

An Evaluation of Acid-Producing Sandstones in Warrick County, Indiana

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Abstract

Two lenticular sand bodies, a neutral and an acid-producing channel-fill sandstone, occur in Warrick County, southeast of Lynnville, Indiana. Framework constituents of both sandstones consist of quartz, feldspar, and mica. Matrix and cement constituents differ: 1) The acid-producing sandstone contains greater quantities of kaolinite and carbonaceous matter; 2) The neutral sandstone contains a greater quantity of calcium carbonate in form of sparry calcite and Fe-rich micrite cement. Both contain equivalent pyrite (framboidal-type) content. Total sulfur within the neutral sandstone decreases upward from a maximum 0.9 per cent at the base to a minimum 0.1 per cent at the top; mean value is 0.4 per cent. The acid sandstone more closely approaches homogeneity, with a maximum 0.8 per cent and a mean of 0.6 per cent. Sulfate salt encrustations on weathered exposures reflect inherent petrographic and subsequent acid potential differences between sandstones, *i.e.*, epsomite on the neutral sandstone, and the more acid aluminum and iron sulfates, halotrichite and pickeringite, on the acid-producing sandstone.

Introduction

The 1967 Indiana Surface Mining Act required a written "Reclamation Plan" to be submitted for approval to the Natural Resources Commission prior to the opening of any coal, clay and/or shale surface mine operation. This plan must outline the steps to be taken by the mine operator to assure successful reclamation and to prevent acid pollution of streams draining affected areas (1). Compliance with the law has brought about greater reclamation costs. One solution to reduce such costs lies in the coal industry's ability to identify toxic overburden materials prior to exposure and subsequent planned handling and burial during the normal strip-mining process. The purpose of this study was to evaluate those inherent factors of a specific overburden material which are responsible for the formation of sulfuric acid.

By studying strip mine areas where toxic materials were exposed and acidic problems exist, the present becomes a key to the future with respect to future mining of similar overburden materials. A compilation of such studies, which identify the various acid-producing formations, their areal pattern and stratigraphic relations, physical and chemical characteristics, etc., should ultimately lead to the establishment of guidelines aiding in the prediction of potential problem areas prior to their exposure. This brief investigation adds to such a compilation.

Statement of Problem

Two abandoned surface mine areas were visited southeast of Lynnville, Indiana, in Warrick County (Fig. 1). Both areas were similar in that they were confined to the cropline region of the Springfield Coal (V) and both contained overburden material consisting predominantly of sandstone with minor amounts of shale. The Folsomville surface mine area, located approximately 1 mile northwest of Folsomville, Indiana (Fig. 1, Location 1), is characterized by iron-red, acid-water impound-

ments ($\text{pH} < 4.5$) essentially void of aquatic plant and animal life. Failure of revegetation efforts is evident. Massive sandstone boulders, making up a major portion of the east overburden banks, are essentially blanketed with white sulfate salts. The Lynnville (East) surface mine area (adjacent to Peabody's active Lynnville (East) Mine operation), located 3.5 miles southeast of Lynnville, Indiana (Fig. 1, Location 2), is characterized by neutral- to slightly acidic-water impoundments ($\text{pH} \text{ -6.5-7}$) full of aquatic plant and animal life. Revegetative reclamation efforts have been successful, but still, the majority of sandstone boulders as well as the abandoned highwall exposure appear to be covered with a white film of sulfate salts. Thus the questions: 1) Why such drastic differences in quality of water and success of reclamation efforts when both sandstone bodies, presumably a source of sulfur, physically and chemically react similarly to weathering upon exposure? 2) How do the sandstone bodies differ? 3) What are the sulfate salts and how do they differ? These were just a few of the unanswered questions which led to this brief investigative effort. Field observations were combined with laboratory petrographic, x-ray, and chemical analytic data in obtaining plausible explanations.

