Fall 1997 Ohio Geology

THE GEOLOGY OF OHIO--THE ORDOVICIAN

by Michael C. Hansen

To geologists, the Ordovician System of Ohio is probably the most famous of the state's Paleozoic rock systems. The alternating shales and limestones of the upper part of this system crop out in southwestern Ohio in the Cincinnati region and yield an incredible abundance and diversity of well-preserved fossils. Representatives of this fauna reside in museums and private collections throughout the world. Indeed, fossils from Ohio's Ordovician rocks define life of this geologic period, and the rocks of this region, the Cincinnatian Series, serve as the North American Upper Ordovician Standard. Furthermore, in the late 1800's, Ordovician rocks in the subsurface in northwestern Ohio were the source of the first giant oil and gas field in the country.

Compared to other geologic systems, however, the Ordovician is a relative newcomer. Not geologically, of course--it began about 500 million years ago and ended about 440 million years ago--but in terms of being recognized as a separate geologic system. The controversy began in Wales in 1831 when Adam Sedgwick defined a sequence of rocks he called Cambrian and Roderick Murchison studied a younger sequence of rocks he called Silurian. The controversy centered on the fact that Murchison considered Sedgwick's Upper Cambrian rocks to belong to his Lower Silurian sequence. It wasn't until 1879 that another Englishman, Charles Lapworth, settled the problem by placing the controversial beds in a new system, the Ordovician.

Ohio Geological Survey reports of the last half of the 19th century refer to these rocks in Ohio as the Lower Silurian. Indeed, the U.S. Geological Survey did not accept the Ordovician as a distinct geologic system until 1903, and the term was not used officially in Ohio until 1909 by State Geologist John A. Bownocker on the geologic map of the state.

ORDOVICIAN PALEOGEOGRAPHY, OROGENY, AND VOLCANISM

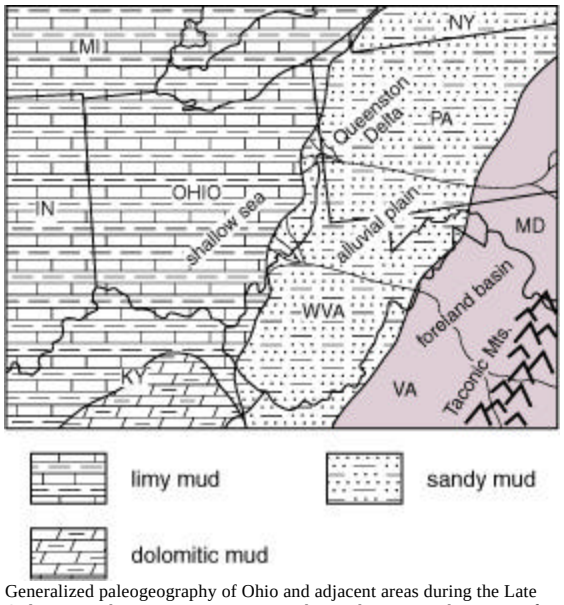
During the Ordovician, Ohio was in southern tropical latitudes and dominated by warm, shallow seas. The Iapetus, or proto-Atlantic, Ocean, which formed in Late Precambrian and Cambrian time, began to close during the Ordovician. Collision between the North American and European continents during the Middle Ordovician formed a series of island arcs and mountains to the east of Ohio. This event, the Taconic Orogeny, which culminated in the Late Ordovician, is recorded in rocks stretching from Newfoundland to Alabama.

Although Ordovician rocks in Ohio were not directly involved in the collisional event, they record these activities. The widespread Knox unconformity (see *Ohio Geology* , Winter 1997), an episode of emergence and erosion, was formed when the land surface bulged upward (known as a peripheral bulge), accompanying development of a foreland basin to the east at the edge of the orogenic belt. As the Taconic Orogeny reached its zenith in the Late Ordovician, sediments eroded from the rising mountains were carried westward, forming a complex delta system that discharged mud into the shallow seas that covered Ohio and adjacent areas. The development of this delta, the Queenston Delta, is recorded by the many beds of shale in Upper Ordovician rocks exposed in southwestern Ohio.

