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# ASSESSMENT OF RESEARCH AND DEVELOPMENT NEEDS AND PRIORITIES FOR ACID MINE DRAINAGE ABATEMENT

(BCR Report L-822)

Prepared for

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF MINES

By

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Final Report on Contract No. J0265044

Submitted June 30, 1977

REPORT DOCUMENTATION PAGE

1. Report No.

2.

3. Recipient's Accession No.

4. Title and Subtitle

Assessment of Research and Development Needs and
Priorities for Acid Mine Drainage Abatement

5. Report Date
Published February 1978

6.

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8. Performing Organization Report No.
L-822

9. Performing Organization Name and Address
Bituminous Coal Research, Inc.
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10. Project/Task/Work Unit No.

11. Contract or Grant No.
J0265044

12. Sponsoring Organization Name and Address
U. S. Bureau of Mines
Office of the Assistant Director--Mining
Department of the Interior
Washington, D.C. 20241

13. Type of Report
Final

14.

15. Supplementary Notes

16. Abstract

In this report, recommendations are made for programs to develop workable techniques to stop or prevent acid mine drainage formation in those underground coal mines where acid production could take place. These recommendations include development of mine closure technology, development of surface water infiltration control procedures, study of the effect of roof collapse on mine water characteristics, evaluation of the long-term effects of flooding underground mines above drainage, investigation of the effectiveness of section sealing in active mines, development of a simple model for predicting mine water quality and quantity, preparation of a manual on mine drainage abatement procedures, and development of a program to disseminate information on mine drainage abatement to the coal industry. These recommendations are based on an in-depth evaluation of information acquired over years of research on acid mine drainage formation, on numerous laboratory and field studies of methods of preventing or minimizing acid mine drainage formation, and on review of the geological, hydrological, and mineralogical factors involved. There are 772 references.

17. Originator's Key Words
Bacteria, Coal mines, Hydrogeology, Mine waters, Pollution abatement, Pyrite, Water treatment, Underground mining, Acid mine drainage formation At-source abatement, Mine sealing, Research needs

18. Availability Statement
Release Unlimited

19. U. S. Security Classif. of the Report
UNCLASSIFIED

20. U. S. Security Classif. of This Page
UNCLASSIFIED

21. No. of Pages
162

22. Price

# FOREWORD

This report was prepared by Bituminous Coal Research, Inc., 350 Hochberg Road, Monroeville, Pa. 15146, under USBM Contract Number J0265044. The contract was initiated under the Coal Mine Health and Safety Program. It was administered under the technical direction of TCMRC, with Mr. William H. Engelmann acting as the Technical Project Officer. Mr. David L. Vila was the contract administrator for the Bureau of Mines.

This report is a summary of the work recently completed as part of this contract during the period June 30, 1976 to January 31, 1977. This report was submitted by the authors on June 27, 1977.

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To accomplish the objectives of this project, nearly 800 documents, listed in the bibliography, Section V, were reviewed and evaluated. The index to the bibliography includes references to the following subject areas which were investigated: chemical and biological aspects of mine-drainage formation; abatement methods, including operating procedures, mine sealing, hydrologic controls, and use of various kinds of inhibitors; geologic parameters such as the conditions existing during coal formation, particularly those that affected pyrite content; water quality, including data on quality of ground water, streams and mine effluents, and information on coal characteristics.

In addition, researchers involved in mine-drainage control studies were contacted as were coal industry representatives who are responsible for mine-drainage control programs at active underground mines. BCR is indebted to these many experts who were willing to express candid opinions concerning past and present research as well as the need for development of new technology.

A significant percentage of the underground coal reserves may produce acid mine water when mined. During active mining, the quantity of acid mine water formed might be reduced, but not eliminated, by implementation of abatement measures that have been demonstrated previously. Any acid water that is formed can be neutralized before discharge to prevent surface water pollution. Other than in Appalachia, essentially all of the new underground mines will be situated below drainage; and, unless pumping is required to protect adjacent mines, will become flooded and have no discharges when abandoned. Flooding will eliminate the oxygen-pyrite contact, with the result that little additional acid will be formed. Even in the steeply rolling terrain that typifies Appalachia, most of the higher elevation coal seams have been mined and the majority of future mines will be located below drainage. However, many mines will still be situated above drainage, and procedures are not available for eliminating the acid discharge from them when abandoned. The major thrust of future Bureau of Mines' research, therefore, should be focused on developing methods of mine closure.

