Ohio Geology

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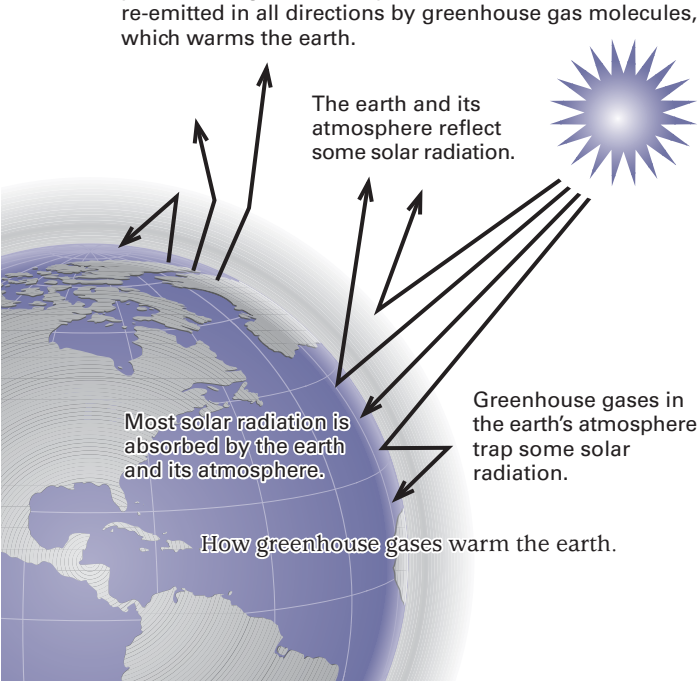
Geologic sequestration of carbon dioxide in Ohio

By Larry Wickstrom

Much research on carbon dioxide sequestration is taking place worldwide, yet many people do not understand what sequestration is and why so much effort is going into researching it.

Carbon dioxide (CO_2) naturally occurs in the air we breathe and within the earth's crust. We also use it in fire extinguishers and dry ice and as the source of bubbles in soda pop. So, why are we trying to get rid of such a common and useful gas?

Carbon dioxide is one of many gases known to cause an elevated warming of the earth through the greenhouse effect. Known greenhouse gases (GHGs) include carbon dioxide, methane, nitrous oxides, and hydrofluorocarbons. Carbon dioxide comprises nearly 80% of the GHGs emitted into the atmosphere by humans. Many people feel that human contributions of GHGs into the atmosphere may be having a significant impact on global climate change. Thus, research is taking place on ways to reduce the amount of GHGs that society emits into the atmosphere.



How greenhouse gases warm the earth.

The United States emits more CO_2 than any other country in the world. Total world anthropogenic (human-made) CO_2 emissions for 2002 are estimated to have been 24,405 million metric tons. In 2005, the U.S. Energy Information Administration reported that the United States emitted 5,746 million metric tons of carbon dioxide. During the same year, Western Europe was the second-largest producer of CO_2 emissions at 3,585 million metric tons, and China was the third-largest producer at 3,176 million metric tons (it is projected that China will emit more CO_2 than the United States within the next several years). Within the United States, Ohio is the fourth-largest producer of CO_2 emissions behind California, Texas, and Pennsylvania, respectively.

It is estimated that in 2003, Ohio emitted 265.5 million metric tons of CO_2 into the atmosphere. This amount is distributed between electric power generation, transportation, industry, and commercial and residential output. The primary sources of anthropogenic CO_2 are activities that involve burning hydrocarbons. Other activities, such as the manufacture of iron and steel, cement, and fertilizers, also contribute significantly to Ohio's carbon footprint (a carbon footprint is the total amount of carbon dioxide directly or indirectly caused by a specific activity, entity, or product life cycle). The two largest sources of Ohio's CO_2 from hydrocarbons are electric power generation and transportation. Nearly 90% of Ohio's electricity comes from coal-burning power plants, and coal-burning power plants are the single largest emitter of CO_2 in Ohio.

To be sustainable in the long-term, our society must develop more fuel-efficient vehicles and, ultimately, an alternative energy source for transportation. For near-term planning, large industrial point-sources of CO_2, such as coal-burning power plants, provide the best and most cost-efficient opportunity to capture and sequester CO_2 before it is emitted into the atmosphere.

