

# 45<sup>th</sup> Forum on the Geology of Industrial Minerals

Program with Abstracts and Field Trip Guide

“Building The Future”

Delaware, Ohio, USA

October 4–6, 2009

Hosted by:

Ohio Department of Natural Resources

Division of Geological Survey

Sponsored by The Ohio Geological Society

45<sup>th</sup>



Forum on the  
Geology of  
Industrial  
Minerals  
2009



**Forum on the  
Geology of  
Industrial  
Minerals  
2009**

Host



Sponsors



Field trip host



## Annual Meetings of the Forum on the Geology of Industrial Minerals

|                  |      |  |
|------------------|------|--|
| 1 <sup>st</sup>  | 1965 | Columbus, Ohio   |
| 2 <sup>nd</sup>  | 1966 | Bloomington, Indiana   |
| 3 <sup>rd</sup>  | 1967 | Lawrence, Kansas   |
| 4 <sup>th</sup>  | 1968 | Austin, Texas  |
| 5 <sup>th</sup>  | 1969 | Harrisburg, Pennsylvania                                     |
| 6 <sup>th</sup>  | 1970 | Ann Arbor, Michigan  |
| 7 <sup>th</sup>  | 1971 | Tampa, Florida   |
| 8 <sup>th</sup>  | 1972 | Iowa City, Iowa  |
| 9 <sup>th</sup>  | 1973 | Paducah, Kentucky  |
| 10 <sup>th</sup> | 1974 | Columbus, Ohio   |
| 11 <sup>th</sup> | 1975 | Kalispell, Montana   |
| 12 <sup>th</sup> | 1976 | Atlanta, Georgia   |
| 13 <sup>th</sup> | 1977 | Norman, Oklahoma   |
| 14 <sup>th</sup> | 1978 | Albany, New York   |
| 15 <sup>th</sup> | 1979 | Golden, Colorado   |
| 16 <sup>th</sup> | 1980 | St. Louis, Missouri  |
| 17 <sup>th</sup> | 1981 | Albuquerque, New Mexico                                      |
| 18 <sup>th</sup> | 1982 | Bloomington, Indiana   |
| 19 <sup>th</sup> | 1983 | Toronto, Ontario, Canada                                     |
| 20 <sup>th</sup> | 1984 | Baltimore, Maryland  |
| 21 <sup>st</sup> | 1985 | Tucson, Arizona  |
| 22 <sup>nd</sup> | 1986 | Little Rock, Arkansas  |
| 23 <sup>rd</sup> | 1987 | North Aurora, Illinois                                       |
| 24 <sup>th</sup> | 1988 | Greenville, South Carolina                                   |
| 25 <sup>th</sup> | 1989 | Portland, Oregon   |
| 26 <sup>th</sup> | 1990 | Charlottesville, Virginia                                    |
| 27 <sup>th</sup> | 1991 | Banff, Alberta, Canada                                       |
| 28 <sup>th</sup> | 1992 | Martinsburg, West Virginia                                   |
| 29 <sup>th</sup> | 1993 | Long Beach, California                                       |
| 30 <sup>th</sup> | 1994 | Frederickton, New Brunswick/<br>Halifax, Nova Scotia, Canada |
| 31 <sup>st</sup> | 1995 | El Paso, Texas   |
| 32 <sup>nd</sup> | 1996 | Laramie, Wyoming   |
| 33 <sup>rd</sup> | 1997 | Quebec, Canada   |
| 34 <sup>th</sup> | 1998 | Norman, Oklahoma   |
| 35 <sup>th</sup> | 1999 | Park City, Utah  |
| 36 <sup>th</sup> | 2000 | Bath, England  |
| 37 <sup>th</sup> | 2001 | Victoria, British Columbia                                   |
| 38 <sup>th</sup> | 2002 | St. Louis, Missouri  |
| 39 <sup>th</sup> | 2003 | Reno, Nevada   |
| 40 <sup>th</sup> | 2004 | Bloomington, Indiana   |
| 41 <sup>st</sup> | 2005 | Istanbul, Turkey   |
| 42 <sup>nd</sup> | 2006 | Asheville, North Carolina                                    |
| 43 <sup>rd</sup> | 2007 | Boulder, Colorado  |
| 44 <sup>th</sup> | 2008 | Oklahoma City, Oklahoma                                      |
| 45 <sup>th</sup> | 2009 | Delaware, Ohio   |

## **Exhibits and Displays**

Ohio Department of Natural Resources, Division of Geological Survey  
The Ohio State University

### **Forum Steering Committee**

Don Gunning, Chair  
Tom Newman, Past Chair  
Mark E. Wolfe, Secretary  
Lynn Carpenter, Observer  
Stan Krukowski, 2008 Meeting Chair  
George Love, 2010 Meeting Chair

### **45<sup>th</sup> Forum Planning Committee**

Mark E. Wolfe, General Chair  
Michael Angle, Technical Sessions  
E. Mac Swinford, Administration/Field Trip  
John Miller, Financial  
Gregory Schumacher, Core Workshop  
Chuck Salmons, Publications Editor  
Lisa Van Doren, Electronic Designer  
Ed Kuehnle, Logistics/Publication Coordinator

### **Acknowledgments**

The 45<sup>th</sup> Forum Planning Committee would like to express its gratitude to the Ohio Geological Society for assisting in the financial aspects of the event. We would like to thank the National Lime and Stone Company for allowing access to two area quarries for the field trip. Thanks also to Lafarge North America Inc. for providing financial support for the publication of the Forum Program with Abstracts and Field Trip Guide. The Ohio State University should also be recognized for preserving an important collection of industrial mineral specimens and photographic slides assembled by Robert Latimer Bates and making a portion of the collection available to Forum attendees.

**Cover photo:** A view of the upper portion of the Devonian-age Columbus Limestone, Delhi Member exposed at the Warrensburg Quarry operated by National Lime and Stone Company in Delaware County, Ohio.

## CONTENTS

|  |    |
|--|----|
| Annual Meetings of the Forum on the Geology of Industrial Minerals ..... | i  |
| Exhibits and Displays .....  | ii |
| Forum Steering Committee .....   | ii |
| 45 <sup>th</sup> Forum Planning Committee .....                          | ii |
| Acknowledgments .....  | ii |
| Schedule of Events .....   | 1  |
| Sunday, October 4, 2009 .....  | 1  |
| Monday, October 5, 2009 .....  | 1  |
| Tuesday, October 6, 2009 .....   | 2  |
| Field trip .....   | 3  |
| Posters .....  | 3  |
| Special Display .....  | 4  |
| Abstracts .....  | 5  |
| Oral Presentations .....   | 5  |
| Poster Presentations .....   | 25 |
| Field Trip Guide .....   | 32 |
| Stop 1 .....   | 33 |
| Geology .....  | 35 |
| Stop 2 .....   | 38 |
| Geology and Fossils .....  | 39 |
| References Cited .....   | 41 |



## SCHEDULE OF EVENTS

SUNDAY, OCTOBER 4, 2009

5:00 P.M.–7:00 P.M.      **Reception**  
Poster set-up and reception at Horace R. Collins Laboratory and Core Repository

MONDAY, OCTOBER 5, 2009

### Technical Sessions

7:30 A.M.–8:00 A.M.      **Registration & Continental Breakfast**

8:00 A.M.–8:15 A.M.      **Welcome & Opening Remarks**  
Sean Logan, Director, Ohio Department of Natural Resources  
(ODNR)

8:15 A.M.–9:00 A.M.      **Geologic CO<sub>2</sub> Sequestration in Ohio—Background and Near-term  
Scenarios**  
Larry Wickstrom, State Geologist and Chief, ODNR Division of  
Geological Survey

9:00 A.M.–9:30 A.M.      **Carbon Dioxide Emissions by the U.S. Cement Industry: Sources  
and Trends**  
Hendrik van Oss, U.S. Geological Survey

9:30 A.M.–10:00 A.M.      **Industrial Minerals and Aggregates in Ohio—An Industry  
Perspective**  
Pat Jacomet, Ohio Aggregates and Industrial Minerals Association

10:00 A.M.–10:30 A.M.      **Break**

10:30 A.M.–11:00 A.M.      **Activities and Projects of the ODNR Division of Geological  
Survey Geologic Mapping & Industrial Minerals Group**  
Mike Angle, ODNR Division of Geological Survey

11:00 A.M.–11:30 A.M.      **Salt Deposits of Ohio—Geology, Mining, and Uses**  
Tom Tomastik, ODNR Division of Mineral Resources Management

11:30 A.M.–12:00 P.M.      **Geology of Potash-bearing Salt Basins: A World View**  
Mark Cocker and Greta Orris, U.S. Geological Survey

12:00 P.M.–1:00 A.M.      **Catered Lunch**

- 1:00 P.M.–1:30 P.M. **Adelbert Hall, a Rare Surviving Example of a Northeastern-Ohio Structure Built Using All Three Major Historic Northeastern-Ohio Building Stones**  
Joe Hannibal, Cleveland Museum of Natural History
- 1:30 P.M.–2:00 P.M. **Ohio Rocks!—Creating a Successful Partnership with Public Media**  
Krystal Cleaver, Cincinnati Educational Television
- 2:00 P.M.–2:30 P.M. **A Mine is a Terrible Thing to Waste—Profitable Reuses of Mined Lands**  
Nelson Shaffer, Indiana Geological Survey
- 2:30 P.M.–3:00 P.M. **Rocks That Work: Industrial Minerals in the Ohio Oil Patch**  
Mark Wolfe, ODNR Division of Geological Survey
- 3:00 P.M.–3:30 P.M. **Break**
- 3:30 P.M.–4:00 P.M. **Characterization of Illinois Limestone Fines—A Potentially Viable Source of Sorbents for Desulfurization in Coal-Fired Power Plants**  
Zakaria Lasemi, Shane Butler, Yongqi Lu, Massoud Rostam-Abadi, and David Ruhter, Illinois State Geological Survey, Institute of Natural Resource Sustainability, University of Illinois and Francois Botha, Illinois Clean Coal Institute
- 4:00 P.M.–4:30 P.M. **Let's Clear the Air: Industrial Minerals for Air Quality**  
Nelson Shaffer, Indiana Geological Survey
- 4:30 P.M.–5:00 P.M. **Regional Aggregate Mapping Using Airborne EM, Animation, and 3-D Visualization**  
Heather Budney, Alberta Geological Survey

## TUESDAY, OCTOBER 6, 2009

- 7:15 A.M.–7:45 A.M. **Steering Committee Meeting & Breakfast**
- 7:30 A.M.–8:00 A.M. **Continental Breakfast**

### Technical Sessions

- 8:00 A.M.–9:00 A.M. **Geologic Framework of Selected Ohio Industrial Minerals (Core Workshop)**  
Greg Schumacher, ODNR Division of Geological Survey

- 9:00 A.M.–9:30 A.M.     **Recent Developments at the Okorusu Fluorspar Mines, North-Central Namibia**  
Richard Hagni, Department of Geological Sciences, Missouri University of Science and Technology
- 9:30 A.M.–10:00 A.M.     **Organic Matter of the Middle Georgia Kaolins**  
Michael Cheshire and David Bish, Indiana University, Department of Geological Sciences
- 10:00 A.M.–10:15 A.M.     **Break**
- 10:15 A.M.–10:30 A.M.     **Pennsylvania in 2010, George Love**
- 10:30 A.M.–11:00 A.M.     **Forum Business Meeting**
- 11:00 A.M.–1:00 A.M.     **Lunch (on your own)**

### Field Trip

- 1:00 P.M.–5:00 P.M.     **Aggregates and More: Economic Geology of the Delaware and Warrensburg Quarries, Delaware County, Ohio**

The Devonian-age Columbus Limestone is a major aggregate producer in central Ohio. This trip will visit one of the largest producing quarries by annual tonnage in the state, located in one of the fastest growing counties in the United States. As is typical in Ohio, the quarry is being deepened to access additional reserves. The Devonian/Silurian contact is exposed, as well as the underlying Silurian-age Salina Group dolomites. Geologic controls on aggregate quality will be illustrated. We will also visit a nearby quarry in which building stone, primarily for landscape purposes, is being produced. There will be an opportunity to closely examine the upper member of the Columbus Limestone. Abundant fossils are available for collection.

*Field Trip Leaders:* Chad Doll, Group Vice President–Southern Region, National Lime & Stone Company and Mark Wolfe, ODNR Division of Geological Survey. Additional assistance from David Stith, ODNR Division of Geological Survey (retired).

### Posters

**Black Hand Sandstone: A Building Stone of Unique Distinction from Richland County, Ohio**  
Mark Wolfe, ODNR Division of Geological Survey

#### **Illinois Industrial Minerals**

Zakaria Lasemi and Donald Mikulic, Illinois State Geological Survey, Institute of Natural Resource Sustainability, University of Illinois

### Mineral Industries Map of Ohio

Mark Wolfe, ODNR Division of Geological Survey

### New Uses for Coal Combustion Byproducts

Nelson Shaffer, Indiana Geological Survey

### The U.S. Geological Survey's Global Minerals Assessment Program for Potash

Mark Cocker, Greta Orris, Jeffrey Wynn, Bruce Lipin, and Gregory Spanski, U.S. Geological Survey

## Special Display

Selected industrial mineral specimens from the Collections of Ohio State University Geological Sciences Professor Robert Latimer Bates (1912–1994)—An index for industrial rocks & minerals and photographic slides, compiled by Russell O. Utgard and Stephen R. Jacobson: Columbus, Ohio State University, Geological Sciences, 1998, 74 p. <<http://hdl.handle.net/1811/38934>>.