The island arcs associated with continental collision were the sites of active volcanoes, as documented by the widespread beds of volcanic ash preserved in Ohio's Ordovician rocks (see *Ohio Geology* , Summer/Fall 1991). The ash layers, which to geologists are wonderful time lines because they were deposited instantaneously over a wide geographic area, have been altered to a special type of clay known as a bentonite. There are a number of bentonite beds in Ohio's Ordovician rocks, but two beds in Middle Ordovician rocks, the Deicke bentonite and the Millbrig bentonite, may represent some of the largest explosive volcanic eruptions in the geologic record. These beds have been traced from the Mississippi River eastward across North America and Europe and into Russia. It has been estimated that these eruptions generated about 5,000 times the volume of volcanic ash produced by the eruption of Mt. St. Helens in 1980.

Continental positions in Late Ordovician time. The shaded area depicts the extent of the Millbrig bentonite (altered volcanic ash) at the top of the Black River Group (Middle Ordovician). This bentonite has a volume of about 175 cubic miles and represents the largest known explosive volcanic eruption in Earth's history. The source of the eruption is thought to have been in the southeastern United States along an island arc formed by the closing of the Iapetus Ocean during the Taconic Orogeny. Modified from Coogan (1996) and Potter (1995).

The Cincinnati Arch, a north-south-oriented, positive structural feature in southwestern Ohio and adjacent areas to the south, began to form in the Late Ordovician, perhaps initiated by the Taconic Orogeny. The axis of the arch is east of Cincinnati and continues northward until it splits into the Findlay Arch to the north and the Kankakee Arch to the west. The broad area formed by the three arches is called the Indiana-Ohio Platform.



Generalized paleogeography of Ohio and adjacent areas during the Late Ordovician. The Taconic Mountains to the southeast were the source of mud carried far out into the shallow sea that covered Ohio. Modified from Coogan (1996).

The Cincinnati Arch was first discovered by John Locke during his work with the First Geological Survey of Ohio in 1838. It was viewed in a classical interpretation as an anticline, that is, the oldest rocks are exposed along the central axis and progressively younger rocks lie on the flanks. A cursory glance at the geologic map of Ohio implies an anticlinal feature: the oldest rocks exposed in Ohio--Ordovician--crop out along the axis and younger Paleozoic rocks dip eastward into the Appalachian Basin, westward into the Illinois Basin, and northward into the Michigan Basin.

Recent revelations about the geology of the deeply buried Precambrian rocks of the state (see *Ohio Geology* , Winter 1996) indicate that the Cincinnati Arch overlies a sediment-filled rift basin that formed in Late Precambrian time. The area underlain by the rift basin appears to be a comparatively stable crustal block surrounded by subsiding basins. The Cincinnati Arch, therefore, may be viewed not as an anticlinal structure but as a positive feature around which the crust has subsided. This development may have been initiated by the Taconic Orogeny in the Late Ordovician and further accentuated by later Paleozoic orogenic events.

