MINE DRAINAGE PREDICTION AND OVERBURDEN ANALYSIS IN PENNSYLVANIA

By

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The Pennsylvania Department of Environmental Resources (DER) is in the process of writing a manual that will provide guidance to mine operators, permit review staff and others in Pennsylvania. It will consist of two parts, procedural and interpretative. The procedural part will address the permitting requirements for submittal of an overburden analysis and the interpretation section will address mine drainage quality prediction using overburden analysis as well as techniques other than overburden analysis.

PART 1: PROCEDURAL REQUIREMENTS

Overburden Analysis Requirements

Acid-base accounting (ABA) is the most commonly used method of overburden analysis in Pennsylvania. When performing acid-base accounting, the following information is required: (1) Neutralization Potential; (2) Percent Total Sulfur; (3) and "fizz" testing with dilute HCl. Other analyses which are sometimes submitted, but not generally required are forms of sulfur and paste pH.

Presently there are numerous methods and variations on methods being used for weatherization (leaching) tests. Because of this variety of methods it is very important that the method used be described in detail. The description must include: (1) the amount of water added at any time; (2) the amount of water withdrawn at any time; (3) the amount of sample being Leached, (4) the particle size(s) of the sample; (5) chemical analysis of the water used in "Leaching; (6) the frequency and duration of leaching, including flushing cycles and contact times; (7) the water level(s) relative to the position of the rock sample; (8) a description of the atmosphere in which the samples are in contact; (9) temperature; (10) how strata samples were composited; and (11) a sketch or photograph of the apparatus. This paper will not address the interpretation of leaching tests.

Criteria for Requiring Overburden Analysis

Pennsylvania regulations allow DER to require overburden analysis for any surface mine permit application, coal or non-coal. To date, however, most overburden analyses have been performed in the bituminous coal regions. The bituminous coal regulations require overburden analysis unless equivalent information is available. Generally overburden analysis is required in the following situations: (1) sensitive watersheds (primarily High Quality and Exceptional Value watersheds according to DER's Rules and Regulations); (2) proximity to public water supplies; (3) absence of mining in watershed or insufficient mining on the coal seam of interest; (4) indications of acid mine drainage from nearby mines; and (5) proposed removal of alkaline material from a mine site.

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Planning an Overburden Analysis

The number and distribution of overburden holes must be adequate to represent the site. A minimum of two holes are required for each coal seam on a mine site. Large sites will require more holes. A suggested rule of thumb for calculating the minimum number of holes per seam based on acreage alone is:

$$\text{number of holes} = \frac{\text{Acres}}{100 \text{ Acres}} + 2$$

The acreage term is rounded to the closest whole number.

Analytical and sampling methods are given in Sobek and others (1978) and Noll and others (1988). Generally the methods described in these publications are followed in Pennsylvania. All coals must be sampled, the stratum below the coal must be sampled, the sample interval above and below the coal must be one foot or less, the maximum thickness of any sample interval must not exceed three feet, and all individual strata must be sampled.

Overburden Proposals

DER suggests that operators submit a proposal outlining the analytical methods they propose to use, the spacing and depth of the proposed overburden holes, sampling techniques and other relevant information. A proposal can help eliminate the possibility of an operator expending money on a plan that would be unacceptable to DER.

Overburden Analysis Report

A report must be submitted with every overburden analysis addressing the relationships between the overburden data and the overall site geology and hydrogeology, using cross sections, fence diagrams and other means to convey the information. A narrative must provide an interpretation of the analytical results and identify the potentially acidic and alkaline zones. Special mining practices such as selective handling of strata or alkaline addition must also be addressed. Additionally the narrative must address probable hydrologic consequences.

PART 2: MINE DRAINAGE PREDICTION

"Mine drainage prediction" generally brings to mind overburden analysis. In Pennsylvania overburden analysis is just one of the tools considered in mine drainage prediction. Other considerations are: post mining water quality on similar or adjacent sites, premining water quality, lithologic factors, and weathering of overburden. This section addresses these considerations plus acid-base accounting. A complete site assessment requires that all available data be considered. Our experience has shown that the different methods are generally consistent in what they show and inconsistencies between the methods generally indicate that additional information is needed or some information may be in error.

