Ohio Geology

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THE GEOLOGY OF OHIO—THE DEVONIAN

by Michael C. Hansen

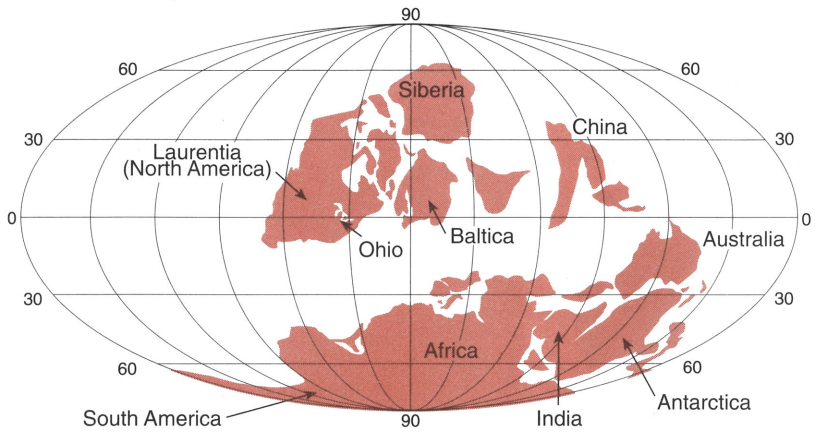
The Devonian Period was an important episode in the history of the Earth. For the first time, the land surface began to show a noticeable hint of green from terrestrial plant life, which evolved from simple, ground-hugging forms early in the period to great trees late in the period. Concurrent with the proliferation of forests, vertebrates began their first tentative forays out of the water. The warm, tropical seas accumulated limy sediments that would become economically important deposits of limestone, and the organic remains of countless organisms that flourished in Devonian marine waters became a source of hydrocarbons. During this 48-million-year span, beginning about 408 million years ago and ending about 360 million years ago, Ohio was just south of the Equator and experienced a warm, tropical climate.

The Devonian System was named in 1839 by Roderick Murchison and Adam Sedgwick for a series of greatly disturbed sedimentary rocks that lay between the Silurian and the Carboniferous rocks in Britain. Corals found in thin marine beds in these rocks in Devonshire, England, were determined by paleontologist William Lonsdale to be intermediate between those of the Silurian and those of the Carboniferous; therefore, Murchison and Sedgwick proposed a new geologic system named after the province where the corals were obtained. Most of the Devonian rocks in Britain consist of a thick series of reddish sandstones, shales, and conglomerates that collectively were named the Old Red Sandstone. The Old Red Sandstone was made famous by Hugh Miller, a self-educated Scottish quarryman who collected and studied fossil fishes from these rocks. Miller's 1841 book, *The Old Red Sandstone*, is a classic in geology.

DEVONIAN ROCKS IN OHIO

Devonian rocks crop out in two areas in Ohio. They are best exposed in a 20-mile-wide, north-south-oriented belt in the central part of the state. At its northern terminus, the outcrop belt narrows and swings eastward along the southern shore of Lake Erie. These rocks dip and thicken southeastward into the Appalachian Basin and are present in the subsurface of eastern Ohio. An arcuate belt of Devonian rocks is present in northwestern Ohio, although there are few exposures of these rocks because of a thick mantle of glacial sediment. These rocks dip northwestward into the Michigan Basin. A small area of Devonian rock crops out on the Bellefontaine Outlier (see *Ohio Geology*, Winter 1991) in Logan and Champaign Counties.

With one exception, all of the outcropping Devonian rocks in the state are of Middle or Late Devonian age. The exception is the Holland Quarry Shale, a Lower Devonian unit known only from a single, small, lens-shaped outcrop in a now-reclaimed quarry in Lucas County, west of Toledo. This dark-gray shale was exposed in a highwall in the France Stone Company's Holland Quarry when it was discovered by J. Ernest Carman of The Ohio State University during the course of mapping Lucas County for the Survey in the 1920's. This shale would have been given no more than cursory attention by Carman or other geologists were it not for the suite of remarkable fossils it contained. Particularly noteworthy were the remains of two species of primitive, jawless, armored fishes, an arthrodire, and an acanthodian. The specimens of jawless fishes are the only ones of this type known from Ohio. In addition to fishes, the Holland Quarry Shale produced fossils of eurypterids, other invertebrates, and plants. The fishes, eurypterids, and the stratigraphy of the deposit were described in a series of papers published by the Chicago Field Museum of Natural History in the early 1960's.



Continental configuration during Devonian time. Modified from C. R. Scotese and others (1979, Paleozoic base maps, Journal of Geology, v. 87, fig. 24).

The fossils determined the age and gave clues to the environment of deposition of the Holland Quarry Shale. It is interpreted to have been a brackish-water embayment that may have been connected to the sea to the northwest in the Michigan Basin. Much of Ohio, to the south and west, was above sea level and not accumulating sediment. The Holland Quarry Shale, therefore, is so far the only known deposit of Lower Devonian rocks exposed in the state. However, the sea was present in southeastern Ohio, on the edge of the Appalachian Basin, during Early Devonian time as recorded by the presence in the subsurface of the Helderberg Formation, the Oriskany Sandstone, and the Bois Blanc Formation.

