

## THE HAZARDS OF MINE SUBSIDENCE

by Douglas L. Crowell

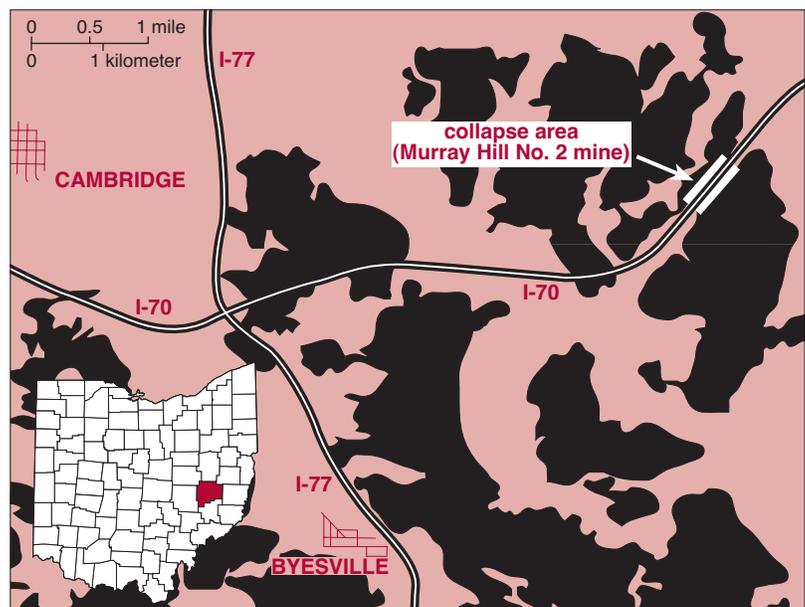
**M**ine subsidence, like an earthquake, is a geologic hazard that can strike with little or no warning and can result in very costly damage. Mine subsidence, unlike an earthquake, generally affects very few people. But, when a mine collapses under an interstate highway, many lives and industries are affected. On Saturday, March 4, 1995, at about 7 p.m., mine subsidence caused a portion of the eastbound lane of Interstate Route 70 (I-70) in Guernsey County to collapse. This subsidence event and the ensuing repair work closed the eastbound and westbound lanes of I-70 between March 4 and August 16, 1995. Approximately 3.4 million vehicles using I-70 had to be rerouted onto Interstate Route 77 and U.S. Route 40, a two-lane highway, through the community of Old Washington. According to Renee Payette, Project Engineer for the Ohio Department of Transportation (ODOT), the cost of the repair work has been estimated at \$3.8 million.

The I-70 collapse occurred over a portion of the Murray Hill No. 2 coal mine, located about 4½ miles east of the interchange of I-70 and I-77 in Center Township, Guernsey County. This mine, operated by the Akron Coal Company, was opened in 1912 and abandoned in August 1935. A report by the State Inspector of Mines stated that the Murray Hill No. 2 mine used a slope opening 125 feet in length to mine the Upper Freeport (No. 7) coal, which was 5 to 5½ feet thick. The style of mining was room and pillar, using double main and cross entries developed in a somewhat regular pattern. Many entries were developed at right angles; however, some entries were developed at odd angles, so that some rooms and pillars were quite variable in shape and dimension. Generally, the cross entries are every 440 feet, the rooms are 30 feet wide and up to 400 feet long, breakthroughs are every 60 to 80 feet, and the pillars are 30 feet wide. The State Inspector of Mines stated in a 1913 report that electric coal-cutting machines and motor and mule haulage were used in this mine. Because mules were used for coal haulage, the height of the entries was enlarged by removing some of the roof or floor rock to provide a working height sufficient to accommodate the mules. A 1914 report by the State Inspector of Mines indicates that some miners in the Murray Hill No. 2 mine were involved in pillar work. A common practice in Ohio deep mines, prior to abandonment of a portion of the mine, was to mine the pillars of coal that provide roof support during mining. It is suspected that many pillars in the Murray Hill No. 2 mine had been removed prior to abandonment.

Instability beneath I-70 was first indicated on March 16, 1994, when minor subsidence occurred along the westbound lane. Between April and December 1994, ODOT drilled 49 boreholes along I-70 overlying the Murray Hill No. 2 mine. These borings

showed that the Murray Hill No. 2 mine is partly overlain by unconsolidated material (clays, silts, and minor lenses of sands and gravels) ranging from 23 to 53 feet in thickness; most range from 40 to 50 feet thick. Bedrock between the unconsolidated material and the mine void includes interbedded sandy shale and shaly sandstone 10 to 25 feet thick. According to a 1995 report by Hoffman and others, the Upper Freeport coal was 5 to 7 feet thick and underlain by soft clay.

Between the first subsidence in March 1994 and completion of the repair work on I-70 in August 1995, about eight subsidence events, including



Location of March 1995 mine collapse along I-70 in Guernsey County. Black areas represent known extent of underground coal mines in the region.

the subsidence of March 4, 1995, occurred along a quarter-mile stretch of I-70. Stabilization of the subsidence required drilling nearly 2,200 boreholes, averaging 66 feet deep, on approximate 12-foot centers along 1,800 feet of I-70. The top halves of these holes were 8 inches in diameter and drilled to bedrock. The bottom halves of the holes were 6 inches in diameter and drilled into either a pillar of coal or the mined-out area. Following drilling, the mined-out area and the drill holes were filled with 30,385 tons of grout (18,740 tons of fly ash and 11,645 tons of cement, sand, and gravel). In addition, two reinforced-concrete land bridges, 110 feet and 700 feet long, respectively, were constructed on the westbound lanes of I-70 to protect the highway from subsidence due to collapse voids in the unconsolidated material underlying the westbound lanes. These collapse voids are a result of mine-roof col-



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# From The State Geologist...

