PENNSYLVANIA GEOLOGY

THE PENNSYLVANIA GEOLOGICAL SURVEY VOL. 20/3

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ON THE COVER: Reproduction of a copper-plate engraving by W. A. Rogers of the scene at the railroad bridge during the Great Johnstown Flood of May 31, 1889. Provided courtesy of Alice Marshall, Camp Hill, Pennsylvania, from an original copy of *Harper's Weekly* of June 15, 1889.

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VOL. 20, NO. 3 **JUNE 1989**

The Lessons of the Conemaugh

John Wesley Powell, the fiery, one-armed Civil War veteran, explorer of the Colorado River, found lessons to be learned from the Great Johnstown Flood of May 31, 1889. The centennial of the "Great Flood" is commemorated throughout Pennsylvania this year in newspaper and magazine articles, on the cover of this issue, and in many events in Johnstown, including the 1989 meeting of the Field Conference of Pennsylvania Geologists.

In 1889, Powell was attempting to map our nation by preparing topographic maps of eastern states through the U.S. Geological Survey and of the arid land states by the Irrigation Survey. He wrote in the *North American Review* that "the lesson of the Conemaugh," the title of his article, was "a very old one; that must be taught to mankind again and again." Powell was a visionary who believed in long-range planning. He knew that in order to avoid disasters caused by natural events it is essential to have foreknowledge of all of the natural conditions and expectations of an engineering project. Careful topographic and hydrographic surveys are a necessity prior to construction of dams and reservoirs.

The same needs exist today! Topographic maps must be continually updated; modern geologic and hydrogeologic surveys must be accomplished to provide the information needed for planning the wisest use of our land for the greatest public benefit.

A Footnote

Clara Barton, Founder of the American Red Cross, writing with Powell in the *North American Review*, spoke of the perplexities she and her Red Cross workers faced during the Great Johnstown Flood. A deluge of relief supplies was received, but none with indication of the contents. Needed items could not be found. Recent reports of the relief shipments to Armenia showed similar circumstances; boxes were unlabeled or in languages unknown to the recipients.

Some lessons are learned in disasters caused by natural events such as floods and earthquakes; others are quickly forgotten. Geologists must never forget, and, following the example of Powell, must never give up their efforts to teach the importance of our science to the commonweal of our state and nation.

Donald M. Hoskins

Donald M. Hoskins
State Geologist

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AN UNUSUAL AGGREGATE SOURCE: GETTING THE SQUEAL OUT OF THE PIG IRON

by Robert C. Smith, II, and Samuel W. Berkheiser, Jr.
Pennsylvania Geological Survey

Northwestern Pennsylvania has limited resources of high-friction construction aggregate suitable for maintaining and building high-use roads. However, Dunbar Slag Company, Inc., of Sharon, processes air-cooled slag from blast furnaces into a product that meets this and many other needs. As stated in an old adage, "One man's trash is another man's treasure"—and treasure this is! At one time, large dumps of this type of slag, which was considered to be trash, littered the landscape in the steelmaking area of Sharon, but no more.

Slag is the nonmetallic top layer of a melt formed during metal smelting, and "air-cooled blast-furnace slag" generally refers to waste material resulting from solidification of blast-furnace slag under atmospheric conditions. Air-cooled slag has certain physical and chemical characteristics that set it apart from the more common construction aggregates. Although not considered a true lightweight aggregate, the individual slag flows are blended with one another to weigh approximately 75 pounds per cubic foot compared to crushed stone, which typically weighs about 100 pounds per cubic foot. This low density means more volume per ton of material. Also, its rough, vesicular surface promotes excellent bonding in concretes. When crushed, air-cooled blast-furnace slag commonly tends to form cubical particles, another desirable physical property for construction aggregates. It is a tough, hard, PennDOT-approved aggregate that gives a high skid-resistance value to bituminous road surfaces. Table 1 lists typical ranges in physical properties of air-cooled blast-furnace slag.

ORIGIN AND PREPARATION OF PRODUCT. Dunbar Slag Company, Inc., processes air-cooled blast-furnace slag, a by-product of pig-iron production at Sharon Steel, at the rate of 1,200 tons per day. Slag availability is dependent on Sharon Steel's production of pig iron. As the molten slag is drawn off the nearby furnaces, it is poured into slag-buggies (ladle-like side-dump railroad cars), which take it on a half-mile journey to the slag dump. Here, the still-molten slag is dumped to form lava-like flows that are a few inches thick and extend up to 100 feet from the rail siding (Figure 1). The slag nearest the slag-buggies tends to be smooth and glassy; at the distal ends of the flows it is highly vesicular. Freshly poured slag is reminiscent of lava fields, complete with

Table 1. *Physical Properties of Air-Cooled Blast-Furnace Slag*

(From McCarl and others, 1983)

Property	Range
Unit weight	70–85 lb/ft^3
Absorption	1–6%
Bulk dry specific gravity	2.0–2.5

smoking fumaroles (Figure 2). The poured slag behaves much like basaltic lava, and if it were lava, it would be classified as pahoehoe because of its ropey texture. On windy days, a small amount of delicate glass fibers, analogous to "Pelee's hair" found in volcanic regions, forms near the buggies, only to be broken by later breezes. The slag also forms a small amount of glass that tends to attach itself to the walls of the buggy ladles and must often be knocked out. Because it has less time to react, this glass probably most nearly represents the bulk composition of the slag.

Figure 1. View of slag-buggies and freshly poured slag flow showing pahoehoe textures in the foreground.

Figure 2. Overview of the largely mined-out slag dump parallel to the rail siding containing the slag-buggies (right side of photo). Notice the smoking fumarole-like effect from the still-molten slag.

Prior to processing, a loader-operator must blend each 15-ton haul-truck load of slag from the frothy distal ends of the flow with the more massive glassy portions near the head of the flow to ensure product consistency. Blending also controls absorption values. The processing plant consists of a primary jaw crusher in tandem with a secondary gyratory crusher. This equipment and screens are kept busy producing the more popular 1-inch and 3/8-inch materials. Metallic iron is removed magnetically and recycled back to the furnaces.

MARKETING. Bedrock sources of high-quality, PennDOT-approved aggregate are scarce in the northwestern part of the Appalachian Plateaus province because the rocks in that region are largely composed of unsound siltstone, mudstone, and claystone. Glacial sand and gravel are found in the region, but often fail to win approval as an aggregate source because much of the material was derived from the local, "substandard" bedrock. Most of the aggregate produced by Dunbar is sold within a 30-mile radius of Sharon and enjoys limited competition. According to Jim Barnicle of Dunbar Slag, who is also the newly elected President of the Pennsylvania Aggregates and Concrete Association, "because of its unique properties, air-cooled blast-furnace slag almost markets itself."

By virtue of its vesicular nature and density, construction aggregate made by this process presents a classical good news/not-so-bad news situation with respect to the consumer. The not-so-bad news is that bituminous concrete made with slag absorbs more asphalt, a costly raw material. The good news is that slag, which is sold by weight, is 20 percent lighter than traditional aggregate on a per-volume basis. For bituminous concrete, coarse aggregate, which slag can provide, makes up half of the matrix; the result is that the consumer gets 10 percent more bulk per ton of purchased product. The weight savings gained in the construction of high-rise buildings, roofs, and bridge decks using this material is a significant advantage.

Dunbar Slag Company, Inc., and its employees turn a waste product into a valuable mineral resource that makes life a little easier and safer. Credit is also due to the National Slag Association, which has been instrumental in developing uses, markets, and public acceptance of slag as a quality construction material.

REFERENCES

McCarl, H. N., Eggleston, H. K., and Barton, W. R. (1983), *Construction materials; Aggregates—slag*, in Lefond, S. J., editor-in-chief, *Industrial minerals and rocks*, 5th ed., New York, Society of Mining Engineers of the American Institute of Mining, Metallurgical, and Petroleum Engineers, v. 1, p. 111–131.

EXOTICALLY SCULPTURED DIABASE— AN ADDENDUM

by W. D. Sevon
Pennsylvania Geological Survey

The following paragraph should have appeared at the end of the section entitled "Potholes" in my recent paper on erosional forms at Conewago Falls (Sevon, 1989):

"Considerable research on the relationship of hydraulic vortices and riverbed nickpoints to the formation of potholes has been done by Glenn Thompson farther downstream along the Susquehanna River in Holtwood Gorge, southwestern Lancaster County, Pennsylvania (Thompson, 1988). His work strongly influenced development of ideas discussed in this paper, and his concepts about the initial position of pothole erosion may have greater applicability to Conewago Falls than is suggested here."