Industrial rocks and minerals of the Bates collection are stored in cabinets located in the basement of Mendenhall Laboratory at The Ohio State University, Columbus, Ohio. There are more than **580 specimens**, primarily from the United States. Specimen preservation and identification is generally good to excellent.

A brief summary of specimen type and approximate number follows: granites, basalt, slate, and marble (69); clay (64); limestone and dolomite (55); trona and potash (46); sandstone (41); gypsum, anhydrite, and salt (34); talc (30); asbestos (22); barite and magnesite (20); phosphate (19); wollastonite and kyanite (14); diatomite and vermiculite (14); flourospar (14); borax (13); leipidolite (12); mica (10); pumice, perlite, feldspar, beryl, pegmatite, garnet, sulfur, novaculite; graphite, etc. (>85).

The collection also contains **429 photographic slides** of various industrial mineral locations, primarily in the U.S. Slides are currently stored in the office of Dale Gnidovec, curator of the Orton Geology Museum in Orton Hall at The Ohio State University, Columbus, Ohio.

A special thank you goes to Dale Gnidovec, Orton Geological Museum, The Ohio State University, for his assistance in compiling the special display at the 45<sup>th</sup> Forum on the Geology of Industrial Minerals.

## ABSTRACTS

### ORAL PRESENTATIONS

Abstracts are arranged according to presentation schedule.

#### Geologic CO<sub>2</sub> Sequestration in Ohio—Background and Near-term Scenarios

Lawrence H. Wickstrom

Ohio Department of Natural Resources, Division of Geological Survey

2045 Morse Rd., Bldg. C-1, Columbus, OH 43229-6693

Contact: [larry.wickstrom@dnr.state.oh.us](mailto:larry.wickstrom@dnr.state.oh.us); (614) 265-6598

Geologic sequestration involves the capture of carbon dioxide (CO<sub>2</sub>) from large industrial point sources and its storage in a geologic reservoir. Coal-fired power plants are by far the largest CO<sub>2</sub> point sources in Ohio, followed by the iron and steel industry, refineries, ethanol plants, and cement plants. Reservoirs appropriate for sequestration include producing and depleted oil-and-gas fields, unmineable coal seams, and deep saline formations. Such reservoirs have naturally stored crude oil, natural gas, brine, and CO<sub>2</sub> for millions of years. CO<sub>2</sub>-assisted enhanced oil recovery (EOR) provides an attractive value-added option for moving carbon capture and storage technology forward in the region but has large challenges for implementation. The Ohio Department of Natural Resources (ODNR), Division of Geological Survey has been researching Ohio's potential for geologic sequestration since 2000. Geological and geophysical data, largely from the state's oil and gas records, are integrated through mapping and geostatistical techniques to provide three-dimensional models of the subsurface units. These models form the basis for the calculation of CO<sub>2</sub> sequestration capacity.

If Ohio's energy mix is to change to include clean coal technologies, EOR, ethanol, and synthetic fuels, while limiting the amount of green house gases emitted into the atmosphere, geologic CO<sub>2</sub> sequestration must play a significant role. Developing Ohio's potential for sequestration in conjunction with the development of these new energy sources will be a great challenge involving proper planning and siting of facilities, implementation of new regulations, training a new work force, and construction of proper infrastructure, including CO<sub>2</sub> pipelines. The ODNR Division of Geological Survey has combined its knowledge of prospective geologic reservoirs with known and planned large-CO<sub>2</sub> sources to create a potential scenario for matching "sources with sinks" and illustrating the magnitude of pipeline development that will be necessary.

## Carbon Dioxide Emissions by the U.S. Cement Industry—Sources and Trends

Hendrik G. van Oss

U.S. Geological Survey

983 National Center, Reston, VA 20192

Contact: [hvanoss@usgs.gov](mailto:hvanoss@usgs.gov); (703) 648-7712

Hydraulic cement, the binding agent in concrete, has in recent years been produced at a rate of about 90–100 million metric tons per year (Mt/yr) in the United States and about 2,700 Mt/yr worldwide. World cement output is enough to produce about 22,000 Mt/yr of concrete, which is about three tons of concrete per person on the planet. The overwhelming majority of the hydraulic cement produced worldwide is portland cement or similar cement having portland cement as a base. The cement industry is under increasing scrutiny in terms of its carbon dioxide (CO<sub>2</sub>) emissions. About 1.5% of total U.S. anthropogenic emissions of CO<sub>2</sub> are from cement manufacture; worldwide, cement's contribution is about 5% of total emissions.

Ordinary portland cement is made by grinding together portland cement clinker and a small amount (typically 5% by weight) of gypsum. Clinker is made in a kiln and is composed mainly of calcium oxide (CaO; typically about 65% of the total mass), silica (about 22%), alumina (about 6%), and ferric oxide (about 3%), manifested mainly within hydraulic calcium silicate, calcium aluminate, and calcium aluminoferrite compounds or minerals. Although a wide variety of materials can be used as raw materials to make clinker, traditionally, most of the CaO has been sourced from calcium carbonate within limestone or similar rocks; “limestone” makes up about 1.5 of the 1.7 metric tons of raw materials consumed per ton of clinker produced.

Overall, nearly one ton of CO<sub>2</sub> is released per ton of clinker manufactured. The stoichiometry of the thermal dissociation (calcination) of calcium carbonate into CaO yields about 0.5 ton of CO<sub>2</sub> per ton of clinker. Most of the remainder of the CO<sub>2</sub> is from the combustion of fuels. Calcination is highly heat intensive and accounts for most of the 3–7 gigajoules of heat energy consumed per ton of clinker (depending on kiln technology). Coal and petroleum coke are the major fuels used by the U.S. cement industry to supply this heat.

Plant technology upgrades, especially of the kiln lines, can yield dramatic reductions in unit heat (hence fuel) requirements but are very expensive. Such upgrades have, however, been largely responsible for a steady unit emissions decline (about 22% for the period) by the U.S. industry over the past half-century. Substitution of alternative raw materials (such as ferrous slags and coal combustion ashes) for traditional materials for clinker manufacture can reduce calcination and related fuel combustion emissions of CO<sub>2</sub> to the degree that the substitutions contribute CaO from a non-carbonate source. Such substitutions by the U.S. cement industry have reduced the industry's overall calcination emissions by 2–3% in recent years; the reductions have been up to about 10% at the specific plants that are using the alternative raw materials. Fuel savings by these plants are harder to quantify because of several variables, but most of these plants have

unit heat consumptions below the U.S. averages for the respective kiln technologies. Plants can also make use of alternative fuels, some of which have lower unit CO<sub>2</sub> emissions, others of which (such as biofuels) may offer the plant carbon credits or deductions for carbon-neutrality, and yet others of which may bring in waste disposal fees. Addition of supplementary cementitious materials, such as pozzolans, as well as bulking agents, into the finished cement reduce the unit emissions associated with the finished product but may not reduce the total emissions of the cement plant itself. Various alternatives to portland cement have been proposed, and while most of these may offer lower carbon footprints, they face hurdles to market acceptance.

### **Industrial Minerals and Aggregates in Ohio—An Industry Perspective**

Patrick A. Jacomet

Ohio Aggregates & Industrial Minerals Association

162 N. Hamilton Rd., Gahanna, OH 43230

Contact: patj@oaima.org; (614) 428-7954

The Ohio Aggregates & Industrial Minerals Association (OAIMA) has been representing the aggregates industry for over 90 years. Much has changed over this period and the industry faces many challenges and opportunities in the coming years. The OAIMA and its member companies continue to work to educate the customer—both private and public—as to the need for good, quality, locally available and sustainable aggregate and industrial minerals resources. Pat Jacomet, Executive Director of the OAIMA, has over 25 years experience in the construction materials and testing industry and will present some of the educational and partnering initiatives undertaken by the OAIMA and its over 200 member companies.

### **Activities and Projects of the ODNR Division of Geological Survey Geologic Mapping & Industrial Minerals Group**

Michael P. Angle

Ohio Department of Natural Resources, Division of Geological Survey

2045 Morse Rd., Bldg. C-1, Columbus, OH 43229-6693

Contact: mike.angle@dnr.state.oh.us; (614) 265-6602

The Ohio Department of Natural Resources (ODNR), Division of Geological Survey's Geologic Mapping & Industrial Minerals Group (GMIMG) staffs a dedicated group of geoscientists working on a diverse set of projects, ranging from surficial and bedrock mapping and compiling annual mineral industries production statistics to identifying areas of shoreline

erosion and other geohazards. Many of these projects and resultant maps and publications affect the mineral industries of Ohio either directly or indirectly.

Current projects of the GMIMG include mapping the surficial materials of the Marion and Piqua 30 x 60-minute quadrangles. These maps use a system of polygons and a “stack” of labels to portray a 3-D view of surficial deposits. This series of maps is funded by the U.S. Geological Survey’s national STATEMAP initiative. Derivative maps can be created from the base stack maps by querying specific attributes, such as thickness of sand and gravel deposits, proximity of mineable bedrock to the land surface, or thickness of overlying till or other fine-grained units.

The Great Lakes Geologic Mapping Coalition (GLGMC) and the National Geological and Geophysical Data Preservation Program (NGGDPP) are two other funding sources for the GMIMG. Ongoing projects utilizing GLGMC funding include karst terrain studies in both Bellevue and Delaware counties and development of 3-D geologic models that can be used to identify and depict various geologic units to help solve either groundwater or geologic materials problems. The GLGMC funding is also being used to help develop a statewide seismic and geotechnical engineering record database. The NGGDPP funding is being used to inventory and convert paper records to digital format for collections at the H. R. Collins Core Repository.

The GMIMG also compiles annual mineral industries production statistics for the state into a comprehensive report that includes annual tonnages and dollar amounts of extracted materials, information on the industry work force, and a comprehensive directory of all operating quarries, pits, and mines. Data from this report is included in a number of national compilations and the is useful for a number of applications by both industry and other governmental agencies.

The GMIMG also is now working to identify a number of geohazards including karst terrain, abandoned underground mines, landslide-prone units throughout the state, and shoreline erosion along Lake Erie’s coastline. The latter of these initiatives includes releasing a new set of Coastal Erosion Area (CEA) maps for the Lake Erie shoreline. Rectifying and helping to stabilize many of these geohazards will require materials from the minerals industry of Ohio.

## Salt Deposits of Ohio—Geology, Mining, and Uses

Thomas E. Tomastik

Ohio Department of Natural Resources, Division of Mineral Resources Management

2045 Morse Rd., Bldg. H, Columbus, OH 43229-6693

Contact: tom.tomastik@dnr.state.oh.us; (614) 265-1032

What does the word *salt* mean to you? To most people, *salt* is associated with table salt used for seasoning food. To the rural person, it’s the salt blocks for livestock or the water-softening salt used for their domestic water wells. For the Ohio motorist, it means safer driving conditions in ice and snow.

*Salt* is the general term for naturally occurring sodium chloride and is often referred to as *rock salt*. Its mineral name is *halite*. Halite or salt is easily recognized by its cubic crystal form, its taste, and its high solubility in water.

Historically, natural brine springs, such as the Scioto Saline in Jackson County, were used by both man and animal as a source of salt for at least 8,000 years. Between the late 1700s and the early 1800s, the Scioto Saline, or Scioto Salt Licks, supported Ohio's early salt industry. The first natural brine well was drilled in Ohio in 1809. The early natural brine/evaporation furnace industry continued to operate in Ohio for many years. The Excelsior Salt Works in Pomeroy was still in operation in 1959. Today, however, naturally occurring brines as a source of salt have been replaced by Ohio's development of its underground salt deposits.

Since the discovery of rock salt in Cuyahoga County in 1886, Ohio salt production has relied on the solution mining and underground mining industries. The salt beds in Ohio also have been used for the underground storage of hydrocarbon products, such as propane and butane.

In 1886, while drilling for natural gas at its rolling mill in Newburg, Ohio, the Cleveland Rolling Mill Company encountered rock salt at a depth of 1,990 feet. The discovery led to the creation of the Newburg Salt Company in 1889 and the establishment of the first artificial-brine operation in Ohio. Since 1889, ten salt-solution-mining facilities have been operated in Ohio. Approximately 267 salt-solution-mining wells have been drilled in Ohio at these ten facilities. Today, only three of these facilities and 46 wells remain in operation.