## Thomas M. Berg

### OUR ROLE IN FORMING PUBLIC POLICY

I recently had the privilege of speaking to a mixed audience on a Saturday morning at Miami University here in Ohio. The audience included people from the general public who had an interest in science, particularly geology, but it was not an audience of other geologists. I was not preaching to the choir, as sometimes happens. Most gratifying was the large number of high-school students present.

My general theme was the importance of geology and minerals in our everyday lives and the urgent need to increase general public awareness about geological issues. I began by poking a little fun at the various images that people have of geologists and what geologists do. There is the rugged outdoorsman image of geologists trudging through uncharted terrains in search of who knows what. There is the crusty prospector image. There is the pallid, bespectacled, white-lab-coat scientist image as well. Rarely does anyone have the image of a geologist as one who spends time in the State House or on Capitol Hill trying to educate legislators about geoscience issues or pressing for legislation that clearly reflects geologic facts. Rarely do we have the image of the geologist testifying before legislative committees or serving on vital advisory commissions or committees. In fact, there are geologists who do spend a lot of time working with legislators and serving in advisory capacities. Most people just never hear about those geologists.

As I spoke to the people in that audience, I particularly tried to encourage the young people that geology is a worthwhile career, but that being a geologist today cannot continue in the prevailing images. I tried to encourage them that being a geologist is terribly important now, and that geologists should have a significant impact on the reshaping of our society as we head toward the next millennium. Whether we like it or not, the functions and concerns of geologists (and therefore, their images) must change as the general public and as government leaders question or change their own positions on scientific research, environmental problems, and mineral economics.

Many state government geological surveys, and the U.S. Geological Survey, have come under close scrutiny as government is being "reinvented." Some state surveys and the USGS have been threatened with abolishment. It is a sad state of affairs when legislators and government policy-makers fail to perceive the present urgent need for strong government-supported geological agencies. Today, the State of Ohio faces increasingly serious geological concerns including water supplies, energy independence, waste management, geological hazards, zoning and land-use planning, construction materials availability, and a host of environmental matters. New ground-water supplies need to be identified and aquifers need to be mapped to protect water quantity and quality. Coal, oil, and gas are precious fossil energy resources that need to be located and characterized systematically. Municipal-, hazardous-, and nuclear-waste management issues need to be addressed in light of the best possible geologic information. Urban and suburban development is greatly expanding in Ohio and needs to be managed in balance with development of our rich mineral heritage. We are becoming increasingly aware of geologic hazards including earthquakes, sinkholes, landslides, coastal erosion, indoor radon, and abandoned-mine collapse (see article by Doug Crowell in this issue). All of these growing geological concerns require a strong state geological survey. In addition, the value of fossil fuels and industrial minerals extracted in Ohio during 1994 amounted to **\$1.816 billion**. The geological survey provides the basic data on the location, quantity, and quality of these resources. A strong, efficient, effective, and objective state geological survey is required so that legislators and policy-makers will have the impartial geologic information needed to make today's heavy-duty environmental and economic decisions.

But making public officials and policy-makers aware of the importance of the science of geology cannot be left to state survey or USGS geologists alone. Geologists in the academic arena urgently need to see their responsibility as constituents of elected officials, and make them aware of geological issues on a regular basis. A liaison committee of geology department chairs in Ohio could make regular visits with key legislators in Columbus. Geologists in the consulting arena need to be quite vocal about the development of public policies that are not in balance with geologic realities. Consulting geologists need to work through statewide groups such as the Ohio Section of the American Institute of Professional Geologists and make their voices heard in the State House and in the Governor's Office.

Finally, as I tried to point out in my Saturday morning presentation at Miami, I think it is also the responsibility of every citizen to participate in raising public awareness of the importance of geology and reliable geological information in our everyday lives and in the development of public policy. When local issues such as development, waste disposal, water supply, mineral resource supply, zoning, and infrastructure deterioration come to the attention of public policy-makers, every citizen should insist on ferreting out reliable geological information and involving geologists in the decision-making process.

## Topographic map price increase

Effective October 1, 1995, U.S. Geological Survey 7.5-minute (1:24,000) topographic quadrangle maps increased in price to \$4.00 each, plus tax and mailing. According to the U.S. Geological Survey, this increase was necessary to reflect their true cost of preparing and printing these maps. Topographic maps at a scale of 1:100,000 and 1:250,000 still remain at \$4.00 each, plus tax and mailing. A free brochure on Ohio topographic maps is available from the Division of Geological Survey, 4383 Fountain Square Drive, Columbus, OH 43224-1362, telephone 614-265-6576. The brochure contains an index of Ohio topographic maps, prices, and the schedule of mailing charges.

continued from page 1

lapse and subsequent migration of overburden downward into the void space. These collapse voids were detected by drilling and geophysical techniques after the injection of grout and were not completely filled during grouting. Collapse voids were not detected under the eastbound lanes.

