valley, the unglaciated portion of the state, and the ice-scoured and water-eroded portions of glaciated Ohio (C = Circleville, W = Wheelersburg).

Known and Probable Karst in Ohio



Karst is a landform that develops on or in limestone, dolomite, or gypsum by dissolution and that is characterized by the presence of characteristic features such as sinkholes, underground (or internal) drainage through solution-enlarged fractures (joints), and caves. While karst landforms and features are commonly striking in appearance and host to some of Ohio's rarest fauna, they also can be a significant geologic hazard. Sudden collapse of an underground cavern or opening of a sinkhole can cause surface subsidence that can severely damage or destroy any overlying structure such as a building, bridge, or highway. Improperly backfilled sinkholes are prone to both gradual and sudden subsidence, and similarly threaten overlying structures. Sewage, animal wastes, and agricultural, industrial, and ice-control chemicals entering sinkholes as surface drainage are conducted directly and quickly into the ground-water system, thereby posing a severe threat to potable water supplies. Because of such risks, many of the nation's state geological surveys, and the U.S. Geological Survey, are actively mapping and characterizing the nation's karst regions.

The five most significant Ohio karst regions are described below.

BELLEVUE-CASTALIA KARST PLAIN

The Bellevue-Castalia Karst Plain occupies portions of northeastern Seneca County, northwestern Huron County, southeastern Sandusky County, and western Erie County. Adjacent karst terrain in portions of Ottawa County, including the Marblehead Peninsula, Catawba Island, and the Bass Islands, is related in geologic origin to the Bellevue-Castalia Karst Plain. The area is underlain by up to 175 feet of Devonian carbonates (Delaware Limestone, Columbus Limestone, Lucas Dolomite, and Amherstburg Dolomite) overlying Silurian dolomite, anhydrite, and gypsum of the Bass Islands Dolomite and Salina Group.

The Bellevue-Castalia Karst Plain is believed to contain more sinkholes than any of Ohio's other karst regions. Huge, irregularly shaped, closed depressions up to 270 acres in size and commonly enclosing smaller, circular-closed depressions 5 to 80 feet in diameter pockmark the land between the village of Flat Rock in northeastern Seneca County and Castalia in western Erie County. Surface drainage on the plain is very limited, and many of the streams which are present disappear into sinkholes called swallow holes.

Karst in the Bellevue-Castalia and Lake Erie islands region is due to collapse of overlying carbonate rocks into voids created by the dissolution and removal of underlying gypsum beds. According to Verber and Stansbery (1953, Ohio Journal of Science), ground water is introduced into Salina Group anhydrite ($CaSO4$) through pores and fractures in the overlying carbonates. The anhydrite chemically reacts with the water to form gypsum ($CaSO4 \cdot 2H2O$), undergoing a 33 to 62 percent increase in volume in the process. This swelling lifts overlying strata, thereby opening fractures and creating massive passageways for conduction of greater volumes of ground water through the Silurian Bass Islands Dolomite and into underlying Salina Group strata. Gypsum, being readily soluble in water, is dissolved, creating huge voids. Overlying carbonates then collapse or break down, leaving surface depressions similar to those resulting from roof failure of an underground mine.

DISSECTED NIAGARA ESCARPMENT

The dissected Niagara Escarpment of southwestern Ohio includes the largest single area of karst terrain in the state and the greatest number of surveyed caves. It also is estimated to include the second-largest number of sinkholes in the state. The area is underlain by Silurian rocks of the Peebles Dolomite, Lilley Formation, Bisher Formation, Estill Shale, and Noland Formation in Adams, Highland, and Clinton Counties and the Cedarville Dolomite, Springfield Dolomite, Euphemia Dolomite, Massie Shale, Laurel Dolomite, Osgood Shale, and Dayton Formation in Greene, Clark, Miami, Montgomery, and Preble Counties. The Peebles-Lilley-Bisher sequence and the Cedarville-Springfield-Euphemia sequence constitute the Lockport Group.

