CHAPTER 2: HOW GEOLOGY AFFECTS MINE DRAINAGE PREDICTION

by

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INTRODUCTION

Acid mine drainage (AMD) is a major problem in the northern Appalachian Basin, particularly within the Allegheny Group stratigraphic section (Appalachian Regional Commission, 1969; Wetzel and Hoffman, 1989). AMD is much less significant in the midwestern states, and so this chapter and the next emphasize the Appalachian states. Figures 2.1 and 2.2 illustrate the extent of contamination in the northern Appalachian Basin, using data from Wetzel and Hoffman (1983). It should be noted that the distribution of contaminated mine water is not simply a function of the amount of pyrite and limestone in the overburden. For instance, some watersheds are much more intensely mined than other watersheds, and some watersheds on the periphery of the basin may have little or no coal. However, some general statements on the distribution of water quality problems can be made. The West Branch of the Susquehanna River has the highest percentage of streams with pH less than 6.0 (56%). This watershed has a correspondingly high percentage of streams with sulfate above 75 mg/L, indicating that the proportionally low pH is due to mining. The other two watersheds with greater than 35% of the streams having a pH less than 6.0 occur where mining would have encountered the Allegheny Group. Watersheds in southern West Virginia and Kentucky that have sulfate concentrations above 75 mg/L in greater than 35% of the streams illustrate that high sulfate does not necessarily correspond with low pH; none of the sampled streams have a pH less than 6.0.

Although there is a general relationship between geology and mine drainage quality, no comprehensive study relating geology and mine drainage quality has been attempted for the entire Appalachian basin. An examination of geologic studies suggests some significant differences in mineralogy for the southern (Pottsville) and northern (Allegheny through Dunkard) Appalachian strata (e.g., Cecil et al., 1985; Donaldson et al., 1985a). Four principal geologic processes have contributed to the variability of coal properties and the chemistry/mineralogy of the intervening strata. Two of these, paleoclimate and paleodepositional environment, date back hundreds of millions of years to the Pennsylvanian Period. The other two, surface weathering and glaciation (in the northern part of the basin), are more recent, occurring within the past few million years.

The paleoclimatic and paleodepositional environmental influences on rock chemistry in the northern Appalachians resulted in the formation of coal overburden with greatly variable sulfur content (0% to >10% S) and calcareous mineral content (0% to >90% $CaCO_3$). The wide variations in rock chemistry contribute to the wide variations in water quality associated with coal mines.

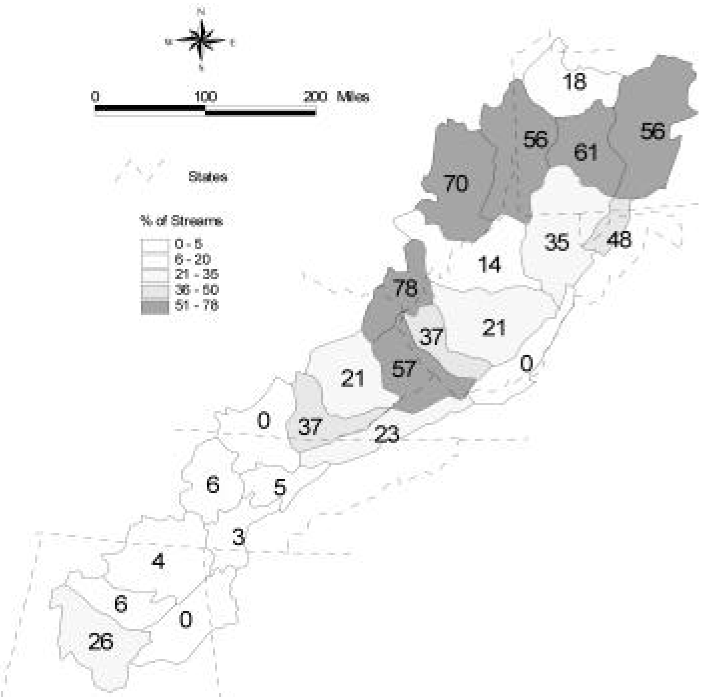

Figure 2.1. Percentage of Streams in the Watersheds with a pH less than 6.0

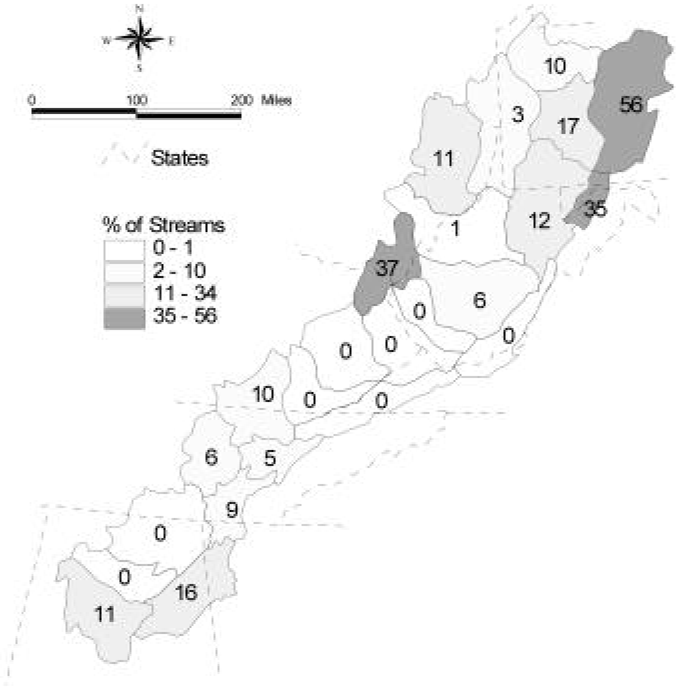

Figure 2.2. Percentage of Streams in the Watersheds With Median Sulfate > 75 mg/l

GEOLOGIC FACTORS

Paleoclimatic Influences

Various attempts have been made to reconstruct the paleoclimate of the northern and central Appalachian Basin during the Pennsylvanian (Cecil et al., 1985; Donaldson et al., 1985a; Phillips et al., 1985; Winston and Stanton, 1989). The models developed in these studies differ as to how wet or dry the upper Pottsville was, but they agree that at the time of deposition of the Allegheny Group, the climate was moderately wet, although drying as the deposition continued. All agree that during deposition of the Conemaugh Group, it was dry. The base of the Monongahela was deposited in a wet period, and the climate probably became drier higher up in the section. Cecil et al. (1985) and Donaldson et al. (1985a) concluded that the period during which the Dunkard was deposited was comparatively dry.

Cecil et al. (1985) suggest that climate affected the shape of the peat deposits, the chemistry of the swamp and ultimately the chemistry of the coals. Periodic dry conditions would allow the surface of the peat to dry, oxidize, and degrade, thus increasing ash content. These conditions, taken together, would result in higher sulfur and ash in the northern Appalachian coals. Cecil et al. believe that this explains why the coals of the southern Appalachian Pottsville Group are lower in sulfur (typically <1% sulfur) and ash (typically lower than 10% ash) than the younger coals of the northern Appalachians (typically >1% sulfur and >10% ash) (Figures 2.3 and 2.4).

As with coal quality, Cecil et al. (1985) and Donaldson et al. (1985a) concluded that overburden strata are also influenced by paleoclimate. The drier conditions during the Upper Pennsylvanian (upper Allegheny and younger strata) resulted in the common occurrence of freshwater limestones, calcareous cements, and calcareous concretions in non-marine sandstones and shales.

A second category of geologic processes that influenced the chemistry and mineralogy of Pennsylvanian Period coal-bearing sediments, including the distribution of calcareous and pyritic rocks, was depositional environment. Typically, within the Pennsylvanian, paleoenvironment is classified as freshwater, brackish and marine (Williams, 1960). These three categories are not evenly distributed geographically or stratigraphically.