The specific conclusions and recommendations that have been drawn are as follows:

| Conclusions | Recommendations |
|---|---|
| 1. Although the exact mechanisms involved in acid formation by pyrite oxidation are not completely understood, the theories of AMD formation proposed by researchers at Ohio State University appear to most closely describe the chemical oxidation of pyrite in the natural mine environment. | 1. Further research by the Bureau of Mines on acid mine drainage formation is not recommended. It would be interesting and, from a scientific viewpoint, should be continued, but it will not contribute to "at-source" abatement technology. |

| Conclusions | Recommendations |
|---|---|
| 2. Sulfur and iron-oxidizing bacteria have been identified in natural mine drainages and have a role in acid mine drainage production. Although research has been carried on for a number of years by different investigators, there are still questions about the actual mechanism of bacterial action. | 2. Further research by the Bureau of Mines on biological processes in pyrite oxidation is not recommended. While it would be of academic interest and perhaps contribute to a better understanding of the role of bacteria in mine drainage formation, it would not advance "at-source" abatement technology. |
| 3. The occurrence of acid mine water cannot be correlated with the sulfur content or the abundance of pyrite in the coal. Other factors, including pyrite reactivity and the acid-forming potential or neutralization capability of adjacent rock structures, control the rate of acid formation. | 3. Further research should be conducted to develop a method for determining the acid-forming potential of coal and adjacent stratigraphic measures that make up the natural mine environment. |
| 4. Laboratory investigations, at best, poorly simulate the acid-formation reactions that take place at the mining site. | 4. A laboratory procedure should be developed for producing acid under all of the conditions which exist in the underground mine. This procedure should accurately simulate such variables as oxygen concentration, character of infiltrating water, moisture content, and product removal processes. Such a procedure is necessary to bridge the gap between the laboratory and the actual mine-drainage situation that exists in the field. |
| 5. Mathematical modeling to predict flow and acid load has been successful for relatively small and simple mines. Even in these situations, too much field data are required for too many parameters. | 5. In order to make the modeling technique a useful and usable tool for predicting mine-water quality, a simple model, requiring the input of only a few critical variables, should be developed. |

| Conclusions | Recommendations |
|---|---|
| 6. The most important factors influencing the quality and quantity of mine drainage are: (a) pyrite presence, mode of occurrence (reactivity), and availability; (b) oxygen level; (c) bacteria; (d) quantity of water entering the mine; (e) quality of water entering the mine; and (f) water-flow pattern within the mine. | |
| 7. The basic mine drainage abatement principles are: (a) placement of acid-forming materials to eliminate or minimize contact with mine water; (b) inundation of acid-forming materials to eliminate contact with air; and (c) careful handling of water that does gain entrance to the mine to minimize contact with acid-forming materials and to expedite the water flow from the mine. | |
| 8. Each of five separate mining regions in the United States can be characterized by relative similarities in mine-water quality. | |
| 9. Acid mine drainage occurs mainly in the Northern Appalachian Region which includes Pennsylvania, Ohio, Maryland, and Northern West Virginia. However, even in this region, a large number of mines have drainages which are not acid. | |
| 10. Acid formation may be more widespread in the Illinois Basin than previously expected. However, the alkaline nature of the infiltrating water and the minimum amount of water produced at the mining sites, in general, precludes the acid formation | |

| Conclusions | Recommendations |
|---|---|
| situation from developing into an acid mine drainage pollution problem. | |
| 11. While occasional acid production has been recorded for a number of coal seams, and while a few seams have been identified as having a probability of producing acid, no single seam has been shown to produce acid drainage at all times and at all places. | |
| 12. Based on surveys of the coal industry conducted by EPA and BCR, and on review of the mine drainage publications, 38 coal seams have been shown to produce acid mine drainage. However, in many instances, only a single reference could be found indicating that the seam produced acid. | 12. When opening a new mine in one of these coal seams, the coal industry should be alert to the possibility that acid problems may develop even though adjacent mines in the same seam have alkaline discharge. |
| 13. In surface mining, mine drainage abatement procedures, in addition to reclamation technology, are sufficiently developed to minimize the problem when the mine is operating and to eliminate it when the mine is abandoned. | 13. Surface mining should be encouraged wherever possible for those coal seams located above drainage. |
| 14. Underground mine-sealing technology is not sufficiently developed to guarantee that the mine-drainage problem will be eliminated when the mine is closed. | 14. The thrust of the Bureau of Mines future research efforts should focus on developing mine-closure (sealing) technology. |
| 15. During mine or panel development, mine-water quality is similar to the quality of the local ground water. | |
| 16. Rock dusting has a positive effect on the quality of some mine drainages. | 16. Studies should be carried out to determine the extent to which rock dusting affects drainage quality. |