Post Mining Water Quality

Examination of water quality emanating from adjacent abandoned or reclaimed mine sites has proven a very useful prediction tool. The assumption is that if the same coal is being mined in the same general area, hydrogeologic conditions will be sufficiently similar that the water quality from the proposed mine will approximate the adjacent mine. Usually this is the case. An advantage with this method is that it provides actual chemical results under field conditions. The major limitations to its use occur where: (1) stratigraphic or chemical changes occur between sites (i.e., overburden on adjacent site may not be similar to the proposed site, or differing highwall height is responsible for the chemical and stratigraphic changes), (2) mining practices, such as tipple refuse disposal, may have adversely affected water quality, (3) multiple seam mining has occurred on adjacent sites and the observed water quality can not necessarily be tied to any one particular coal seam and overburden, and (4) hydrologic complications make it difficult to relate water quality to previous mining (such as the absence of discharges, dilution of discharges by water unaffected by mining, interference from other pollution sources, neutralization from unaffected strata and so forth).

Premining Water Quality

Premining water quality can be a useful indicator of overburden chemistry. If wells penetrating the overburden or springs emanating from the coal cropline are significantly alkaline (e.g., > 70 mg/1 $CaCO_3$), then alkaline strata are probably present in the overburden. If the water is low in alkalinity or slightly acidic and has a naturally low pH, the overburden most likely lacks alkaline strata. Premining groundwater is never highly acidic, even when the rocks contain abundant pyrite. The evaluation of premining water quality is used to corroborate overburden analysis results. The ground water flow system must be properly understood in order to use premining water quality as a predictive tool. Some cropline springs may have low pH and low alkalinity because they represent shallow flow through weathered overburden. Further into the hillside under higher cover where alkaline material occurs, the ground water may be alkaline. Another potentially misleading exception occurs where a stratigraphic interval lacks alkaline strata but the groundwater is alkaline because strata elsewhere within the recharge area (i.e., within the upper reaches of the ground water flow path) includes limestone or other calcareous rocks. Figure 1 illustrates the various scenarios described above.

Paleoenvironmental and Lithologic Factors

Williams (1960) mapped the paleo-geographic environments for the Pottsville and Allegheny Groups in western Pennsylvania based on fossil fauna. The fauna were classified into three inferred environmental groups: freshwater, restricted marine, and marine. Hornberger and others (1981) compiled water quality data from deep mines in western Pennsylvania (Figure 2). Mines in freshwater deposits (Upper Allegheny Group) were generally nonpolluting, whereas brackish environments (much of the Middle Allegheny Group) generally resulted in acid mine drainage (AMD). Marine environments (much of the Lower Allegheny) can result in acid or alkaline mine drainage depending upon whether or not limestone (such as the Vanport) is present, although the examples in Figure 2 represent only acid producing mines from this group.

Paleoenvironment influences the amount of pyrite present and the deposition of calcium carbonate (Williams and others, 1982; Caruccio, F.T., 1968; Guber, 1972). Williams and Keith (1963) found that the Lower Kittanning coal had higher sulfur where the roof rocks were marine and lower sulfur where the roof rocks were continental in origin. Cecil and others (1985) related sulfur in coal to paleoclimate. Lower sulfur (< 1%) and less carbonates were the result when rainfall was high and evenly distributed throughout the year, whereas higher sulfur (> 1%) and greater carbonate deposition resulted when the climate was more seasonal and drier.

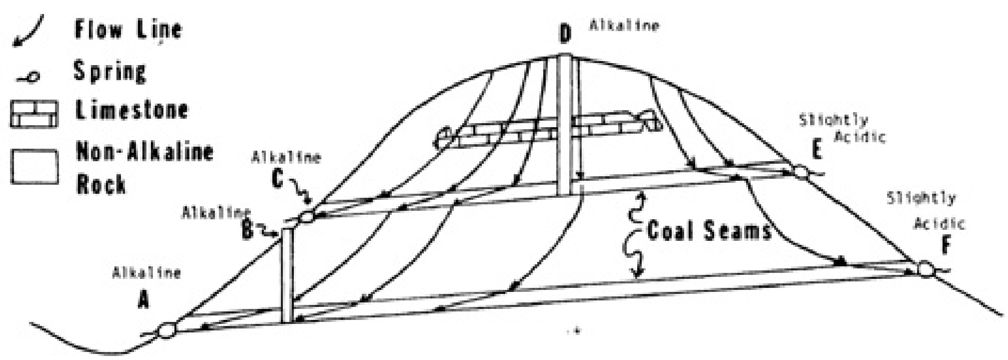

Figure 1. Schematic cross-section showing relationships between overburden, flow system and water quality. Although spring A and well B are alkaline, they do not reflect the quality of the overburden above the lower coal. The source of the alkalinity is from a higher part of the flow system. Spring C and well D are alkaline and reflect the alkaline producing potential of the overburden above the upper coal. Spring E is slightly acidic and represents shallow flow through mostly weathered rock leached of limestone. The recharge area for spring F does not encounter any alkaline producing rocks and shows that there is no significant alkaline material associated with the lower coal.