Paleoenvironmental Influences

Paleoenvironment is an important control on the distribution of carbonates and pyrite. Marine limestones can have significant alkalinity-generating capability, and mines that encounter these limestones generally produce alkaline drainage. Freshwater limestones are common in the upper Allegheny and Monongahela Groups. Mines that encounter these limestones, likewise, routinely produce alkaline drainage. Brackish environments typically lack calcareous minerals, with siderite being the only carbonate present. Overburden of marine and brackish origin often have much greater thicknesses of high sulfur strata than overburden of freshwater origin. Brackish environments therefore cause strata to be high in sulfur and low in calcareous minerals, which often results in AMD. These paleoenvironmental influences on the distribution of carbonates and sulfur (pyrite) will be examined in more detail below.

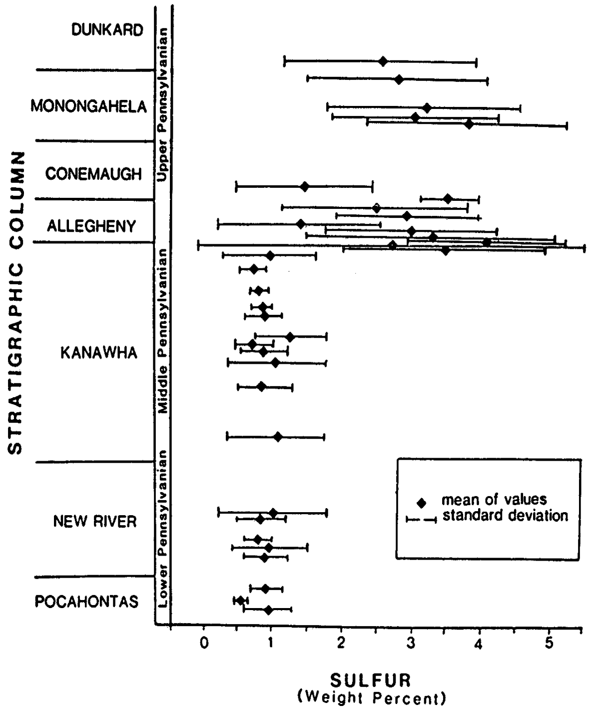

Figure 2.3. Stratigraphic variation of sulfur content for 34 coal beds of the central Appalachians (Cecil et al., 1985).

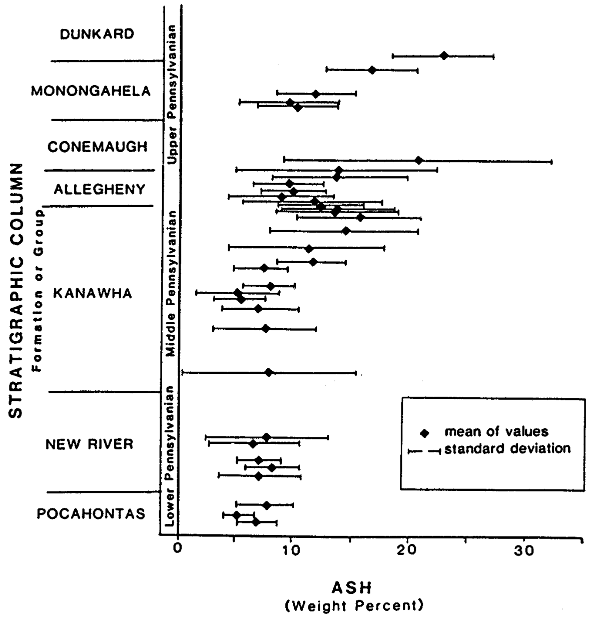

Figure 2.4. Stratigraphic variation of ash content for 34 coal beds of the central Appalachians (Cecil et al., 1985).

Depositional Environments of Iron Sulfide Minerals

Guber (1972) found that the highest sulfur in rocks overlying the lower Kittanning coal in north-central Pennsylvania was associated with sediments deposited under brackish conditions (Degens et al., 1957; Williams and Keith, 1963). Guber concluded that a brackish environment provides optimum conditions for pyrite formation, with sulfate derived from the brackish water and iron from the nearby terrestrial sources. These sources, coupled with high organic content, provide optimum conditions for pyrite formation: a reducing environment with an ample supply of sulfur and iron.

Relationships between sulfur and depositional environment for coal have also been documented in Texas and Australia. In Texas, Eocene coals deposited in marine and brackish lagoonal environments typically have the highest sulfur (S) concentrations (1.5 to 2%), while alluvial plain coals exhibit the lowest S values (< 1%). Deltaic coals are intermediate in S (1 to 1.5%) (Kaiser 1974, 1978). Permian coals in Australia deposited in lower delta plain facies usually contain > 0.55% S, whereas those associated with braided fluvial facies found further inland, usually on alluvial plains, contain < 0.55% S. Upper delta plain coals, which are located between the lower delta plain and the alluvial plains, are typically of intermediate sulfur (Hunt and Hobday, 1984).

Englund et al. (1986) noted that sulfur in the Pottsville Group Pocahontas No. 3 coal in southern West Virginia and western Virginia was highest at the margins of the deposit (0.9%) and lowest away from the margins (0.4%). Two studies of the Allegheny Group upper Freeport coal in southwestern Pennsylvania show similar trends. Skema et al. (1982) found that coal near the margins contained 4 to 5% sulfur, while coal toward the center of the deposit had 1 to 2% S. Sholes et al. (1979) found that coal near the margins had 5 to 6% S, and 3% or less in the center.

Some of the examples cited above show well-documented relationships between sulfur in coal and paleodepositional environment. However, even where present, the relationships between sulfur and paleodepositional environment are region-specific. For example, the freshwater coals of northern Appalachia are generally higher in sulfur than the marine coals of Texas. Therefore, the use of high and low sulfur as a predictive tool for paleodepositional environment should be used with extreme caution.

Changes in percent sulfur have also been observed at a more local level than discussed above. Studies of the vertical distribution of sulfur in coal have been done for coals around the world, encompassing various geologic periods and coal rank. Increased sulfur at the top and bottom of coal seams appears to be typical. This has also been observed in coal seams of the northern Appalachian basin. Reidenour et al. (1967) found higher sulfur at the top and (sometimes) bottom of Clarion and lower Kittanning coals in Clearfield County that have roof rocks that were deposited in a brackish depositional environment. Appalachian coals interpreted to have been deposited in a freshwater depositional environment also show high sulfur at the top and bottom of the seam (Cheek and Donaldson, 1969; Donaldson et al., 1979; Donaldson et al., 1985b; Hawkins, 1984).

It cannot be assumed that high sulfur in the upper portion of a coal bed, or high sulfur within a coal bed, are evidence of marine influence. Paleoenvironmental interpretations using sulfur alone may not be valid. The fact that high sulfur is frequently found at the top and bottom of coal seams, regardless of paleoenvironment, is, however, important from a mining standpoint. The top and bottom of a coal seam are the most likely to be left behind on the mine site as pit cleanings because of high sulfur or ash, or as coal that is not recoverable in the mining process. The acid potential from this source must be considered in any evaluation of potential acid-materials problems.

Pyrite and Other Forms of Sulfur

Although pyrite may comprise only a few percent, or even a fraction of a percent, of the overburden rock, its importance to post-mining water quality far outweighs its seemingly minor presence. An overburden that averages just a fraction of a percent sulfur, in the absence of neutralizing rocks, can create significant post-mining water quality or revegetation problems, if not dealt with properly.