Sincere apologies to Glenn for my omission!

REFERENCES

Sevon, W. D. (1989), *Exotically sculptured diabase*, Pennsylvania Geology, v. 20, no. 1, p. 2–7.

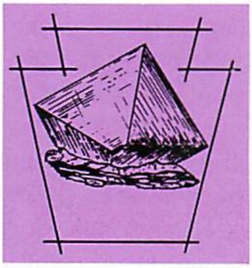
Thompson, G. H., Jr. (1988), *The Susquehanna River gorge at Holtwood, Pa.*, in Thompson, G. H., Jr., editor, *The geology of the lower Susquehanna River area: a new look at some old answers*, Harrisburg Area Geological Society Annual Field Trip, 7th, Guidebook, p. 27–44.

New USGS Publication Aids Rural Homeowners

If you already own or are considering ownership of a home in an area where private water supplies and septic systems are necessary, the booklet **Ground Water and the Rural Homeowner** should be of interest. Published by the U.S. Geological Survey, this excellent report provides important information on groundwater and the types of problems one might encounter. Tips are given on what to look for before purchasing or building in a rural area, how to avoid problems with a private well or septic system, and how to cope with a problem should it occur. For example, if building a home, drill the well before starting construction. This will help assure that an adequate supply of water is available.

The U.S. Geological Survey deserves compliments for preparing and publishing this very informative report that will be useful to a large number of citizens in the United States.

Single copies of the booklet are available free of charge by writing to Book and Open-File Reports Section, U.S. Geological Survey, Federal Center, Box 25425, Denver, CO 80225.

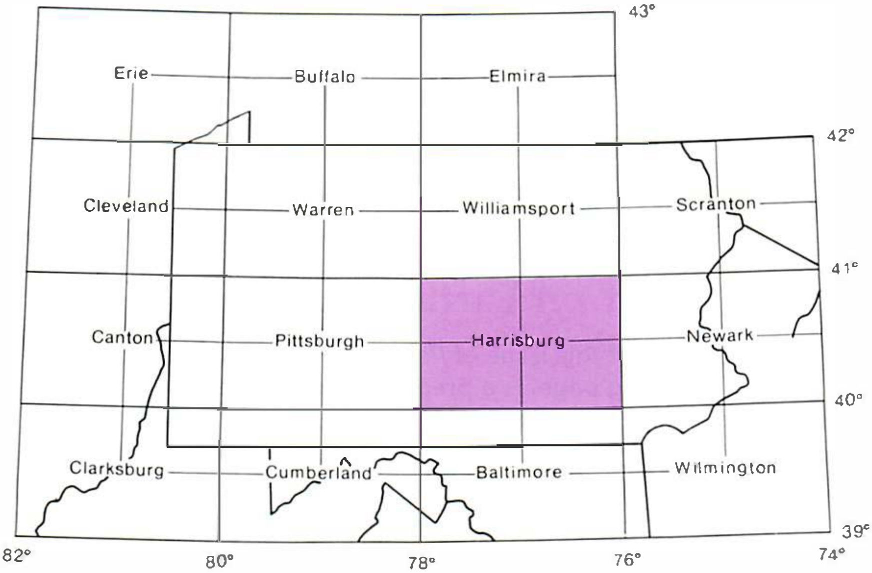


EARTH SCIENCE TEACHERS' CORNER

New Tool For Earth Science Teachers—Satellite Image Map of South-Central Pennsylvania

Based on the Harrisburg 2-degree map, a new type of map product, called a satellite image map, has been published for part of Pennsylvania. Composed of rectified images collected by the earth satellite Landsat–3 multispectral scanner (MSS), the image map is combined with the standard topographic map of the same area. The new map was prepared by the U.S. Geological Survey, in cooperation with the Pennsylvania Geological Survey.

The combination of image map and topographic map makes a useful educational tool for teaching about maps and how they portray actual and symbolized information. The standard 1:250,000-scale topographic map of the Harrisburg area is printed on one side of the new map. On the reverse is the image map, which is a mosaic of four different satellite images taken on May 4, 1982. The mosaic image is controlled to fit symbolized map features identified on the topographic map.



Colors on the satellite image map are predominantly red, but range from white, which represents smooth, cleared areas, to black, which represents deep, clear water. The Susquehanna River, which nearly bisects the area represented by the image map from north to south, appears as a broad black band, and islands in the river appear in dark to bright reds. The dominant red colors of the image map show areas of conifer trees, grasses, and crops. Urban areas and strip mines are in blue; the urban corridor from Lebanon to Carlisle is a very prominent east-west band, as are anthracite strip-mine areas. Deciduous trees, marshes, and fallow crops are in shades of gray. Fallow crop lands, together with growing crop lands portrayed in shades of red, create a densely packed gray-red "checkerboard" pattern in many agricultural areas.

By cutting along the central meridian, the topographic map and image map can be placed side by side so as to compare the scene collected by the Landsat–3 MSS with the cartographic symbols used in portraying topography, drainage, culture, and forested areas on the standard topographic map. As a further aid in the comparison of cartographic symbols to the MSS image, the Universal Transverse Mercator grid is printed on the image map, as well as on the topographic map.

The Pennsylvania Geological Survey has obtained a limited supply of these new maps, which will be sent to earth science teachers and other requestors at no cost until the supply is exhausted. Copies of the map may be obtained by writing to the State Geologist, Pennsylvania Geological Survey, P. O. Box 2357, Harrisburg, PA 17105. The maps are also available for sale by the U.S. Geological Survey, Map Distribution, P. O. Box 25286, Federal Center, Denver, CO 80225, for a cost of $6.00 (plus a $1.00 handling charge for orders that total less than $10.00). Prepayment is required; please make checks payable to *Department of Interior–U.S.G.S.*

New Educational Series Report on Earthquake Hazard

The center part of this issue of *Pennsylvania Geology*, which begins on the following page, is a preprinting of the newest Educational Series report of the Pennsylvania Geological Survey, **Earthquake Hazard in Pennsylvania.**[1] Accounts of nearby earthquakes in the United States and Canada have occurred with great frequency in the press in recent months. Most recently, on April 28, 1989, a moderate earthquake, centered near New Madrid, Missouri, was felt in nearby states.

To provide the most up-to-date information on Pennsylvania earthquakes, we are using the central signature of *Pennsylvania Geology* to quickly make this new publication available to the earth science community and concerned citizens. The report, prepared by Charles K. Scharnberger of Millersville University, contains information on how earthquake hazard estimates are calculated. The author concludes that earthquakes pose only a slight hazard in Pennsylvania. The report will also be printed in bulk quantity as a separate booklet (Educational Series 10) and will be provided free to earth science teachers, students, and others who wish to learn more about the earthquake hazard in Pennsylvania. To order additional copies of Educational Series 10, please write to the Pennsylvania Geological Survey, P. O. Box 2357, Harrisburg, PA 17105.

[1]Preprinted from Scharnberger, C. K. (1989), *Earthquake hazard in Pennsylvania*, Pennsylvania Geological Survey, 4th ser., Educational Series 10, 14 p., copyright © 1989 by the Commonwealth of Pennsylvania.

Educational Series 10

Earthquake Hazard in Pennsylvania

by Charles K. Scharnberger
Millersville University

PENNSYLVANIA GEOLOGICAL SURVEY
FOURTH SERIES
HARRISBURG
1989

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Earthquake Hazard in Pennsylvania

by
Charles K. Scharnberger

Introduction

Compared to other states, especially California and Alaska, Pennsylvania is relatively free of earthquake activity. Even considering only the eastern half of North America, Pennsylvania has experienced fewer and milder earthquakes than most other states or Canadian provinces. Nevertheless, earthquakes do occur in our Commonwealth, and Pennsylvania may be subject to the effects of earthquakes that have epicenters located outside our borders. Therefore, it is worth considering how much hazard earthquakes present to Pennsylvanians.

What is an Earthquake?

Earthquakes occur when there is a sudden release of stored energy from a portion of a fault plane within the earth. Faults are fractures in the lithosphere—the rather brittle outer layer of the solid earth. Energy in the form of *strain*, small elastic distortion of the lithosphere, accumulates over a period of time due to *stress* acting on the rock of the lithosphere. The origin of this stress is believed by most geophysicists to be slow convective motion, driven by heat energy, which occurs below the lithosphere in the mantle. One consequence of this slow convection is the fragmentation of the lithosphere into tectonic plates, and the slow movement of these plates relative to each other. Much of our understanding of earthquakes, as well as other geologic phenomena such as volcanic eruptions and mountain-building, is based on this theory of *plate tectonics*.

