Coal Extraction—Environmental Prediction

Introduction

Coal from the Appalachian region has supplied energy to the Nation for more than 200 years. Appalachian coal fueled America through a civil war and helped win two world wars. Appalachian coal has also provided fuel for keeping America warm in the winter and cool in the summer and has served as the basis for the steel, automobile, organic chemicals, chlorine, and aluminum industries. These benefits have not come without environmental costs, however. Coal extraction and utilization have had significant environmental impacts.

Historically, coal extraction in the northern Appalachian coal fields has resulted in serious problems related to contaminated mine drainage. Acid drainage from closed and abandoned mines (both surface and underground) has far-ranging effects on water quality and, therefore, on fish and wildlife. Drainage from closed mines is particularly acidic in streams in Pennsylvania, Ohio, northern West Virginia, and Maryland. In contrast, drainage from abandoned mines in southern West Virginia, Virginia, and eastern Kentucky is rarely acidic, but in these areas other contaminants such as manganese and selenium are problematic in certain locations. Mine drainage from future mine closures may cause extensive degradation of rivers, particularly in the northern Appalachian coal region. Therefore, improved methodologies for mine-drainage prediction, mitigation, and remediation are urgently needed; such improvements will require an enhanced understanding of the geology and geochemistry of coal and coal-bearing strata.

To predict and help minimize the impact of coal extraction, the U.S. Geological Survey (USGS) is addressing selected mine-drainage issues through the following four interrelated studies:

- First, the spatial variability of deleterious materials in coal and coal-bearing strata is being evaluated systematically. This evaluation will aid in predicting mine-drainage water quality, will help regulatory agencies to improve mine-permitting procedures, and may thus enhance the recovery of coal reserves that might otherwise not be permitted under current conditions.
- Secondly, the kinetics of pyrite (FeS_2) oxidation and the formation of acid drainage from coal mines are being studied in the laboratory to improve the prediction of mine-drainage water quality.
- Thirdly, improved spatial geologic models are being developed to assess the potential for drainage from abandoned underground mines.
- Finally, methodologies for the remediation of waters discharged from coal mines are being tested, with the goals of reducing coal-mine-drainage treatment costs and improving water quality.

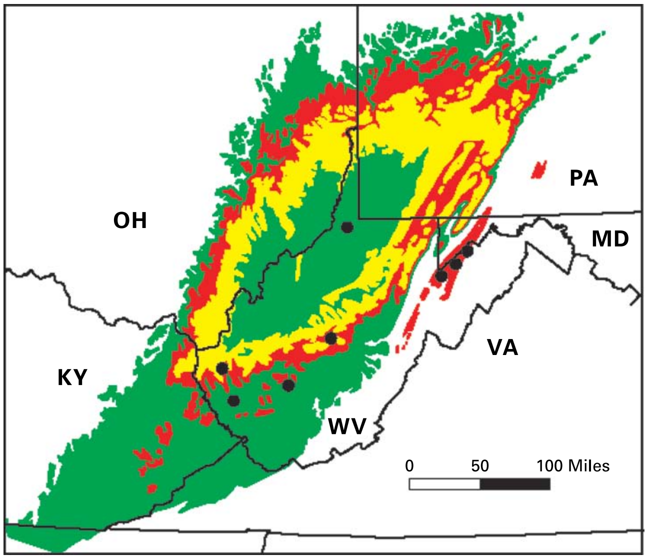


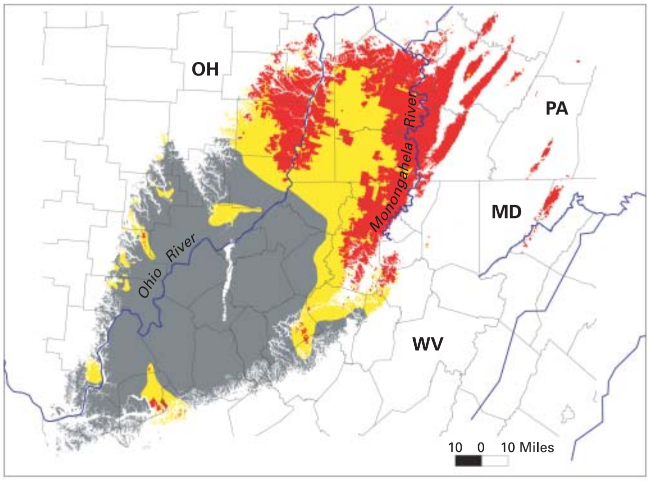
Figure 1. Distribution of coal-bearing strata in the Appalachian region study area. Dots indicate core-hole locations. Green, areas having a low potential for acid mine drainage (AMD) from surface mining; red, areas having high AMD potential; yellow, areas having intermediate AMD potential.

Spatial Variability of Deleterious Materials in Coal and Coal-Bearing Strata

The stratigraphic and regional variation of deleterious materials in coal and coal-bearing strata are controlled by geologic processes. The composition of coal that remains in the ground after mining influences ground-water contamination through oxidation and the leaching of minerals in the remanent coal. Scientists use the USGS coal-quality database (COALQUAL) to interpret geologic parameters that control the amount and composition of mineral matter in coal. Coal, however, is not the only contributor of contaminants, and so the USGS is conducting a systematic geological and geochemical study of strata associated with coal. This study will define the geologic parameters that control the spatial distribution of minerals in rocks that contribute to contaminated coal-mine drainage.

