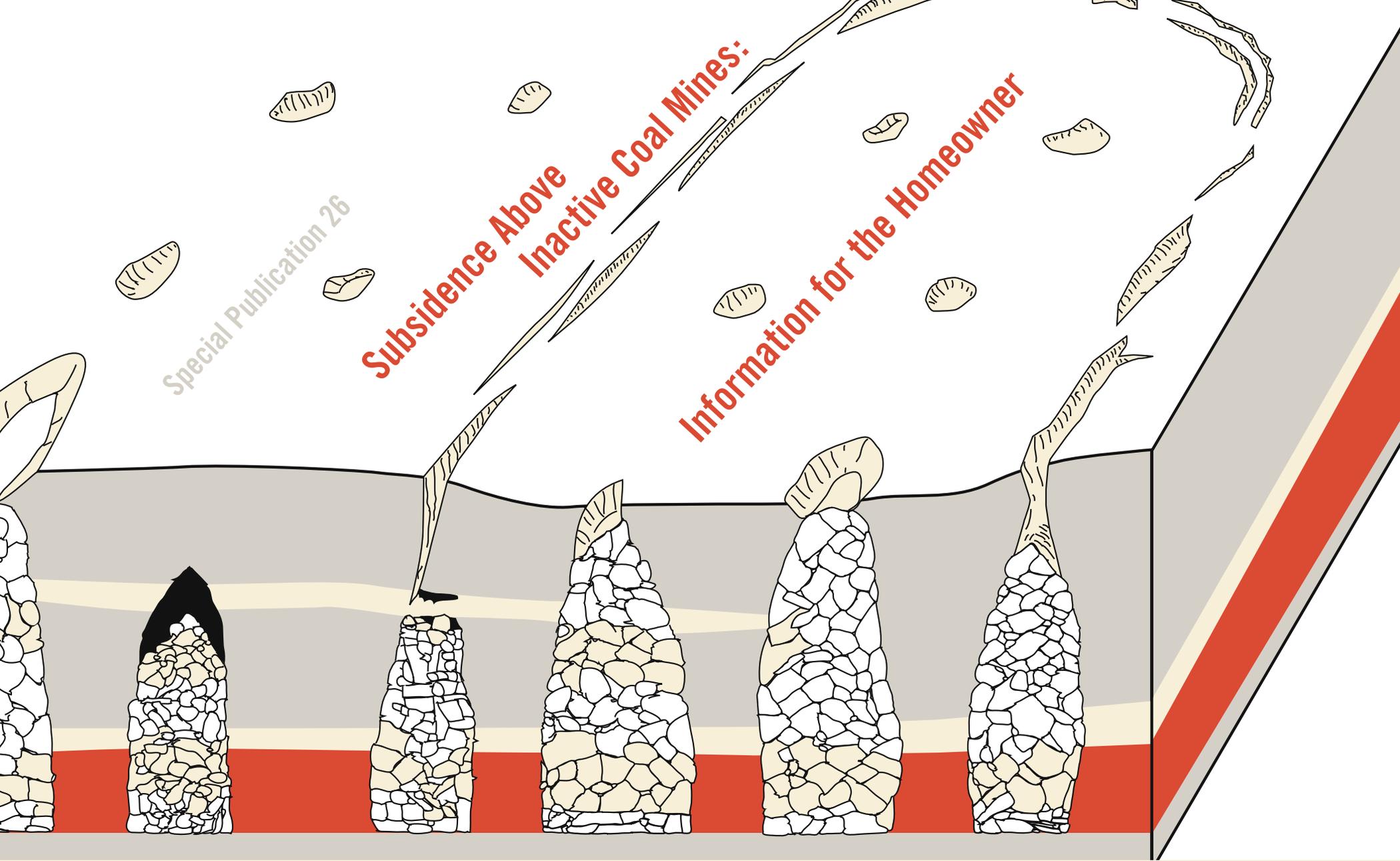


Special Publication 26

Subsidence Above Inactive Coal Mines:

Information for the Homeowner



by **J.E. Turney** 1985

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STATE OF COLORADO | DEPARTMENT OF NATURAL RESOURCES | COLORADO DIVISION OF RECLAMATION, MINING & SAFETY
AND THE COLORADO GEOLOGICAL SURVEY
DENVER | COLORADO

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Introduction

There are hundreds of abandoned underground coal mines throughout Colorado that present potential subsidence hazards to structures and surface improvements. As Colorado's population grows, development often encroaches into these subsidence hazard areas. These hazards include the potential for sagging ground, sinkhole development, and the collapse of mine shafts that have not been appropriately closed. Any of these conditions can cause damage to structures, pavement, and utility lines, and in some cases, can pose a safety hazard.

Many areas located over abandoned mines have already been developed for residential and commercial use. Homeowners in these areas should recognize that there is a potential subsidence risk associated with abandoned underground coal mines. Damage to structures and property due to mine subsidence is not covered by standard homeowners' insurance.

The dictionary defines subsidence as the action of sinking and settling. Settling may be caused by a variety of natural and man-caused mechanisms. This publication specifically addresses settlement caused by underground coal mining, referred to as mine subsidence.

Mine subsidence starts with the removal of coal from underground (Figure 1). Gravity and the weight of the overlying rock cause the layers of rock to collapse into the void left by the removal of coal. Over time, this process of collapse works upward through the strata overlying the coal mine and ultimately can affect the surface. Ground-sag, cracks, and holes that form could severely damage or destroy overlying residences. A few inches of differential settlement beneath a residential structure could cause many thousands of dollars of damage.

Subsidence can happen suddenly and without warning or gradually over a period of many years. Detailed investigations of an undermined area are needed *before* surface construction to determine the magnitude of the subsidence hazard and to decide if safe construction is possible. While investigations performed after surface development can determine the extent of undermining and potential subsidence, in most cases existing buildings and improvements cannot be protected against subsidence hazards. It is difficult to predict exactly where, when and how much subsidence will take place at any given location over an abandoned underground coal mine.



The following information provides an introduction to mine subsidence hazards over inactive coal mines.

Appendix A: What to do in a Subsidence Emergency gives the homeowner contact information and steps to take in the event of subsidence. *Appendix B: Federal and State Agencies with Subsidence Information* gives the homeowner or prospective buyer the location of information specific to their site. *Appendix C: Information Available on the Internet* gives the homeowner or prospective buyer internet addresses for on-line information. Specific mine subsidence information is found in several publications listed in *Appendix D*. These books and maps provide technical information on subsidence and specific data for Colorado. Additional information, reports and maps are located on the internet, including the state websites colorado.gov/geosurvey and mining.state.co.us.

Technical and geological terms found in this report and commonly found in subsidence investigations are defined in the glossary, *Appendix E*.

The prospective home buyer should review the available mine subsidence hazard information before purchasing a house or property over inactive mines. If the home is over an inactive mine, and was built prior to 1977, the homeowner can enroll in the State of Colorado-sponsored Mine Subsidence Protection Program (MSPP), which covers approved repairs of damage caused by mine subsidence. Annual premium costs for this protection are very affordable. To receive information on the MSPP, contact Marsh USA, Inc. at 303.308.4614 or 1.800.44.MINES, or contact the Colorado Division of Reclamation, Mining & Safety (DRMS) at 303.866.3567. Mine subsidence protection is normally *not included* in most homeowners insurance policies.

Figure 1. Underground coal miners working in a mine near Lafayette, Boulder County, Colorado. (Photo courtesy of the Denver Public Library, Western History Department.)

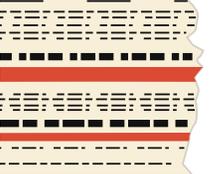
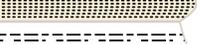
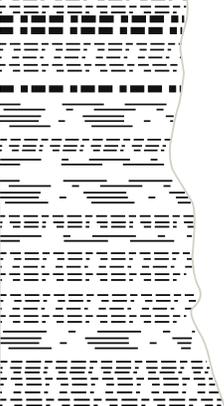
Inactive Coal Mine Subsidence

Coal mining in Colorado started in the 1860's and continues in many areas of the state. As of August 1977, federal and state laws require that potential surface subsidence be taken into account in mining plans. Prior to that time, the effect of mine subsidence was not fully considered. A lack of awareness of subsidence potential, combined with urban expansion, resulted in many homes and neighborhoods being built over these old mines. Subsidence over abandoned coal mines is a potential hazard for an estimated 25,000 people and 7,500 houses along the Front Range Urban Corridor (2004 figures).



Figure 2. Colorado Coal Deposits

Where Coal & Coal Mines Occur

AGE	FORMATION	THICKNESS IN FEET	LITHOLOGY	DESCRIPTION
TERTIARY	Green Mountain	600		Bouldery conglomerate. Forms the upper part of Green Mountain in Lakewood, Colorado.
	Denver-Arapahoe	1200		Mudstone, sandstone and conglomerate. Volcanic flows cap Table Mountains near Golden, Colorado. There are some minable coal beds (lignite) in this formation. Landslides are common.
CRETACEOUS	Laramie	1100		Sandstone and claystone. Major coal zone in the Denver Basin.
	Fox Hills	600		Sandstone.
	Pierre	6000-8000		Predominantly shale, some siltstone and sandstone. Contains swelling clays which cause poor foundation conditions.

Coal deposits are located in eight geologic basins in the eastern and western portions of Colorado (Figure 2). The coal is found as layers within sedimentary rocks composed of sand (sandstone), clay (shale, mudstone) and silt (siltstone). Figure 3 shows a general stratigraphic section of the Denver region.

Coal was formed millions of years ago in low-lying, marshy areas where plant debris and organic matter accumulated and was then buried by other sediments. The organic matter was compacted by the weight of the continuing deposition of overlying sediments to form coal. Typically, nearly horizontal layers of coal and sediments are present in the center of the basins, but these layers may be tilted, becoming nearly vertical near the western basin edges (Figure 4, next page).

Figure 3. A stratigraphic column of the Denver Basin

Mines were opened where coal beds were relatively shallow (0 to 500 feet deep), thick, and extensive enough to be economically mined. The discontinuous structure and irregular depth to the coal beds caused the mines to be distributed

mostly along the shallow flanks of the basins. Figure 5 is a map of coal mining areas. Mining methods, depth of mining, and the amount of subsidence varies across the state and within individual coalfields. Coal mining methods also

influence the kind and amount of subsidence that can appear at the surface.