The rock of the lithosphere can accommodate only so much strain energy. Eventually, the rock must fracture. When this happens, strain is relieved, the stress level drops, some energy is converted into heat, some movement (slip) occurs along the plane of fracture (the fault plane), and some energy is radiated away from the area of fracture in the form of elastic waves—called *seismic waves*—which travel through the earth or along the surface of the earth. The arrival of these seismic waves at a point on the surface causes rapid and complex motions of the ground. This is what we feel as an earthquake. Once a fault has formed as the result of an initial fracture, earthquakes are likely to recur along the same fault, because this plane is now a zone of weakness in the lithosphere.

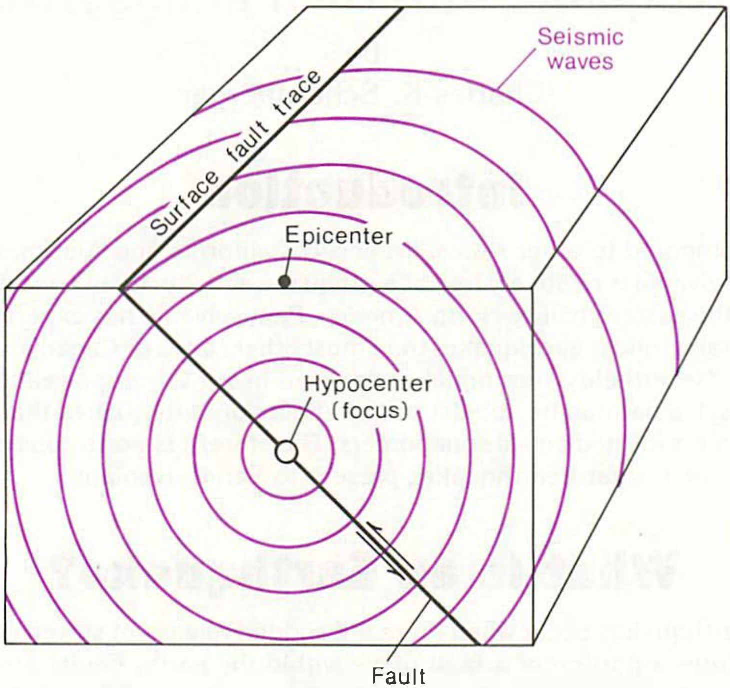

Figure 1. Relationship among fault plane, fault trace on surface of the earth, earthquake hypocenter (focus), epicenter, fault slip (arrows), and seismic waves. (Based on Plummer, C. C., and McGeary, David, *Physical geology*, 4th ed., Figure 16.2, p. 345. Copyright © 1988 by Wm. C. Brown Publishers, Dubuque, Iowa. All rights reserved.)

Figure 1 shows the relationship of a fault plane to the origin point of the seismic waves (called the *hypocenter* or *focus* of the earthquake) and the *epicenter*, the point on the surface of the earth directly above the hypocenter. Note that, unless the attitude of the fault plane is vertical, the epicenter will be located some distance from the trace of the fault along the surface of the earth. In eastern North America, no earthquake in historic time has caused a displacement of the surface along a fault trace.

Earthquakes and Plate Boundaries

The great majority of the earthquakes in the world occur along the boundaries between tectonic plates. The reason for this is not completely clear, but it may be that stress levels are higher along plate boundaries, or that strain energy builds up more rapidly in those areas. Pennsylvania today is far from the nearest plate boundary—the Mid-Atlantic Ridge, some 2,000 miles to the east. However, about 200 million years ago, when the Atlantic Ocean was just beginning to open as the supercontinent Pangaea broke up, the east coast of North America was at a plate boundary, and many faults in eastern North America were formed at that time. Measurements show that the maximum stress in this region now is a compression acting horizontally in approximately an east-west sense. Where 200-million-year-old faults are oriented roughly north-south, they are susceptible to reactivation by the present-day stress field. This seems to be what is happening to cause at least some of the earthquakes felt in eastern North America.

Earthquake Magnitude

Seismic waves are detected and measured by seismographs. The energies of earthquakes are compared on the basis of their magnitudes, a concept first defined in the 1930's by Charles Richter of the California Institute of Technology. Richter wished to have a single number to describe an earthquake, independent of the distance from the epicenter at which the earthquake waves were recorded. The system he devised commonly is called the *Richter Scale*, a term that often leads to the mistaken impression that there is a kind of physical instrument—a scale similar to those used to measure weights—to which the term applies. The numbers of the Richter Scale are logarithms; that is, numbers that express powers of 10. As originally defined by Richter on the basis of California earthquakes recorded locally on a particular type of seismograph, the magnitude represented the maximum amount of ground movement at a distance of 100 kilometers (62 miles) from the epicenter of an earthquake. Each whole number on the scale represented a 10-fold difference in this amplitude of ground motion.

As the concept of magnitude came to be used worldwide and had to be calculated from many different types of seismographs, new ways of defining the magnitude were introduced, so that today several different magnitude numbers might be found for the same earthquake. Thus, magnitudes are useful mostly for comparing earthquakes (the purpose Richter had in mind), rather than for finding the actual energy of an earthquake with more than rough precision.

There is no upper or lower limit to the Richter Scale, but as a matter of historical fact, no magnitude greater than about 9 has ever been calculated for an earthquake. Earthquakes in eastern North America seldom have magnitudes greater than 5.

Earthquake Intensity

Before the development of the Richter Scale, earthquakes were compared on the basis of *intensity*. Today, intensity values are an important supplement to the magnitudes because intensity is a semiquantitative expression of the effects caused by an earthquake. These may be effects on people, on man-made structures, or on natural features of the landscape. Intensities are determined after the earthquake on the basis of field observations made by trained personnel, or from survey forms filled out by persons who experienced the earthquake. The U.S. Geological Survey uses reports sent in by postmasters, and compiles intensity data by postal ZIP code.

Obviously, intensity is not a single number for a particular earthquake, but varies from place to place. Usually, the intensity is greatest in the immediate vicinity of the epicenter and decreases with increasing distance from the epicenter. However, many factors affect intensity; among them are topography, type and thickness of soil, direction from the epicenter relative to regional rock structure, and type of bedrock. The greatest intensities are often caused by landslides induced by the seismic waves rather than by the direct effects of the waves.

In the United States, intensities are expressed in terms of the *Modified Mercalli Scale*. This scale was first proposed in Italy by Giuseppi Mercalli early in this century, and was modified in 1931 by the American seismologists H. O. Wood and F. Neumann (for this reason, it is also called the Wood-Neumann Scale). Table 1 is an abridged version of the Modified Mercalli Scale; Roman numerals usually are used to avoid confusion with earthquake magnitude.

Earthquake Hazard and Earthquake Risk

Although the words "hazard" and "risk" may seem synonymous, there is a distinction to be made between them, at least for natural phenomena. Gere and Shah (1984, p. 112) define "hazards" as "those natural events that threaten life and property." "Risks" are defined as "everything that we have to lose—including both life and property." Thus, in two areas that have similar earthquake histories, the hazard may be approximately equal, but the risk is much greater in the area that is more densely populated. Hazard and risk together determine probability of loss, the factor most relevant to public policy questions. In this paper, only the question of seismic hazard in Pennsylvania is addressed, and no attempt is made to evaluate seismic risk.

Table 1. *The Modified Mercalli Scale of 1931 (Abridged Version)*

I. Not felt except by a very few under especially favorable circumstances.

II. Felt only by a few persons at rest, especially on the upper floors of buildings. Delicately suspended objects may swing.

III. Felt quite noticeably indoors, especially on the upper floors of buildings, but many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibration is like the passing of a truck. Duration is estimated.

IV. During the day felt indoors by many, outdoors by few. At night some are awakened. Dishes, windows, and doors are disturbed; walls make a creaking sound. Sensation is like a heavy truck striking a building. Standing motor cars are rocked noticeably.

V. Felt by nearly everyone; many are awakened. Some dishes, windows, etc., are broken; a few instances of cracked plaster occur; unstable objects are overturned. Disturbance of trees, poles, and other tall objects is sometimes noticed. Pendulum clocks may stop.

VI. Felt by all; many are frightened and run outdoors. Some heavy furniture is moved; a few instances of fallen plaster or damaged chimneys occur. Damage is slight.

VII. Everybody runs outdoors. Damage is *negligible* in buildings of good design and construction; *slight* to *moderate* in well-built ordinary structures; *considerable* in poorly built or badly designed structures. Some chimneys are broken. Noticed by persons driving motor cars.

