

FIELD OBSERVATIONS OF POTENTIAL ACID SOURCES WITHIN SURFACE MINE BACKFILLS

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INTRODUCTION

Acid mine drainage (AMD) results from the oxidative dissolution of pyrite in the presence of oxygen and water, and migration of the oxidation products into the hydrologic system. Numerous laboratory and field studies have led to a good understanding of the reactions involved in producing AMD. However, the complex hydrogeochemical environment of a backfilled surface mine is not uniformly conducive to acid production and transport. Certain locations within the spoil, such as the near-surface zone, provide ideal conditions for AMD production: high oxygen content in the pore spaces, high moisture content, and access to hydrologic flow paths.

The concept of specific oxidative environments is the basis for many practices currently used or being tested to reduce acid formation. These practices include selective placement of pyritic material in the backfill, either "high and dry" or below the post-mining water table. In the former case, AMD is thought to be restricted by the lack of water and by isolation from the hydrologic flow path. Inundation supposedly restricts acid formation by restricting the availability of oxygen. Selection of appropriate abatement practices depends on a clear understanding of the important AMD sources within the backfill.

Over the past four years, the Bureau of Mines has conducted monitoring programs at several regraded surface coal mines. The contributions of various pyritic zones to AMD discharges were determined and related to the placement of the material with respect to oxygen sources and hydrologic flow paths. The results of these studies provide some insight into the inherent oxidative capacity of certain backfill locations. In this paper, field observations are presented according to pyritic material location in the backfill and summarized in a conceptual model. The model is then used as a framework for discussion of the effectiveness of practiced and proposed AMD abatement procedures.

FIELD OBSERVATIONS

Most of the observations discussed in this section were made during the course of detailed studies at three regraded surface mines located in Upshur County, West Virginia (UP1), and Fayette (FA1) and Clarion Counties (CL1),



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Pennsylvania. Additional data were obtained during limited investigations at three other sites in Pennsylvania (GR1, CF1, and WE1). More detailed discussions of several of the sites have been presented elsewhere (Ladwig and Campion, 1985; Lusardi and Erickson, 1985; Bureau of Mines, 1985).

Methods applied to assess the acid drainage system varied somewhat from site to site. All studies had in common monitoring of discharge seeps and the saturated zone within the backfill. In some cases, preliminary evaluation of potential acid sources and backfill hydrology were accomplished by the use of electromagnetic conductivity surveys (Ladwig, 1982).

Spoil analyses by the acid-base account (Sobek et al., 1978) and simulated weathering (Caruccio and Geidel, 1981) methods were conducted on selected drill cutting and core samples obtained during monitoring well installation. Pore gas composition was determined on samples collected from multi-port sampling wells (Erickson et al., 1985) located in the unsaturated spoil at several sites.

For the purposes of this paper, data from the field studies were examined in terms of pyritic material location with respect to oxygen sources, water sources, and hydrologic flow paths. The field observations are presented according to vertical and lateral placement within the spoil.

Vertical Placement

The role of vertical position on AMD formation from pyritic spoil appeared to depend most strongly on the availability of oxygen. Oxygen enters the spoil at the air/backfill interface and diffuses downward. Within the spoil, oxygen is consumed in the acid-producing reactions, the rates of which are thought to be linearly dependent on oxygen availability (dissolved oxygen concentration or pore gas partial pressure). Pore gas composition data obtained at several sites were used to determine vertical oxygen profiles and identify oxidation zones.

As expected, the oxygen content of spoil pore gas decreased with depth. However, the O₂-depth profile shape varied among sites and within a single site, as shown in Figure 1. The sharpest gradient (change in O₂ per depth change) was almost invariably found near the surface. We interpreted the gradient to be an indicator of pyrite oxidation. The interpretation is supported by spoil and pore gas composition data from site CL1 (Table 1): the highest O₂ gradients were associated with the most pyritic spoil.

Although the sharpest O₂ gradients were usually located near the surface, significant gradients were also observed at greater depth (see G1 profile, fig. 1). These zones are interpreted as evidence that pyrite oxidation occurs well below the spoil surface. High gradients were found where the pyrite concentration was high and where less pyrite was available nearer to the surface (figure 2). These observations are consistent with the expected reaction kinetics.

