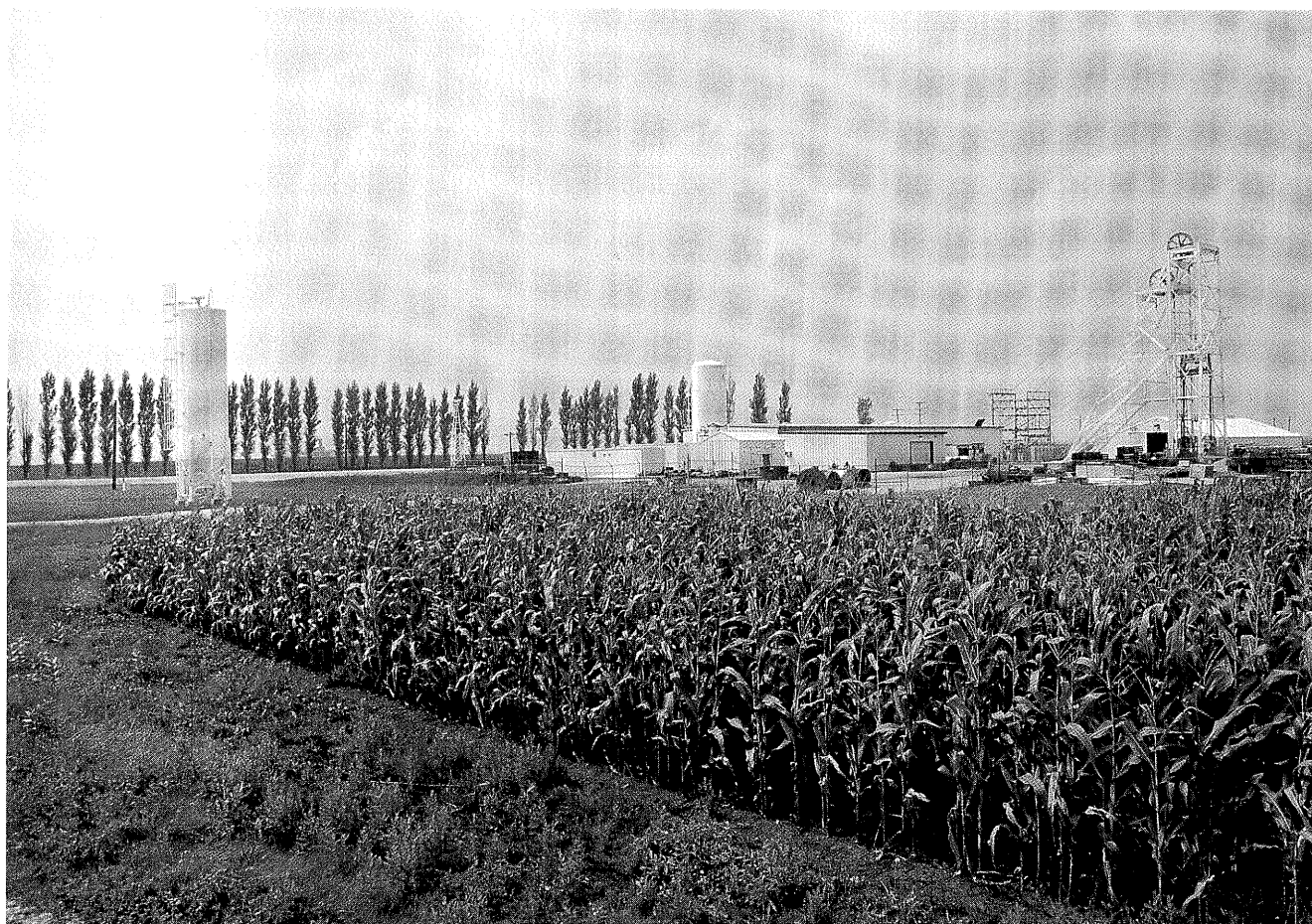


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Subsidence in Illinois  
A Public Information Booklet*

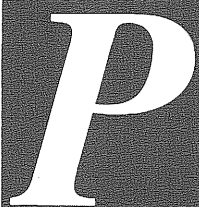


**ILLINOIS MINE SUBSIDENCE RESEARCH PROGRAM VII**

Department of Energy and Natural Resources

ILLINOIS STATE GEOLOGICAL SURVEY

1995

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*lanned Coal Mine  
Subsidence in Illinois  
A Public Information Booklet*

**R. A. Bauer, B. A. Trent, B. B. Mehnert, and D. J. Van Roosendaal**

**ILLINOIS MINE SUBSIDENCE RESEARCH PROGRAM VII**  
**ILLINOIS STATE GEOLOGICAL SURVEY** 1995  
Jonathan H. Goodwin, Acting Chief  
Natural Resources Building  
615 East Peabody Drive  
Champaign, IL 61820-6964

***Cover photo Surface facilities of an underground  
coal mine surrounded by cornfields.***

***Printed by authority of the State of Illinois/1995/10,000***



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# *Introduction*

This booklet was produced to respond to community concerns about the possible effects of underground mining and surface subsidence (the sinking of land surface). The coal industry is important to the economies of Illinois and the United States. The main purchasers of Illinois coal are electric power-generating stations. Coal generates about 40% of the electricity in Illinois and about 60% nationally. Coal mining directly and indirectly provides about 41,000 jobs in Illinois. The U.S. coal industry employs about 130,000 people and contributes more than \$21 billion yearly to the national economy. "Each coal job leads to seven other jobs in the country," according to the Illinois Coal Association (1992, p. 2-3). Many Illinois towns depend on the tax base and employment income that coal mining provides. Coal is the largest commodity carried by the rail industry, and the second largest carried by barges on the nation's inland waterways (ICA 1992).

The Illinois coal mining industry is using high-extraction mining methods, such as longwall, with greater frequency. Planned subsidence methods, such as high-extraction mining, enable Illinois coal mine operators to maximize mining productivity and decrease the cost of the delivered product. Increased productivity through longwall mining reduces mining costs per ton, thus improving coal's marketability. Electric power utilities can pass these reduced costs on to consumers.

Also, high-extraction mining methods waste less coal than other methods, which leave considerable amounts of coal behind. Consequently, by using longwall mining, coal companies are conserving and extending the coal resource for future use.

As a result of the trend toward planned subsidence coal mining methods, the public needs current, useful information on the effects of planned subsidence on the environment. Concerns about these effects on water resources, farmland productivity, and the economy are real. The Illinois Mine Subsidence Research Program was established by the Illinois Coal Association and the Illinois Farm Bureau in 1985 to answer questions about planned subsidence in Illinois. Background information on the coal industry and mining methods will help those concerned with understanding planned subsidence.



# *O* *origin and Formation of Coal*

Coal is called a fossil fuel because it is made up of materials that were once living plants. The stored energy from the ancient plant materials is released when the coal is burned (ICA 1992). The formation of individual minable coal beds took place over many tens of thousands of years. One of the major coal-forming periods began about 320 million years ago when much of what is now the United States was repeatedly covered by swamps where giant ferns, reeds, and other plants grew. When the plants died, they fell into the swamp water and accumulated. The plant material, deprived of oxygen after it was buried, did not decay but formed peat. The peat was compacted and covered by other layers of materials, and eventually dried and hardened. Under conditions of increasing burial, and thus pressure and temperature, the peat was transformed into coal. From softest to hardest, the stages of coal formation after peat are lignite, subbituminous, bituminous, and anthracite. The hardest coal produces the greatest energy per unit volume. The coal mined in Illinois is bituminous.



# C*oal Mining and Coal Reserves in Illinois*

Historians date the discovery of bituminous coal in America by Europeans to a sighting in 1673 in what is now the Ottawa-Utica area of Illinois. The discovery is attributed to explorers Joliet and Marquette. Joliet's map of 1674 shows the location of *charbon de terre* (coal) (Andros 1915).