VIII. Damage is *slight* in specially designed structures; *considerable* in ordinary substantial buildings, with partial collapse; *great* in poorly built structures. Panel walls are thrown out of frame structures. Chimneys, factory stacks, columns, walls, and monuments fall; heavy furniture is overturned. Sand and mud are ejected from the ground in small amounts. Changes occur in well water. Persons driving motor cars are disturbed.

IX. Damage is *considerable* in specially designed structures; well-designed frame structures are thrown out of plumb; damage is *great* in substantial buildings, with partial collapse. Buildings are shifted off their foundations. Ground is cracked conspicuously. Underground pipes are broken.

X. Some well-built wooden structures are destroyed; most masonry and frame structures are destroyed along with their foundations. Ground is badly cracked. Rails are bent. Considerable landslides occur on river banks and steep slopes. Sand and mud are shifted. Water is splashed (slopped) over banks.

XI. Few, if any, masonry structures remain standing. Bridges are destroyed. Broad fissures occur in the ground. Underground pipelines are completely out of service. Earth slumps and land slips occur in soft ground. Rails are bent greatly.

XII. Damage is total. Waves are seen on the ground surface. Lines of sight and level are distorted. Objects are thrown upward into the air.

Hazard of Earthquakes Having Epicenters Outside Pennsylvania

Historically, large earthquakes have occurred in three regions of eastern North America: (1) the Mississippi Valley, especially near the town of New Madrid, Missouri; (2) the St. Lawrence Valley, especially near the mouth of the St. Lawrence River, where a magnitude 6 earthquake occurred in November 1988; and (3) Charleston, South Carolina.

New Madrid, Missouri

Three great earthquakes struck the vicinity of New Madrid in December 1811, January 1812, and February 1812. Although there were no seismographs to record these events, each earthquake in the series is estimated to have had a magnitude in excess of 7. These earthquakes were felt in western Pennsylvania, but no damage is known to have occurred there (Abdypoor and Bischke, 1982; all other references to the effects of large historic earthquakes in Pennsylvania are from this source). It is unlikely that future New Madrid earthquakes would be any greater than those of 1811–12, so Pennsylvanians probably do not have to worry about a threat from that quarter.

The St. Lawrence Region

One of the largest earthquakes to have occurred in eastern North America since the time of historic records occurred in 1663 and had an epicenter in Quebec, probably not far from that of November 25, 1988. According to reports of French missionaries, the earthquake of February 5, 1663, triggered large rockslides along the banks of the St. Lawrence; the magnitude is estimated to have been about 7. An earthquake on February 28, 1925, in this area was recorded by seismographs, and its magnitude was calculated at 7.0. It was felt with intensity IV in northeastern Pennsylvania. The earthquake of September 4, 1944, although of relatively modest magnitude (5.6), caused serious damage to the towns of Cornwall, Ontario, and Messina, New York. Northwestern Pennsylvania falls within a western extension of the St. Lawrence seismic region; however, historic earthquakes in this part of the region have been less severe than those farther east. The only St. Lawrence earthquake known to have caused damage in Pennsylvania (at Sayre, Bradford County) occurred on August 12, 1929, and had an epicenter near Attica, New York.

Charleston, South Carolina

Charleston was the site of the largest historic earthquake to have occurred along the eastern seaboard. On August 31, 1886, an earthquake with estimated magnitude between 6 and 7 produced intensities as high as X in the vicinity of Charleston. The intensity was IV throughout most of southern and eastern Pennsylvania. Charleston is 600 miles from Philadelphia, so it seems that, as in the case of New Madrid, a recurrence of the great Charleston earthquake would pose little hazard to Pennsylvania.

Other East Coast Areas

Boston, Massachusetts, felt earthquake shocks in 1744, 1755, 1903, and 1925. The largest of these seems to have been the 1755 event, which had an epicenter offshore near Cape Ann. This earthquake was felt strongly in eastern Pennsylvania, and had an intensity around IV or V in Philadelphia. Northeastern Pennsylvania is, at its closest point, about 230 miles from Cape Ann. This is close enough that intensities of VI might be expected in Pennsylvania from a magnitude 7 earthquake.

Southeastern New York and northern New Jersey have been the sites of moderate earthquakes. Perhaps the largest of these was on December 18, 1737, felt with intensity VII in New York City and intensity IV in eastern Pennsylvania. It is impossible to estimate the probability of a magnitude 7 earthquake occurring in northern New Jersey. However, such an earthquake, if it did occur, would almost certainly produce intensities as high as VIII in eastern Pennsylvania.

Hazard of Earthquakes Having Epicenters in Pennsylvania

Seismicity in Pennsylvania

Figure 2 shows the locations of historic epicenters in Pennsylvania; a list of Pennsylvania earthquakes is given in Table 2. The seismic history of Pennsylvania has been poorly known until recently. Sometimes, nonseismic events such as mine collapses have been mistaken for earthquakes. Many historic earthquakes were forgotten until the work of

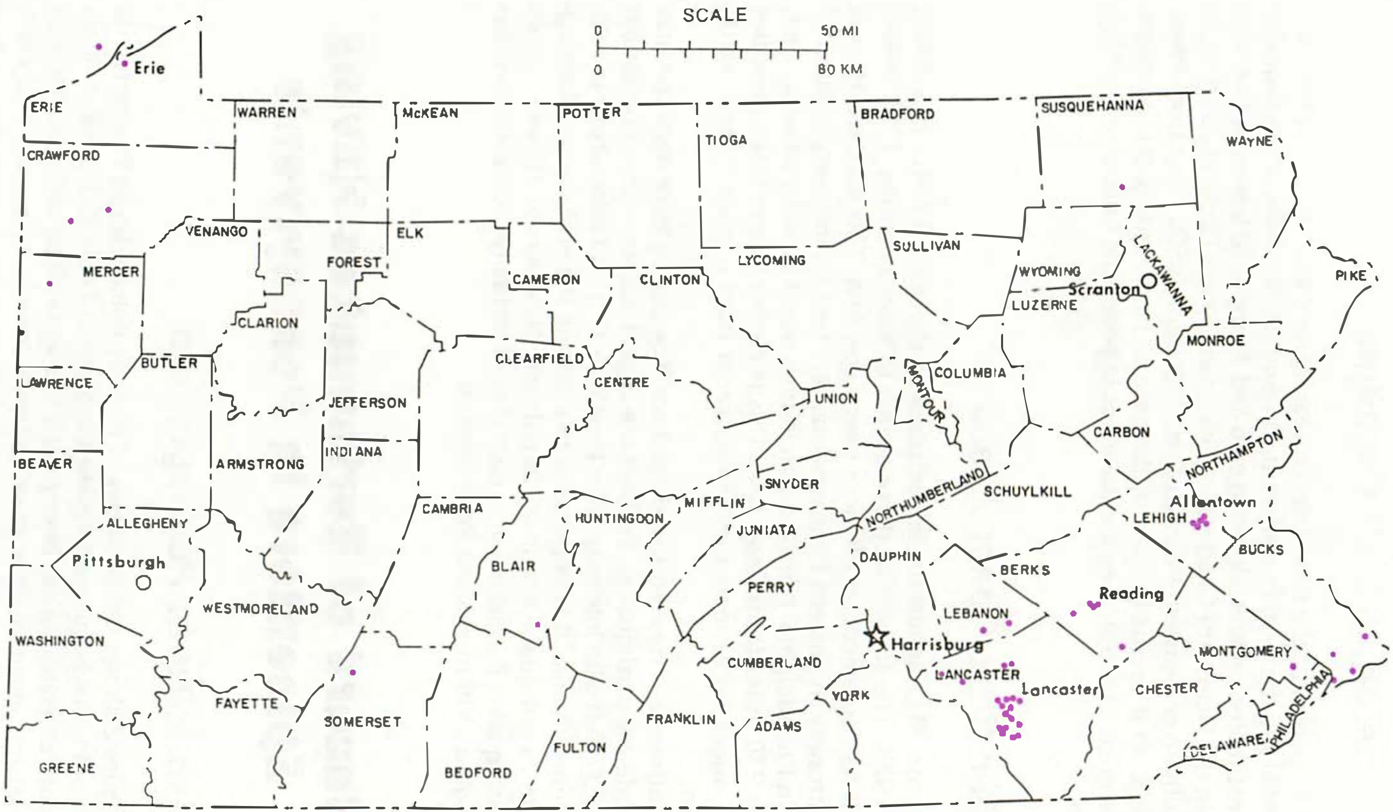

Figure 2. Locations of historic earthquake epicenters in Pennsylvania. Many locations are approximate.