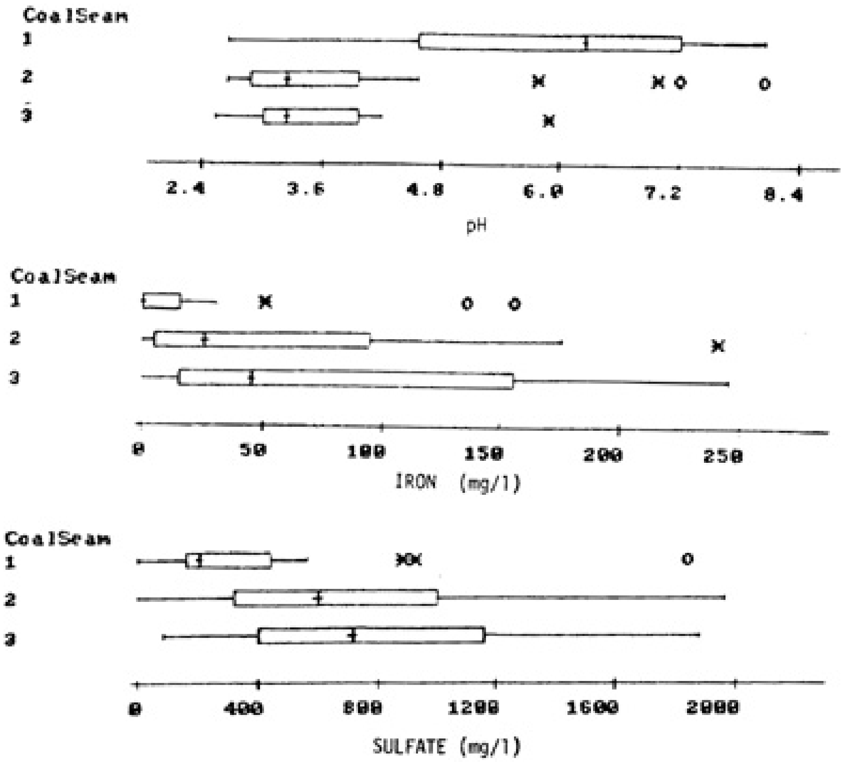

Figure 2. Boxplots of deep mine discharge median values. Coal Seam 1: Upper Allegheny Group (Upper and Lower Freeport coals). Coal Seam 2: Middle Allegheny Group (Lower Kittanning coal). Coal Seam 3: Lower Allegheny Group (Brookville and Clarion coals). Boxplots show medians, quartiles and ranges. The "*" and "o" represent outlier values. Adapted from Hornberger (1985).

Stratigraphic and lithologic data derived from drill logs and highwall sections can provide useful information in regards to mine drainage prediction. Limestones and other calcareous rocks generally produce alkalinity, whereas black shales, binder/partings and other pyrite-rich rocks are likely acid producers (Figure 3).

The presence of predominantly sandstone overburden has been linked to acid mine drainage production (Williams and others, 1982; diPretoro, 1986, diPretoro and Rauch, 1987; Brady and others, 1988). One explanation is that sandstone is deposited in high energy environments not conducive to limestone deposition (Brady and others, 1988), also channel sands may cut out or replace the limey muds. Sandstone, which is composed largely of quartz lacks any appreciable ion exchange capacity and any ability to neutralize acid that would be generated by ion exchange. Massive sandstones tend to have small discrete zones with high pyrite content (such as coal stringers). Although they may be important in AMD generation, a sulfur analysis of the rock may show low sulfur due to dilution of the zone by the surrounding sandstone. diPretoro (1986) also suggests that low pH water generated by sandstones is favorable for AMD catalyzing bacteria, and sandstone, which during mining breaks into large blocks, allows greater permeability to air and water.