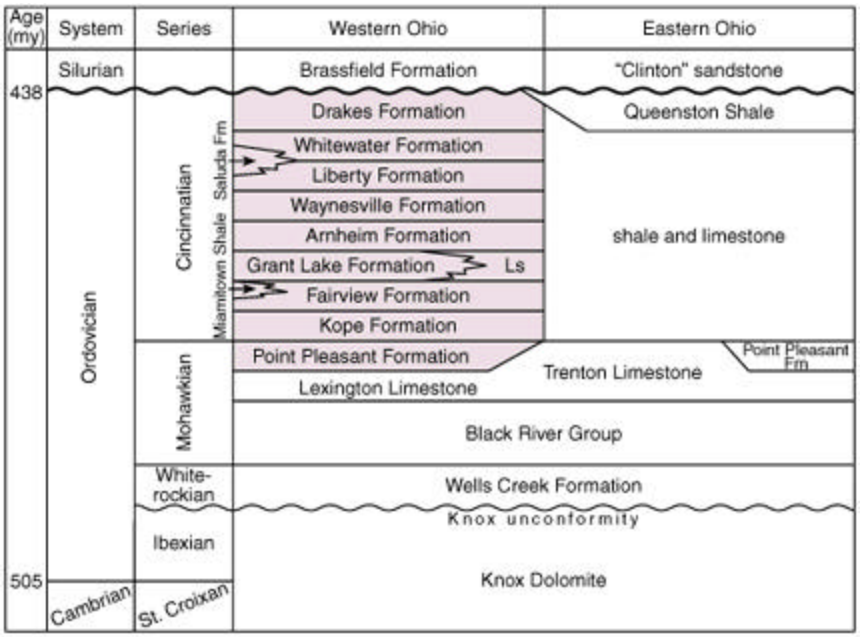
THE ORDOVICIAN SYSTEM IN OHIO

Ordovician rocks crop out in southwestern Ohio and adjacent parts of Indiana and Kentucky along the axis of the Cincinnati Arch. These rocks are well exposed in Hamilton, Clermont, Butler, Warren, and Montgomery Counties; there are lesser areas of exposure or subcrop in Adams, Highland, Clinton, Greene, Clark, Miami, and Preble Counties. Ordovician rocks are particularly well exposed in the southern tier of Ohio counties where the surface is mantled only by thin glacial drift of Illinoian age. Exposed Ordovician rocks belong to the upper third of the system, the Cincinnatian Series, except for

some small exposures of the Middle Ordovician Point Pleasant Formation along the Ohio River. However, nearly the entire system is represented in the subsurface of the state to the east and north of the Cincinnati area.

The base of the Ordovician System in Ohio is nowhere exposed in the state and was long interpreted to be at the Knox unconformity, the boundary between the Knox Dolomite and the overlying Wells Creek Formation. The upper part of the Knox Dolomite is now thought to be Early Ordovician in age.

The Ordovician Period is sometimes characterized as the greatest submergence of the North American plate because shallow seas covered such an extensive area, including all of Ohio. The beginning of the Ordovician saw a continuation of shallow-water, tidal-flat environments of the Cambrian portion of the Knox Dolomite. The Knox is sometimes called "The great American tidal flat" because this environment was so extensive.



Stratigraphic column of Ordovician rocks in Ohio. The highlighted units crop out in southwestern Ohio. The remaining units are present in the subsurface of northwestern and eastern Ohio. my = millions of years.

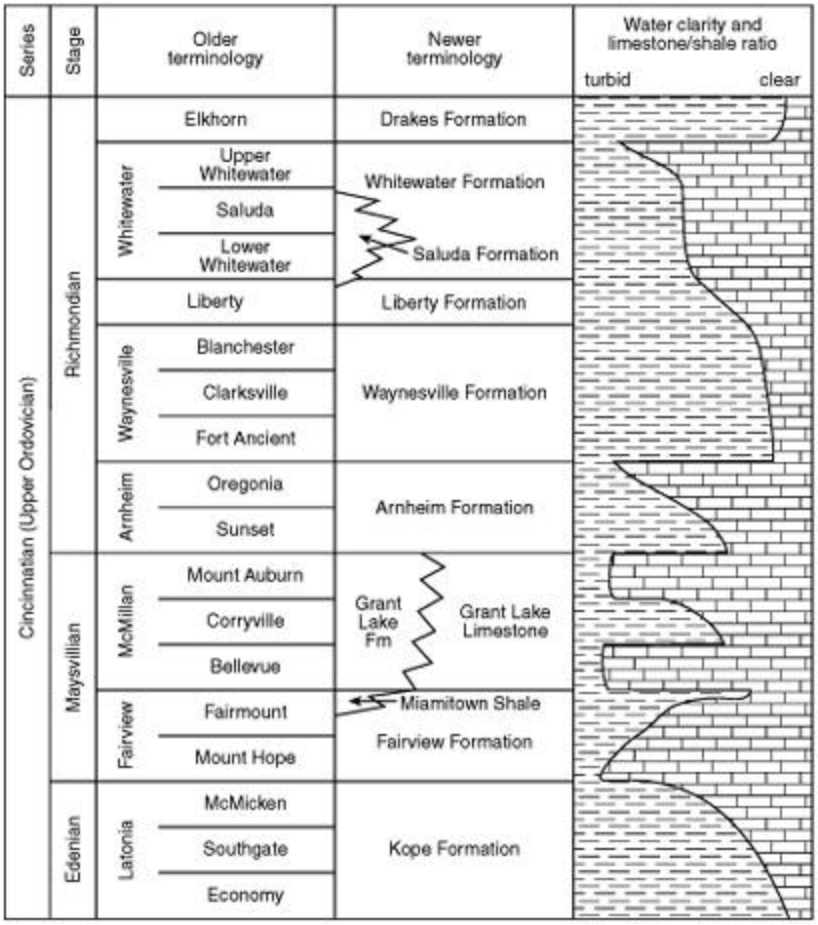
Some time after the erosion that formed the Knox unconformity the seas returned, depositing the Wells Creek Formation, which consists of shale, siltstone, sandstone, and dolomite. This subsurface unit is highly variable in thickness because it was deposited on the topographically irregular surface of the Knox unconformity. The Wells Creek averages about 20 feet in thickness but can be absent on highs on the Knox surface and be up to 60 feet thick in Knox lows. In general, the unit thickens to the east.