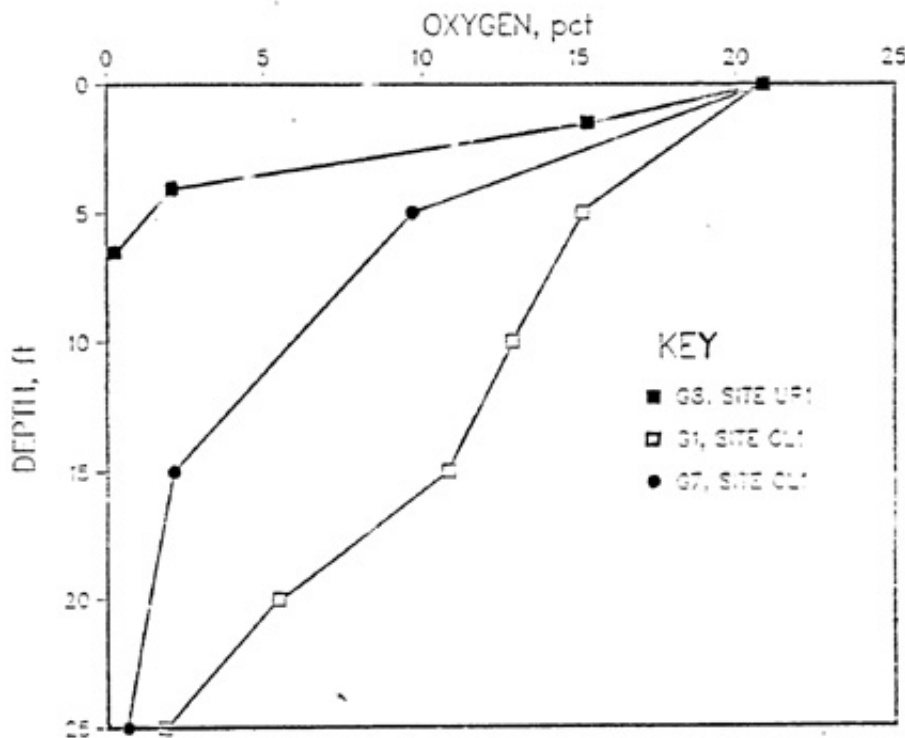


Figure 1. Typical average oxygen profiles in coal mine spoil.

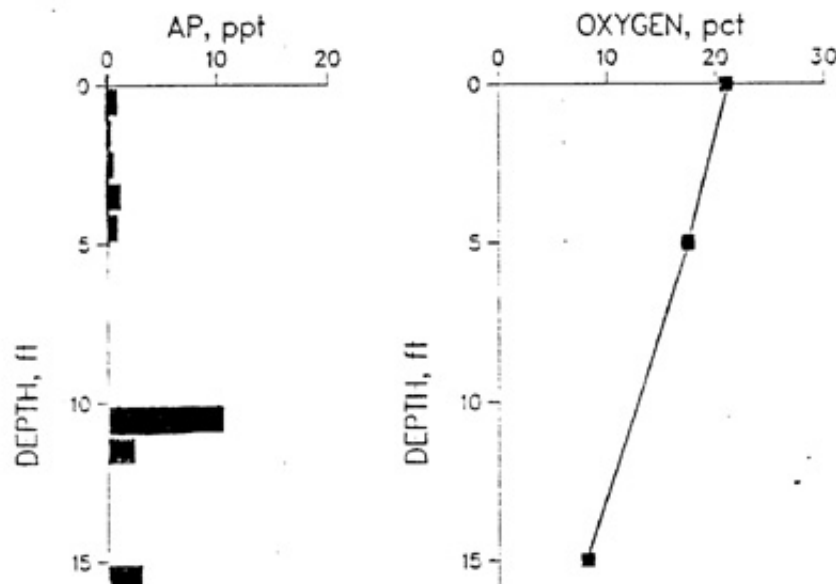


Figure 2. Spoil acid potential (tons/1000 tons or ppt) and oxygen profile for well pair G9-W10 at site CL1. Gradient is slightly steeper in lower zone.

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Well Pair ¹	O ₂ pct O ₂ /5 ft	AP tons CaCO ₃ /1000 tons
G1 - W2	5.9	2.4
G3 - W4	13.8	7.3
G5 - W6	15.4	10.5
G9 - W10	3.5	0.8
G11 - W8	6.3	4.3

¹Spoil samples from water wells (W) and oxygen measurements from gas-sampling wells (G) located within 120 ft of each other.

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In most cases, little oxygen was available in the pore gas near the saturated zone. For example, at site CL1, mean O₂ values within 5 ft of the water table ranged from 0.6 to 6.4 pct. One would expect that the saturated zone in equilibrium with oxygen-depleted pore gas would have a low dissolved oxygen concentration. At sites UP1 and FA1, well water samples contained only 0.1 to 0.2 mg/L dissolved oxygen. Thus, the rate of acid production in the saturated zone should be slow in comparison to shallowly-buried spoil of equal pyrite content.