Most karst features along the Niagara Escarpment in southwestern Ohio are developed in Lockport Group strata. More than 100 sinkholes and caves developed in the Lockport have been documented in the field, and more than 1,000 probable sinkholes in the Lockport have been identified on aerial photographs, soils maps, and topographic maps. As with most karst terrain, sinkholes developed on the Niagara Escarpment commonly show linear orientations aligned with prevailing joint trends in the area. The greatest concentration of sinkholes on the escarpment is south of the Wisconsinan glacial border in southern Highland and Adams Counties, where highly dissected ridges capped by Silurian carbonate rocks rise 150 to 200 feet above surrounding drainage. Illinoian till in these areas is thin to absent, and soils are completely leached with respect to calcium and calcium-magnesium carbonate. Such geologic settings are ideal for active karst processes, as downward-percolating, naturally acidic rain water is not buffered until it has dissolved some of the underlying carbonate bedrock. Other significant karst features of the Niagara Escarpment include small caves in escarpment re-entrants created by the valleys of the Great Miami and Stillwater Rivers in Miami County.

BELLEFONTAINE OUTLIER

The Bellefontaine Outlier in Logan and northern Champaign Counties is an erosionally resistant "island" of Devonian carbonates capped by Ohio Shale and surrounded by a "sea" of Silurian strata. Though completely glaciated, the outlier was such an impediment to Ice Age glaciers that it repeatedly separated advancing ice sheets into two glacial lobes—the Miami Lobe on the west and the Scioto Lobe on the east. Most Ohioans recognize the outlier as the location of Campbell Hill—the highest point in the state at an elevation of 1,549 feet above mean sea level.

Although it is not known for having an especially well-developed karst terrain, the outlier is the location of Ohio's largest known cave, Ohio Caverns. The greatest sinkhole concentrations are present in McArthur and Rushcreek Townships of Logan County, where the density of sinkholes in some areas approaches 30 per square mile. Sinkholes here typically occur in upland areas of Devonian Lucas Dolomite or Columbus Limestone that are 30 to 50 feet or more above surrounding drainage and are covered by less than 20 feet of glacial drift and/or Ohio Shale.

SCIOTO AND OLENTANGY RIVER GORGES

The uplands adjacent to the gorges of the Scioto and Olentangy Rivers in northern Franklin and southern Delaware Counties include areas of well-developed, active karst terrain. These uplands also are among the most rapidly developing areas of the state, which means karst should be a consideration in site assessments for commercial and residential construction projects.

The Scioto River in this area has been incised to a depth of 50 to 100 feet into underlying bedrock, creating a shallow gorge. The floor, walls, and adjacent uplands of the gorge consist of Devonian Delaware and Columbus Limestones mantled by up to 20 feet of Wisconsinan till. Sinkhole concentrations up to 1 sinkhole per acre are not uncommon in Concord, Scioto, and Radnor Townships of Delaware County. The sinkholes range in diameter from about 10 to 100 feet and commonly are aligned linearly along major joint systems.