Some areas of northwestern Pennsylvania contain unconsolidated glacial deposits overlying the coal strata. Mines developed in these areas often produce alkaline water due to the presence of alkaline till as part of the overburden.

Weathering of Overburden

Weathering processes can result in the near surface dissolution of carbonates. Complete or partial loss of carbonates to a depth of as much as 30 feet in bedrock is common. A similar loss of carbonates in tills in western Pennsylvania has been observed. While overburden holes drilled at maximum cover may indicate the presence of alkaline strata, the same strata under less cover may lack carbonates due to weathering. Brady and others (1988) found that in an area of southwestern PA. high sulfur zones persisted under much lower cover than carbonates (Figures 4 and 5). Loss of sulfur due to weathering does occur, however. Figure 6 is a plot of percent total sulfur in a coal through the life of a mine in Indiana County, Pennsylvania. Mining proceeded through a hill such that low cover was encountered at the beginning and end of the operation and maximum cover during the middle of the operation. Low sulfur corresponds with the time that low cover was being mined and high sulfur when higher cover was being mined.

The potential influence of loss of carbonate and sulfur at shallow depth must be kept in mind when considering adjacent post mining water quality as a mine drainage predictor. If adjacent mining only encountered shallow cover the water quality may not be representative of a more extensive mine in which deeper overburden is taken. This factor can result in both positive and negative influences on overburden quality. Figure 7 shows water quality as a result of shallow cover mining and subsequent deeper cover mining. The mine is located in Cambria County, Pennsylvania. The initial mining disturbed weathered rock that was relatively inert. The deeper mining disturbed fresh rock containing pyrite, but no neutralizing strata were encountered. The result was production of acid mine drainage.

Acid forming strata often occur directly above, below, or within the coal seams, while limestones and calcareous shales often occur higher in the section. Therefore shallow alkaline strata are typically preferentially weathered relative to the deeper acidic rock (Figure 8).