Above the Wells Creek is the Black River Group, which in Ohio consists primarily of fine-grained tan or gray limestone. It is about 300 feet thick in northwestern Ohio and thickens eastward to more than 500 feet. The Black River Group is thought to have been deposited in shallow subtidal to supratidal environments.

Overlying the Black River Group is the Trenton Limestone and its equivalent to the south, the Lexington Limestone of Kentucky. This dark-gray to brown fossiliferous limestone includes thin gray to black beds of shale and has abundant zones of secondary *dolomitization* . The Trenton is not exposed at the surface in Ohio. It ranges from 40 feet thick in west-central Ohio to more than 300 feet thick in northwestern Ohio. It was deposited in platform to open-shelf marine environments that were deeper than those of the Black River Group. This deepening of the sea is interpreted to be the result of increased tectonic activity to the east associated with the Taconic Orogeny. The Trenton Limestone was once the most important economic unit in Ohio for the production of oil and gas.

The Trenton Limestone grades upward and laterally into the Point Pleasant Formation, named for exposures of interbedded gray shales and limestones exposed near the Clermont County town of Point Pleasant. Exposures of the Point Pleasant Formation along the Ohio River have been quarried for many years and it was long known as the "River Quarry Beds." The Point Pleasant Formation marks the end of Middle Ordovician time.

Upper Ordovician rocks form the Cincinnatian Series, named for the magnificent exposures in the Cincinnati area (and adjacent parts of Kentucky and Indiana). They consist of about 750 feet of interbedded limestones and shales that at first glance appear lithologically monotonous and repetitive. However, these rocks are full of exquisitely preserved fossils that have been the focus of attention of a diverse group of collectors, ranging from curious children to professional paleontologists, for more than a century and a half. Indeed, an uncommon number of these curious children from the Cincinnati area became professional geologists and paleontologists, many of national and international prominence. Literally hundreds of technical papers and reports on Cincinnatian rocks and fossils have been published through the years, and these rocks serve as the official reference section for Upper Ordovician rocks in North America.



Stratigraphic terminology and comparative limestone/shale ratio of Cincinnatian (Upper Ordovician) rocks in southwestern Ohio. Older terminology, which was determined on both lithology and fossil distribution, has now been replaced by lithologic terms. However, older terminology is commonly encountered in the literature. Units dominated by shale are interpreted to have been deposited in deeper, more turbid waters, whereas units dominated by limestone are interpreted to have been deposited in comparatively shallower and clearer waters.

The interbedded limestones and shales of the Cincinnatian Series have been subdivided into a number of formations and members using a variety of schemes. Older classifications used a combination of lithology (rock type) and biostratigraphy (fossil distribution) to subdivide the Cincinnatian. Modern classifications use lithology, bedding type (such as wavy or planar), and percentage ratios of shale and limestone as a basis of subdivision of units. Some of the older unit names have been redefined to adhere to modern classifications, and new names have been introduced for some formations. The result is a large number of unit names, which can be confusing, especially when consulting both vintage and modern literature.

Overall, the Cincinnatian rocks represent a transgressive sequence in which most shale-dominated units reflect deposition in deeper, quieter waters and the limestone-dominated units represent deposition in clearer, shallower waters. Many of the thin beds of limestone show evidence, such as graded bedding, of having been deposited during storm events and are called "tempestites."

Cincinnatian rocks can be divided classically into three vertically repetitive facies or intergrading suites of rocks: offshore, transitional, and shoreface. Offshore facies formed in deeper (perhaps 150 feet or

more), open-marine waters in which the sea bottom was below the fair-weather wave base. The offshore facies is dominated by shale and generally has well-preserved fossils that have not been broken and abraded by wave action. The Kope Formation, Waynesville Formation, and Miamitown Shale were deposited in this offshore environment. The lower part of the Kope Formation is dominated by dark, graptolite-bearing shales (informally called "Utica" shale) that were deposited in deeper water in the Sebree Trough, an elongate basin that extended from western Kentucky into northwestern Ohio.