Forms of sulfur that occur in coal overburden are sulfide, sulfate and organic. Two iron sulfide minerals occur in the majority of bituminous coal and overburden: pyrite and marcasite. Both have the chemical formula FeS_2 and are 53.4% S, with the remainder being iron, but the two minerals have different crystallinity. For simplicity, we will refer to iron sulfide minerals as pyrite. Excellent explanations of the series of chemical reactions by which AMD is produced from pyrite and other iron sulfide minerals are found in Evangelou (1995), Kleinmann et al. (1981), Lovell (1983), Rose and Cravotta (1998), and Singer and Stumm (1968, 1970). Data and discussion of factors related to pyrite oxidation rates are contained in Braley (1960), Clark (1965), Cravotta (1996), Hammack and Watzlaf (1990), McKibben and Barnes (1986), Moses et al. (1987), Moses and Herman (1991), Nicholson et al. (1988), Rimstidt and Newcomb (1993), Rose and Cravotta (1998), and Watzlaf (1992).

Sulfate minerals are generally secondary weathering products of pyrite oxidation. Nordstrom (1982) shows the sequence by which these minerals can form from pyrite. Many sulfate minerals have been identified in overburden, including those listed in Table 2.1. These minerals (with the exception of barite) are typically very soluble and transient in the humid east. They form during dry periods and then are flushed into the groundwater system during precipitation events. The phases that contain aluminum or iron are essentially stored acidity and will produce acid when dissolved in water. Gypsum, which is not acid forming, is relatively uncommon in Northern Appalachian Basin coal-bearing rocks, whereas other sulfate minerals such as pickeringite and halotrichite occur more commonly. Additional information about these sulfate minerals is found in Cravotta (1994), Lovell (1983), and Rose and Cravotta (1998).

Organic sulfur is sulfur that is tied up in organic molecules. This sulfur can originate by two processes: it can be associated with the original plant material, and it can be complexed with organic molecules during diagenesis. Organic sulfur is not acid forming (Casagrande et al., 1989).

When overburden is analyzed, weight percent total sulfur is generally determined as a means of estimating pyritic sulfur and thus the acid-producing potential of the rock. Because of difficulties with analytical methods, added cost of analysis, and the fact that most sulfur in overburden rock is pyritic, typically only total sulfur is determined. However, when forms of sulfur are determined, organic sulfur estimates are usually determined by difference (Noll et al., 1988); that is, total weight percent sulfur minus pyritic sulfur and sulfate sulfur. As a result, pyritic or sulfate sulfur are sometimes underestimated during analysis, which causes the organic sulfur fraction to be artificially elevated and apparently acid-forming.

Table 2.1. Secondary sulfate minerals identified in western Pennsylvania mine spoil and overburden. (Minerals from Cravotta (1991, 1994), L. Chubb and R. Smith (PA Geologic Survey, personal communications), and observations by the authors. Mineral chemistries are from Roberts et al. (1990).

Acid-Producing

Pickeringite: $MgAl_2(SO_4)_4 \cdot 22\ H_2O$
Halotrichite: $Fe^{+2}Al_2(SO_4)_4 \cdot 22\ H_2O$
Alunogen: $Al_2(SO_4)_3 \cdot 17\ H_2O$
Copiapite: $Fe^{2+}Fe^{3+}(SO_4)_6(OH)_2 \cdot 20\ H_2O$
Copiapite Group: aluminocopiapite with Mg?
Coquimbite: $Fe_2(SO_4)_3 \cdot 9\ H_2O$
Roemerite: $Fe2+Fe23+(SO_4)_4 \cdot 14\ H2O$
*Jarosite: $KFe_3^{+3}(SO_4)_2(OH)_6$

Non-Acid-Producing

Gypsum: $Ca(SO_4) \cdot 2\ H_2O$
Epsomite: $MgSO_4 \cdot 7\ H_2O$
Barite: $BaSO_4$

*Jarosite is less soluble than the other acid-producing sulfate minerals.

Typically, higher sulfur values will be found in marine mudstones than in freshwater mudstones, and carbonaceous rocks will typically contain more pyrite than non-carbonaceous rocks for any given paleoenvironment. A positive linear relationship has been shown between percent organic carbon and percent sulfur for Recent and Pleistocene marine sediments (Goldhaber and Kaplan, 1982; Raiswell and Berner, 1986). The higher the content of organic matter, the darker the rock tends to be. If a mudstone is known to be of marine or brackish origin and it is dark in color, there is a good chance that it is also high in sulfur. Carbonaceous rocks (> 5% organic carbon) may be high in sulfur, at least relative to other rocks, regardless of paleoenvironment. This can be useful in helping to identify potentially high sulfur rocks in the field or in drill cuttings/cores.

Considerable effort has been expended over the years looking at pyrite morphology and attempting to relate this to acid generation. Some of the earliest work is by Caruccio (e.g. 1970); however, numerous other individuals have also examined this issue. Pyrite occurs in several crystal morphologies, ranging from micron-size to millimeter (or larger) crystals and coatings. Pyrite genesis has been suggested as a factor influencing pyrite reactivity. For example, sedimentary pyrite is more reactive than hydrothermal pyrite (Borek, 1994; Hammack et al., 1988). Most pyrite associated with the northern Appalachian Basin is sedimentary in origin.

Morrison (1988) defined nine classes of pyrite morphology, end members being framboidal and euhedral crystal structures. Framboidal pyrite consists of aggregates of very small pyrite crystals (<1 micron in size), while euhedral are generally larger (tens to thousands of microns). Framboidal pyrite therefore has a proportionally larger surface area than euhedral crystals. Classification systems have also been discussed (e.g., Arora et al., 1978; Hawkins, 1984). Caruccio (1970) and Morrison (1988) found a relationship between relative surface area and acid production, with the small particles being more reactive.

Normally, determination of total sulfur will adequately serve as a proxy for acid potential. This is because it includes the sulfur from acid-generating sulfide and sulfate minerals and typically the amount of organic sulfur in overburden rock is insignificant. In locations where gypsum and other sulfur-bearing, non-acid-forming materials are abundant, accurate determination of sulfide sulfur should provide a better prediction of acid potential.

Table 2.2 is included in this section to provide typical and extreme examples of acidity, alkalinity and related water quality parameters in coal mine drainage and nearby well and spring samples. These water samples were compiled from tables contained in Hornberger and Brady (1998) and Brady et al. (1998a) to illustrate mine drainage quality variations in Pennsylvania. Similar variations in mine drainage quality exist in the other states in the Appalachian Basin.

In Pennsylvania coal mine drainage, some of the most extreme concentrations of acidity, iron and sulfate have been found at the Leechburg Mine refuse site in Armstrong County, and at surface mine sites in Centre, Clinton, Clarion and Fayette Counties, as shown in Table 2.2. Acidity concentrations of seeps from Lower Kittanning Coal refuse at the Leechburg site exceed 16,000 mg/L (as $CaCO_3$), while the sulfate concentration of one sample exceeds 18,000 mg/L. At a surface mine on the Clarion Coal in Centre Co., a 35 gpm (132.5 L/min) post-mining discharge had an acidity concentration over 9,700 mg/L with an iron concentration of almost 2,000 mg/L. A water sample from a pit in Fayette County had an acidity concentration greater than 5,900 mg/L and an iron concentration greater than 2,000 mg/L. Schueck et al. (1996) reported on detailed AMD abatement studies conducted at a backfilled surface mine site in Clinton County. A monitoring well there penetrated a pod of buried coal refuse and produced a maximum acidity concentration of 23,900 mg/L and a mean acidity concentration of 21,315 mg/L, based on 13 samples. The maximum concentration of iron was 5,690 mg/L and the maximum sulfate concentration was 25,110 mg/L in the same monitoring well. Toe of spoil seeps at the Clinton County site have acidity and sulfate concentrations greater than 3,500 mg/L and 3,700 mg/L, respectively.

Carbonate Minerals and Their Importance in Mine Drainage Quality

Carbonate minerals form under marine and freshwater environments. Marine limestones, or other calcareous marine rocks, play a significant role in preventing acid drainage in the Appalachian Basin. Marine limestones also significantly contribute to the alkaline water of the Illinois Basin and the Western Interior Coal Province.