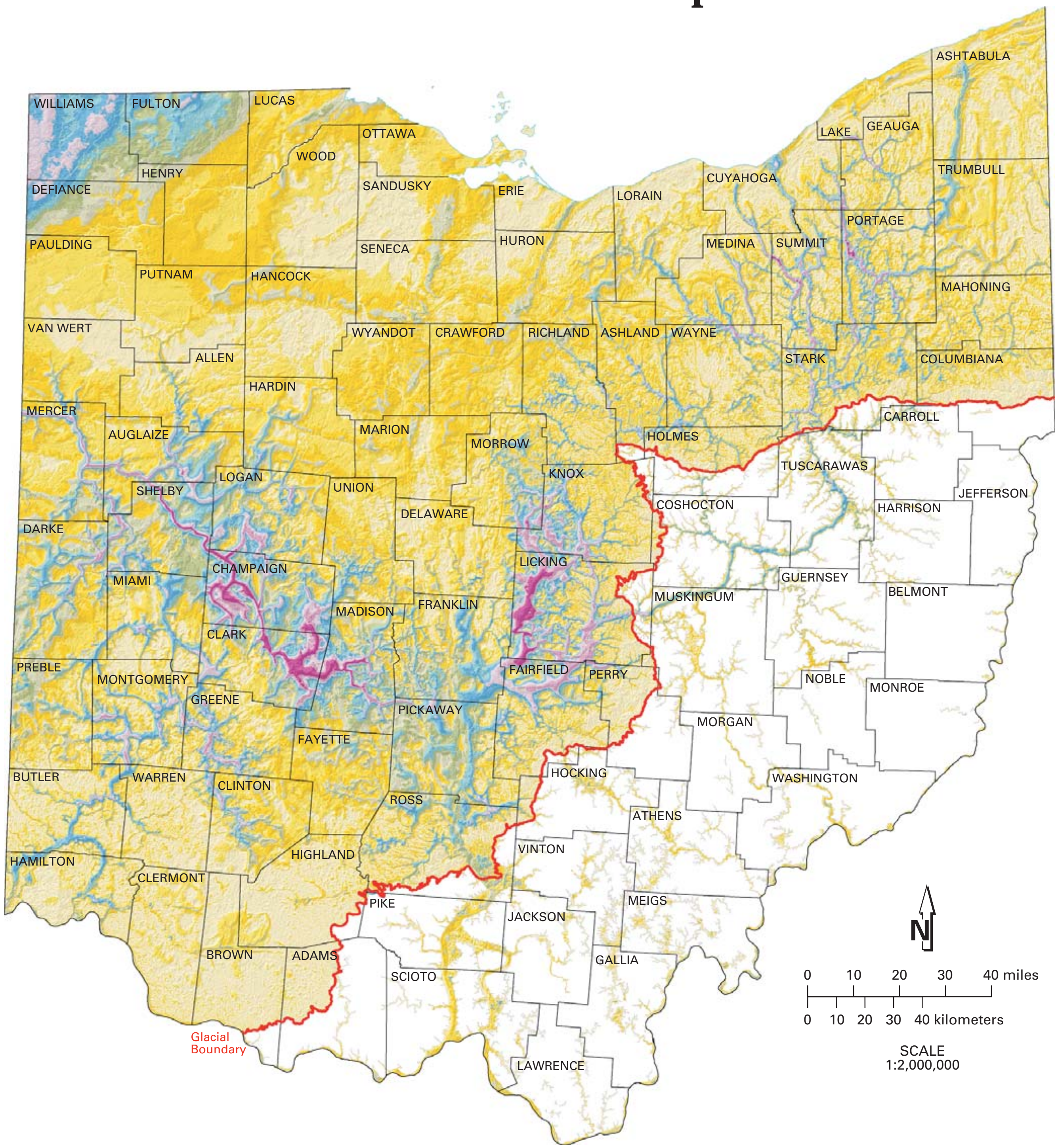
The Olentangy River is approximately 5 miles east of the Scioto River in southern Delaware County and occupies a gorge that is narrower and up to 50 feet deeper than the Scioto River gorge. The floor and the lower half of the walls along the Olentangy gorge are composed of Delaware and Columbus Limestones, the upper half of the walls is composed of Devonian Ohio and Olentangy Shales mantled by a thin veneer of glacial drift. Karst terrain has developed along portions of the gorge in a manner similar to karst terrain along the Scioto River.

ORDOVICIAN UPLANDS

The Ordovician uplands of southwestern Ohio are the location of surprisingly well-developed karst terrain despite the large component of shale in local bedrock. Numerous sinkholes are present in Ordovician rocks of Adams, Brown, Clermont, and Hamilton Counties.