All the salt produced in Ohio prior to 1959 came from either natural brines or artificial brine produced by salt-solution-mining operations. In 1959 and 1961, operations began at two underground rock salt mines beneath Lake Erie in northern Ohio. The Fairport mine is operated by the Morton Salt Division of Rohm and Haas, Inc.; its surface operation is on the shoreline of Lake Erie on the west side of the mouth of the Grand River in Fairport Harbor (Lake County). The surface operation of the other mine is on Whiskey Island at the mouth of the Cuyahoga River along the Lake Erie shore in Cleveland. The Cleveland mine was originally developed by the International Salt Company and has had several owners; it is currently owned and operated by Cargill, Inc. Both Morton and Cargill lease thousands of acres under Lake Erie from the State of Ohio and pay royalties to the State.

## Geology of Potash-bearing Salt Basins: A World View

Mark D. Cocker\* and Greta J. Orris

U.S. Geological Survey

520 N. Park Ave., Suite 355, Tucson, AZ 85719

\*Contact: mcocker@usgs.gov; (520) 670-5506

Marine and transitional evaporite basins contain most of the world's supply of soluble potash. Brines in lacustrine deposits are other important potash resources. Potash occurs in marine evaporites generally in the form of multiple, layered sequences of sylvite +/- carnallite +/- kieserite +/- langbeinite +/- polyhalite within thick, bedded halite + anhydrite. Potash-bearing basins have been classified as chloride, chloride-sulfate, or sulfate types based on the specific types and relative abundances of the contained potash minerals.

Generally very large, conformable, flat to gently dipping, potash-bearing, marine evaporites deposited in platform carbonate-bearing, cratonic basins are relatively well-reported in the English-language literature. This group includes the Devonian Elk Point Basin, the Delaware sub-basin of the Permian Basin, the Silurian Michigan Basin, and the Werra sub-basin of the Permian Zechstein Basin. Also within this group are the lesser known Permian Cis-Uralian (or Upper Kama/Solikamsk) Basin and the Early Cambrian (?) Nepa Basin in Russia.

Other less well-reported or well-known potash-bearing basins are those characterized by the presence of numerous diapiric salt structures produced by halokinesis or by regional tectonics, both of which may result in extreme flowage of salt and associated potash to higher structural levels. Within some basins, halokinetic salt diapirs reached the surface and produced salt glaciers. Halokinetic, diapiric salt structures may range from 100s of meters to 10–15 km in vertical extent. Halokinesis may be initiated by reactivation of basement faults, differential sediment-loading, or by listric faulting resulting in differential overburden pressure on the salt. Regional tectonism, commonly associated with development of foreland basins, can cause mild to extreme folding and flowage of salt into diapiric structures that include halokinetic-type diapirs to anticlines to extremely distorted and faulted structures. These basins are generally dominated by clastic sediments with minor carbonates and include continental rift basins, continental/marine rift basins split by seafloor spreading, foreland basins, and transverse or pull-apart basins. Within this group are non-platform portions of the Permian Zechstein Basin (northern Europe), the Cretaceous Sergipe (eastern Brazil)-West African (Gabon and Congo) basins, the Miocene Red Sea Basin, the Devonian Pripyat Basin (Belarus), the Devonian Dnieper-Donets (Ukraine), the Permian Pricaspian (Russia and Kazakhstan), the Miocene Carpathian Basin (Ukraine and Romania), the Central Asia Jurassic Basin, the Cretaceous Khorat Basin (Thailand and Laos), the Mississippian Maritimes Basin (eastern Canada), and the Pliocene Dead Sea Basin (Israel and Jordan).

Post-depositional processes that may affect potash grade include dissolution and structural deformation. Descending saline brines may dissolve primary, lower-grade carnallite and

precipitate higher-grade sylvite or kainite such as observed in the Khorat, Zechstein and Elk Point basins. Patchy to widespread salt dissolution documented in the Delaware, Elk Point and Cis-Uralian basins is attributed to ascending less saline brines from dewatering of underlying gypsum or to downward circulation of groundwater from overlying aquifers. Extreme folding within salt diapirs or tectonically deformed salt can result in potash grade dilution making bulk mining less efficient or result in using more selective but costlier mining methods.

### **Adelbert Hall, a Rare Surviving Example of a Northeastern-Ohio Structure Built Using All Three Major Historic Northeastern-Ohio Building Stones**

Joseph T. Hannibal

Cleveland Museum of Natural History, 1 Wade Oval Drive, Cleveland, OH 44106 Contact: hannibal@cmnh.org; (216) 231-4600, ext. 3233

Adelbert Hall (also known historically as Adelbert Main) was dedicated in October of 1882. It is a grand historic structure on the campus of Case Western Reserve University in Cleveland. The building exterior remains much as it was when first built except for the removal of most of a tower in the 1890s and reconstruction of the upper part of the structure after a fire in 1991.

Primary records (invoices, hand-written notes, etc.) of the original stonework for this structure are lacking in the university archives, and historic records noting stonework disagree with each other. A newspaper account in 1882 announced that it was “a grand monument of granite,” and a card in a university archive card file indicates that the building’s exterior was Berea Sandstone and pink Triassic sandstone. A September, 1882 article by Edwin Mean published in the journal *Education* notes, however, that the building was faced with Ohio buff sandstone and “trimmed with Euclid blue-stone and Twinsburgh [*sic*] brown-stone.”

The main exterior stone is Berea Sandstone (Upper Devonian), probably from the Amherst, Ohio, area, as various sources indicate. Most fire-damaged exterior sandstone, especially for the fourth-floor, was replaced with Berea Sandstone from the Amherst area quarries after the 1991 fire. Much of the original trim is Euclid bluestone (Euclid Member of the Upper Devonian Bedford Formation), a very fine-grained sandstone historically quarried in northeastern Ohio. Some iron staining is seen in this stone.

Red-sandstone trim bands are composed of a conglomerate with light-colored quartz pebbles of varying size and abundance. This stone has characteristics of the Pennsylvanian Sharon Formation of northeastern Ohio. Red-colored Sharon Formation was historically quarried in Akron and Cuyahoga Falls. Brownstone from these areas and Twinsburg also has been noted as being used for other Cleveland structures, including the 1887 Western Reserve University Medical School, but these structures have been demolished. The Sharon quarried in Twinsburg, however, was mostly light-colored.

Adelbert Hall is a rare, perhaps unique, example of an extant historic northeastern-Ohio structure built using all three major northeastern-Ohio building stones: Euclid bluestone, Berea Sandstone, and the Sharon Formation.

### ***Ohio Rocks!*—Forming a Successful Partnership with Public Media**

Krystal Cleaver

Cincinnati Educational Television

1223 Central Pkwy., Cincinnati, OH 45214-2890

Contact: [kcleaver@cetconnect.org](mailto:kcleaver@cetconnect.org); (513) 345-6559

In 2007 CET produced a multimedia project entitled *Ohio Rocks!* The multimedia project included four 10-minute videos, a resource CD, a website, and a Teacher's Guide. Project partners were the Ohio Department of Natural Resources (ODNR), Division of Geological Survey and Cincinnati Museum Center. Funding was provided by eTech Ohio; The Robert Gould Foundation; and the H. B., E. W., and F. R. Luther Charitable Foundation, Fifth Third Bank, and Narley L. Haley, co-trustees.

An earth science project was recommended by CET's Educational Advisory Council made up of curriculum, technology, and library/media specialists from public and private schools from our eight-county viewing area. Ohio Academic Content Standards testing indicated a need for increased concentration in this area. CET's research indicated that there had been no recent multimedia project focused on Ohio geology for several years. CET chose to center the project on Cincinnati's Ordovician era fossils and how this fits into the bigger picture of Ohio geology with an emphasis on fourth grade earth science standards. To this end, CET contacted the Cincinnati Museum Center and the ODNR Division of Geological Survey and asked them to partner on the project.

Our partnership with the ODNR Division of Geological Survey was essential for developing the concept of the videos. Through e-mail and phone calls, ODNR Division of Geological Survey advised CET on the important concepts we should cover and provided us with a list of places in the state where we could film good examples of Ohio geology. In addition, the agency accompanied us on one day of shooting and helped us understand how what we were filming played into the concepts we were covering. We also spent a day collecting interview footage at the agency's offices at Alum Creek. The ODNR Division of Geological Survey contributed expertise in reviewing scripts to insure that their interviews had been edited correctly to reflect the points they wanted to make.

The project was distributed free of cost to the elementary schools designated as low-wealth in our viewing area. The project was made available at no cost and upon request to the remaining 200 low-wealth districts in Ohio. In addition, copies of the kit were sold at cost to schools not

designated as low-wealth. To date, 217 of the physical 250 kits produced have been distributed. Copies have also been provided upon request to Soil and Water Conservation District education specialists and others involved in environmental education with school children.

*Ohio Rocks!* video has shown on CET and the other seven Ohio public television stations. The original broadcast dates were during the week of May 7, 2007. According to our 2008–2009 ITV schedule, an *Ohio Rocks!* episode was aired 16 times during 2008–2009 school year on CET. Our instructional media specialist indicates that we aired them about as many times during the 2007–2008 school year. eTech Ohio reports that an *Ohio Rocks!* episode was fed out to an Ohio television station 129 times during 2007–2008 and 2008–2009.

Approximately 470,395 K–12 students are within our viewing area (Ohio–Kentucky–Indiana) and could have viewed a broadcast. Based on the information on the Ohio Department of Education website and then extrapolating that data to the CET region, there are approximately 17,000 fourth graders in southwest Ohio who might have viewed the videos.

Presentations on *Ohio Rocks!* were given at a teacher workshop for the Southwest Center of Excellence for Science and Math in spring of 2007. Presentations have also been made at the Educational Technology of Southeast Ohio (ETSEO) teacher conference and the Greater Cincinnati Environmental Educator Expo, in September 2007, and at the statewide eTech Ohio Educational Technology Conference in February 2008. These presentations were publicized in flyers and catalogs. The ODNR Division of Geological Survey got thanks and credit at all presentations.

CET won a Bronze Telly for *Ohio Rocks!* in 2008 in the 29th annual Telly Awards. The Telly Awards were founded in 1978 to honor excellence in local, regional, and cable TV commercials. Non-broadcast video and TV program categories were soon added. Today, the Telly is one of the most sought-after awards by industry leaders, from large international firms to local production companies and ad agencies. The 29th Annual Telly Awards received over 14,000 entries from all 50 states and five continents.

Promotion of the *Ohio Rocks!* project in the CET Learning Services newsletters began in winter of 2006 and continued in spring 2007 and fall 2008. Approximately 10,000 copies of each newsletter are distributed to teachers in member schools in our area. CET announced that *Ohio Rocks!* won a Bronze Telly in our membership magazine, *Connected*, in fall 2008. The magazine is sent to 17,000 homes in our viewing area in Ohio, Kentucky, and Indiana.

## **A Mine is a Terrible Thing to Waste: Profitable Reuses of Mined Areas**

Nelson R. Shaffer

Indiana Geological Survey

Indiana University, 611 North Walnut Grove, Bloomington, IN 47405-2208

Contact: shaffern@indiana.edu; (812) 855-2687

Robert G. Jones

Indiana Mineral Aggregates Association

11711 North College Ave., Suite 180, Carmel, IN 46032-5601

Mining must make holes or voids in rock. Many abandoned underground mines (mostly limestone mines) are currently used for warehousing, cold storage, and manufacturing. Mines located near population centers or transport routes are especially useful for repurposing. When assessing a mined area, consideration must also be given to potential postmining uses of the surface land above the mine. In Indiana, more than 480,000 acres are underlain by mined areas. Mined areas occur in other states as well, and these hold great possibilities for conventional reuse.

Additional opportunities for more unconventional uses of mine voids are being developed and should also be considered in mine and reclamation plans. Many mines are filled with water that is rarely used for human consumption but which could be used for the production of biofuels and in nonenergy industries. Mine waters can enhance geothermal systems or, conversely, act as heat sinks. Mine voids naturally act as defacto bioreactors and could be modified to become very large, efficient geobioreactors. Geobioreactors are natural rock-hosted areas wherein microbes perform a desired function or produce a useful product. Natural geobioreactors are known to produce methane from residual oil in depleted reservoirs or in coal beds. At least one U.S. company is now promoting geobioreactors for fuel production and many other products could be made using large-scale geobioreactors.

Underground voids can also be used for storage of compressed gas or pumped water for load leveling in electricity generation, the storage of liquids or gases, and even other exotic uses, such as laboratories. Geologic, hydrologic, and environmental details must be assessed to assure confinement of fluids, gases, or microbes to the void space before such uses can be safely made. Abandoned mines are also used as educational or tourism sites.

Mined areas offer potential to address pressing problems. Society needs to understand and make best uses of the opportunities that mined spaces offer. Planning for postmine uses will allow optimal operations.