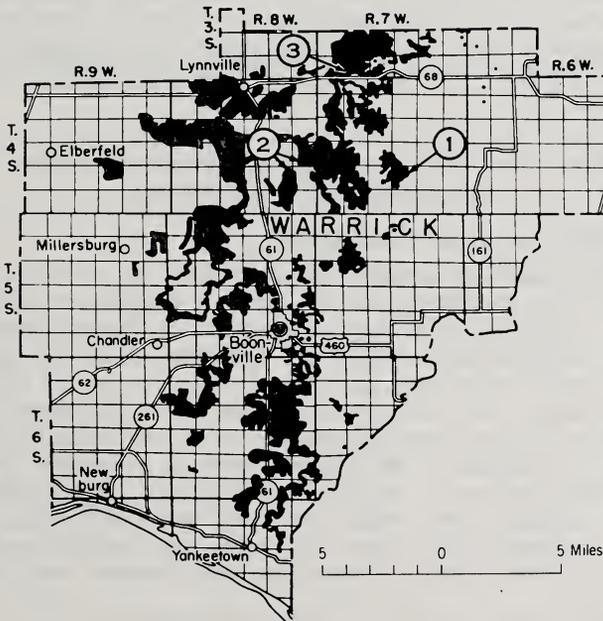


FIGURE 1. Strip-mine map of Warrick County showing general location of sampling areas (4).

Sampling Localities

Because highwall exposures in the abandoned mine areas are considerably weathered, it was necessary to sample the fresh sandstone

bodies in adjacent active mine areas. Sulfate salt encrustations and water samples were collected in the older mined areas. Exact location and kind of samples collected are as follows:

- 1) Folsomville Mine area (Fig. 1, Location 1). Sulfate salts exposed on weathered surfaces of the acid sandstone were collected from abandoned highwall and soil banks. Water samples were collected from impoundments within the same quarter section (SE $\frac{1}{2}$, Sec. 21, T4S, R7W).
- 2) Lynnville Mine (East) area (Fig. 1, Location 2). Samples representative of the neutral sandstone were collected from active pit highwall exposures in the north end of the Lynnville Mine (East) of Peabody Coal Company (NW $\frac{1}{4}$, NW $\frac{1}{4}$, NW $\frac{1}{4}$, Sec. 25, T4S, R8W). Sulfate salts exposed on weathered surfaces of the neutral sandstone were collected from abandoned highwall and spoil bank adjacent to the active Lynnville Mine (East). Water samples were collected from the water impoundment at the base of the abandoned highwall (NW $\frac{1}{4}$, NE $\frac{1}{4}$, SW $\frac{1}{4}$, Sec. 24, T4S, R8W).
- 3) Enos Mine (South) area (Fig. 1, Location 3). Samples representative of the acid sandstone were collected from active pit highwall exposures in the west end of the Enos Mine (South) of Old Ben Coal Corporation (SW $\frac{1}{4}$, SE $\frac{1}{4}$, SW $\frac{1}{4}$, Sec. 21, T3S, R7W).

Megascopic Field, Petrographic, and Chemical Analytic Comparisons Between Sandstones

Geometry and Stratigraphic Comparisons

Geometric and stratigraphic comparisons of the sandstone bodies were made along abandoned final-cut highwall exposures in both areas (Fig. 2). In addition, active mines adjacent to the research areas were examined. Both sandstone bodies are lenticular, range in maximum thickness from 25-40 feet and extend from $\frac{1}{2}$ to more than 1 mile wide. Stratigraphically, both sandstones are confined to the Lower Dugger Formation but they maintain different positions relative to the Springfield Coal (V) Member of the Upper Petersburg Formation. The acid (Folsomville) sandstone is stratigraphically bound between Coal (V) and its overlying rider seam. For the most part, the neutral (Lynnville) sandstone lies above and locally cuts through the Coal V rider horizon thus making it stratigraphically younger than the acid sandstone.

Petrographic Comparisons

Framework constituents (sand-size grain fraction) of both sandstones are essentially equivalent, consisting of quartz, feldspar (orthoclase, microcline, and minor Na-plagioclase), mica (muscovite and chlorite), and minor heavy minerals (zircon, tourmaline, opaques, etc.). Table 1 discloses the various mean and range values. Mineral composition is based on the study of 12 thin sections (six representative slides

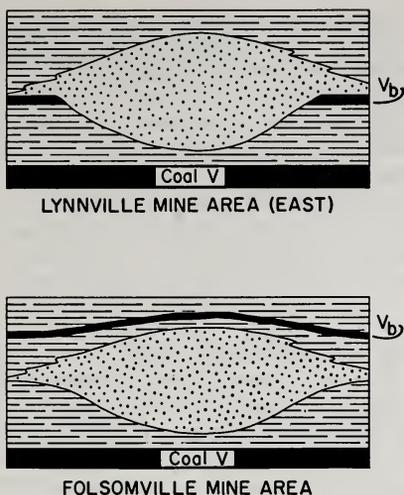


FIGURE 2. Generalized geometry and stratigraphy comparisons between sandstone exposed in the strip mine areas studied in Warrick County.

of each sandstone) taken from rock samples collected in vertical profile sequence. Composition was determined by 300-point counts per slide.