Table 2. *Known Earthquake History of Pennsylvania Through January 1989*

Date (local time)	Location of epicenter	Magnitude[1]	Remarks
LANCASTER SEISMIC ZONE			
1738 or 1739	(?)		
Dec. 17, 1752	(?)	3.6*	
Sept. 1793	(?)		
Jan. 11, 1798	Lancaster(?)		
Nov. 20, 1800	Lititz(?)	4.1*	
Jan. 27, 1801	Lancaster(?)		
Mar. 19, 1818	Lancaster(?)		
Aug. 21, 1820	Mt. Joy(?)	3.4*	
May 4, 1822	Lancaster(?)		
Sept. 5, 1829	Lancaster(?)		
Feb. 5, 1834	Marticville(?)	4.0*	
Sept. 17, 1865	Willow Street(?)		
Nov. 7, 1866	(?)		
Jan. 15, 1885	Schaefferstown		
Mar. 8, 1885	Lancaster(?)		
Sept. 26, 1886	Elizabethtown(?)		
Mar. 8, 1889	Conestoga(?)	4.3*	
May 12, 1964	Cornwall	3.2*	
Dec. 7, 1972	Lititz		
July 16, 1978	Conestoga	3.0	
Oct. 6, 1978	Lancaster	3.1	
Apr. 22, 1984	Marticville	4.1	Foreshock near Mt. Nebo 4 days earlier; many aftershocks
Sept. 19, 1984	Lancaster		
May 2, 1986	Conestoga	2.6	
NORTHWESTERN PENNSYLVANIA			
Sept. 15, 1852	Meadville		
Aug. 17, 1873	Sharon		
Sept. 26, 1921	Erie		
Oct. 29, 1934	Erie		Aftershock near Albion 7 days later
Aug. 26, 1936	Greenville		
Apr. 14, 1985	Conneaut Lake	3.2	
LEHIGH COUNTY			
May 31, 1884	Allentown		
May 31, 1908	Allentown		

Table 2. *(Continued)*

Date (local time)	Location of epicenter	Magnitude[1]	Remarks
	LEHIGH COUNTY *(Continued)*		
June 22, 1928	Allentown		
Nov. 23, 1951	Allentown		
Sept. 14, 1961	Allentown		
	BERKS COUNTY		
May 28, 1906	Geigertown		
June 8, 1937	Reading		
Jan. 7, 1954	Sinking Spring		Beginning of earthquake swarm lasting 1 year
June 25, 1972	Wyomissing		Beginning of earthquake swarm lasting a few days
Aug. 12, 1973	Wyomissing		
	PHILADELPHIA AREA		
Dec. 27, 1961	Bristol		
Mar. 5, 1980	Abington		Foreshock 3 days earlier; aftershock 6 days later
Nov. 14, 1981	Lower Bucks Co.		
Apr. 12, 1982	Cornwells Heights		
May 12, 1982	Lower Bucks Co.		
	BLAIR COUNTY		
July 15, 1938	Clover Creek		
	SOMERSET COUNTY		
Feb. 3, 1982	Jennerstown	2.6	
	SUSQUEHANNA COUNTY		
Aug. 14, 1982	Hop Bottom	2.1	

[1]Asterisk indicates inferred magnitude.

Armbruster and Seeber (1987) brought them to light. The most active part of the state is the Lancaster seismic zone of Lancaster and Lebanon Counties. Next most active is northwestern Pennsylvania, from Erie southward along the Ohio border. Earthquakes are also known from Lehigh, Berks, Montgomery, Bucks, Blair, Somerset, and Susquehanna Counties. Because of the number and magnitude of the earthquakes in the Lancaster seismic zone, that area is examined here in some detail.

Magnitude-Frequency Relationship for the Lancaster Seismic Zone

Gutenberg and Richter (1954) discovered a simple relationship between the magnitudes of earthquakes and the frequency of their occurrence. When one plots on a logarithmic scale the number of earthquakes that have magnitudes equal to or greater than a given value against the magnitude numbers, the points fall on a straight line having negative slope. From the slope of this line, one might predict the number of earthquakes expected to occur within the period of time for which the plot has been made, up to any magnitude cutoff. The result of doing this for earthquakes of the Lancaster seismic zone is shown in Figure 3. In making this plot, the earthquake of September 17, 1865, has been considered as an event having a magnitude of at least 4, based on contemporary newspaper accounts, and the foreshock of the April 22, 1984, earthquake has been included in the count of events having magnitudes of 3 or greater. The magnitudes of many of the early earthquakes in

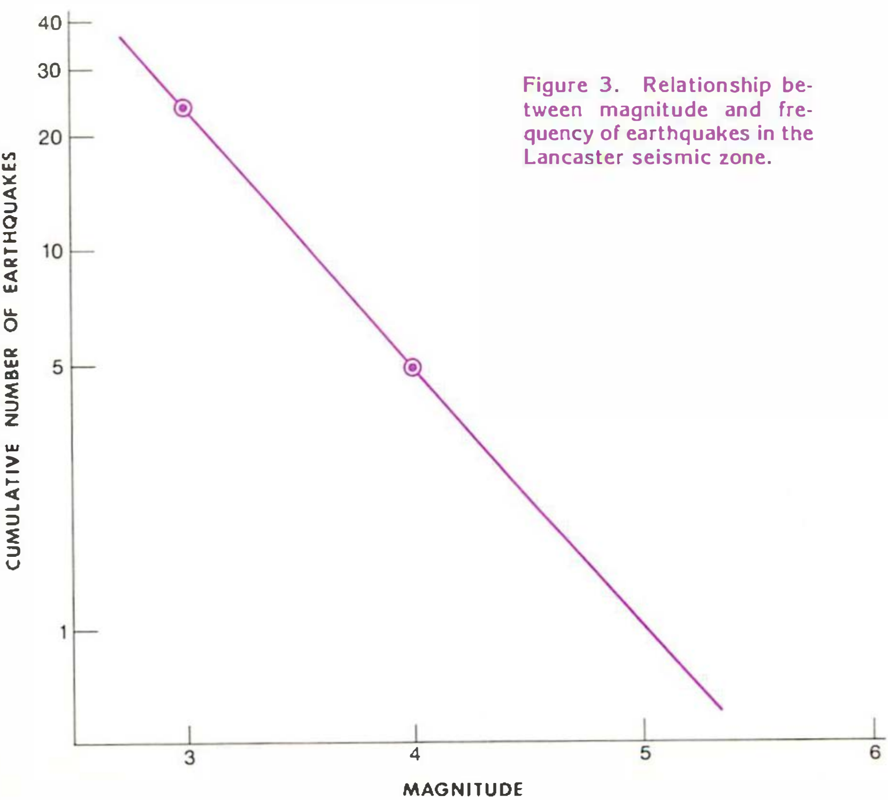

Figure 3. Relationship between magnitude and frequency of earthquakes in the Lancaster seismic zone.

the historic record are not known very precisely, the historical record may not be complete, and the total number of earthquakes is small; therefore, Figure 3 must be interpreted with some caution.

The slope of the line in Figure 3 is -1.13. Extending this line to magnitude 5, we see that one such event is expected to occur in about 250 years, the length of the historic record. No earthquake of this great a magnitude is known to have occurred in the Lancaster seismic zone, but a count of 0 when the expected count is only 1 does not have a great deal of significance. Based on this analysis, then, it seems possible that an earthquake having a magnitude of around 5 could occur in the Lancaster area.

A Probabilistic Approach

Another way to try to estimate the seismic hazard in the Lancaster seismic zone is to use the probabilistic method applied by Howell (1979) to all of Pennsylvania. Howell's analysis suffered from the fact that much of the historic earthquake record was not known in 1979, and from the inclusion of a number of nonseismic events, particularly the 1954 Wilkes-Barre mine collapse. His method, however, seems worth trying on what probably is a fairly complete record for the Lancaster seismic zone.

Howell's approach was based on the same method used to estimate the likelihood of extreme floods, such as the so-called 100-year or 200-year flood. The essence of the method is to divide the historical record into time intervals of equal length and then to identify the largest earthquake to have occurred in each interval. The usual interval is one year, but because earthquakes are rather rare events, it seems better to use a longer time interval; for the present study, four-year periods were used, beginning in 1730. There are 62 four-year periods in the 258 years from 1730 through 1987. The earthquakes are plotted on probability paper (Figure 4) in order of increasing magnitude and increasing improbability. The improbability of an event is $(1 - P)$, where P is the probability. The smallest magnitude used was 2.6; the smaller historical earthquakes for which no magnitude is known were assigned an estimated magnitude of 3.0. Magnitudes for the larger historical events have been taken from Armbruster and Seeber (1987).