By Middle Devonian time the warm, shallow seas once again spread across the state and limy

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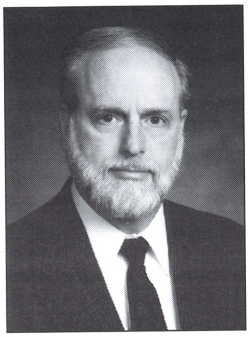

Thomas M. Berg, Division Chief and State Geologist

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Bob Taft, Governor
Samuel W. Speck, Director

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From The State Geologist...

Thomas M. Berg

MOVING CONFIDENTLY TOWARD THE NEW MILLENNIUM—A NEW DIRECTOR FOR THE DEPARTMENT OF NATURAL RESOURCES

Governor Bob Taft has appointed Dr. Samuel W. Speck as Director of the Department of Natural Resources. Dr. Speck, originally from Canton, Ohio, brings an outstanding background to ODNR, which is about to celebrate its 50th anniversary. He is a graduate of Muskingum College in New Concord, Ohio, and received his doctoral degree in government from Harvard University. He served the citizens of Ohio in the state legislature—in the House from 1971 to 1976 and in the Senate from 1977 to 1983. Most recently, Dr. Speck has been President of Muskingum College for the past 11 years. When he was appointed to his new position, Dr. Speck said, "I care deeply for the natural resources and I was deeply involved with these areas while I was in the Legislature. This position offers a wonderful opportunity to serve the region in an important new way while I'm also supporting the governor and his vision for Ohio." Sam Speck also has had experience with the federal government, serving as Associate Director of the Federal Emergency Management Agency (FEMA) under President Reagan. While at FEMA, he was head emissary to NATO's Senior Civil Emergency Planning Council, was one of the U.S. representatives to the U.N. Vienna Conference on Chernobyl, and served on the Board of Governors of the American Red Cross. Importantly for the Division of Geological Survey, Dr. Speck is very interested in the science of geology. He grew up on an Ohio farm and had an avid interest in geology. His first article ever published was in *Rocks and Minerals* magazine when he was in eighth grade; it was about crystals collected in northern Michigan. The Ohio Geological Survey looks forward to working under Sam Speck's direction. The next four years will be exciting times for ODNR as we move into the new millennium.

At the same time that we welcome Samuel W. Speck to the Department of Natural Resources, we bid fond farewell to Donald C. Anderson, who served as ODNR Director during Governor Voinovich's second term. Don was an outstanding Director and embraced a culture of honesty, respect, and trust in ODNR that will surely continue as his legacy. The Department accomplished many successes during his administration, including funding of the Ohio Coastal Management Program, setting of strategic priorities for the Department, and moving aggressively ahead with a broad spectrum of state-park and natural-resource infrastructure projects under the NatureWorks program. Don Anderson has accepted an administrative position in the Ohio Department of Mental Health. We thank him for his dedication to ODNR and wish him well in his continued service to Ohioans.

Division Employee of the Year

Michael R. Lester, Data Systems Coordinator for the Division, was named the Employee of the Year for 1998 at the annual Christmas luncheon. Nominations for this award are submitted by employees and the selection is made by a committee representing various groups of the Survey.

Mike came to the Survey in 1984 after receiving a B.S. degree in visual communications technology from Bowling Green State University. He began work as a cartographer and was involved in all aspects of map and publication production. In 1994, as the Survey began to become intensively computerized, especially in digital cartography, Mike moved into the newly created position of Data Systems Coordinator. In this position, Mike is responsible for setting up and configuring all of the Surveys computers, getting them hooked up to the ODNR network, and answering all of the questions we all have on how to do one thing or another on our computers. This never-ending task is complex at times, and Mike always responds quickly to any problem, no matter how major or how trivial. On his own, Mike enrolled in a number of evening computer classes to expand and sharpen his skills, and he keeps up on the latest hardware and software to make everyone's job easier. In this position, Mike enjoys interacting with people, problem solving, and the opportunity to teach computer skills.

His efforts have not gone unnoticed or unappreciated by the staff, and it is a small reward to recognize these contributions by the Employee of the Year award. Mike lives in Reynoldsburg with his wife and three children. He enjoys golf and is an avid Monopoly player.

Mike Lester (left) receives the Employee of the Year award from Division Chief Thomas M. Berg.

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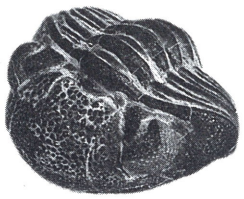
sediment began to accumulate. These limestones were part of the "Cliff limestone," which also included Silurian limestone units, in the classification of John Locke in 1838 during his reconnaissance work for the first Geological Survey of Ohio. New York State Geologist James Hall in 1843 referred to the Middle Devonian limestones of Ohio as the "Corniferous Limestone," correlating them with carbonate rocks of that name in New York State. In 1859, William W. Mather, Ohio's first State Geologist (1837-1838), used the name Columbus Limestone in reference to Middle Devonian limestones encountered during drilling of an artesian well at the Ohio State House in Columbus. In 1878, Edward Orton, Ohio's third State Geologist (1878-1899), formally divided this limestone sequence into the Columbus Limestone and the overlying Delaware Limestone, subdivisions that are still used. Clinton R. Stauffer, in his 1909 Ohio Survey bulletin (No. 10), *The Middle Devonian of Ohio*, divided the Columbus and Delaware Limestones into a series of alphabetical zones. Later researchers have proposed other subdivisions.