Marine rocks in the northern Appalachian Basin occur principally in the lower Allegheny Group and the Glenshaw Formation. The rocks represent open marine to marginal marine (brackish) conditions. The open marine facies are frequently limestone or calcareous shales. Brackish facies often lack

Table 2.2 Water Quality Parameters at Mine Sites in Pennsylvania.

Site Name	County	pH	Alkalinity	Acidity	Fe	Mn	Al	SO_4	Type of Sample
			mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	
Leechburg	Armstrong	2.4	0.0	16594.0	> 300.0	16.5	> 500.0	11454.0	Seep
Leechburg	Armstrong	2.4	0.0	16718.0	> 300.0	19.3	> 500.0	18328.0	Seep
Leechburg	Armstrong	3.1	0.0	1368.0	> 300.0	13.9	82.3	1896.0	Deep Mine Discharge
Leechburg	Armstrong	2.0	0.0	10383.5	2200.0	3.3	N.D.	14565.2	Diversion Ditch Discharge
Trees Mills	Westmoreland	2.5	0.0	3616.0	190.4	13.5	73.1	1497.8	Deep Mine Discharge
Lawrence	Fayette	2.2	0.0	5938.0	2060.0	73.0	146.0	3600.0	Pit Water
Lawrence	Fayette	2.6	0.0	1840.0	166.0	89.0	85.0	2700.0	Surface Mine Discharge
Blue Lick	Somerset	2.9	0.0	2594.0	> 300.0	35.7	180.0	2701.0	Seep
Stott	Centre	2.7	0.0	9732.0	1959.8	205.3	N.D.	4698.0	Surface Mine Discharge
Stott	Centre	2.8	0.0	4520.0	4880.0	149.5	N.D.	5139.4	Surface Mine Discharge
Orcutt	Jefferson	3.2	0.0	4784.4	6118.4	510.0	N.D.	7500.0	Spoil Piezometer
Orcutt	Jefferson	3.9	0.0	5179.6	2848.0	349.0	N.D.	11120.0	Spoil Piezometer
[†]Fran	Clinton	2.2	0.0	23900.0	5690.0	79.0	2240.0	25110.0	Monitoring Well
[††]Old 40	Clarion	2.2	0.0	10000.0	3200.0	260.0	550.0	14000.0	Monitoring Well
[††]Old 40	Clarion	2.0	0.0	10000.0	44.0	92.0	380.0	10000.0	Monitoring Well
[††]Old 40	Clarion	2.4	0.0	5000.0	700.0	90.0	180.0	3300.0	Spoil Drain
[††]Old 40	Clarion	2.2	0.0	4400.0	1200.0	75.0	250.0	4000.0	Spoil Drain
[††]Old 40	Clarion	3.1	0.0	1100.0	260.0	55.0	26.0	2100.0	Seep
[††]Old 40	Clarion	2.6	0.0	1200.0	1900.0	140.0	58.0	1900.0	Seep
Zacherl	Clarion	2.3	0.0	9870.0	2860.0	136.6	583.0	7600.0	Toe-of-spoil Discharge
Waynesburg	Greene	7.8	379.0	0.0	0.12	0.04	N.D.	165.0	Deep Mine Discharge
Redstone	Fayette	7.4	626.0	0.0	1.65	1.05	< 0.5	1440.0	Spring
Redstone	Westmoreland	8.1	338.0	0.0	0.66	0.33	0.5	181.0	Spring
Blue Lick	Somerset	6.8	166.0	0.0	2.86	0.52	< 0.5	220.0	Pit Sump
Blue Lick	Somerset	7.9	276.0	0.0	< 0.3	< 0.05	< 0.5	436.0	Spring
Blue Lick	Somerset	7.7	138.0	0.0	1.12	0.86	< 0.5	494.0	Stream
Blue Lick	Somerset	6.9	226.0	0.0	0.81	0.83	< 0.5	1102.0	Stream
Vanport	Lawrence	7.5	324.0	< 2	2.10	0.07	N.D.	40.0	Well
Wadesville	Schuylkill	6.7	414.0	0.0	3.61	3.37	< 0.5	1038.0	Deep Mine Pumped Discharg
Wadesville	Schuylkill	6.9	370.0	0.0	1.95	3.42	< 0.5	884.4	Deep Mine Pumped Discharg
Valentine 1	Centre	7.5	226.0	0.0	< 0.01	< 0.01	< 0.135	145.0	Pit Water Outfall
Valentine 2	Centre	7.5	146.0	0.0	0.29	< 0.01	0.4	105.0	Pumped Pit Water
Valentine 3	Centre	7.6	102.0	0.0	2.07	0.05	3.9	44.0	Raw Pit Water
Valentine 4	Centre	8.0	164.0	0.0	0.22	< 0.01	0.59	68.00	Deep Mine Discharge
Ledger	Chester	8.0	284.0	0.0	0.04	0.01	< 0.135	41.0	Pit Sump
Loyalhanna	Westmoreland	7.7	152.0	0.0	< 0.3	< 0.05	< 0.5	143.2	Pit Water

alkalinity-generating calcareous minerals, although siderite ($FeCO_3$) can be abundant. Marine rocks can also be an important component of coal overburden in southern Appalachian (Pottsville) rocks [Alabama -

Horsey (1981), Pody (1987), and Demko and Gastaldo (1996); Tennessee - Dorsey and Kopp (1985); Kentucky - Chestnut (1981); and southern West Virginia - Martino (1994, 1996)].

Freshwater calcareous rocks, including lacustrine limestones, occur in the upper portion of the Allegheny Group and throughout the Conemaugh, Monongahela and Dunkard Groups of the northern Appalachian Basin. The extensive lateral distribution of some of these limestones was discussed in the stratigraphy section of Brady (1998b). These limestones, and other calcareous rocks, are responsible for the alkaline nature of many of the mining-associated discharges within these stratigraphic horizons. Freshwater calcareous rocks also occur in the Conemaugh Group, and are important when they occur above the upper Freeport coal.

In addition to freshwater limestones, the upper Allegheny Group frequently contains an abundance of calcareous claystones, mudstones and siltstones. Much of this interval is distinctly calcareous (>10% $CaCO_3$), but only small portions are limestone (> 50% $CaCO_3$). Additional information on stratigraphic changes in this interval is included in Chapter 3 and in Brady et al. (1988, 1998).

The most common carbonate minerals found in coal mine overburden are listed in Table 2.3. Carbonate minerals are often not “pure” end members, but form solid solution series with cation substitution, and vary with respect to their capacity for acid neutralization. Calcite is more soluble than dolomite although the overall dissolution is similar to that shown for calcite (Geidel, 1982). Both calcite and dolomite will neutralize acid, and potentially inhibit pyrite oxidation. Siderite is less soluble than calcite and dolomite, and does not contribute alkalinity.

Table 2.3. Common carbonate minerals in mine overburden, listed in descending order of their capability to neutralize acid.

Mineral	Chemistry
Calcite	$CaCO_3$
Dolomite	$CaMg(CO_3)_2$
Ankerite	$Ca(Fe,Mg)(CO_3)_2$
Mn-Siderite	$(Fe, Mn)CO_3$
Siderite	$FeCO_3$

Freeze and Cherry (1979) state that the solubility of carbonates is dependent on the partial pressure of carbon dioxide (pCO_2), and show a range of values that are relevant for natural groundwater. They show solubility for calcite in water at 25° C, pH 7, 1 bar total pressure, and a pCO_2 of 10^{-3} bar is 100 mg/L, while the solubility at a pCO_2 of 10^{-1} bar is 500 mg/L, using data from Seidell (1958). However, these relationships may be more complex than they initially appear. According to Rose (personal communication, 1997), the range of bicarbonate concentrations for calcite dissolution in pure water ranges from 83 mg/L at a pCO_2 of 10^{-3} to 370 mg/L at a pCO_2 of 10^{-1}, using the methods (i.e. Case 4) described in Garrels and Christ (1965). Additional discussion of carbon dioxide partial pressures is found in Hornberger and Brady (1998).