#### OTHER RECENT MINE-SUBSIDENCE EVENTS

In addition to the I-70 subsidence events, at least six other mine-subsidence events have occurred in Ohio since March 1994 within 130 feet of several duplexes and other buildings in North Canton, Stark County. These subsidence events, including one on March 3, 1995 (see photo), occurred on the east side of Ellesmere Drive, north of Applegrove Road, as a result of mine-roof collapse in the Hoover mine. This drift mine in the Brookville (No. 4) coal was operated by the Hoover Company (formerly the G. F. Smith Company) and was abandoned in 1929. Room-and-pillar mining was used in the Hoover mine, but the pattern is highly irregular; entries are at odd angles and rooms and pillars are of varying shapes and dimensions. The abandonment map for the Hoover mine shows numerous areas marked "worked out" with no details of entry direction or room or pillar dimension.

Six bore holes drilled by CTL Engineering showed that the Hoover mine is overlain by unconsolidated material (sand and silt) ranging from 26½ to 33 feet thick. Bedrock overlying the mine includes fractured limestone 2 to 6 feet thick or fractured shale 5 to 8½ feet thick. The coal was 4½ feet thick, the height of mine voids was 5 feet, and the floor rock was shale. Remediation of the site included filling the subsidence pits with aggregate and stabilizing the mine roof beneath the duplexes by injecting about 2,000 cubic yards of concrete through 26 holes drilled into the Hoover mine.

#### MECHANICS OF MINE SUBSIDENCE

Subsidence, in the context of underground mining, is the lowering of the Earth's surface due to collapse of bedrock and unconsolidated materials (sand, gravel, silt, and clay) into underground mined areas. Ohio has had a history of mine subsidence problems dating to at least 1923. Subsidence can cause structural damage to buildings, highways, sidewalks, and curbing and disrupt gas, water, and sewer lines and water wells.

There are two types of subsidence: (1) pit (also called sinkhole or pothole) and (2) sag or trough. Pit subsidence is characterized by an abrupt sinking of the surface, resulting in a steep-sided, craterlike feature that has an inward drainage pattern. It is associated with roof collapse of shallow mines, which have cover (overburden) less than 165 feet, incompetent roof rock of shale or mudstone, and a ratio of unconsolidated-material thickness to rock thickness of less than 1.2. Pit subsidence does not occur where the thickness of the unconsolidated overburden is more than 90 feet. Sag subsidence is a gentle, gradual settling of the surface. It is associated with pillar crushing or pillar punching (discussed below) of deeper mines (overburden of more than 75 feet). Sag subsidence features may be water filled where the surface of the subsidence intersects the water table. Subsidence pits generally do not hold water because the pit drains into the underlying mine.



Subsidence pit, about 6 feet in diameter and 8 to 10 feet deep, on I-70 resulting from roof collapse of the Murray Hill No. 2 mine. Photo courtesy of Gannett Fleming, Inc.

Mine subsidence is controlled by many factors, including height of mined-out area, width of span, depth of seam, competency of bedrock, pillar dimension, hydrology, fractures/joints, and time. The vertical component of subsidence is proportional to the height of the extraction area. Generally, the vertical component of subsidence does not exceed the height of the mine void. However, according to Renee Payette (ODOT), the I-70 subsidence of March 4, 1995, measured 24 feet in diameter and 10 to 12 feet deep, even though the height of the mined-out area was about 5 feet. Also, according to Mike Smith of the U.S. Office of Surface Mining and Reclamation, the North Canton subsidence of March 3, 1995, measured 35 feet in diameter and 25 feet deep and developed over a mine void about 5 feet high. In both cases, unconsolidated material was carried downward by ground-water action through fractured bedrock overlying the mines. Thus, pip-



Subsidence stabilization of the westbound lanes of I-70 in Guernsey County. Large-diameter holes were drilled into the Murray Hill No. 2 mine and a mixture of fly ash and cement was pumped into the mine voids to prevent further subsidence. Photo courtesy of Gannett Fleming, Inc.

ing (subsurface erosion by water washing away fine-grained soil) of unconsolidated material created a cavity deeper than the height of the mine.

The area of mine subsidence increases proportionally with increasing width of unsupported roof rock. The potential area of subsidence is equal to the extraction area plus an area surrounding the extraction area measured by an angle up to 35°, called the angle of draw, taken from the vertical at the edge of the extraction area. For example, roof collapse in a mine 160 feet deep could cause subsidence more than 75 feet beyond the edge of the mine. The deeper the mine, the larger the area potentially affected by mine subsidence at the surface.



Subsidence pit behind a residence in North Canton, Stark County. This pit was 35 feet in diameter and 25 feet deep. Photo courtesy of Ohio Division of Mines and Reclamation.

The vertical component of subsidence decreases with increasing depth or thickness of overburden, especially bedrock. As the roof rock sags, ruptures, and eventually collapses into a mined-out area, the roof rock rotates, twists, splinters, or crumbles as it falls, resulting in incomplete compaction. In other words, the mine void is not completely filled during a mine-roof collapse. Because bedrock collapses with incomplete compaction, the deeper the extraction area, the smaller the vertical component is at the surface.