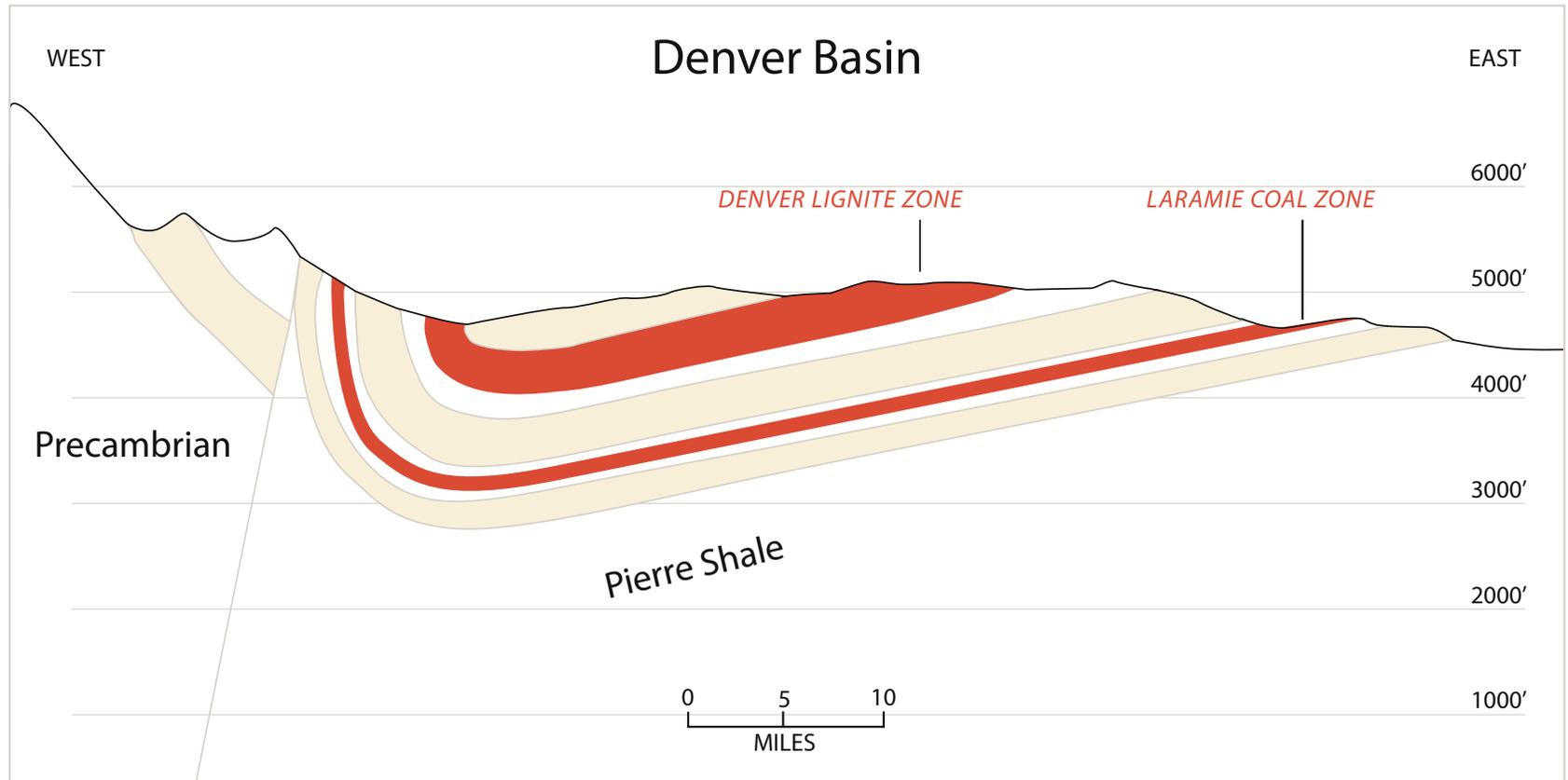


Figure 4. A general east-west section showing the structure and stratigraphic location of coal beds mined in the Denver Basin.

MAPS OF ABANDONED MINES

Mine operators were required to routinely submit mine maps to the state regulatory agency, and these maps are often the only documentation of mining in an area. However, the maps are in many cases inaccurate for the following reasons:

- Often mining continued after the last map was drawn.
- Because of changes in land surveys and landmarks it is sometimes not possible to establish a datum to correctly orient or locate the workings relative to the surface. Therefore,

the map may not be positioned accurately relative to the surface. In addition, maps of some of the older, smaller mines no longer exist, or were never made.

- Some mined areas were intentionally not drawn on the maps due to property and mineral ownership boundaries (“coal poaching”).

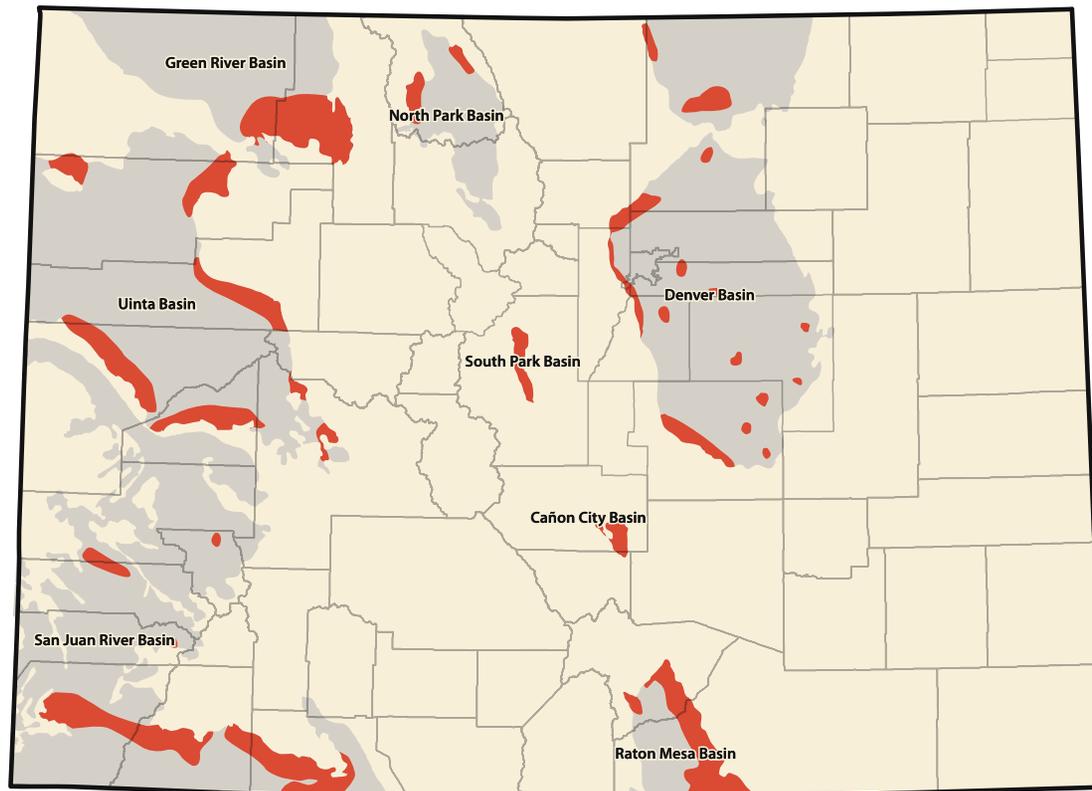


Figure 5. The general locations of historic coal mining in Colorado, shown in red.

The underground workings of all abandoned coal mines along the Front Range are inaccessible due to either caving or flooding, making direct observation of subsurface conditions impossible. For all of the reasons listed above, the prediction of future subsidence events is extremely difficult.

The Colorado Geological Survey (CGS) operates the Colorado Mine Subsidence Information Center (MSIC) which is the repository for all the known existing maps of inactive or abandoned coal mines in the state. These maps can be reviewed by appointment with a staff geologist. The CGS is located at 1313 Sherman Street, Room 715, Denver, Colorado 80203, telephone number 303-866-2611.

Mining Methods

ROOM AND PILLAR MINING

Room and pillar mining is the principal underground mining technique used in Colorado from the discovery of coal in the state until about 30 years ago. In the past 30 years, longwall mining has become the predominant method of underground coal production in Colorado.

Room and pillar mining was the technique used in mines along the Front Range (Figure 6a). The mines were accessed either by two or more entries (horizontal openings) developed in the coal seam, or two or more shafts (vertical openings sunk through the soils and rock that overlies the coal seam). Once the coal seam was accessed, two or more 10- to 15-foot wide entries were driven approximately 30 to 40 feet apart toward the property boundary. The entries were connected to each other for ventilation by a 10- to 15-foot wide crosscut approximately every 100 feet. This configuration created chain pillars between the two entries that were between 20 and 30 feet wide, and 80 to 90 feet long. When the entries reached a property boundary, a fault, or an area where the coal was too thin to mine, the miners began to develop rooms approximately 200 feet long on 30- to 40-foot centers laterally into the un-mined coal from one of the

entries. Each room was approximately 10 to 12 feet wide. When it reached the desired length, the room was connected to the adjacent room for ventilation. Once this network of rooms and pillars was established, the miners began mining the pillars at the far reaches working their way back out of the mine for safety reasons. The room was then widened by mining part of the pillar between adjacent rooms, retreating back toward the entries. Rooms were widened to a width determined by ground conditions, usually 20 to 25 feet, but would occasionally be wider.

The pillars were mined (or “shaved”) generally until timbers cracked, the roof caved, or pillars squeezed into the room. Timbers were set as the room was widened to protect the

miners by replacing the support lost as the coal was removed. After the room was widened as much as safely possible, it was abandoned and allowed to cave.

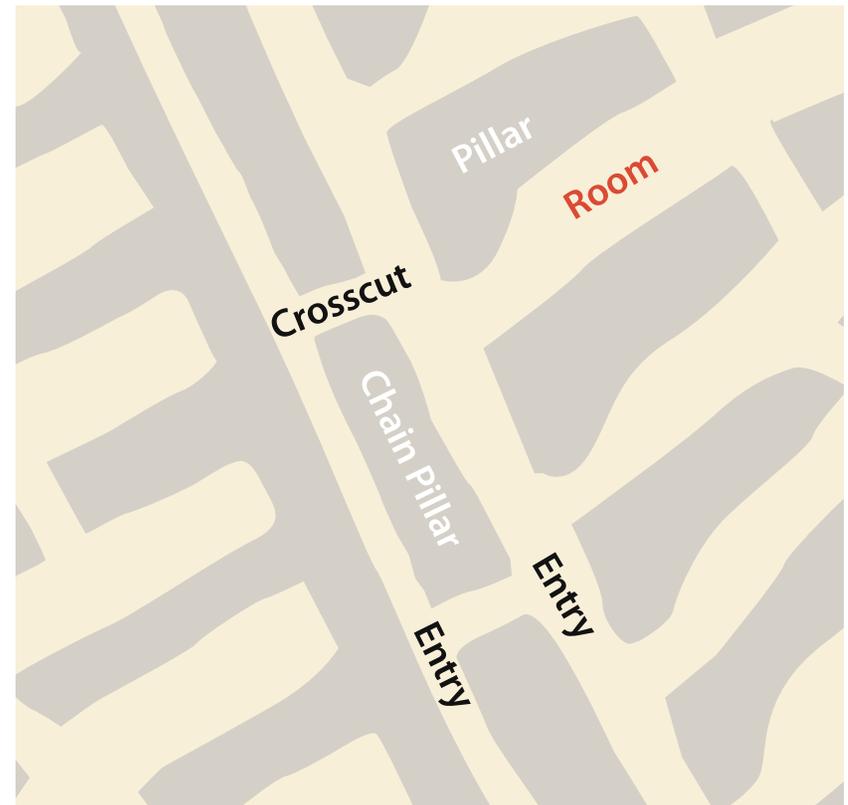


Figure 6a. Plan view of the Rapson Coal Mine in Colorado Springs, Colorado, showing entries, chain pillars, rooms and pillars. Coal left in place is shown in gray.