TABLE 1. Petrographic summary of the acid and neutral sandstone bodies in Warrick County, Indiana (Data obtained from thin section analyses, 300 point counts per slide).

| | Lynnville (East) Neutral Sand | | Folsomville Acid Sand | |
|-----------------------------|----------------------------------|-----------|--------------------------|-----------|
| | Avg (%) | Range (%) | Avg (%) | Range (%) |
| Framework Components | | | | |
| Quartz | 47 | 37-54 | 42 | 37-45 |
| Feldspar | 12 | 8-16 | 14 | 13-16 |
| Mica | 3 | 1-4 | 4 | 2-5 |
| Heavy Minerals | 1 | tr-1 | 1 | tr-1 |
| Matrix Components | | | | |
| Clay Minerals | 18 | 12-24 | 20 | 16-25 |
| Cements(s) | | | | |
| Sparry Calcite | 9 | 8-23 | 5 | tr-8 |
| Fe Micrite | 5 | tr-6 | 4 | tr-9 |
| Silica | 5 | 3-8 | 5 | 4-7 |
| Pyrite | 2 | 1-3 | 2 | tr-3 |
| Carbon Matter | tr | tr | 3 | tr-7 |

Both sandstones are bonded with varying amounts of illite, kaolinite, chlorite, and random mixed (mixed-lattice) layered clays and both are at least partially cemented by sparry calcite and iron-rich micrite. Major compositional differences, however, are found within the fine-silt and clay-size matrix and cementing components. Based upon x-ray diffractogram and petrographic observations, the acid sand con-

tains a greater quantity of authigenic kaolinite. Large "books" of kaolinite ($> 4 \mu$) can be seen filling original void-space. The neutral sand contains essentially twice as much sparry calcite. This difference is significant from the standpoint of the sandstone's inherent neutralizing potential. The twofold increase in carbonate availability, at the in-situ pyritic-oxidation sites, has undoubtedly played a decisive role in combating the formation of acidic conditions within the Lynnville surface mine area. In addition to the differences in amount of clay matrix and cement, a significant difference in amount of carbonaceous matter exists between sandstones. The acid (Folsomville) sandstone contains a greater quantity of fragmented carbonized plant remains and unidentifiable carbonaceous matter.

Petrographically, the sandstones contain equivalent pyrite content. Framboidal textured pyritic grains are disseminated throughout the silt-clay and carbonaceous fractions of the matrix. Individual grains range in size from 0.005mm to 0.050mm. This variety of pyrite has been demonstrated to be the most reactive with respect to rapid chemical breakdown resulting in the production of sulfuric acid (2, 3).

Sulfate Salt Comparisons

The differences in amount and type of matrix and cement constituents must account for the observed contrast in oxidation products found on weathered surfaces of both sandstones. Although the chemical pathways of the oxidation process are not fully understood, mineralogic differences noted in the sulfate salt encrustations undoubtedly reflect inherent acid potentials. Positive identifications of these minerals were obtained through the combined efforts of x-ray and optical emission spectrography. Essentially all sulfate salts collected on weathered sandstone in the Lynnville (East) Mine area consist of hydrated magnesium sulfate identified as epsomite ($\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$). Epsomite is essentially neutral with respect to acidity. Leachate from dissolved crystals yields pH values ranging from 6.5 to 7. In the Folsomville Mine area, however, a complex suite of sulfate salts coat weathered exposures of sandstone. Although epsomite is present, the majority of sulfates consist of the more acid aluminum and iron sulfates such as halotrichite ($\text{FeAl}_2(\text{SO}_4)_4 \cdot 22\text{H}_2\text{O}$) and pickeringite ($\text{MgAl}_2(\text{SO}_4)_4 \cdot 22\text{H}_2\text{O}$). Leachate from these minerals yields pH values ranging from 3 to 3.5.

