continues until it reaches the surface, or the rock strata at the surface deform, causing a sag, slump, or actual hole. Of course, if this happens beneath a house, even in amounts far less than the maximum possible subsidence (Figure 7), it can damage the structure (Figures 8, 9, and 10).

It is difficult to predict if, when, or how much subsidence will occur over an abandoned mine, and the timing varies with geologic conditions and the mining method used. In room-and-pillar mines, such as those beneath Fairmont, the removal of pillars was often incomplete or haphazard. As a result, subsidence could have occurred in some areas right after mining, and in other areas may not happen for years to come. In contrast, subsidence occurs fairly soon over those areas mined by modern longwall machinery.

Subsidence Assistance

Once the Fairmont resident contacts the West Virginia Geological and Economic Survey, he is underminded, where can he go for further help? He should contact either the Abandoned Mine Lands section of the West Virginia Department of Energy (WVDOE), or the U.S. government's Office of Surface Mining (OSM). These two agencies work together investigating coal mining-related hazards which include not only mine subsidence but also abandoned mine portals, gob piles, old surface structures, and other dangers.

The mandate for this work comes from the Surface Mining Control and Reclamation Act (Public Law 95-87) signed into law on August 3, 1977 by President Jimmy Carter. Title IV of that law provides for a levy on current underground and surface-mined coal to finance correction of problems associated with mining that took place before the enactment date. Title V of the act places the liability for hazards or damages from mining after the enactment date on the responsible coal mining company.

If a coal mining-related hazard is life-threatening, OSM is responsible for investigating and taking action as quickly as possible. All other problems are referred to the WVDOE. Once the Fairmont resident files a complaint with the WVDOE, a field worker will inspect the damage. The most severe cases are given attention first, and after more investigation and review, a State-wide list of projects is compiled. The WVDOE then applies for a grant from OSM. A review of the proposed projects by OSM results in a final list and awarding of grant money to carry out the work. From 18 to 24 months are needed from the time a complaint is filed until work is begun to alleviate the problem.

Aid for the homeowner from the WVDOE comes in the form of an attempt to stabilize the surface, stopping further mine subsidence. This is done by drilling holes to locate the mine voids and attempting to fill them with gravel or a grout mixture of fly ash, sand, cement, and water. Since 1977, about $3 million has been spent on projects in the Fairmont area to stabilize mine subsidence.

The Surface Mining Control and Reclamation Act of 1977 does not allow the WVDOE to make repairs to a house. This expense is the responsibility of the homeowner. However, in 1982 the West Virginia Legislature made mine subsidence insurance available to all homeowners. If a homeowner has this coverage, and the damage is determined to be from mine subsidence, repair expenses up to $75,000 (minus a small deductible) will be paid by the insurance company. Normally, claims are not paid until surface stabilization efforts are completed.

If you want to know whether your property is undermined, or have questions about the geology of your area, contact the Coal Resources Section, West Virginia Geological and Economic Survey, P. O. Box 879, Morgantown, WV 26507-0879 (phone 304/594-2331). If you have a mine-related problem, contact the West Virginia Department of Energy, Abandoned Mine Lands Section, or the United States Government Interior Department, Office of Surface Mining. Consult the phone book for the office nearest you.
Figures 11 and 12. Fairmont then (Figure 11) and now (Figure 12). The exact date of the photo in Figure 11 is unknown, but it was probably made during the 1860s. The Watson-Pierpont mine tipple is shown on the B & O Railroad. The mine entry was above the tipple near the two low buildings in the center of the photo. This is the level of present-day Washington Street on which the first row of houses above the river is located in the center of Figure 12. The gabled house in the upper left of Figure 11 was the Ogden home. This site is now occupied by the Times-West Virginian newspaper offices on the corner of Quincy Street and Ogden Avenue (the low building behind the large house with two chimneys in the upper left of Figure 12).

(Figure 11 photo provided by West Virginia and Regional History Collection, West Virginia University Library. Figure 12 photo by Ray Strawsen)
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X-Radiographs of Coal

William C. Grady, Microscopist
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The same X-ray technique which shows fractures in bones is being used to show microscopic structures in West Virginia coals.