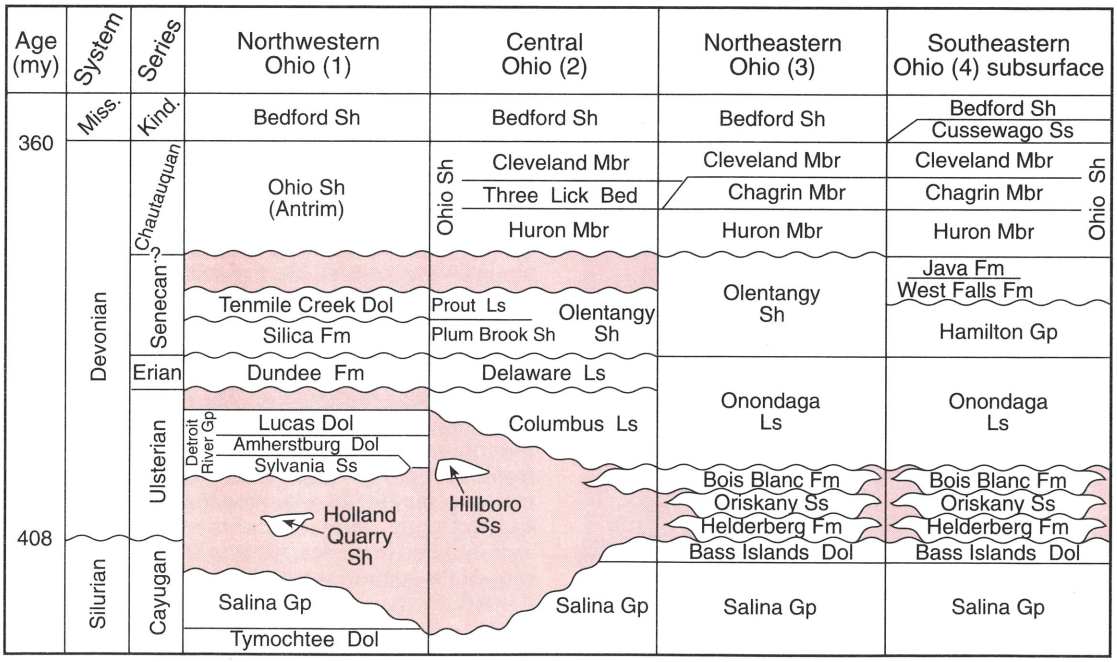
The Columbus Limestone reaches a thickness of a little more than 100 feet, whereas the Delaware averages about 35 feet in thickness. These units pinch out to the south but continue northward to Lake Erie. The Columbus Limestone is present on the Bellefontaine Outlier in Logan County, 30 miles west of the contiguous outcrop belt in central Ohio, but the Delaware Limestone appears to be absent. The Columbus is a fairly pure limestone, dolomitic in the lower part and very fossiliferous in the upper part. The Delaware Limestone, by contrast, is less pure, having a higher silt content that gives it a darker gray or bluish color; this unit has been referred to informally as the "Blue Limestone." The change in lithology between the Columbus and the Delaware reflects large-scale events, namely the beginning of the Acadian Orogeny, as North America and Europe met once again on their periodic collisional course. The rise of the Acadian Mountains to the east is reflected not only by clastic sediment beginning to be washed into the Middle Devonian seas, but also by the evidence for significant volcanic activity associated with this mountain building. A series of ash beds, collectively called the Tioga Bentonite, are present in Middle Devonian rocks throughout much of the Appalachian Basin and into the Illinois and Michigan Basins. The Tioga volcanism is thought to have originated from a source in eastern Virginia. In the subsurface of eastern Ohio, the Columbus and Delaware Limestones are referred to as the Onondaga Limestone.

In northwestern Ohio, on the west side of the topographically positive Findlay Arch, Middle Devonian rocks equivalent to the Columbus and Delaware Limestones, but having different lithologies and terminologies, were deposited on the southern edge of the Michigan Basin. The northwestward equivalents of the Columbus Limestone, in part, are the Sylvania Sandstone, the Amherstburg Dolomite, and the Lucas Dolomite and, into the Michigan Basin, the Detroit River Group. The equivalent of the Delaware Limestone is the Dundee Formation. Above the 60-foot-thick Dundee Formation, which is primarily limestone, is one of the most famous and most meagerly exposed rock units in Ohio, the Silica Formation. This interbedded limestone and shale unit is known worldwide for the abundant and exquisitely preserved Middle Devonian fossils that have been collected for many years from the light-gray shale beds. Although crinoids, brachiopods, and other invertebrates are sought by fossil collectors, the most highly prized are specimens of a trilobite, *Phacops rana*, which are preserved in both prone and enrolled positions. The Silica Formation ranges from 10 to 54 feet in thickness. Above the Silica Formation is the Tenmile Creek Dolomite, which averages about 40 feet in thickness.

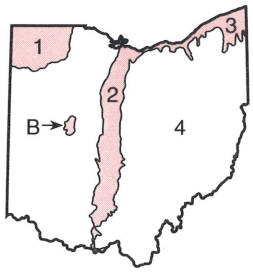
In central Ohio, the Delaware Limestone is overlain by the Olentangy Shale, which is equiva-



Phacops rana, *a trilobite of Middle Devonian age, is one of the most prized fossils from the Silica Formation in northwestern Ohio.*



Generalized nomenclature and relationships of Devonian rocks in various parts of Ohio and their relationships to underlying and overlying geologic systems. Rocks in eastern Ohio (region 4 and part of region 3) are in the subsurface. my = millions of years; Miss. = Mississippian; Kind. = Kinderhookian.



Stratigraphic column areas. B = Bellefontaine outlier.