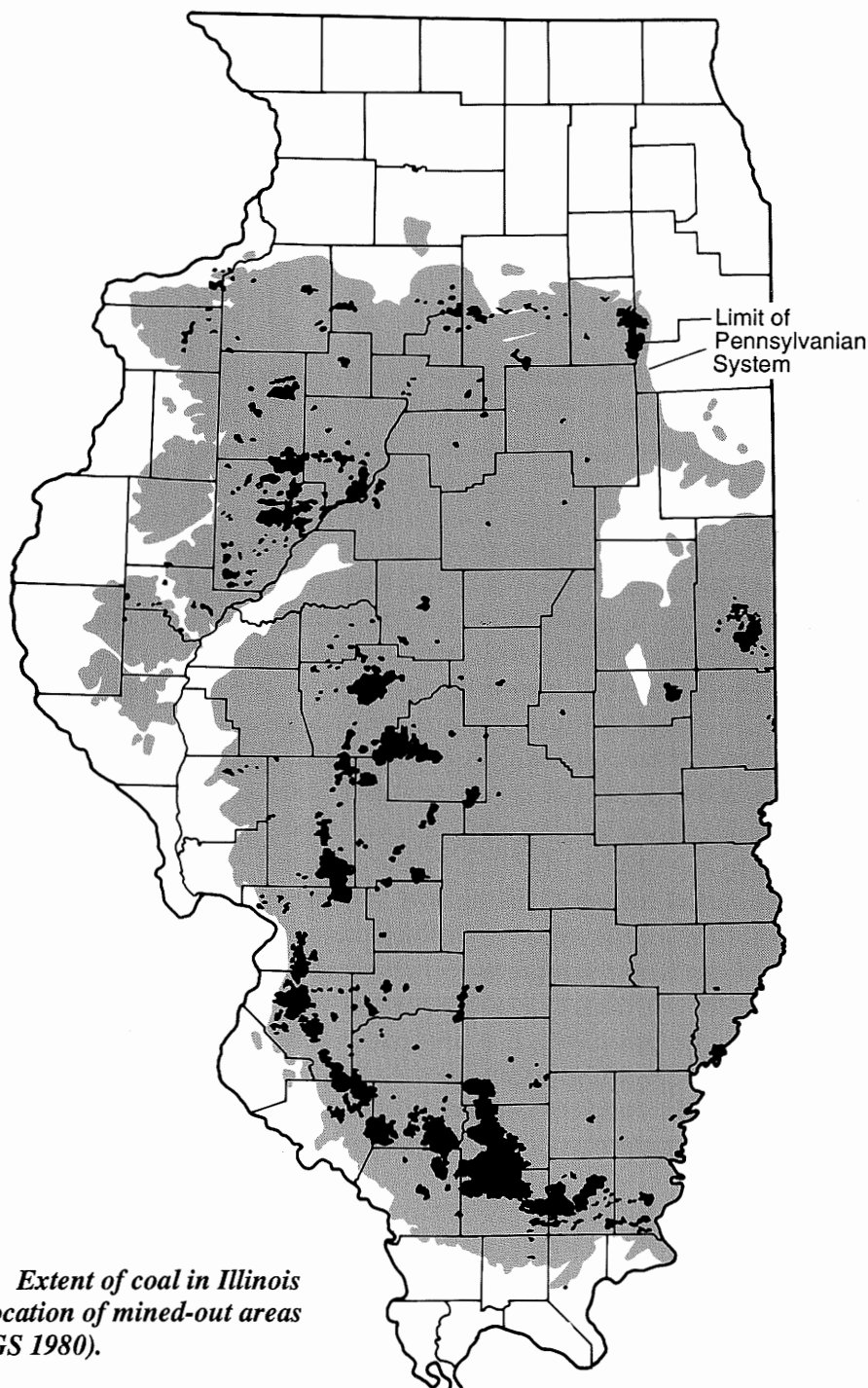
Commercial mining in Illinois is believed to have started in Jackson County about 1810, when coal barges proceeded down the Big Muddy River and Mississippi River to New Orleans. In the early 1820s, boats loaded with coal in Peoria also made their way to New Orleans. Early mines were located near rivers, where drifts or slopes were cut into seams exposed in the bluffs. Later, shaft mines were started in Belleville in the early 1840s. By 1900, coal was produced in at least 52 counties to supply industry in such towns as St. Louis and Chicago. Coal was also used to fuel local residential furnaces and stoves (ICA 1992). Towns grew up around the mines and railroads, which were also major users of coal and suppliers of much of the transportation. As a result, many urban and residential areas are built over or near old abandoned mines in Illinois. Treworgy and Hindman (1991, p.1) concluded that "approximately 178,000 acres of residential and other built-up areas in Illinois are in close proximity to underground mines and may be exposed to subsidence.... An estimated 320,000 housing units in the state are over or adjacent to underground mines."

The expansion of the rail system allowed mines to be located farther away from their markets. Today most underground mines are located in southern Illinois; a few are in the central part of the state (IDMM 1990). Transportation costs have increased because the coal must be shipped to its major markets, which are electrical power-generating plants. The mines are located where the coal is thickest, most accessible, and best in quality.

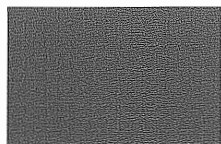
Today underground mines in Illinois operate at depths of 72 to 1,006 feet below the ground surface; the average depth is 375 feet. In 1991, underground mines produced about 73% of the annual tonnage mined in the state (ICA 1992). The other 27% was from surface mining.

## Reserves and Location

Illinois has abundant coal resources. All or parts of 86 of the 102 counties in the state have coal-bearing rocks below them. Figure 1 shows where coal is present in Illinois and the location of mined-out areas. The state ranks fifth nationwide in coal production, with an average annual total of about 60 million tons. The state is first in reserves of bituminous coal, the most widely used coal in the nation (IDMM 1990, ICA 1992).



*Figure 1 Extent of coal in Illinois and the location of mined-out areas (from ISGS 1980).*







# *U*nderground Coal Mining Methods

Underground mining methods have evolved as technology has changed, and laws have been enacted to regulate the industry. Room and pillar, high-extraction retreat, and longwall are several modern methods used to mine coal. Current methods reflect the coal companies' compliance with federal and state regulations requiring approved mine plans, improved ventilation, roof support plans, and liability for surface effects of subsidence. Coal companies in Illinois are rapidly moving toward using high-extraction mining methods to decrease costs and improve productivity, but room-and-pillar (low extraction) methods are still used in many areas. Longwall mining requires a high initial capital investment for equipment, an expense many smaller coal companies cannot afford. Figure 2 depicts the surface and underground facilities of a modern mine.

## Room and Pillar

**Mines in the early 1900s** Many mines at the turn of the century had entries varying in length, width, and direction, forming irregular mining patterns. After about 1910, mining was conducted in a room-and-pillar pattern. In the production areas or panels, workers created rooms and crosscuts at right angles to form a grid pattern. The widths of these rooms ranged from about 20 to 40 feet (Hunt 1980). Blocks of coal called pillars were left unmined to support the roof of the mine and the surface. A distinction should be made between older and modern (post-1983) room-and-pillar mines, which are designed on the basis of the strength of the local geology to prevent subsidence. In the older mines (1930s and before), 40% to 80% of the coal was extracted (Hunt 1979). Most of the subsidence problems associated with the room-and-pillar method have occurred over older mines. More information about the design of older mines is in *Mine Subsidence in Illinois: Facts for Homeowners* (Bauer et al. 1993). Subsidence from these old room-and-pillar mining operations can occur years after mining.



This illustration is a conceptual representation of a mine. It is not complete in every detail. It is intended to illustrate the general layout of a modern mine, the methods of mining used and the technology employed.

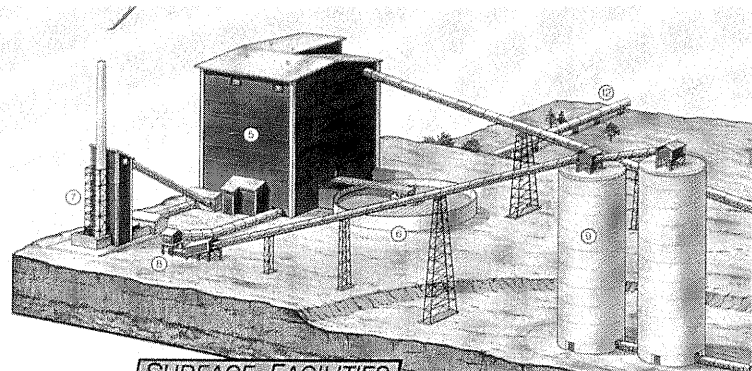
#### UNDERGROUND MINE:

- A. PORTAL FACILITIES
- B. EXHAUST FAN
- C. VENTILATION SHAFT
- D. LONGWALL MINING SECTION
- E. GOB
- F. SHEARER
- G. SHIELD
- H. CONVEYOR
- I. CONTINUOUS MINING SECTION
- J. CONTINUOUS MINER
- K. INTEGRATED ROOF BOLTERS
- L. LOADING MACHINE
- M. SHUTTLE CAR
- N. SECTION FAN
- O. SECTION CONVEYOR BELT
- P. TRACK
- Q. SLOPE BELT
- R. STOPPING
- S. OVERCAST

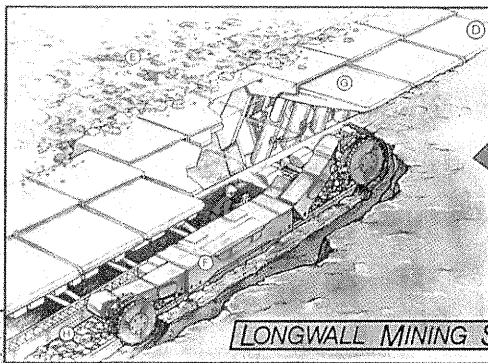
#### SURFACE FACILITIES:

- 1. TRANSFER BUILDING
- 2. RAW COAL CONVEYOR
- 3. RAW COAL SILO
- 4. BREAKER BUILDING
- 5. PREPARATION PLANT
- 6. THICKENER
- 7. THERMAL DRYER
- 8. PLANT SAMPLE BLDG
- 9. CLEAN COAL SILO
- 10. RAILROAD LOADOUT
- 11. RAILROAD
- 12. REFUSE CONVEYOR
- 13. FRESH WATER IMPOUNDMENT

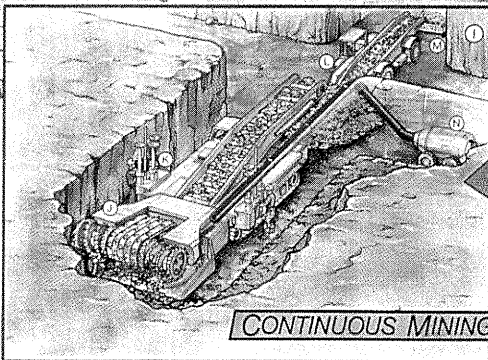
→ indicates Intake Air  
→ indicates Return Air