| | Conclusions | | Recommendations |
|---|---|---|---|
| 17. | The application of both biocides and bacteriophages in preventing acid mine drainage in actual underground mining environments is virtually an impossible task. | 17. | Further attempts to develop biological inhibition of pyrite oxidation are not recommended. |
| 18. | A number of chemicals have been investigated for their use either in coating pyritic surfaces or in reacting with these surfaces in order to render them inert and unable to initiate the formation of acid. While several substances have looked promising in laboratory investigations, chemical methods of inhibiting pyrite oxidation were not successful in mining environments. | 18. | Although chemical inhibition of pyrite oxidation has academic interest, further attempts to develop underground "at-source" abatement techniques based on this method are not recommended. Some justification for future research in this area would be for treating coal-cleaning refuse piles. Indirectly, this would have a positive effect on underground mine-water quality, as such refuse could then safely be placed on the surface. |
| 19. | Water infiltration control techniques can be used to reduce the volume of water that enters an underground mine. | 19. | Further work on infiltration control should be carried out with appropriate monitoring to provide proper evaluation. |
| 20. | Acid mine drainage abatement by interception of ground water before it enters the mine is in the theoretical stage of development and does not now appear practical. | 20. | The results of pilot dewatering projects, currently being conducted, should be critically evaluated before additional research on dewatering techniques is considered. |
| 21. | The most effective abatement procedures that can be utilized in an operating mine involve minimizing the contact time between the water and acid-forming materials and removing the water as expeditiously as possible. | 21. | A manual on <u>Control of Acid Mine Drainage</u> should be provided and, in order to achieve wider use of these practices, a program to disseminate this information throughout the coal industry should be developed. |
| 22. | Development of a mine to the dip may greatly reduce the acidity of the mine discharge. | 22. | Studies should be conducted to provide better methods of estimating the thickness of the barrier pillar or outcrop that will be required to maximize coal recovery and minimize barrier failure. |

| Conclusions | Recommendations |
|---|---|
| 23. Caving that normally attends longwall mining could possibly reduce or inhibit acid mine drainage formation. | 23. The effect of total roof collapse on mine drainage quality should be studied to determine whether roof collapse is a potential abatement method. |
| 24. The maximum demonstrated effectiveness of air sealing in reducing acid loads is only about 50 percent. | 24. Further research on air sealing appears impractical and is not recommended. |
| 25. Mine flooding appears to be the best method of minimizing or eliminating acid discharges from underground mines following abandonment. However, there are several drawbacks: | 25. |
| (a) The tremendous volumes of water which will be contained may be inadvertently released with catastrophic results. | (a) The Bureau of Mines should accept the responsibility of mapping these mines and monitoring all surface activities that might interfere with the integrity of the system. |
| (b) The quality of the overburden ground water may be affected at those sites where a large hydrostatic head results from mining. | (b) Future Bureau of Mines research should determine whether or not ground-water pollution might result from sealing. |
| (c) A considerable amount of coal will be wasted when leaving outcrop and pillar barriers. | (c) Further research should be conducted to determine pillar size requirements for providing adequate support for surface water bodies. |
| (d) Most mine-sealing projects were conducted at abandoned mines and the long-term effectiveness of sealing was not documented. | (d) The Bureau of Mines should sponsor a project to provide continuous monitoring, maintenance, and evaluation of some completed projects in order to determine the true effectiveness of mine sealing. |
| (e) Section sealing of abandoned portions of active mines may minimize mine drainage problems. | (e) Investigations into the effectiveness of section sealing should be conducted. |

# II. INTRODUCTION

## A. JUSTIFICATION

Acid mine drainage is a naturally-occurring phenomenon. Where pyritic materials are exposed, they can be oxidized and the resulting oxidation products can be removed by water flowing across the reaction site. Such water will be acid in nature, and surfaces contacted by this water may be subject to a characteristic orange or "yellow boy" coating. Early records note that coal was discovered by observers who were aware that such seepages were often a sign of the presence of coal.