Within a few months of Wilhelm Roentgen's reported discovery of X-radiation in 1897, the new "roentgen rays" were being used in medicine. Since that time, radiography has been used extensively in medical investigations and has been adopted by other fields as a basic analytical tool.

Our laboratories have been using a new application of X-radiography to reveal the microscopic internal structures of coal. These structures are important to the users of coal, for they indicate how easily a coal can be cleaned and how much air pollution may be created when the coal is burned.

How X-Radiographs are Produced

X-ray photographs of coal are made in much the same way as chest X-rays are produced. The equipment required is a radiation-tight box, within which is placed an X-ray tube, the coal, and the film (Figure 1). The box is a lead-lined enclosure which looks much like an oven. However, the door is equipped with fall-safe interlocks which will shut off power to the X-ray tube should the door be opened while X-rays are being generated.

X-rays are generated by an X-ray tube which is in the top of the enclosure, and are directed down toward the coal and the film. The coal is placed directly upon the film. The X-rays preferentially pass through the coal and strike the film, thereby exposing it and producing the X-radiograph.

The intensity of the X-rays which pass through an object depends upon the chemical elements which make up the material. X-rays pass more easily through materials composed of "lighter" elements, but are absorbed by materials composed of "heavier" elements. This is why bones (composed mostly of the heavier element calcium) appear as clear, less-exposed parts of an X-ray negative, while muscles (composed of the lighter elements carbon, hydrogen, and oxygen) appear dark on the same X-radiograph. More X-rays pass through the muscle to expose the film than pass through the bone. The resulting radiograph is a film negative which can be used to produce photographs.

The passage of X-rays through coal is very similar. The bulk of coal is composed of carbon, hydrogen, and oxygen, which allow most X-rays to pass with little absorption. But minerals that form the ash and sulfur in coal are made up of silicon, aluminum, potassium, iron, sulfur, and calcium, which absorb X-rays. Thus these minerals tend to show up as light or white areas on X-radiographs.

What's So Unique About Our Radiographs?

The key factor in producing the detailed X-radiographic images shown here is the thinness of the coal slab. Using a thin saw blade imbedded with very small grains of industrial diamonds, we are able to cut slices of coal only 1/100th of an inch thick. Thin slabs of coal result in a much sharper radiograph because there is less blurring of the image.

Figure 1. Faxitron 804 unit for producing radiographs.
(Photo by the author)
The X-ray tube used for these images differs from the standard medical tube by having a small "focal spot." This results in more resolution, thereby revealing much finer detail than a typical chest X-ray. To achieve this detail we must expose the film for an extended period of time. Such long exposures would be dangerous to humans, but are obviously no problem with coal.

Although any black-and-white or color film could be used, special X-ray film works best. The film we use is even finer-grained than typical X-ray film, making it capable of producing very detailed radiographs. Because this fine-grained film is much slower than typical X-ray film, we must use an even longer exposure.

Useful Applications of X-Radiographs

The remarkably detailed X-radiograph in Figure 2 is an enlargement of the original radiograph. This image shows structures within the coal which can only be revealed by X-radiography. Further details in the radiograph can be seen under even higher magnification, as in Figures 3, 4, and 5.

Minerals in the coal show up extremely well, especially pyrite (the white spots in Figure 3). Pyrite is composed of iron and sulfur and accounts

Figure 2. Radiograph of a slab sawed from a 1-inch block of coal. Minerals, which absorb X-rays, appear white or light-gray. Coal, which passes X-rays, appears dark on the radiograph. (Photo by the author)

Figure 3. Radiograph showing pyrite crystals (white) in coal. The largest crystals are 200 microns (1/100 inch) across, and the smallest are about 20 microns (1/1000 inch). (Photo by the author)
for much of the sulfur in coal. Because it contains about 50% iron (by weight), it absorbs X-rays more than any other mineral in coal. This radiograph shows that the pyrite is scattered throughout the coal, and that the pyrite crystals are less than 1/250th of an inch in diameter. To coal-preparation engineers, this cautions that the pyrite cannot be effectively "cleaned" from this coal, and that this high-sulfur coal has limited use.

The "ash-forming" minerals, clays and quartz, appear as light bands in radiographs (Figure 4). The individual mineral grains are usually too small to be resolved. In this particular example, the radiograph shows that these mineral bands are too thoroughly mixed with the coal to be "cleaned" by coal preparation.