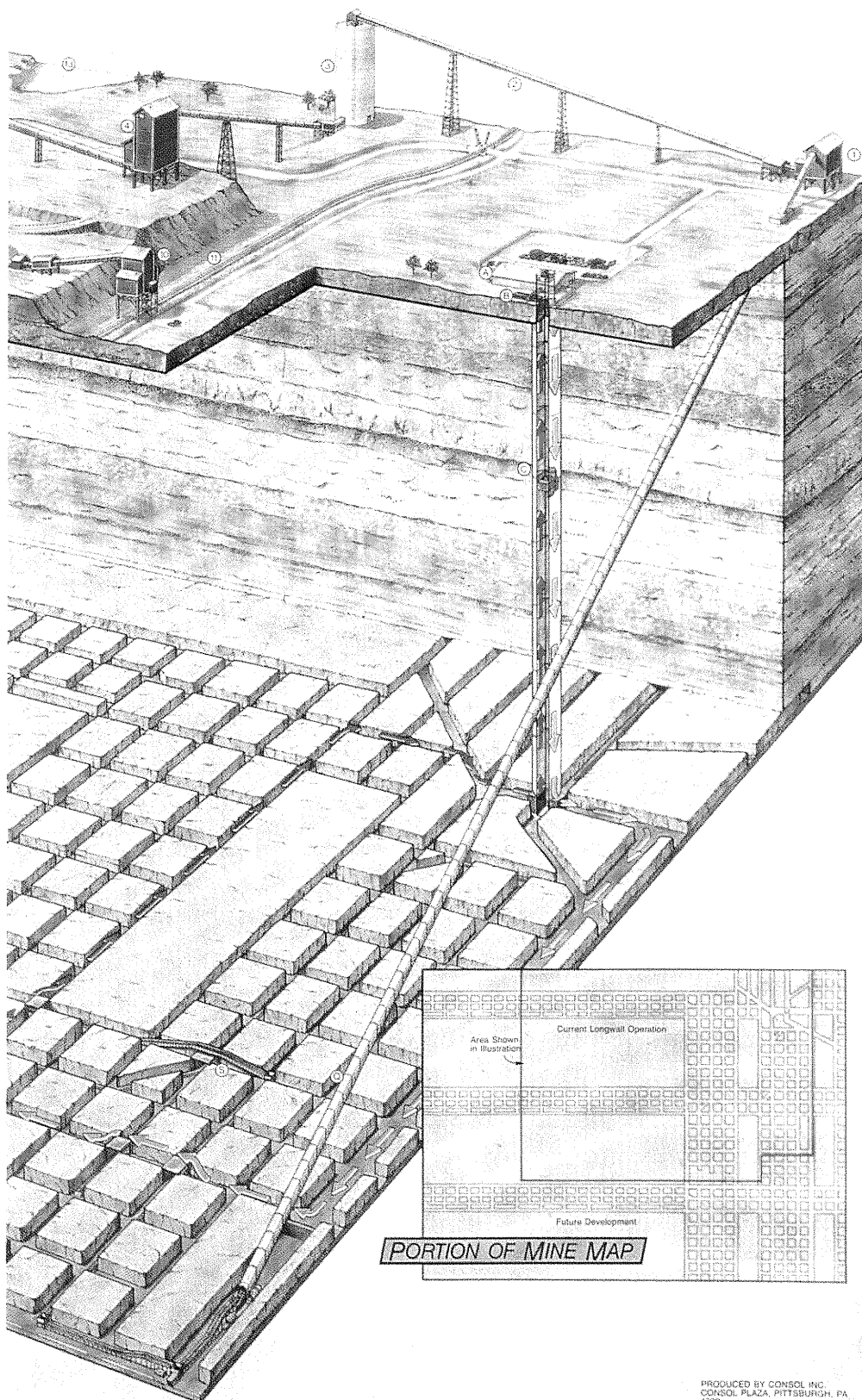
**SURFACE FACILITIES**



**LONGWALL MINING SECTION**



**CONTINUOUS MINING SECTION**



PRODUCED BY CONSOL INC.  
CONSOL PLACA, PITTSBURGH, PA.  
1992

**Figure 2** Sketch of a modern mine (used by permission from Consol, Inc.).

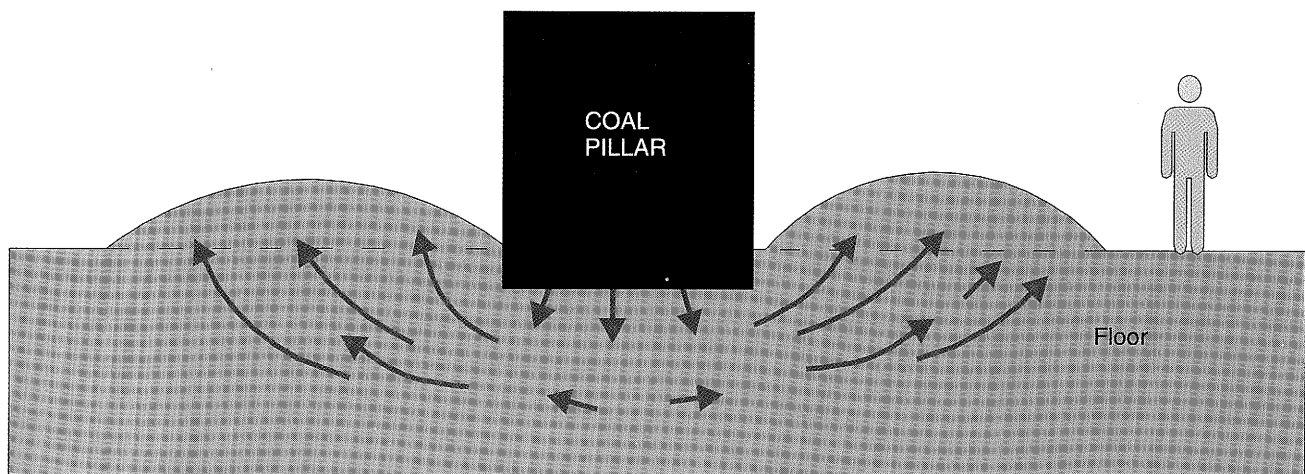
**Modern mines** In modern room-and-pillar mines, production areas are still called panels. Figure 2 shows the checkerboard pattern of a room-and-pillar area. The structure of a modern room-and-pillar mine is designed to leave enough coal unmined in pillars to support the overburden and prevent subsidence. Instead of irregular patterns, modern mines consist of a regular configuration of production areas, entryways, and ventilation areas. Modern rooms and entries are considerably narrower than those in older mines. The widths of rooms and entries in modern mines range from 18 to 24 feet (Hunt 1980).

The machine used to cut the coal is called a continuous miner. The workers install roof bolts (steel anchors) in the roof of the mine to support it as the continuous miner advances. The unmined areas between the panels and between the entries and the panels are called barrier pillars. Modern room-and-pillar mining generally recovers less than 50% to 60% of the coal.

**Subsidence and room-and-pillar mines** Subsidence is possible wherever coal has been removed in a room-and-pillar mine. The roof, pillars, and floor are the components that surround the openings in a room-and-pillar mine. The capacity of these components to keep an entry open and maintain a stable working area (and thus prevent subsidence) is based on their geologic characteristics.

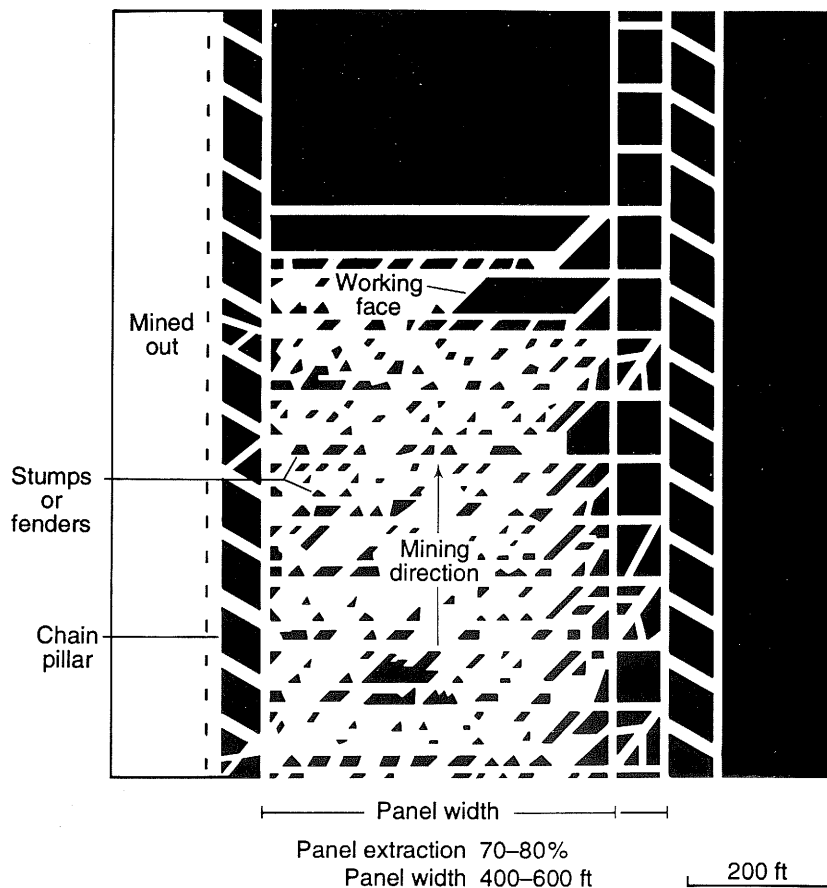
Floor failure is the most common cause of subsidence in today's room-and-pillar mines. The claystone usually found underneath coal seams in Illinois is weaker than the coal or the roof rock, a condition that makes the floor the most unstable component in the mine (Hunt 1980). When the floor of the mine fails, the weak claystone beneath a pillar is squeezed out from underneath, like toothpaste, into the mine opening, and allows the pillar to be lowered into the floor (fig. 3). Roof falls are fairly common and threaten worker safety. Roof falls are not considered a cause of subsidence, however, except when the mine is located at a very shallow depth (less than 200–300 ft), and the bedrock between the mine level and the ground surface is thin and contains no competent layer such as limestone. In this instance, holes or pits may form on the ground surface. Pillar failures are rare in modern mines.

*Figure 3 Failure of a mine floor is shown by this diagram.*



## High-Extraction Retreat

In certain mines, part of the coal is removed from the pillars in specific areas after the rooms are mined. This method, called pillar extraction, punching pillars, pulling pillars, or pillar robbing, is the basis for high-extraction retreat mining. In this system, the panel and entries are created and mining occurs in a retreating fashion from the outer edges toward main entries. Most coal pillars, which support the roof, are removed shortly after a few rows of rooms and pillars are formed. More coal is recovered by high-extraction retreat (up to 80–90% in a panel) than by room-and-pillar mining. Only small pillar stumps or fenders are left. The size and number of pillars that must be left to maintain worker safety varies with underground geologic conditions (Hunt 1980). The roof collapses in a manner that is controlled by temporary supports, and planned subsidence is initiated immediately. Sometimes pillars are left unmined in a certain area to control surface subsidence and protect a structure. Figure 4 shows a high-extraction retreat panel.