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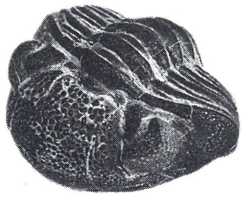

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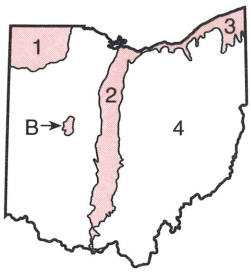


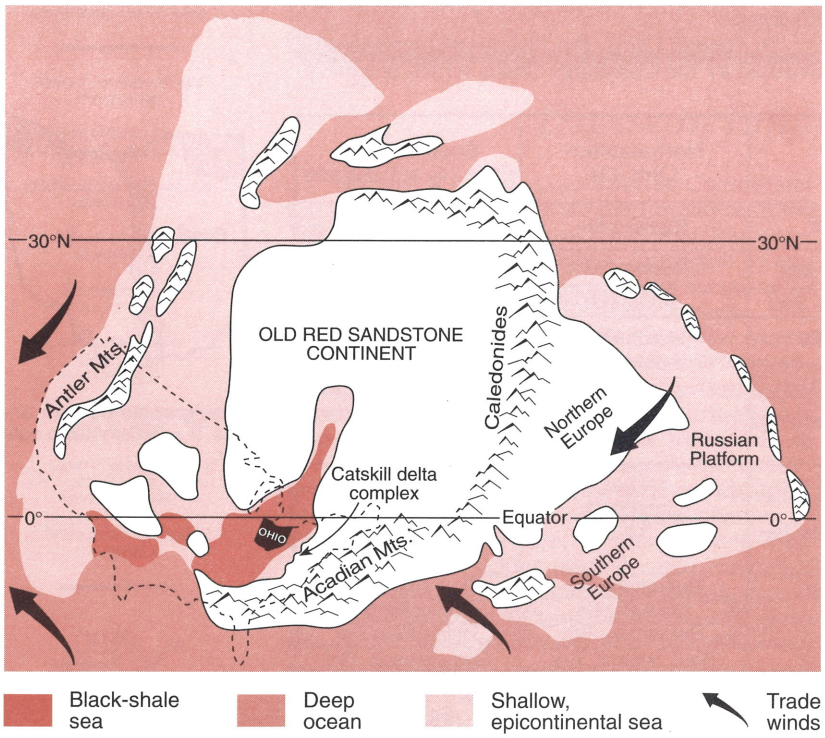
Stratigraphic column areas. B = Bellefontaine outlier.

Age (my)	System	Series	Northwestern Ohio (1)	Central Ohio (2)	Northeastern Ohio (3)	Southeastern Ohio (4) subsurface
360	Miss.	Kind.	Bedford Sh	Bedford Sh	Bedford Sh	Bedford Sh / Cussewago Ss
	Devonian	Chautauquan	Ohio Sh (Antrim)	Ohio Sh: Cleveland Mbr / Three Lick Bed / Huron Mbr	Cleveland Mbr / Chagrin Mbr / Huron Mbr	Cleveland Mbr / Chagrin Mbr / Huron Mbr (Ohio Sh)
		Senecan?	Tenmile Creek Dol / Silica Fm	Prout Ls / Plum Brook Sh / Olentangy Sh	Olentangy Sh	Java Fm / West Falls Fm / Hamilton Gp
		Erian	Dundee Fm	Delaware Ls	Onondaga Ls	Onondaga Ls
		Ulsterian	Detroit River Gp: Lucas Dol / Amherstburg Dol / Sylvania Ss; Holland Quarry Sh	Columbus Ls; Hillboro Ss	Bois Blanc Fm / Oriskany Ss / Helderberg Fm / Bass Islands Dol	Bois Blanc Fm / Oriskany Ss / Helderberg Fm / Bass Islands Dol
408	Silurian	Cayugan	Salina Gp / Tymochtee Dol	Salina Gp	Salina Gp	Salina Gp

Generalized nomenclature and relationships of Devonian rocks in various parts of Ohio and their relationships to underlying and overlying geologic systems. Rocks in eastern Ohio (region 4 and part of region 3) are in the subsurface. my = millions of years; Miss. = Mississippian; Kind. = Kinderhookian.

lent, in part, to the Silica Formation and the Tenmile Creek Dolomite of northwestern Ohio. The Olentangy Shale is bluish to greenish gray, has thin interbeds of limestone, and contains flattened, disc-shaped concretions, especially in the lower part. Fossils are uncommon in this unit, which is about 28 feet thick in its type area in central Ohio and nearly 60 feet thick in southern Ohio, where the limestone beds are not present. The Olentangy Shale does not crop out north of Delaware County owing to thick glacial cover. In Erie County, limited exposures of the Plum Brook Shale and Prout Limestone appear to represent a transitional facies of the Olentangy.

Interbedded in the upper part of the Olentangy Shale are thin stringers of black shale, which reveal the beginnings of a major change in the generally clear, shallow seas that dominated the state throughout the Cambrian, Ordovician, Silurian, and most of the Devonian Periods. The Olentangy Shale is succeeded by a thick, widespread black shale, called the Ohio Shale, which is equivalent to the Chattanooga Shale to the south in Tennessee and Alabama, the New Albany Shale to the west in Indiana, Illinois, and part of Kentucky, and the Antrim Shale in Michigan. The Ohio Shale ranges from 250 to 500 feet thick in its Ohio outcrop area in a narrow band along the southern shore of Lake Erie then southward to the central and southern parts of the state. It is exposed also on the Bellefontaine Outlier in Logan County and is present in northwestern Ohio (Antrim Shale) beneath thick glacial cover. From the central Ohio outcrop area, the Ohio Shale thickens dramatically eastward in the subsurface, reaching a thickness of 3,000 feet in the Appalachian Basin. The Ohio Shale is divided, in ascending order, into the Huron Shale Member, the Chagrin Shale Member, and the Cleveland Shale Member.