The carbonate-rich members of the Grant Lake Formation (Bellevue and Mount Auburn), Grant Lake Limestone (Bellevue and Straight Creek), and the upper portion of the Arnheim formation are the Ordovician units most prone to karstification; however, the shale-rich (70 percent shale, 30 percent limestone) Waynesville Formation also has been subjected to a surprising amount of karst development in southeastern Brown and southwestern Adams Counties, just north of the Ohio River.

Shaded Drift-Thickness Map of Ohio



EXPLANATION

Thickness (in feet) of drift in glaciated areas and some non-glaciated areas along glacial boundary, and of outwash and glaciolacustrine deposits in sediment-filled valleys beyond the glacial boundary.

The drift-thickness map of Ohio depicts the thickness and distribution of glacially derived sediments (called drift) and post-glacial stream sediments overlying the buried bedrock surface. This map was produced by subtracting bedrock-surface elevations from land-surface elevations to produce a residual map of drift thickness. Colors portray thickness intervals of glacial and modern sediments, which can range up to several hundred feet.

Prior to the onset of continental glaciation in the Early Pleistocene Epoch, approximately 1.8 million years before present, the Ohio landscape was dominated by rolling hills and deeply incised, mature rivers and streams. A reduced version of the Division of Geological Survey's Shaded-Bedrock Topography map of Ohio (fig. 1) reveals some aspects of this old land surface. Erosion and deposition by Ice-Age continental glaciers advancing into northern and western Ohio produced a low-relief land surface compared to the unglaciated, high-relief land surface of southeastern Ohio (fig. 2). Comparing the shaded elevation map (fig. 2) with the shaded bedrock-topography map (fig. 1) reveals the dramatic impact of glaciation on the state's current landscape.

Drift thickness in western and northern Ohio (fig. 3) is highly variable, a consequence of numerous geologic factors acting in combination or alone. In some areas, drift has been deposited on a relatively flat bedrock surface and changes in drift thickness are primarily the result of variations in the amount of glacial material deposited. In other areas, drift has infilled a deeply incised buried-bedrock surface, and changes in drift thickness are primarily the result of variations in bedrock-surface elevation. In still other instances, the drift surface parallels the underlying bedrock surface to produce areas of relatively uniform drift thickness.

Distinct, narrow linear patterns of thick drift in western and central Ohio are the result of deep incisions in the underlying limestone and dolomite bedrock by a large, northwest flowing drainage system, the Teays Valley system, that existed prior to and during early glaciations (fig. 1). The main Teays Valley entered the state at Wheelersburg (Scioto County), where remnants of the Teays Valley are still evident on the modern land surface. At Chillicothe (Ross County), the valley disappears under glacial sediments which cover western Ohio. However, the valley continues north, below the surface, to Circleville (Pickaway County) and then northwest to Mercer County where the valley exits the state into Indiana. Early southward-advancing glaciers blocked the north-flowing river system of the Teays and created immense lakes in southeastern Ohio.

In northeastern Ohio, narrow thick-drift areas south of Lake Erie were also preglacial bedrock valleys. These valleys were partially filled with thick deposits of till and glaciolacustrine (glacial lake) sediment and then re-excavated by later northward-flowing rivers such as the Cuyahoga River and the East Branch of Rocky River.

In northwestern Ohio, repeated scouring of the relatively soft bedrock surface by glacial ice flowing southwestward from the Lake Erie Basin destroyed most pre-existing drainage systems. In this part of Ohio, the bedrock surface is smooth and the upper surface of the drift has been planed off by wave action and deposition by a post-glacial, high-level ancestral Lake Erie. In the extreme northwest corner of Ohio, in Williams County and portions of Defiance County, drift thickens considerably because of numerous moraines that formed along the northwestern edge of the Erie Lobe.