**Figure 4** Diagram of a high-extraction retreat panel. Small stumps of pillars are left for safety, and chain pillars may be mined to increase panel width (after Hunt 1980).



## Longwall

In the United States, mining companies began using the mechanized longwall method in the 1960s, although it was developed and used much earlier in England and Europe. A completely different type of equipment is used in longwall mining than is used in room-and-pillar or high-extraction retreat mining. In longwall mining, coal is removed by a rotating cutting drum or shearer that works along the coal face, cutting off coal as thick as the coal seam (5–9 ft) and as wide as 30 to 39 inches. The coal falls onto a conveyer and is transported out of the mine (fig. 5).

As the coal is mined, a series of steel shields supports the mine roof and protects the shearer, conveyer, and most importantly, workers. The shields advance as the shearer cuts coal from the longwall face. The mine roof material then collapses behind the shields, and the shearer and shields retreat toward the main entries. Planned subsidence happens shortly after mining. A safe work environment for the miners is maintained because they are always shielded by steel supports (ICA 1992).

Some room-and-pillar areas, including entryways, are required in longwall mining. Entryways are driven around the perimeter of longwall panels to allow access for workers, ventilation, and mining equipment. Like high-extraction retreat, longwall mining begins at the outer edges and works toward entries or retreats. In the longwall system, all the coal is removed from a panel, but a few rows of pillars (called chain pillars) are left between panels. In Illinois, longwall panels may be 600 to 900 feet wide, up to several miles long, and 350 to 800 feet below the ground surface. Figures 2 and 5 show examples of longwall production areas.

*Figure 5 Longwall mining equipment showing hydraulic shield supports on the left and cutting drum on the right.*



## Federal and State Regulations

Many laws govern the mining industry, but coal mine subsidence was not regulated until a federal act was passed in 1977. State laws also regulate subsidence from underground coal mining operations. These laws and their associated rules and regulations have become increasingly stringent.

**Federal law** Public Law 95-87, the 1977 Surface Mining Control and Reclamation Act (SMCRA), governs surface and underground mines. SMCRA established national standards for land reclamation. Under SMCRA, each state was required to develop its own rules to fulfill the federal act. The federal Office of Surface Mining (OSM) oversees each state's mine permitting and reclamation program. The law requires mine operators to adopt measures consistent with known technology to (1) prevent subsidence from causing material damage to the extent technologically and economically feasible, (2) maximize mine stability, and (3) maintain the value and reasonably foreseeable use of such surface lands, except in those instances where the mining technology used requires planned subsidence in a predictable and controlled manner (ISGS 1980). Planned and controlled subsidence methods are available to operators under SMCRA and state law.

**State law** Illinois' current regulation concerning subsidence from underground mines went into effect February 1, 1983, with implementation of the state's permanent rules to fulfill the federal SMCRA (Ehret 1986). Active mines in Illinois must submit a mine subsidence control plan. This plan is part of the mine operator's application for a permit, which must be reviewed and approved by the Illinois Department of Mines and Minerals (IDMM) before mining can begin. The plan includes mine maps, geologic information, details on planned subsidence, a survey of surface structures and features, and plans for monitoring subsidence. A subsidence control plan is required regardless of whether the mine operators will use planned subsidence methods (longwall or high-extraction retreat) or mining methods designed to prevent subsidence (room and pillar).

Landowners and residents in areas that could be affected by proposed underground mining must be notified by mail at least 6 months before mining begins. If active mining that began on or after February 1, 1983, is found to have caused damage to surface structures, the mine operator must repair or replace the structures, or compensate the owner. Damage to land and drainage must also be fully repaired. For example, cracks in the ground surface must be filled, and ditching or filling could be used, if necessary, to restore proper surface drainage. Intermediate measures, such as relocating utilities and moving homes up off their foundations, may be used to prevent structural damage during subsidence. Final repairs to land and structures are performed only after the area is completely mined and the land surface is relatively stable. This precaution ensures that repairs will not have to be repeated (IDMM 1985).

In addition to complying with subsidence and reclamation regulations, mine operators must comply with local, state, and federal laws concerning worker safety, clean air and water, historic preservation, and many others. Mining regulations can be expected to evolve continually as more information becomes available through research on mine design and subsidence monitoring.

# Subsidence

## History of Subsidence Research

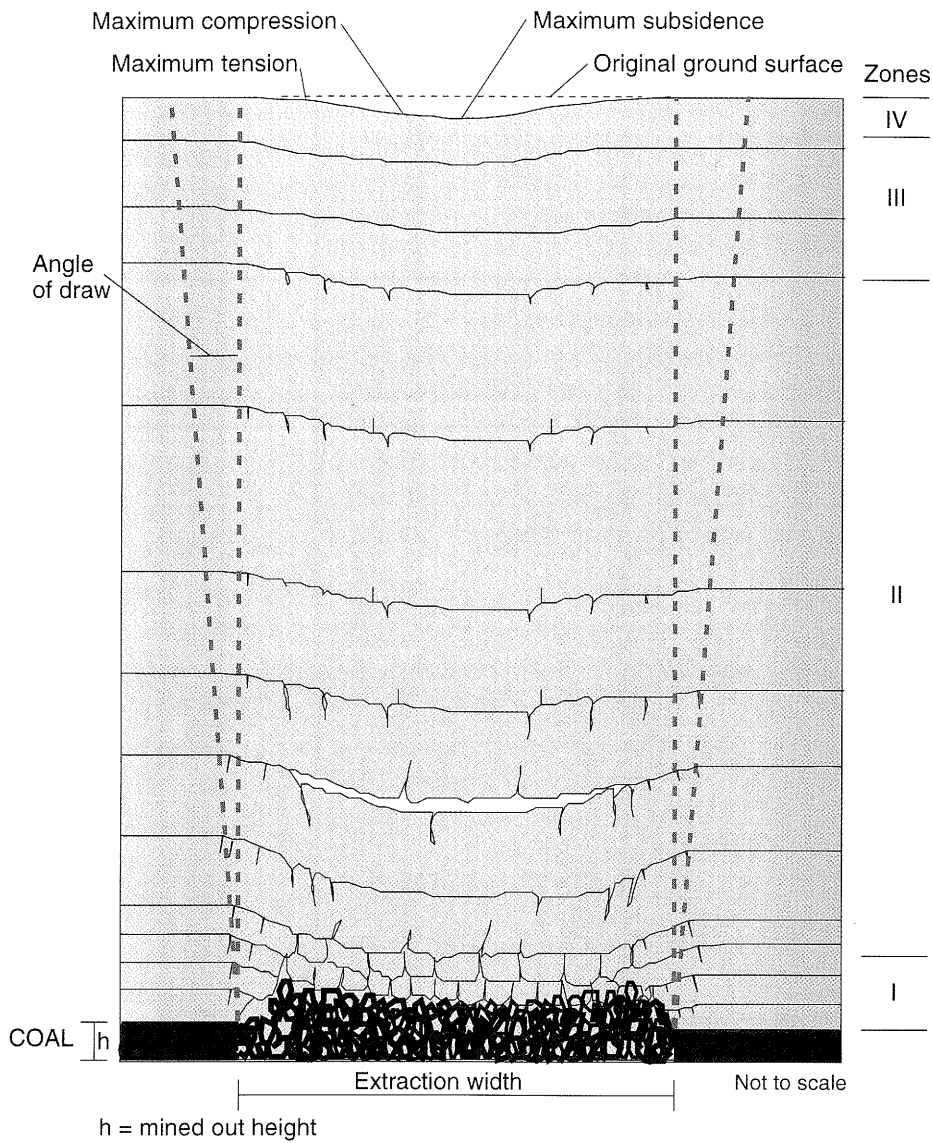
Subsidence research related to coal mining has been conducted for many years in Europe, the United Kingdom, China, South Africa, Australia, and the United States. In the 1820s, Belgian engineers started a systematic study of mine subsidence because of surface damage to structures (New South Wales Coal Association 1989). Until the early 1900s, most studies were conducted in Europe and the United Kingdom, where subsidence research continues to the present. *The Subsidence Engineer's Handbook*, a landmark publication produced in the United Kingdom in 1965, became the basis for geotechnical studies in the United States (Yarbrough 1983).

Early researchers in the United States first studied mine subsidence and its effects on the surface and structures in Illinois and Pennsylvania. The Illinois State Geological Survey (ISGS) has documented coal mine subsidence since 1908. The first studies began when an investigation of the state's coal resources and mining practices was authorized by the 47th Illinois General Assembly. This resulted in cooperative research by the ISGS, the University of Illinois, and the U.S. Bureau of Mines. Subsequently, publications on coal mine subsidence were produced from 1916 to 1938. Several modern ISGS studies were developed in the mid-1970s because of renewed interest in environmental issues. Hunt's thesis (1980) presented a comprehensive review of subsidence in Illinois and documented many case histories.

## Mechanics of Subsidence

The amount, effects, and timing of subsidence differ depending on the mining technique. The average maximum subsidence over a high-extraction retreat operation is about 4 feet or about 50% to 60% of the mined-out height underground. Over a long-wall mine, maximum subsidence averages about 4 to 6 feet or about 60% to 70% of the mined-out height underground (fig. 6). The amount of subsidence is never as much as the mining height. Subsidence occurs within days to several weeks after an





- Zone I Caved zone thickness,  $2h$  to  $8h$
- Zone II Fractured zone thickness,  $28h$  to  $42h$
- Zone III Continuous deformation zone
- Zone IV Near surface

**Figure 6** Maximum vertical subsidence is shown by this schematic diagram (modified from Peng and Chiang 1984 and New South Wales Coal Association 1989).