Mine subsidence is related to the competency of bedrock, which is a measure of a rock's load-bearing capacity. Sandstones and limestones are capable of withstanding greater loads than are shales and mudstones. Therefore, sandstones and limestones can span larger unsupported distances or support thicker amounts of overburden before failing. The roof rock overlying the Murray Hill No. 2 mine was shale; the roof rock at the Hoover mine included limestone and shale. However, because the roof rock at the Hoover mine was fractured, its load-bearing capacity was greatly diminished.

Mine subsidence increases with decreasing size of pillar dimension. In room-and-pillar mining, the most common style of underground mining in Ohio, about 50 percent of the seam is left in place as pillars for roof support. However, it was a common practice of 19th- and early 20th-century coal operators to mine the pillars, partially or wholly, as an area of the mine was abandoned in order to maximize production. Complete mining of a pillar is called "pillar robbing." Reducing the size of a pillar is called "pillar slicing." Creating small, multiple pillars out of a single, large pillar is called "pillar splicing." Mining the pillar increases the width of unsupported roof, which increases the likelihood of subsidence. Also, diminishing the

size of a pillar increases the chance of pillar crushing or pillar punching and increases the chance of mine-roof collapse. Pillar crushing results when the weight of the overburden exceeds the load-bearing capacity of the coal pillar and it is crushed. Pillar punching results when the weight of the overburden exceeds the load-bearing capacity of the floor rock, and the pillar is pushed downward by the roof rock into the floor. In pillar punching, the floor rock is generally a soft, plastic clay that flows upward into the mine void, a phenomenon miners term a "squeeze."

Mine subsidence is affected by water circulation or the fluctuation of water level in a mine. Some underground mines remain dry after abandonment; many others fill with water. Circulating water in an underground mine can deteriorate roof support or the roof rock. Because of its incompressibility, water provides support to the roof of a mine that is filled with water. However, the likelihood of roof collapse may be enhanced or accelerated in mines where the roof rock is repeatedly saturated and left unsupported by fluctuating water levels (either by seasonal weather conditions or intentional pumping) and where the pillars of coal are eroded by flowing water. The dewatering of an adjoining underground mine by a nearby surface mine probably contributed to the roof collapse of the Murray Hill No. 2 mine.

The likelihood of subsidence increases when fractures (joints) intersect the mine roof. Fractures or joints are natural planes of weakness where collapse of the mine roof is likely to occur. Fractures also may allow the subsidence to extend beyond the limit of the mined area.

The length of time for mine subsidence to occur increases with increasing depth of mining and increasing competency of overburden. The type and amount of roof support in addition to pillars of coal left in the mine also affect subsidence. Most underground mines in Ohio used wooden timbers as additional roof support. Steel I-beams were used in Ohio mines as roof support beginning in the early 20th century. By the mid-20th century, roof bolting was another type of roof support being used in Ohio mines. With time following abandonment of an underground mine, these types of roof support eventually rot or deteriorate, allowing subsidence to occur. Because of the complexity of the variables which contribute to mine-related subsidence, no acceptable system exists which is capable of accurately predicting the time or amount of subsidence in a variety of geological settings, especially for mines that have an irregular pattern of room-and-pillar mining.

In addition to mine subsidence, the collapse of improperly stabilized mine openings presents a great risk to public property and safety. The collapse of an improperly sealed shaft may equal the original depth of the shaft. For example, on June 13, 1977, an improperly stabilized shaft to the Foster No. 1 mine (abandoned in 1884) collapsed underneath a garage in a residential neighborhood in Youngstown, Ohio, leaving a 115-foot-deep opening. (This shaft was originally 230 feet deep.) Fortunately, there was no loss of life or personal injury associated with this collapse, but this shaft collapse illustrates the potential for life-threatening situations due to collapse of mine openings.