In western Ohio, draping linear features of thick drift, called ridge moraines, formed along the temporarily stationary ice-front as glacial sediment was released from the ice. These ribbons of thick drift define the lateral dimensions of glacial ice lobes, particularly those of the last Wisconsinan ice sheet (figure 4). Many ridge moraines in western and northeastern Ohio have a draped appearance because south-flowing ice, impeded by bedrock highlands, moved more easily along major lowlands. The numerous resistant bedrock highlands in northeastern Ohio caused ridge moraines to be especially arcuate and closely stacked.

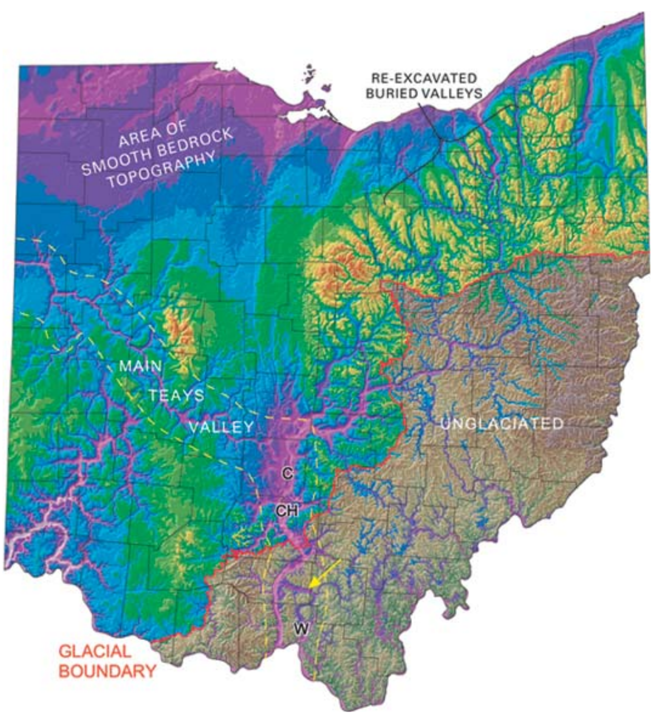


FIGURE 1.—Shaded bedrock-topography map of Ohio showing the sculpted bedrock surface that lies beneath glacial drift in northern and western Ohio and the land surface in unglaciated southeastern Ohio. Note the surface expression of the Teays Valley System south of the glacial boundary (arrow), the location of the main Teays Valley (between yellow dashed lines), the area of smooth bedrock topography, and the area of re-excavated preglacial bedrock valleys in northeastern Ohio. (**W** = Wheelersburg, **C** = Circleville, **CH** = Chillicothe) (modified from Ohio Division of Geological Survey, 2003).