Shallow mines less than 200 feet below the surface generally do not have enough roof rock to overload and crush the shaved pillars. In these cases, the principal type of mine failure is roof fall caused by the rooms being widened, or the pillars being forced into a soft floor. Early miners did not have an efficient means for deal-

ing with much fallen rock, so a roof fall would end mining in a given room, sometimes before the pillar was trimmed as planned. The resulting lack of uniformity in mine layouts contributes to the difficulty in evaluating the severity and timing of collapse or subsidence into room and pillar mines.

Figure 6b shows an aerial view of a shallow room and pillar mine that exhibits the resultant subsidence at the surface. It is nearly possible to map the coal mine rooms and pillars from the subsidence pits.

Barrier pillars are normally left to separate and protect shafts, main entries, and working areas. Generally, the more modern the mine, the more uniform the pillars and rooms, leading to better prediction of mine subsidence. Most coal mines cave in soon after pillar mining is finished. This collapse begins the process that leads to subsidence of the surface.

In many mining areas, historic photos show signs of early surface subsidence caused by mining. This indicates that most, but perhaps not all, of the subsidence has occurred.



Figure 6b. An aerial photo of subsidence over shallow mining in Boulder County, Colorado. The location of rooms and pillars are visible in outline.

LONGWALL MINING

Modern longwall mining began in Colorado in the 1960's (Figure 7). This coal-extraction method removes a panel of coal ranging from 500 to 1,000 feet in width to form a large continuous room leaving the roof unsupported except along the face of coal being mined by machinery. As the working face advances, the roof sags or caves into the panel's void, as shown in Figure 8. This mining technique is more likely to produce an immediate subsidence effect at the surface. In Great Britain, where longwall mining has been practiced for many years, subsidence prediction theories have developed to a high degree of accuracy, and mining beneath existing development is conducted using engineering calculations to control surface effects. All of Colorado's longwall mines are located in areas on the Western Slope and in southern Colorado where there is little surface development. For all active underground coal mines, the effects of subsidence must be addressed in the mine permit filed for these mines with the DRMS Coal Program.

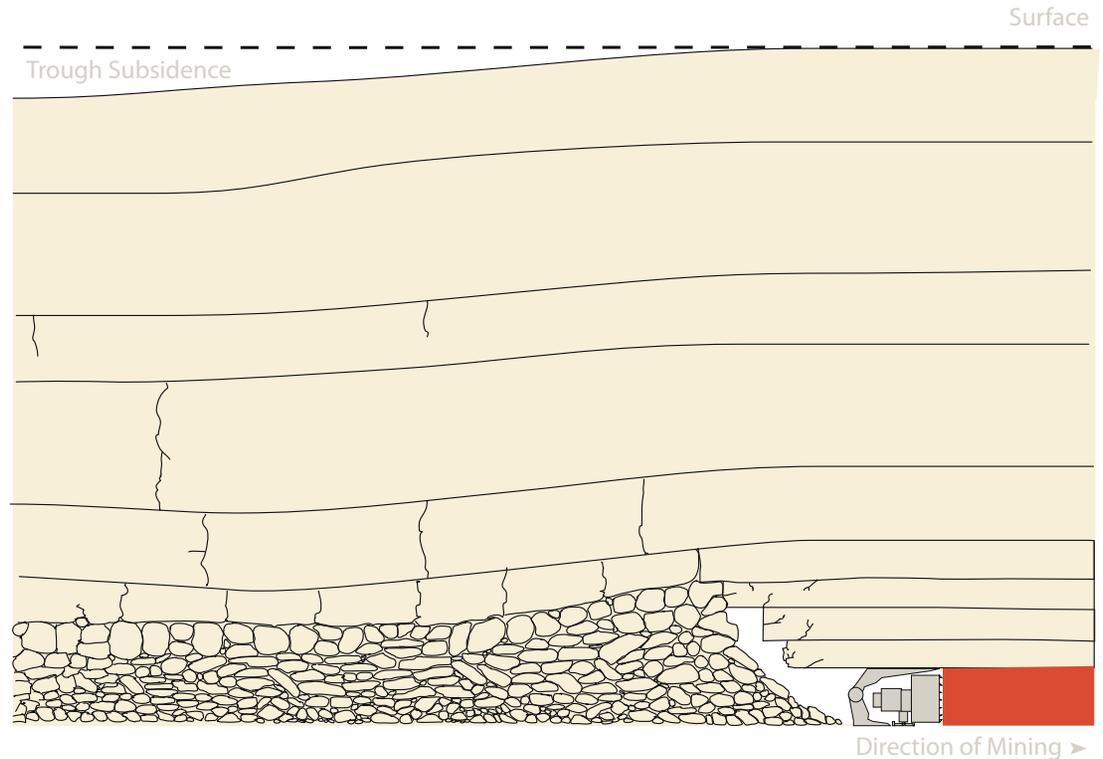
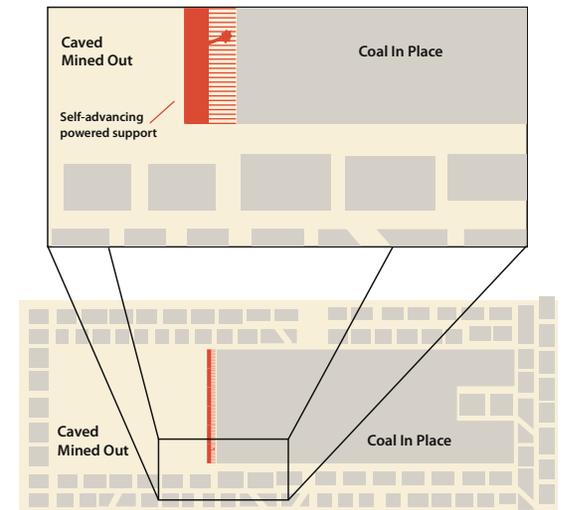


Figure 7 (at right). Plan view of a longwall Panel, which can range from 500 to 1,000 feet wide, and extract 90 percent of the coal. (used with permission, Illinois South Project, 1983)

Figure 8 (above). Cross-sectional view of a longwall mine, showing from right to left, the coal seam, shearer on face conveyor, shields, and caved rock. This shows the effect of subsidence on the overlying rock. (used with permission, S.S.Peng ed., 1981, Workshop on Surface Subsidence due to Underground Mining).



When & How Much Subsidence Can Occur

Where longwall mining is used, and subsidence is measured and predictable, surface response to undermining can be accurately estimated. In the case of room and pillar mining, particularly where the mines are inaccessible and records may not exist, accurate predictions of when and how much subsidence may occur are not possible. Several factors contribute to the timing of caving at the mine level and subsidence appearing at the surface. Pillars and timber left in place can support the roof of the mine for long periods of time. Generally, the smaller the void height (the thickness of the mined seam), and greater the width of pillars, the longer the roof is supported after mining.

Groundwater in abandoned underground mines provides a buoyant force that helps support the roof. Also, pillars submerged in groundwater do not oxidize, allowing them to maintain their integrity. Conversely, the presence of water can also lubricate and soften certain types of rocks in the mine roof and floor, contributing to movement or failure. Therefore, periodic flooding and draining of the mine increases the chance of pillar failure or the pillar being forced into a soft floor. Changes in subsurface conditions can con-

tribute to the initiation of subsidence 100 years or longer after mining ceases.

Once caving or sagging occurs above a mine, time and the physical characteristics of the overburden and void space will determine if, and how much, subsidence reaches the surface. The magnitude of surface subsidence and the features that appear at the surface depend not only on the type of mining, but also on overburden geology and the dimensions of the voids left by mining. A general rule of thumb is that the larger the mine's opening height and width, and the shallower the mine's depth, the higher the probability of surface expression of subsidence. The strength of the rock and any fractures, faults, and joints above the coal seam also factor into the potential for subsidence extending to the surface, and influence the kind of features that can appear.

subsidence features

HOLES

Subsidence pits, chimneys and potholes are names for holes of various sizes that appear at the surface over mines (Figure 9). Holes occur as caving allows voids to migrate upward from the mine. Holes are usually circular in shape, but can be of different diameters and depths. When newly formed, pits have vertical walls or bell-shaped overhanging walls.