As an example, consider the earthquake of 1820, which had an estimated magnitude of 3.4 (Table 2). There are 17 time periods in which earthquakes have occurred. In seven of these, the magnitude of the largest earthquake was greater than or equal to 3.4. From this, we can conclude that the improbability of an earthquake having a magnitude of 3.4 or greater occurring in any four-year period is $(62 - 7)/62 = 0.89$. This corresponds to a probability of 0.11 (or 11 percent) that such an

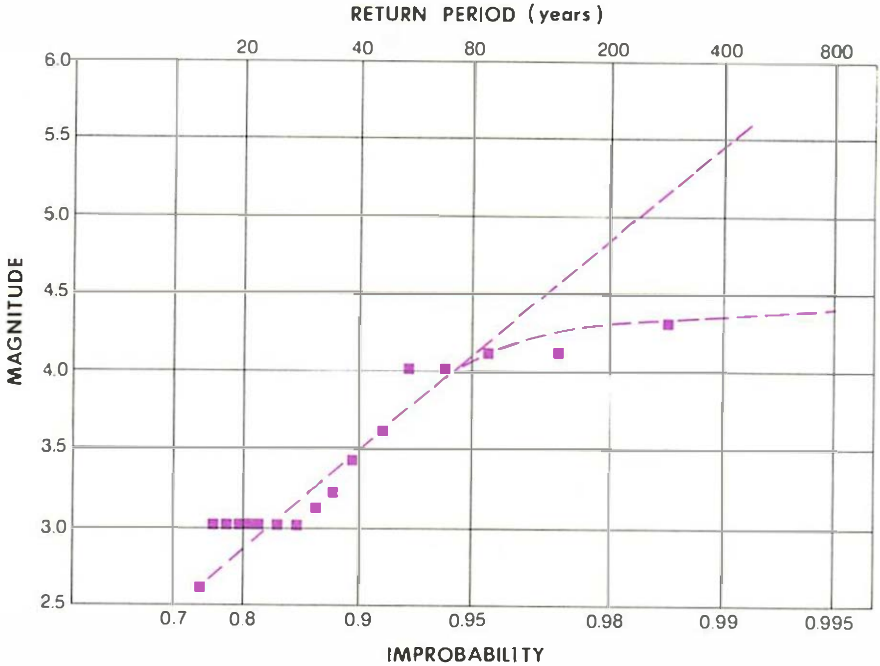

Figure 4. Relationship among magnitude, improbability, and the return period of earthquakes in the Lancaster seismic zone.

earthquake *will* occur. This is approximately 1 chance in 10, and since there are 40 years in 10 four-year periods, we could refer to a magnitude 3.4 event as the "40-year earthquake" for the Lancaster seismic zone. Note, however, that this does not mean that an earthquake of at least that magnitude is certain to occur every 40 years. The probability of the "40-year earthquake" actually occurring in a 40-year period is $(1 - 0.9^{10}) = 0.65$, or 65 percent.

If there is no upper bound to the magnitudes that can occur, then the distribution on probability paper should be a straight line. A fairly good straight-line fit can be made through the first 15 points on Figure 4. The extension of this line suggests that the 200-year earthquake has a magnitude of about 4.8 and the 400-year earthquake has a magnitude of about 5.5 (a 1 percent chance of a magnitude 5.5 earthquake occurring in any 4-year period). The return period for a magnitude 5.0 earthquake is about 250 years, a result consistent with the result obtained from the first method of analysis.

However, considering the remaining two points in Figure 4, we see that the curve through all 17 points deviates significantly from a straight line. This suggests that the magnitudes of earthquakes in the Lancaster seismic zone are not unbounded, but rather have a limit of about 4.5.

Conclusion

Two of the areas that have generated the largest historical earthquakes in eastern North America—New Madrid, Missouri, and Charleston, South Carolina—are too far away for earthquakes having epicenters there to cause damage in Pennsylvania, although earthquakes occurring in those areas that have magnitudes near 7 would be felt in Pennsylvania. Eastern Massachusetts is closer, and a magnitude 7 earthquake there could produce intensity VI effects in northeastern Pennsylvania. Similar intensities might be expected in north-central and northwestern Pennsylvania from earthquakes that have epicenters in the western part of the St. Lawrence zone. The possibility that a magnitude 7 earthquake could occur having an epicenter near New York City cannot be completely discounted, and such an earthquake could produce significant damage (intensity VIII) in eastern Pennsylvania.

Within Pennsylvania, Lancaster, York, Erie, Reading, Allentown, and Philadelphia probably will continue to feel earthquakes generated on local faults. A few earthquakes are likely to occur in other areas, including, perhaps, some that up to now have not been known to be seismic. The largest Pennsylvania earthquakes have been generated in the Lancaster seismic zone, and analysis of the historic record suggests a limit of about 4.5 on the magnitudes of earthquakes that are likely to occur there. This conclusion, however, must be regarded as a very tentative one.

The earth is an extremely complex natural system; even after 200 years of organized geological study, we understand only partly how our planet works. This is true for seismology as much as for any branch of the earth sciences, and the earth may have some seismic surprises in store for us. Thus, the best we can say is this: based on the historic record of earthquakes in eastern North America and on the current state of scientific knowledge, earthquakes pose only a slight hazard in Pennsylvania.

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"*Clams Mahantango* and *Escargots to Go*," Perry County Style

by Jon D. Inners
Pennsylvania Geological Survey

For more than a hundred years, geologists and paleontologists have recognized the Mahantango Formation of Perry County as a veritable fossil smorgasbord. This Middle Devonian age rock unit underlies a half-dozen zigzag outcrop belts in the eastern two thirds of the county. Throughout this area, innumerable borrow pits, roadcuts, and stream gullies abound in a wide variety of invertebrate fossils. Despite a wealth of good localities, relatively few have been the subject of paleontologic descriptions (see Ellison, 1965, and Inners and Nork, 1983). Because some of the best sites are on private property that is closed to collecting, it is important to publicize localities that are freely open to collectors. One such site known to the author is a borrow pit in the northeastern part of the county.

The site is an active borrow pit near the intersection of U.S. Route 11–15 and Pa. Route 104, three miles northeast of Liverpool in Liverpool Township. It is situated 400 feet west of U.S. Route 11–15 directly behind the former Martin's Motel (Figure 1; 40°36′52″N/76°57′21″W, Millersburg quadrangle). The pit is on the property of Mr. Chester Strawser, R. D. #1, Liverpool, who also owns the Seven Stars collecting site in Juniata County (Hoskins and others, 1983). Please call Mr. Strawser at 717–444–3525 to obtain permission to visit the site.

Exposed in the Strawser pit is medium-dark-gray, massively bedded, bioturbated silty claystone and fissile, silty clay shale belonging to the medial part of the Sherman Ridge Member, the uppermost of several subdivisions of the Mahantango Formation in the lower Juniata and Susquehanna River valleys (Hoskins, 1976). The claystones typically exfoliate into large spheroidal masses that break down into splintery and chippy fragments. About 75 feet of section crops out in the pit, the best exposures being on the south wall (Figure 2). Bedding in the pit strikes N51°E and dips 35 degrees to the southeast.

Invertebrate fossils abound in the Strawser pit. In fact, they are so abundant that nearly every fragment picked from the rubble piles contains a shell or two. The fossils are mainly internal and external molds, but original shell material is not uncommon. The delicate calcitic valves of a tiny chonetid brachiopod (unidentified as to genus and species) are particularly well preserved. Whereas an abundance of bivalves and gastropods is the most distinctive feature of the pit, other invertebrates, including brachiopods, cephalopods, and trilobites are also common.

