USE OF ACID-BASE ACCOUNTS IN PREMINING PREDICTION OF ACID DRAINAGE POTENTIAL: A NEW APPROACH FROM NORTHERN WEST VIRGINIA[1]

Richard S. diPretoro and Henry W. Rauch[2]

Abstract.--Premining prediction of postmining drainage quality is required by law, but the method most often used, involving acid-base accounting, was never intended to predict mine drainage quality and as used in the past has proven unreliable. In this study, postmining drainage chemistry was measured at base flow in a one-time sampling program for 75 surface coal mines in Monongalia and Preston Counties in West Virginia. The drainage chemistry was then compared to available acid-base account parameters to identify reliable premining predictors, if any, of drainage quality. Sampling locations included seeps, springs, first order streams, and inflows to ponds if they primarily contained mine drainage. Each sampling location was paired with the closest available acid-base account log, which was mathematically adjusted to yield the volume percentage of each geochemical unit in the mined coal overburden, plus one foot of pavement. Both total and net neutralization potentials (NP) of overburden are significantly and directly related to net alkalinity (alkalinity minus acidity) of mine drainage. Every sampled mine is producing drainage with positive net alkalinity if it has greater than 40 tons of $CaCO_3$ equivalent of total NP per thousand tons of overburden, or greater than 30 tons of $CaCO_3$ equivalent of net NP per thousand tons of overburden. Conversely, every mine with less than 20 tons per thousand tons of total NP or less than 10 tons per thousand tons of net NP is producing drainage with negative net alkalinity. Total sulfur content and hence maximum potential acidity (MPA) in overburden bears very little relation to mine drainage quality. All mines in this study with very low (<0.2%) sulfur content in overburden produce acid drainage. The ratio of NP to MPA is significantly and directly related to net alkalinity of mine drainage. Every sampled mine is producing drainage with negative net alkalinity if it has an NP to MPA ratio of less than 2.4.

INTRODUCTION

Public Law 95-87 (Surface Mining Control and Reclamation Act 1977) requires premining planning. The law states that surface coal mining permits are not to be issued where required reclamation is not feasible or cannot be accomplished by the plan submitted. Acceptable drainage quality is one of the components of required reclamation and such quality is to be insured in part by pre-identifying acid-producing materials so as to avoid acid drainage. Thus, the Federal government has produced a legal requirement that acid-producing materials in coal overburden and pavement be identified in advance of mining. To aid operators and state agencies in pre-identifying acid-producing materials, the U.S. Environmental Protection Agency (EPA) published a method developed at West Virginia University known as the acid-base account method (Sobek et al. 1978). The method was intended to aid revegetation by identifying the best choices for topsoil substitute material. Although it was not intended by its authors to be used to predict postmining drainage quality, acid-base accounting has been used for that purpose and has produced mixed results (Renton 1985).

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[2] Richard S. diPretoro is a Consulting Geologist in Morgantown, WV and Henry W. Rauch is a Professor of Geology at West Virginia University, Morgantown, WV.

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This study attempted to identify reliable premining predictors of acid drainage potential. This paper reports on reliability of acid-base account parameters for the premining prediction of acid postmining drainage.

Description of the Study Area

The area of study for this project comprises all or part of the areas shown on thirteen 7.5-minute topographic quadrangles of the U.S. Geological Survey in northern Preston and eastern Monongalia Counties, WV (fig. 1).

The coal-bearing rocks are middle Pennsylvanian to Permian in age and consist primarily of sandstone and shale with lesser amounts of limestone and coal. The structures are low-lying open folds trending northeast-southwest.

The climate of the study area is of the humid, continental type characterized by mild summers and cold winters. Rainfall ranges from 42 to 52 inches (Herb et al. 1981). All ground water that is eventually discharged from the study area is generated by the infiltration of precipitation except for minor amounts being flushed from deep saline aquifers.