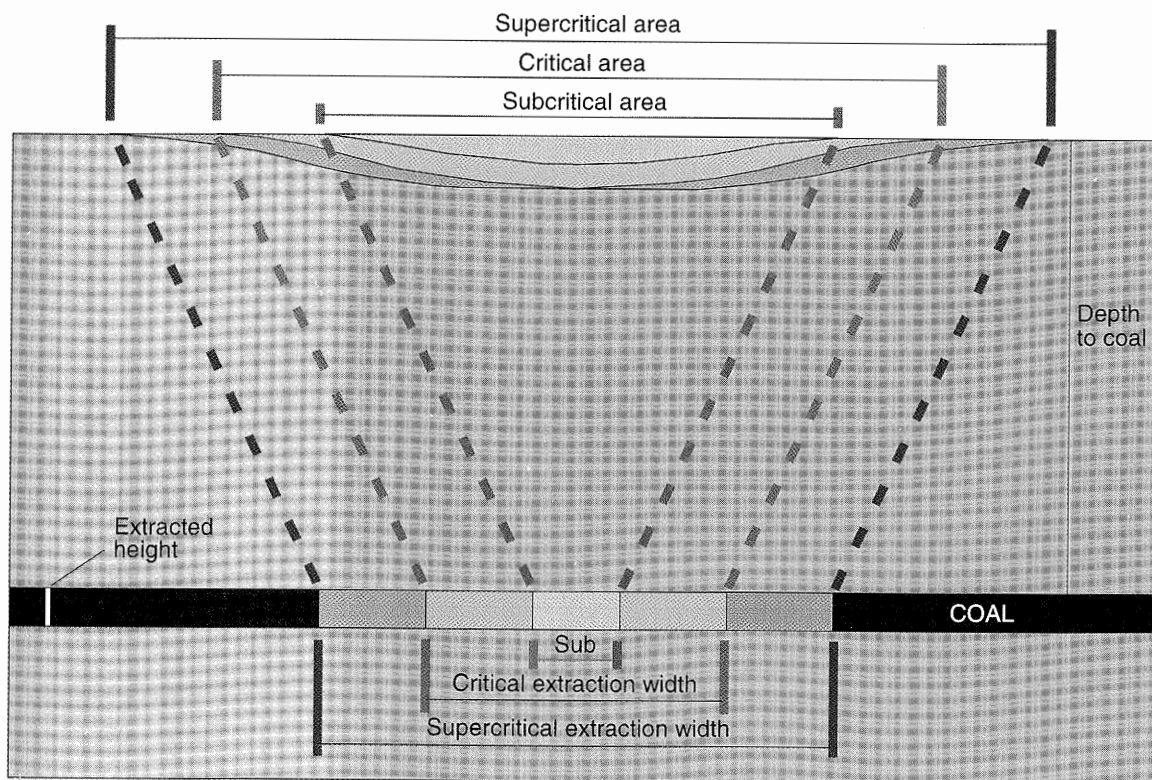
area is undermined by the longwall or high-extraction retreat methods, depending on the actual rate of mining.

On the surface, cracks are usually caused by tension (pulling apart) near the edges of the mining area during subsidence. These cracks usually close naturally, whereas some along the sides of the panel may need to be filled. Areas inward from the tensile cracks (closer to the center of the panel) are compressed (pushed together), causing the soil to buckle upward. The surface effects of subsidence depend on the original slope of the land before mining. The subsidence may or may not be visible if the land is hilly because the slope changes caused by subsidence are slight.

The effects of subsidence from longwall mining are uniform and anticipated. The surface over the center of the panel drops approximately 4 to 6 feet. The decline tapers off toward the edges of the panel and forms a gentle trough. Less subsidence occurs over the entryways and chain pillars between panels; maximum subsidence occurs over the center of the mined-out panel. The areas of surface subsidence beyond the edges of the panel are defined by a point where zero subsidence occurs. This area is defined by an angle called the angle of draw, which varies according to differences in local geology, seam depth, and the width of the panel. The distance out from the panel edge to zero subsidence may be 0.35 to 0.45 times the depth to the mine.

High-extraction retreat mining produces similar surface effects except that, depending on the topography, high-extraction retreat panels may be less clearly demarcated on the surface than longwall panels (Darmody et al. 1988). Depending on the amount of pillar extraction, the final subsidence profile for high-extraction retreat mining is less regular and predictable than the profile for longwall mining. The irregular effects of high-extraction retreat mining may indicate uneven stump pillar sizes, which can collapse at various times after mining (Peng 1992).

Longwall mining creates a large opening in the coal seam, an occurrence that changes the equilibrium of nearby rock materials. Peng (1992) divided the overburden between the mine and the surface into four zones (fig. 6).



**Figure 7** The development of subsidence is affected by the width of the extraction area (after New South Wales Coal Association 1989).

- **Caved zone** is the area where roof materials bend and break irregularly and fall into the newly created opening after the coal is mined.
- **Fractured zone** over the caved zone is formed by rocks that bend and break.
- **Continuous (deformation) bending zone** is the area where overburden rocks bend downward without breaking. It is above the fractured zone.
- **Near surface or soil zone** consists of soil and rocks, depending on local geologic conditions.

The size of each zone is related to the strength properties of the rocks that make up the overburden. The bending of rocks moves upward from the mine to the surface and forms the subsidence trough. The overburden rocks then settle and compact until they stabilize.

The width of the panel generally determines the shape of the final subsided area (fig. 7).

- **Subcritical panel** is narrow. It causes less than maximum possible subsidence.
- **Critical panel** is slightly wider. Only its center point reaches the maximum possible subsidence. The critical width of a panel is generally considered to be at least 1.5 times the depth to the coal seam, if maximum subsidence is to occur at a point at the center of the panel.
- **Supercritical panel** is wider than the critical width. It causes a flat area of maximum subsidence in the center of the surface trough. Although the lateral area of maximum subsidence increases, the angle of draw does not increase.

## Subsidence Movements

Longwall and high-extraction retreat mining cause vertical and horizontal surface movements. The ground drops vertically and moves horizontally toward the center of the trough (Bauer et al. 1993). These movements may affect structures or other surface features.

**Vertical subsidence** Structures such as railroads, canals, and sewers, which must retain a certain elevation, are most affected by vertical subsidence (Peng 1992). Water may pond in flat areas that have subsided vertically; hilly areas are less affected.

**Tilt** A difference in the amount of vertical movement between two points is called tilt. Tilt may also affect surface structures that depend on gravity, including gutters, drains, and water treatment plants (New South Wales Coal Association 1989).

**Strain** Horizontal strain is a change in the length between two surface points. If the length between the points increases, a tensile strain is produced. If the length decreases, a compressive strain develops. Horizontal strain is a major factor in surface structural damage, especially tensile strain (Peng 1992). Some building materials are more susceptible than others to horizontal strain. Steel is tolerant of tensile strain; masonry is not. Rocks and masonry are more tolerant of compressive strain than wood. Buildings and foundations can be designed, however, to withstand strain.

## Subsidence Related to Time and Advance of Coal Face

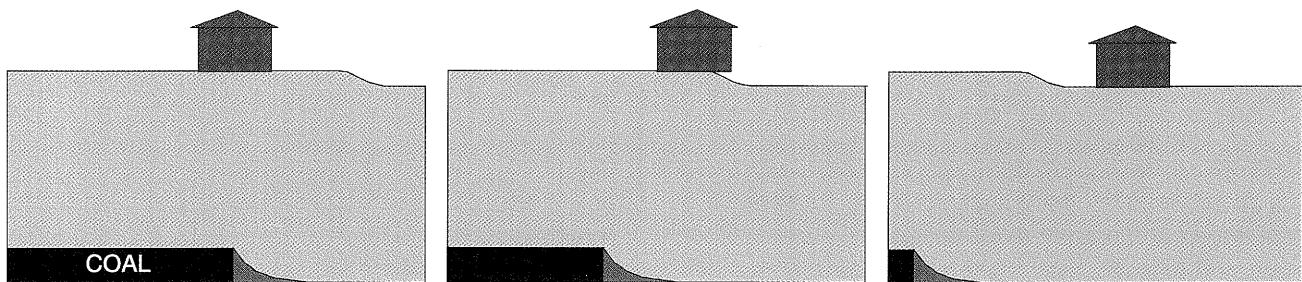
Surface subsidence occurs more quickly when the shearer advances rapidly along the coal face than when the shearer advances more slowly. Thus, the development of subsidence can be indicated by an increase in ground displacement through time, or by the nearness (horizontally) of the coal face to a point on the surface.

For any surface point, extremely small subsidence movements begin before the coal face is directly under the surface point (fig. 8). The depth from the surface to the coal seam controls when these movements begin. Peng (1992) found that subsidence affected a point when the horizontal distance between the coal face and surface point equaled the distance between the surface point and coal seam. The largest amount of movement occurs after the longwall face has undermined and passed a surface point.

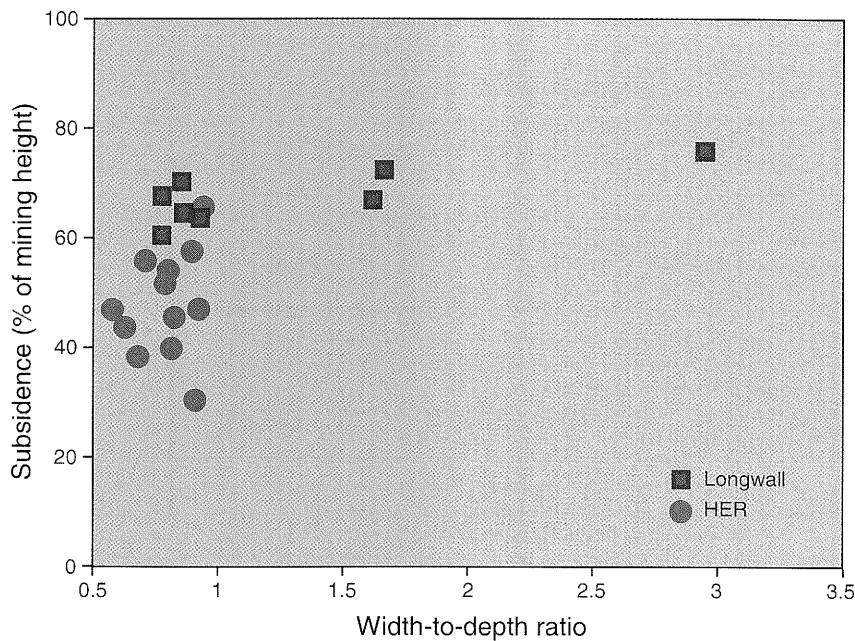
At one site, researchers in Illinois showed that subsidence movements continued for years after an area had been undermined by longwalls; this is called residual subsidence (Mehnert et al. 1992). These movements were measured 6 months to 3 years after mining and amounted to 5% (about 0.3 ft) of the mined-out height. Residual subsidence seemed to be fairly uniform over the panel and the pillars between panels. Residual subsidence caused no differential subsidence and no strains over the sides of the panel, two effects that would damage structures. This occurrence is similar throughout many areas of the world where residual subsidence may last 6 months to 7 years, depending on the strength of the strata above the coal seam (Whittaker and Reddish 1989, Orchard and Allen 1975, and Fejes 1985).

