Geoderma 308 (2017) 302–311

Contents lists available at ScienceDirect

Geoderma

journal homepage: www.elsevier.com/locate/geoderma

A methodology for geologic testing for land disturbance: Acid-Base Accounting for surface mines

Jeff Skousen

Professor of Soil Science and Land Reclamation Specialist, West Virginia University, Morgantown, WV 26506, USA

ARTICLE INFO

Handling Editor: M.J. Vepraskas

Keywords:
Acid mine drainage
Acid soils
Neutralization potential
Potential acidity
Pyrite
Reclamation

ABSTRACT

Acid mine drainage and acid sulfate soils are common consequences of disturbing earth materials containing pyrite and other sulfide-bearing minerals. In order to predict the acid-producing potential of geologic layers in eastern US coal mining regions, Acid-Base Accounting (ABA) was developed by researchers at West Virginia University. The objective of this paper is to demonstrate the use of this method and its interpretation as a prediction tool, and to evaluate its accuracy from literature sources. ABA is an analytical procedure that provides an assessment of the acid-producing and acid-neutralizing potential of soils, sediments and rocks prior to coal mining, highway construction, and other large-scale earth-moving excavations. ABA includes techniques that measure the reactive sulfur content (which is converted to the acid-producing potential, Maximum Potential Acidity or MPA) and the reactive carbonate content (which is converted to acid-neutralizing potential, Neutralization Potential or NP). These two quantifiable properties in ABA are primarily used to predict the quality of drainage and soil quality by subtracting MPA from NP, resulting in a net NP value (either positive or negative). If the MPA value is higher for the sample (negative net NP), the rock sample is predicted to produce acidic drainage upon weathering and leaching. If the number for NP is higher (positive net NP), the rock is predicted to produce alkaline drainage. Other parameters such as rock type, color and paste pH help to refine the interpretation and prediction of net NP. After passage of laws requiring an assessment of surface mining on water quality, ABA became the preferred method to predict post-mining water quality, and permit decisions for surface mines are largely based on the net NP values of ABA. With this information, mining plans are developed which may include mixing overburden materials during mining and reclamation or removing acid-producing materials from the site, selective handling of these materials and placing in specific areas within the backfill, and amending these acid materials with alkaline material. ABA has proven to be a good tool to predict overburden quality that allows the application of prevention procedures to alleviate post-mining water and soil quality problems. Studies comparing the post-mining water quality with predictions made by ABA have confirmed the utility of ABA for permit decisions, pre-mine planning and reclamation practices.

1. Introduction and history

The purpose of this paper is to explain the need for an analytical method for determining the quality of rock disturbed during surface mining and other deep excavations into the earth, demonstrate the use of the Acid-Base Accounting (ABA) method to predict the acid-producing potential of sulfide-bearing geologic layers in eastern US coal mining regions, and to evaluate the accuracy of this method based on data from literature sources.

In North America, coal mining was first recorded in 1750 near Richmond, VA. Coal was removed by hand where the coal outcropped along hillsides. Mining for coal increased to a larger scale during the late 1800s as the Industrial Revolution progressed and as high energy resources were needed to generate steam for engines. Most of the coal was mined by underground mining methods from 1880 to 1940, but soon after World War II surface mining became more prominent with large equipment available to remove the soil and rock covering the coal seams. As surface mining operations spread and mining equipment increased in size, these larger excavations caused mining to reach deeper depths and created bigger land disturbances. With increased size and number of operations, state regulatory authorities began requiring operators to reclaim these pits and land disturbances. The first laws recognizing the need for reclamation were passed in the eastern USA by states like West Virginia and Pennsylvania, which required that mine operators register with the state and pay a bond for reclamation (Imhoff et al., 1976; Skousen and Zipper, 2014).

Abbreviations: ABA, Acid-Base Accounting; MPA, Maximum Potential Acidity; NP, Neutralization Potential; SMCRA, Surface Mining Control and Reclamation Act

E-mail address: jskousen@wvu.edu.

http://dx.doi.org/10.1016/j.geoderma.2017.07.038
Received 7 October 2016; Received in revised form 25 July 2017; Accepted 27 July 2017
Available online 09 August 2017
0016-7061/

As reclamation became more important on surface mines, engineers and scientists soon recognized that some rock materials disturbed during the surface mining process were better for plant growth and should be placed at the surface for reclamation than others (Grim and Hill, 1974). During the mining process, unweathered geologic materials were brought to the surface where oxidation and weathering reactions released dissolved elements (Daniels et al., 2016). In many mining areas, reactive carbonates and sulfur-bearing minerals were unearthed and exposed to the environment, and acid and base reactions occurred leaving either acid mine drainage and acid soils, or highly alkaline waters and soils (Dudka and Adriano, 1997; Skousen et al., 1999). Soil or weathered rock materials when placed on the surface promoted vegetation establishment and did not react to form dissolved iron oxides that colored surrounding streams with red and orange. In this paper, overburden refers to rock materials (weathered or unweathered) that are between the land surface and the coal seam and can be used interchangeably in this context. It excludes soil materials that are classified as O, A, E, B, and C horizons which, in general, will be referred to as soil. Overburden is comprised of layers of any rock type, including sandstones, shales, mudstones, limestones, or others overlying the coal seam. In the eastern US coal mining region, topsoil is often defined more broadly than just the O and A horizons common in the soil science literature, and in this context topsoil can include both B and C horizons. When salvaging topsoil in mining situations, it is most desirable to save the O and A horizons for replacement during reclamation, but it is common that soil materials from B and C horizons may be mixed with other soil or substitute materials and placed on the surface as "topsoil." Hence, the term soil materials will be used in this paper to represent the topsoiling requirement specified in regulations.