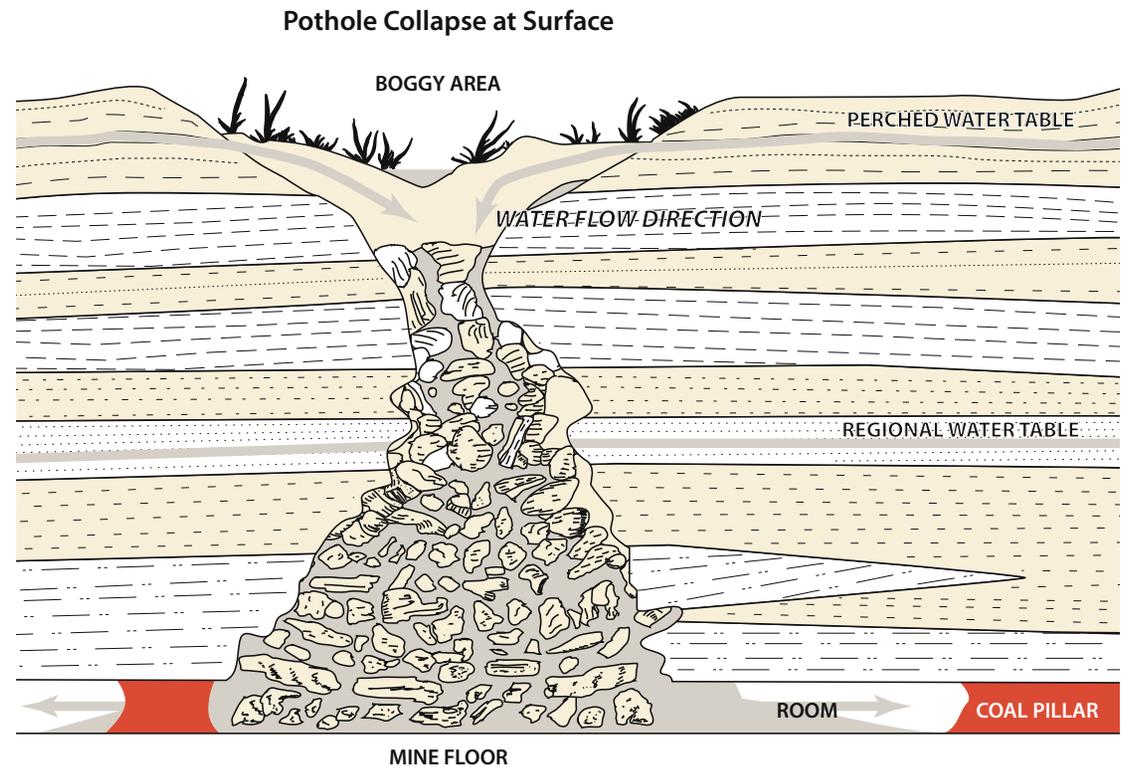


Figure 9. Cross-sectional view of a subsidence pit (original drawn by Bruce Stover, DRMS).

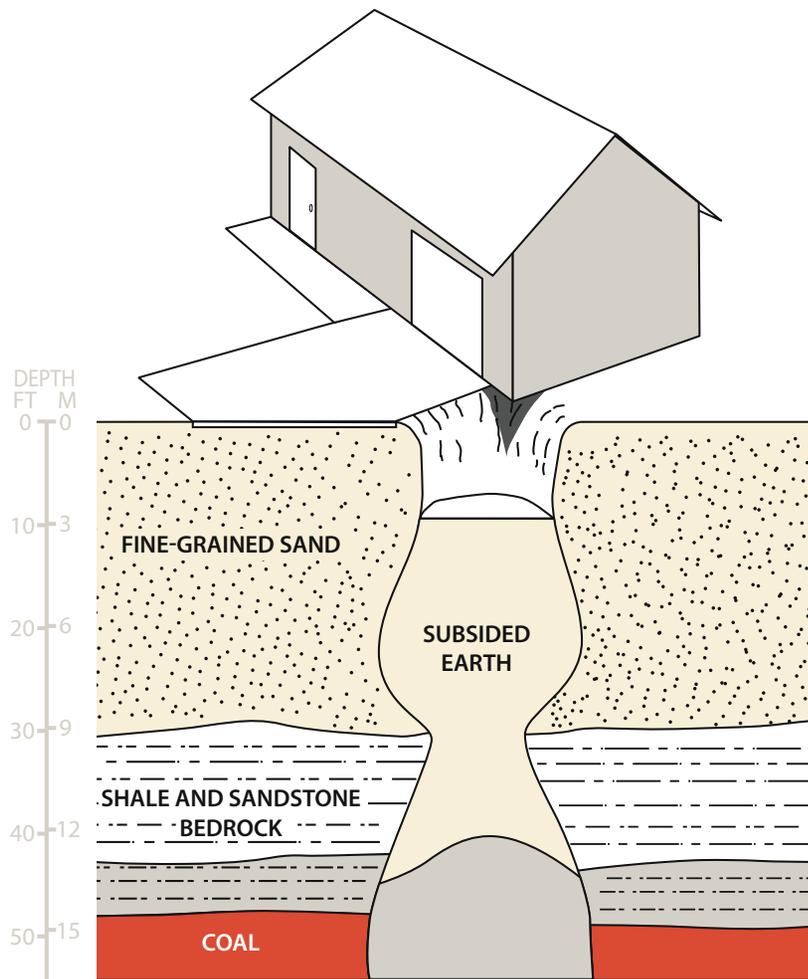


Figure 10 shows a cross section of a hole that formed under a residence. Bell-shaped pits, also known as crown holes, have a small opening at the surface that widens with depth. In areas that have thick soils or unconsolidated sediments, a pit can be deeper than the thickness of coal removed from the mine. This happens when the loose surficial material is washed into the mine and dispersed by groundwater movement.

Subsidence features can occur over relatively flat-lying coal seams and over steeply dipping coal seams on the upturned edge of basins. In dipping coal beds voids can propagate vertically and up-dip along the seam toward the surface, through a process called stoping. Pits usually form where mining is within 100 feet of the surface. Once at the surface, holes usually increase in size as the sides cave and materials continue to move downward.

Figure 10. Cross-section of a subsidence pit under a house, in an area of thick soil cover. (Modified from P.B. DuMontelle, 1981, Mine Subsidence in Illinois: Facts for the Homeowner, I.G.S., Environmental Notes 99.)

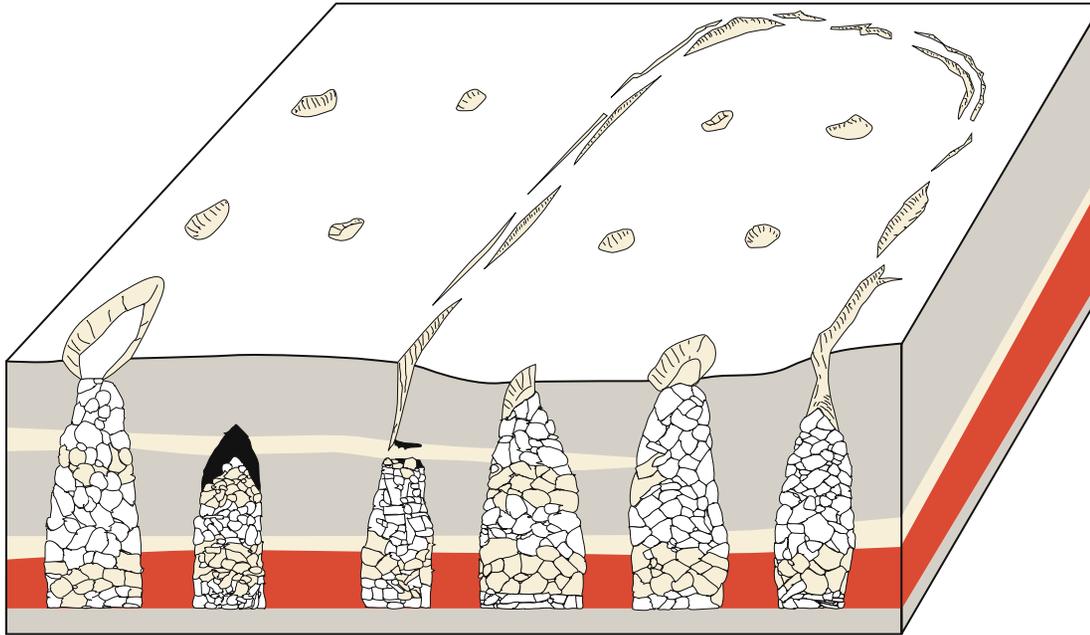


Figure 11. Block diagram of pit subsidence and trough subsidence; the trough formed over an area where several pillars collapsed. (Modified from Dunrud and Osterwald, 1978).

SAGS OR TROUGHS

Trough subsidence forms as a gentle depression over a large area. Sags can occur where a large panel of coal was mined, or where several adjacent pillars have failed or been forced (punched) into the floor simultaneously (Figure 11). Over time, the weight of the overburden overcomes the strength of the coal left in the pillars. A small or particularly weak pillar may collapse suddenly. The weight carried by this pillar is then transferred to adjacent pillars. This sudden change can cause several pillars to fail in a chain reaction until a new equilibrium is reached. As the roof sags into the void, the surface may eventually sag correspondingly.

As the ground sags, it pulls away from the edge of the trough and creates tension cracks around the perimeter (Figure 12). Correspondingly, the ground is compressed in the center of the trough and a small ridge can form. The surface tilts where the ground curves into the trough. This activity produces vertical movement, and several other physical processes as illustrated in Figure 13. These processes result in horizontal tension and compression and tilt of the ground surface.



Figure 12. A subsidence trough in a vacant lot in Colorado Springs. Tension cracks are visible around the sag. (Photo courtesy of Colorado Division of Reclamation, Mining & Safety).