Presently, the permitting of surface mines, as related to potential mine-drainage water quality, is based on chemical data from analyses of core extracted from coal overburden. These data are collected without regard to geologic information other than lithology. A USGS coring study (fig. 1) will provide detailed geologic information on coal-bearing strata and quantify the spatial variability of minerals such as pyrite (FeS_2) and siderite (Fe_2CO_3), which contribute to contaminated mine drainage.

Figure 2. Areal extent of the Pittsburgh coal bed. Gray, area of thin and unminable coal; red, mined-out areas; yellow, area of possible future mining. Blue lines, major river courses.



Current USGS drilling and analyses have focused on coal-bearing strata in northern West Virginia that tend to be acid prone, as well as strata in the southern area that rarely produce acid mine drainage. The concentric patterns in figure 1 depict both the extent of coal-bearing strata in the study area and the possible risk of contaminated mine drainage from surface mining. Geological, chemical, and mineralogical data from the cores are then used to develop models that predict the spatial variability of deleterious materials in coal and coal-bearing strata.

Kinetics of Pyrite Oxidation

The acidity of coal-mine drainage is caused primarily by the oxidation of the mineral pyrite (FeS_2), which is found in coal, coal overburden, and mine waste piles. Pyrite oxidation and the consequent generation of sulfuric acid have long been recognized as major contributors to acid rock drainage, yet pyrite reactivity remains poorly understood. Some studies have suggested that pyrite reactivity is inversely related to particle size; other studies suggest that this relation is not always valid. For example, some varieties of megascopic pyrite are stable for years once exposed to the atmosphere, while other varieties begin to oxidize almost instantaneously.

Empirical results show that some coal-mine sites that appear to have similar sulfide contents and geologic settings have very different acid mine drainage (AMD) susceptibilities. These differences may be related to trace element occurrences in the pyrite crystal structure rather than to pyrite particle size and surface area. Arsenic is generally the most abundant minor constituent in pyrite, and its presence is thought to destabilize the pyrite structure, thereby making the pyrite more reactive. The USGS is further evaluating pyrite structure and composition to improve predictions of pyrite oxidation. To date, the studies have focused on determining the distribution of arsenic in pyrite in coal roof rocks (above a coal bed) and underclays (below a coal bed), both of which are potential waste rocks remaining after mining. Followup studies will monitor changes in the speciation of arsenic and other trace metals as pyrite undergoes controlled oxidation.

Improved Spatial Geologic Models of the Potential for Drainage from Abandoned Coal Mines

Abandoned underground coal mines in the Appalachians fill with water through surface recharge. These mines may act as a single hydrologic unit ("pool") if coal barrier pillars fail between mines. Water quality in the mines varies from nearly potable in southern West Virginia and eastern Kentucky to acidic water having high metal concentrations in the northern part of the Appalachian coal region. Mine pools in the Pittsburgh coal bed are of particular concern because of the vast areas of past and present mining (fig. 2). Water from abandoned mines along the eastern side of the Pittsburgh coal bed is being pumped and treated to prevent direct mine-water discharge into the Monongahela River drainage basin. In contrast, abandoned mines along the west side of the Pittsburgh coal bed (in the vicinity of the Ohio River) have had slower surface recharge, and their current surface discharge is minimal.

Because the impact of drainage from future mining is largely unknown, the USGS is developing a three-dimensional geologic model where scenarios can be tested to determine the size of barrier pillars necessary to prevent hydrologic connection between the eastern and western mined areas of the Pittsburgh coal bed. A "worst-case" scenario, in which barrier pillars fail and mine pools connect across the coal basin, could result in significant amounts of acidic water discharge into the Ohio River. A "best-case" scenario, in which barrier pillars are impervious, would limit contaminated drainage to presently affected areas.

Methodologies for the Remediation of Waters Discharged from Coal Mines

New and improved methodologies for the remediation of contaminated coal-mine drainage are needed in the Appalachian basin. Bench-scale testing of a method that uses ozone to oxidize and precipitate up to nine elements as oxides or hydroxides has been completed. This laboratory testing has demonstrated that ozone is effective at removing manganese, which is one of the more difficult metals to remediate. Ozone remediation, as developed by the USGS, is being field tested at a reclaimed surface mine in Lycoming County, Pennsylvania.

Summary

The U.S. Geological Survey has undertaken an interrelated set of activities that evaluate the following:

- the geologic controls on the spatial variability of deleterious materials in coal and coal-bearing strata that contribute to contaminated coal-mine drainage
- the factors that control the oxidation of pyrite—the primary cause of acid mine drainage
- the potential for drainage from abandoned underground coal mines
- improved methodologies for the treatment of waters discharged from coal mines

The goal of these activities is to improve the technologies underlying the prediction (prevention), mitigation, and remediation of contaminated mine drainage associated with coal extraction. As these goals are achieved, the recovery of coal resources will be enhanced.

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