## Rocks That Work: Industrial Minerals in the Ohio Oil Patch

Mark E. Wolfe

Ohio Department of Natural Resources, Division of Geological Survey

Horace R. Collins Laboratory, 3307 South Old State Rd., Delaware, OH 43015-7635

Contact: mark.wolfe@dnr.state.oh.us; (740) 548-7348, ext. 26

If oil and gas is the blood that allows the world to grow and prosper, then industrial minerals are the muscle and bone of modern society. The drilling and completion of a typical oil-and-gas well uses as many as 24 different industrial minerals. The drill bit may contain industrial diamonds or tungsten carbide; the drilling fluids have varying amounts of barite, bentonite, mica, perlite, or other industrial minerals; the cement used to secure the casing is made from high-calcium limestone, clays, shales, gypsum, and silica; and the fracture proppant is usually sandstone of exacting specifications. The construction of the drill site includes limestone, dolomite, sand, gravel, or granite aggregates. Low-permeability clays are used to contain drilling fluids and to plug wells that are no longer productive. Another type of clay, kaolin, is used as a catalyst in the refining of the produced oil and gas.

The United States leads the world in the production of 16 industrial minerals; 7 of those commodities have global trade and limited sources. Bentonite, synthetic diamonds, attapulgite, kaolin, mica, perlite, and silica sand are extremely important to the oil and gas industry and are produced in greater volumes in the U.S. than elsewhere in the world.

In Ohio, prepared clay from an approved source can be used to plug and abandon a cable-tool-drilled well and may be used to plug the lower-most producing formation of a rotary-drilled well. The plugging material must have a clay content (grain size of 4 microns or less) of greater than 40% and a sand content (greater than 62.5 microns) of less than 30%. Low-permeability clays that meet the specifications for plugging of oil and gas wells in Ohio are found in several counties located in the southeastern portion of the state. Most of the geologic units used for plugging are Pennsylvanian-age paleosols associated with coal beds and include the Lower Kittanning, Putnam Hill and Middle Kittanning clays of the Allegheny Group and the Tionesta clay of the Pottsville Group.

Most modern drill bits contain either tungsten carbide or synthetic/industrial diamonds. Industrial diamonds can be either natural or synthetic. Diamondiferous kimberlites generally contain a high percentage of non-gem material that can be used for industrial purposes. South Africa and Russia have long been important diamond producers; Australia and Canada have become much more important recently.

Synthetic diamonds were first manufactured in 1954. Graphite was dissolved with molten nickel, cobalt, or iron in a pyrophyllite container. The graphite was later replaced by a "seed" diamond to which carbon and catalysts are added. The largest producer of synthetic diamonds in the world is located in Worthington, Ohio.

Cement is used to bond both the surface casing and production string with the formation, thus isolating oil- and gas-bearing zones from other permeable geologic formations, particularly those containing potable water. Cement is also used when a depleted well or dry hole is abandoned. High-calcium/low-magnesium limestone is the major ingredient in the production of Portland cement. Clay, shale, sandstone, and gypsum are added to the limestone in varying amounts so that the resulting cement will have the proper chemistry for the final end-use. In 2008 more than 1,500 wells were either drilled or plugged and abandoned in Ohio. Approximately 25,000 tons of cement were used in the drilling, production, or abandonment of oil-and-gas wells in Ohio during 2008.

High-calcium geologic units that have been mined or quarried to produce portland cement in Ohio, either currently or historically, include the Pennsylvanian-age Putnam Hill and Vanport Limestones, as well as the Mississippian-age Maxville Limestone in eastern and southern Ohio. The Devonian-age Columbus Limestone and Dundee Limestone in northern Ohio and Silurian-age Brassfield Limestone in southwest Ohio have also been used to produce cement. Two portland cement plants were active in Ohio in 2009. The geologic units used to produce cement were the Brassfield Limestone east of Dayton and the Dundee Limestone in Paulding County of northwest Ohio.

Agricultural limestone and dolomite are used to control soil acidity and help establish vegetation when reclaiming drill sites. Aggregates are used to construct drill roads and access roads to tank batteries. Approximately 200,000 tons of limestone, dolomite, sand, and gravel aggregate were used for these purposes in Ohio during 2008.

High-silica, clean sandstones with round grains are preferred as fracture proppant during hydraulic stimulation of oil and gas wells. Uniformly graded sand will give better permeability. The average fracture stimulation uses 20,000 pounds of sand proppant, therefore the potential Ohio market is over 15,000 tons per year. Ohio sandstones generally do not meet American Petroleum Institute (API) specifications of roundness and crush test but can be used successfully in certain situations and are particularly important when shortages of API sand occur. Approximately 40,000 tons of fracture sand produced from Ohio, predominantly from Pennsylvanian-age Sharon and Massillon sandstones, were sold annually from 2005 to 2008.

Industrial minerals are essential to the oil-and-gas industry. Conversely, petroleum products are required to quarry and transport industrial minerals. These important interrelationships can be found throughout the mineral industry.

## Characterization of Illinois Limestone Fines—A Potentially Viable Source of Sorbents for Desulfurization in Coal-Fired Power Plants

Zakaria Lasemi\*, Shane Butler, Yongqi Lu, Massoud Rostam-Abadi, and David Ruhter  
Illinois State Geological Survey

Institute of Natural Resource Sustainability, University of Illinois, 615 E. Peabody Dr.,  
Champaign, IL 61820

\*Contact: lasemi@isgs.illinois.edu; (217) 244-6944

Francois Botha

Illinois Clean Coal Institute

5776 Coal Drive, Box 6, Carterville, IL 62918

Because of the importance of limestone as a sulfur scrubbing agent, it is essential that scrubber materials suitable for flue-gas desulfurization (FGD) and fluidized bed combustion (FBC) be available locally and at a low cost. Each year, millions of tons of limestone and dolomite fines are produced during the crushing and processing of limestone and dolomite quarried in Illinois. It is estimated that crushing and processing of stone produces 10% to 20% fines and, because of limited uses, a large portion of the fines ends up in waste piles or is used to backfill mined out areas. These potentially valuable, yet largely unknown resources could provide an effective and affordable raw material for the FGD and FBC scrubbing systems in coal-fired power plants. However, the use of fines in scrubber systems has been very limited partly because many in the power-generating industry are not aware of the availability of these potentially valuable resources. In addition, the quality of these resources is not generally known and their suitability as scrubbing agents has not been previously investigated.

The primary goal of this study, funded in part by the Illinois Clean Coal Institute, was a detailed characterization of the quality of quarry fines from selected limestone quarries in Illinois to determine the fines that are most suited for use in scrubber systems. To achieve this goal we conducted a detailed characterization of fines collected from 36 limestone and dolomite quarries and mines, focusing on those near existing and potential coal-fired power plants. The main objectives of the proposed project were to (1) select and sample by-product fines from the representative quarries in the state; split the samples into particle-sized fractions appropriate for application in FBC and FGD units; and characterize each sample fraction for its chemical, mineralogical, and physical properties; and (2) measure the reactivity of selected samples with respect to sulfur dioxide capture under FGD and FBC conditions.

To characterize the quality of limestone and dolomite fines, twenty of the samples were subjected to sieve analysis to determine the proportion of various size fractions. The Tyler mesh sieves and interval used for this initial analysis included 4–20, 20–40, 40–60, 60–100, 100–200, 200–325, and –325. On average, about 49 percent of the fines were found to be

between -4 and 20 mesh, 17 percent between 20 and 40 mesh, and 15 percent below 200 mesh. Using this information, we split all 36 samples and grouped them into 4-60, 60-200 and -200 mesh sieve fractions for chemical and mineralogical analysis. Each of these size categories were characterized chemically (major, minor and trace element constituents); mineralogically (calcite, dolomite, clay minerals, quartz, etc.); and petrographically. X-ray diffraction (XRD) results showed that quartz ( $\text{SiO}_2$ ) was the major impurity in the quarry fines that were examined. The fines with a high silica (or quartz) content were mainly from quarries that extract cherty limestones (e.g., Burlington-Keokuk Formations in western Illinois). This suggests that the source of silica is mainly chert and/or siliceous horizons within the quarry. There is a moderate positive correlation between the amount of  $\text{Al}_2\text{O}_3$  and silica in the 60-200 and -200 mesh size fractions, which suggests contribution from clay minerals. However, XRD results indicate that, except for a few samples, the amount of clay minerals is low (below the detection limit of the XRD machine). Another source of silica could be from quartz in siltstone, sandstone, or from disseminated quartz sand grains in the parent material. However, petrographic examination showed a very limited amount of silt and sand size grains in the majority of the fines that were analyzed. The amount of calcium carbonate calculated from chemical analysis ranges from 0.7%-95%. The higher-calcium limestones come from quarries in central, western, and southern Illinois. A number of samples are dolomitic with up to 97% dolomite. Dolomitic samples are mainly from quarries in the northeastern part of the state. There is a strong positive correlation between MgO and CaO and calcite and dolomite, suggesting that the source of these oxides is primarily from carbonates.

The acid dissolution rate of limestones has been used as an indicator of limestone reactivity with respect to sulfur capture under FGD conditions. A pH-stat auto-titration experiment was conducted to measure the relative reactivity of 25 limestone fine samples (-325 mesh) for removal of  $\text{SO}_2$  in wet FGD processes. The dissolution performances of the limestones varied significantly. The dissolution fraction ranged from 2%-75% in 10 minutes and from 5%-99% in 60 minutes. The dissolution rate constant, as an indication of chemical reactivity of limestone, was estimated for 14 selected samples. The rate constant ranged from  $4.8 \times 10^{-9}$  to  $8.5 \times 10^{-8}$ . The dissolution rate constant showed moderate dependence on both CaO content (positive dependence) and MgO content (negative dependence). The performance of the limestone dissolution was correlated with the chemical and mineralogical properties of the limestone fines that were tested. A strong correlation was observed between the dissolution fraction of limestone and MgO (and dolomite) content. The limestone reactivity as indicated by the dissolution rate constant showed moderate dependence on both the CaO content (positive dependence) and MgO content (negative dependence).

The desulfurization reactivity of six limestone fine samples also was measured with the TGA technique using the 16-20 Tyler mesh particle size fraction. These samples were either dolomite or a mixture of dolomite and calcite. The results showed that the calcium utilization of the samples varied from 42%-74% after a 90-minute reaction. The amount of  $\text{SO}_2$  captured

ranged from 0.14 to 0.22 g SO<sub>2</sub>/g limestone. The results were compared to samples tested in our earlier study. The samples from this study demonstrated higher desulfurization reactivity than those of the previous studies. Both sample sets followed the same trend in correlation with the main mineral and chemical constituents in limestone. Weak to moderate correlations were observed between the calcium utilization and the main constituents of limestone (MgO, CaO, dolomite and calcite); positive correlations with the MgO/dolomite content and negative correlations with the CaO/calcite content.

The results of this study provide a useful database for the abundantly available by-product limestone fines that could be used as an affordable sorbent for desulfurization in coal-fired power plants. Utilization of quarry fines as a scrubbing agent could provide two major cost-saving advantages: (1) because the material has already been crushed down significantly, there will be reduced energy cost associated with grinding; and (2) in many cases, the fines are considered waste material, therefore, they are widely available at quarries at a relatively low cost

### **Let's Clear the Air: Industrial Minerals for Air Quality**

Nelson R. Shaffer

Indiana Geological Survey

Indiana University, 611 North Walnut Grove, Bloomington, IN 47405-2208

Contact: shaffern@indiana.edu; (812) 855-2687

Increasingly stringent clean air requirements necessitate extensive use of SO<sub>x</sub> and NO<sub>x</sub> scrubber technology at most electric-generating plants and CO<sub>2</sub> control will require additional air cleaning. Indiana has large deposits of limestone—the major raw material for SO<sub>x</sub> scrubbers—that should meet expected demands of several million tons per year. Different limestone units behave quite differently when used as scrubbing agents. Matching geological characteristics of the existing limestones and prospective scrubber systems should allow for greatly improved operation of flue gas desulfurization (FGD) systems with attendant lower overall costs to all electric users. The FGD-PRISM model of the Electric Power Research Institute predicts FGD system operations. This model requires geologic and geochemical data such as grindability or SO<sub>x</sub> reactivity that are often unavailable from standard analyses.

In this study several hundred limestone samples from more than 30 active quarries in Indiana were collected and their physical properties determined. Grindability values ranged from 7.2 to 21.7 for 50 selected samples. Acid-insoluble residues ranged from less than 1 percent to 55 percent. Dissolution rates, as an index of reactivity, varied over two orders of magnitude for the selected set of samples. These data, plus chemical analyses and calcium-to-magnesium ratios, were entered into the PRISM model to determine rates of stone use and scrubber efficiency for different limestones.

Removal of sulfur dioxide (SO<sub>2</sub>) as projected by this model ranged from 89 to 98 percent. Stone utilization rates varied from 91 to 93 percent. Excellent scrubber stone sources were found in Mississippian age rocks in central and southern Indiana. Rocks of the Paoli, Ste. Genevieve, and Salem Limestones (Mississippian) were especially efficient; however, even small amounts of dolomite, clay minerals, and quartz diminished a stone's usefulness for FGD scrubbing.

Reagents for capturing and storing of CO<sub>2</sub> represent a huge new potential market. Several laboratory techniques use clays, olivine, or other minerals to capture and hold power plant CO<sub>2</sub>, and other materials may prove useful in the future. The wise supplier will be ready for this market.

Scrubber sludge, the sulfite and sulfate residue from FGD, is now used in a number of applications, usually large-scale agriculture or construction projects. Research on additional conventional or high-value uses deserves attention as does the ability of the residue to sequester certain pollutants.