## Subsidence Monitoring

Planned subsidence over active mines is monitored by researchers and mining companies. Various methods and equipment are used to document vertical and horizontal movements associated with subsidence. Surveying is used to measure movements on the surface. Several types of instrumentation placed in the ground measure vertical and horizontal movements beneath the surface and monitor fracturing and other changes (or their absence), such as groundwater levels and chemistry, during subsidence. With any type of instrumentation, a set of baseline data is generally collected well before subsidence begins. Measurements are taken most frequently during the event, and follow-up monitoring continues to detect residual movements. Monitoring may be required as part of a company's legal permit to mine. More importantly, data



**Figure 8** Position of advancing longwall face in relation to where major surface movements occur behind the mining operation (after New South Wales Coal Association 1989).



**Figure 9** *Percentage of subsidence versus width-to-depth ratio for longwall and high-extraction retreat (HER) mines in Illinois (ISGS data).*

collected during monitoring help the mining company to design mitigation for the land and plan better for effects on surface structures.

Figure 9 depicts measured percentage of subsidence versus the width-to-depth ratio for several Illinois mines. (Percentage of subsidence is the ratio of surface subsidence to the height of the mined-out coal.) Panel width, mining depth, and extraction method influence the magnitude of subsidence. Regional geology also plays a part because the strength properties of the overburden can influence the amount of surface subsidence.

Scientists can compare subsidence monitoring data to known geologic conditions to predict (or model) the amount and extent of subsidence that might result from various mining methods. Models may be based on data collected in the laboratory, field, or both. Models may be derived from mathematical formulas based on collected data (Triplett and Yurchak 1990) or from physical replicas of geologic and mining features. Physical replicas can be made of sand, blocks, wax, modeling clay, or wood (Triplett and Drescher 1988).

## Planned Subsidence Regulated by Law

Protection from the negative effects of planned subsidence is mandated by law. Mining companies operate under regulations and must have previously obtained permission and negotiated the right to subside any property. Homeowners should check their deed and seek legal advice to be sure of their situation, which may vary according to deed, mining company, or location. Most coal companies negotiate an agreement with the homeowner to protect surface structures during undermining. Figure 10 shows two photos of a home raised from the foundation and kept level while it was being undermined, and two photos of the home replaced on a new foundation after mining was completed. People lived in the house during this time. Figure 11 shows an unoccupied wood frame house, located on the centerline of a longwall panel, subsided 4.5 feet. The white line painted on the house represents the level of the original ground surface.



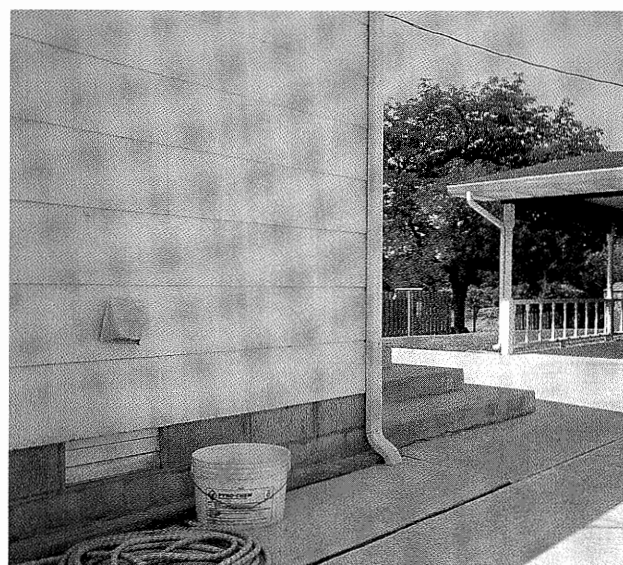


## Mine Subsidence Insurance

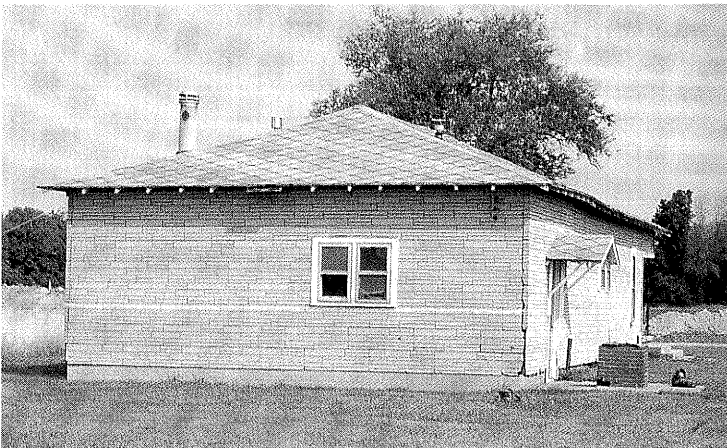
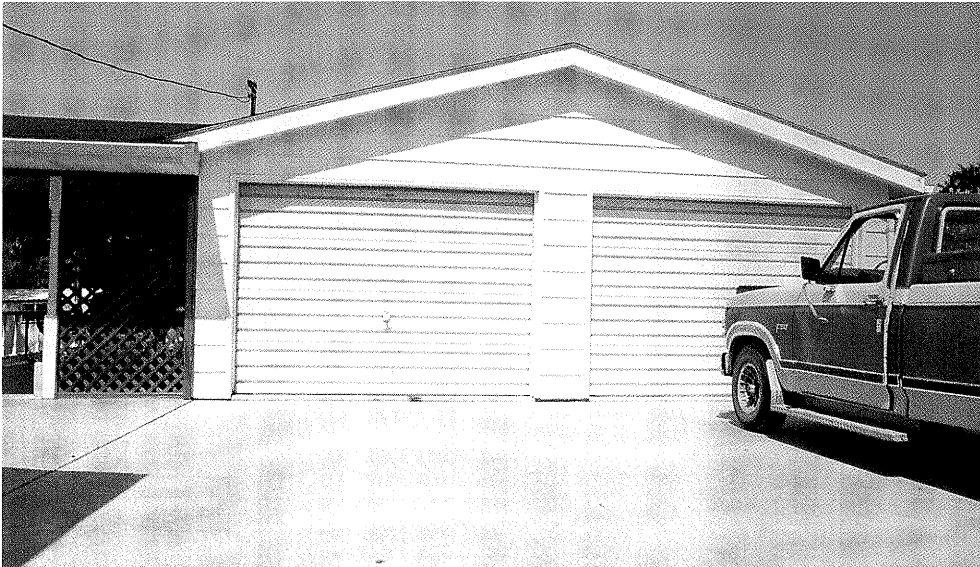
In 1979, the Mine Subsidence Insurance Act created subsidence insurance for Illinois as part of a homeowner's policy. Homeowners in any of the Illinois counties that are approximately 1% or more undermined automatically have mine subsidence insurance as a part of their policy, unless coverage is waived in writing by the homeowner. This insurance is a built-in safeguard for the property owner. Mine subsidence insurance is especially important for homes located near mines that began operation before the 1977 Surface Mine Control and Reclamation Act. The companies that operated these mines may no longer be in business. Homeowners should contact their local insurance agent or the Illinois Mine Subsidence Insurance Fund (IMSIF) for more specific information on mine subsidence insurance. Nearly 5,000 claims were filed during the past 10 years. Murphy et al. (1986) state that only 16% of claims to IMSIF through 1985 were attributed to damage caused by coal mine subsidence.

## Information Sources


Information on current or previous mine workings is available from the Illinois Department of Mines and Minerals in Springfield and the Illinois State Geological Survey in Champaign. Uncertainty and undue fears can be dispelled by obtaining adequate information. Owners should seek advice as soon as possible after damage to a building is suspected. Agencies to contact for additional information are listed at the end of this booklet.



*Figure 10 Coal companies take measures to protect homes in advance of subsidence. (top left and right) Homes are raised from the foundations and kept level during subsidence. (bottom) Foundations are restored and structures are lowered onto them after ground movements cease.*



*Figure 11 This house, above the centerline of a longwall panel, subsided 4.5 feet. The white line represents the level of the original ground surface.*



# *Illinois Mine Subsidence Research Program*

Coal, water, and farmland are valuable natural resources. Concerns about the effects of subsidence on these resources prompted research. The Illinois Mine Subsidence Research Program (IMSRP) was established in 1985 to develop guidelines for underground mining methods to maximize coal extraction while preserving the agricultural productivity of farmland. Specific research on Illinois' geologic conditions was necessary, even though modern subsidence information has been collected in Europe, the United Kingdom, and the eastern United States. Differences in geologic settings among these areas result in different subsidence effects. Mining depth and overburden conditions vary greatly among Europe, England, Appalachia, and the Illinois Basin. By collecting data in Illinois, including new and critical data about aquifers and crops, IMSRP researchers acquired a base of fundamental knowledge about the Illinois Basin. With this information, researchers will be better able to develop the basis for sound solutions to social and environmental issues facing the coal and agriculture industries.