Sulfur Content Comparisons

Wet chemical analyses of samples collected in vertical profile sequence disclose differences in total sulfur concentrations (Fig. 3). The neutral sandstone, exposed in the Lynnville (East) Mine area, displays a vertical decrease in sulfur concentration from a maximum 0.9% at the base to a minimum 0.1% in the upper sections, with a representative mean value of 0.4%. The acid (Folsomville) sandstone displays a vertical increase in total sulfur with a maximum concentration of 0.8% and representative mean of 0.6%. Although the chemical results show an increased concentration of total sulfur within the acid sandstone, a greater contrast was anticipated. A greater total sulfur concentration was anticipated based on the following preliminary observations: 1) concentration of the more acid sulfate salts within the Folsomville

areas; and 2) extremely high concentration of aluminum (50-60 ppm) within the water impoundments sampled.

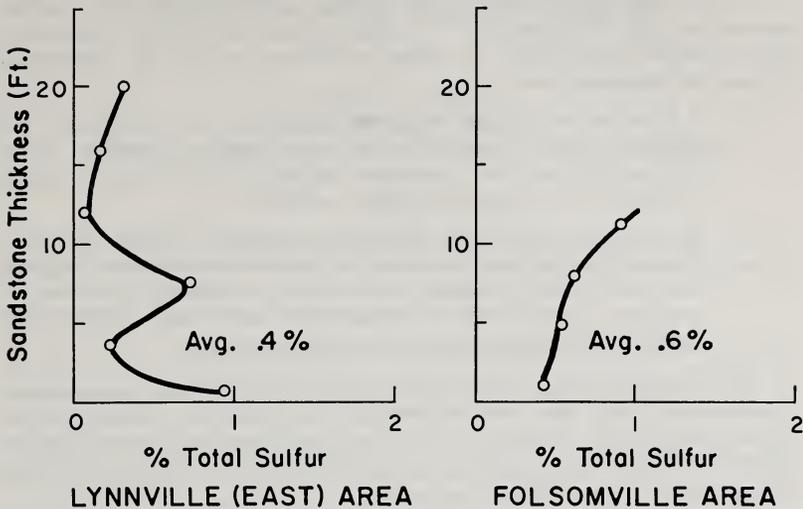


FIGURE 3. Comparison of total sulfur profiles between the neutral and acid sandstone exposed in the Lynnville Mine (East) and Folsomville Mine areas, respectively.

The three varieties of sulfur present within both sandstones are pyritic, organic, and sulfate sulfur. Wet chemical analyses disclose pyrite to be the major contributing source and sulfates to be the least. Since the petrography and chemical analyses show equivalent pyrite and pyritic sulfur contents, respectively, the difference in total sulfur between the sandstones is undoubtedly related to the difference in organic sulfur content. The observed differences in amount of carbonaceous matter (Table 1) disclose the source of the organic sulfur.

Possible interpretations of the contrasting Lynnville and Folsomville sulfur profiles are: 1) Both curves are accurate representatives and differences in their average sulfur concentrations reflect a threshold value between the creation of acid versus neutral conditions (*i.e.*, mean total sulfur values greater than 0.5% occurring in overburden materials will ultimately lead to acid conditions upon exposure); and 2) Problems associated with obtaining representative samples of the Folsomville sandbody have rendered a total sulfur curve which does not reflect original sulfur concentrations within the abandoned Folsomville Mine area.

Valid arguments against the first interpretation are: 1) The present data is too limited; more petrographic and chemical analyses are needed; in addition, a number of similar comparative studies between other contrasting mine areas are needed prior to the establishment of any threshold value, and 2) The ultimate threshold value established must be representative of both the inherent acid (sulfur availability) and neutralizing (carbonate availability) potentials.

Conclusions

Megascopic, petrographic, x-ray, and chemical comparisons between the acid versus neutral sandstones disclose the major inherent factors responsible for the formation of acidic water and spoil conditions. Those factors contributing to such conditions within the abandoned Folsomville Mine area are:

- 1) A greater total sulfur concentration within the sandstone overburden. Although pyrite is the major source of sulfur within both sandstones, the increased contribution of organic sulfur accounts for the increased sulfur content.
- 2) A significant deficit in carbonate availability within the sandstone overburden as compared to the neutral sandstone exposed in the Lynnville Mine area where a twofold increase in carbonate availability is noted. The more acid sulfate salt encrustations reflect the low carbonate content.

In conclusion, this investigation clearly illustrates the necessity of examining both sides of the inherent acid-alkalinity balance of the overburden material prior to the establishment of any threshold value which will ultimately be utilized in predicting potential (acid) problem versus (neutral) productive mine areas.

Acknowledgements

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