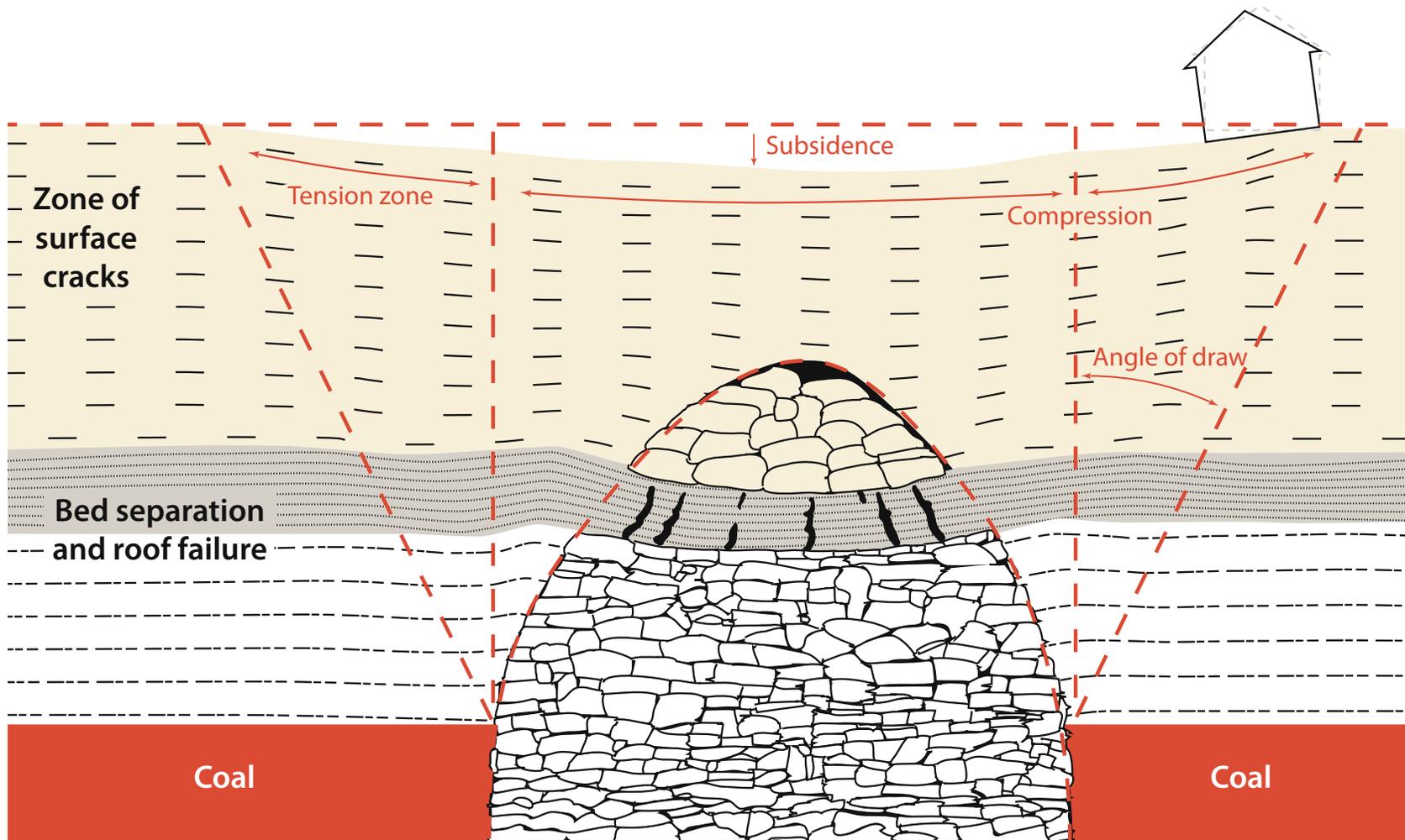


Figure 13. Cross-sectional view of roof caving through subsidence above a large collapsed room, and the effects on overlying rock. (Modified from: S.S.Peng, 1981, Workshop on Surface Subsidence due to Underground Mining).

MINE OPENINGS

Mine shafts represent a special case of potential subsidence. Vertical or nearly vertical shafts were often closed by dumping mine debris and waste into the shaft. Little attention was usually given to the long-term stability of the fill. The uncompacted material often bridged off and did not completely fill the shaft; or the loose material would settle downward and cause the shaft to re-open, often to great depths. Figure 14 is a sketch of a shaft in Fremont County.

Horizontal and inclined mine entries (slopes and adits) often lead underground through weak, unconsolidated surficial material and can be just beneath the surface for tens of feet (Figure 15). These shallow entries may cave because of extra surface weight or vibrations as slight as the weight of a person walking across the surface. The collapse of shafts and near surface entries are often very sudden, very dangerous, and can be large in extent.

Figure 14. Cross-sectional view of the Fremont Air Shaft. (Modified from: Amuedo and Ivey, 1981, Inactive Coal Mines of the Front Range Area, a Mine Inventory and an Evaluation of Hazards Arising from Past Mining, Colorado Inactive Mine Reclamation Program)

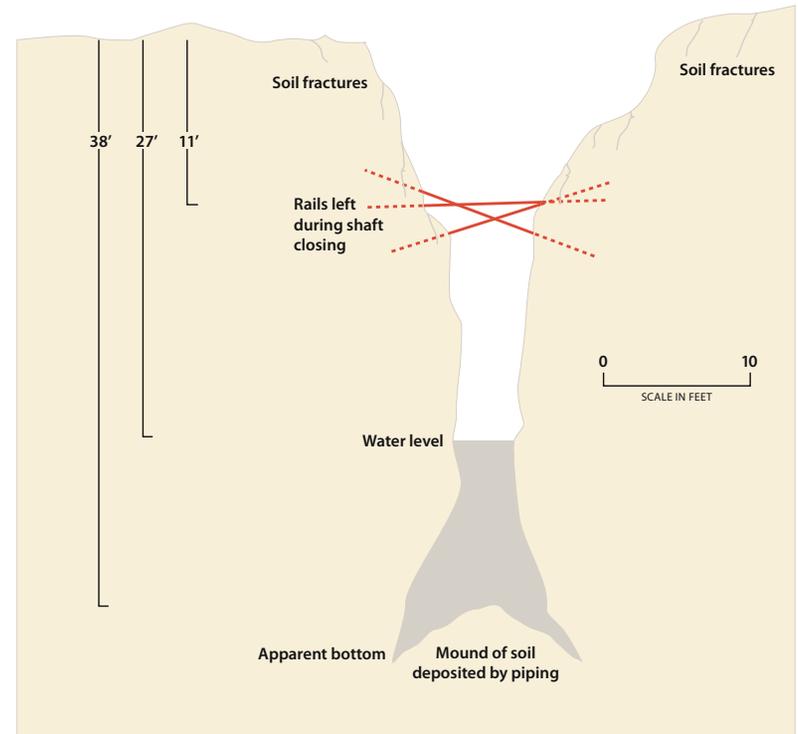
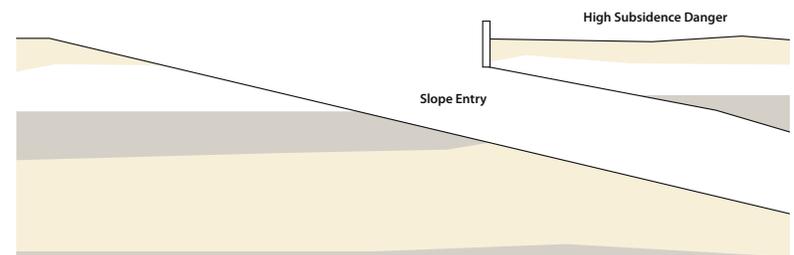


Figure 15. Cross-sectional sketch of slope entry.



Subsidence Hazard Area Identification

A residence or other structure may be subject to subsidence if it is located over or close to an undermined area. Therefore, the first step in determining the subsidence potential at a specific location is to determine if the area is undermined or near an area where underground mining took place.

Several published sources of information are available showing the locations of inactive mines (see Appendix B). These sources give an outline of the undermined areas with street maps superimposed, and normally indicate the mine name.

Examples of maps showing the extent of inactive coal mines are shown in Figures 16 and 17. These maps are available from the Mine Subsidence Information Center (MSIC).

More specific layouts of mine workings are present on the historic mine maps themselves. These maps were made during mine operation and filed on a yearly basis with the Colorado Division of Mines beginning in the 1880s. The individual mine maps provide factual information such as

mine location, specific locations of existing surface subsidence features and mine openings.

This historical background information has been used to create various derivative maps, including extent of mining maps, and in some locations, subsidence hazard maps. A statewide composite map showing areas that have been undermined by historic coal mines is available on the CGS website, or at the MSIC. Additionally, for some regions like the Colorado Springs and portions of the Boulder-Weld coal fields, more detailed subsidence hazard investigations have been commissioned by the State. These investigations include depth of mining, thickness of a mined coal seam, existence of multiple mining levels, and remaining coal pillars information that was subsequently used to estimate the degree of potential subsidence hazards for a particular coal mine. Even further detailed subsidence studies have been done for certain similar areas, such as towns and subdivisions. This information is available through the MSIC.

CONVENTIONAL LAND SURVEYS

Section, township, and range, as well as street address, are the basis for locating a piece of property in association with extent-of-mining maps

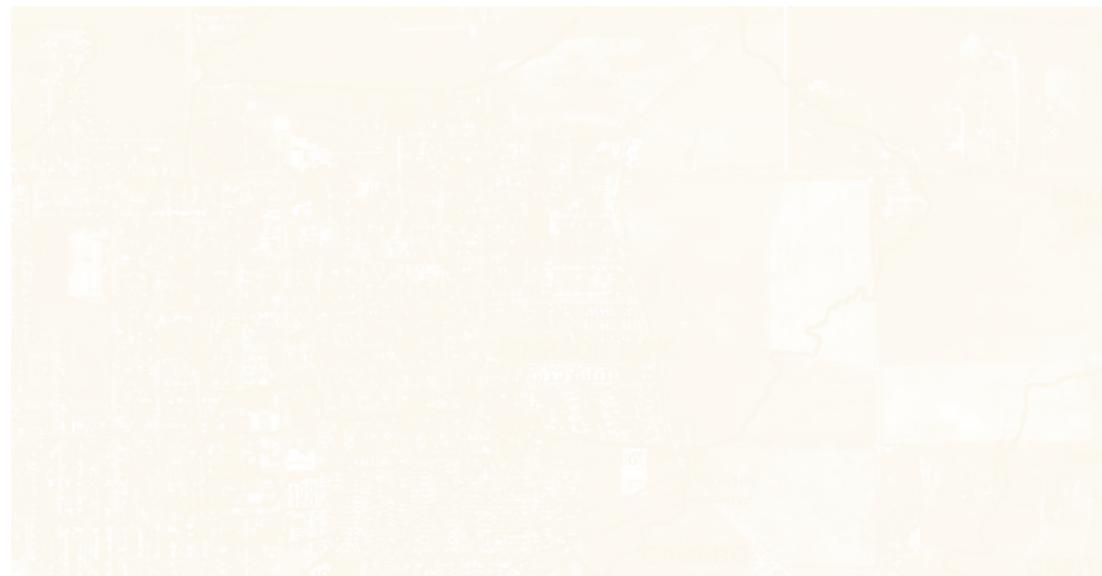


Figure 16. Detail of a subsidence investigation map in Boulder County created by Dames and Moore. The outlines represent the general boundaries of the mine; mine depths below surface grade are indicated as well. This investigation and those for similar areas are available through the MSIC.

and mine maps of different scales. Because of the scales of the maps, a lot-specific determination of undermining may not be possible. A legal description and a street map will usually provide enough information to approximately locate a city block area on extent-of-mining maps.

If a check of the extent-of-mining maps shows that a property of interest is over or close to an old coal mine, additional detailed information can be obtained from mine maps at the MSIC. Mine maps show the mine plan relative to a surface legal description, such as township, range and section. However, the maps should be used with some caution. Many old maps have surveying errors, the extent-of-mining may be in error, and pillars might be shown as removed when they are still in place. In addition, there are many coal mines that have records for production, name and date of mining but the actual location of the mine is unknown. Because of this uncertainty, buildings located close to mine areas may be subject to subsidence.