With the growth of the coal industry and the exposure of vast quantities of pyritic materials in many mines, acid mine drainage pollution increasingly became a problem. Although industrial and governmental efforts have been directed at varying rates since World War I at defining and eliminating this condition, acid mine drainage is still a serious effect of coal mining in many places. The work carried on over these past 60 years is well documented. It includes: research on the factors contributing to mine drainage formation, programs to control acid formation by chemical and biological means, implementation of mining practices to minimize the problem, and development of mine-drainage treatment processes.

As a result of these activities, methods have been developed that will virtually eliminate acid mine drainage pollution caused by surface and auger mining. Such methods include both "at-source" abatement procedures and mine-drainage treatment processes. The "at-source" abatement procedures involve the application of the two basic mine-drainage control principles; i.e., controlled placement of pyritic materials and efficient water handling. By careful implementation of these procedures, acid mine drainage formation and its subsequent discharge are greatly reduced.

According to the 1969 Appalachian Regional Commission Report, "Acid Mine Drainage in Appalachia," 19 percent of the acid load carried by Appalachian streams originates in active underground mines. The acid mine drainage control options available to operators of underground mines also include "at-source" abatement procedures and treatment. However, due to the nature of underground mining, "at-source" abatement procedures are exceedingly difficult, if not impossible, to implement. This load is being eliminated or greatly minimized by construction of mine-drainage treatment plants by the coal industry. However, construction and operation of such plants is costly, and treatment can only be considered a temporary solution to the problem. Temporary, in the sense that while stream pollution has been reduced, the source of the acid production has not been eliminated, and the stream may revert to an acid condition once mining has ceased. Temporary, also, since strikes, power failures, normal treatment-plant malfunctions, etc., may result in the occasional release of acid water in sufficient quantity to cause periodic pollution of the receiving stream.

Due to the increasing demand for coal, it is anticipated that underground mining will be greatly expanded in the near future. In order to provide permanent and reasonable cost control of acid mine drainage from underground coal mines, it is imperative that "at-source" abatement procedures be developed.

## B. OBJECTIVES AND SCOPE

The purpose of this project is to recommend specific objectives of a research program that will lead to the development of "at-source" acid abatement procedures for active underground mines. This objective was approached by using available information: to make a critical evaluation of the "at-source" abatement work that has already been done; to describe the present knowledge concerning the formation of acid mine drainage and identify areas where more research is needed to more fully understand the problem; and to delineate the present and probable future extent of the acid mine drainage problem, and to characterize the environmental and mining parameters that contribute to its formation.

## C. SUMMARY

The overall reaction which describes acid mine drainage formation is well documented in the literature. Acid mine drainage is formed as a result of the removal by mine water of the products formed by the oxidation of pyritic materials associated with the coal seam and the surrounding strata. Ferrous sulfate and sulfuric acid are the initial products of oxidation. Ferrous sulfate can subsequently be oxidized to ferric sulfate, and ferric ions can oxidize additional pyrite. Although numerous investigations have been carried out to define and to quantify the individual steps of the reaction and to determine which step is rate-controlling, a lack of information still exists concerning these basic aspects of acid formation.

The factors which contribute to the rate at which acid is formed are well defined and include the availability of oxygen and moisture. Increased acid production rates have also been attributed to the activity of sulfur-oxidizing and iron-oxidizing bacteria, which have been isolated consistently from acid mine drainage. Based on laboratory experiments to resolve the biological and chemical components of acid formation, investigators have attributed as much as a 17-fold increase in acid production directly to bacterial activity. The bacterial role in increasing the ferric-ferrous ratio in effluent water is well established. Microorganisms also have a significant influence on pyrite oxidation.

Another factor which controls the rate of acid formation is pyrite particle size. Laboratory studies have demonstrated that fine-grained pyrite was oxidized at a faster rate than coarser pyritic material. Other studies have indicated that the occurrence of acid mine drainage can be directly related to the occurrence of fine-grained (framboidal) pyrite.

The occurrence of acid mine drainage cannot be directly related to the sulfur content or the pyrite content of the coal being mined. According to a recent survey, coal seams containing less than 1 percent sulfur rarely produce acid mine drainage, while those containing greater than 1 percent sulfur may or may not produce acid. It is apparent that other variables--including pyrite reactivity, oxygen concentration, character of infiltrating water, moisture content, and product removal processes--control the rate of acid formation and the opportunities for its release from the mine.