Since the alkalinity production process has a dramatically different set of controls, the resultant maximum alkalinity concentrations are typically one or two orders of magnitude less than the maximum acidity concentrations found in mine environments. Examples of relatively high alkalinity concentration in mine drainage, groundwater and surface water associated with surface and underground mines in Pennsylvania bituminous and anthracite coals are shown in Table 2-2. The highest natural alkalinity concentration found in PA DEP mining permit file data (and reported in Table 2.2) is 626 mg/L in a spring located near the cropline of the Redstone Coal in Fayette County. Thick sequences of carbonate strata, including the Redstone Limestone and the Fishpot Limestone, underlie and overlie the Redstone Coal. A curiosity is that some of the highest alkalinity concentrations shown in Table 2.2 are accompanied by equivalent or greater sulfate concentrations, so that bicarbonate may not be the dominant anion in some of these highly alkaline groundwaters.

Carbonate minerals play an extremely important role in determining post-mining water chemistry. They neutralize acidic water created by pyrite oxidation, and there is evidence that they also inhibit pyrite oxidation (Hornberger et al., 1981; Perry and Brady, 1995; Williams et al., 1982). Brady et al. (1994) determined that the presence of as little as 1% to 3% carbonate (on a mass weighted basis) on a mine site can determine whether that mine produces alkaline or acid water. Although pyrite is clearly necessary to form AMD, the relationship between the amount of pyrite present and water quality parameters (e.g., acidity) is only evident where carbonates were absent.

Neutralization potential, a measure primarily of the carbonate content of the overburden, relates positively to the alkalinity of post-mining water. A knowledge of the distribution, amount, and type of carbonates present on a mine site is extremely important in predicting the potential for post-mining problems and in designing prevention plans.

Lithologic and Stratigraphic Factors Affecting Mine Drainage Quality

Lithology is controlled by geologic factors such as paleoclimate and paleodepositional environment. Sandstones are deposited in high-energy environments, whereas shales and siltstone are deposited in quieter environments.

Published studies of Allegheny Group mines with abundant sandstone overburden attest to a problem with water quality. For example, diPretoro (1986) found that all but one mine site within his study area (northern WV) containing greater than 63% sandstone produced net acidic drainage. Sixty-seven percent of sites with less than 30% sandstone had net alkalinity (Figure 2-7). An examination of 41 mine sites in western Pennsylvania by the Department of Environmental Protection (DEP) and the Office of Surface Mining (OSM) also shows relationships between % sandstone and water quality. They found a similar relationship between the % sandstone and acid production for the Allegheny Group. However, in contrast, the sandstones of the Monongahela and Dunkard Groups are typically calcareous (cements) and were found to usually produce alkaline drainage. Both studies show that when there is a low percentage of sandstone, the mine drainage is generally alkaline (Figures 2.5 and 2.6). Although there are certain rules of thumb regarding the relationship between sandstone and mine drainage quality, site-specific information is necessary to accurately predict water quality from a particular mine site.

Brady et al. (1988) looked at the overburden above the upper Kittanning coal in the Stony Fork watershed in Fayette Co., PA. Mine sites with predominantly channel sandstone overburden produced acidic drainage. The sandstone lacked calcareous minerals or cements. Overburden in areas away from the sandstone channels contained calcareous shales and muddy limestone, and mining in these areas resulted in alkaline drainage.

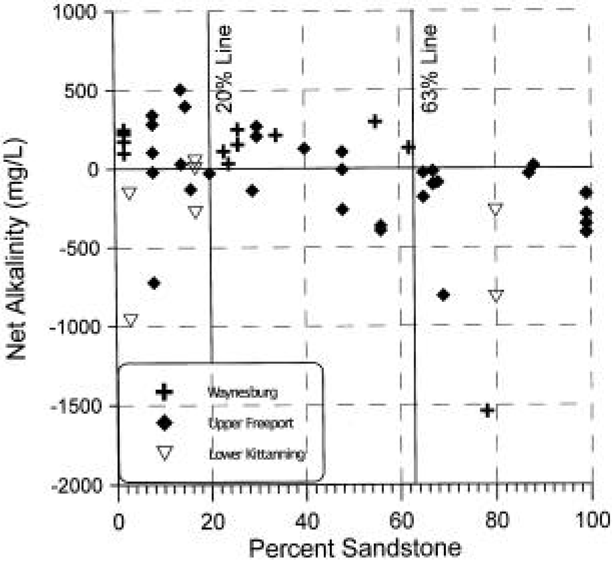

Figure 2.5. Net alkalinity as a function of percent sandstone for surface mines that encountered the Waynesburg, upper Freeport and lower Kittanning coals. Sites are in northern Preston County, WV. Most sites with greater than 63% sandstone are acidic, and most sites with less than 20% sandstone are alkaline (diPretoro, 1986).

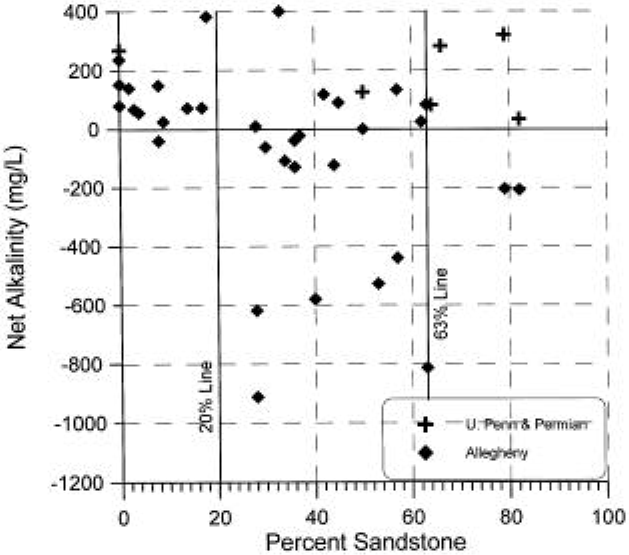

Figure 2.6. Net alkalinity as a function of % sandstone for 41 surface mines in western PA. Mines in the Conemaugh, Monongahela and Dunkard Groups are all alkaline, regardless of % sandstone. Most sites with less than 20% sandstone are alkaline.

Sandstone is typically low in sulfur, even when acid-producing. Channel sands can contain eroded material, including ripped up mats of peat (present day "coal spars") and even fossilized, and often coalified, logs. Individually these coal inclusions can be high in sulfur, but during typical overburden sampling, the inert quartz and other minerals that compose the sandstone dilutes this high sulfur. Thus, such sandstones may contain acid-forming material (coal spars), and yet yield samples that have low overall sulfur concentrations. Occasionally there are pyrite-rich sandstones. Some of these are black and high in organic carbon, while others are light in color, but high in sulfur. The light- colored high-sulfur sandstones seem to occur just above coal or organic-rich shale. Additional discussion is found in Williams et al. (1982) and Brady et al. (1998b).

Frequently, the highest sulfur strata are high-ash coals and other organic-rich rocks. Typically, these organic-rich rocks are immediately above, below or within a coal seam (e.g., a parting) and the shale above the coal is also high in sulfur (Guber, 1972).

As mentioned earlier, calcareous carbonates are more important than pyrite in controlling water quality from surface mines. The presence of only 1 to 3% carbonate minerals can influence whether acidic or alkaline drainage is produced (Brady et al., 1994; Perry and Brady, 1995). The amount of sulfur present is not directly related to acid production except in the absence of calcareous strata.