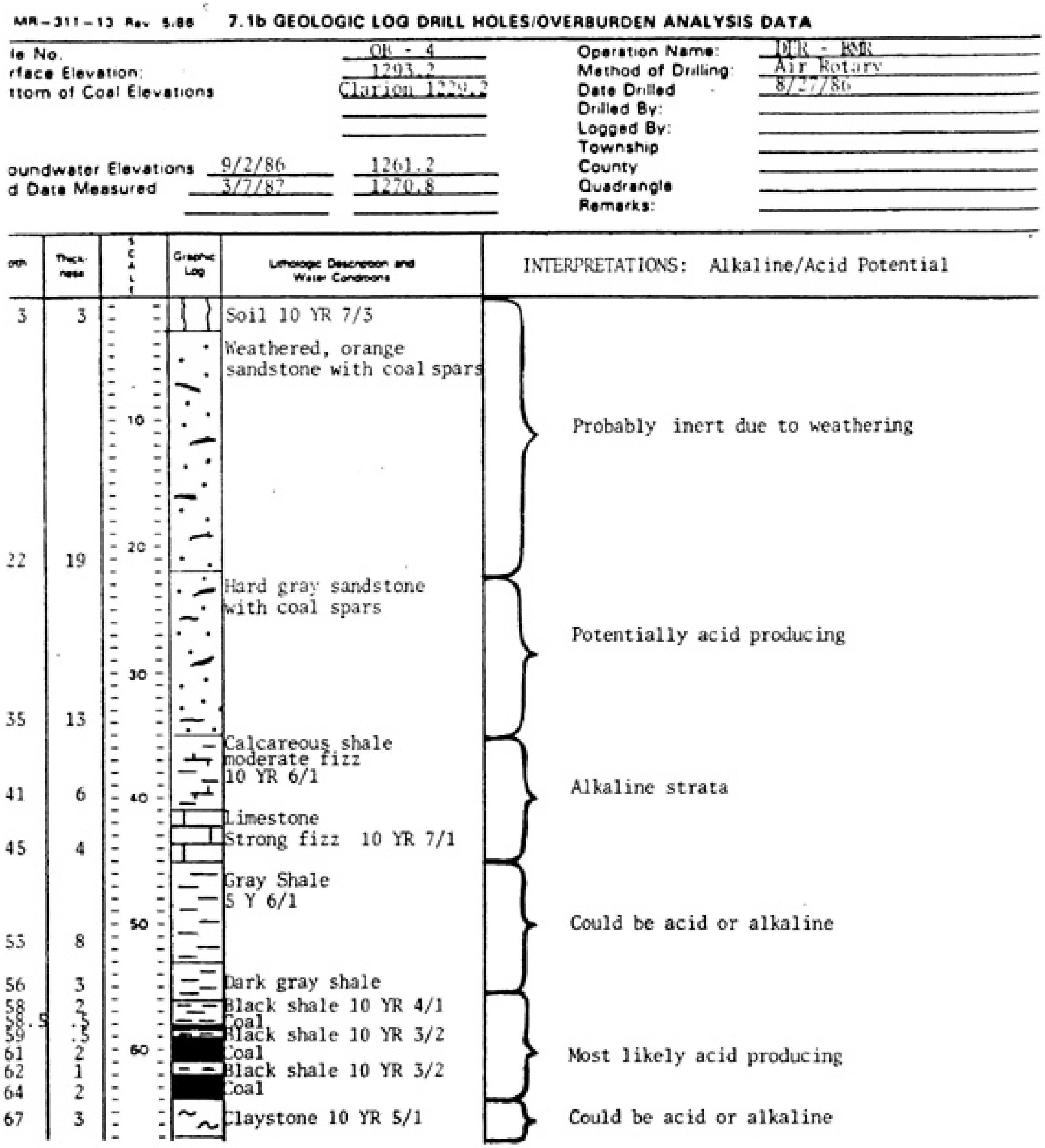

Figure 3. Idealized drill log showing alkaline and acid potential of various strata.

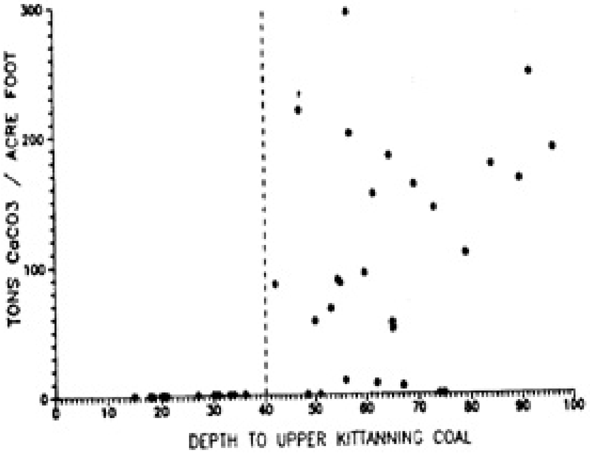

Figure 4 .--Graph showing relationship between calcareous material per acre foot and depth to bottom of Upper Kittanning coal. calculations were made based on neutralization potentials above 30 tons/1000 tons. From Brady and others (1988).

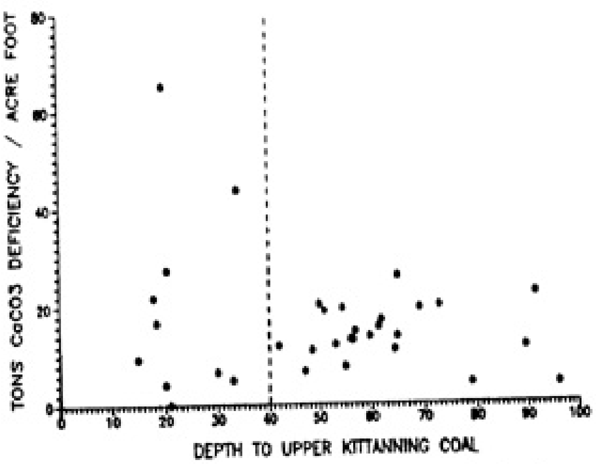

Figure 5 .--Graph showing relationship between potentially acid producing strata and depth to bottom of Upper Kittanning coal. Calculations were made based on sulfur values above 0.5%. From Brady and others (1988).