Mathematical models utilizing these variables, in addition to geologic and meteorologic data, to predict flow and acid load have been only moderately successful when applied to small, existing underground mines for which extensive field data were available. The difficulties of predicting acid formation from more complex or from proposed mines may be insurmountable.

Two approaches were used in evaluating the present and probable future extent of acid mine drainage occurrence. One method of assessing the problem was to compile and analyze available data on mine discharge quality. Information from two recent surveys was organized for each of five mining regions having generally characteristic water problems. The data were tabulated according to pH range of the mine effluent: less than four; from four through six; greater than six. In evaluating the data, all discharges having a pH below six were considered acid. This analysis showed that acid drainage was not a major problem for the coal industry taken as a whole. Even in the Northern Appalachian Region where acid drainage was most prevalent, approximately half or more of the mines surveyed reported the pH of their drainage to be above six.

In the second method of defining the problem, coal seams were evaluated for characteristics of the drainage they produced, and an attempt was made to identify acid-producing seams. Several coal seams in the Northern Appalachian Region were most likely to produce acid, but these seams were not invariably acid producers. A number of mines showed both acid and alkaline discharges. Water-handling techniques as well as mine hydrology and geochemistry can affect the character of mine discharges.

"At-source" abatement measures have been proposed based on eliminating one or more of the fundamental constituents of acid formation--bacteria, pyrite, water, and oxygen. "At-source" abatement also includes those procedures designed to minimize the transportation of acid from the reaction site or prevent its release from the mine.

Inhibition of acid-producing bacteria has been demonstrated in laboratory tests, but attempts to abate acid formation by applying inhibitors directly to underground mines were not successful. In the opinion of the authors the feasibility of successfully utilizing biological control to prevent acid formation in underground mines is very low for the following reasons; (1) The production and use of biocides may be prohibitive, both as to cost and toxicity; (2) The actual points of acid formation may not be accessible or perhaps not even known; (3) All of the infiltrating water would have to be inoculated; (4) Periodic applications would be necessary; (5) Acid formation from pyrite oxidation is a slow, continuing process occurring over long periods of time, and any inhibitor or coating applied for the purpose of abatement must be kept in place for equally long time periods; (6) Chemicals which have been proposed to inhibit bacterial acid formation may result in additional pollutants which would have to be removed from the effluent; and (7) The chemical oxidation and leaching process would continue regardless of bacterial inhibition.

Coating of pyritic surfaces with an impervious shield to eliminate air and moisture contact with pyrite has been suggested as an "at-source" abatement control technique, but reported experience in this area is limited. The inaccessibility of acid-forming materials and the fact that new pyritic surfaces are constantly being exposed as a result of subsidence, make this control method impractical. Periodic applications would be necessary, and the additional pollutants that may result from any inhibitor would compound the problem.

If water could be completely eliminated from underground mines, acid mine drainage would not be formed. Although it is not possible to completely prevent water from entering underground workings, effective handling of water once it gains entrance to the mine can minimize water-pyrite contact. Careful mine planning can be used to minimize the mine's total production of water. Barriers can be left in place to reduce water infiltration through highly permeable or fractured overburden. A mine can be developed in such a manner as to take advantage of basic hydrological principles. For instance, mining down-dip, so that the mine can be completely flooded following closure, might eliminate all mine-water discharges. Diversion of surface waters away from mine openings is another way of reducing water infiltration into underground mines, thereby decreasing the potential pollution load. This technique has been successfully demonstrated in a number of projects. Careful placement of refuse would also reduce the amount of pollutants that may enter the effluent stream.

Longwall mining may be an effective and economical way to inhibit acid formation. The caving which results upon completion of mining may effectively bury acid-forming pyrites under a blanket of non-reactive materials, thereby reducing or eliminating air-pyrite contact.

Underground mine sealing to completely exclude air (air sealing) was attempted as early as the 1930's under Civil Works Administration (CWA) and Works Progress Administration (WPA) projects. The effectiveness of the air-sealing work accomplished during that period is inconclusive. In the 60's and 70's, projects to demonstrate air sealing were conducted in Pennsylvania and West Virginia. Evaluation of these programs has led to the conclusion that air sealing, at best, reduces acidity by only 50 percent. Periodic maintenance of the seals is necessary, and new air passageways are opened as a result of fracturing and subsidence. With every change in barometric pressure, the mine "breathes" thus replenishing its oxygen supply and negating any benefit derived from air sealing.