Paleogeography of North America during the Late Devonian, at the time of deposition of the Ohio Shale. Ohio was in equatorial latitudes west of the Acadian Mountains. One speculation is that the mountains blocked the westerly trade winds, creating a rain shadow and a sediment-starved, stagnant sea in which black shale accumulated. Modified from Ettensohn and Barron (1981).

The Ohio Shale is one of the most unusual rock units in the state in that it records a long episode of unique environmental conditions during the Late Devonian. This brownish-black to black shale is nearly one-third organic matter by volume and has high concentrations of uranium and heavy metals. Fossils are rare in the shale and consist almost exclusively of terrestrial plants or animals that floated out into the sea or animals that lived in the upper waters. Remains of bottom-dwelling (benthic) animals are almost entirely absent. This circumstance is because the Ohio Shale is interpreted to have been deposited in a stagnant sea in which only the upper surface waters were oxygenated and capable of supporting life. The bottom waters presumably were foul and lacked oxygen (anoxic) and, therefore, were incapable of supporting bottom-dwelling life.

The geologic conditions in which the Ohio Shale and its equivalents formed have been the subject of debate for many years. It is apparent that the Ohio Shale accumulated in an extensive tropical sea into which there was very little sediment influx and that the sea developed a stratified water column; that is, there was no continual or periodic mixing of bottom and surface waters. Thus, abundant organic matter settled into the stagnant bottom sediment and was not destroyed by bacteria.

Some geologists argued that the black shales formed in shallow waters, whereas others postulated that the seas must have been extremely deep to develop a stratified water column. However, neither hypothesis is very likely because (1) epicontinental seas of the Paleozoic apparently were never extremely deep over a wide geographic area, and (2) it is improbable that a shallow sea could have existed over a wide area and maintained quiet, undisturbed bottom waters. As a better understanding developed about continental positions and configurations, and continental collisions that formed mountain chains, a more reasonable, but still debatable, explanation of black-shale deposition emerged.

In 1981, Frank R. Ettensohn and Lance S. Barron of the University of Kentucky proposed a model of deposition for the Ohio Shale that incorporates the geographic position of the Appalachian Basin and mountain building to explain how this unit may have been deposited. By the beginning of Late Devonian time, Ohio was in south equatorial latitudes, a region subject to the westerly trade winds. At this time, North America and Europe were colliding, as they had been since late in Middle Devonian time, forming the Acadian Mountains along the east coast of North America. According to the model of Ettensohn and Barron, the rise of the Acadian Mountains formed an orographic barrier that blocked the trade winds from carrying moisture to the sea on the west side of the mountains, thus creating a rain shadow. The decreased streamflow due to lack of rainfall on the west side of the mountains prevented large amounts of sediment from being carried into the sea to dilute the organic matter generated by plankton in the upper waters, Consequently, large amounts of organic matter accumulated in the sea, where a lack of overturning caused the bottom waters to become stagnant and devoid of oxygen, thus preserving the organic matter.

To the east of Ohio, on the flank of the Acadian Mountains, a large wedge of clastic sediment eroded during the Late Devonian and into the succeeding Mississippian Period formed the Catskill delta. The

distal, subaqueous fringes of this delta are represented by the Chagrin Shale Member of the Ohio Shale, a fossiliferous gray unit in northeastern Ohio. The Chagrin thins southwestward across the Ohio basin and in central and southern Ohio becomes a distinctive thin bed that separates the lower Huron Member from the upper Cleveland Member of the Ohio Shale. This thin equivalent of the Chagrin is called the Three Lick Bed. The enormous extent of the Catskill delta does not seem to fit the rain-shadow model of Ettensohn and Barron because abundant rainfall would be necessary to promote erosion sufficient to produce the large amount of clastic sediment in this delta complex. They explain the presence of the Catskill delta as indicating a break or low area in the Acadian Mountains that permitted moist, equatorial trade winds to cross the mountains and generate rainfall in the delta source area.

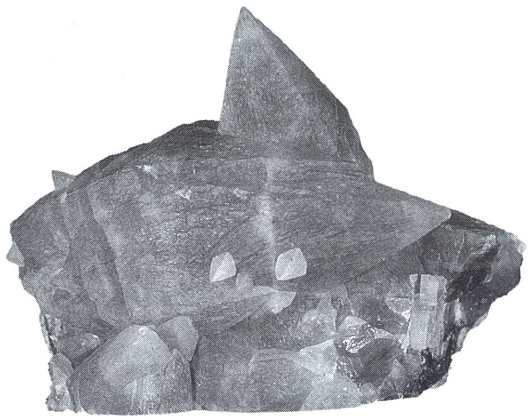
The Huron Member of the Ohio Shale is noted for its large, spherical carbonate concretions, which commonly contain remains of fishes as a nucleus (See *Ohio Geology*, Fall 1994). The Cleveland Member contains fish-bearing carbonate concretions as well, but they tend to be flattened, ellipsoidal masses. These large concretions tend to occur in both vertical and lateral zones and their mode of formation is still not well understood. They have been a source for remarkable fish fossils during more than a century of collecting.