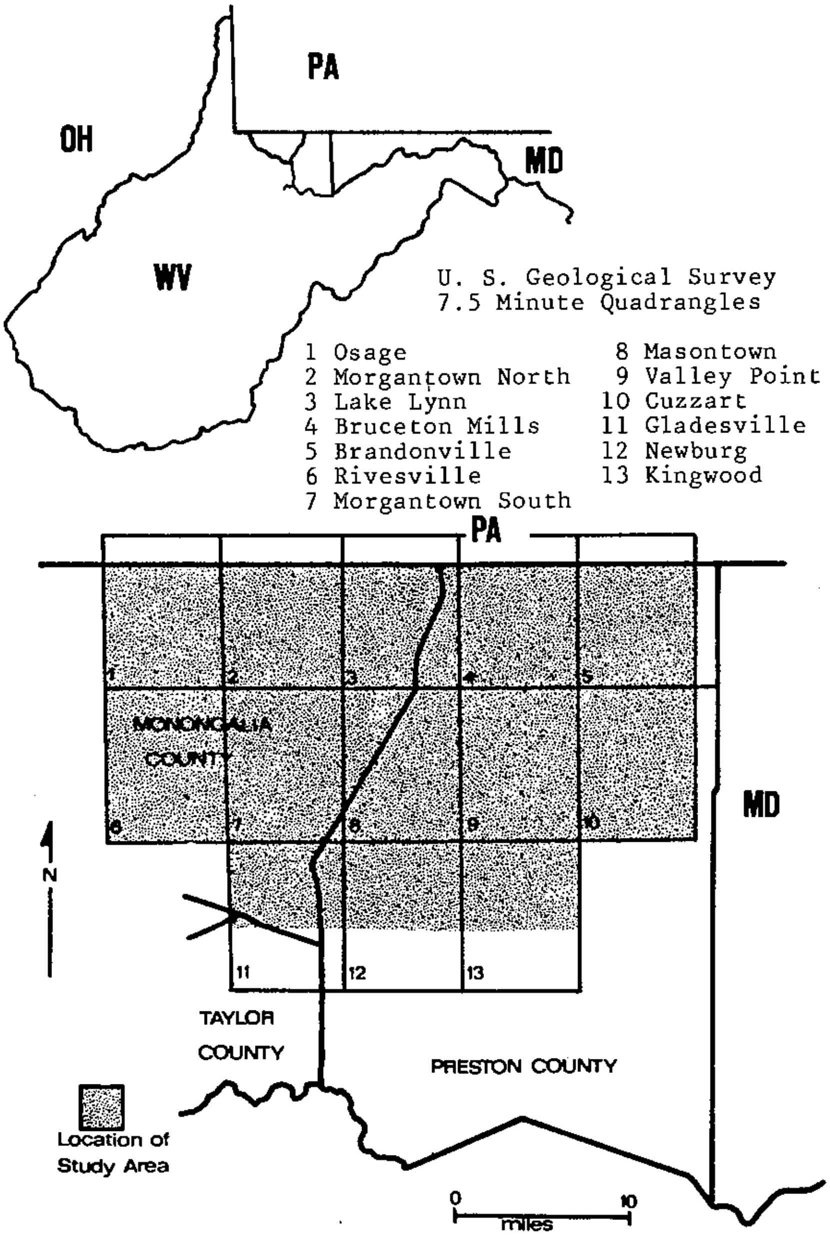

Figure 1.--Location map of the study area.

METHODS OF INVESTIGATION

Sampling

Seventy-five surface water sites were selected for a one-time sampling program designed to indicate in a broad sense the quality of drainage from reclaimed surface coal mine sites. The mine sites were selected based on pre-determined criteria discussed below after examining over 400 permit applications for surface coal mines and other water and overburden data at the U.S. Office of Surface Mining Reclamation and Enforcement (OSM) in Morgantown, WVa. All reclaimed surface coal mines in Monongalia and Preston Counties in the Waynesburg, Upper and Lower Freeport, and Upper, Middle, and Lower Kittanning Coal Seams were selected for sampling where the mines could be reached on the ground and had observable drainage. Seventy-five such sites were sampled.

Mine drainage sampling locations included seeps and springs located in and near the mine backfill, both undeveloped and developed for domestic or livestock uses. First order streams and inflows to ponds were also sampled if they primarily contained mine drainage. The selected water sampling sites were usually near vegetated mine backfills that usually had been reclaimed for 2 or more years. They were mostly chosen on the downdip side from the mine drainage source with the highest flow rate. Where possible, they were established at or below the original level of the coal near the center of the mine to increase the chances of discerning any mining effects and to decrease the chances of dilution by unaffected ground water or of complicating effects from other nearby mines. Previously mined areas (before recent mining) were generally avoided, as were mines which had disposed tipple refuse or treatment residues.

The field sites were sampled during base flow (at least 3 days after the last measurable rain), in the spring of 1985. Base flow is not subject to wide fluctuations and is indicative of shallow aquifer ground-water characteristics (Hem 1970, Todd 1980, Helsel 1983). The sampling sites were all located in heavily dissected upland areas not subject to any regional ground-water discharge. Temperature, specific conductance, Eh, pH, and flow rate were measured. Three water samples were collected and treated (as appropriate) for laboratory analysis at each site.