Carbonate minerals form under both marine and fresh water environments. Marine units contribute significantly to alkaline water in the Illinois Basin and the Western Interior Coal Province, but are also significant in the Appalachian Basin, such as within the lower Allegheny Group. A good example of this is the Vanport horizon, which occurs above the Clarion Coal. In Butler County, Pennsylvania, where the Vanport limestone is thick and in close proximity to the coal, mining of the Clarion coal will result in alkaline drainage. Where the Vanport-equivalent facies are brackish shale and the shale lacks calcareous minerals, such as in Clearfield County, Pennsylvania, the mine water is typically acidic. It should also be noted that in addition to limestones, other marine sediments are often calcareous.

Freshwater calcareous rocks, including lacustrine limestones, are also important. For example, the Monongahela and Dunkard groups have numerous thick, laterally persistent, lacustrine limestones. However, in general, freshwater limestones often contain relatively high concentrations of clay and silt, and can be thin and discontinuous.

State Practices

Alabama, Illinois and Indiana require drill logs with narrative descriptions for any holes drilled on the permit property. Geologic cross sections to assess lateral continuity of the strata and a structure contour map at the bottom of the coalbed are also required using all the available drill hole information. Depositional analysis is not required but permit reviewers are aware of acid-producing units associated with the various coal seams being mined within their state.

Kentucky requires only that the data presented be adequate to describe each aquifer and hydrogeologic regime. A description of the depositional environment is rarely required.

Maryland and Tennessee require a geologic cross section covering the permit area and a descriptive log of any available drill holes. They do not use depositional environment information during the AMD predictive process.

Ohio requires a general description of the geology within the proposed permit area and adjacent areas down to and including the first stratum below the lowest coal seam to be mined or any aquifer below the lowest coal seam that may be adversely affected by mining. The description must include information on the areal and structural geology and any other geologic parameters that may influence required reclamation. A description on how the areal and structural geology may affect the occurrence, availability, movement, quantity, and quality of potentially affected surface water and ground water is also required. Test holes containing lithologic descriptions are required. A description of the depositional environment is not required, but is accepted and reviewed if submitted.

Pennsylvania requires that all drill hole information on a property include narrative logs, and that they be used to build geologic cross sections to assess lateral continuity of the strata, and to construct structure contour map of the bottom of the coalbed. Pennsylvania does not require any depositional analysis by the permit applicants, but does use depositional information internally during review.

Virginia requires a geologic cross section of the permit area from core holes or measured sections of highwalls to assess lateral continuity of the strata. Permit reviewers do not use depositional environment information but are aware of acid-producing units associated with the coalbeds mined within the state.

West Virginia requires drill logs with narrative descriptions for any holes drilled and geologic cross sections to assess lateral continuity of the strata. West Virginia does not use depositional environment information during the AMD predictive process.

State practices for the evaluation of site geology and depositional environment are outlined in Table 2.4.

Effects of Surface Weathering and Glaciation on Mine Drainage Quality

This section will deal with a much more recent geologic process, the physical and chemical weathering of rock, which has occurred within the past million or so years. The significance of this influence on the distribution of carbonate and sulfide minerals (pyrite) can be as great as that which occurred in the more distant past. Weathering results in the near-surface removal of carbonates and sulfide minerals; carbonates by dissolution and sulfides by oxidation. This zone is usually recognizable by the yellow-red hues (indicative of oxidized iron) of the rocks. Generally, in the unglaciated portions of the Appalachian Plateau, the intensely weathered zone extends to 15 to 60 ft (6 to 20 m) below the surface.

Chemical weathering of bedrock is enhanced by physical factors such as stress-relief fracturing on hill slopes and bedding-plane separations due to unloading. Clark and Ciolkosz (1988) have also suggested that periglacial conditions during the Pleistocene contributed to the shattering of near-surface rock, which accelerates weathering by increasing surface area. All of these processes acting together increase the permeability of the weathered zone. The ground water associated with the weathered zone

Table 2.4 State Requirements for Site Geology and Depositional Environment Information

STATE	SITE GEOLOGY	DEPOSITIONAL ENVIRONMENT
AL, IL, IN	Drill logs with narrative descriptions required for any holes drilled on the permit property. Geologic cross sections used to assess lateral continuity of the strata. Requires structural contour map for the bottom of the coalbed using all the available drill hole information.	Does not require any depositional analysis by applicants. Reviewers are familiar with the depositional environment of the coalfields and keep that information in mind during the review process.
KY	The data must be adequate to describe each aquifer and hydrogeologic regime.	A description of the depositional environment is rarely required.
MD	Geologic cross section covering permit area and descriptive log of overburden analysis required.	Does not use any depositional environment information during the predictive process.
OH	Geologic description of the permit area and lithologic description of all test holes are required, along with a discussion of how the surface and ground water might be affected.	A description of the depositional environment is not required, but is accepted and reviewed if submitted.
PA	All drill hole information must include narrative logs. Information is used to build geologic cross sections to assess lateral continuity of the strata and construct a structure contour map of the bottom of the coalbed.	Does not require any depositional analysis by the permit applicants. Uses depositional environment information internally during review, mainly as a regional indicator of AMD potential.
TN	Requires a geologic cross section of the permit area and a descriptive log of any available drill holes.	Does not use any depositional environment information during the predictive process.
VA	Requires a geologic cross section of the permit area from core holes or measured sections of highwalls to assess lateral continuity of the strata.	Reviewers do not formally use depositional environment information, but are aware of acid-producing units associated with the coalbeds.
WV	Requires drill logs with narrative descriptions for any holes drilled and geologic cross sections to assess lateral continuity of the strata.	Does not use any depositional environment information during the predictive process.

is dilute, in terms of dissolved solids, because readily soluble products have been removed by chemical weathering (Brady, 1998b).

Chemical weathering is also influenced by lithology. Coarser, more permeable lithologies may allow oxidation to extend to a greater depth. Kirkaldie (1991) measured the depth of the highly weathered zone. He noted that the maximum thickness of highly weathered rock was 28.9 ft (8.8 m) in sandstone, and only 11 ft (3.3 m) in shale. His observations were based on the physical appearances during drilling and may not directly correlate with chemical weathering. This weathered-rock zone exists throughout the Appalachian Plateau. In spite of this, it has been little studied. Smith and his colleagues (Grube et al., 1972; Smith et al., 1974; and Singh et al., 1982) investigated the effects of weathering on the Mahoning sandstone in northern West Virginia, and noted a “pyrite-free weathered zone approximating 20 feet (6 m) of depth below the land surface...”. Singh et al. (1982), in addition to noting the pyrite-free zone, also noted a loss of “alkaline earth” elements within 20 ft (6 m). Loss of alkaline earth elements (calcium and magnesium) is best explained by a loss of calcareous minerals (calcite and dolomite). Brady et al. (1988; 1996) and Hawkins et al. (1996) all noted similar weathering depths in Appalachian strata.

It is hard to provide rules of thumb for the depth of leaching of carbonates and oxidation of pyrite because these minerals can only occur where they were originally present (before weathering). If no pyrite was ever present within a stratigraphic horizon, its absence is not due to weathering, but to the fact that it was never there in the first place. The same is true for calcareous strata. Brady et al. (1998) concluded that rarely do NPs greater than 3% $CaCO_3$ or S greater than ~0.5% occur within 20 ft (6 m) of the surface in Pennsylvania. A good example of this effect is the Blue Lick coal. Where the coal is under shallow cover, it has less than 0.7% S; however, where the coal occurs under about 60 ft (20 m) of cover, the coal averages over 2% S.

Brady (1998) examined shallow groundwater chemistry from sites in the northern and southern Appalachians. Springs, which would represent water associated with the shallow weathered zone, had low concentrations of ions regardless of geographic location, indicating the widespread presence of a shallow weathered zone.

An accurate knowledge of the extent (depth) of the weathered zone is important from an overburden-sampling standpoint. Overburden sampling should adequately represent the weathered zone and unweathered bedrock. This will entail drilling overburden test holes at maximum cover to be mined and at lesser cover. Drilling only maximum cover or only lower cover overburden holes will probably not adequately define the overburden chemistry of the entire mine.