The end of the Devonian Period in Ohio traditionally has been marked by the sudden cessation of black-shale deposition and the appearance of the gray Bedford Shale. This change in sediment type suggests sufficient lowering of the Acadian Mountains so that the moist trade winds could cross and drop rainfall on the western slopes. Some workers have suggested that the Devonian-Mississippian boundary lies above the Ohio Shale-Bedford Shale contact, perhaps as high as the Berea Sandstone. The relative sparsity of fossils in the Bedford and Berea make this time boundary difficult to place with precision.

ECONOMIC GEOLOGY

Devonian carbonate rocks (limestone and dolomite) have long been important to Ohio's economy. The Columbus and Delaware Limestones have been quarried since the early 1800's in their outcrop belt from Pickaway County northward to Lake Erie, including Kelleys Island, and in west-central Ohio on the Bellefontaine Outlier in Logan County. In the 1800's, these units were used extensively as building stone, and many structures have foundations and steps of Columbus or Delaware Limestone. The Ohio State House in Columbus is constructed entirely of Columbus Limestone quarried nearby along the Scioto River. Today, these units are important sources of crushed stone that is used in road construction and building, asphaltic concrete, in portland cement and concrete, railroad ballast, riprap, and for aglime. In northwestern Ohio, the Tenmile Creek Dolomite, Dundee Formation, and Detroit River Group are quarried for similar uses. At least 24 operations in 12 counties extract Devonian carbonate rocks. Many museum-quality mineral specimens have been collected from quarry exposures of Middle Devonian rocks in northwestern Ohio.

Although Devonian rocks have not been the most productive geologic system in the state for oil and gas, two units have made contributions to the energy picture in Ohio. The most important formation has been the Ohio Shale, which contains large amounts of organic matter and natural gas. It is estimated that this unit contains up to 390 trillion cubic feet of gas (tcfg) in Ohio, of which between 6 and 22.5 tcfg are recoverable. Dark, uranium-bearing, organic-rich zones in the Huron Member of the Ohio Shale are most productive; however, natural gas production is closely related to the presence of interconnected fractures in the shale. The Eastern Gas Shales Project, an ambitious and detailed study of the Ohio Shale funded by the U.S. Department of Energy in the late 1970's and early 1980's, was a major focus for state geological surveys and many universities. The numerous reports and maps that resulted from these efforts were designed to stimulate hydrocarbon exploration in shales. In addition, there has been periodic interest in mining these dark shales as a source of oil. However, the cost of mining and processing the shales at this time is not economic.



Crystals of dogtooth spar calcite. These amber-colored crystals are abundant in some quarries in Middle Devonian rocks in northwestern Ohio and are highly prized by collectors. Barite, celestite, fluorite, and marcasite are common minerals associated with calcite in this area.

The Oriskany Sandstone, of Early Devonian age, is present in the subsurface of eastern Ohio and, since drilling of a discovery well in 1900 in Ashtabula County, has been a source of a modest amount of natural gas production from Cuyahoga and Summit Counties in the north to Athens, Meigs, and Washington Counties in the south. Discovery of natural gas in the Oriskany in the Cambridge area in the 1920's sparked the development of glass and brick manufacturing in this area.

DEVONIAN LIFE

Life flourished in the tropical seas of the Devonian Period and began to gain a stronghold on the land as well. The fossil record in Ohio Devonian rocks is a rich one, and several units exhibit a wide variety of well-preserved fossils, many of which are known to paleontologists worldwide.

Middle Devonian rocks, particularly the Columbus Limestone and the Silica Formation, are noted for their abundant remains of brachiopods, corals, echinoderms, trilobites, and a host of other invertebrates. Certain beds in the Columbus Limestone contain remains of colonial corals, some of which are several feet in diameter. Solitary corals are abundant as well. The Columbus Limestone is exposed in many quarries and in natural outcrops

Outcrop of the Columbus Limestone at the Martin Marietta Aggregates quarry (formerly the Owens quarry) near Ostrander, western Delaware County.

along streams; however, because of safety concerns, most of the quarries are no longer open to collectors.

The shale of the Silica Formation is perhaps one of the most remarkable fossil-bearing rock units in the state, rivaling Ordovician rocks for producing abundant and well-preserved fossils. Unlike the widespread Ordovician rocks, the Silica Formation is known in Ohio only from quarry exposures in Lucas County, in northwestern Ohio. Although these quarry exposures were once readily available to fossil collectors, they have long been closed to collecting. Invertebrate fossils from many groups are exquisitely preserved in the soft, gray Silica shale, revealing delicate structures and details when they weather free from the matrix. Although *Phacops rana* trilobites are the most well-known fossils from this unit, experienced collectors prize specimens of a large, robust brachiopod, *Paraspirifer bownockeri*; a more delicate brachiopod, *Mucrospirifer mucronatus*; and a variety of crinoids.

The Devonian is sometimes called "the Age of Fishes" because these vertebrates underwent a broad diversification during the period and were truly the rulers of the seas. By the end of the period, crossopterygian fishes had given rise to amphibians, the first terrestrial vertebrates. This significant occurrence would forever change the landscape.