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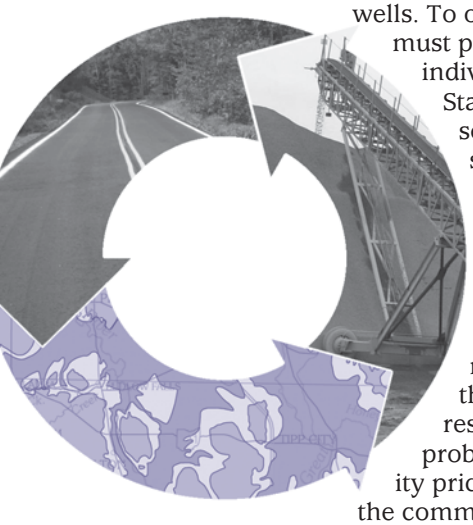
OHIO ROCKS!

Larry Wickstrom,
Division Chief and State Geologist

Recently, stakeholders in many natural resources issues have placed much emphasis on the term *sustainable development*, which was defined by the 1987 Brundtland Commission as "meeting the needs of the present without compromising the ability of future generations to meet their own needs." I think the popularity of this concept is long past due and I hope the momentum of sustainable development continues in its *wise* application.

The Division of Geological Survey investigates many aspects of Ohio's geology that are relevant to sustainable development in the state. Geology is the ground we live on; the rocks and minerals we use to produce building materials and energy; the geologic hazards (such as landslides and earthquakes) that threaten us; and so much more. How our society uses natural resources and interacts with our geology (building roads or shopping malls, for example) affects the sustainability of such developments. By striving for sustainable development, we are recognizing that we cannot control what nature gives us any more than we can control earth processes like erosion or the rising and falling of water levels. We can only control *how* we use our natural resources for short- and long-term development.

Each of us uses a large amount of energy and mineral resources every day. To meet our own demands, we must operate sand, gravel, and limestone quarries; mines; and oil and gas wells. To obtain sustainable development, we must practice conservation methods on an individual and national level. The United States, and Ohio in particular, have some of the highest environmental standards and regulations in the world. When we deny development of extractive industries locally, we are often transferring the burden of producing the commodities that we use to somebody who will develop the resources using environmental standards that are lower than our own. By displacing this responsibility, we make environmental problems worse and increase commodity prices for ourselves, especially when the commodities have to be transported from remote locations to our own localities.



The Five P's—Proper Planning Prevents Poor Performance. We've all heard this saying before, but, until recently, few of our communities actually took into account their natural resources management when planning for development (even though communities are built and maintained using natural resources). Here's a scenario that has happened over and over again across the nation: A local zoning commission allows developers to build wherever they want; for example, next to an existing quarry. In this situation, rock material from the quarry is used to build houses and roads in the development, and then the quarry cannot be expanded because of the dense housing development around it. Soon, all of the "neighbors" complain about the dust and noise from the quarry and start efforts to shut it down. Inevitably, the quarry operator is portrayed as the source of the problem when in reality the lack of planning from developers and community leaders began the problem. This is just one example of how our society needs to take control of our development in a sustainable manner. Thankfully, some local and regional commissions are now considering our natural resources when planning. It is short-sighted to develop over our best sand and gravel deposits and our access to the best groundwater just as it is short-sighted to build in landslide prone areas.

The work products of the Ohio Geological Survey are an integral part of long-range planning for sustainable development, which helps prevent future conflicts, shortages, and myriad other problems. Our mapping shows where the best sand and gravel, aggregate, and coal deposits exist and helps identify and delineate lake coastal erosion and other geohazards, as well as groundwater resources.

While on the topic of sustainable development, readers should know that the Division of Geological Survey has been very involved for several years in characterizing the geology of the state for geologic sequestration of carbon dioxide, which is released during many natural and human-caused processes, such as when coal is burned for electric power generation. The lead article in this month's *Ohio Geology* attempts to explain a little more about carbon dioxide sequestration and how it affects our state.

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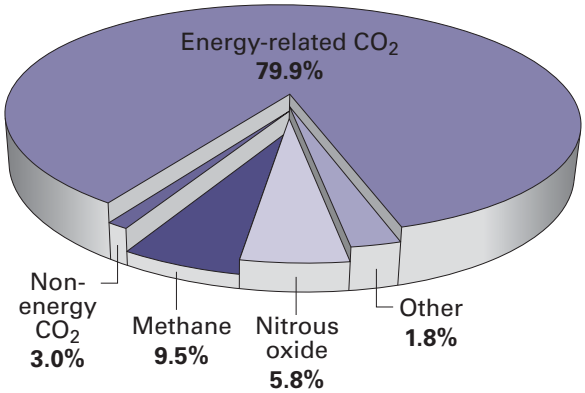


Percentage breakdown of greenhouse gases (excluding water vapor) that humans emit into the atmosphere. (Data source: <http://www.climatetechnology.gov>)

What is CO_2 Sequestration?