Mine flooding has been demonstrated to be the only viable method of minimizing or eliminating acid discharges from underground mines following abandonment. Abatement by flooding the mine is based on the fact that covering pyritic surfaces with water greatly decreases the amount of oxygen which can come in contact with pyrite. Reductions in acidity of as much as 99 percent have been reported when this technique was implemented.

Effective abandonment procedures that would eliminate post-abandonment acid mine drainage problems should be emphasized in future Bureau research programs. This research should include determination of width of barriers to be left in place and investigations into the effectiveness of section sealing of abandoned portions of active mines.

Since underground mining has historically been conducted in the Appalachian region, material relating to the acid mine drainage problem is most extensive for this region. Numerous data have been generated pertaining to sulfur in coal, geology of the associated strata, and stream and effluent quality. Many recent studies, particularly in Pennsylvania, have been conducted to evaluate the acid mine drainage problems of specific mining circumstances and to recommend abatement work that would eliminate these problems. Many of these abatement programs, utilizing mine-sealing and water-infiltration control techniques to demonstrate mine drainage abatement, have been completed. However, an evaluation of the long-term results of the abatement work is available for only a few projects. A monitoring program to evaluate the true effectiveness of these abatement projects should be undertaken, since valuable information can be gained from these experiences.

## D. INVENTIONS

There are no patentable results or inventions from the work performed under this contract.

# III. STATUS OF CURRENT KNOWLEDGE AND TECHNOLOGY

## A. ACID FORMATION

### 1. Chemical Oxidation

a. Early Investigations: There is general agreement in the literature that the fundamental chemical reactions resulting in the formation of acid mine drainage involve the oxidation of pyritic sulfur in the presence of atmospheric oxygen and water to form sulfuric acid and iron sulfate. However, prior to the 1930's, few efforts were made to determine the mechanism of these reactions. During this early period considerable research was conducted on iron sulfides but not in relation to acid mine drainage.

Using laboratory-controlled conditions to simulate the exposed coal seam, Burke and Downs[148*] studied the effect of variables such as hydrogen ion, oxygen, and ferrous ion concentrations on the rate of pyrite oxidation. Based on their laboratory experiments, they proposed the following reaction sequence for pyrite oxidation:

$$FeS_2 + 3O_2 \rightarrow FeSO_4 + SO_2 \qquad (1)$$

$$2SO_2 + O_2 + 2H_2O \rightarrow 2H_2SO_4 \qquad (2)$$

They postulated that since reaction (1) would proceed much slower than reaction (2), the formation of $SO_2$ was the rate-determining step in the oxidation of pyritic sulfur. It also was noted that sulfur balls reacted about 10 times faster than "museum grade" pyrite.

Nelson, et al.[496] demonstrated that ferric sulfate assisted in the oxidation of pyritic sulfur and that oxygen content was an unimportant factor in the oxidation process. They also determined experimentally that pyritic sulfur in the finer sizes was oxidized at a faster rate than the larger sizes.

Early laboratory investigations at Ohio State University[491] involved basic research on the formation of acid in coal mines. In order to determine which mechanism was operative in acid formation, studies were made on iron disulfides. The Ohio State group found that oxygen was a critical factor in the rate of oxidation and that moisture influenced the rate. Since there was no indication that $SO_2$ was produced, they concluded that the pertinent reaction relating to acid mine drainage formation was

$$2FeS_2 + 2H_2O + 7O_2 \rightarrow 2FeSO_4 + 2H_2SO_4 \qquad (3)$$

and not

$$FeS_2 + 3O_2 \rightarrow FeSO_4 + SO_2$$

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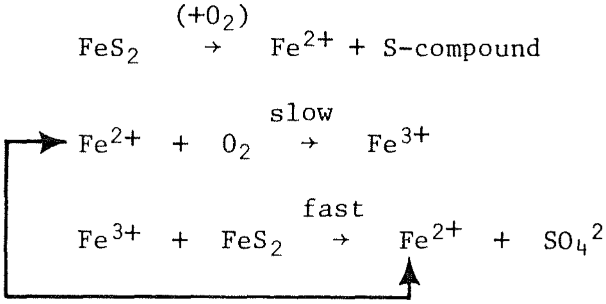
[*] Superscript numbers refer to items in the list of references, Section V.

as was stated by Burke and Downs. They also determined that the surface area of pyritic materials had a direct effect on acid formation.