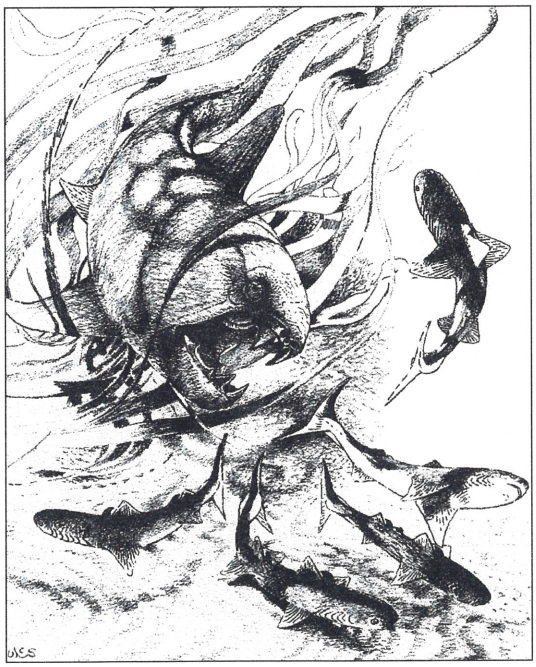
Ohio's record of Devonian fishes is an important one. The earliest occurrence of Devonian fishes in the state is the remarkable fauna from the Holland Quarry Shale in Lucas County. As noted previously, this isolated, single outcrop yielded numerous remains of Early Devonian fishes to the systematic collecting efforts of J. E. Carman of The Ohio State University. The brownish-black shale produced plates of jawless fishes, collectively called agnathans, the only remains of this group of fishes known from the state. Two new heterostracans, *Pteraspis carmani* and *Allocryptaspis laticostatus*, were described from this deposit, as well as fossils of an arthrodire and eurypterids, among other groups. Although the Holland Quarry Shale was long ago quarried and covered over, there is the possibility that similar deposits may be discovered.

Fish remains cannot be considered common in the Columbus and Delaware Limestones; however, skulls of an arthrodire, *Macropetalichthys*, and the sharp-toothed jaws and other plates of a crossopterygian, *Onychodus sigmoides*, have been found. Very small to microscopic teeth and scales of a variety of fishes are concentrated in thin zones, or bone beds, within these limestones.

The most remarkable assemblage of Devonian fishes from Ohio is that of the Ohio Shale, particularly the upper part, the Cleveland Shale Member. Many of these remains consist of large, isolated bones or plates preserved in the center of large carbonate concretions. Most common are the bones of armored arthrodires, of which *Dunkleosteus* is the best known. At least 22 species of arthrodires have been reported from the Cleveland Shale Member. Remarkable also are the remains of the earliest well-known sharks, preserved in exquisite detail in concretions from the Ohio Shale. Most of these sharks belong to the genus *Cladoselache*.

The emergence of amphibians onto the land in the Late Devonian would not have been possible if terrestrial plants had not already taken hold on the land. Although the Ohio Shale likely was deposited far offshore, remains of tree trunks and other parts of terrestrial plants have been found in this unit, presumably washed into the sea from the Catskill delta to the east in Pennsylvania. The most common plant is *Callixylon*, which is now known to be the trunk of a tree whose leaves were earlier named *Archaeopteris*. Some of these logs are several feet in length, and some have been found with crinoids attached to them, suggesting that they floated in the sea for a long time before sinking into the foul bottom muds of the Ohio Shale sea.

A thin (6-foot) zone in the Huron Member of the Ohio Shale has yielded abundant remains of an alga commonly called *Foerstia*, but correctly known as *Protosalvinia*. These fossils are small, shiny, black carbonaceous compressions that are lobed or discoid in shape. It has been suggested that *Protosalvinia* was a seaweed that drifted in the surface waters, similar to the modern *Sargassum* in the Sargasso Sea. It has been found in this narrow vertical zone from Ontario to Oklahoma and is common in Ohio.



A reconstruction of the Late Devonian Cleveland shale sea in which the arthrodire Dunkleosteus *is pursuing a group of sharks of the genus* Cladoselache. *Drawing by W. E. Scheele.*

Devonian rocks reveal evidence of important events in the history of life on Earth from the remarkable fossils preserved in them. Indeed, worldwide perspectives on the Devonian Period are based in part on the fossils found in Ohio's Devonian rocks. Locally, Middle Devonian rocks are an important source of carbonate rock for a variety of purposes to keep our economy healthy and vital. The vast amount of hydrocarbons stored in the Ohio Shale may one day be a critical source of fuel for society. Scenically, the cliffs of Ohio Shale form some of the highest precipices in the state and provide a dramatic view along many streams.

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Editor's note

Because of other staff commitments, no Fall 1998 issue of *Ohio Geology* was published. With this issue, we have dropped the Fall, Winter, Spring, Summer designations and have gone to a numbering system; this issue is 1999, No. 1. *Ohio Geology* will still be published quarterly.

Arie Janssens 1998 Mather Medal recipient

Dr. Adriaan (Arie) Janssens, former Survey geologist and head of the Subsurface Geology Section and long-time consulting geologist, was the 1998 recipient of the Mather Medal of the Division of Geological Survey. He received the medal at a banquet held in his honor on September 25, 1998, in Columbus.

The Mather Medal is awarded periodically by the Division of Geological Survey in recognition of lifelong contributions to the knowledge of the geology of Ohio. The award is named in honor of William W. Mather, the first State Geologist of Ohio (1837-1838). The medal was first given in 1987 and since then 11 individuals have received the award.