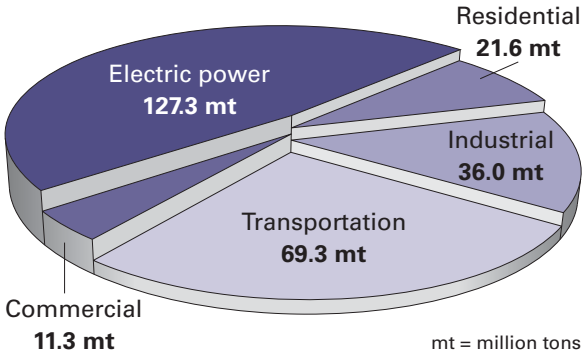
Carbon dioxide sequestration, simply put, is capturing and securely storing carbon dioxide from the atmosphere and/or human-made sources before it is released into the upper atmosphere. There is a natural carbon cycle in which earth processes consume carbon (e.g., photosynthesis; weathering of silicate rocks) as well as produce carbon dioxide (e.g., volcanoes; oxidation of plant life). Most of the CO_2 released into the atmosphere is from these natural processes. Anthropogenic CO_2 emissions account for only 3 to 4% of the world's carbon output, but many scientists feel that this amount is enough to cause global climate change.

We can use natural processes to sequester CO_2 from the atmosphere and mitigate anthropogenic CO_2. Through agriculture, development, mining, and other activities, humans have removed a significant amount of carbon from our soil systems. Terrestrial sequestration methods such as no-till farming seek to replenish this lost carbon by capturing carbon from the atmosphere via photosynthesis and locking it into the soil. However, there is a limit to how much carbon the soil can hold, so terrestrial sequestration cannot mitigate the effects of all anthropogenic CO_2.

Geological sequestration involves injecting CO_2 into appropriate rock units in the deep subsurface (generally greater than 2,500 feet deep) where it is securely stored, or trapped. Once it is trapped in the subsurface, it will slowly combine with the native fluids found in the rocks and react with the minerals and organic matter in the geologic formation to form (precipitate) stable compounds/minerals, primarily calcium, iron, and magnesium carbonates. Mapping of geologic sequestration capacities by the Division of Geological Survey and other resource professionals has shown hundreds of years of storage capability in Ohio. The wide-scale deployment of geologic and terrestrial sequestration technologies appears to be key in facilitating sustained and significant reductions in CO_2 emissions.

The primary attraction of geologic sequestration for public planners and resource professionals is the potential for direct and long-term storage of CO_2 emissions in close proximity to large CO_2 sources (such as ethanol or power plants). However, to achieve this objective, the potential capacity of any geologic reservoir needs to be verified by detailed regional assessments, as well as site-specific investigations to allow decisions-makers to fully understand the characteristics of the geologic sequestration system. The Division of Geological Survey has been working on both regional and site-specific projects over the past seven years.

Natural geologic reservoirs have held oil, natural gas, water, and even CO_2 for millions of years with minimal to no leakage. These same systems are thought to offer both near-term opportunities and longer-term possibilities for future management of anthropogenic CO_2. Some industries use these natural reservoirs for storage of industrial wastes (hazardous and industrial waste injection wells) and the disposal of oilfield brines (brine injection wells). Natural gas is also stored in geologic reservoirs for later withdrawal during peak (winter) usage periods to lessen the demand on the interstate pipeline system. Additionally, the injection of CO_2 in oil field reservoirs to stimulate additional oil production (enhanced oil recovery [EOR]) has been taking place since the early 1970s and is a growing methodology in the petroleum industry. Thus, substantial experience with geologic injection operations already exists.