### **Regional Aggregate Mapping Using Airborne EM, Animation, and 3-D Visualization**

Heather Budney

Alberta Geological Survey

Twin Atria Building, 4th Floor, 4999-98 Ave., Edmonton, AB, T6B 2X3

Contact: heather.budney@ercb.ca; (780) 427-9921

The Alberta Geological Survey (AGS) is animating and visualizing in 3-D multiple data sets for two purposes: (1) to test two airborne electromagnetic (EM) techniques for sand and gravel mapping and (2) to determine the aggregate resource potential of the area from Wetaskiwin to Lacombe, Alberta, Canada.

The AGS has a history of mapping sand and gravel with the results of ground EM surveys. However, this is the first time the AGS is applying airborne EM data to sand and gravel mapping. The AGS is testing two airborne EM techniques: Fugro's RESOLVE and GEOTEM. The RESOLVE technique is a frequency-domain EM system involving a geophysical instrument suspended from a helicopter. Approximately 4,279.4 line-km (2,659.1 mi) were flown with a line spacing of 200 m (656 ft) and a tie-line spacing of 2,000 m (6562 ft). Fugro delivered digital cross sections, maps, and data sets showing resistivity, inversion resistivity, and magnetic response. The apparent resistivity is interpreted at 5, 10, 20, 30, and 50 m (16, 33, 66, 98, and 164 ft) below surface. The GEOTEM technique is a time-domain EM system mounted on a fixed-wing aircraft. Approximately 1,200 line-km (746) were flown with a line spacing of 800 m (2,625 ft) and a tie-line spacing of 14,500 m (47,572 ft). Fugro delivered digital cross sections, maps, and data sets showing magnetic response, apparent resistivity, and resistivity depth slices at 10, 30, 60, and 120 m (33, 98, 197, and 394 ft) below surface.

The AGS maps sand and gravel deposits with aggregate potential at a regional scale to provide information to support the sustainable development of Alberta's earth mineral resources. Between 1980 and 1981, the AGS mapped sand and gravel from Wetaskiwin to Lacombe by interpreting the surficial geology of the area, assessing stereopairs of black and white air photos, and test drilling the shallow materials. To update this mapping, at least eight datasets are being compared to and integrated with the airborne EM data, including colour air photos, water-well-drilling records, surficial geology maps, drilling/trenching reports, outcrop descriptions, and ground EM data.

The need to integrate many datasets led to 3-D visualization and animation. The AGS is using ESRI's ArcGIS suite of tools to model lithological tops observed in water wells, drillholes and outcrops, and geological and geophysical maps at multiple depths. Adobe Premiere Pro is a film-editing software that the AGS is using to animate a series of cross sections showing resistivity, inversion resistivity, and magnetic response.

The greatest challenge the AGS faced so far is structuring the data for 3-D visualization and animation. The data must be digital and formatted to meet software requirements. Even though this project is still in the data collection phase, animation and 3-D visualization have been useful techniques for integrating diverse data sets. In our opinion, 3-D visualization and animation are easy. However, preparing the data for modelling requires time and a systematic approach.

## Geologic Framework of Selected Ohio Industrial Minerals

Gregory A. Schumacher

Ohio Department of Natural Resources, Division of Geological Survey

Horace R. Collins Laboratory, 3307 South Old State Road, Delaware, OH 43015

Contact: [greg.schumacher@dnr.state.oh.us](mailto:greg.schumacher@dnr.state.oh.us); (740) 548-7348, ext. 25

Have you ever wondered why many deposits of Ohio's industrial minerals reoccur throughout Ohio's rock column? For example, why does high-calcium, micritic limestone occur in the Ordovician Black River Group and then reoccur in the Devonian Dundee Limestone and Pennsylvanian Maxville Limestone. Participants of the core workshop for the 45<sup>th</sup> Forum on the Geology of Industrial Minerals will learn how the repeated interaction of major Appalachian orogenies, sea level change, cyclic sedimentation, exposure and erosion, diagenesis, and glaciation produced the wealth of repeating industrial mineral deposits in Ohio. Workshop participants also will have ample opportunity to study core present at each station. In addition to high-calcium limestone, salt, coal, clay, sand, and gravel will be highlighted in this workshop. The workshop will conclude with a group exchange of ideas as to the geologic processes responsible for the repeated occurrence of industrial mineral deposits throughout Ohio's geologic framework.

## Recent Developments at the Okorusu Fluorspar Mines, North-Central Namibia

Richard D. Hagni

Department of Geological Sciences, 161 McNutt Hall, Missouri University of Science and Technology, Rolla, MO 65401-0410

Contact: rhagni@mst.edu; (573) 341-4657

The fluorspar mines at Okorusu in north-central Namibia are closely associated with the early Cretaceous Okorusu Alkaline Igneous-Carbonatite Complex. Fluorspar production at Okorusu has increased significantly each year for the past ten years—recently exceeding 130,000 tons of fluorspar concentrate per year—and this productivity ranks Okorusu as one of the world's great fluorspar-producing mines. The increase in production has resulted from the open pit mining of multiple fluorite deposits that occur along the southern rim of the complex where the fluorite ores have mostly replaced carbonatites of the igneous complex and partly replaced regional metamorphic marbles belonging to the intruded Precambrian Damara Series.

Okorusu Limited initiated mining in 1988 at the A fluorite orebody. Fluorite mining in the A open pit has been continuous except for short breaks to establish pushbacks of waste rocks above the northerly dipping orebody, and current drilling has established the presence of previously unknown ore at depth beneath the present pit floor. Geological study of the A pit ores has shown that those fluorite ores formed almost entirely by the replacement of carbonatite and that the relatively high-phosphorus contents in the concentrates from the A pit fluorite ores is due to remnants of unreplaced apatite, an original constituent in the replaced carbonatite. Very minor amounts of fluorite ore that formed by the replacement of marble have recently been recognized along the northwest edge of the A orebody. Underground mining is currently being considered to exploit the deeper fluorite ore in the A orebody.

Open pit mining of the B orebody, located north of the A pit at the summit of Okorusu mountain, began in 1994 and has involved two distinct northwest-trending ore runs. Fluorite ore in the more northerly B run, that formed largely by the replacement of carbonatite, has been entirely mined out. Minor amounts of fluorite ore were formed by replacement of marble at the northwest end of the B run in an area termed the B band satellite. Small amounts of fluorite ore were also formed by the filling and replacement of fenite breccias at the southeast end of the B band in an area known as the B band extension.

By contrast, fluorite ore in the A run of the B orebody has formed by replacement of marble at the contact with a carbonatite intrusion, and mining of that ore run continues today. Fluorite concentrates from fluorite ores that replaced marble do not contain phosphorus but commonly have high silica contents that are largely the result of the presence of abundant quartz in the replaced marbles.

Open pit mining has recently been initiated at two additional orebodies—the C orebody located to the west of the B orebody and the D orebody located to the north of the A and

B orebodies. Mine exposures, drill core, and geophysical evidence indicate that the C orebody formed by the replacement of both carbonatite and marble. In contrast fluorite ores in the D orebody have formed entirely by the replacement of carbonatite. Ores from the D orebody form a significant contribution to the total production from Okorusu, but production from the C orebody has been insignificant to date.

Exploration by drilling has recently targeted two additional fluorite deposits. The G deposit, located east of the A orebody, has been extensively drilled and found to consist of two orebodies—the G Main portion that replaces carbonatite and the G Extension, located to the northwest of the G Main, that replaces marble. A second deposit, called the wishbone deposit, lies far to the northwest of the other fluorite deposits, at the edge of the region of fenitization and mineralization at Okorusu, and it is currently being bulldozed in preparation for exploratory drilling. Limited outcrops indicate that both carbonatite replacement and marble replacement fluorite ores are present in that deposit.

In summary, mining and exploration of fluorite ore deposits to date at the Okorusu mines indicate that 83% of the ores have formed by replacement of carbonatite, 16% by the replacement of marble, and 1% by filling and replacement of fenite breccias.

## Organic Matter of the Middle Georgia Kaolins

Michael C. Cheshire\* and David L. Bish

Indiana University

Department of Geological Sciences, Bloomington, IN 47405

\*Contact: mcheshir@indiana.edu; (806) 438-8274

The presence of pyrite throughout the kaolin deposits of the southeastern United States suggests that these deposits may have originally been deposited as organic-rich muds. Following deposition, extensive groundwater and microbial interactions appear to have reduced the organic matter concentrations, forming organically poor kaolin units. However, many questions remain pertaining to the distribution of organic matter and its role and evolution during diagenesis and post-depositional maturation. The focus of this study was to clarify the source and evolution of organic matter during depositional and post-depositional maturation of the kaolin deposits.

Samples from open mine faces and 7.6-cm drill cores were collected from kaolin lenses in the Buffalo Creek Fm., the Marion Member (Paleocene), and the Jeffersonville Member (Eocene) of Central Georgia. Organic carbon concentrations (TOC) and organic  $\delta^{13}\text{C}$  were determined via combustion techniques coupled with mass spectrometry. Identification of organic compounds was performed by Soxhlet extraction with dichloromethane:methanol (90:10 vol.%) and subsequent analysis via gas chromatography-mass spectrometry (GC-MS). TOC analyses showed that kaolin units contain 0.014–0.176 wt.% TOC, with discontinuous

lignitic beds ranging from 0.278–9.44 wt.% C. Extracted lipid fractions from the oxidized kaolin samples consisted primarily of resin-derived constituents (di- and triterpenoids) with minor amounts of medium-chained (C16 and C18) fatty acids. Kaolin from the underlying reduced zones contained elemental sulfur and minor amounts of medium-chained fatty acids. Organic matter was increasingly enriched in  $^{13}\text{C}$  as TOC decreased, ranging from  $-27\text{‰}$  in lignitic kaolin to  $-22\text{‰}$  in C-poor kaolin. The shift in  $\delta^{13}\text{C}$  as a function of TOC suggests a variety of organic carbon sources associated with the kaolin deposits. As organic matter became depleted, it is possible that  $\delta^{13}\text{C}$  was more influenced by microbial contributions. Microbial metabolism appears to have initially depleted the organic matter, leaving residual fatty acids (decomposition products or microbial cell components) and its  $\delta^{13}\text{C}$  composition within Georgia kaolins. The observed di- and triterpenoids may have been leached from overlying horizons through groundwater migration, leaving these resin-derived molecules restricted to oxidized layers. It is still unclear as to what effects (if any) these various organic molecules have on the kaolin mineralogy.

## Bowing of Marble inside Historic Northeastern Ohio Buildings†

Joseph T. Hannibal\* and David B. Saja

Cleveland Museum of Natural History

1 Wade Oval Drive, Cleveland, OH 44106-1767

\*Contact: hannibal@cmnh.org; (216) 231-4600, ext. 3233

It is well known that marble slabs used to clad the exterior of buildings will bow. The Amoco Building (now the Aon Building) in Chicago is the “type building” for such phenomena. We have found that interior marble bows as well. We have investigated bowing of thin (2.5-cm up to 4-cm thick) marble tablets and limestone panels inside of several northeastern Ohio buildings including the 1876 Memorial Chapel in Akron’s Glendale Cemetery and the 1894 Cuyahoga County Soldiers and Sailors Monument in Cleveland. In the case of these two structures, all of the large panels measured were bowed. Conditions in these two structures varied from each other, but it is likely that heat cycling played a key role in the bowing observed. In the Soldiers and Sailors Monument, at times temperature in space behind the tablets tended to be much higher than the temperatures in front of the tablets. New heating and cooling systems have been put in place to control the temperature within the Soldiers and Sailors Monument and to prevent heat build-up behind the marble slabs. The replacement or flattening of some of the tablets in this monument was discussed, but the marble slabs were left as is, except for some repairs.

(**Note:** This information is an update of information previously presented at meetings of the Geological Society of America.)

†This presentation will take place from 4:30–5:00 P.M. on Monday, October 5 (originally slated for “Regional Aggregate Mapping Using Airborne EM, Animation, and 3-D Visualization” by Heather Budney).

## POSTER PRESENTATIONS

**Black Hand Sandstone: A Building Stone of Unique Distinction from Richland County, Ohio**

Mark E. Wolfe

Ohio Department of Natural Resources, Division of Geological Survey

Horace R. Collins Laboratory, 3307 South Old State Rd., Delaware, OH 43015-7635

Contact: mark.wolfe@dnr.state.oh.us; (740) 548-7348, ext. 26

The quarries have been silent for nearly a century, but the legacy of one of Ohio's most beautiful building stones lives on in the impressive churches, homes, and commercial structures of Mansfield and elsewhere. The Mississippian-age Black Hand Sandstone, commonly called the "Mansfield" stone, was well known in the latter half of the nineteenth century for its unique coloration of reds, browns, and grays that are often arrayed in stripes, swirls, and bands. In the hands of a skilled stone mason, the rich tapestry of the Black Hand Sandstone found in Richland County rivals marbles and granites.