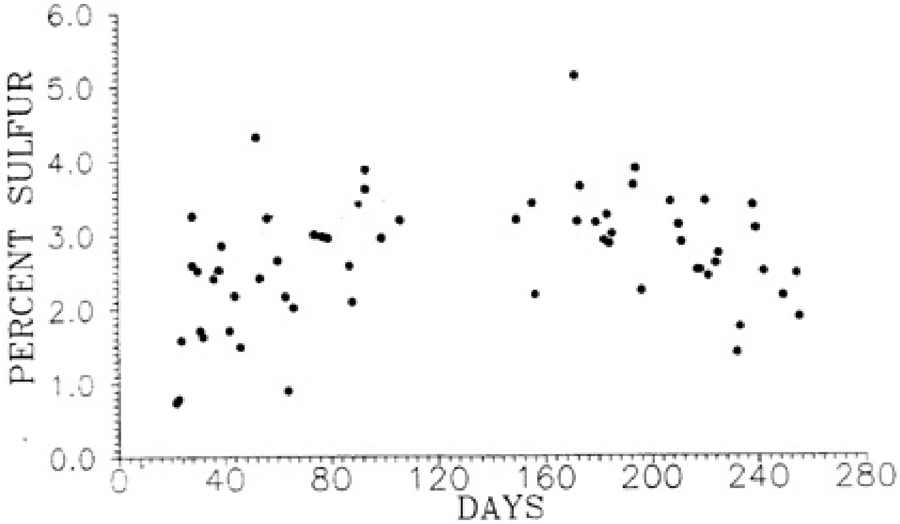

Figure 6 . This graph is a plot of the change of a coal seams percent sulfur through the life of a mine. The line shows the general trend of the values. The change in values is due to weathering of sulfur under low cover (low cover occurring early and late in the mining operation).

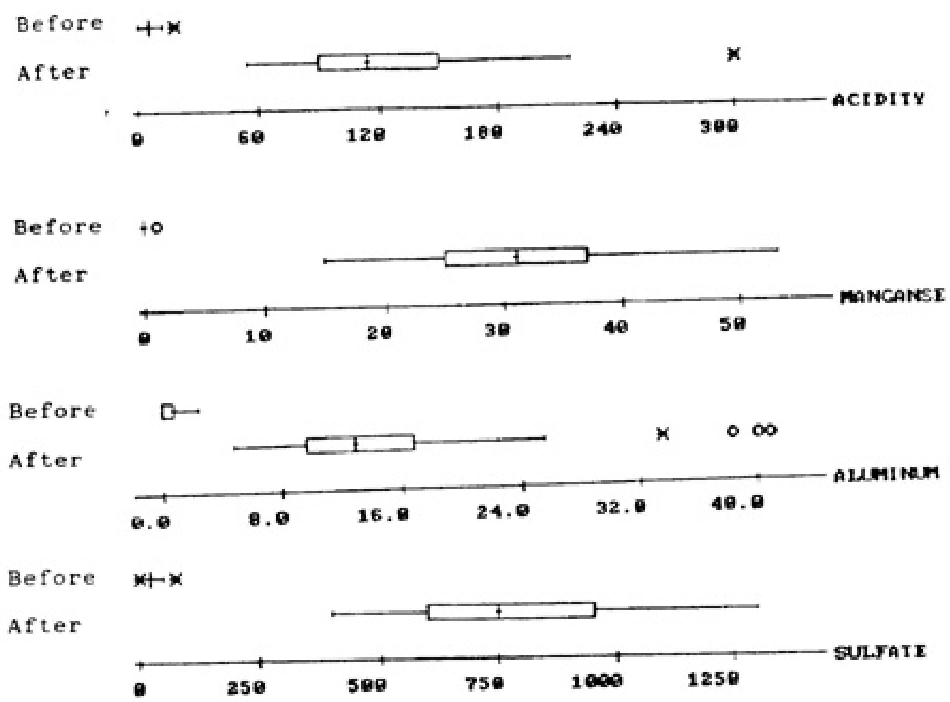

Figure 7. Water quality comparison showing quality following mining of shallow cover (Before) and following mining of more extensive cover (After). The "*" and "o" symbols represent outlier values.