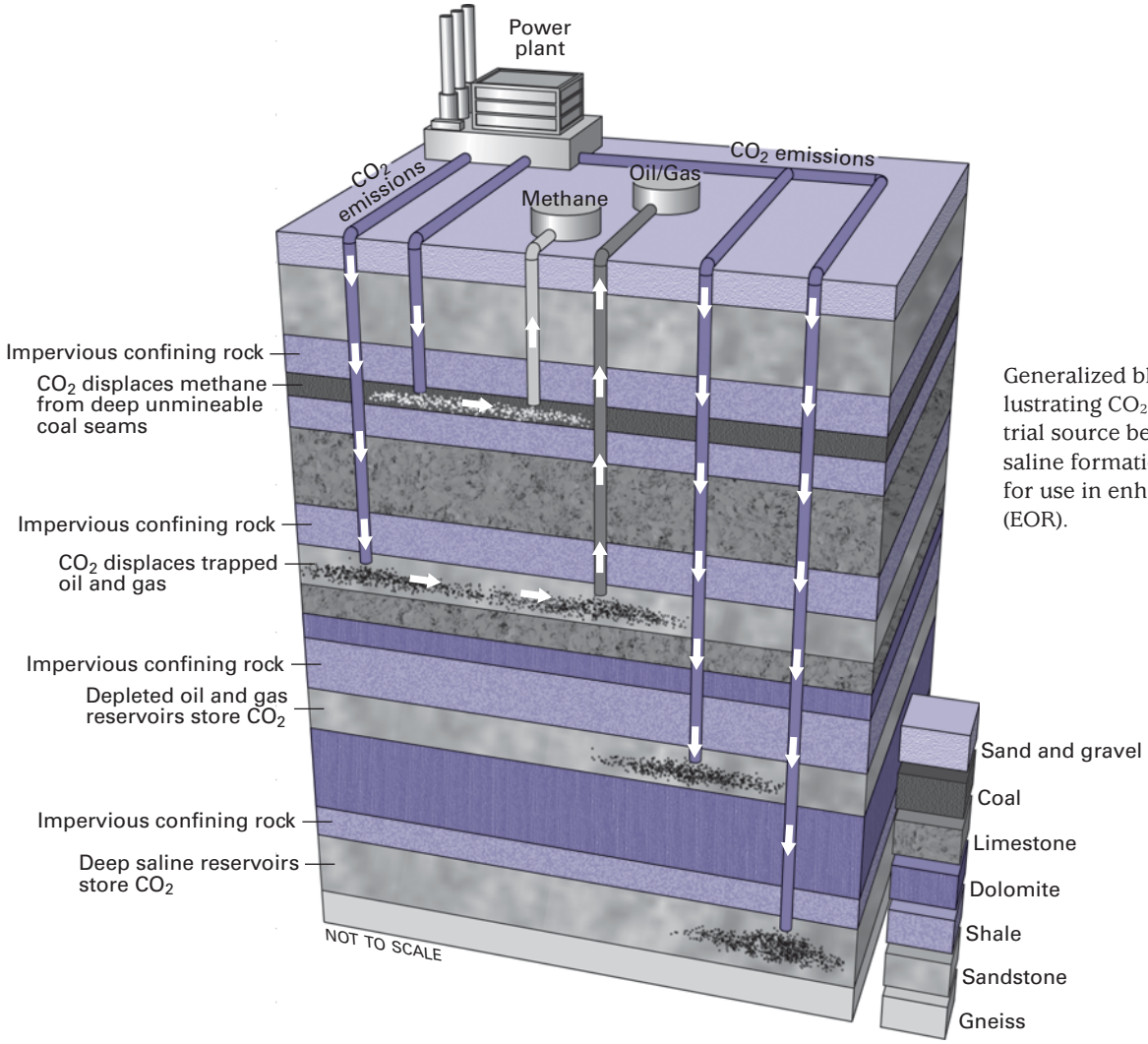
Ohio's anthropogenic CO_2 emissions by sector (2003). (Data source: U.S. Energy Information Agency)

What are Ohio's primary potential geologic reservoirs for CO_2?

There are several types of geologic reservoir systems that are being investigated for potential CO_2 sequestration. In Ohio, two types have the largest near-term capacity for storage and use. These are deep saline formations and oil and gas fields.