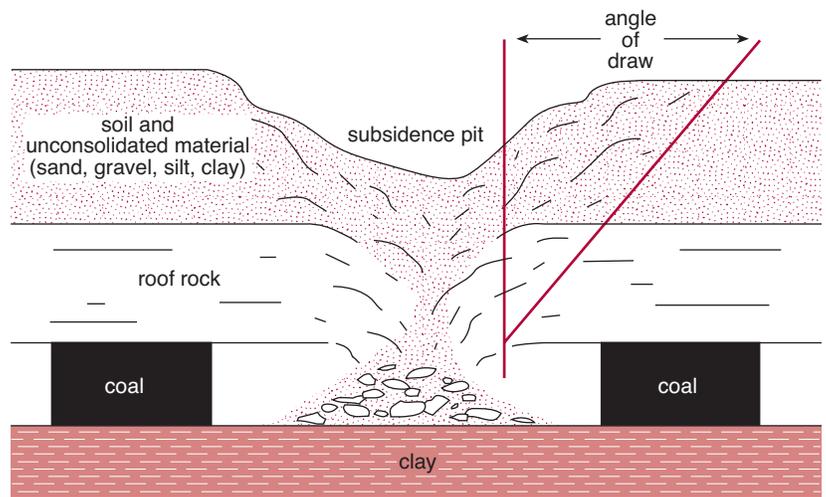
#### ABANDONED UNDERGROUND MINE MAPS

The Murray Hill No. 2 mine and the Hoover

mine are two of an estimated 6,000 abandoned underground mines in Ohio. The Division of Geological Survey has detailed abandonment maps (scale: 1 inch equals 400 feet) for 4,138 mines. In addition to those mines for which detailed maps are available, the Division estimates there are approximately 2,000 mines for which no detailed maps of the mine workings are available. The Division's extensive database on abandoned underground mines includes mine-information sheets, detailed maps of individual abandoned underground mines, and an Abandoned Underground Mine Map Series. The maps in this series are plotted on 7.5-minute topographic quadrangle bases (scale: 1 inch equals 2,000 feet) and show the areal extent of mapped abandoned underground mines, the location and type of mine openings (air shaft, drift, slope, and hoisting shaft) for mapped mines, and the location of openings to abandoned underground mines for which no mine maps exist. Copies of the quadrangles in the Abandoned Underground Mine Map Series can be purchased from the Division for \$4.00 per map, not including tax and postage. To order an abandoned-mine map or to find out more about abandoned underground mines in Ohio call the Division of Geological Survey at 614-265-6576.

#### MINE SUBSIDENCE INSURANCE

Between October 1987 and January 1993, mine-subsidence insurance coverage was available in 37 Ohio counties on an optional basis. This insurance provided Ohio homeowners with modest damage protection against mine subsidence because most Ohio homeowners do not know if the land on which their home is built has been undermined. In 1992, Ohio's Mine Subsidence Insurance Law was passed. This law, which became effective in 1993, mandates mine-subsidence coverage for all basic homeowner insurance policies in 26 Ohio counties: Athens, Belmont, Carroll, Columbiana, Coshocton, Gallia, Guernsey, Harrison, Hocking, Holmes, Jackson, Jefferson, Lawrence, Mahoning, Meigs, Monroe, Morgan, Muskingum, Noble, Perry, Scioto, Stark, Trumbull, Tuscarawas, Vinton, and Washington. The insurance is available on an optional basis for 11 Ohio counties: Delaware, Erie, Geauga, Lake, Licking, Medina, Ottawa, Portage, Preble, Summit, and Wayne. The maximum amount of coverage for the principal dwelling allowed by the insurance is \$50,000. From 1988 through June 1995, 364 mine-subsidence claims were filed with the Ohio Fair Plan, Mine Subsidence Insurance Underwriting Association. Of these damage claims, only



Diagrammatic cross section of typical subsidence resulting from mine-roof collapse. No scale implied.

30 were documented to be a result of mine subsidence. According to Tracey A. Brinneger of the Ohio Fair Plan, damage payments for the 30 claims totalled \$629,136. In addition to the mine-subsidence claims handled by the Ohio Fair Plan, since 1980 the Ohio Division of Mines and Reclamation and the U.S. Office of Surface Mining and Reclamation have treated 195 mine-subsidence events at an estimated cost of \$5,697,000.

Subsidence seems to be increasing owing to the age of underground mines. The extent to which mine-subsidence problems will reach in Ohio is uncertain. For information concerning mine-subsidence insurance, call the Ohio Fair Plan, Mine Subsidence Insurance Underwriting Association at 1-800-282-1772 or 614-436-4530.

#### FURTHER READING

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- Crowell, D. L., 1991, Drilling for mine subsidence mitigation, in 1990 Report on Ohio mineral industries: Ohio Division of Geological Survey, p. 5-11.
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- Hoffman, A. G., Clark, D. M., and Bechtel, T. D., 1995, Abandoned deep mine subsidence investigation and remedial design, Interstate 70, Guernsey County, Ohio, in 46th Highway Symposium: Charleston, West Virginia, May 14-18, 1995, 15 p.

## MILLFIELD TRAGEDY REVISITED

On Wednesday, November 5, 1930, 182 Sunday Creek Coal Company miners were gathered near two hoisting cages waiting their turn to descend, in groups of 10, 189 feet into the main-shaft opening of the No. 6 mine. It was a cool, cloudy day, temperatures were dipping into the low 40's. Nine Sunday Creek Coal Company officials and visitors were, perhaps, the subject of some miner's conversations. The officials had gathered for a tour and would follow the miners into the mine. Included in the group were W. E. Tytus and P. A. Coen, President and Vice-President of Sunday Creek Coal Company; H. H. Upson, Assistant to Mr. Tytus; H. E. Lancaster, Chief Mine Engineer; and Walter

Hayden, Mine Superintendent. Apart from the unusual presence of Sunday Creek's top officials, this day appeared no different to the miners than any other day mining coal at the No. 6 mine. However, this day would end tragically as no other day in Ohio's mining history. A total of 82 men were killed—73 employees, five company officials, and four visitors—in a mine explosion at the No. 6 mine, making this the worst coal-mining disaster in Ohio history.

The No. 6 mine was located about 1 mile east of Millfield, Dover Township, Athens County. In 1930, Millfield was a community of about 1,500, many of whom worked in the No. 6 mine. Other miners who

worked in the No. 6 mine lived in nearby communities, including Glouster, Jacksonville, Sand Hill, Sugar Creek, and Trimble.