An understanding of the effects of weathering on the distribution of pyrite, sulfate salts, and carbonates is important in accurately defining their distribution within unmined overburden, designing a mine plan to prevent post-mining problems, and accurately predicting post-mining water quality. An understanding of the weathering profile is just as important as understanding the lateral and vertical distribution of strata and their pyrite and carbonate content, as shown in Figure 2.7.

As with bedrock, the weathering of tills and other glacial sediments results in a change in their effect on water quality. At least 8 tills have been identified in Pennsylvania (White et al., 1969) and in northeastern Ohio (White, 1982). The bedrock in the Lake Erie basin, which was the source for the glacial sediments, consists of a large amount of limestone and dolomite. Therefore, the sediment contained in the glaciers was high in carbonate minerals when it entered Pennsylvania and Ohio.

In the Illinois Basin, most of the coal field is within the glaciated region and the bulk of the tills have carbonate contents greater than 10% in the clay fraction, and up to 64% in the coarse sand fraction (Fleeger, 1980). The presence of glacial deposits is thus more significant for the prevention of AMD in Illinois than in Pennsylvania. Although coal and associated strata in the Illinois Basin are sometimes high in sulfur (Maksimovic and Mowrey, 1993), acid streams (pH< 6) were only identified south of the glacial border (Hoffman and Wetzel, 1993, 1995).

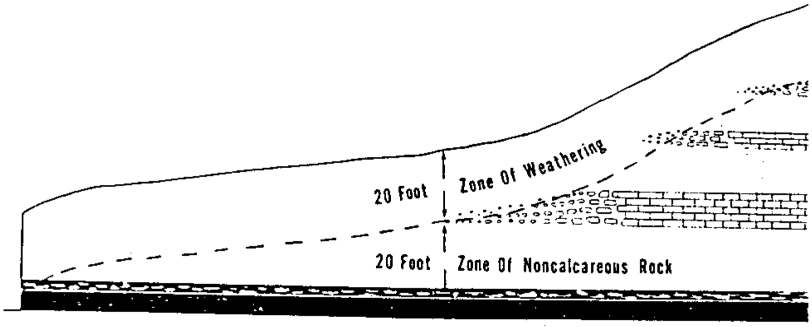

Figure 2.7. Schematic cross-section showing relative positions of high-sulfur strata and calcareous strata (brick pattern). In this example, 40 ft (12 m) or more cover must be mined in order to encounter the alkaline material.

Weathering produces a vertical mineralogical gradation within tills (Leighton and MacClintock, 1930, 1962). Sulfide concentrations are typically negligible, even in unweathered tills, but weathering can remove carbonate minerals that would otherwise be present in significant quantities. In general, the upper portion of the till has lost sulfides and carbonates, while the lower portions retain them. Because a number of factors control the depth of leaching (and other weathering characteristics), the same till may be leached to different depths in different locations. As a rule of thumb, older tills are leached of carbonates to a greater depth than younger tills.

In glaciated areas of Pennsylvania, post-mining water quality is frequently good, presumably due to the carbonate content of glacial sediments. However, not all mines in glacial overburden have alkaline drainage. Older tills, especially in their outcrop area, are low in carbonate and may not provide much neutralization.

In summary, glacial overburden can be beneficial in preventing AMD if it is calcareous. Because of the small grain size, unlithified nature, and the source of carbonates in glacial sediments, the NP determinations of glacial overburden probably more accurately reflect the ability of the glacial sediments to prevent and neutralize acidity than is sometimes the case with bedrock overburden. Site specific data are required to determine the NP of glacial sediments because of their variability in texture and composition due to dilution and weathering.

CONCURRENT RECLAMATION AND SPECIAL HANDLING PRACTICES

Experience indicates that AMD production is strongly influenced by the length of time between mining and reclamation. In theory, leaving a site open accelerates oxidation of the pyritic minerals and subsequently increases acid production. Concurrent reclamation and burial of acidic material can inhibit oxidation and ameliorate AMD formation. The importance of concurrent reclamation is generally accepted.

Special handling of acidic spoil materials, although not well documented in terms of success, is often used to prevent the formation of AMD. ABA data, either as an NP value for a unit or as the percent sulfur contained, is generally used to determine the need and scope of special material handling to prevent or mitigate AMD.

There are currently two commonly recognized methods of special handling. The first, and most common, is to place the acid-producing material above the highest projected ground water table level: the *high and dry* scenario. This should reduce the formation and mobilization of acid and metals. The second is to place acid-producing material so that it will always be below the water table: the *dark and deep* scenario. The *dark and deep* method controls AMD production by preventing contact between atmospheric oxygen and the pyritic material. In theory, and in laboratory studies, placing the pyrite below the water table should be superior to the *high and dry* placement method. However, maintaining a permanent water table over acid-forming materials can be difficult given the hydrologic conditions at many Appalachian surface mines.

An active surface mine in Clearfield County, Pennsylvania provides an example of how predicting the post-mining water table level can be a problem. The special handling plan at this mine placed acidic material 10 feet above the pit floor to keep it *high and dry* (Hawkins, 1996). However, less than a year after backfilling, ground water levels were at times at least 14 feet above the pit floor, putting the acid-forming materials in the zone of water table fluctuation. While studies indicate that placing acid-forming materials in a fluctuating ground water zone is highly undesirable, Leach and Caruccio (1991) concluded that a reduction in acid load resulted from any time pyrite spent under water. Subaqueous burial of acidic material was advocated by Cederstrom (1971) and is coming back into favor, due to research supported by the Canadian MEND program and work performed by the U.S. Bureau of Mines (USBM) (Watzlaf and Hammack, 1989; Watzlaf, 1992) and others (Leach and Caruccio, 1991). A review of the many studies on special handling of acidic material can be found in Robins and Associates (1982).

Alkaline addition is commonly used to raise the neutralization potential of the mine spoil to prevent or abate the formation of AMD. Limestone and dolostone are the most frequently used materials because of their widespread availability and relatively low cost (Hawkins, 1995). Other materials, such as hydrated lime and alkaline coal combustion wastes, are also used where they are cost effective due to their availability. ABA data, usually the overall NNP value, is generally used to determine the need for alkaline addition and the amount of alkaline material necessary to mitigate AMD formation.

Determining the quantity and placement requirements for the alkaline material are two difficulties associated with alkaline addition. The most common alkaline placement practices include liming the pit floor, blending alkaline materials into the backfill with overburden of lower neutralization potential, and capping the backfill with alkaline material below the soil horizon. Brady and others (1990) conclude that alkaline addition "to prevent AMD from surface coal mines may be effective provided that the alkaline-addition rates are sufficient (to offset negative NNP) and the overburden has relatively low-sulfur content." They also recommend incorporation of the alkaline material concurrently with mining and backfilling, and note that while neutral or alkaline discharges may result, metals concentrations may not be reduced.

State Practices

Current State requirements regarding concurrent reclamation, special handling and alkaline addition are summarized below and in Table 2.5. Given time, some of these requirements may change so if you are with a mining company, you should check to see that the statements are still valid.

Alabama encourages concurrent reclamation, but relies on laws governing and limiting the amount of exposed highwall, spoil, and ungraded acres. Overburden units with an NP deficiency of 5 tons $CaCO_3$ per thousand tons of material or greater are considered acid-producing. Alabama's special handling provision allows only for *high and dry* placement of acidic material. Applicants have the option of overcoming the acidity potential of those units using either alkaline addition or special handling. With respect to alkaline addition, Alabama generally assumes that alkaline drainage will result from overburden with an NNP of 5 tons or greater of excess $CaCO_3$ per thousand tons of material. Overburden with an NNP below -5 tons $CaCO_3$ per thousand tons of material is considered acid-forming, and the applicant is then required to develop a plan to overcome the inherent acidity through any or all of the tools available to them (special handling, alkaline addition, mining methods). Sites with overburden NNP values between -5 and 5 tons $CaCO_3$ per thousand tons of material are considered candidates for alkaline addition if the NNP can be altered to ensure an excess of alkalinity.