The transitional facies is represented by units that have nearly equal percentages of limestone and shale. These rocks were deposited in shallower (less than 50 feet) waters, but the sea bottom was still below the fair-weather wave base. The Fairview Formation; portions of the Grant Lake Formation, the Grant Lake Limestone, and the Arnheim Formation; and the Liberty Formation were deposited in this environment.

The shoreface zone has the highest percentage of limestone beds, which are composed of broken and worn fossils, and represents deposition in a shallow, high-energy environment where waves and currents extensively reworked and winnowed bottom sediments. Portions of the Grant Lake Formation, the Grant Lake Limestone, and the Arnheim Formation and the Whitewater Formation were deposited in this environment. The Saluda and Drakes Formations represent deposition in a tidal-flat environment, the ultimate in shallowing marine conditions.

ORDOVICIAN LIFE

The marine invertebrate life that appeared in abundance in the Cambrian Period (see *Ohio Geology*, Winter 1997) continued into the Ordovician, and many groups diversified into numerous species. Testimony to the abundance and success of marine invertebrates during the Ordovician is the diversity and abundance of fossils preserved in the rocks of southwestern Ohio. It has been suggested that if all of the fossils could be removed from the Ordovician rocks of the Cincinnati area, Cincinnati would be below sea level. Anyone who has examined these rocks in the field immediately notes that, volumetrically, many beds are tightly packed with fossils.

Perhaps the most common fossil remains are those of bryozoans, colonial animals that lived in branching, treelike colonies or flattened, encrusting masses on shells of other invertebrates. In some areas bryozoans litter the outcrop. Brachiopods are no less spectacularly abundant than bryozoans and are a favorite of the beginning collector. They range in size from tiny species to the walnut-sized *Platystrophia ponderosa*.

The most desirable fossils from Cincinnatian rocks seem to be trilobites. The remains of these arthropods are found in considerable abundance in some beds. The most common Cincinnatian trilobite, *Flexicalymene*, is best known from the Corryville Member of the Grant Lake Formation and from the middle part of the Waynesville Formation. Much less common are well-preserved specimens of *Isotelus*, Ohio's official State Fossil. This trilobite may have reached lengths of nearly 2 feet.

Advanced fossil collectors seek the rare and exquisitely preserved echinoderm fossils found in the Cincinnatian. Perhaps the most recognizable echinoderm fossils are starfish, which look very similar to those found in modern oceans. Crinoids, edrioasteroids, carpoids, cystoids, cyclocystoids, and machaeridians are other echinoderms found in Cincinnatian rocks.

These rocks produce spectacular fossils of many other kinds of organisms, including mollusks (cephalopods, gastropods, and pelecypods), corals, graptolites, and many other macroscopic and microscopic remains. Also included in this list are trace fossils such as tracks, trails, burrows, and feeding traces impressed into the soft bottom muds in the teeming Late Ordovician sea. Many fossils occur only in certain beds or zones, and the serious fossil collector soon learns where to seek specific fossils among the thousands of outcrops in the tri-state area that centers on Cincinnati.

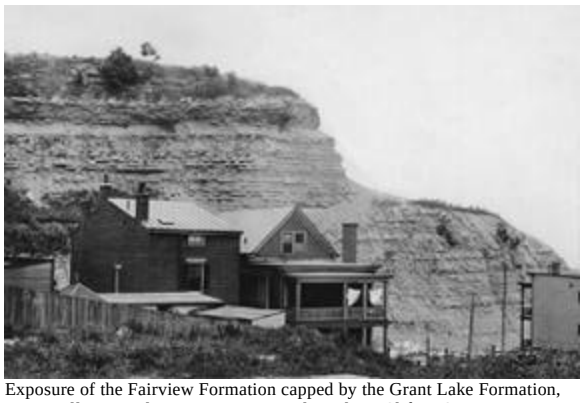
Perplexingly, Cincinnatian rocks have yet to yield remains of fishes. These vertebrates are well known from rocks of similar age in other areas, primarily in the form of small bony plates. These fishes were jawless and are referred to as agnathans (without jaws). They lived by ingesting bottom sediments and digesting organic matter. Most Ordovician occurrences of agnathans appear to be in nearshore marine environments. Perhaps the sediments represented by Upper Ordovician rocks in Ohio were deposited too far offshore or in unsuitable environments for these fishes.