The research program was initiated at the request of the Illinois Coal Association (ICA) and the Illinois Farm Bureau (IFB). It was directed by the Illinois State Geological Survey (ISGS), a division of the Department of Energy and Natural Resources. Projects funded under the IMSRP were studies of the subsidence process from the ground surface down through the floor of the mine. Participants in the research projects included the ISGS, Northern Illinois University, Southern Illinois University at Carbondale, the University of Illinois at Urbana-Champaign, and the Twin Cities Research Center of the U.S. Bureau of Mines.

## **Effects of Planned Subsidence**

**Farmland** The first priority of the IMSRP was to assess the impact on farmland of subsidence caused by high-extraction mining. Several agricultural studies were initiated. In 1985, aerial surveys and field sampling were used to assess the relative impacts of longwall and high-extraction retreat mining on corn yields. For 3 years, corn



yields in subsided areas were statistically compared with yields from unmined areas under the same farm management. Aerial photos were used to locate and classify subsided areas (fig. 13). Results showed that yields varied yearly because of weather, mining activity, and farm management. The study indicated, however, that the overall



**Figure 12** *Aerial photos were used to locate subsided areas (indicated by circles) for study of the effects of nonmitigated subsidence on corn yields.*

impact of subsidence on crop yield is slight. The average reduction for corn yields on mostly unmitigated land was approximately 5% over longwall mines and 2% over high-extraction retreat mines (Darmody et al. 1988).

**Mitigation** Another IMSRP agricultural study investigated the effectiveness of efforts by the coal companies to mitigate subsided land. This study was designed to determine the impact of current subsidence mitigation practices on crop production. Soil scientists compared corn and soybean yields from mitigated farmland with yields from comparable nonsubsided areas. Subsided areas that had problems, such as ponding, are not extensive (1–2 acres per mine panel). In addition, soil fertility and

other characteristics were tested and compared. Results were influenced by unusually dry weather in 1988 and unusually wet weather in 1990. Corn plants in mitigated soils were generally more sensitive to wet weather than soybean plants in mitigated soils. A 4-year study determined no significant differences in average soybean yields on mitigated soils, whereas corn yields per acre averaged 21 bushels (or 19%) less. Mitigation, however, significantly improves corn yields in subsided areas. Yield reductions of 42% to 95% were reported in other IMSRP studies for unmitigated subsided areas (the 1–2 acre problem areas) (Darmody et al. 1988). Results were very site-specific and some sites had no significant yield differences. Increased soil wetness can be an asset in dry years, such as 1988, when corn yields were slightly higher in mitigated areas.

This study showed that all types of mitigation (ditch, fill, or both) can be successful. Rainfall amounts and other site-specific factors must be added into calculations of yield response at any site regardless of mitigation methods used. A set of practices that will improve mitigation success was identified. These include avoiding soil compaction, minimizing number of trips over the field with tractors and other farm equipment, using deep tillage, improving drainage, and adding sufficient fill to low areas (Hetzler and Darmody 1992).

**Soils** Agronomists from the University of Illinois are evaluating the effects of planned subsidence on agricultural soils. Soils above active longwall panels were described and analyzed before and after subsidence. Researchers monitored the ways water moves through soils before and after subsidence. Some soil types respond to subsidence and subsequent ponding differently from others, and some soils may require different management practices after subsidence. Seasonal patterns of rainfall distribution, including how precipitation affects the timing and duration of ponding, were also investigated. In a field study, water movements were traced in soils using dye before and after subsidence, and subsidence cracks at the edge of the mine panel were recognizable up to 8 months after subsidence. The center of the mine panel had no visible postsubsidence cracks (Seils et al. 1992). Information from the soils studies on how water moves through soils, as well as on the effects of subsidence on groundwater contamination, is being used to improve mitigation techniques and to better plan and manage mitigated areas.

**Overburden and groundwater** Another priority of the IMSRP was to document the impact of planned subsidence mining techniques on the overburden (all the earth materials overlying the mine). ISGS scientists are monitoring the hydrology and the amount and location of fracturing in bedrock over several active mining areas. A high-extraction retreat panel and several longwall panels were studied; this is the first time that some of this information was collected in Illinois. Various types of instruments are used, including automatic recorders to measure water levels in test wells. Other equipment is used to document vertical and horizontal movements and possible fracturing in the overburden. Geologic information from drill holes is then correlated with data collected from instruments and analyzed before and after subsidence. At one site, a grid of monuments and other instruments was used to document three-dimensional surface movements during active subsidence; the instrumentation was arranged to simulate the dimensions of a residential foundation (Van Roosendaal et al. 1992).

The IMSRP was also concerned with the effect that subsidence may have on water resources. Geologists from Northern Illinois University and the ISGS are monitoring water levels in deep and shallow test wells before, during, and after subsidence. Water levels are checked continuously by electronic recorders. Water chemistry and quality are evaluated. Preliminary results over several deep longwall panels show that rural wells in glacial materials (sand, clay, and silt) were unaffected by subsidence. Water levels in test wells in bedrock were temporarily lower, but most recovered several months after mining (Booth 1992).

Overburden, groundwater, and soils studies are conducted concurrently at the same active mining locations. This practice allows researchers to compare and correlate information from the mine level to the ground surface. For example, information collected about fracturing in the overburden after subsidence helps to explain groundwater fluctuations. Scientists speculate that the water yield of bedrock aquifers may be enhanced by longwall subsidence; however, this enhancement also depends on site-specific geologic factors that control the occurrence of groundwater. At the study sites, subsidence-induced fracturing improved the way water flowed through bedrock. The storage capacity of the bedrock aquifer was also enhanced.

**Mine design** Researchers study the strength characteristics of the mine floor and pillars. Mine stability problems associated with weak floor conditions were addressed by on-site strength testing by researchers at Southern Illinois University at Carbondale (SIUC). Researchers also monitored elevation changes of the ground surface over floor-squeeze areas of a room-and-pillar mine. Results of these investigations will be applicable to all types of mines. Analysis of these data is leading to the design of models that predict movements of the mine floor and pillars on the basis of the properties of materials.

Researchers are also assessing the effectiveness of present mine designs. Understanding the current practices and problems found in Illinois underground mines is basic to creating a workable predictive model. Geologists and engineers from ISGS and SIUC surveyed several mines to identify geologic, mining, and operating conditions and procedures for design of stable partial-extraction and high-extraction mines. Interviews were conducted with mine company staff, and observations were made underground. This information was then compared with maps and other data provided by the mine operators. Recommendations drawn from the IMSRP's rock characterization studies of mine floors and pillars and investigations of mine designs will allow development of environmentally sound, yet more productive mines.

**Structures** Research is being conducted on the effects of planned subsidence on foundations and structures of homes and buildings as the subsidence occurs. Several projects have been implemented, including one to test foundations undermined by high-extraction retreat and longwall panels (Awasthi et al. 1991, Bennett et al. 1992). Different types of building materials and methods are tested for their reaction during subsidence. Participants in these studies include the Twin Cities Research Center of the U.S. Bureau of Mines, the University of Tennessee Department of Civil Engineering, the Illinois State Geological Survey, the Illinois Mine Subsidence Insurance Fund, and coal companies. Data from the test foundations will be used to refine computer models. These models may help engineers develop techniques to reduce or eliminate structural damage caused by subsidence.

# **A** *dvantages of Planned Subsidence*

The main advantages of planned subsidence are immediacy, predictability, and more efficient use of the coal resource. The longwall system allows high extraction, even at great depth. Companies can efficiently produce more coal from a given area.

## **Immediate and Predictable**

Planned subsidence occurs immediately after mining in a predictable, manageable way. Subsidence due to older partial-extraction methods often occurred years or decades after companies went out of business. It was unplanned and unpredictable. Coal companies are required to repair effects of planned subsidence. Another advantage of planned subsidence is that a smaller surface acreage is affected per ton of coal extracted because higher extraction rates remove more coal per area.

## **Improved Mine Productivity**

An ISGS study concluded that Illinois coal producers needed to reduce the delivered cost of coal to customers to stay competitive in the market (Bhagwat 1987). Illinois coal was losing markets throughout the United States because of its high delivered price and sulfur content, which is higher than that of coals from other parts of the nation. Increased mine productivity was shown to be the best way to lower the price. In longwall mining, the use of workers and machinery can be improved by reducing unproductive activities, such as moving equipment (shuttle cars, bolters, and continuous miners), roof bolting in production areas, and maintenance associated with room-and-pillar mining. Productivity can be increased while a safe working environment is maintained. Longwall mining concentrates equipment and workers to increase mine productivity, in turn achieving better economic results for the coal companies, and thus keeping them in business. The trend toward longwall mining in the United States and other countries is the case for the Illinois coal industry today. Higher extraction rates also make better use of coal found in low-sulfur deposits; a greater percentage can then be extracted instead of abandoning one-half or more of a valuable resource.