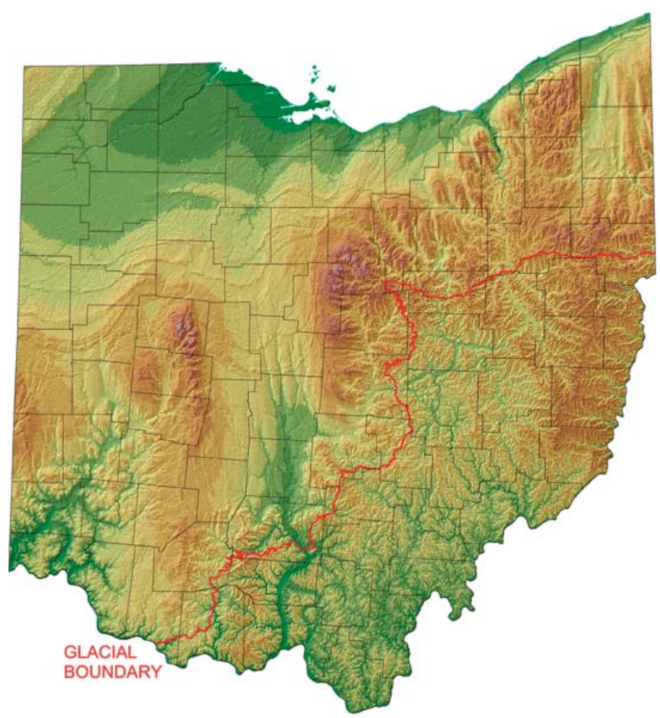


FIGURE 2.—Shaded elevation map of the land surface of Ohio with glacial boundary. Note the smooth landscape of glaciated northern and western Ohio compared to the high-relief landscape of unglaciated southeastern Ohio (modified from Powers, Laine, and Pavey, 2002).

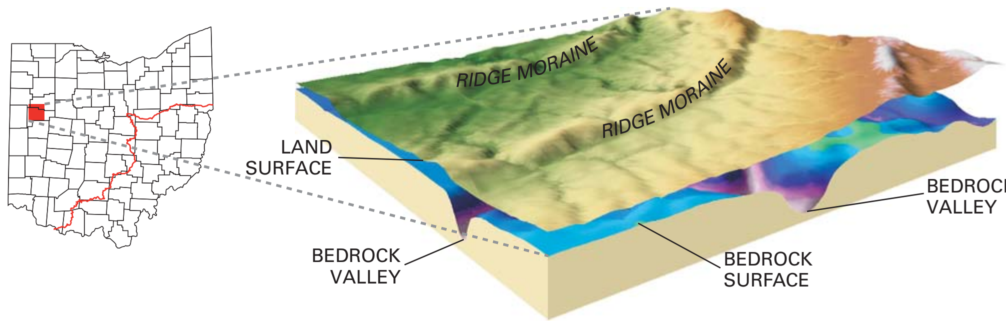


FIGURE 3.—Schematic cross section of glacial drift overlying the bedrock surface. Note areas where drift thickness is controlled by thickening of glacial sediment over a relatively flat bedrock surface, by drift infilling bedrock valleys, or by fluctuations in both the land surface and the bedrock surface. Also note areas where valleys in the buried-bedrock surface are not evident on the land surface.

Southeastern Ohio is unglaciated and devoid of ice-deposited sediment (glacial till). Many southeast Ohio valleys, however, carried huge volumes of glacial meltwater away from the ice front and toward the Ohio River. In the process, many of these valleys were at times made deeper by the erosive force of fast-flowing meltwater streams, and at other times were partially filled with sediment. Some valleys in unglaciated Ohio contain thick deposits of clay and silt that accumulated on the bottoms of lakes that formed when glacial ice blocked the flow of rivers or when rapidly accumulating meltwater sediments blocked the mouths of smaller tributaries.

METHODS

Two digital data layers are required to generate the drift-thickness map: the surface-elevation layer and the bedrock-topography layer. Drift thickness is calculated by subtracting the bedrock-topography elevation from the land surface elevation. The bedrock-topography component is one of the products resulting from a multi-year effort by the ODNR, Division of Geological Survey to map the bedrock geology of Ohio. Bedrock-topography maps are required to determine the relief on the bedrock surface beneath thick layers of glacial drift. Bedrock-topography maps were created by the Division of Geological Survey for all 788 7½-minute topographic quadrangles in the state as part of a process to produce accurate bedrock-geology maps for glaciated portions of Ohio and for those areas beyond the glacial boundary where valleys are infilled with sediment. Data concentration and contour intervals on the original, hand-drawn bedrock-topography maps vary widely across the state in response to changing geologic and topographic conditions. These data consist mainly of water-well logs on file at the ODNR, Division of Water, supplemented by outcrop data, Ohio Department of Transportation bridge-boring data, and oil-and-gas-well data. During the course of mapping, over 162,000 data points were interpreted for bedrock-surface elevation and in some cases drift thickness. These points were plotted on maps and used as control for the bedrock-topography lines. Individual 24,000-scale bedrock-topography maps are available from the Division's Geologic Records Center.