The No. 6 mine (formerly known as the Poston No. 6) was opened by the Millfield Coal Mining Company (founded by Clinton L. Poston and George H. Smith) and leased to the Poston Consolidation Company in 1911. The first coal from the mine was loaded on March 4, 1912. In September 1929, Sunday Creek Coal Company acquired the Poston No. 6 mine. The Sunday Creek Coal Company was a major corporation—the second largest coal company in the world in 1905. Included in the company's holdings were 60 mining properties, 33 of which were in Ohio. The new owners suspended regular operation of the Poston No. 6 mine on April 11, 1930, in order to make much-needed repairs and improvements. Upgrades to the mine included the



Relatives and friends gathered at the mouth of the Sunday Creek Coal Company Mine No. 6, at Millfield, Athens County, awaiting news of the fate of trapped miners. Photo from the *Black Diamond*, November 11, 1930, p. 1.

addition of brick walls and 8-inch steel I beams 22 feet in length to support the roof along the main haulage road; double rows of electric lighting several hundred feet in length strung along the entries; new double haulage tracks and switches; and the construction of a new ventilation shaft located about 1.4 miles northwest of the main hoisting shaft. The renovated No. 6 mine resumed full operation by August 11, 1930.

The No. 6 mine had been developed on the room-and-pillar system and had double and triple entryways for ventilation, passage of men, and coal haulage. Conventional mining was used in the No. 6 mine. The working face of the Middle Kittanning (No. 6) coal seam was undercut using coal-cutting machines that looked like oversized chain saws. Once the coal had been undercut, several holes were drilled into the working face. Explosive charges of pellet powder were then inserted into the holes and detonated. Following the explosive shot, the loosened blocks of coal were loaded into coal cars by hand. The loaded coal cars were taken to the main hoisting shaft by electric shuttle engines and then raised up the shaft to be unloaded at the tippie. As the miners advanced the working face farther into the seam of coal, track layers would hammer

additional rails into place and other workers would install steel I beams or wooden timbers for roof support. By November 1930, about 5,000 tons of coal were being mined every 24 hours, 5 days a week; the mine operated by double shifts. The coal was shipped from the No. 6 mine by the Kanawha & Michigan Railroad. Conventional mining was strenuous and dirty work even with the best mining machinery of the day. Usually work stopped only for 30-minute meal breaks.

Without warning, tragedy struck suddenly, at 11:45 a.m., shortly after the miners' lunch break. A tremendous explosion erupted at the rear of the mine, several hundred feet from the working face. A group of 79 miners working about 4,700 feet from the main shaft heard a "terrific slam and a whistling noise" of a powerful gale approaching them from the northern portion of the mine. Instinctively, some miners dropped to the floor of the mine, while others were knocked down as a great gust of wind passed over them. This gust of wind was followed shortly afterward by a second rush of air passing in the opposite direction. E. W. Smith, in an unpublished 1930 report, stated, "These men were thrown about by the force of the explosion but none of them were seriously injured and all of them were able to leave the mine by the main motor road which was the intake airway of the mine." Initially, some of the miners thought the noise and wind were a result of a major roof fall. However, they quickly realized that an explosion had occurred in the mine, and retreated to safety out of the mine under the direction of Section Foreman Robert Marshall. The first indication at the surface of trouble in the mine was when Ed Dempsey, a miner working at the top of the new air shaft, was knocked off the ventilation housing by a sudden burst of air followed by thick smoke.

Word of the explosion spread quickly. Within minutes of the explosion, distress calls for assistance were made for medical personnel and supplies. Calls also were made to the Ohio Division of Mines and the U.S. Bureau of Mines for mine-rescue personnel and equipment because the No. 6 mine did not have any mine-rescue equipment on hand. First news reports stated that 150 miners were trapped underground as a result of a gas explosion. Families and relatives of the miners, news media personnel, and spectators surged into Millfield to learn the fate of the miners. Two companies of the Ohio National Guard were ordered to the mine to help maintain order. Twenty-four Red Cross nurses, several doctors, and Salvation Army volunteers arrived at the No. 6 mine to tend to the injured.

About an hour after the explosion, Andrew Ginnan, District Mine Inspector for the Ohio Division of Mines, arrived at the scene and, with Section Foreman Robert Marshall and Mine Superintendent Pete McKinley, entered the No. 6 mine to start clean-up work and restore proper ventilation to the mine. The northern portion of the mine contained carbon monoxide, the deadliest of all mine gases. Carbon monoxide or whitedamp, is a colorless, odorless, tasteless, lighter-than-air gas that is a combustion product of mine fires or the explosive ignition of methane or coal dust. The mine would not be cleared of carbon monoxide until Sunday morning, November 9, 1930.

By 4 p.m., November 5, E. W. Smith, Chief Inspector for the Ohio Division of Mines, and three other mine inspectors arrived with mine-rescue equipment. Included among the mine-rescue equip-

ment were carbon monoxide detectors, gas masks, and several canaries. Several hours later, J. J. Forbes, Chief Engineer for the U.S. Bureau of Mines, and two other mining engineers arrived at Millfield in a railroad car converted into a mobile safety-training and mine-rescue facility. The U.S. Bureau of Mines personnel brought with them self-contained breathing apparatuses which allowed workers into the most gas-filled portion of the mine.