Deep saline formations are natural saltwater-bearing intervals of porous and permeable rocks that occur beneath the level of potable groundwater. Currently, a number of saline formations in Ohio are used for waste-fluid disposal; thus, a long history of technological and regulatory factors exists that could be applied to CO_2 injection/storage. Saline formations are widespread, close to many large CO_2 sources, and are thought to have large pore volumes available for potential injection. In order to maintain the injected CO_2 in liquid form, the injection zone must be approximately 2,500 feet or greater in depth. Maintaining the CO_2 in a liquid phase is desirable because it can more readily mix and go into solution with a native formation's brine and, as a liquid, it takes up less volume than when it is in gaseous form. One ton of CO_2 at surface temperature and pressure (in its gaseous phase) occupies almost 18,000 cubic feet. The same amount of CO_2 injected to a depth of approximately 2,500 feet will occupy only 50 cubic feet. The 2,500-foot minimum sequestration depth also helps insure that there is an adequate interval of rocks (confining layers) above the potential injection zones to serve as a geologic seal.

In these types of reservoirs, CO_2 is injected under pressure down a specially constructed well into the reservoir where it displaces and mixes with saline water and fills the pore spaces between the mineral grains of the rocks in the reservoir. The CO_2 is trapped within the rock matrix. Depth, permeability, injectivity, reservoir pressure, reservoir integrity, and water chemistry are some of the variables that control the seques-



Generalized block diagram illustrating CO_2 from an industrial source being injected in deep saline formations for storage and for use in enhanced oil recovery (EOR).

tration potential of deep saline formations. In addition to the properties of the injection zone or reservoir, characterization of the overlying seal units (confining layers) is necessary. The injected CO_2 has a lower specific gravity than natural formation fluids, thus it is more buoyant and will rise to the top of the porous zones. Cap rock units must be relatively impermeable and sufficiently thick to arrest any appreciable vertical movement of the CO_2 within the sequestration interval, thereby trapping it in the deep subsurface.

Oil and gas fields represent geologic traps (structural or stratigraphic) that contain hydrocarbons within a reservoir with a known cap or seal. In depleted or abandoned petroleum fields, CO_2 sequestration would take place by injecting CO_2 into the reservoir to fill the pore volume left by the extraction of oil or natural gas resources. The injected CO_2 would be trapped by the same limits as the original hydrocarbon for secure storage in the reservoir. Volume, permeability, injectivity, pressure, reservoir integrity, water chemistry, the nature of the cap rock or reservoir seal, and the history of production are some of the variables that control the sequestration potential of depleted oil and gas fields. This may be an attractive sequestration option in some parts of Ohio because large areas of the state have a long history of oil and gas recovery (to view an Ohio oil and gas fields map online, go to <www.ohiodnr.com/Portals/10/pdf/pg01.pdf>. However, much caution must be exercised when investigating this potential because of the large number of old, undocumented wells abandoned within some areas of the state. These wells could provide pathways for the CO_2 to leak upward.

In active oil fields, it has been demonstrated in other parts of the country that CO_2 can be used for enhanced oil recovery (EOR). In this process, some of the oil that remains in reservoirs after primary production is recovered by injecting CO_2 that 1) repressurizes the reservoir and displaces and drives the remaining oil to a recovery well, and 2) directly mixes and chemically interacts with the remaining oil to make it more mobile, allowing more oil to be pushed to the producing wells (miscible flooding). Approximately 70 oil fields worldwide (most of these in the western US) currently inject CO_2 for EOR, and over 1 billion barrels of additional oil have been produced, which demonstrates the effectiveness of this value-added sequestration option. The Division of Geological Survey maintains the oil and gas field maps of Ohio and performs research to characterize the reservoirs for more efficient production of oil and gas and for possible use of them as CO_2 containers. The Division of Geological Survey is currently attempting to form partnerships and the funding necessary to investigate the effectiveness of using specific Ohio reservoirs for CO_2 EOR.