Hot total acidity (HTA), alkalinity, sulfate, total and dissolved iron, and dissolved manganese were determined (for each set of water samples) in the Hydrogeology Laboratory in the Department of Geology and Geography at West Virginia University.

After the drainage sites had been sampled, acid-base accounts from OSM permit files were chosen to be paired where possible with each water sampling point for later comparison. Such logs were taken from the same mine or a mine working the same coal seam within 2 km of the watershed draining to the sampling point. In most cases, logs fell within 1 km of the sampling point watershed as per recommendations of the Suggested Guidelines (Surface Mine Drainage Task Force 1979). Such pairs were created for 30 out of the 75 mines studied.

Adjustment of Core Log Data for Volume

Core logs record the thickness and type of each rock lithology over an area that is so small compared to the area to be mined that they can be considered lines in cross-section. Mined overburden in the field area is not rectangular in cross-section, as it is in Illinois for example, but is more nearly triangular in cross-section because of the notable terrain slopes. Therefore, the volumes of each lithology represented by the core log are not in fact in the same volume proportion to each other in the mined overburden as they are in the linear record of the log. Those near the top are over-represented and those near the bottom are under-represented by an unadjusted log.

Volumetric adjustment is in order if better predictions are to be made of the combined effects that the different overburden rocks will have on water after mine reclamation, assuming that water quality is related to the mass of certain constituents in the rocks. The ideal solution would be to have a closely spaced grid of cores that would be stratigraphically correlated, allowing the strata to be projected to their crop lines according to the dip and strike. The average area of each lithologic unit would then be measured by planimeter and multiplied by its average thickness to arrive at a total volume for each rock lithology. Tonnages would be computed if necessary, based on estimated (or measured) rock densities.

An effort similar to that just described was successfully carried out and described in the literature by Caruccio and Geidel (1981). Such efforts were also carried out for some West Virginia surface mine reclamation permit applications for a brief time in 1981 (diPretoro 1986). The reason for such calculations in permit applications was to compute the amount of limestone that is supposed to be needed to compensate for deficiencies identified by acid-base accounting.

For this study, a simpler volumetric adjustment was designed that could be applied quickly to limited core log data. This volumetric adjustment was conceived by the senior author and carried out by means of a computer program written by Mr. Paul Sutter, systems analyst for the West Virginia University Department of Geology and Geography.

The volumetric adjustment yields the approximate percentage of the total overburden volume occupied by each rock unit and requires knowing only the total thickness of the stratigraphic overburden column, the thickness of the individual rock units, and their relative positions. It starts with the recognition that every mined tract in the field area is part of a slope, hill, or mountain. It assumes that the shape of a mined hill can be approximated as one of a number of three-dimensional shapes, each of which is a triangle in cross-section. These include shapes similar to those for contour mines and area or mountaintop removal mining operations where the top of the mountain is cone or prism shaped (fig. 2). The core log's top is usually located at the highest point of the triangle, and the coal or pavement forms the triangle's base leg which is roughly perpendicular to the core log. Symmetry about the core (vertical axis) is not required on conical shapes, and triangular cross-sections need not be isosceles. (In this study, some logs represented more, or less, overburden than was present at the mine producing the drainage samples. Where the log represented more overburden, the extra amount was removed from the calculations. Where the log represented less overburden, the missing amount could not be evaluated.