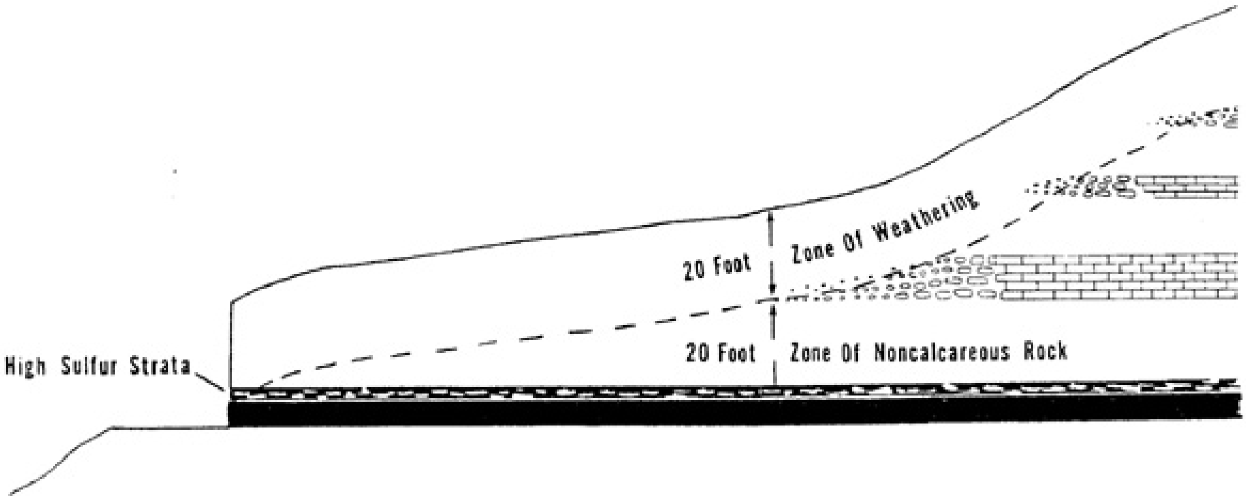

Figure 8 . Schematic cross-section showing typical position of high sulfur strata and alkaline strata (brick pattern). In this example 40 ft or more cover must be mined in order to encounter the alkaline material.

Interpretation of Acid-Base Accounting

Acid-base accounting is a method used to identify potentially alkaline and acidic strata. Alkaline strata are reported as neutralization potential (NP) which is reported as tons/1000 tons $CaCO_3$ equivalent. Identification of toxic strata is accomplished by measuring the percent sulfur. The percent sulfur is multiplied by the constant 31.25 to obtain maximum potential acidity which is also reported as tons/1000 tons $CaCO_3$ equivalent (Sobek and others, 1978).

Originally acid-base accounting was used to identify suitable soil substitutes. Interpretations were made by literally balancing Maximum Potential Acidity (MPA) with Neutralization Potential (NP). Sobek and others (1978) stated that "potentially toxic material is defined as any rock or earth material having a net potential deficiency of 5.0 tons of calcium carbonate equivalent or more per 1000 tons of material" or "materials which have a pH of less than 4.0 in a pulverized rock slurry... are defined as being acid-toxic" (p. 3). These numbers, which were developed for identification of soil substitutes quickly became applied to mine drainage quality prediction.

DER in the early years of overburden analysis review evaluated permit applications in this light. Some of the permits issued resulted in severe acid mine drainage pollution. It was clear that this method of interpretation was not a reliable one. By 1980 additional experience showed that sites with an abundance of alkaline strata (many feet of strata with NP's in the hundreds) almost invariably produced alkaline drainage. If the site also contained significant amounts of high sulfur strata (several feet of strata with sulfur greater than 1.0 percent) the result generally was alkaline water with high sulfate and often high metals. Sites with significantly high sulfur strata and little or no strata with NP's above 100 resulted in acid mine drainage.

Based on these early results, DER permit reviewers became critical of arithmetic summations of overburden data and adopted a more qualitative approach. A two by two matrix was developed to visually portray decision making based on a qualitative approach to overburden analysis interpretation (Figure 9). The boundaries between the four categories were not well defined and numerous gray areas existed, due to the need for additional data and a better understanding of test results and limitations. Consequently, this was more of a conceptual approach than an explicit tool.

Later experience showed that some mine sites had NP's seldom higher than in the 30's and 40's yet were producing alkaline discharges. The strata on these sites was generally low in sulfur with abundant NP's of 30 or 40. Generally, rocks with NP's above 30 tons/1000 tons CaC03 exhibited a "fizz" when diluted HCl was applied. NP's less than 30 generally did not fizz. The fizz although qualitative, can suggest relative reativities of rocks, and has also proved useful in helping to distinguish siderite from calcium carbonate. If the rock does not react with HCl its neutralizing capabilities in the field are probably limited. Fizz and NP can be used comparatively to identify anomalous results. Conversely, numerous low NP sites with sulfur below 1.0 percent (excluding the coal) resulted in acid mine drainage, in some cases the AMD was very severe.