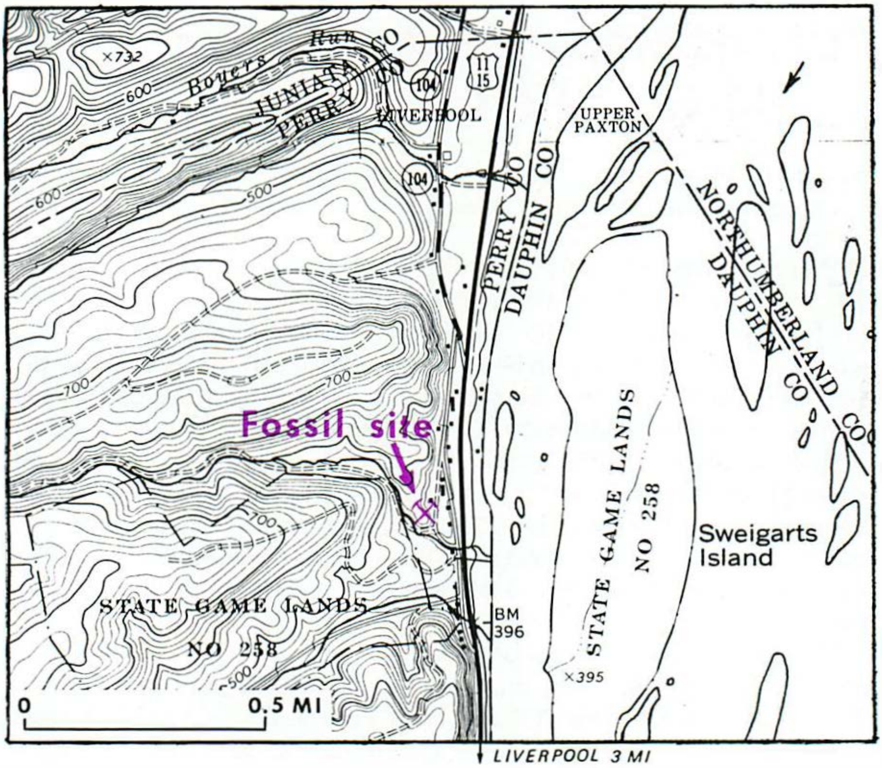

Figure 1. Location map.

Conspicuous by their absence are the many genera of bryozoans that characterize some other sites in the upper Sherman Ridge (Ellison, 1965).

The author collected the following invertebrate fossils at the site (relative abundance: A, abundant; C, common; U, uncommon; and R, rare).

BRACHIOPODS

- *Devonochonetes scitulus* (Hall) R
- *Leiorhynchus* sp. U
- *Mucrospirifer mucronatus* (Conrad) A
- *Mediospirifer audaculus* (Conrad) C

BIVALVES

- *Nuculoidea* sp. C
- *Nuculites oblongatus* (Conrad) C
- *Goniophora hamiltonensis* Hall U
- *Cypricardella bellastriata* (Conrad) C
- *Paracyclas lirata* (Conrad) C
- *Palaeoneilo constricta* (Conrad) U

GASTROPODS

- *Bembexia* sp. A
- Small unidentified types C

CEPHALOPODS

- *Michelinoceras* sp. U

TRILOBITES

- *Greenops (Greenops) boothi* var. *calliteles* (Green) C
- *Phacops rana* (Green) C [The new Pennsylvania "State fossil"]

CRINOIDS

- Columnals C

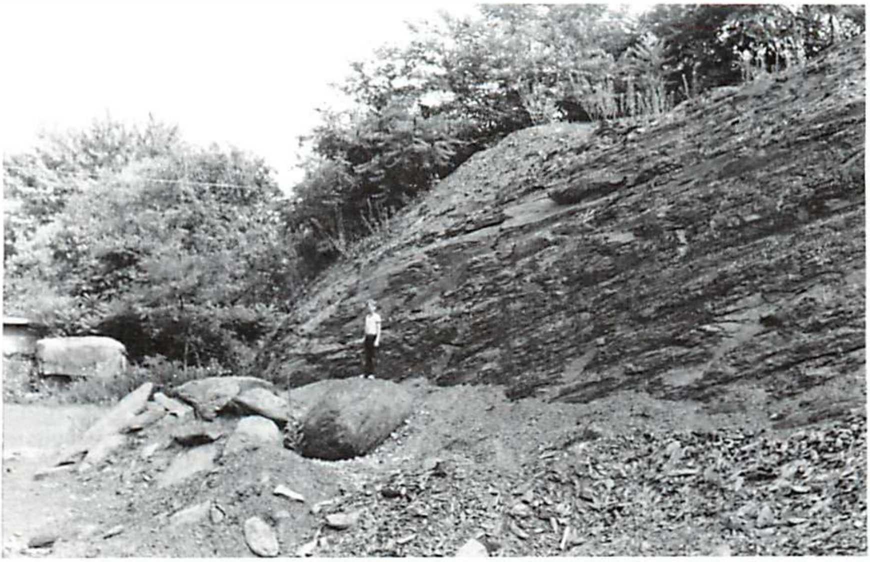

Figure 2. View of the Strawser borrow pit, looking southeast. The large exfoliated mass on which the boy is standing contains enrolled phacopid trilobites.

The shales and claystones exposed in the Strawser borrow pit were originally deposited as fine-grained sediments in a shallow tropical sea that covered much of central and northeastern North America during the late Middle Devonian, about 380 million years ago (Bofinger and Compston, 1967). At that time, central Pennsylvania lay at about 5 degrees south-latitude (Scotese and others, 1979), a position it apparently occupied for at least another 100 million years.

As mapped by Hoskins (1976), the borrow-pit beds occur in the lower part of a sedimentary cycle (100+ feet thick) that coarsens upward from claystone and shale to sandstone—one of many such coarsening-upward cycles in the Mahantango of Perry County and adjacent areas. Kaiser (1972) and Faill and Wells (1974) ascribed this cyclical character to intermittent progradation of a submarine delta. More recent detailed studies, however, suggest that the Mahantango cycles resulted from deposition on storm-tossed shoals and offshore bars at times of fluctuating sea level (Sarwar, 1984; see Brett, 1986).

I thank Dr. Edward Cotter of Bucknell University for supplying me with information on the nondeltaic interpretation of Mahantango cycles.

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NEW PUBLICATIONS OF THE PENNSYLVANIA GEOLOGICAL SURVEY

OIL AND GAS DEVELOPMENTS IN PENNSYLVANIA IN 1987

The latest edition of the Pennsylvania Geological Survey's annual report on developments in the state's oil and gas fields, covering the year 1987, has recently been released. Authors John A. Harper and Cheryl L. Cozart have compiled a report that, not surprisingly, should be useful to those engaged in the serious business of oil and gas exploration and production in Pennsylvania. The report contains many pages of statistical tables, including a massive 40-page table of summarized records of wells that penetrated rocks of at least Middle Devonian age. Stratigraphic data in this report could be of use to geologists beyond those involved in the oil and gas industries. Summaries of current research activities by the Survey's Oil and Gas Geology Division are also included.

What many might find surprising is that any person, geologist or not, who is curious about Pennsylvania's oil and gas industries could find much of interest in this report. The first half of the 80-page volume, in addition to summarizing industrial activity in 1987, contains clear explanations of the kind of activity that took place and, to some extent, how it was accomplished and why it was done. Whether the reader lives in McKean County or Warren County, which between them have over 8,000 producing oil wells, over half the total for the state; in Bradford County, the site of a single producing well that marks the first new oil-field discovery in Pennsylvania in over 20 years (Mark Resources #1 in the Brace Creek field, which produced 174 barrels from the Lock Haven Formation in 1987); or in southeastern Pennsylvania, where there is no reported oil or gas production, but where several test holes have been drilled in recent years, this book can provide interesting insights into an industry that, although declining following a boom in the early 1980's, yielded production worth more than $424 million in 1987.

Progress Report 201, **Oil and Gas Developments in Pennsylvania in 1987**, is available for $2.65, plus 16¢ sales tax if shipped to an address in Pennsylvania, by writing to State Book Store, P. O. Box 1365, Harrisburg, PA 17105. Prepayment is required; please make your check or money order payable to *Commonwealth of Pennsylvania*.

WATER RESOURCES OF GREENE COUNTY

The Pennsylvania Geological Survey is pleased to announce the publication of Water Resource Report 63, **Water Resources and the Effects of Coal Mining, Greene County, Pennsylvania**. The report is the product of a joint county-state-federal project, and was written by U.S. Geological Survey personnel Jeffrey D. Stoner, Donald R. Williams, Theodore F. Buckwalter, John K. Felbinger, and Kenn L. Pattison. The geologic map and cross section were compiled by Pennsylvania Geological Survey staff geologist Clifford H. Dodge.

About 20 percent of the minable bituminous coal reserves in Pennsylvania underlie Greene County. Most of the coal remains in the western part of the county, which has not yet been extensively mined. Concern for the potential effects of future coal subsurface and surface mining on water resources is the central issue of this report.

Topics included in the new publication are the hydrogeologic framework of the county, the hydrologic setting, the groundwater system, the surface water, and the hydrologic effects of coal mining on groundwater and surface water. A full-color geologic map (scale 1:50,000) containing structure contours and well and spring locations is included.