Elevation contours and data points from the 788 bedrock-topography maps were digitized and compiled for the glaciated portions of the state and for the valleys beyond the glacial boundary containing significant accumulations of sediment deposited during and after glaciation. The bedrock-topography contours were digitally converted in an ArcGIS environment to create a continuous grid model (60 meter grid spacing). A statewide compilation map and digital dataset of the bedrock topography of Ohio (modified from Ohio Division of Geological Survey, 2003) are available from the Division of Geological Survey.

Uncolored areas of southeastern Ohio represent extensive portions of unglaciated Ohio where the land surface and the bedrock surface are essentially the same. On the original maps in these areas, bedrock-topography lines were restricted to the buried-valley portions of the map and were not drawn in upland portions.

The second component needed to create the drift-thickness map, the land-surface topography, is based largely on data derived from the U.S. Geo-

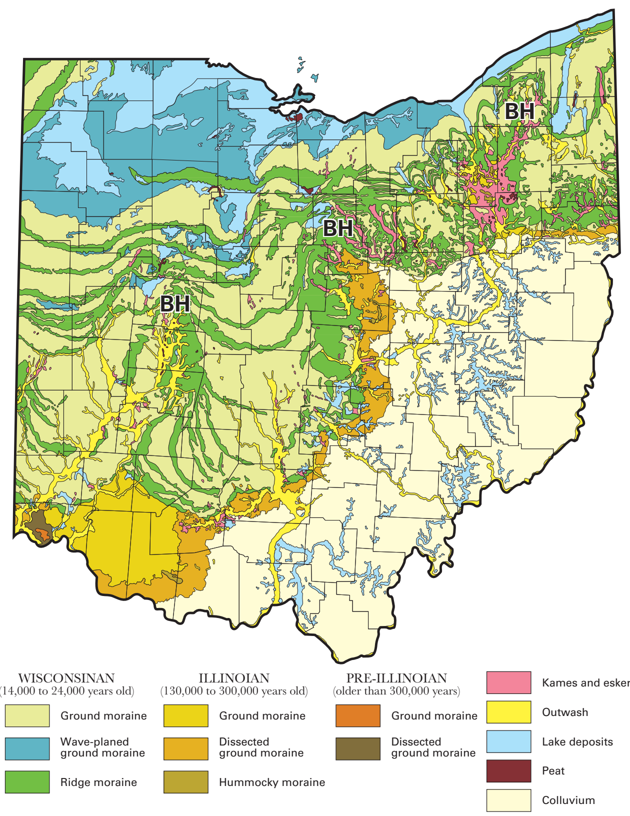


FIGURE 4.—Glacial map of Ohio showing the distribution of glacial sediments and their relative ages. Note glaciated northern and western Ohio, unglaciated southeastern Ohio, and the position of ridge moraines and the lake deposits and wave-planed ground moraine of the Lake Erie Basin. Bedrock highlands (**BH**) impeded the southward advance of glacial ice causing the moraines to form a lobate configuration (modified from Pavey and others, 1999).

logical Survey's National Elevation Dataset (30 meter grid spacing). These data have been modified extensively by the Ohio Division of Geological Survey to replace some anomalous errors that are inherent in portions of the National Elevation Dataset. A statewide compilation map and digital dataset of the shaded elevation of Ohio (modified from Powers, Laine, and Pavey, 2002) are available from the Division of Geological Survey.

A grid of the digitized bedrock-topography contours was subtracted from a grid of the land-surface Digital Elevation Model to derive a third grid (60 meter grid spacing) representing the thickness of the drift. This grid surface was shaded from the northwest, slightly above the horizon, to produce the appearance of a three-dimensional surface.

NOTES

CENTRAL OHIO'S GEOLOGY IN CORE AND OUTCROP WORKSHOP II—Ohio Division of Geological Survey Open-File Report 2011-1