ECONOMIC AND ENVIRONMENTAL GEOLOGY

Currently, Ordovician rocks of Ohio are not of great economic importance in comparison to rocks of other geologic systems exposed in the state. In the last century, some of the Upper Ordovician limestones in southwestern Ohio were quarried for building stone and other uses. Limestone of the

Point Pleasant Formation was quarried at several locations, including Cincinnati and Point Pleasant, where it is exposed along the Ohio River. This unit was known to the quarrymen as the "River Quarry Beds."

Limestone beds in the Fairview Formation were quarried from exposures on hilltops in Cincinnati. Such a readily available source of limestone in the Cincinnati area would seem to be an ideal situation. However, the fossils that pack these limestone beds, making the area so paleontologically famous, spoil the stone for building purposes. The surface of the stone weathers unevenly because of the fossils and is difficult to carve for the same reason. Also, very few of the beds are more than a foot or two thick and have interbedded shale units that must be removed and discarded. Too much waste material, therefore, must be removed and handled to make the Cincinnati limestones economically competitive.



Exposure of the Fairview Formation capped by the Grant Lake Formation, near "Bellevue Incline," a street-car incline along Clifton Avenue in Cincinnati. The Fairview Formation was the source of local building stone in the Cincinnati area and was referred to as the "Hill Quarry Beds." Note the alternating, repetitive, thin beds of limestone and shale. Photo by R. S. Bassler, circa 1915. From Fenneman (1916).

Although very little oil or gas is currently produced from Ordovician rocks in Ohio, the Trenton Limestone was once the most important oil-bearing unit in the United States and was the first giant oil field to be discovered in North America. Commercial quantities of oil and gas were first discovered in northwestern Ohio in 1884. Frenzied drilling soon began in a 185-mile-long area stretching from Toledo to Indianapolis that became known as the Lima-Indiana Oil and Gas Trend. At least 60 individual fields were named within this trend.

Records from this era are poor, but it is estimated that at least 100,000 wells were drilled in the trend, 76,000 of them in Ohio. By 1910 the trend had been depleted, but at least 500 million barrels of oil and 1 trillion cubic feet of gas had been produced during its life. From 1895 until 1903 Ohio was the nation's leading producer of oil. The fascinating story of Trenton drilling and production was faithfully recorded by third State Geologist Edward Orton, who published detailed accounts in Survey publications, particularly Volume 6 in 1888. More recently, Survey geologist Lawrence H. Wickstrom and former Survey geologists John D. Gray and Ronald D. Stieglitz published a historical summary of Trenton drilling and a modern interpretation of the geology of this oil and gas field in Survey Report of Investigations No. 143.

Flexicalymene meeki

Environmentally, few would suspect that the Cincinnati area has the highest per capita cost from landslide damage of any city in the United States, according to a 1980 U.S. Geological Survey study. Most of these landslides occur in colluvium (slope accumulations of fragmental, weathered rock) formed over outcrops of the Kope Formation, a 220-foot-thick, shale-rich unit at the base of the Upper Ordovician Cincinnatian Series. Rotational slumps and earthflows occur in the Kope when it becomes wet. The shale slakes and hydrostatic pressure builds up, causing failure along the contact between the colluvium and unweathered bedrock. Most of these slope failures occur on shaded, north-facing slopes, which tend to have excess moisture.

The Miamitown Shale also is prone to landslide problems. However, the Miamitown is much less of a problem in the Cincinnati area because of its limited distribution and because it is a comparatively thin unit, only reaching about 20 feet in thickness.

Although Ohio's Ordovician rocks may not be the most important in the state economically, they form scenic vistas that are enjoyed by all and yield such wonderful fossil remains that only those individuals devoid of curiosity about the natural world would not be impressed. To geologists, these rocks have long been, and will continue to be, a source of inspiration and fascination.

ACKNOWLEDGMENTS

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[Back to the Fall 1997 Contents] [Ohio Geological Survey Home Page]

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