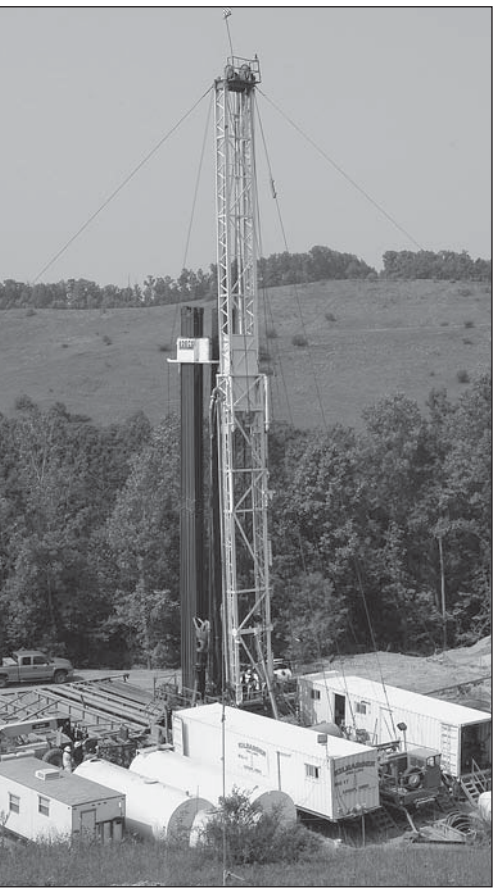
A third type of geologic reservoir, deep, unmineable coal beds, may have (limited) potential for storing CO_2 in Ohio. Carbon dioxide injected into unmineable coal beds would not only occupy pore space but bond, or adsorb, onto the carbon in the coal. Because of this adsorption, miscibility would not be a concern like in oil and gas reservoirs and saline formations, and CO_2 injection (and resulting enhanced recovery of coalbed methane) could occur at shallower depths than in depleted oil reservoirs or saline formations.

Coal beds often contain large amounts of methane within the pore space of the coal as well as adsorbed onto the coal itself. The adsorption rate for CO_2 in coals is approximately twice that of methane; thus, injected CO_2 displaces methane and allows for potentially enhanced gas recovery while sequestering CO_2.

Is Ohio well suited for geologic CO_2 sequestration?

The Division of Geological Survey has been analyzing data from tens of thousands of wells and producing dozens of maps of favorable Ohio sequestration reservoirs and cap rocks as part of a multi-state partnership, the Midwest Regional Carbon Sequestration Partnership (MRCSP). Some of the resultant maps and data can be viewed as an interactive map available on the Division's website <www.dnr.state.oh.us/website/geosurvey/MRCSPGEO/disclaimer.htm>; you may also want to visit the MRCSP website <www.mrcsp.org> for more information about the partnership and CO_2 sequestration in general. The Division of Geological Survey will soon release a publication about the regional mapping and capacities estimate for the state and the Midwest region.

The partnership's initial assessments of Ohio's deep CO_2 storage capacity indicate that Ohio can potentially sequester approximately 45 billion tons of CO_2. This represents about 350 years of Ohio's current output of CO_2 from stationary point sources. However, that capacity is not equally distributed around the state—some geologic areas have high storage potential while other areas have little to no potential. This is very important information to help the public and large CO_2-producing industries plan for future CO_2 sequestration sites and/or pipelines that distribute CO_2 from point-source locations to appropriate storage sites.



Drill rig on location at the Ohio Geological Survey CO_2 No. 1 carbon sequestration research well in Tuscarawas County, Ohio.

In addition, we still have much to learn about the rate at which reservoirs will accept CO_2 and how pressure buildup from neighboring injection operations might interact with one another. This information is vital in determining how many wells would be needed and the spacing intervals between them, which determine the level of compression needed, pipeline lengths, and the overall distribution of operations. Therefore, the Division of Geological Survey continues to develop more detailed data, maps, and models related to CO_2 sequestration. Working with the Ohio Air Quality Development Authority, Battelle Memorial Institute, and the U.S. Department of Energy, we recently completed drilling a deep test well < www.ohiodnr.com/Home/ogcim/ogcim/Co2/tabid/17870/Default.aspx > in Tuscarawas County. We are now performing detailed analyses on its rock materials and data and will issue a report on this important project in early 2008. We also continue to gather and analyze data from existing and new deep wells.

Through geologic sequestration research, the Division of Geological Survey has gained close partnerships with dozens of companies and trade associations, including the U.S. Department of Energy, Battelle Memorial Institute, the Ohio Coal Development Office, the Ohio State University, Western Michigan University, the Interstate Oil and Gas Compact Commission (IOGCC), and the state geological surveys of Indiana, Illinois, Kansas, Kentucky, Maryland, Michigan, Pennsylvania, and West Virginia. Through these efforts and partnerships, the Division of Geological Survey has assumed a regional leadership role in carbon sequestration and is nationally recognized for this role. The knowledge gained and the contacts maintained through this work have helped prepare Ohio for future greenhouse gas registries and regulations and for companies that plan to build clean fuel and power plants in our state.