The action of ferric sulfate solution on the rate of oxidation of pyrite was studied by Garrels and Thompson[294] who postulated that between pH 0 and 2, the rate of oxidation was proportional to the fraction of pyrite surface occupied by ferric ion. They noted that the three pyrite specimens used, which were obtained from the Harvard Museum collection, oxidized at markedly different rates although the mechanism was the same.

b. Recent Studies: More recently, Stumm and others[584,612,759] at Harvard University studied the rates of reactions related to mine-drainage formation. They proposed that $FeS_2$ reacted initially by a simple dissolution or by oxidation. They observed that in the absence of ferric iron no oxidation of iron pyrite occurred. Hence, the major oxidant of iron pyrite was ferric ion. Oxygen was involved only indirectly. It served to regenerate $Fe^{3+}$, which was the specific oxidant of pyrite. The oxidation rate was independent of pyrite surface area. The Harvard group concluded that the rate-determining factor in the oxidation of iron pyrite and subsequent formation of acid mine drainage was the oxidation of ferrous iron. Pyrite oxidation, as discussed by Singer and Stumm, can be represented as follows:



$$FeS_2 \xrightarrow{(+O_2)} Fe^{2+} + \text{S-compound}$$

$$Fe^{2+} + O_2 \xrightarrow{\text{slow}} Fe^{3+}$$

$$Fe^{3+} + FeS_2 \xrightarrow{\text{fast}} Fe^{2+} + SO_4{}^{2-}$$

The Harvard group based their conclusions on data obtained from "museum grade" pyrite. Since this form of pyrite has been shown to be less reactive than naturally-occurring pyritic material found in coal measures, considerable doubt must be cast on the experimental results reported by the Harvard group and by other investigators who used "museum grade" pyrite.

Based on thermodynamic grounds, Clark[174,176-177] refuted the theory by Singer and Stumm that pyrite went into solution by an ordinary chemical reaction. Since pyrite has a low solubility in water ($1.48 \times 10^{-2}$ mg/l at pH 2, $1.48 \times 10^{-4}$ at pH 4, and $2.09 \times 10^{-7}$ mg/l at pH 7), Clark postulated that the initial reaction resulting in pyrite going into solution was an electrochemical reaction; that is, a chemical oxidation-reduction reaction in which oxidation and reduction occurred at different locations on the pyrite surface. On thermodynamic grounds, both $O_2$ and $Fe^{3+}$ can serve as oxidizing agents for pyrite.

Smith, Shumate, Sasmojo, and others[490,559,590,591] at Ohio State University investigated the sulfide-to-sulfate reaction relative to acid mine drainage chemistry. They measured the oxidation rate of pyrite under aerobic and anaerobic conditions and demonstrated that oxidation involving either oxygen or ferric ion can be a major contributor to acid formation and that oxidation rates were dependent on pyrite surface area. However, they disagreed with Singer and Stumm's theory that the rate-determining step was the oxidation of ferrous iron.

The Ohio State group stated that for the mechanism proposed by Singer and Stumm to be rate-controlling, two conditions must be satisfied. First of all, pyrite oxidation by ferric ion should be at least equal to the oxidation of pyrite by oxygen. And secondly, the oxidation by oxygen of $Fe^{2+}$ to $Fe^{3+}$ in solution must be 14 times the rate of pyrite oxidation by $O_2$. Under the experimental conditions used, the $Fe^{3+}$ concentration had to be at least five times the $Fe^{2+}$ concentration to satisfy the first condition. They determined that the aerobic oxidation rate of pyrite in a solution containing 0.01 gm-moles Fe was $5.0 \times 10^{-6}$ gm-moles/hr-gm at pH 2.2. The rate of $Fe^{2+}$ oxidation in a solution of 0.01 gm-moles/l $Fe^{2+}$ was reported[772] to be $10^{-7}$ gm-moles/hr. These measurements yielded a ratio of pyrite oxidation to ferrous iron oxidation of only 0.02. Therefore, the second condition could not be satisfied. Based on these experiments, they concluded that the dissolved oxygen concentration was rate controlling in pyrite oxidation.

Smith, Shumate, _et al_. concluded that ferric ions may be an oxidizing agent for both aerobic and anaerobic oxidation. Based on experimental data, they proposed the following mechanism for the ferric iron oxidation of pyrite:

1. Ferric iron is adsorbed on a "reactive site" of pyrite to form an activated complex.

2. Ferrous ion is adsorbed on the "reactive site."

3. The activated complex decomposes to yield an adsorbed ferrous ion and transfer of electron.

4. Desorption of adsorbed ferrous ion occurs.

They proposed that Step 3, the surface transfer of electrons, was the rate-controlling step.