Illinois requires concurrent reclamation and regulates the number of open pits, the amount of exposed spoil, and grading activities. Timely burial of high sulfur material is viewed as very important in reducing the risk of AMD. AMD treatment is rarely addressed in permit applications except for the possibility of short term treatment of sedimentation ponds. AMD problems are rare, except in instances where approved reclamation plans are not implemented. Secondary recovery operations (carbon recovery or re-mining) has the greatest potential for exposing large amounts of acid-generating material. The most common special handling methods are blending the acidic material with available alkaline material and adequate cover. *Dark and deep* is the preferred cover option. Alkaline addition is generally limited to surface application of graded spoil in coal refuse disposal areas and locations where acidic material inadvertently ends up on the final graded surface and cannot be adequately covered.

Indiana requires concurrent reclamation and regulates the number of open pits, the amount of exposed spoil, and grading activities. Timely burial of high sulfur material is viewed as very important in reducing the risk of AMD. AMD problems are rare, except in instances where approved reclamation plans are not implemented, and so are rarely addressed in permit applications. Sediment control structures are sometimes used temporarily to meet effluent limits. To insure that water quality problems do not occur, any overburden unit with a calcium carbonate equivalent deficiency of 5 tons $CaCO_3$ per thousand tons of material or greater or a pH less than 4 must be addressed by special handling. Generally, this ranges from less than 5% up to 30% of the overburden. Most commonly, the special handling method used is to blend acidic material with available alkaline material, and then cover. *Dark and deep* is the preferred cover option. Alkaline addition is generally limited to surface application of graded spoil in coal refuse disposal areas and locations where acidic material inadvertently ends up on the final graded surface and cannot be adequately covered.

In practice, Kentucky permit applications do not usually propose special measures to treat or avoid AMD since the applications almost always predict no significant AMD. If problems arise after mining has commenced, treatment is proposed in revisions to the permit. In cases where a permit would otherwise be denied, special handling can change the determination. Typically, special handling includes lime addition, selective spoil handling, and accelerated reclamation.

In Maryland, overburden units with a total sulfur content of 0.3% or greater are considered potentially acid-producing and candidates for special handling. *High and dry* is the preferred method. Material must be placed at least 4 ft above the coalbed floor in backfill that is expected to remain dry, or 10 to 15 ft above the floor if the backfill is expected to hold water.

Ohio requires contemporaneous reclamation, unless a variance is granted (for special circumstances only). Limited amounts of acid-forming and toxic-forming materials are usually handled by all or most of the following practices: they must be kept away from the final highwall, buried above the pit floor and above the predicted reestablished water table elevation (high and dry), away from natural or reconstructed drainage courses (to prevent exposure by erosion) and surrounded by at least four feet of non-toxic material. For larger amounts of toxic-forming material, a more intense waste disposal plan (involving discreet calculations for either neutralization or sealing) must be submitted. This usually is triggered when coal refuse is brought to the site for disposal. Alkaline addition is used in a limited number of cases if other mechanisms for preventing AMD are not practical or are not expected to be successful. Drainage controls, positive drainage, and impermeable bases are required for coal stockpiles.

Pennsylvania requires concurrent reclamation and views quick burial of high sulfur material as very important in reducing the risk of AMD. Overburden units with a total sulfur content of 0.5% or greater are considered acid-producing and candidates for special handling if the units are laterally consistent and recognizable. Miners must be able to handle them with the tools that are available. Special handing (preference for *high and dry* or *dark and deep* was not identified) is generally not requested for any individual rock units if the overburden analyses results in an overall high NNP. If NNP is low, special handling must be combined with alkaline addition.

Tennessee requires concurrent reclamation of every permit applicant. No threshold numbers for identifying acid producing units were cited, but *high and dry* placement in compacted lifts was indicated as the preferred special handling method.

Virginia mostly relies on laws limiting the amount of exposed highwall to drive reclamation, but reserves the right to set specific limits on the time that acidic material can be exposed to the weather. Any overburden units with greater than a 5 ton $CaCO_3$ deficiency per thousand tons of material are required to be addressed with special handling. The most common special handling method identified in Virginia was the blending of acidic material with that of higher NP. *High and dry* handling is also allowed with at least 4 ft between the acid material and the floor and compaction of the enclosing material.

West Virginia has contemporaneous reclamation standards that must be met. Threshold standards for identifying acid units were not cited, but special handling provisions were acknowledged as common and important permit requirements. Applicants must have a storage plan for any acidic

Table 2.5. State Requirements for Concurrent Reclamation, Special Handling and Alkaline Addition.

STATE	CONCURRENT RECLAMATION (CR)	SPECIAL HANDLING AND ALKALINE ADDITION (AA)
AL	CR is encouraged, limiting the amount of exposed highwall, spoil, and ungraded area.	Special handling provisions allow only for *high and dry* placement of overburden with NP deficiency of at least 5 tons $CaCO_3$ per 1000 tons of material. If NNP is <-5, overburden is considered acid-producing and a plan is required to overcome the inherent acidity. If the NNP value is between -5 and 5, the overburden is a candidate for AA.
IL	CR is required.	AMD is rare when approved reclamation plans are implemented. Secondary recovery can cause AMD. *Dark and deep* placement preferred. AA applications are limited.
IN	CR is required.	AMD is rare. Overburden with NP deficiency of at least 5 tons $CaCO_3$ per 1000 tons of material or a pH of 4 requires special handling. *Dark and deep* placement is preferred, along with blending of alkaline and acidic material.
KY	See entry under Special Handling.	Significant AMD problems are rarely predicted before mining. For post-mining AMD problems, permit revisions are used. For otherwise deniable permits, the inclusion of special handling provisions can change the determination. AA should result in an overburden NNP with excess alkalinity.
MD	No CR standards or general requirements.	Overburden with total $S \geq 0.3\%$ considered for special handling. *High and dry* is preferred: at least 4 ft above the pit floor if backfill is expected to be dry, or 10-15 ft above the floor if backfill is expected to hold water. AA should result in an overburden NNP with excess alkalinity.
OH	CR required unless variance is granted.	*High and dry* generally required, plus must be away from watercourses and surrounded by at least 4 feet of non-toxic material; more intense waste disposal plan required for coal refuse. AA used when necessary.
PA	CR is required. Quick burial of high S material is viewed as very important.	Overburden with a total $S \geq 0.5\%$ considered for special handling if the units are laterally consistent and recognizable. If NNP is low, special handling must be combined with AA, producing an overburden NNP with excess alkalinity.
TN	CR is required.	No threshold numbers for identifying acid producing units. *High and dry* placement in compacted lifts is preferred. AA plans that will result in an overburden NNP with excess alkalinity accepted.
VA	VA reserves right to set limits on the time that acidic material can be exposed to the weather.	Any overburden unit with greater than a 5 ton $CaCO_3$ deficiency per thousand tons of material must be addressed with special handling, most commonly blending of acidic material with that of higher NP. AA that will result in an overburden NNP with excess alkalinity accepted. *High and dry* is also allowed with at least 4 ft between the acid material and the floor, and compaction of the enclosing material.
WV	CR is required; storage plan for any acidic material can't exceed 45 days.	Special handling provisions are common. High and dry isolation is the accepted method. WV will assist in developing a training program to facilitate identification of key overburden units and proper mining techniques. AA plans should result in an overburden NNP with excess alkalinity.

material (that may include covers or other special conditions to reduce exposure to the weather), which cannot exceed 45 days. *High and dry* isolation of acidic material in the backfill is the accepted special handling method. Permit reviewers will meet with applicants and inspectors to assure that special handling plans are feasible and can be monitored, and will assist in developing a training program for workers to facilitate identification of key overburden units and proper mining techniques.

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