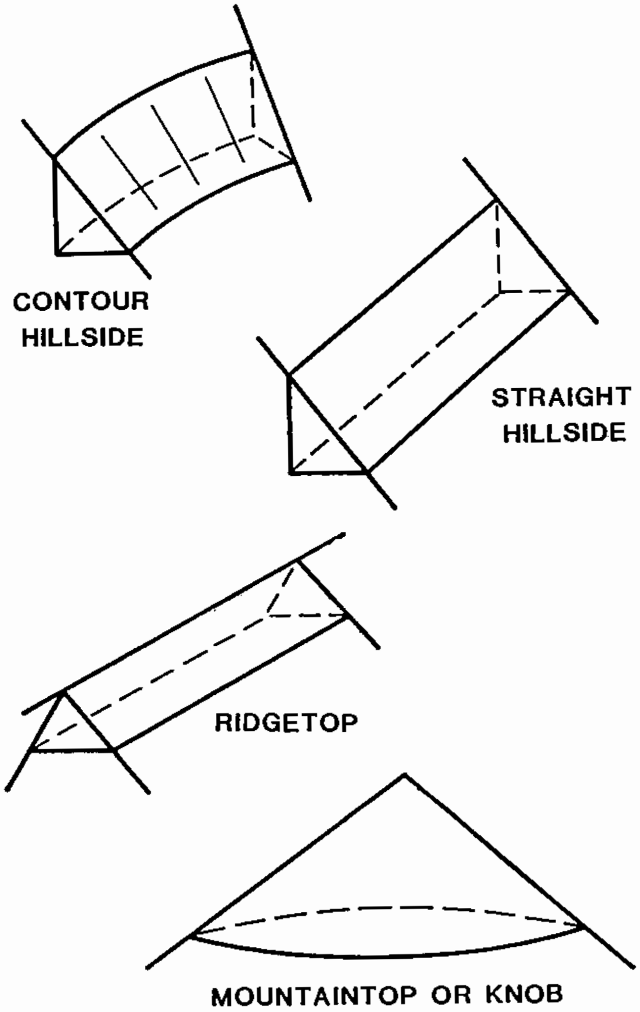

Figure 2.--Idealized shapes of hills having triangular cross-sections when mined.

The program takes the thickness of each layer of rock and calculates the percentage of the area of the whole cross-sectional triangle occupied by that layer. The areas of the triangle and its parts are proportional to the volumes of the corresponding parts of the overburden as a whole (fig. 3).

Because the coal is, for the most part, gone after reclamation, its contribution is removed and the relative percentages of each remaining layer are recalculated. (Bottom coal, partings and other wastes are often left on the pavement but in the interests of simplicity are ignored in this study.) The percentage for each layer is then multiplied as a decimal fraction by the acid-base NP or MPA for that layer to arrive at its contribution to the total for each parameter. The adjusted NP and MPA for each layer is then summed to produce an adjusted NP and MPA for the entire column. Totals of unadjusted NP and MPA are physically meaningless because layer thickness and volume have not been taken into account.

This right triangular method incorporates simplifying assumptions. The core does not always represent all the overburden. The dip is ignored, but the maximum dip is low in the study area, rarely approaching 10 percent. Cross-sections are not exactly triangular, but are slightly elliptical. Lithologic units are usually laterally discontinuous and may thicken, thin or pinch out altogether away from the core hole. Despite its shortcomings, however, the volumetric adjustment technique used in this study is an adequate first approximation and is an improvement over an assumption of a linear relationship between percentage of a certain lithologic unit in a core log and its volume in the mine backfill.

Characterization of Post-Mining Drainage

For the purposes of this study, the legal definition of acid mine drainage (AMD) was used as a basis for characterization of postmining drainage. AMD is legally defined as water discharged from an active, inactive, or abandoned mine and from areas affected by surface mining with a pH of less than 6.0 in which total acidity exceeds total alkalinity (Code of Federal Regulations 1986). The legal definition of acid mine drainage creates an operational parameter to characterize water quality, herein called "net alkalinity," which is calculated by subtracting the acidity from the alkalinity of a drainage water sample with both measured in the same units (mg/L as $CaCO_3$). Net alkalinity can be positive (when alkalinity exceeds acidity) or negative (when acidity exceeds alkalinity). In this study, most drainage samples had only acidity or alkalinity. In the samples that had both acidity and alka-

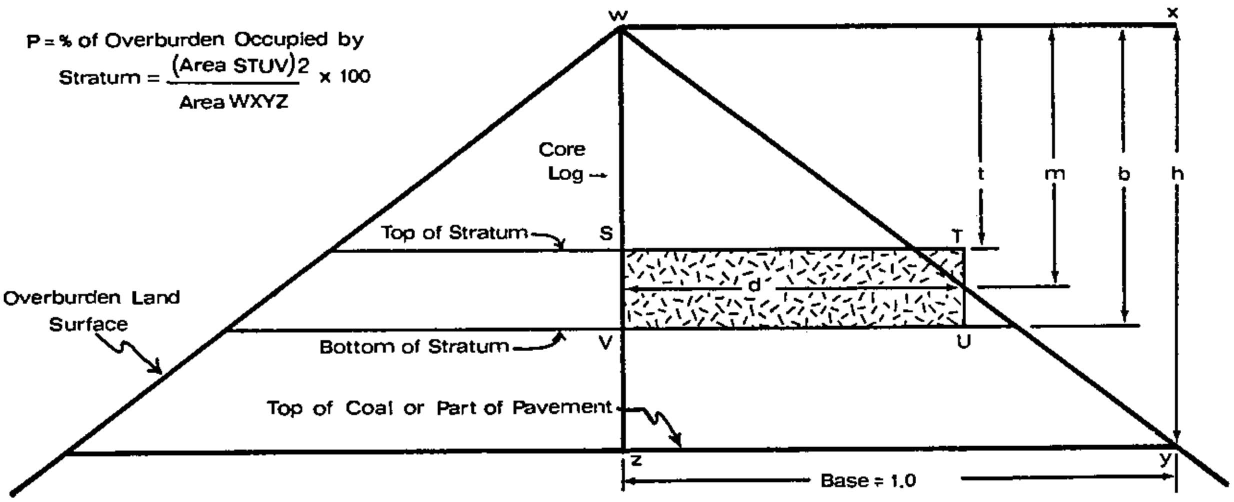

Figure 3.--Triangular cross-sections of idealized hill, showing variables used in the volumetric adjustment program.