# amage and Repair

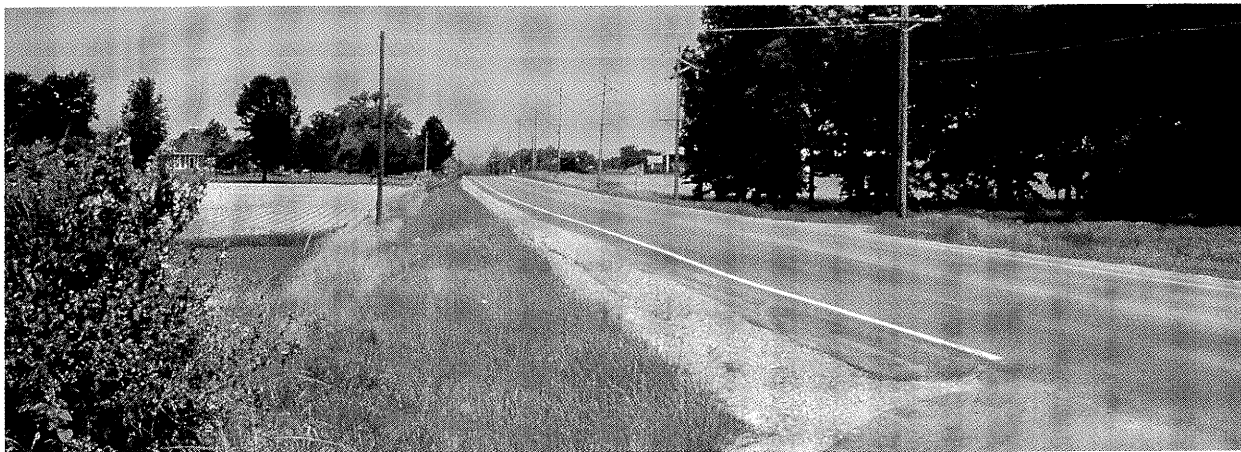
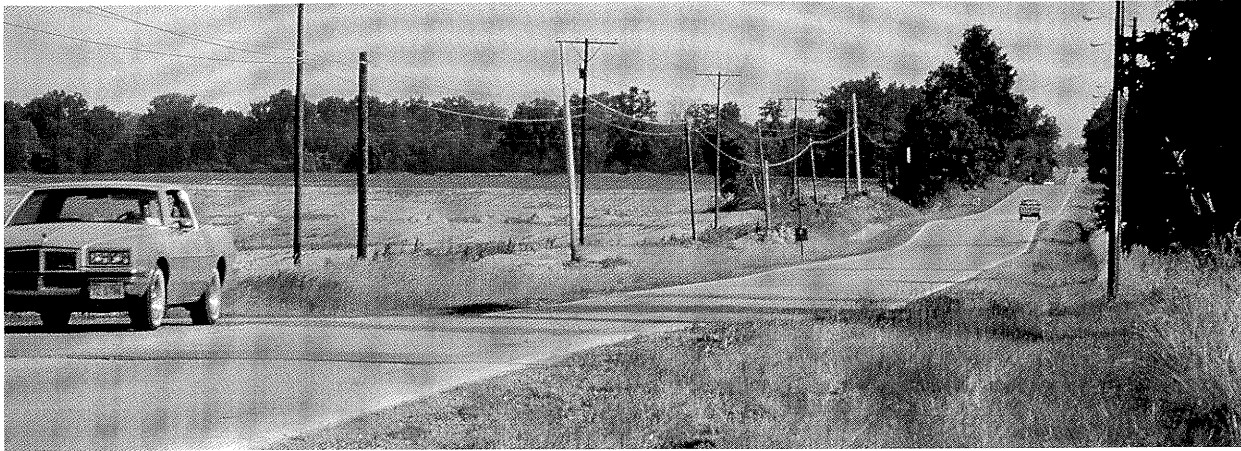
The effects of subsidence from longwall mining depend on the topography of the land and the position and type of surface structures. Coal mine operators are now required by law to restore the land to its presubsidence capabilities and repair subsidence damage to buildings, although many companies already perform repairs voluntarily. Repairs to land affected by longwall mining can be planned more easily than repairs to land that has randomly occurring depressions caused by older room-and-pillar methods. With planned subsidence, procedures to avert possible damage are established before mining begins.

## Land

Subsidence can affect agriculture by changing the original topography of the land surface. After subsidence, closed depressions may form and pond water. The effects of ponding are weather-dependent. Crops can be damaged if surface water stands for significant periods in closed depressions. In dry years, however, these lower areas may actually benefit crops by retaining rainfall. Operators of coal mines using planned subsidence methods restore the land either by recontouring, improving drainage, or both. Soil material may be moved from nearby areas to fill in depressions. Surface and subsurface drainage structures may be constructed to remove excess surface water. A farm pond may be built if sufficient borrow material is required to fill the subsided areas.

When areas are mitigated, strategies learned from studies of soil replacement at surface mines are used to make decisions about moving soils in farming areas. Research has shown the importance of keeping original topsoil as the top layer in reclaimed areas; soils with different chemical and physical makeup have been shown to be detrimental to growing crops. Consequently, when mitigation occurs after planned subsidence, the topsoil is often removed and set aside. Then, the subsoil is filled in with soil from borrow areas to restore the drainage of the land, and finally, the original topsoil is replaced. This procedure ensures that the original chemical and physical makeup of the crop-growing medium is intact.





**Figure 13** *Examples of a road subsided over a longwall panel (top) and a repaired area (bottom).*

Any mitigated areas are subject to soil compaction problems from soil-moving machines; compaction may alter soil properties or diminish yields by inhibiting root growth. Again, technology and equipment to alleviate soil compaction are borrowed from soil replacement research at surface mines. The success of mitigation techniques in farming areas is related to managing compaction problems, replacing the original topsoil so that soil fertility and chemistry are maintained, and maintaining surface drainage so that ponding does not occur.

## Structures

Steps to avoid damage to structures during planned subsidence are usually taken before mining begins. Homes can be raised off foundations to a level position and then lowered after subsidence is complete. Other techniques to minimize problems during the mining process are used, such as installing flexible connections for water and utility service. Measures taken to minimize subsidence effects depend on the position of the structure over the longwall panel and the building's stability, age, and materials. Structures are closely monitored during subsidence.

## Roads and Pipelines

State highways in Illinois are successfully undermined by longwall operations. One of the first such projects was extensively planned and monitored by the mining company and the Illinois Department of Transportation to ensure safety (Sneed 1990). Traffic continues on the roads during and after subsidence, and final repairs to the roads are completed about 1 year after undermining. Roads have also been undermined in other states, where a similar process of planning, monitoring, and remediation is followed. Figure 13 shows before and after photos of a road that was subsided by longwall mining and was subsequently repaired.

In Illinois and other states, pipelines have been safely undermined without being taken out of service. From these experiences, pipeline operators and mining companies have outlined proper monitoring and intervention responses for successful pipeline undermining. Usually, the pipeline is exposed for monitoring, then covered again after subsidence (fig. 14).

## Building Damage Due to Other Causes

Homeowners who suspect their home is being affected by subsidence may notice the following signs: cracks in foundations, walls, or ceilings; cracks

in the ground around the house; doors and windows sticking; chimney, porch, or steps separating from the house; and water or utility lines cracking or breaking (Bauer et al. 1993). Mine subsidence will trigger several of these symptoms in a short time, but other causes may be responsible if only one or two of these problems are visible.

The shrinking and expanding of moisture-sensitive soils is a common cause for building damage that may be initially mistaken for mine subsidence. Murphy et al. (1986) found that the broad category of soil volumetric change accounted for 44% of the foundation problems investigated by researchers at the Illinois Mine Subsidence Insurance Fund. This category included soil problems such as shrink/swell, freeze/thaw, settlement by loading, hydrocompaction of fill, and settlement of uncompacted fill. Many yearly cycles of shrinking and expanding soils can build up pressure on foundation walls and cause cracking and other damage. Around a home, saturated soils caused by poor drainage or inadequate gutters and downspouts can also cause foundations to tilt or sink (Bauer et al. 1993). More information about structural damage not due to coal mine subsidence is available in Bauer (1983). Additional information about the effects of soils, geology, and weather on movements of survey monuments and other structures is in Bauer and Van Roosendaal (1992).



**Figure 14** This pipeline was successfully undermined by several active longwall panels. It was uncovered and monitored during subsidence.



# **S**afeguarding Our *Future*

## **Illinois' Best Bet for Competing in Coal Markets**

Illinois coal is not only losing markets because of its high sulfur content but also because of its high delivered price. Increased productivity through longwall mining reduces mining costs per ton. Lower production costs for coal eventually result in lower electricity bills for consumers. Greater mining productivity can be achieved by optimizing the use of workers and machinery. High-extraction mining methods help companies to reach this goal. Longwall mining methods help to reduce unproductive activities, such as moving equipment and maintenance. A safer work environment is ensured because of the longwall mining equipment. High-extraction mining methods such as longwall help Illinois coal companies compete in today's market.

In 1992, 89 longwall systems were operating in the United States; ten of these systems were in Illinois (Merritt 1993). In 1989, three new systems were implemented in Illinois, which led all states that year in the installation of longwalls (Sprouls 1990). The 1990 annual report of IDMM noted that the longwall method of mining accounted for 22.3% of the coal extracted by underground mines. Longwall production has more than doubled in the last 5 years with more and more underground mines looking at longwall units. Many persons view longwall mining as Illinois' best bet for staying competitive with other states that produce coal.

## **Advantages of Planned Subsidence**

The effects of subsidence from longwall mining are immediate, planned, and known. The homeowner, farmer, and mining company can prepare for and manage these effects. By law, mining companies that use planned subsidence methods must plan for and repair damage to land and structures affected by subsidence.

Greater efficiency is achieved with longwall mining. Higher extraction rates allow companies to make the best use of low-sulfur coal deposits, a factor that became crucial because of the Clean Air Act Amendments of 1990. Coal is a nonrenewable resource, and planned subsidence methods maximize the use of available coal reserves.



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## Contacts for Additional Information

### **Mined-out area maps, general information**

Illinois State Geological Survey  
615 East Peabody Drive  
Champaign, IL 61820-6964  
217/333-4747

### **Assistance with abandoned mine subsidence**

Abandoned Mined Lands Reclamation Council  
928 South Spring Street  
Springfield, IL 62704-2725  
217/782-0588

### **Mine subsidence insurance**

Illinois Mine Subsidence Insurance Fund  
Two Prudential Plaza  
180 North Stetson Ave., Suite 1410  
Chicago, IL 60601-6710  
312/819-0060

### **Coal research, development, and marketing**

Illinois Department of Energy and Natural Resources  
325 West Adams Street, Room 300  
Springfield, IL 62704-1892  
217/785-2800

### **Coal industry information**

Illinois Coal Association  
212 South Second Street  
Springfield, IL 62701-1121  
217/528-2092

### **Active mine permit information**

Illinois Department of Mines and Minerals  
300 West Jefferson Street, Suite 300  
P.O. Box 10137  
Springfield, IL 62791-0137  
217/782-6791

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