Williams and others (1982) performed rock weatherization experiments with rocks that lacked carbonates. They plotted percent total sulfur versus acidity and found that at around 0.75 percent sulfur the acidity increased exponentially. The laboratory results were derived from discrete rock samples. With overburden samples combined intervals of two or three feet are common. This results in dilution of zones with high sulfur, so lower sulfur determinations in overburden samples may be significant.

STRATA POTENTIAL FOR ACID MINE DRAINAGE

STRATA POTENTIAL FOR ALKALINE MINE DRAINAGE	Low % Sulfur	High % Sulfur
LOW N.P.	Evaluate additional data. If can't be demonstrated that pollution will not occur, then deny.	Probable Denial
HIGH N.P.	Probable Issuance	Possible issuance or denial - based upon detailed evaluation of mining plan/overburden special handling plan and additional data.

Figure 9. Contingency table showing decision making process used by the DER in the early 1980's.

A need arose to define levels of significance for NP and percent sulfur to use in determining which strata to special handle and in calculating alkaline addition rates. Based on the above observations and experience, as well as the need for guidelines, the guideline numbers for significant impact on mine drainage quality were set at NP of 30 or greater with a fizz and percent total sulfur of 0.5 or greater. These guidelines do not mean that any percent sulfur less than 0.5 or NP less than 30 will not impact water quality. In fact, strata with sulfur contents of less than 0.5 percent have been responsible for mine drainage generation. The numbers therefore are only to be used as general guidelines.

Evaluations based on the above guideline values have proved to be a more useful and reliable method for mine drainage prediction than a strict summation of the ABA results for all strata, especially for sites with low sulfur and low NP. The NP guideline number of 30 is not of equal value when compared to the MPA guideline number that would be computed from 0.5 percent sulfur; the MPA would be 15.6, approximately half the NP value. In terms of post mining water quality low sulfur values are more significant than low NP's.

Skousen and others (1987) suggested their own guidelines. They reported: --" "Experience over the past 15 years with Acid-Base Accounting has shown at layers which provide values greater than 5 tons/1000 tons in the max needed c**olumn** (the column which represents excess acidity in the layer) produce acid, while values greater than 20 tons/1000 tons in the max needed column (the column which represent excess alkalinity in the layer usually produce alkaline drainage" (p. 4). These numbers are "net" numbers (NP minus MPA). Values between these numbers could be acid or alkaline. They further cautioned against summing together the entire overburden column, even when volume adjustments are made.

Two recent studies (diPretoro and Rauch, 1988; and Erickson and Hedin, 1988) relate volume adjusted net excess and deficiency data from acid-base accounting to post mining water quality. In general the probability of a mine producing AMD increased with decreasing net NP. Ferguson and Erickson (1988) combined the two studies and found that all mines with net NP greater than 34 tons/1000 tons produced positive net alkalinities. Forty-one percent of the mine sites with net NP between 7 and 27 produced AMD, and of the sites where net NP was less than 7, 89 percent produced AMD.

Discussion on Acid-Base Accounting Interpretations

Although much work remains to be accomplished in order to better interpret acid-base accounting, the following serve as current guidelines:

1. To assure alkaline post mining water quality the volume weighted average NP must exceed the volume weighted average MPA. When NP and percent sulfur values are low, and NP approximately equals MPA the mine site will likely result in acid mine drainage.
2. Acid-base accounting cannot accurately predict the post mining concentrations of acidity, alkalinity, or concentrations of cations and anions.
3. DER has found that strata with NP's less than 30 tons/1000 tons do not generally contribute significant alkalinity to post mining water quality. Strata with sulfur greater than 0.5 percent and low NP will most likely form acid mine drainage.
4. Where massive sandstone is the predominant overburden material and NP is low (which is usually the case due to paleodepositional controls), acid mine drainage is virtually

always the result, even when sulfur values are low. This has been a consistent observation of several researchers and DER experience.

5. Interpretation of acid-base accounting must be made in the context of all other tools of mine drainage prediction. Generally all methods will be consistent. When the different predictive techniques are not consistent it may indicate such things as nonrepresentative overburden holes or rapid lateral facies changes between the proposed mine and the adjacent mines. Sites where the various predictive tools contradict one another should be dealt with quite cautiously on sensitive watersheds.
6. The review of overburden analysis must be made in the context of the stream classification and stream use. The limitations of the predictive methods must always be considered in evaluating the risk of environmental harm.

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