House Bill 1041 (CRS 1973, 29-20-101, et. Seq.) identifies mine subsidence as a geologic hazard and Senate Bill 35 (CRS 1973, 30-28-101, 110 (3) - (5), 133-137), requires that geologic hazards

be evaluated in a geologic report prior to final property subdivision. These statutes are used by local jurisdictions to assess geologic hazards. Many recent housing developments in the Front Range Urban Corridor have had subsidence hazard investigations completed prior to development. Check with your city or county planning department for clarification on the process for subsidence investigations for subdivisions. Individual site-specific investigations examine the available data, and drill exploratory holes to develop site-specific information on the present condition of the mine. These investigations are completed to determine the following:

- if mining exists under the site,
- if void space is still present underground,
- if subsidence has taken place (from drill hole data and surface evidence),

- how the subsidence hazard can affect the proposed development,
- where safe building areas exist, and
- what areas should be avoided.



Figure 17. Detail of an extent-of-mining map in Colorado Springs created by Dames and Moore. The outlines represent the general boundaries of the mine; mine depths below surface grade are indicated as well. This investigation and those for similar areas are available through the MSIC.

Identifying Subsidence Damage

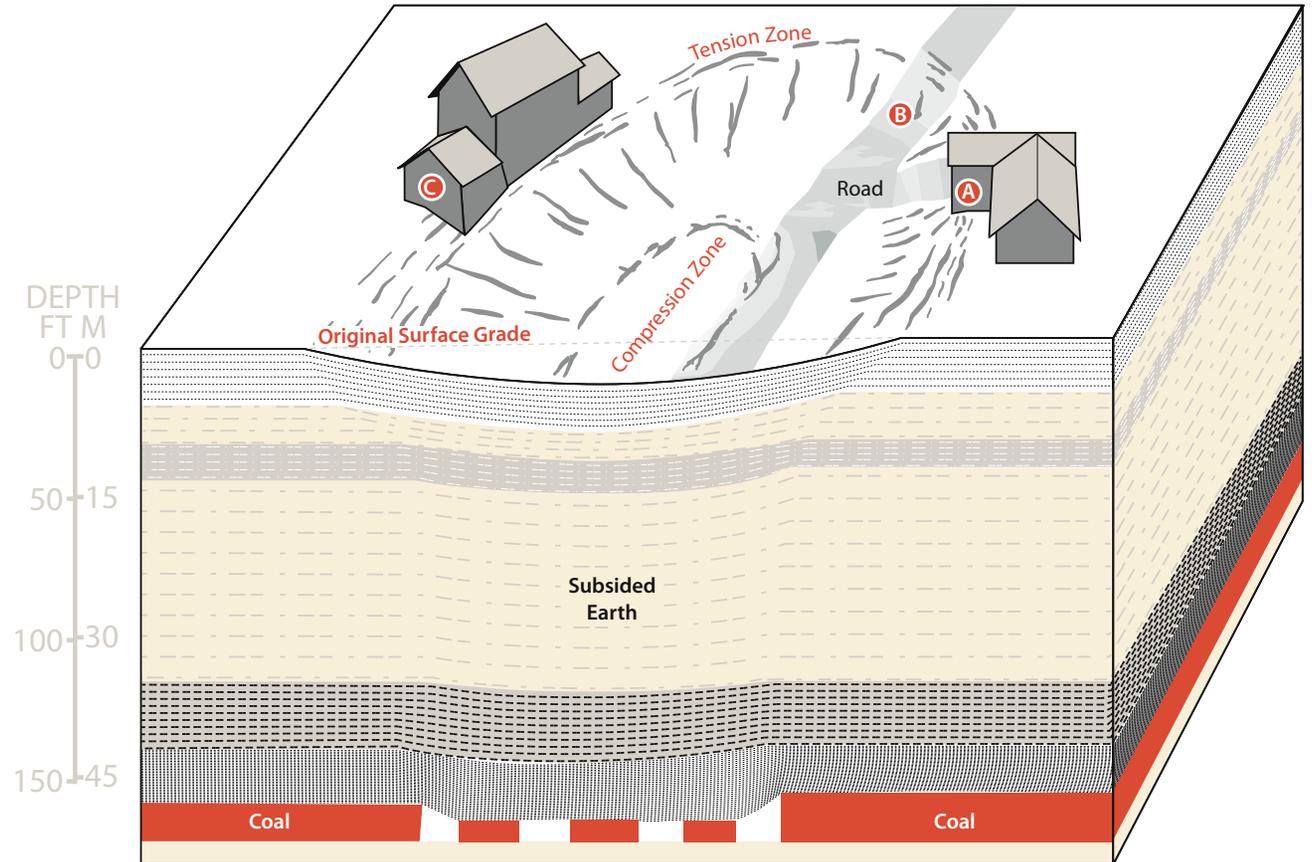
Subsidence studies, when available, are often on file with the builder, city or county. They also may be available for inspection from the files of the MSIC. To determine if one of these studies is available for a specific subdivision, the subdivision name (as platted) and legal location must be known.

Pit subsidence and trough subsidence, because of their different physical processes, will produce different types of damage. The pit subsidence shown in Figure 18 near a house took 56 cubic yards of grout to stabilize and backfill it to the surface.



Figure 19. A subsidence pit under the corner of a house. (Photo courtesy of L. Floyd, Office of Surface Mining)

Figure 18. Pit subsidence over mine rooms. (Photo courtesy of L. Floyd, Office of Surface Mining).



- A** Wooden frame house in tension zone (right side).
The foundation has pulled apart and dropped away from the superstructure in one corner.
- B** Road in compression zone. Asphalt has buckled.
- C** Brick house (left side) in tension zone. Walls, ceilings, and floors have cracked.

*Figure 20. Block Diagram of a typical sag subsidence event
(Used with permission, P.P. DuMontelle, 1981, Mine subsidence in
Illinois; Facts For the Homeowner. I.G.S., Environ. Notes 99).*

The tension and compression of trough subsidence causes the strains and differential movement that can severely damage buildings and utilities. Buildings can be pulled apart as the ground sags and tilts into the edge of a trough (Figure 20, next page). Utilities such as water, sewer, phone and gas lines can be damaged or disrupted by these processes (Figure 19).

Damage to residential buildings may appear as:

- cracks in brick or stone facing;
- sags in the roofline;
- separation of steps or fireplace from building;
- appearance or widening of cracks in drywall or plaster;
- pits or sags around the building or regular pattern of cracks in ground (that lead to cracks in building as in Figure 21);
- distorted window and door frames and sticking of windows and doors;
- basement or foundation pulling away from building or superstructure; or
- sudden pits or sags around the home and popping or cracking noises.

Damage to Roads, Driveways, and Sidewalks:

- Cracked, sagging or tilting concrete or asphalt (Figure 22).

Damage to Utilities:

- Sudden breaks in water, gas, and sewer pipes;
- saturated ground;
- dirty tap water;
- gas leaks (smell of natural gas); or
- gravity flow systems such as water and sewer lines may drain improperly.



Figure 21. Driveway settlement over an abandoned coal mine. (Photo courtesy of Colorado Division of Reclamation, Mining & Safety)

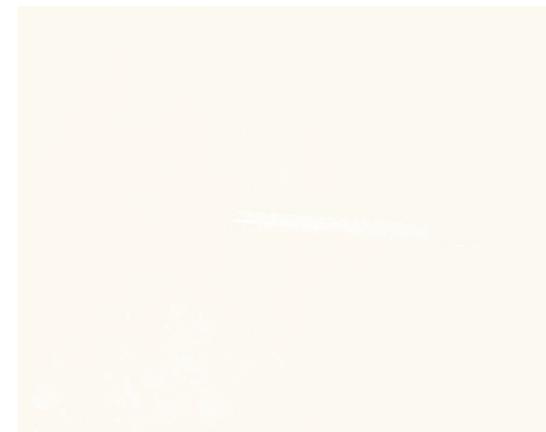


Figure 22. Tensional forces cracked and separated this garage slab. (Photo courtesy of Colorado Division of Reclamation, Mining & Safety)

Other processes that can cause damage similar to subsidence

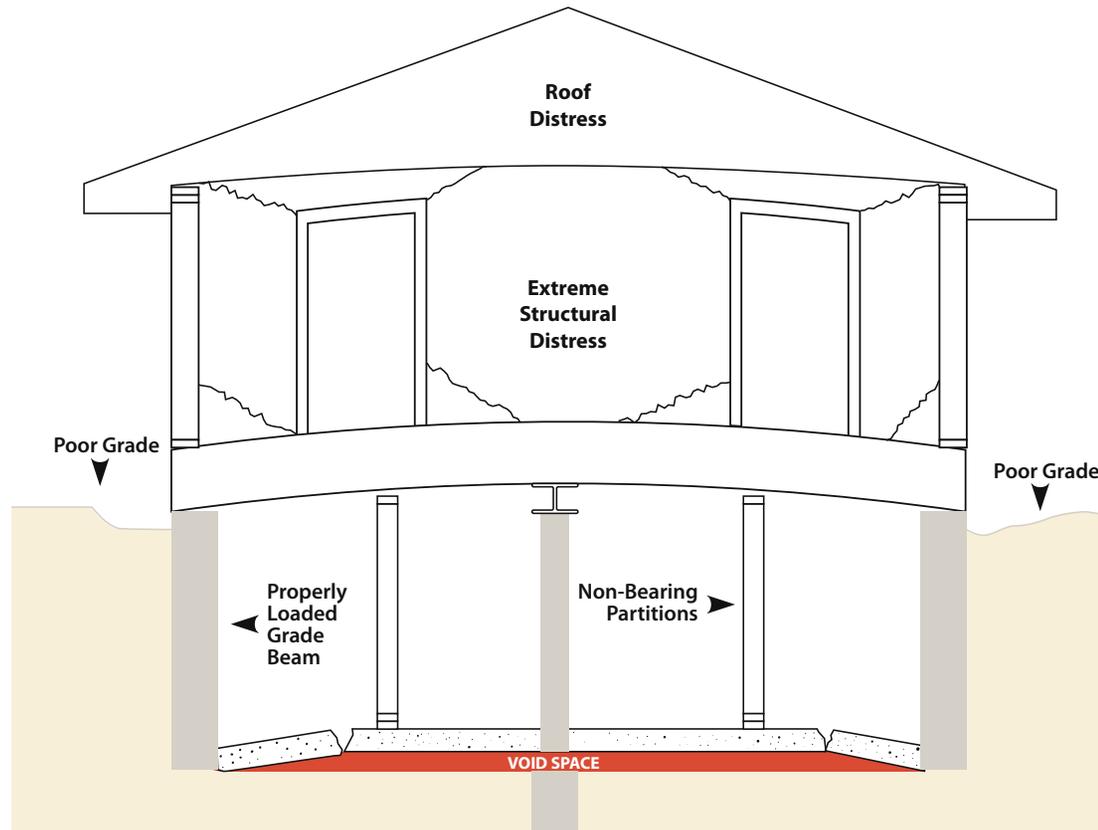


Figure 23. Typical major house damage from swelling soils. (From Holtz and Hart, 1978)

Several other foundation and construction issues can mimic the damage caused by mine subsidence. The most common natural and man-made causes of structural and cosmetic damage include swelling soils, poor or inappropriate construction techniques, and hydrocompacting soils. These conditions are discussed below.