The carbon-rich coal itself appears dark in the radiograph. This part of the coal was formed 300 million years ago from plants which fell into a swamp. Some of the original plant structures are still preserved and are revealed in the radiograph. A small stem is shown by the wide, dark band near the top of Figure 2, and the lighter patches inside the stem are the cell-wall remnants of the original wood.

Cells within wood often contain waste products produced during the life of the plant. These too are preserved in the coal and appear as small dark ovals (center of Figure 5). These reveal a cross-section through some of the wood from which this coal formed.

Based on best estimates, the 1-inch-thick slab of coal shown here represents a span of 30 to 100 years of plant accumulation in a swamp that existed 300 million years ago.

This method of X-radiography provides scientists and engineers with unique images of coal which show its internal structure, its mineral composition, the distribution of the minerals, and the plant structures preserved in the coal.
How Fossil Fuels Cook

Joseph F. Schwietering, Stratigrapher

Take buried organic matter; add heat, pressure, time, and mineral catalysts; and voila! Fossil Fuels!

Fossil fuels such as natural gas, petroleum, peat, lignite, and coal are formed in the earth’s crust when organic matter is subjected to high temperatures and pressures in the presence of mineral catalysts. In essence, the organic matter is “cooked in a pressure cooker.” Which type of fossil fuel is produced depends mainly on the nature of the organic matter, the temperature at which it is cooked, and how long it is cooked. Let’s look closer at this analogy between cooking food and cooking fossil fuels.

Lower Temperature Equals Immature Fuels

A minimum temperature must be reached before cooking takes place. If food is left on the counter at room temperature (20°C/68°F) for a long time, it not only won’t cook, but will spoil as a result of the activities of microorganisms (mostly bacteria), fungi, and scavengers. Similarly, organic matter buried in swamps, and in sediments deposited in lakes and oceans at temperatures below 30°C (86°F) will be eaten or chemically and physically altered by microorganisms, fungi, worms and other burrowing animals. Aerobic organisms (those plants and animals that live in the presence of free oxygen) begin to consume the organic matter. When the free oxygen is used up, anaerobic organisms (bacteria that live in the absence of free oxygen) begin to digest the organic matter.

Any partially decomposed organic matter that remains after the aerobic and anaerobic organisms have finished is the source material of fossil fuels. At temperatures less than 60°C (140°F), immature fossil fuels are formed. These include peat, brown coal, lignite, biogenic gas (methane produced by bacteria; sometimes called “swamp gas”), and early dry gas (methane produced by chemical reactions)—see illustration.

Higher Temperature Equals Mature Fuels

Food cooked in a pressure cooker releases oils and gases to the air and water in the cooker as the temperature and pressure rise. Organic matter cooked in the earth’s crust also releases oils and gases to the surrounding environment when the temperature rises above 60°C (140°F). The pressure rises due to burial beneath, typically, several thousand feet of sediments. This rising pressure is important to the maturation of coal. At these temperatures and pressures, mature fossil fuels form, including wet gas (methane plus liquid hydrocarbons), oil, sub-bituminous coal, and high-to-medium-volatile bituminous coal (see illustration).

Here it is important to note that the temperatures shown in the illustration are only approximate. The exact temperature range in which a particular fossil fuel will form depends on the type of organic matter, the type of associated minerals and fluids, and the amount of time the organic matter is subjected to the highest temperatures in its burial history. The same level of “doneness” can be achieved by cooking either food or fossil fuels slowly at low temperatures, or rapidly at high temperatures.

Well Done

If we like food well done, we can cook it at high temperatures for long periods. At high temperatures, almost all the oils and gases are driven from food, and if the temperature is high enough, the oils are even converted to gases. Similar reactions take place in the earth’s crust. At very high temperatures, supramature fossil fuels form, including condensate (similar to gasoline), dry gas, low-volatile bituminous coal, and anthracite coal (see illustration). At temperatures above the “oil window” (the range in which oil forms), oil is converted to natural gas.

If food is cooked at a high temperature too long, only gas and the charred residue (charcoal) of the food will remain in the pressure cooker. In the earth’s crust, organic matter that is subjected to very high temperatures for a long time is converted to gases and graphite. (Graphite, like charcoal,