linity, one outweighed the other by a factor of at least 10 in most cases.

Net alkalinity for the sampled drainage sites was compared by use of graphical data plots and statistical analyses with values for the geochemical parameters evaluated. All the raw data were reported by diPretoro (1986); diPretoro and Rauch (1987) reported other results of the same study having to do with lithologic parameters.

RESULTS AND DISCUSSION

In spite of their shortcomings, acid-base accounts were used in this study because they are available in large quantity and they do give some useful information on the geochemical nature of the individual strata.

Neutralization Potential (NP) and Net NP

Figure 4 compares net alkalinity of mine drainage to the acid-base account parameter of net NP in overburden, with each plotted point representing a sampled mine site. The statistically significant regression line depicts the average rise of net alkalinity of drainage with increasing net NP. Figure 4 also shows that all sites having net NP of less than 10 tons of calcium carbonate equivalent per thousand tons of overburden had drainage with negative net alkalinity, while all sites having net NP of greater than 30 tons per thousand had drainage with positive net alkalinity. Note that the acid-base account method defines potentially toxic material in individual strata as that having a net NP of less than -5 (Sobek et al. 1978). This study indicates that the threshold level of concern for net NP for the overburden as a whole must be set higher. A similar trend (with a slightly lower R value that is statistically significant at 0.05 alpha) was also observed for total NP. All sites with total NP greater than 40 tons per thousand tons had drainage with positive net alkalinity while all sites with less than 20 tons per thousand tons had drainage with negative net alkalinity.

Maximum Potential Acidity (MPA)

MPA, calculated by multiplying total sulfur content as a decimal fraction by 31.25 (Sobek et al. 1978, p. 55), was found to have no statistically significant relationship (at 0.05 alpha) to net alkalinity of mine drainage. As shown in figure 5, there appears to be a slight rise in average net alkalinity with rising sulfur content, and all sites with very low sulfur produce acid. This seeming anomaly relates to the NP/MPA ratio present. NP of overburden rises as MPA rises, but NP rises at a faster rate. Very low MPA values are on average associated with proportionately less NP (and hence neutralizing capability) than are higher MPA values (above 5). The median value of NP/MPA ratio for sites in this study with MPA below 5 is 0.5. The median value of NP/MPA ratio for sites with MPA above 5 is 2.9.

NP/MPA RATIO

Caruccio et al. (1980) and Caruccio and Caruccio (1982) have found a strong relationship between drainage quality and carbonate to sulfur ratio. In this study, the ratio of NP to MPA (herein called RATIO) was assumed to approximate the ratio of carbonate to sulfur. The regression line showing the relationship of RATIO to net alkalinity in mine drainage had the