SWELLING SOILS

Swelling clay soil and bedrock causes the most common and extensive damage to construction in Colorado. Fluctuations in moisture content in some clay soils and rock affect the volume of the material and can cause floor slabs to heave and buckle. Loss of moisture can shrink soils, causing loss of support to foundation walls. This stress is transferred to building superstructures, producing cracks in drywall, brick facings and distressed windows and doors (Figure 23). Swelling soils can also cause heaving and cracking of roads and sidewalks and rupturing of utility lines. Trees and other plants can extract water from clay soils, causing the soil to shrink. In some cases, soils have shrunk away from foundations allowing them to settle and crack or tilt outward. Maintaining a constant water content in soil prevents volume changes and damage. The most effective method of controlling changes in

soil moisture around a building is careful management of surface and subsurface drainage.

POOR CONSTRUCTION METHODS

Poor or inappropriate construction methods, low quality concrete mix, settlement of backfill, and poor structural support can cause foundation and internal building damage. Older construction techniques, which are not suitable for swelling soils, have been used along the Colorado Front Range Urban Corridor for many years.

PIPING

Piping is the process whereby fine-grained sediments are removed by flowing water. This can create a cavity in the subsurface, causing leaks or breaks along sewer or water lines. Settlement of overlying material into these cavities can look like mine subsidence.

HYDROCOMPACTION

Some windblown fine sands and silts are deposited with a very open structure between soil grains. The internal structure may give the material adequate strength when dry, but these types of soils can compact when loaded or when excessive moisture is added to the soil. Hydrocompaction often occurs as lawn watering or water leaks weaken the internal structure of the soil and cause settlement and compaction of the materials.

Measures to Minimize Subsidence Damage

EXISTING STRUCTURES

There is no accurate method to determine when subsidence might occur over abandoned room and pillar mines. Some buildings constructed in a subsidence-prone area might never be affected. The simplest preventative measure to reduce both subsidence damage (where there is a thick soil cover over shallow mines) and damage caused by problem soil is to ensure positive drainage away from the foundation. These measures include:

- excluding vegetation within 5 feet of the foundation,
- providing gutters with downspout extensions, and
- adding drainage control blocks under garden hose valves.

These measures serve to minimize the introduction of water to the ground near the foundation.

One of the greatest subsidence hazards to existing buildings results from gas line breaks and leakage. A quick and relatively inexpensive way to avoid this hazard is to install flexible couplings for gas lines where they penetrate foundation walls, and attach to furnaces and hot water heaters (Figure 24). This will reduce the hazard of broken gas lines and the

potential for explosions.

Gas lines next to structures can be vented to the surface with porous material such as pea-sized gravel, to prevent migration of gas into the building (Figure 25), and outside gas meters can be fitted with swing joints to prevent distress (Figure 26).

Structural modifications of existing buildings to prevent subsidence damage are often expensive and may be as damaging to light residential buildings as the actual subsidence. Where the

potential for trough subsidence exists, narrow trenches can be dug around buildings and backfilled with compressible material. These trenches will then absorb ground compression. Additional structural support for bearing walls and reinforcing foundations are other methods used to prevent damage. In several cases,



Figure 24. Furnace and water heater flexible gas connections.

once active subsidence has started, a part or all of a structure may need to be supported to prevent extensive damage. Support beams and jacks could be placed between the house and foundation to level and hold the building in position (Figures 27 and 28).

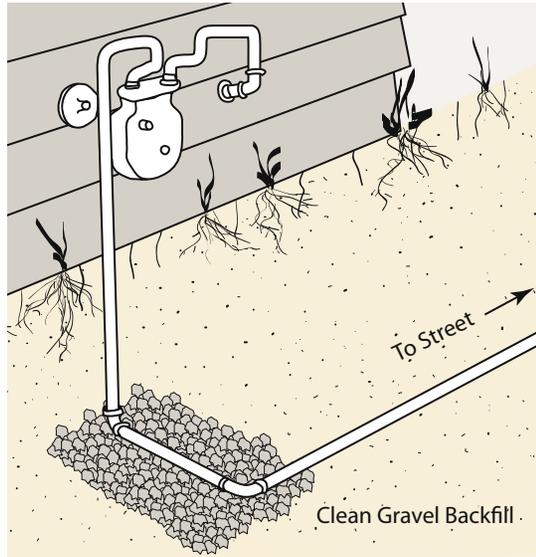


Figure 25 (top left). Vented gas line outside of a building. Any work of this kind should be completed by a contractor familiar with natural gas lines.

Figure 26 (bottom left). Gas meter in extreme distress caused by apparent subsidence (Division of Reclamation, Mining & Safety 2004).

Figure 27 (top right). Subsidence pit under the corner of a house. The beam, drilled pier and jack hold the house in position and level the building. (Photo courtesy of L. Floyd, Office of Surface Mining)

Figure 28 (bottom right). Closeup of a helical pier and jack. (Photo courtesy of Colorado Division of Reclamation, Mining & Safety)

NEW CONSTRUCTION

If construction is proposed for an undermined area, a subsidence investigation should be completed to determine the feasibility of developing the site. In certain circumstances, specialized construction techniques can be used to prevent or minimize subsidence damage. These construction techniques are discussed in a publication, *Building Code Supplement for Construction in Subsidence Prone Areas in the State of Colorado*.

Special construction techniques include proper building orientation, rigid buildings with reinforced concrete slab type foundations, and flexible structures with devices for leveling. These specialized designs may not always be compatible with other site geologic conditions and should be evaluated by an architect or structural engineer familiar with subsidence mitigation.

Utilities should be constructed with flexible joints to absorb ground tilts and strains. Special soil/fill compaction around utilities can also help absorb tension and compression to lines. Roads should be constructed of asphalt or some other type of flexible material.

When serious subsidence hazards exist in undeveloped areas, construction of permanent structures

should be avoided. Zoning and land use policies can be used to set aside subsidence-prone sites for open space and other non-structural uses. In extreme cases, these areas might still need to be monitored and posted with signs.

Other measures include:

- slurry backfilling of open, continuous voids at or near mine level;
- drilling and grouting to stabilize the collapsed mine overburden;
- hybrid slurry/grouting to backfill and stabilize large undeveloped areas; and
- using drilled piers and a foundation that bears on stable strata below mine level.

A slurry backfill, normally consisting of sand or gravel transported in water, serves to fill voids at the mine level. This is generally the least expensive mine treatment method. It is a passive void filling technique that will minimize the amount of subsidence in proportion to how completely the void is filled. As it is difficult to assure complete filling in complex mine geometries, caution should be used in relying totally on this method.

Drilling and grouting mine voids is intended to arrest subsidence that has already started in the

mine. Holes are drilled into the mine and a mixture of sand, fly ash and cement is pumped into the void space. The grout hardens and provides support to the mine roof. Grouting can be a passive void fill, placed under no-to-low pressure, or it may be an active method when placed under pressure. Pressure grouting may initiate subsidence or lift the ground in some cases, so it should be performed carefully.

Combination slurry grouting can be used for large area stabilization. In this method, a loose, fluid grout is pumped into the mine, similar to standard grouting procedures. This system is more effective where the mine voids are at or near mine level, and are interconnected. Complex abandoned mine conditions make it difficult to backfill the entire subsurface void and the results can be variable.

Where a mine is shallow, it is possible to support a building on drilled piers or pilings extending below the mine level. The foundation is heavily reinforced, and supported on the piers. With this system, surface subsidence would not affect the structure constructed on the deep foundation system.

Appendix A: What to do in a Subsidence Emergency

If the ground sinks suddenly on or near your property and you have reason to believe the area is undermined, you should:

1. **Determine if your building is served by natural gas.** Next, check for gas odors and leaks, and for distress or strain on the gas meter or on visible gas piping. If you ever smell natural gas, do not touch anything electrical, leave the house, and call the gas company from a neighbor's house. Even your cell phone may set off the gas, so, do not touch the light switch, stereo, garage door opener, or anything electrical. If any of these conditions are observed, Denver residents should contact the Xcel Energy Emergency Services at 800-895-2999. Residents of Colorado Springs are served by Colorado Springs Utilities, contact their Emergency Services at 719-238-5434. If gas lines are cracked or broken, there is a potential for fire or explosion.
2. **Contact your city or county safety department/fire department.**
3. **Contact Colorado Division of Reclamation, Mining & Safety (DRMS)** at 303-866-3567.
4. **Contact Office of Surface Mining (OSM),** 303-844-1400. (OSM controls Federal abandoned mine reclamation emergency funds. If the office representative determines the incident qualifies as a subsidence emergency, they will monitor the situation and repair the subsidence feature. They will not repair damage to a structure.)
5. **If you are covered by Mine Subsidence Protection Program (MSPP), contact the representative for Marsh USA, Inc.,** the program administrator at 303-308-4614. They are the firm that oversees repairs due to subsidence damage.
6. **Contact your city water and sewer department** so that these lines can be checked for damage.
7. If the subsidence feature is near the house, **large windows should be taped to help prevent flying glass,** if distorted windows shatter.
8. **If any of the features mentioned under “subsidence damage” should suddenly appear, the homeowner should start a written log.** This log will help investigators determine if the damage is caused by subsidence. The log should include when signs of damage appear as well as where and what kind of damage is taking place. Cracks should be measured daily and in the same spot. Permanent marks on the cracks and by windows and doors will make it easier to see if progressive movement is taking place. Photographs can also help document ongoing damage (Figure 29).

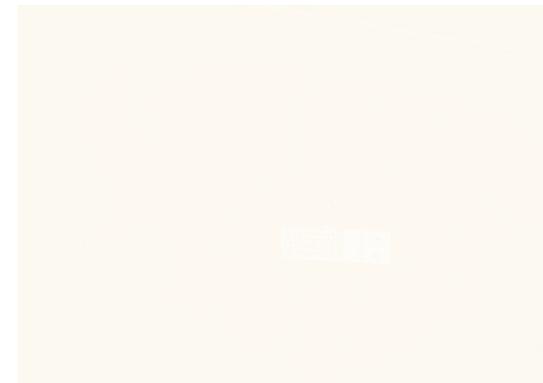


Figure 29. Tension fracture in foundation. A crack monitor is used to monitor the movement. (Photo courtesy of Division of Reclamation, Mining & Safety)

Appendix B: Federal & State Agencies that Have Inactive Mine Subsidence Information

United States Department of the Interior Office of Surface Mining (OSM) Western Regional Office

1999 Broadway, Suite 3320
Denver, CO 80202-5733
303-293-5000

OSM handles emergency subsidence reclamation projects in Colorado and other western States. This activity is part of their responsibility for coal mining regulation in the United States.