The force of the explosion was so great that near the point of the explosion (10,200 feet from the main shaft) electric shuttle engines and mine cars were knocked off their tracks, steel I beams were twisted and blown about like sticks, and wooden timbers were smashed into kindling. In addition, the force of the explosion demolished numerous brick stoppings (ventilation barriers between adjoining rooms and entries), knocked down trolley wires, ripped up track for a distance of about 760 feet, and scorched equipment for a distance of 1,640 feet from the point of ignition.

Some of the miners speculated that the explosion was caused by a pocket of methane, ignited by the open flame of a miner's lamp. Even though the No. 6 mine was known to be somewhat gassy, open-flame carbide lamps were used by the miners working in the mine. Another theory was that a mine car containing pellet powder exploded. However, careful examination of the debris by state and federal mine inspectors revealed that the explosion was triggered by a rock fall that broke an electrical (trolley wire) cable, which then shorted against an underground train rail, producing an arc, which ignited a pocket of methane gas that had collected in that portion of the mine.

Ventilation to the damaged portions of the No. 6 mine was restored slowly. Canaries carried by mine-rescue personnel were overcome in 3 to 4 minutes by high concentrations (0.3 percent) of carbon monoxide. Carbon monoxide concentrations greater than 0.25 percent can cause a person to lose consciousness very quickly and apparently without any pain or suffering. Because the haulage equipment used in the No. 6 mine was electric and electricity to the damaged portion of the mine could not be immediately restored for fear of a second explosion, a dozen mules were brought into the mine to assist in clearing the entries and removing the bodies. By midday November 6, rescue personnel wearing self-contained breathing apparatuses had found the last of the bodies. By 7:15 p.m. November 6, 78 bodies had been removed from the mine. Four remaining bodies were recovered the following day. Apparently most of the deceased were killed by asphyxiation from the carbon monoxide that resulted from the ignition of the methane gas.

The bodies of the official party were found about 200 feet east of the base of the new air shaft. The official party had no chance of escape as they were on a nearly direct path with the force of the explosion, and carbon monoxide would have flowed past them on its way out the new air shaft. A few miners survived by climbing out a ventilation shaft, and an additional 19 miners were rescued 10 hours after the blast. The group of rescued miners were found, most of them unconscious, behind a ventilation partition located about 1,500 feet southwest of the new air shaft (almost 2 miles northwest of the main shaft). John Dean, Inside Foreman, is credited with saving the lives of the rescued miners, including himself. Dean and the other miners erected and gathered behind a ventilation partition which pro-

tected them from a deadly cloud of carbon monoxide. Dean risked several trips into the smoke-filled entries to carry some of his comrades to safety before he collapsed and had to be carried to safety. Another heroic effort was shown by James Mackey, Fire Boss, who nearly lost his life as he climbed part way down into the new air shaft to rescue a stricken comrade, who died just as Mackey arrived. Mackey was barely able to climb back out the smoke-filled air shaft; had he delayed, the effects of the gas would have been fatal.

A storage room, a pool hall, and the Sunday Creek Coal Company store at Millfield were turned into temporary morgues. Funeral services were held for the miners on Sunday, November 9, 1930. As a result of this mine explosion, C. H. Harris stated, "fifty-nine women were widows and seventy-nine sons and seventy-five daughters of various ages, were made fatherless. The health of the few who survived was wrecked in a number of cases. Many families were several times sorrowed—one mother lost five sons . . . Burial of the victims was paid by the state, allowing \$150 in each case. Dependents of the miners were compensated at the rate of \$18.75 a week until exhaustion of a death claim of \$6,500 under the workmen's compensation law. By March 1940, the state had paid to the No. 6 miners and dependents a total of \$712,391."

The No. 6 mine reopened a month later and operated until 1945. The tippie of the No. 6 mine, which had stood as a sentinel over the disaster site for nearly 65 years, was recently razed for safety reasons. To the writer's knowledge, no known survivors of the Millfield mine disaster remain living. A monument with the names of the miners killed in the disaster was erected in the town of Millfield. Since the disaster, a memorial service commemorating the victims has been held annually at Millfield and the tragedy lives in the minds of community residents who were in the area at the time of the disaster.

—Douglas L. Crowell

Note to our readers: we welcome any photos from this mine disaster or other historic mine-related photos or memorabilia for the Survey files.

#### FURTHER READING

The report by Smith (1930) is on file at the Ohio Division of Mines and Reclamation; the reports by Earich, Ray, Ray and Bonnet, and Wilson are in the archives of the Alden Library at Ohio University in Athens.

- Earich, Adolph, undated, What I remember about Millfield: unpublished, 18 p.
- Harris, C. H., 1957, The Harris history; a collection of tales of long ago of southeastern Ohio and adjoining territories: The Athens Messenger, 329 p.
- Koster, J. W., 1919, Gases commonly met within coal mines: The Coal Industry, v. 2, no. 2, p. 66-68.
- Ray, F. A., 1930, Notes taken from U. S. Bureau of Mines report on their investigation, rescue work, etc. on the explosion in the Sunday Creek Coal Company's mine Poston No. 6 at Millfield, Athens County, Ohio which occurred November 5th, 1930: unpublished, 25 p.
- Ray, F. A., and Bonnet, E. S., 1930, Report of the explosion which occurred November 5th, 1930 in Poston No. 6 mine owned by the Sunday Creek Coal Company located at Millfield, Athens County, Ohio: unpublished, November 14, 1930, 23 p.
- Smith, E. W., 1930, Report of Millfield mine explosion: unpublished, 6 p.
- Wilson, Bob, Jr., 1977, Millfield mine disaster, November 5, 1930: Millfield Memorial Committee, Patterns in Preservation, 13 p.