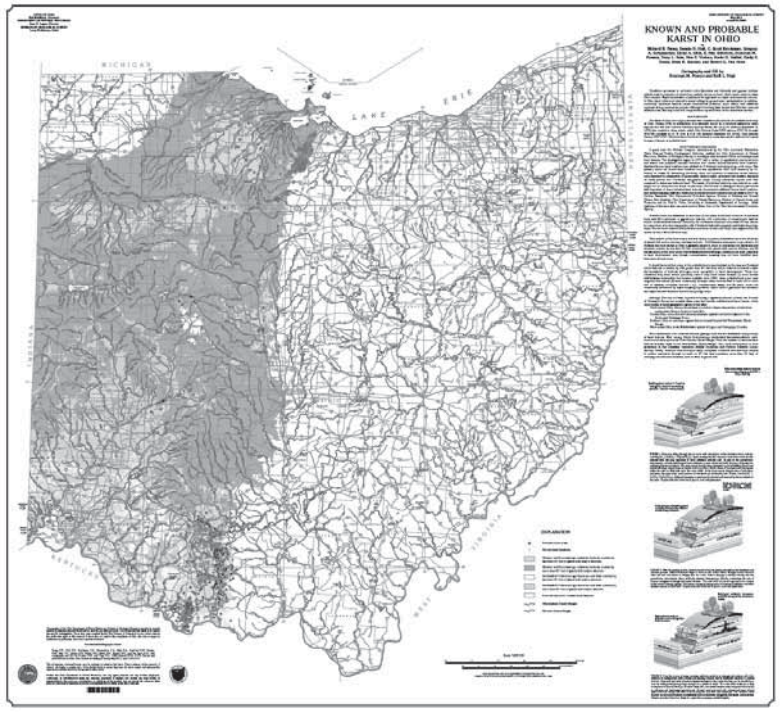
Further Reading

The Brundtland Commission, 1987, Our Common Future: Oxford, Oxford University Press, 400 p. *The full text of the Brundtland Report, hosted by the Swiss Federal Office for Spatial Development ARE, can be downloaded as a scanned copy of the UN General Assembly document A/42/427—a 16 MB pdf file at < http://www.are.admin.ch/themen/nachhaltig/00266/00540/00542/index.html?lang = en > .*

Revised karst map available

The 2007 release of *Known and Probable Karst in Ohio,* originally released in 1999 and revised in 2002, includes new drift thickness and karst data—including 57 newly documented sinkholes and caves—giving map users a more comprehensive product to use when identifying karst areas. The map depicts areas of known and probable karst terrain, where dissolution processes in carbonate rocks (limestone and dolomite) and gypsum have produced networks of conduits below the surface and sinkholes and caves at the surface. Environmental and societal concerns related to karst include groundwater contamination and unexpected construction costs and delays.

Known and Probable Karst in Ohio can be purchased from the Ohio Geological Survey for $15. Please see ordering information on page 8.



Book review of Roadside Geology of Ohio

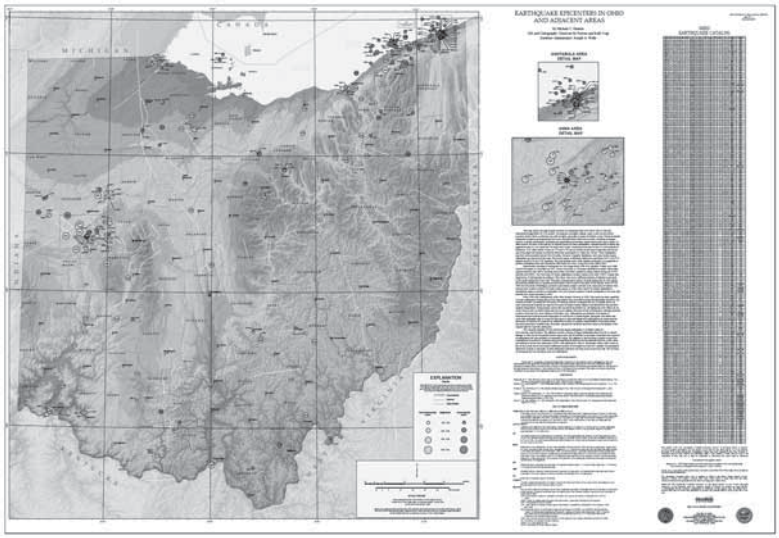
Roadside Geology of Ohio is University of Toledo Geology Professor Dr. Mark Camp's second book in Mountain Press's Roadside Geology series. The series' six-by-nine-inch paperback format and vision-friendly text and graphics make the book easy to use while traveling. Instead of chapters in a book or a map in an atlas, this book features 25 driving routes, such as "I-71: Columbus to Cincinnati." Each route has an overview map, usually with several geologic or historic features labeled on it, and a few pages describing the geology along the route. Camp expands on his book's introductory review of geology by including a discussion on the geology, bedrock formations, and Ice Age deposits and features in four Ohio regions. He also describes significant geologic and historic events specific to each region.