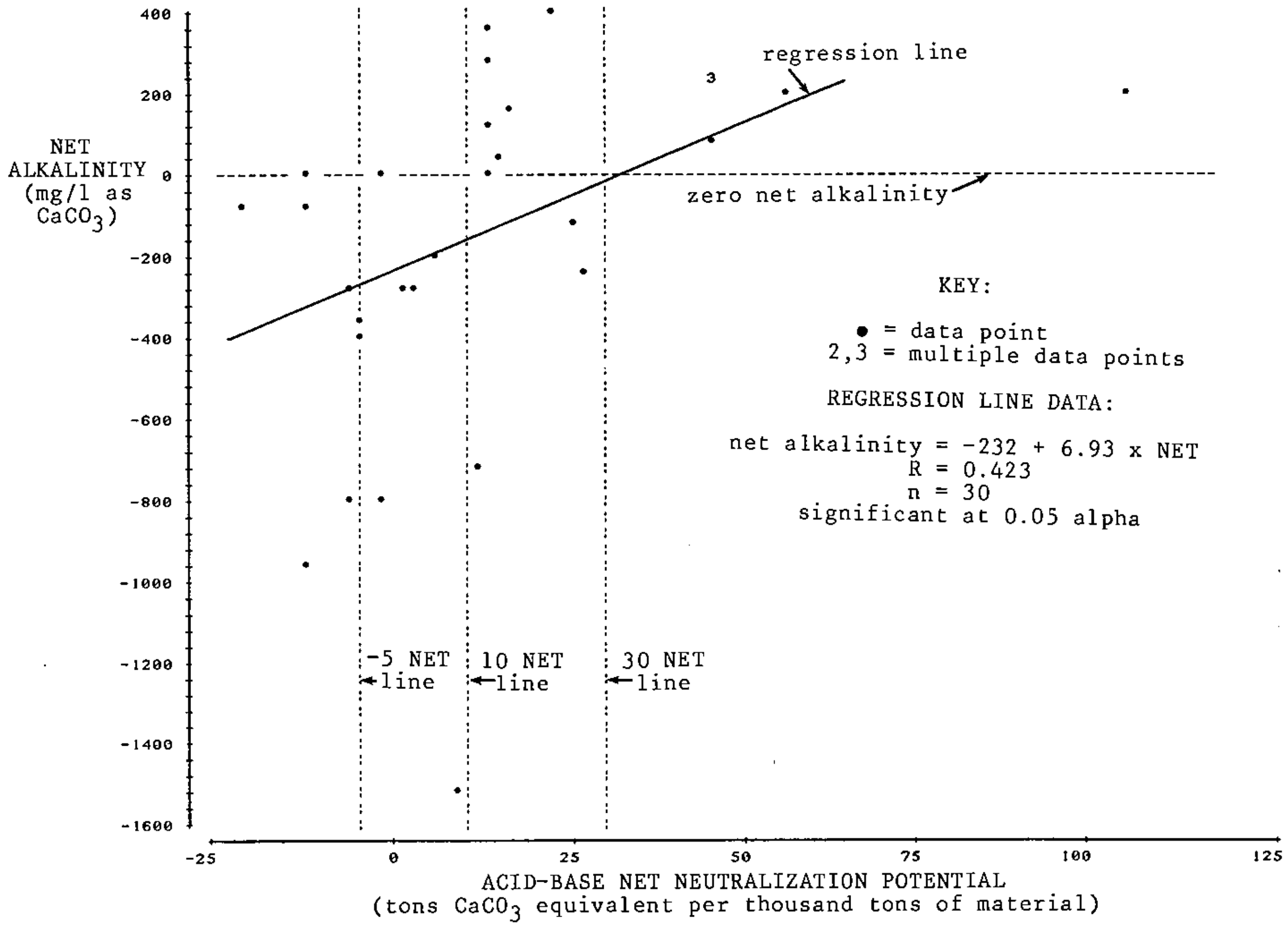

Figure 4.--Net alkalinity in mine drainage versus acid-base net neutralization potential in coal overburden.

greatest degree of statistical significance of those for the acid-base account parameters tested in this study. Figure 6 shows that all of 15 sites having a RATIO of less than about 2.4 had drainage with negative net alkalinity, while 11 of 14 sites having RATIOs greater than about 2.4 had drainage with positive net alkalinity. Note that the presently used acid-base account method would place the critical RATIO boundary below 1.0 (or even below zero) because geologic units having net NP greater than -5 are considered not potentially toxic (Sobek et al. 1978, Surface Mine Drainage Task Force 1979, Erickson et al. 1985). For example, one acid-base account in this study has an NP of 0.3 and an MPA of 4.6, producing a RATIO of 0.1. Strict application of acid-base account guidelines would result in this overburden being considered by some persons not potentially toxic because 0.3 minus 4.6 is greater than -5.0. The drainage from the two sampling locations within 2 km of this acid-base account, however, is highly acid.

CONCLUSIONS

This investigation of reclaimed surface coal mine sites in the northern West Virginia study area has led to four conclusions about the study results and a fifth general conclusion about acid-base accounting:

1) After adjusting acid-base account core logs for volume, all sites with acid-base neutralization potential (NP) greater than 40 tons per thousand tons of overburden equivalent calcium carbonate yield drainage having positive net alkalinity; all sites with NP less than 20 tons per thousand tons equivalent calcium carbonate yield drainage having negative net alkalinity.

2) Acid-base maximum potential acidity (MPA, calculated by multiplying percentage sulfur by 31.25) in premining coal overburden bears very little relation to net alkalinity of post-mining drainage in the study area except that below about 0.2 percent sulfur, reclaimed overburden is likely to produce acid drainage because of concomitant low neutralizing capacity.