The most important quarries were located to the immediate northeast of Mansfield. Approximately 60 feet of medium- to coarse-grained Black Hand Sandstone is exposed. The sandstone is predominantly brown to tan in color, often with black, red, and gray laminations. The sandstone with Liesegang rings or banding occurs near the bottom of the quarry and varies from 10 inches to 4 feet thick. Rapid lateral variations in color are evident throughout the quarries. Prominent near-vertical joints trending northeast–southwest to southeast–northwest are exposed in the north wall of the west quarry. The original quarry (east) opened about 1840; the west quarry was opened in 1894 and closed about 1906. The quarries were worked intermittently into the 1930s.

The stone quarried at Mansfield was marketed in Ohio and surrounding states. The massive and forbidding State Reformatory, northeast of Mansfield, specified that the lightest-colored "Mansfield" sandstone be used. A remarkable example of the Black Hand building stone in the Mansfield area is the Martin Bushnell residence, built in 1892. The Universal Unitarian Church, built in 1894 in Bellville; commercial buildings scattered throughout the Carousel District of downtown Mansfield; the restored bathhouse at Liberty Park, Mansfield; and the First Presbyterian Church in Shelby are also handsome examples of the Black Hand sandstone dimension stone. Four additional Presbyterian churches in Ohio—located in Napoleon, Dayton, Barnesville, and Upper Sandusky, respectively—used the Black Hand Sandstone from the Mansfield area for construction.

The National Institute of Standards and Technology in Gaithersburg, Maryland, constructed a stone test wall in 1948 of building stones collected from working quarries in the United States during the 1870s. The wall provides an opportunity to study the effects of weathering on stone from throughout the United States, with the climatic conditions being the

same for all stones. Two samples from Mansfield, one from Bellville, and one from Richland County (Weller Township) are available for research. The weathering characteristics of the Black Hand Sandstone in Richland County, Ohio, compares favorably with other sandstones from across the country.

Additional quarries that produced the Black Hand Sandstone include one at Pavonia in Weller Township, Richland County; one at Bellville in Jefferson Township of Richland County; Richland Stone Company north of Lucas in Monroe Township, Richland County; at least two quarries north of Mifflin in Ashland County; two in Ashland County to the east of Pavonia; and four in northeastern Troy Township, Richland County.

The surface bedrock of the area is composed primarily of siliciclastic rocks of Mississippian and Pennsylvanian ages. Underlying the Black Hand is a stratigraphically complex series of shales, siltstones, and silty sandstones—the Pleasant Valley Member of the Cuyahoga Formation. A similar stratigraphic section in Congress Township (Wayne County) consisting of 31 feet of interbedded siltstones and silty shales was named the Armstrong Member of the Cuyahoga Formation. To further complicate matters, the Black Hand in Richland, Ashland, and Wayne Counties has both sandstone and shale facies.

The Black Hand Sandstone member of the Cuyahoga Formation is a prominent ridge former in central and southern Richland County, as well as southern Ashland County. The Black Hand is a thick-bedded to massive sandstone composed primarily of quartz grains. A definite lobate geometry is conspicuous regionally. Low-angle and trough cross-bedding is common. Conglomeritic lenses and graded bedding are often found. Fossils are rare, particularly in the cross-bedded facies, but marine fossils are often found near the top of the Black Hand in thin-bedded and horizontally laminated units.

Overlying the Black Hand is the Berne member of the Logan Formation. The Berne is commonly a sandstone conglomerate 1 to 2 feet thick elsewhere in Ohio. An erosional unconformity often exists at the contact of the Berne conglomerate and the Black Hand Sandstone.

The Byer Sandstone overlies the Berne Conglomerate. The Byer is a fine-grained to silty sandstone that is most often thin-bedded. Thick interbeds of fine-grained sandstone are commonly encountered. The Byer can be up to 75 feet thick.

The Vinton and Allensville members of the Logan Formation overlie the Byer. The Allensville is a thin-bedded, coarse-grained sandstone with occasional siltstone interbeds. Thickness is approximately 1 foot. The overlying Vinton is a silty sandstone 10–50 feet thick. Pennsylvanian-age sandstones, shales, and thin limestones of the Pottsville Group can be found at the highest elevations in southern Richland County.

The Black Hand Sandstone in Richland County was most likely deposited as marine bars or shoals and distributary mouth bars as part of a westward prograding delta. Strong longshore currents continuously reworked sand at the mouth of a distributary channel into bar deposits. Microscopic examination of the Black Hand shows a moderately well-sorted, subrounded, clean,

quartz sandstone, which is further evidence of bar deposition.

Complex bands, rings, stripes and swirls are a distinctive feature in the Black Hand Sandstone of Richland County and are major reasons the Black Hand is such a striking and unique building stone. Liesegang bands in rocks are believed to form at the juncture of two distinct lithologies, such as the sandstone and shale at Mansfield, or when fluids are out of equilibrium with one or more minerals in the aquifer. Additional research into local stratigraphic relationships and the spatial distribution of the uncommon and colorful banding in the Black Hand Sandstone of Richland County could yield a more definitive answer.

### **Illinois Industrial Minerals**

Zakaria Lasemi\* and Donald G. Mikulic

Illinois State Geological Survey

Institute of Natural Resource Sustainability, University of Illinois, 615 E. Peabody Dr.,  
Champaign, IL 61820

\*Contact: zlasemi@illinois.edu; (217) 244-6944

Industrial minerals continue to be one of Illinois' major mineral-resource commodities, accounting for \$1.2 billion (43%) of the total value of minerals produced in the state in 2007. Coal (\$1 billion or 36%) and oil (\$602 million or 21%) are the other main mineral resources. According to the 2006 U.S. Geological Survey mineral industry profile, Illinois ranked twentieth among the 50 states in total value of nonfuel mineral production. By value, crushed stone was the state's leading industrial mineral, accounting for about 47 percent (\$573 million) of the total, followed by portland cement, 25 percent (\$305 million); construction sand and gravel, about 14 percent (\$168 million); industrial sand, about 9 percent (\$110 million); and lime, fuller's earth, tripoli, and other nonfuel minerals, in decreasing order, accounting for most of the remaining 5 percent (\$60 million). Economic analysis indicates that because of their large impact on infrastructure, every dollar's worth of industrial minerals consumed in Illinois contributes \$550 directly and indirectly to Illinois' gross state product (GSP).

Since 1970, Illinois has been consistently among the top seven leading states in production of crushed stone. Illinois also continuously has been a major producer of construction sand and gravel. Metals were last produced in 1996, when small quantities of copper, lead, silver, and zinc were produced from Illinois mines. In 2006 Illinois remained first among the 49 mineral-producing states in the production of industrial sand, tripoli, dolomite, and recycled cement concrete; seventh in crushed stone; ninth in portland cement; and thirteenth in construction sand and gravel. Of the industrial minerals mined or manufactured in Illinois, those that have the highest value include crushed stone, cement, construction sand and gravel, and industrial sand.

Crushed stone, construction sand and gravel, and portland cement combined continued to account for more than 85 percent of the value of Illinois' nonfuel industrial minerals mined or manufactured. Road construction and repair are a major source of demand for the state's crushed stone, sand-and-gravel aggregates, and cement. According to the Illinois Department of Transportation (IDOT), Illinois has the third-largest network of state and local roads and the sixth-largest interstate highway system in the country. The state also has more than 26,000 bridges, 8,227 of which are on the state highway system. The Illinois highway system is heavily used. A significant number of bridges need repair or replacement, as do much of the interstate highway system along with many state and secondary highways and roads. Large amounts of construction aggregates are required to keep interstate highways in top condition, maintain major highways, and improve congested urban and rural highways. The aggregates industry contributes significantly to roadway improvement by providing the needed raw materials, primarily crushed stone and sand and gravel. With the depletion of reserves in existing quarries and pits, urban developments on existing reserves, and opposition to opening new sites, the state will be faced with enormous challenges as to how and where it can economically acquire the material needed for building and rehabilitating its aging infrastructure.

Sand-and-gravel deposits are widely distributed throughout the state, but they are most abundant and of highest quality in northeastern Illinois. They are primarily extracted from glacial deposits in the central and northeastern parts of the state. Production of sand and gravel, however, has not increased significantly since the late 1960s. This is probably related to the better quality and larger reserves of crushed stone aggregate and the difficulty, because of public opposition, in securing permits for new sand-and-gravel operations. Dolomite, mined from the Silurian and Ordovician carbonates in northern Illinois, especially in the Chicago area, accounts for most of the stone produced in the state. Northeastern Illinois is one of the largest aggregate-producing and consuming regions in the country and will likely remain so, long into the future. In the western and southern parts of the state, limestones of the Mississippian System are extracted for construction aggregates, cement manufacture, and other related purposes. Limited amounts of Pennsylvanian-age limestone occur in the central part of the state and are quarried where they are present near the surface. In these areas, underground mining may be necessary to meet the region's crushed-stone needs, because near-surface limestone beds are of limited areal extent or thin and generally unsuited for use in concrete highways.

The depletion of near-surface reserves and the difficulty in obtaining zoning and other permits for new, geologically suitable quarry sites continues to impact the crushed stone and sand-and-gravel industries in northern Illinois. Opposition to aggregates mining is no longer limited to populated areas. Opening or expansion of quarries and pits also is strongly contested by citizens in rural areas throughout the state. In partial response to the opposition to new stone quarries and sand-and-gravel pits, companies continue to evaluate or pursue development of underground mines, especially in northeastern Illinois. Historically, Chicago aggregates have been produced from quarries developed in the Silurian-age rocks that occur throughout the

region. With the depletion of reserves in these rock units in conjunction with the difficulty in opening new quarries, a number of producers have begun to develop underground mines at existing quarries and gravel pits, targeting the deeper Ordovician Galena-Platteville rocks (mainly dolomite) as a new source of aggregates. The first of these mines was opened by the Elmhurst-Chicago Stone Company in the 1970s, and there are currently six underground mines in operation and another two under development. According to the Aggregate Manager and the U.S. Geological Survey, there were 98 underground stone mines in the nation in 2005, and Illinois was third in the amount of crushed stone produced from underground mining operations.

## The Mineral Industries Map of Ohio

Mark E. Wolfe

Ohio Department of Natural Resources, Division of Geological Survey

Horace R. Collins Laboratory, 3307 South Old State Rd., Delaware, OH 43015-7635

Contact: mark.wolfe@dnr.state.oh.us; (740) 548-7348, ext. 26

The Ohio Department of Natural Resources (ODNR), Division of Geological Survey has published the *Report on Ohio Mineral Industries: An Annual Summary of the State's Economic Geology* since 1981. The *Report* contains prior year production statistics, employment data, and geologic summaries of coal, industrial minerals, and oil-and-gas activities in Ohio. The *Report* also features a map with the locations of all producing coal mines and industrial mineral facilities with valid permits. The map allows a user to connect a spatial location to the statistics and information for a particular mine. Available in digital format since 2001, the mineral industries map is updated annually. Analysis of the series of mineral industries maps over time allows a user to spot trends in the industry and regional changes of mining in Ohio. The mineral industries map is an important component of the comprehensive, statewide geographic information system containing geologic information that currently is under development at the ODNR Division of Geological Survey.

## New Uses for Coal Combustion Byproducts

Nelson R. Shaffer

Indiana Geological Survey

Indiana University, 611 North Walnut Grove, Bloomington, IN, 47405-2208

Contact: shaffern@indiana.edu; (812) 855-2687

About 80 million tons of coal combustion byproducts (CCBs, or commonly called “ash” or “sludge”) are generated annually by electric utilities according to the Electric Power Research Institute. Some ash is used as fill for aggregate or cement making, but most (~75 percent) is currently unused. Several Midwestern coals contain appreciable amounts of economically important elements, such as zinc, germanium, and gallium. These and other indigenous elements become concentrated in coal combustion byproducts. In addition, useful forms of carbon, silicates, or glasses are also known to exist in ash. A potential bounty of useful materials can be found at most power plants.

There is potential to recover selected industrial minerals, bulk raw materials, or even exotic elements at relatively low costs from ash. Separations of useful materials by particle size, specific gravity, or other properties have been demonstrated and pilot plants for recovering minerals from ash currently are in operation. Cenospheres—hollow glass spheres that are present in most ash—actually float in water. Unburned carbon occurs in ash as absorbent materials and possibly as carbon whiskers, graphene, or even fullerenes. Simple sieving has been shown to concentrate unburned carbon, rendering remaining ash more suitable for concrete aggregate and providing a carbon-rich raw material.

Proper treatment of CCBs could yield industrial minerals, useful metals, and high-tech materials. Resource geologists and processors should carefully consider unconventional new uses for the abundant low-grade but readily available ash “ore” that is present through the Midwest.

### The U.S. Geological Survey’s Global Assessment Program for Potash

Mark D. Cocker\*, Greta J. Orris, Jeffrey C. Wynn, Bruce R. Lipin, and Gregory T. Spanski

U.S. Geological Survey

520 N. Park Ave., Suite 355, Tucson, AZ 85719

\*Contact: mcocker@usgs.gov; (520) 670-5506

The U.S. Geological Survey (USGS) is completing a quantitative assessment of the more significant potash-bearing, marine-evaporite basins of the world. The assessment required development of geographic information system (GIS) databases of potash mines, occurrences, drill holes, and defining basins or parts of basins that are permissive for undiscovered potash

deposits. Criteria used to define basins or parts of basins as permissive tracts may depend on structural style, available geologic data, or economic variables. Although a maximum depth of about 2 km (1.24 mi) may be attained through conventional mining, a maximum depth of 3 km (1.86 mi) is used for assessments given possible extraction by solution mining.