In addition to the route maps and text, there are numerous sidebar features on points of geologic, historic, and economic interest that are either quickly accessible or visible from many of the routes. This well-illustrated book has numerous historic and present-day black and white photographs highlighting Ohio's geology and how it played a role in the state's development. The book also includes a glossary, a list of additional reading material, and a thorough index. This book will be a valuable asset to anyone living in or visiting Ohio who wants to make traveling through the state both entertaining and educational.

—Doug Shrake

Roadside Geology of Ohio can be purchased from the Ohio Geological Survey for $24. Please see ordering information on page 8.

Revised Ohio earthquake map available



Earthquake Epicenters in Ohio and Adjacent Areas was originally developed in 2002 to document the magnitude and spatial distribution of earthquakes with epicenters in Ohio and surrounding areas. More than 30 earthquakes in the Ohio region have occurred since 2002 and are included on the new 2007 map, which allows map users to easily gain information about the most recent earthquakes, as well as earthquakes dating back to 1776: earthquake event time, location, depth, magnitude, felt-area size and information source. This dataset allows users to determine which portions of the state are historically more susceptible to earthquakes and to apply this knowledge to varied applications, including earthquake insurance rate determinations, construction strength determinations for bridges and buildings, and research on deep-earth structures such as hidden faults.

The new map shows a concentration of earthquake epicenters in two areas of the state: western Ohio in the vicinity of Shelby County, and along the Lake Erie coast in Lake County at Painesville. While it might seem like earthquakes are occurring more frequently in recent years, the Ohio Seismic Network attributes this perceived change to improved technology and communication among people who experience the earthquakes.

Earthquake Epicenters in Ohio and Adjacent Areas can be purchased from the Ohio Geological Survey for $10. Please see ordering information on page 8.

Survey staff changes

Comings:

- Mike P. Angle–Geology Program Supervisor, Geologic Mapping and Industrial Minerals Group
- Christopher P. Gordon (promoted)–Geologist 2, Energy Resources Group
- Katy H. Pan–Publications Editor, Technology Transfer Group

Goings:

- Paul M. Harbulak–Geographic Information Management Systems Specialist 2, Lake Erie Geology Group
- Christiana A. Tickle–Publications Editor, Technology Transfer Group

Ordering information

To order any of the Survey's publications or maps, contact the Geologic Records Center, 2045 Morse Road, Bldg. C-1, Columbus, Ohio 43229-6693; telephone: 614-265-6576; fax: 614-447-1918; email: geo.survey@dnr.state.oh.us. In-state sales tax rates are based upon the county where the map is shipped. Handling charges apply to all mailed orders (please call for rates). Visa and MasterCard are accepted.

Re-release of popular local geology book

With help from their supporters, including the Ohio Geological Survey, the Kentucky Geological Survey recently released the second edition of University of Cincinnati (UC) Geology Professor Emeritus Paul E. Potter's *Exploring the Geology of the Cincinnati/Northern Kentucky Region*. Potter's 128-page report-style paperback is popular with amateur and professional geologists, historians, teachers, and planners because it carefully balances technical information about the area with many illustrations, sidebars, and interesting photographs. Potter says about half of the 87 illustrations in the book have been updated for the new version. The text also reflects new information about subsurface geology and how it affects people at the surface.

Sections of the book are dedicated to today's geological issues, such as land movements, how geology affects groundwater levels, and use of geographic information systems (GIS). However, the immediate and local relevance of geology is present throughout the history sections of the book as well.

Potter's publication is unique in that it focuses on a primarily urban area. It is timely because it reflects the significant population growth of the Cincinnati area in recent years. When the book was first released in 1996, the area's population was 1.7 million. Today it is 2 million.

Exploring the Geology of the Cincinnati/Northern Kentucky Region can be purchased from the Ohio Geological Survey for $15. Please see ordering information at left.

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