Dr. Janssens was given the Mather Medal for his significant and ongoing work on the subsurface Lower and Middle Paleozoic rocks of Ohio. He developed an interest in these rocks when he joined the Ohio Geological Survey in 1967 and, within a short time, became the authority on them. In 1970, he published Survey Report of Investigations No. 78 on the Middle Devonian rocks of northwestern Ohio; in 1973, he published Survey Bulletin No. 64 on the Cambrian and Lower Ordovician rocks of Ohio; and, in 1977, he published Survey Report of Investigations No. 100 on the Silurian rocks of northwestern Ohio. These volumes are still highly regarded, valuable references on the stratigraphy and relationships of these rocks. Bulletin 64 brought together much new information and the first comprehensive interpretation of the poorly known Cambrian and Lower Ordovician rocks, which are nowhere exposed at the surface in the state.

Arie was born in the Netherlands and came to the United States in 1956 after attending automotive school in his homeland. He soon began to pursue higher education and received a B.S. degree in geology from Kent State University in 1961. He then earned M.S. (1964) and Ph.D. (1967) degrees from The Ohio State University.

Arie became head of the Subsurface Geology Section of the Survey in 1971 and began an enthusiastic program of acquiring geophysical logs and well-cutting samples from oil and gas wells drilled in the state. Of course, the well cuttings are given to the Survey after the company geologist has examined them. The story is told that once Arie was so enthusiastic about adding samples to the Survey collection that he picked them up at a well before the company geologist had the opportunity to even look at them. Not only did he have an aggressive program of adding valuable data to the Survey files, Arie organized these data in such a way that they are easily viewed by industry geologists. Over the years, the Survey has received many comments from industry geologists about how these data are so well organized compared to similar data in organizations in other states. During his tenure, Arie was instrumental in assuring that oil- and gas-well location maps were posted in a timely fashion and were easily accessible to industry.

In 1976, Arie left the Survey to become a consultant to Ohio's oil and gas industry. His departure was a tremendous loss to the Survey but certainly an asset to industry, as Arie's unparalleled expertise made him much in demand as a consultant. In 1981 and 1982, Arie went to Australia to

Arie Janssens (right) receives the Mather Medal from Division Chief Thomas M. Berg.

work for the Western Australia Geological Survey. Fortunately for Ohio, he returned and resumed his petroleum consulting business in the state. Even though he has been in the private sector for more than two decades, Arie has continued his research interests in Lower and Middle Paleozoic rocks in Ohio and regularly gives papers at professional and technical meetings on his discoveries and conclusions, thus adding to our fundamental knowledge of Ohio's geologic framework.

Arie is a long-time member of the Ohio Geological Society and, in 1993, he proposed and organized the first of what has become an annual Technical Symposium of the Ohio Geological Society. This symposium, informally known as the "Canton Symposium" because it was first held in that city, has become an important forum for the presentation of geologic and technical information of importance to the state's oil and gas industry. Each year at this meeting, Arie makes available production statistics on Ohio deep wells, information that he personally compiles.

The contributions of Arie Janssens to the knowledge of the geology of Ohio throughout more than a 30-year period have been significant and, indeed, he has single-handedly contributed more to the knowledge of the geology of Cambrian through Devonian rocks than any other individual. Geologists owe Arie a great debt for revealing the wonders and complexities of the great sequences of rock that lie hidden below Ohio, and the petroleum industry and the citizens of the state have been benefactors as well.

Ohio's Mineral Industries & the Environment teachers workshops

Are you a teacher who would like to learn about Ohio's geology and mineral resources? Observe how resources such as sand and gravel, limestone, sandstone, and coal are mined and processed for use? See how mining is compatible with environmental protection? Have an opportunity to collect a variety of rocks and fossils? Then, one or both of the Ohio's Mineral Industries and the Environment—North and South—workshops are for you.

These summer workshops are conducted by the Ohio Department of Natural Resources, Division of Geological Survey and the University of Akron. The northern Ohio workshop is based in Akron and will be held July 12-16, 1999. The southern Ohio workshop is based in Columbus and will be held July 26-30, 1999. Participants must register for 2 semester hours of graduate or undergraduate credit through the University of Akron.

For more information and registration materials contact:

Doug Crowell, Ohio Department of Natural Resources, Division of Geological Survey, 4383 Fountain Square Drive, Columbus, OH 43224-1362; telephone: 614-265-6594; e-mail: doug.crowell@dnr.state.oh.us or Dr. Roger Bain, Department of Geology, University of Akron, Akron, OH 44325-4101; telephone: 330-972-7659; e-mail rbain@uakron.edu.

Erratum for OGS Report of Investigations No. 143 on the Trenton Limestone

Although a 1985 film script by Dr. Joseph J. Arpad is credited as a major source of the information for the discussion of the historical development of the Lima-Indiana trend on pages 35-40 of Ohio Division of Geological Survey Report of Investigations No. 143, *Stratigraphy, structure, and production history of the Trenton Limestone (Ordovician) and adjacent strata in northwestern Ohio*, the material taken directly from Dr. Arpad's script was not properly or fully acknowledged. A copy of the text of the historical discussion that includes indication of the direct quotations from Dr. Arpad is available upon request from the Geologic Records Center of the Survey. The article on *Boom Towns* in the November/December 1994 issue of *Timeline*, published by the Ohio Historical Society, was based on the historical discussion from RI 143 but failed to acknowledge Dr. Arpad's film script as the source of much of the information. The Survey expresses its deep regrets and apologies to Dr. Arpad for the unintentional misappropriation of his work.

Ohio Geology

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