Water quality data supported the generally accepted hypothesis that perennially saturated spoil contributes little to acid production. If oxidation occurs in the saturated zone, then contaminant levels might be expected to increase along the flow path toward the discharge point. This was clearly not the case at site FA1, where sulfate concentration at the discharge seep was somewhat lower than sulfate concentrations in wells located 700 to 2600 ft upgrading (table 2), despite the occurrence of widely disseminated pyrite. In general, variations in saturated zone water quality were found to be due to secondary reactions (Ladwig and Campion, 1985).

Table 2. Mean sulfate concentrations in spoil water measured at various distances from the discharge, site FA1.

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Sampling Location	Mean sulfate concentration, mg/L	Approx. distance from discharge, ft
Well 6	6200	2600
Well 10	5660	1700
Well 17	5790	1300
Well 20	5420	700
Seep 27	4610	0

The intermittently saturated zone may allow for both oxidizing conditions at low water levels and contaminant flushing at high water levels. Assuming that pyritic material is located in this zone, the degree to which it will influence spoil water quality depends on the depth of the zone, amplitude of water level fluctuations, and oxygen availability. The difference can be illustrated by comparison of wells W4 at site UPI and W7 at site FA1.

Characteristics of the two wells are shown in Table 3. At both sites, recharge to the areas appears to be primarily influent ground water rather than direct infiltration. At W4 the water table fluctuates in a near-surface zone, thereby flushing contaminants at high water levels. Conversely, at W7 low-amplitude fluctuations in a deep, oxygen-depleted zone result in a different response. Clean ground water recharge dilutes rather than flushes contaminated spoil water.

Table 3. Characteristics of water quality in the zone of intermittent saturation. Data from 1985.

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Sample location	Depth to high water level, ft	Amplitude of fluctuation, ft	Oxygen	Sulfate, mg/L at extreme water levels	
				lowest	highest
Site UPI, W4	3	8	Yes	445	1600
Site FA1, W7	94	3	No	2850	750

Lateral Placement

The effects of lateral placement on acid production and transport can be described in terms of three zones: near slope faces, interior, and near highwalls. The first of these zones is conducive to oxidation because of high permeability to air and water. The last zone is often a source of ground water recharge that enhances oxidation product transport. The interior of the backfill was the basis for most of the discussion of vertical placement.

In general, the high permeability of sloped areas resulted in higher oxygen content at depth and water quality changes. At site UPI, the outslope was composed of large, blocky rocks, visible where the vegetation was sparse. A gas sampling well located near this area showed an oxygen profile typical of slopes (figure 3). Unlike the profiles from interior -spoil (fig. 1), the oxygen content did not consistently decrease-with depth. Lateral air advection through the slope face could give rise to such a profile. Increased oxygen at depth was also observed at a mined isolated ridge, where moderately steep slopes comprised about three-quarters of the site perimeter.