Generally, huge potash resources, on the order of billions of tons, occur within flat or gently dipping, stratabound deposits as found in the Devonian Elk Point Basin of Saskatchewan and the Permian Basin of the United States. Smaller deposits, generally on the order of tens to several hundred million tons, occur in basins dominated by structural conditions that may elevate deeply buried, potash-bearing salt nearer to the surface above the 3 km (1.86 mi) depth limit. For the purposes of this assessment, diapiric salt structures, such as those found in the Permian Zechstein Basin of north-central Europe and the Pricaspian Basin in Russia and Kazakhstan, were grouped with tectonically folded salt structures, such as those found in the Pennsylvanian Paradox Basin of the western United States and the Miocene Carpathian Basin in southeastern Europe.

Deposit size, potash grade, and mineralogy require consideration in assessments. Many deposits have been developed because they contain abundant sylvite, which has a considerably higher  $K_2O$  (63.2%) content than other potash minerals. Some deposits of this type occur in the Elk Point, Permian, and Pripyat (Belarus) basins. Equally important are deposits containing more intermediate grade carnallite (16.9%  $K_2O$ ), kainite (19.3%  $K_2O$ ), or langbeinite (22.7%  $K_2O$ ), such as those in the Zechstein and Permian basins. Undeveloped and largely unexplored deposits of lower grade but huge resources of polyhalite (15.6%  $K_2O$ ), often associated with anhydrite-bearing strata, may represent a major future potash resource. In fact recent exploration efforts have been focused on the polyhalite-bearing, Rustler Formation within the Permian Basin of New Mexico and Texas.

## FIELD TRIP GUIDE

October 6, 2009    **Aggregates and More: Economic Geology of the Delaware and  
Warrensburg Quarries, Delaware County, Ohio**  
Mark E. Wolfe, Senior Geologist  
Ohio Department of Natural Resources (ODNR)  
Division of Geological Survey

| Mileage (Cumulative)                                       | Road Log   |
|--|--|
| <p><b>0</b> (0)<br/>Galena 7.5-minute quadrangle</p>       | <p>ODNR Division of Geological Survey Horace R. Collins Laboratory and Core Repository at Alum Creek State Park, Delaware, Ohio. Glacial deposits in the area range from 40 to 65 feet-thick (Larsen and others, unpub. data, 2004). Bedrock geology in the area consists of Upper Devonian-age Ohio Shale. Travel north on South Old State Rd.</p>  |
| <p><b>0.5</b> (0.5)</p>                                    | <p>Approach intersection of South Old State Rd. and Cheshire Rd. (C-72). Turn left and continue west on Cheshire Rd.</p>   |
| <p><b>3.2</b> (3.7)<br/>Powell 7.5-minute quadrangle</p>   | <p>Approach intersection of Cheshire Rd. and U.S. 23. Turn right and continue north on U.S. 23.</p>  |
| <p><b>0.6</b> (4.3)<br/>Delaware 7.5-minute quadrangle</p> | <p>Perkins Observatory, on east side of highway (out of view), owned by Ohio Wesleyan University, was completed in 1931. The original 69-inch mirror was cast by the United States National Bureau of Standards due to the destruction of European glass-makers in World War I. The building was designed by architects Talmadge and Watson, Chicago, Illinois, and uses seven shades of rough-faced grey brick, Bedford Limestone from Indiana, and "verde antique" marble, most likely from Vermont (Crump, 1929).</p> |
| <p><b>0.4</b> (4.7)</p>                                    | <p>Approach intersection of U.S. 23 and State Route (SR) 315. Turn left immediately north of the bridge spanning the Olentangy River. Middle Devonian-age Delaware</p>   |

Limestone is exposed in the river bed. Continue south on SR 315. Stone residence and buildings on west side of road constructed from Delaware Limestone circa 1850. The Delaware Limestone was used as a building stone on a number of area buildings. Most notable are Merrick Hall, the gymnasium, and chemical building at Ohio Wesleyan University; Cultural Arts Center; St.Peters Episcopal Church; and Ashbury Methodist Church, in the city of Delaware (Bownocker, 1915).

0.2 (4.9) Approach intersection of SR 315 and Bunty Station Rd. (T-141). Turn right and continue west on Bunty Station Rd.

3.6 (8.5) Approach intersection of South Section Line Rd (C-5) and Bunty Station Rd. Turn right and continue north on South Section Line Rd., crossing U.S. 42.  
Ostrander 7.5-minute quadrangle

1.8 (10.3) **STOP 1:** Entrance to Delaware Quarry, owned by National Lime and Stone Company, on south side of road.

## STOP 1

The Delaware Quarry is located in Scioto Township of Delaware County, Ohio (lat 40.286, long -83.14; see fig. 1). National Lime and Stone Company began operating the Delaware Quarry in 1949 and this locality has produced limestone for building stone, lime, and road materials since the 1850s. Scioto Lime and Stone Company operated the previous “Klondike” quarry for many years in the early 1900s, producing lime from as many as 18 kilns in the late 1920s (Westgate, 1926.). In 2008, the Delaware Quarry produced 2,864,000 tons of limestone and dolomite used primarily for road construction and the production of portland and asphaltic concrete. Lesser amounts of produced stone were used as riprap, building stone, and agricultural limestone (Wolfe, in press). Annual production at the Delaware Quarry since 1989 has averaged 3,231,900 tons, with a maximum production of 5,497,000 tons in 2000. The Delaware Quarry consistently ranks in the top five largest producing aggregate quarries annually in Ohio.

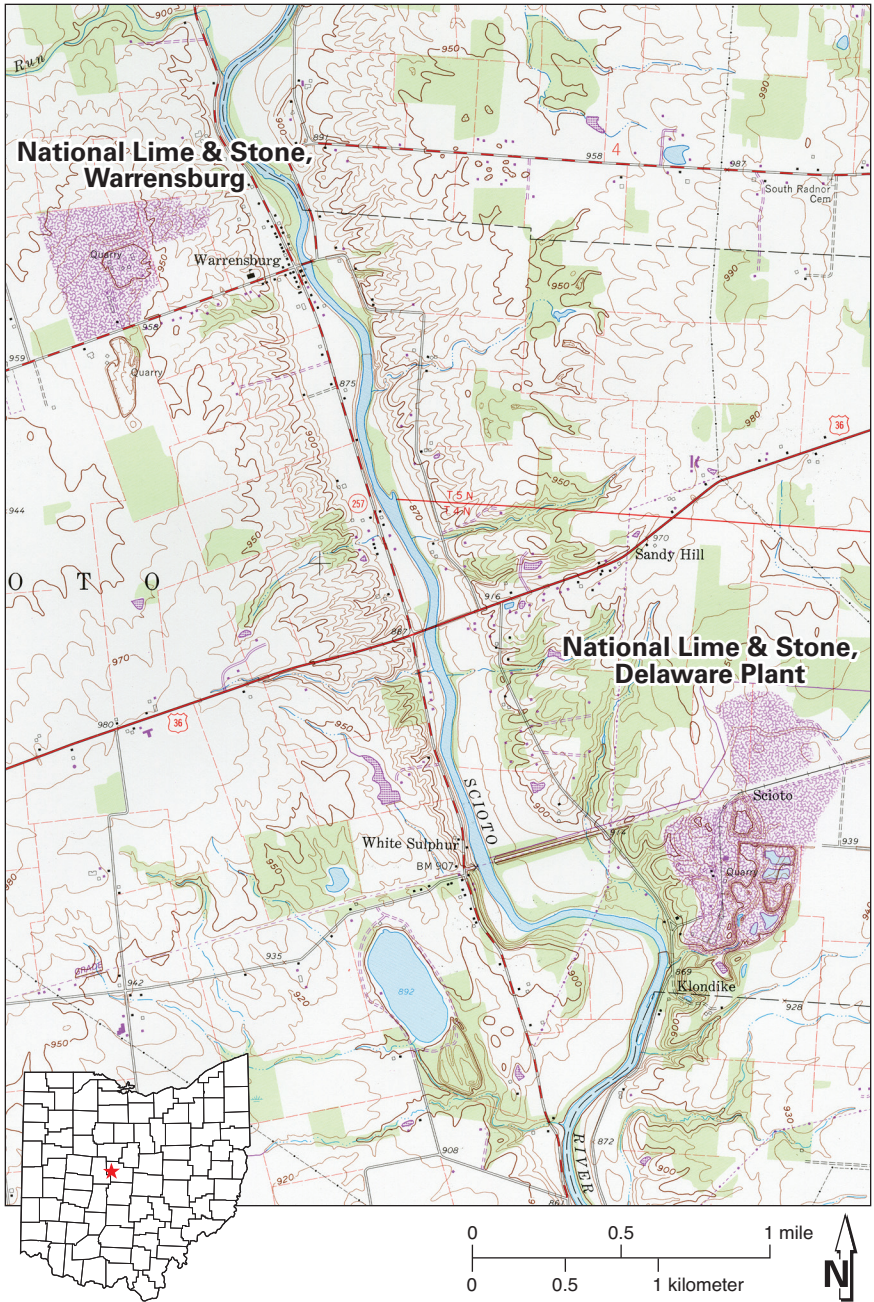


FIGURE 1.—Location map of the Delaware and Warrensburg Quarries, Delaware County, Ohio.

## Geology

Continental glaciation reached central Ohio at least three times during the Pleistocene Epoch, resulting in the presence of glacial features, such as moraines, kames, eskers, outwash deposits, and tills. The Wisconsinan-age till at the Delaware Quarry is generally thin (less than 15 feet-thick) but thickens locally primarily due to the presence of a buried tributary valley that trends northeast-southwest in the northern portion of the quarry. The silty, clay-rich till is associated with ground moraine and may contain varying amounts of sand to cobble-sized material.

Underlying the till is the Middle Devonian-age Delaware Limestone. The lower portion of the Delaware Limestone exposed at the Delaware Quarry is approximately 20 feet thick and similar to the type section of the Delaware Limestone located five miles to the north at Blue Limestone Park in the city of Delaware, Ohio. Approximately 44 feet of dark blue-gray, thin-bedded limestone with thin interbedded shale and chert layers are present at the type section. The Delaware Limestone is highly fossiliferous with abundant *Tentaculites scaleriformis* found approximately 20 feet below the top (Stauffer, 1909; see fig. 2).

The base of the Delaware Limestone is often delineated by a zone 4 to 8 inches thick that contains many small, dark, phosphatic fragments of the bones, teeth, and dermal plates of fish. This “bone bed” is one of several thin, distinctive units that occur in the Delaware Limestone and in the underlying Columbus Limestone. The origin of bone beds is problematic, but they most likely occurred when fish material was transported from fresh-water lakes and rivers and deposited in a near-shore environment. Currents winnowed the clays and other fines from the decomposed fish, concentrating the fish remains in shallow water topographic lows. Abraded ripple-marked surfaces on the surface of the Columbus Limestone at the Delaware Quarry suggest oscillation features formed by storm wave action that may have contributed to the formation of the bone beds (Bates, 1971). An alternative explanation to the occurrence of the bone beds is a nondepositional to very slow depositional environment (lagoonal?) in which the more resistant, phosphatic, fish remains could accumulate.

The Tioga bentonite has been identified in the subsurface of eastern Ohio in the upper-most Devonian carbonate sequence (Collins, 1979) and has been reported as a probable occurrence in central Ohio at the Columbus-Delaware Limestone contact (Conkin and Conkin, 1975). The Tioga bentonite has also been recognized in cores from central Ohio (Swinford, written. comm., 2009). The Tioga bentonite is usually marked by the presence of coarse, euhedral, biotite flakes in brown shale. The thickness of the Tioga in Ohio is not known, but it appears the bentonite thickens eastward, indicating a source area in central Virginia.