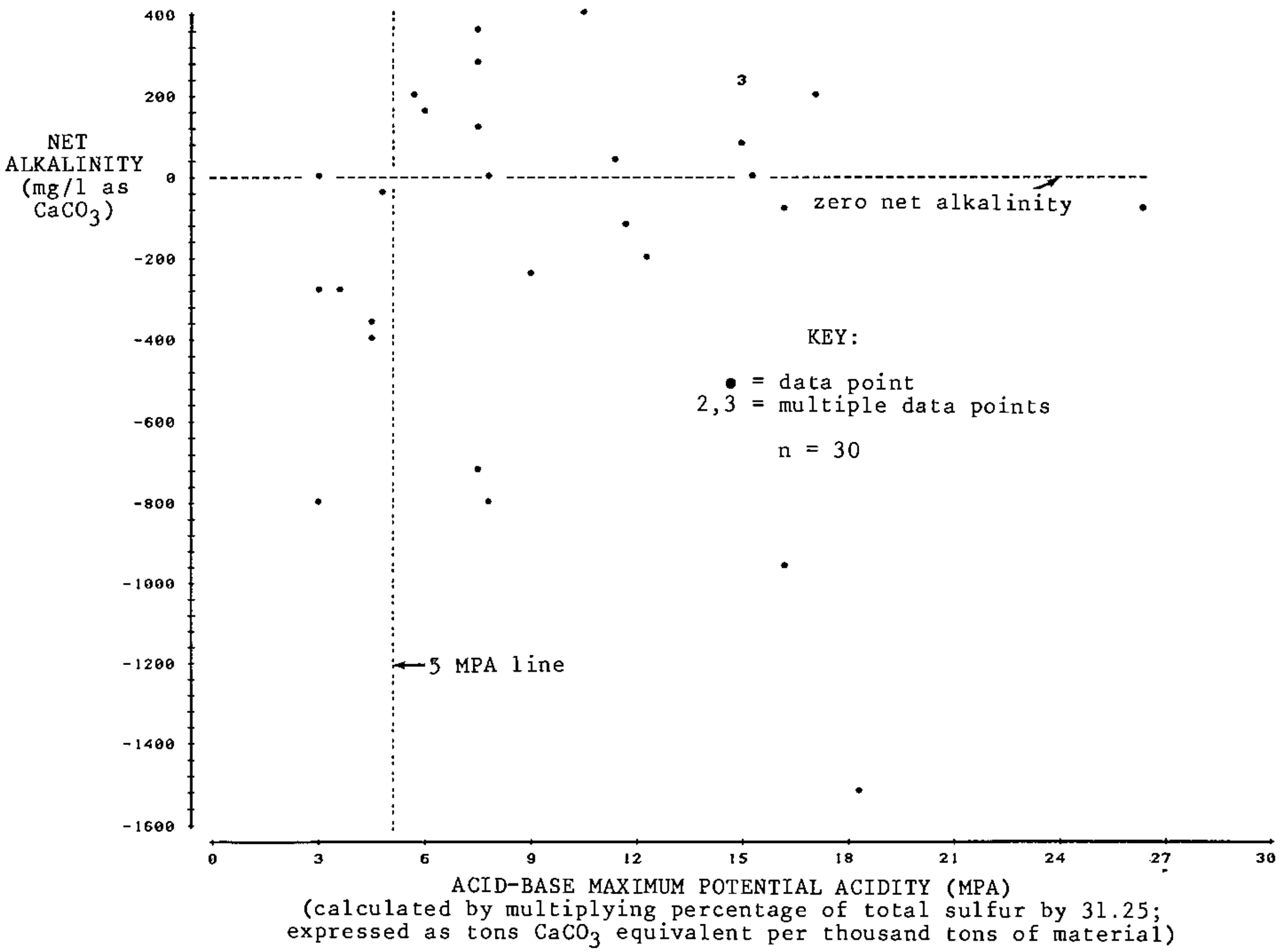

Figure 5.--Net alkalinity in mine drainage versus acid-base maximum potential acidity in coal overburden.

3) All sites with acid-base net NP (NP-MPA) greater than 30 tons per thousand tons of equivalent calcium carbonate (20 percent of sites in this study) yield drainage having positive net alkalinity; all sites with net NP less than 10 tons per thousand tons calcium carbonate equivalent (47 percent of sites in this study) yield drainage having negative net alkalinity. The original acid-base account application, which placed the threshold level of net NP for drainage having positive net alkalinity at -5 (same units), was obviously in error.