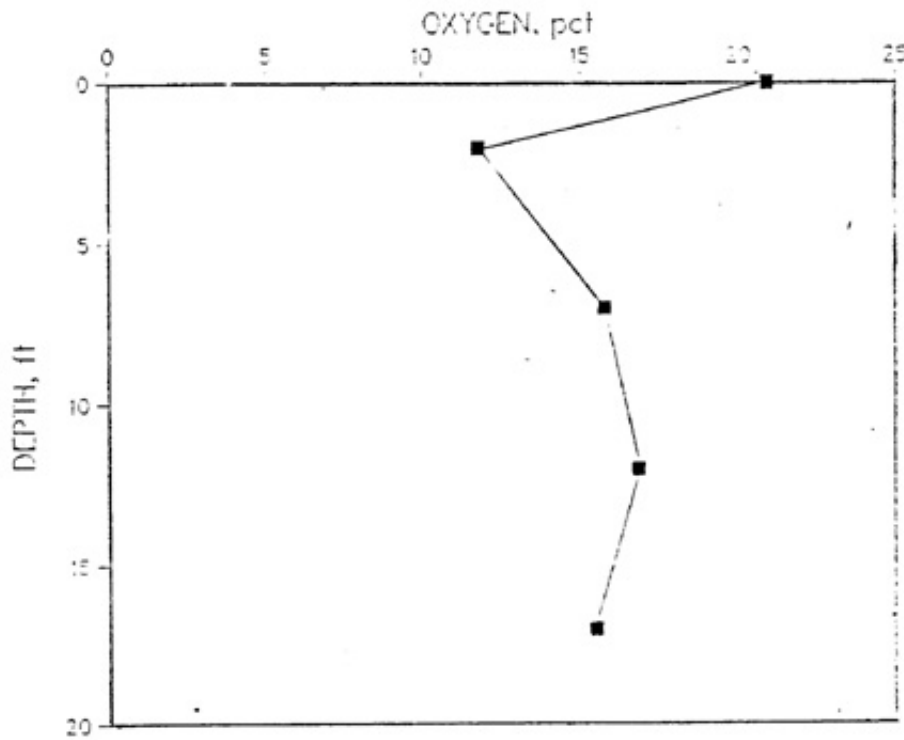


Figure 3. Oxygen profile from gas-sampling well G5 on the outslope of site UP1.

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In the case of site UPI, spoil sampled from a drill hole near the oxygenated slope showed a relatively low acid potential (total sulfur less than 0.3 pct by weight). Although the outslope appeared to contribute little to the acid load, secondary changes occurred in the water as it flowed through the oxygenated spoil. Relative to the nearest interior water well, the seep showed increased acidity and aluminum, decreased pH and iron, and unchanged sulfate content. The oxygenated zone probably caused ferrous iron oxidation; subsequent hydrolysis could lower the pH to the range of aluminum solubility.

In contrast to the outslope at site UPI are slopes composed of highly pyritic material. At site GR1, for example, the slope leading to the toe of spoil was a primary acid source. Contaminant concentrations at the toe seep were approximately 45 pct higher than in spoil water sampled from three wells located in the backfill interior. When the discharge point was relocated away from this zone by breaching a clay vein, the seepage quality improved quickly until it was similar to well water quality. At site M, the most heavily contaminated of the spoil water discharges was an intermittent seepage area on a slope adjacent to moderately acidic material. Contaminant concentrations approximately doubled just prior to discharge at site WE1.

The effect of pyritic material placement near a buried highwall could not be so clearly defined at the study sites. The discontinuity in both material (mined versus intact) and topography at the highwall/fill interface may lead to increased permeability. Evidence for this was observed at site UP1, where a reduced-height highwall remained after regrading. Surface water that ran down the highwall face completely disappeared into the spoil at its base. Although the effect on acid production was not measured, the highwall interface certainly effects product migration through ground water recharge and surface infiltration.

DISCUSSION

The field observations can be summarized and discussed in terms of the conceptual model of backfill environments presented in Figure 4. The most oxidizing conditions prevailed in zone I. Because of high permeability, the most steeply sloped portion of zone I (Ib) is probably inherently most conducive to AMD formation and transport. This area could be most significant at mountaintop removal sites where slopes comprise a greater fraction of the surface area. Placement of pyritic material in zone I, even with a vegetated soil cover overlying it, would most likely result in acid production.

Zone II differs from zone I mainly in the amount of oxygen available for reaction. At the three sites where gas-sampling wells were installed, oxygen content decreased with depth in the backfill interior. Nonetheless, oxygen gradients were observed in zone II when overlying material had a low pyrite content. The demarcation between zones I and II is somewhat arbitrary. In our field studies, the bottom of zone I appeared to be within 5 ft of the surface. However, these sites represented disseminated pyrite or localized placement near the surface; none of the sites allowed investigation of a near-surface layer containing no pyrite. Other studies have shown that a soil cover is not effective in eliminating oxygen transfer into spoil, although some O_2 consumption occurs by processes other than AMD production.



Pyritic material in zone II may contribute significantly to AMD discharges if the overlying zone is deficient in pyrite-and if infiltrating precipitation provides product transport. The concept of "high and dry" selective placement calls for pyritic material to be placed in an impermeable section of zone II. However, we did not observe the necessary dry conditions in zone II of any of the field sites. Special reclamation practices are probably required to induce a non-weathering environment.

The saturated spoil in zone IVb was not found to be a significant source of AMD at the study sites. Little oxygen was found in the water or in pore spaces immediately overlying the water table. Zone IVa contributed to the AMD system at site UPI, where high water table elevations intercepted oxygenated, pyritic spoil. Although zone IVb is, conceptually, least conducive to oxidation, it is difficult in practice to place pyritic material such that it will be permanently saturated. If the material is accidentally placed in zone IVa, as at site UPI, there would be no benefit from selective placement, and AMD discharges may be worse than if the material were placed in an impermeable section of zone II.

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