Colorado Department of Natural Resources Division of Reclamation, Mining & Safety Inactive Mine Reclamation Program

1313 Sherman Street, Room 215
Denver, Colorado 80203
303-866-3567

The Colorado Inactive Mine Reclamation Program has inventoried abandoned mines in Colorado and provides extent-of-mining maps and inactive mine information to the public. The abandoned lands assessment has been done to document environmental and safety hazards associated with inactive

mines and within funding limits, to correct these problems.

Colorado Department of Natural Resources Colorado Geological Survey 1313 Sherman Street, Room 715 Denver, Colorado 80203 303-866-2611

The Geological Survey has copies of subsidence hazard maps for inspection, and provides information on subsidence hazards in Colorado. The Geological Survey is the state's repository of mine maps and mine production information. This includes maps of past and current coal mining, tonnage of coal mined and the dates produced, general mine information, and mine ownership data. Additionally, the Survey has copies of subsidence hazard studies completed for individual developments.

Appendix C: Information available on the Internet

Mine Subsidence Protection Program
information can be downloaded at:
mining.state.co.us/AMLSubsidence.htm

State DRMS Project GIS
information can be located at:
mining.state.co.us/maps/dmgMap.htm

USGS has an excellent map
of Boulder Weld Coal Field at:
pubs.usgs.gov/imap/i-2735/i-2735.pdf

State of Colorado Geological Survey
information can be located on the CGS website
at: colorado.gov/geosurvey

Appendix D: References & Selected Additional Readings on Mine Subsidence

- Amuedo and Ivey, 1975, *Coal Mine Subsidence and Land Use In the Boulder-Weld Coalfield: Boulder and Weld Counties, Colorado*, Colorado Geological Survey, Environmental Geology 9, text and maps*.
- Amuedo and Ivey, 1981, *Inactive Coal Mines of the Front Range Area, a Mine Inventory and Evaluation of Hazards Arising from Past Mining*, Colorado Inactive Mine Reclamation program, Department of Natural Resources, Denver, Colorado, Text and Maps**.
- Colorado Springs Planning Department, 1967, *Mining Report, Colorado Springs Coal Field, a guide to future land use*, Colorado Springs, Colorado, Text.
- Hynes, Jeffrey L., 1984, *Tri-Towns Subsidence Investigation, Weld County Colorado, a Community-Wide Approach to Hazard Evaluation and Land Use in Undermined Areas*. Colorado Geological Survey, OF-87-3, Text and Maps*.
- Hatton, Tom, 1989, *Annotated Bibliography of Subsidence Studies over Abandoned Coal Mines in Colorado*, Colorado Geological Survey, IS-22, Text*.
- Dames and Moore, 1985, *Colorado Springs Subsidence Investigation, El Paso County*, Completed for the Colorado Inactive Mine Reclamation Program, text and maps†.
- Dames and Moore, 1986, *Boulder County Subsidence Investigation, Boulder County*, Completed for the Colorado Inactive Mine Reclamation Program, text and maps†.
- Michael Baker Jr., Inc., 1984, *Colorado Springs Land Use and Building Code Project*, Maps and text**.
- Turney, J. and Murray-Williams, L. 1983, *Colorado Front Range Inactive Coal Mine Data and Subsidence Information*, Colorado Geological Survey, Tables, Text and Maps†.
- Turney, J. and Murray-Williams, L. 1984, *Inactive Coal Mine Data and Subsidence Information, Grand Hogback Region*, Colorado Geological Survey, Tables, Text and Maps**.
- Turney, J. and Murray-Williams, L. 1984, *Inactive Coal Mine Data and Subsidence Information, Yampa Valley Region*, Colorado Geological Survey, Tables, Text and Maps†.
- Sullivan, K.A. 1984, *Inactive Coal Mine Data and Subsidence Information, Rio Blanco County*, Colorado Geological Survey, Tables, Text and Maps†.
- Sullivan, K.A. 1984, *Inactive Coal Mine Data and Subsidence Information, Crested Butte Coal Field*, Colorado Geological Survey, Tables, Text and Maps†.
- Sullivan, K.A. and Jochim, C.L., 1984, *Inactive Coal Mine Data and Subsidence Information, Durango and Pagosa Springs Coal Fields*, Colorado Geological Survey, Text and Maps†.
- Jochim, C.L., 1984, *Inactive Coal Mine Data and Subsidence Information, Somerset and Grand Mesa Coal Fields*, Colorado Geological Survey, Text and Maps†.
- Jochim, C.L., 1984, *Inactive Coal Mine Data and Subsidence Information, Book Cliffs Coal Field*, Colorado Geological Survey, Text and Maps†.
- U.S. General Accounting Office, 1979, *Alternatives to Protect Property Owners from Damages Caused by Mine Subsidence*. CED 79-25, Washington, D.C.**

Yokel, Felix Y., et. Al., 1981, *Construction of Housing in Mine Subsidence Areas*, Department of Housing and Urban Development NBSIR 81-2215**.

Michael Baker Jr., 1974, *Architectural Measures to Minimize Subsidence Damage, Appalachian Regional Commission*; Pennsylvania Department of Environmental Resources. Report ARC-73-111-2551**.

Brauner, Gerhard, 1973, *Subsidence Due to Underground Mining (in two parts)* U.S. Bureau of Mines Information Circular 8571, 8572, Text**.

National Coal Board, 1975, *Subsidence Engineers' Handbook*, NCB Mining Department, Text**.

Building Code Supplement for Construction in Subsidence Prone Areas in the State of Colorado

ADDITIONAL READINGS ON SHRINKING AND SWELLING SOILS AND OTHER GEOLOGIC HAZARDS.

Hart, S.S., 1974, *Potentially Swelling Soil and Rock in the Front Range Urban Corridor, Colorado.*, Colorado Geological Survey Environmental Geology 7*.

Rogers, W.P., et. Al., 1974., *Guidelines and Criteria for Identification and Land-Use Controls of Geologic Hazard and Mineral Resource Areas*, Colorado Geological Survey Special Publication 6*.

Shelton, D.C. and Prouty, Dick, 1979, *Nature's Building Codes - Geology and Construction in Colorado*, Colorado Geological Survey, Special Publication 12*.

Noe, David, 2007, *A Guide to Swelling Soils for Colorado Homebuyers and Homeowners, second edition*, Colorado Geological Survey, Special Publication 43*.

White, Jonathan L. and Greenman, Celia; 2008; *Collapsible Soils in Colorado*; Colorado Geological Survey Publication EG-14*.

* = This publication is available for sale at the Colorado Geological Survey.

**= This publication is available for inspection at the Colorado Geological Survey.

† = This publication is available for inspection at the Colorado Geological Survey; map copies can be reproduced.

Appendix E: Glossary

This glossary contains terms found in this report and common terms that are found in publications and subsidence investigations. These definitions have been adapted from the *Dictionary of Mining, Mineral and Related Terms*.

Abandoned Workings—Mined excavations that are deserted and in which further mining is not intended.

Adit—A horizontal or nearly horizontal passage driven from the surface for the working or dewatering of a mine.

Backfill—In general refers to material placed to refill voids left after mining.

Barrier pillar—A solid block or rib of coal left unworked between two adjacent mines.

Bentonite—material composed mostly of the clay mineral montmorillonite. This rock has great ability to absorb water and swell.

Bituminous—A subclass of coal, high in carbonaceous matter.

Chimney—A pipe-like, more or less vertical, vent or opening in the earth.

Cleat—The main joint(s) in a coal seam along which it breaks most easily.

Coal—Solid, brittle, combustible rock composed of at least 50% (by weight) of carbon; formed from altered plant remains and classified by plant material(type), impurities (grade) and degree of metamorphism (rank).

Compression—The stress that tends to compress material, or shorten its length.

Crownhole—A bell-shaped hole at the surface caused by subsidence.

Depositional Environment—The sum total of all external conditions acting on the natural accumulation of rock forming material.

Drift—Applied to coal mining, an entry on the slope of a hill, driven horizontally into the coal seam.

Drilled piers—A circular column formed by a drilled hole, usually filled with concrete, used to support concentrated loads.

Entry – An opening or set of openings driven in coal for the purpose of developing a mining section.

Fault—A break in a mass of rock along which there has been movement parallel to the fracture.

Helical Pier—A steel tube or rod with helical flights (threads) that is screwed into soil or soft rock to form a support for foundation loads.

Haulageway—The entry or tunnel through which mine cars are hauled in and out of the mine.

Joint—Fractures in rock along which no appreciable movement has occurred.

Lignite—A soft, brownish-black coal of low rank and grade. (see coal)

Longwall Mining—A mining technique where the coal seam is removed in one continuous operation by means of a long working face or wall. The workings advance in a continuous panel which may be several hundred yards in length.

Mudstone—A rock made up of clay and silt sized particles.

Overburden—Material of any nature (rock or soil) that overlies a deposit of ore or coal.

Piping—The action of moving groundwater removing small soil/rock particles and creating new void space.

Potholes—A circular or funnel-shaped depression at the surface, caused by subsidence.

Pull Pillars—To remove the coal pillars.

“Rob”—To extract coal (or ore) previously left for support, to remove pillars without regard to maintaining the mine workings. Also used

where coal is removed illegally from beyond property boundaries.

Room and Pillar—A system of mining in which the coal is mined in rooms separated by narrow pillars.

Sandstone—A rock consisting of cemented or compacted sand-sized grains. These grains are commonly, but not always, composed of quartz.

Section - The working area in a coal mine operated by one crew of men.

Shaft—A vertical (or near vertical) excavation made for ventilation and hoisting equipment and personnel from underground workings. A mine will most often have two or more shafts.

Shale—A fissile, platy rock made up of clay-sized particles.

Siltstone—A rock made up of silt-sized particles.

Slope—An inclined tunnel driven from the ground surface to a coal bed or seam.

Strain—The change in length per unit length in a given direction. See Tension and Compression.

Stoping—upward propagation of subsidence along a dipping mined-out seam.

Subsidence—The lowering of the strata, including the surface, due to underground excavations, withdrawal of fluid, or loss of strength in the supporting material.

Swelling Soils—Clay soils that have the capability to expand when wetted. These soils may contain bentonite. Bedrock composed of clay can also swell.

Tension—A force tending to produce elongation or extension.

Tilt—The change in surface slope of a part of a subsidence trough.

Working Face—The place where the coal is actively being removed from the seam.