4) Acid-base NP divided by MPA yields a variable called RATIO. Sites with RATIO values greater than 2.4 are most likely to produce drainage having positive net alkalinity; sites with RATIO less than 2.4 are most likely to produce drainage having negative net alkalinity. The original acid-base account application which placed the threshold level of RATIO for drainage having positive net alkalinity at or below 1.0, was in error.

5) Despite its limitations, acid-base accounting can be used more effectively than it is currently being used to produce accurate premining assessments of post-mining drainage quality. Because of the complexity of coal mining and reclamation operations, professional judgement (taking into account lithology and history of drainage quality in a given area, as well as acid-base account parameters) will always be required to arrive at a final determination.

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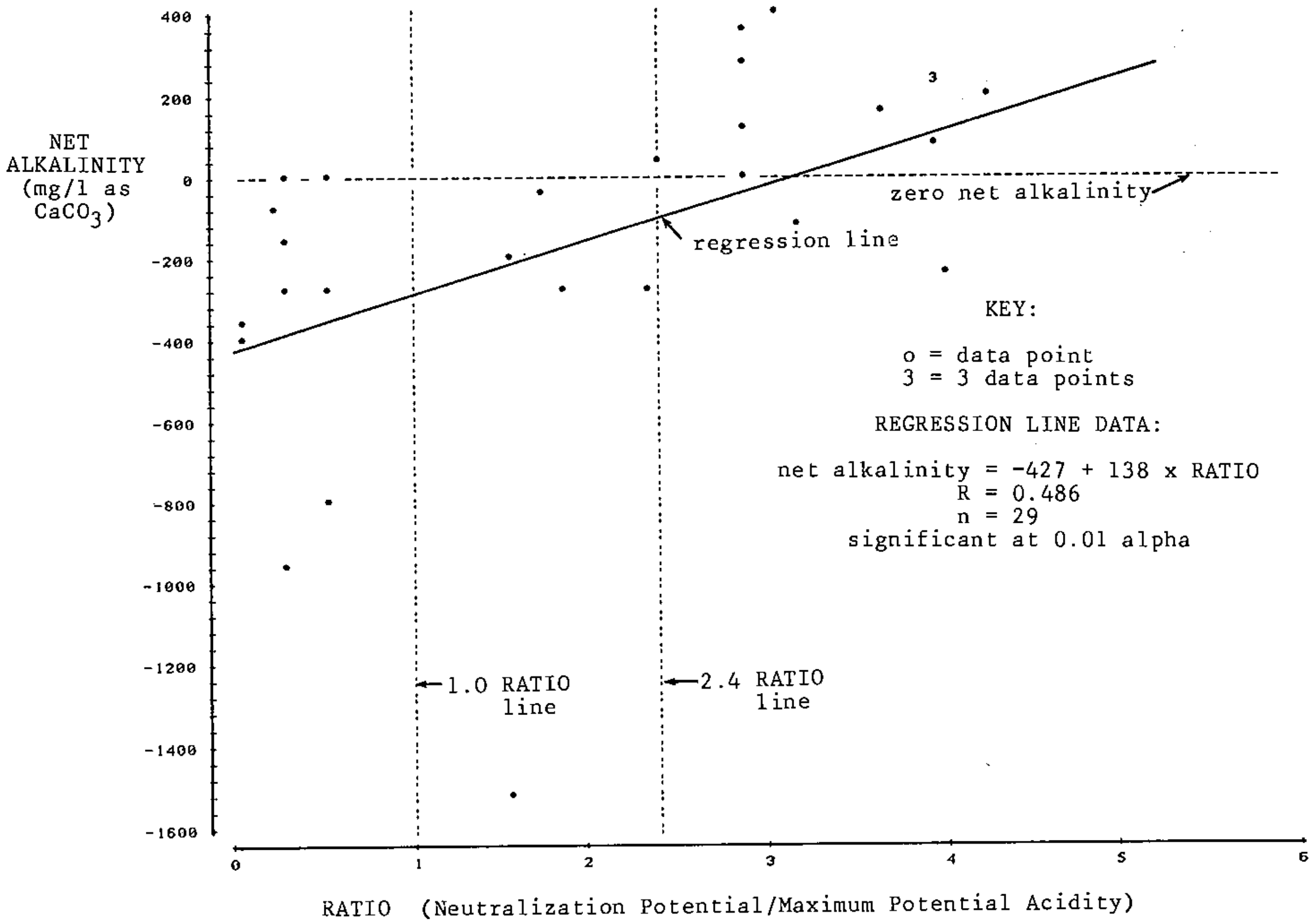

Figure 6.--Net alkalinity in mine drainage versus acid-base account RATIO (NP/MPA) in coal overburden.

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