Well yields in the Pennsylvanian- and Permian-age rocks that underlie the county are typically low (less than 4 gallons per minute), and most groundwater circulation is at shallow depths. From these and other data, the authors conclude that only in about 5 percent of the unmined part of the county should mining of the Pittsburgh coal reduce or deplete the yield of wells less than 150 feet deep, or cause significant depletion of streamflow, unless vertical fracture zones or fractures caused by collapsed mine workings effectively connect shallow aquifers to a deep mine.

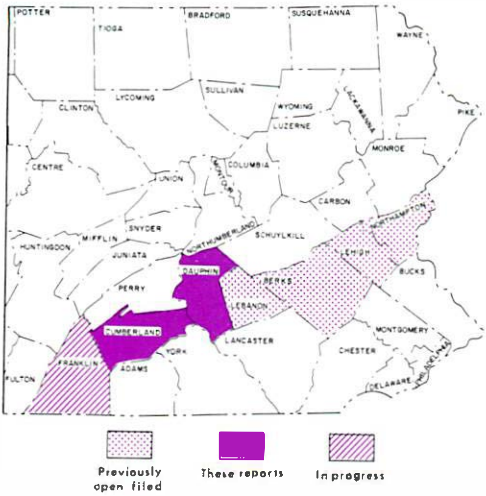
This report will be of interest to anyone involved in obtaining, managing, or protecting water resources in Greene County. By extrapolation, the conclusions can be utilized in other areas of Pennsylvania where mining occurs. A similar report is being prepared on Washington County.

Copies of the report may be ordered from the State Book Store, P. O. Box 1365, Harrisburg, PA 17105; the price is $16.80 (plus $1.01 sales tax if shipped to an address in Pennsylvania). Prepayment is required; please make checks payable to *Commonwealth of Pennsylvania*.

OPEN-FILE REPORTS ON SINKHOLES AND KARST-RELATED FEATURES IN DAUPHIN AND CUMBERLAND COUNTIES

Two new editions of the open-file reports on sinkholes have recently been released by the Pennsylvania Geological Survey. Prepared by staff geologist William E. Kochanov, the reports contain an inventory of sinkholes, closed depressions, and sinkhole-prone areas in Dauphin and Cumberland Counties, compiled on U.S. Geological Survey 7.5-minute quadrangles. The reports also include geologic contacts of carbonate bedrock units, bedding orientations and joint measurements in the carbonate units, cave entrances, and surface mines. This information was obtained through stereoscopic aerial photography examination, field investigations, and contacts with local residents and municipal officials. By using a series of photographs dating back to 1948, the author was able to show sinkholes and karst features that may cause problems for future land use, but that are no longer visible by field investigation or examination of recent aerial photographs.

The two new open-file reports provide a data base that may be used as a starting point for any environmental investigation done by county and township officials, planners, and consultants. Because of the sometimes catastrophic nature of sinkholes, these reports will also be of interest to homeowners and home buyers. Educators will find them useful for classroom or field trip guides. By seeing the patterns of karst fea-



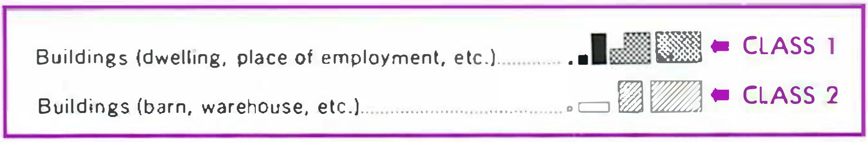
tures and sinkholes plotted on a geologic base map, one is able to gain a general understanding of the carbonate geology and the nature of sinkhole occurrences.

To obtain copies of Open-File Report 89–01, **Sinkholes and Karst-Related Features of Dauphin County, Pennsylvania,** and Open-File Report 89–02, **Sinkholes and Karst-Related Features of Cumberland County, Pennsylvania,** write to the Pennsylvania Geological Survey, P. O. Box 2357, Harrisburg, PA 17105. The price of the Dauphin County report is $12.50 plus 75¢ state sales tax for Pennsylvania residents; the price of the Cumberland County report is $25.00 plus $1.50 state sales tax. Checks must accompany the order and should be made payable to *Commonwealth of Pennsylvania.* The reports may be examined by contacting William Kochanov and visiting the Pennsylvania Geological Survey offices in the Executive House, 101 South Second Street, Harrisburg.

COMMENTS REQUESTED ON USGS PLANS FOR A SYMBOL CHANGE ON TOPOGRAPHIC MAPS

The National Mapping Division (NMD) of the U.S. Geological Survey (USGS) is planning to combine cartographic symbols that presently define two classes of buildings on standard topographic quadrangle maps. At present, the NMD map symbol policy requires use of two distinct symbols for Class 1 and Class 2 structures. Class 1 buildings are structures intended primarily for housing human activities and include residences, hotels, churches, schools, shops, most public and commercial buildings, factories, service stations, and others of similar character.

Class 1 symbols are solid black or are outlined in black and contain a crosshatch pattern (see illustration). Class 2 buildings are structures not intended primarily for housing human activities and include warehouses, barns, greenhouses, sheds, and others constructed to house machinery or animals, or for storage. Class 2 symbols are outlined in black and are either open or contain diagonal line patterns.



Comments are requested by the USGS to determine the use of building class information as currently depicted on standard topographic quadrangle maps, and the impact of eliminating building class distinctions.

In the past, classification of Classes 1 and 2 was based on information acquired during field survey work. As NMD mapping procedures are changed to make maximum use of high-resolution photography, supplemented with additional cartographic source materials and reduced field survey operations, this information will no longer be readily available.

In addition, provisional edition topographic maps (P–maps) and photorevised maps ("purple" revisions) have been published since 1981 with no distinction between classes of buildings, except for schools, churches, and other landmark buildings, which have been shown as on standard-edition maps. No objections have been raised by map users over the lack of building classification on these two types of maps.

Based on the fact that apparently no use is being made of the distinction between Class 1 and Class 2 buildings, and the desire to expedite mapping operations, the NMD is considering the elimination of the classification of most buildings. However, churches, schools, and landmark buildings will continue to be symbolized and/or labeled according to current standards.

If you have a definite need for the distinction of Class 1 and Class 2 buildings as currently shown on standard-edition topographic maps, please submit a brief description of your application to the USGS. In addition, please describe how you have obtained this information where it has been lacking on provisional edition and photorevised maps. The USGS would also appreciate knowing if you do not have any application for the present classification.

For further information, write or call William J. Jones, Chief, Office of Technical Management, National Mapping Division, 510 National Center, Reston, VA 22092, telephone 703–648–4566.

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IN COOPERATION WITH THE U.S. GEOLOGICAL SURVEY

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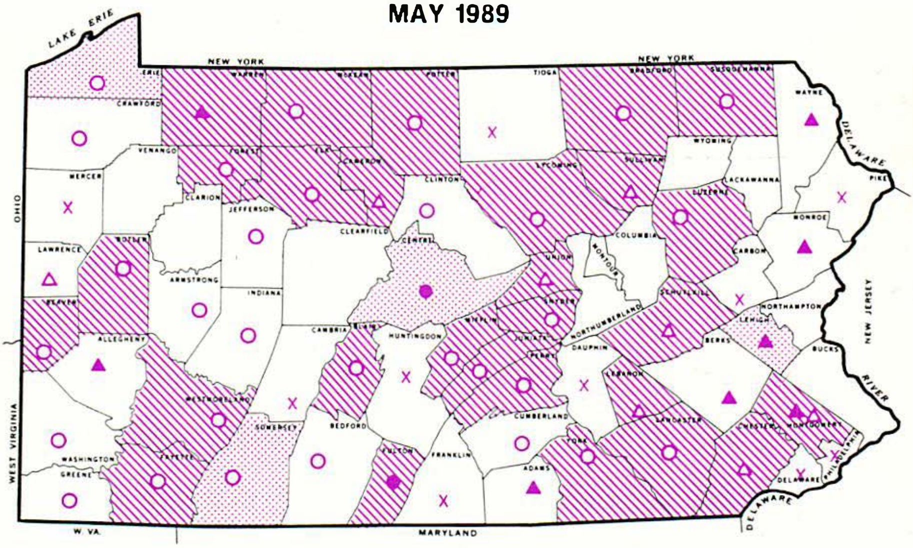
GROUNDWATER-RESOURCE MAPPING

GROUNDWATER LEVELS FOR MAY 1989



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Above last year — Below last year
Observation well

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No data

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