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**Canaries carried by mine-rescue personnel were overcome in 3 to 4 minutes by high concentrations (0.3 percent) of carbon monoxide.**

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## HANDS-ON EARTH SCIENCE No. 6

by Richard Hansgen  
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### HOW TO DETERMINE TRUE NORTH

Can you mark on the ground a true north-south line? Is the Sun directly overhead at noon? Does midday coincide with noon? Such questions can form the basis of an excellent inquiry-based experiment for students ranging from fifth graders through college undergraduates. Although this activity is simple enough to use with middle-school students, it is also worthwhile to pursue with high-school and college students because the vast majority of such students have not made, or even considered, these fundamental determinations.

A straightforward method to lay out a north-south line is to first determine midday. Midday is simply that time halfway between the times of sunrise and sunset, which can be ascertained by calling the local television station or watching the local evening news. The times given will be accurate to within a couple of minutes, depending on your location with respect to the station.

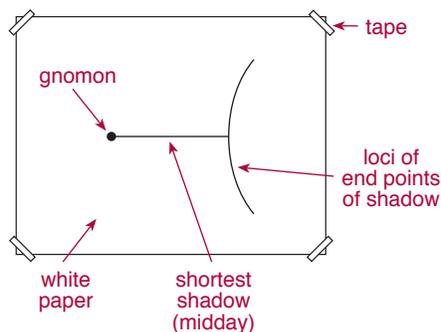
The class can be divided into small groups. Each group will need two large sheets of white paper, masking tape, a standard laboratory support stand with rod (the vertical rod serves as the shadow-casting object, or gnomon), a meter stick, a watch, and a sharp pencil. You should also have available a scout or army-type compass and a large protractor.

Take the class outside on a sunny day about a half hour before your calculated value of midday. They will need a horizontal surface, such as a sidewalk, on which to work. Place the support stand on the level surface and arrange the large sheet of paper so that the shadow of the tip of the rod falls on the paper. Tape the paper to the level surface. (Remember, the shadow is going to move; that is why we have an extra sheet of paper.) The position of the base of the stand should be outlined by pencil on the paper so that if the stand gets bumped, it can be returned to its original position.

To add a worthwhile flair to this experiment, the instructor can set up a similar apparatus in the morning and mark positions of the tip of the shadow every half hour. Record the

times on the paper near the appropriate mark. The teacher can then connect these points with a smooth curve, providing a dramatic representation of how far the shadow (or "Sun") moves in just a couple of hours.

Students should begin their measurements at least 20 minutes before the calculated value for midday and should measure the length of the shadow every 2 minutes for approximately 40 minutes. They should mark the position of the tip of the rod's shadow and note the time beside each mark. Measurements should continue until the length of the shadow begins to noticeably increase. Midday is when the length of the rod's shadow is shortest. A line drawn on the paper between the mark representing the



*Bird's-eye view of set up for determining midday.*

tip of the minimum shadow and the center of the base of the support rod provides a true north-south line.

What the students are witnessing is empirical evidence that the Earth is rotating about its axis. They are watching the Earth spin. One should keep in mind, though, that this is evidence, not proof. A stationary Earth about which the Sun makes a daily orbit provides an alternative explanation. A field trip to a local science museum where a Foucault pendulum is on display would provide more direct evidence that the Earth is rotating.

With the aid of the compass and the protractor, students can now determine the angle

of deviation between the direction the compass needle points and the line they have drawn on the paper. They should compare this angle with the accepted value for the angle of magnetic declination given on a U.S. Geological Survey topographic map of their area. If this experiment is done with moderate care, the students will be pleased with the comparison.

Further questions and experiments come immediately to mind. How did the measured value for midday compare with the computed value? Why wasn't midday at noon? What were sources of error in this experiment and how might they be minimized? For any given time, will the length of the shadow change from day to day? If so, why? On what date will shadows be shortest? Longest?

These questions can best be answered by further shadow measurements. Students can calculate the latitude of their school. This experiment is best done at midday on either the vernal or autumnal equinox. The shadow measurement of midday provides a straightforward technique. All the class needs in order to determine their latitude is either a knowledge of elementary trigonometry or an accurate and large scale drawing of the length of the support rod (from ground to tip) and the length of its shadow. Then simply measure the appropriate angle.

Shadow experiments demonstrate that excellent science can be done with simple apparatus. After all, the old Greeks did remarkably well with what nature provided: a stick, the Sun, and some human ingenuity!

### FURTHER READING

McClure, Bruce, 1987, Watching the Earth move with the shadow clock: *Astronomy*, v. 15, no. 8, p. 32-35.

(This article originally appeared in *The Physics Teacher*, 1995, v. 33, p. 116-117.)

**NOTE:** Contact Sherry Weisgarber at 614-265-6588 or [sherry.weisgarber@dnr.ohio.gov](mailto:sherry.weisgarber@dnr.ohio.gov) if you are interested in submitting a hands-on activity for this column.

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