Mining practices at the time essentially turned the overburden materials upside down relative to their original position. Soils and weathered rock materials that were originally near the surface were placed in the pit while the unweathered materials near the coal seam were placed on the surface. Unweathered rock materials with high sulfur contents reacted in the near-surface environment creating acid soils and acid runoff, which made it extremely difficult to establish grasses or trees (Greene and Raney, 1974). Conversely, carbonate-containing materials placed at the surface often produced soils with high pH. Neither condition was optimum for vegetation establishment.

Early reclamation efforts were conducted to re-establish vegetation (Smith and Tyner, 1945; Tyner et al., 1948). Scientists at West Virginia University recognized three distinct types of rock material that resulted in three types of mine soils if left on the surface. The first mine soil type was derived from acid sandstones and pyritic shales which, when unearthed and left on the surface, became strongly acid with pH below 4 (Smith and Tyner, 1945). The second mine soil type was strongly alkaline and produced pH in soils of nearly 8, originating from carbonate-bearing strata. The third mine soil type was more neutral at the beginning but could move toward more acidic or alkaline pH with time based on the dominance of the acid- or base-producing strata in the original parent material. Over time, scientists and operators noted that native soils and weathered materials were more conducive to vegetation establishment than the unweathered materials that had been originally located lower down in the geologic profile (Zipper et al., 2011).

In the late 1960s, researchers and regulators became interested in predicting the quality of rock materials before mining to determine which should be placed on the surface for plant growth. Reports of such pre-mine planning was being done in Great Britain (Riley and Rinier, 1972; Striffler, 1967); Germany (Knabe, 1964b, 1973); Czechoslovakia (Jonas, 1973, 1974); Poland (Bauman, 1976); Indiana (Wiram and Deane, 1974); Illinois (Dawe, 1975); and West Virginia (West Virginia DNR, 1976).

One of the earliest examples of characterizing rock materials was by Knabe (1964a, 1964b) in Germany. He used a procedure that evaluated the acid and alkaline condition of a geologic material. He quantified the alkaline or acid status by placing a classification (A or T) along with a positive or negative number. For example, A_{15} was a mine soil suitable for agriculture, and the subscript 15 was the percent calcium carbonate in the material. Alternatively, a mine soil classified as T_{-10} was toxic with as much as 10% of the material being acid-producing material. Subsequently, Knabe used a method called a "base-acid balance" that quantified the alkaline and acid potential of a material (Knabe, 1973). The acid potential included acid-producing minerals (sulfides) and exchangeable acids like aluminum and iron. The bases were predominately carbonates and exchangeable bases on cation exchange sites.

Efforts to classify rock materials were occurring at West Virginia University (WVU) under the direction of Dr. Richard M. Smith, who began developing a quantifiable method for identifying acid- and alkaline-producing potential of earth materials. They began defining geologic materials in West Virginia as to their acid-producing potentials (West Virginia University, 1971). Then they identified acid-neutralizing materials in rocks and developed the term neutralization potential (NP) (Smith et al., 1974). They found that this technique, now called "Acid-Base Accounting" (ABA), could be extended to other disturbances beyond mining, and began classifying geologic materials outside of West Virginia (Smith et al., 1976). After confirming the analytical procedures and recognizing the practical nature of this technique for predicting the quality of rock materials for a wide range of mining and geologic conditions, a methods handbook on the field and laboratory procedures for ABA were published in 1978 (Sobek et al., 1978).

2. Acid and base identification

Acid drainage and acid sulfate soils form when sulfide minerals are unearthed and oxidized in near surface environments during coal and metal mining disturbances, highway construction, and other large-scale earth-moving excavations (Dold, 2014; Nordstrom, 1982). Upon exposure to water and oxygen, sulfide minerals oxidize to form acidic products, which can remain in the soil or be leached into nearby streams (Johnson, 2003). The water containing these dissolved products is called acid mine drainage and often has low pH, high amounts of dissolved metals such as iron (Fe) and aluminum (Al), and sulfate (Singer and Stumm, 1970). The degree of acidity and level of pH in acid drainage or acid sulfate soils depend on the type and quantity of sulfide minerals present and the acid-neutralizing (carbonate) minerals contained in the disturbed rock (Nordstrom and Alpers, 1999). Therefore, sulfide-rich and carbonate-poor materials produce acidic drainage and acid sulfate soils, while carbonate-rich materials produce alkaline conditions in drainage and soils. In mining situations, the ultimate acidic or alkaline nature of the site is dependent on the balance between the acid-producing and neutralizing capacity of the disturbed rock layers (Skousen et al., 2002).

3. Acid Base Accounting (ABA)

Analysis of geologic materials before mining to determine acid or base status was not practiced until the late 1960s (Greene and Raney, 1974). But when the Surface Mining Control and Reclamation Act of 1977 (SMCRA) was passed, provisions in the act emphasized pre-mine planning and the use of analytical techniques to determine the potential for environmental pollution before mining (Sobek et al., 2000). Since ABA was already used in several states as a rock quality testing procedure, it was adopted by other states to satisfy the pre-mining rock characterization requirements of SMCRA. After SMCRA was fully implemented, soil and rock sampling to plan new mining operations became mandatory in the USA. Since the methods for ABA were published in Sobek et al. (1978), ABA soon became the method of choice and began being used in other countries as well (Hughes et al., 2007; Ji et al., 2006; Younger and Sapsford, 2006).

The ABA is an inexpensive and dependable analytical procedure to assess the physical and chemical properties of rock layers. It was first