The underlying Lower Devonian-age Columbus Limestone is separated from the Delaware Limestone by a significant unconformity and correlates to the Oatka Creek Formation of the Marcellus Subgroup of New York (Ausich, 2003). The upper 46 feet of the Columbus Limestone (Delhi Member) is a light brown to gray, thick-bedded to massive limestone that is

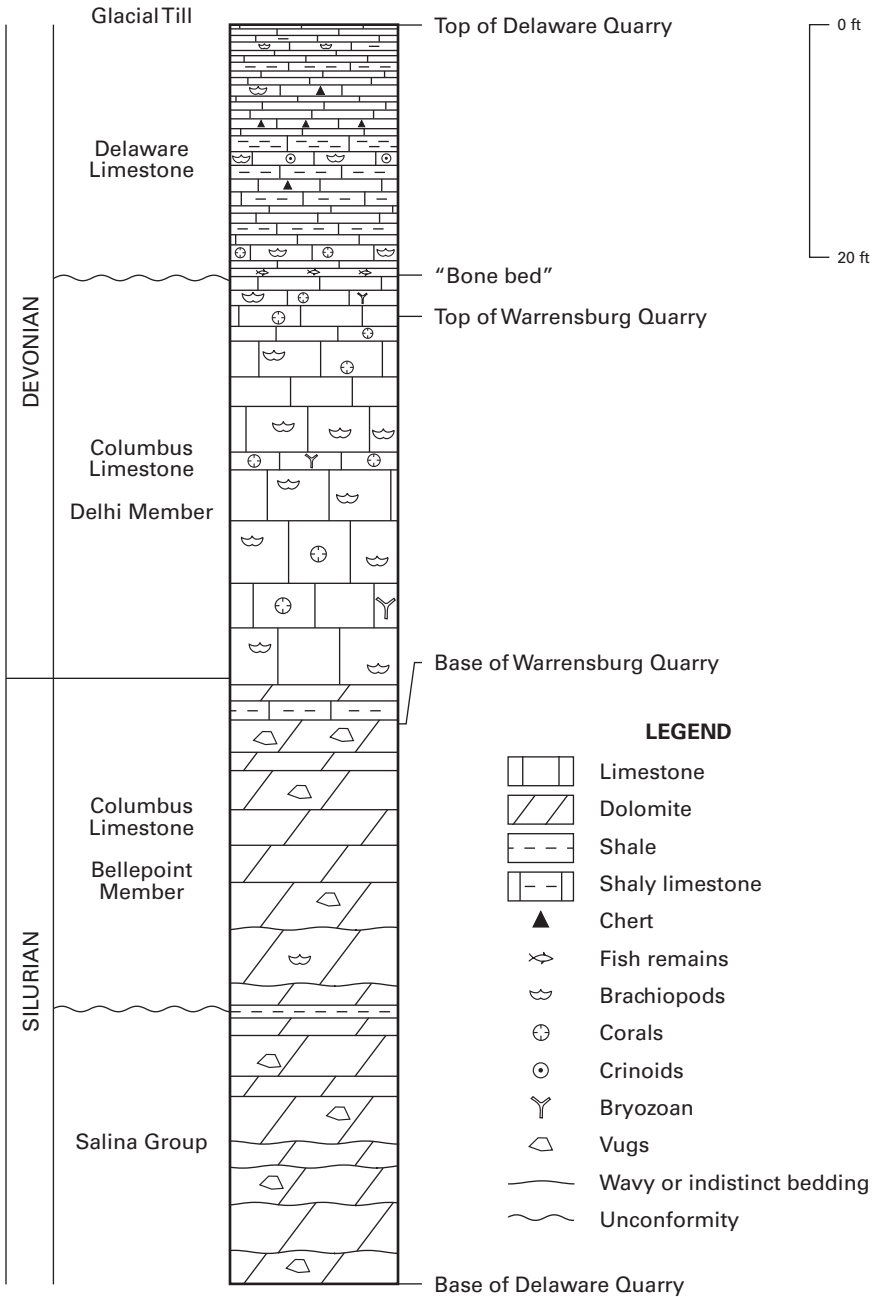


FIGURE 2.—Composite geologic section for the Delaware and Warrensburg Quarries located in Delaware County, Ohio. Compiled from measured sections and core descriptions on file at the ODNR Division of Geological Survey.

very fossiliferous. The fauna is dominated by brachiopods, corals, stromatoporoids, bryozoans, gastropods, and trilobites. Large cephalopods are common (Stauffer, 1909). Zones of white to black chert are commonly found, though these beds are mostly lacking at the Delaware Quarry. The Delhi member of the Columbus Limestone is generally considered high-calcium (greater than 90%  $\text{CaCO}_3$ ) but is normally quarried in conjunction with the overlying Delaware Limestone and underlying Bellepoint Member of the Columbus Limestone, a dolomitic limestone, which may lower overall content of stockpile material to 82%  $\text{CaCO}_3$  (ODNR, 1988).

The Bellepoint Member of the Columbus Limestone is 32 feet thick in the Delaware Quarry. The Bellepoint Member is yellow-brown, finely crystalline, massive dolomite, calcareous in part and characterized by hydrocarbon staining. Fossils are poorly preserved. White to gray chert and small masses of crystalline calcite are found throughout the Bellepoint Member (Stauffer and others, 1911; Swinford and Slucher, 1995). The basal one foot of the Columbus Limestone often contains fine-grained, well-rounded to subangular quartz sand and conglomerate and can be recognized in the subsurface as the Bois Blanc and Oriskany Sandstones; the Hillsboro Sandstone of southern Ohio is a lateral equivalent to the base of the Columbus Limestone. At the Delaware Quarry, this basal zone is represented by six inches of fissile, light-gray shale and dolomitized shale clasts.

The Columbus Limestone is underlain by the Silurian-age Salina Group. The Silurian/Devonian time-stratigraphic boundary is determined faunally by the ostracode *Leperditia alta* (Silurian), with Devonian-age fossils found in the overlying units (Janssens, 1969). A core drilled in the floor of the Delaware Quarry (ODNR, 1987) determined that more than 260 feet of the Salina Group is present at this location. The Salina is a light- to dark-gray, fine-grained dolomite with indistinct to wavy bedding and scattered zones of intergranular, vuggy, and moldic porosity. There are minor thin interbeds of shale, limestone, and gypsum and zones of vertical fracturing. High-pressure, sulfurous gas was encountered 240 feet into the Salina Group between two gypsum-rich zones. The upper portion of the Salina Group at the Delaware Quarry contains low-quality aggregates and is used primarily for road-base, fill, and as a sump for quarry dewatering.

| Mileage (Cumulative) | Road Log (cont.)  |
|----------------------|---|
| 0 (10.3)             | Exit Delaware Quarry. Turn left and continue north on South Section Line Rd.  |
| 1.1 (11.4)           | Approach intersection of U.S. 36 and South Section Line Rd. Turn left and continue west on U.S. 36.   |
| 2.0 (13.4)           | Approach intersection of U.S. 36 and SR 257 after crossing the Scioto River. (O'Shaughnessy Dam is located approximately 10 miles downstream.) Turn right and continue north on SR 257. |
| 1.3 (14.7)           | Approach intersection of SR 257 and Ostrander Rd. (C-163) in the village of Warrensburg. Turn left and continue west on Ostrander Rd.   |
| 0.4 (15.1)           | <b>STOP 2:</b> Entrance to Warrensburg Quarry, owned by National Lime and Stone Company, on north side of road. Locked gate.  |

## STOP 2

The Warrensburg Quarry is located in Scioto Township of Delaware County (lat 40.305, long -83.171, see fig. 1). The Warrensburg Quarry is currently owned by National Lime and Stone Company, who acquired the property in 2004 from Martin Marietta Aggregates. Martin Marietta purchased the property in 1997 from American Aggregates; American Aggregates had taken over operation of the Warrensburg Quarry from Owens Stone in 1991. Owens Stone had produced stone from the quarry since 1942. There are reports that stone was being produced west of Warrensburg prior to 1925. Annual production from 1989–2008 at the Warrensburg Quarry averaged 471,000 tons, with a high of 1,121,897 tons produced in 1998. The last significant aggregate production at Warrensburg occurred in 2002 (884,000 tons). The Warrensburg Quarry was idle in 2009, with some stockpiled stone being sent to the National Lime and Stone Company affiliate Cascades Cut Stone Company in Vanlue, Ohio, for processing into landscape stone and other architectural products. The Warrensburg Quarry also serves as a high-quality aggregate reserve for National Lime and Stone Company in a high-growth area of central Ohio.

## Geology and Fossils

Glacial tills are thin to non-existent, which improves the suitability for quarrying (Stith, 1995). Minor karst development occurs at the top of the quarry and there are unverified reports that small caverns were intercepted during mining (see also Pavey and others, 2007). The entire Delhi Member of the Columbus Limestone is exposed at the Warrensburg Quarry (44 feet thick). The lower portion of the Delaware Limestone was apparently removed by erosion. The Delhi Member is light brown to gray, thin- to thick-bedded, fine- to coarse-grained limestone that is abundantly fossiliferous. Corals and brachiopods are the most common fossils. There is prominent vertical and subvertical, arcuate fracturing in the quarry walls. The lower 4 to 6 feet of the Delhi member exhibits a poikilitic texture, with stylolites and oxidation common. Fossils become much more rare in the lower portion of the Delhi member. A 1-inch to 2-foot-thick zone in the lower-most portion of the quarry reveals an unconformity and a dark-brown to black, argillaceous limestone with abundant corals. A dolomitic limestone that is exposed in the quarry-ditch around the western perimeter of the quarry (now under water) probably represents the Bellepoint Member of the Columbus Limestone.

The Delhi Member of the Columbus Limestone offers an excellent opportunity to collect a diverse assemblage of Devonian-age invertebrate fossils, such as abundant brachiopods, corals, gastropods, pelecypods, bryozoans and large cephalopods, trilobites, and blastoids; well-preserved crinoids are not as common. Vertebrate fossils may also be found in the Delhi Member. Spines from a trunk shield are not uncommon (Feldman and Hackathorne, 1996; Stauffer, 1909; see fig. 3).



FIGURE 3.—*Machaeracanthus peracutus* Newberry, fin spine (left) and *Aleistoceras eximium?* cephalopod (right). Columbus Limestone, Delhi Member, Warrensburg Quarry, Delaware County, Ohio (see Feldman and Hackathorn, 1996).

## References Cited

- Ausich, W.I., 2003, New cladid crinoid from the Middle Devonian Delaware Limestone, Franklin County, Ohio: *Ohio Journal of Science*, vol. 103, p. 19–24.
- Bownocker, J.A., 1915, Building stones of Ohio: *Ohio Division of Geological Survey Bulletin* 15.
- Bates, R.L., 1971, Abraded ripple-marked surfaces in Columbus Limestone, central Ohio: *Ohio Journal of Science*, vol. 71, no. 4, p.233–240.
- Collins, H.R., 1979, Devonian bentonites in eastern Ohio: *AAPG Bulletin* vol. 63, no. 4, p. 655–660.
- Conkin, J.E. and Conkin, B.M., 1975, Middle Devonian bone beds and the Columbus-Delaware (Onondaga-Hamilton) contact in central Ohio: *Bulletins of American Paleontology*, vol. 67, no. 287, p. 99–123.
- Crump, C.C., 1929, The Perkins Observatory of the Ohio Wesleyan University: *Popular Astronomy*, vol. 27, no. 10, p. 554–559.
- Feldman, R.M. and Hackathorn, Merrienne, eds., 1996, *Fossils of Ohio*: Ohio Division of Geological Survey Bulletin 70, 577 p. (Reprinted 2005.)
- Janssens, Arie, 1969, Devonian outcrops in Columbus, Ohio, and vicinity: *Ohio Division of Geological Survey Field Trip Guidebook for North-Central Section of GSA, Field Trip 1*, 22 p.
- ODNR Division of Geological Survey, 1987, Core Record File No. 2633: Ohio Department of Natural Resources, Division of Geological Survey Oil and Gas Interactive Web Map, 6 p., last accessed September 8, 2009, at <[http://www.dnr.state.oh.us/Website/Geosurvey/core\\_pdf/C2633.pdf](http://www.dnr.state.oh.us/Website/Geosurvey/core_pdf/C2633.pdf)>.
- ODNR Division of Geological Survey, 1988, Limestone and dolomite chemical analyses, 1974–1982: Ohio Department of Natural Resources, Division of Geological Survey Open-File Report 88-1, [57] p.
- Pavey, R.R., Hull, D.N., Brockman, C.S., Schumacher, G.A., Stith, D.A., Swinford, E.M., Sole, T.L., Vorbeau, K.E., Kallins, K.D., Evans, E.E., Slucher, E.R., and Van Horn, R.G., 2007, Known and probable karst in Ohio: *Ohio Division of Geological Survey, EG-1*, scale 1:500,000.
- Stauffer, C.R., 1909, The Middle Devonian of Ohio: *Ohio Division of Geological Survey Bulletin* 10, 204 p.
- Stauffer, C.R., Hubbard, G.D., and Bownocker, J.A., 1911, Geology of the Columbus Quadrangle: *Ohio Division of Geological Survey Bulletin* 14, 133 p.
- Stith, D.A., 1995, Potential crushed stone resources of the Bellefontaine, Ohio 30 X 60 minute quadrangle: *Ohio Division of Geological Survey Open-File Map* 302, scale 1:100,000.
- Swinford, E.M., and Slucher, E.R., 1995, Regional bedrock geology of the Bellefontaine 30 X 60 quadrangle: *Ohio Division of Geological Survey Map* 8, scale 1:100,000.
- Westgate, L.G., 1926, Geology of Delaware County: *Ohio Division of Geological Survey Bulletin* 30, 147 p.
- Wolfe, M.E., in press, 2008 Report on Ohio Mineral Industries—An annual summary of the state’s economic geology: Columbus, Ohio Department of Natural Resources, Division of Geological Survey, [101] p.

## NOTES

## NOTES

NOTES