The Ohio State group[5] also described the physical parameters affecting the rate of acid formation. They pointed out that pyrite is contained in a more-or-less porous matrix through which the oxygen must diffuse. A major rate-limiting factor in natural pyritic systems is, therefore, the transport of oxygen to the reaction site. Since air-saturated water does not contain enough dissolved oxygen to produce a significant acid load, and the rate of oxygen diffusion through a water-saturated strata is too low to be significant, they reasoned that the movement of oxygen to a reaction site must be through a vapor phase; i.e., only that pyrite exposed to a vapor phase that is continuous to air will be oxidized at a significant rate.

Based on this conceptual model, the characteristics of the environment surrounding a reaction site in natural systems were described as a vapor phase saturated with water vapor producing a thin film (or filled pores) of water at the surface of the pyrite. The water in contact with the reaction sites would be essentially saturated with oxidation products.

c. Discussion: The following reactions, which describe the chemical oxidation of pyrite and subsequent reactions which may occur, are frequently reported in the literature:

$2\ FeS_2 + 7\ O_2 + 2\ H_2O \rightarrow 2\ FeSO_4 + 2\ H_2SO_4$ (4)
(Pyrite) → (Ferrous sulfate) + (Sulfuric acid)

$4\ FeSO_4 + O_2 + 2\ H_2SO_4 \rightarrow 2\ Fe_2(SO_4)_3 + 2\ H_2O$ (5)
(Ferrous sulfate) → (Ferric sulfate)

$Fe_2(SO_4)_3 + 6\ H_2O \rightarrow 2\ Fe(OH)_3 + 3\ H_2SO_4$ (6)
(Ferric sulfate) → (Ferric hydroxide)

$Fe_2(SO_4)_3 + 2\ H_2O \rightarrow 2\ Fe(OH)(SO_4) + H_2SO_4$ (7)
(Ferric sulfate) → (Basic ferric sulfate)

$14\ Fe^{3+} + FeS_2 + 8\ H_2O \rightarrow 15\ Fe^{2+} + 2\ SO_4^{2-} + 16\ H^+$ (8)
(Ferric iron) + (Pyrite) → (Ferrous iron) + (Sulfate)

Smith and associates at Ohio State University postulated that the rate-controlling step for acid formation in natural systems was the oxidation of pyrite by either oxygen or ferric iron as shown by reactions (4) and (8), respectively. Many workers demonstrated that the rate of pyrite oxidation was directly related to surface area[133,491,496] and reactions (4) and (8) are dependent on this factor. Oxygen concentration was demonstrated to be a critical factor in pyrite oxidation.[176,491,590] However, investigators at Harvard University dismissed direct oxidation by oxygen as insignificant. According to Stumm and associates, the rate-controlling step in acid formation was ferrous-iron oxidation as shown by reaction (5). Other workers postulated that reaction (5) occurred in solution remote from the pyritic surfaces and was not a rate-limiting reaction in acid formation. Reaction (5) was dependent on the number of bacterial cells and on the ferric- to ferrous-iron ratio.

The theories of Smith *et al*., and Stumm *et al*., evolved as the two major theories of AMD formation in the literature. The rate-controlling reaction proposed by Stumm was not consistent with findings such as the critical roles of oxygen concentration and of pyrite surface area in the rate of acid formation. These conflicts were explained by the fact that "museum grade" pyrite, which was used by the Harvard group, was less reactive than pyrite associated with coal. The theories of Smith and Shumate were consistent with the findings of other investigators. Therefore, it must be concluded that the theories of AMD formation proposed by the Ohio State Group more closely describe the chemical oxidation of pyrite in the natural mine environment.

The exact mechanisms by which acid mine drainage is formed are not completely understood, but the gaps in the knowledge are not sufficient enough to warrant further extensive investigation. Further research in this area would be interesting, and from a scientific viewpoint should be continued, but it will not contribute to "at-source" abatement technology.

2. Microorganisms in Acid Mine Drainage: Work conducted at West Virginia University[188,357-363,622-624,626-628,631,634-635] during the 1940's and 1950's showed that bacterial action was involved in oxidation of ferrous iron to ferric iron in coal mine waters. An iron-oxidizing bacterium[187] and another bacterium similar to *Thiobacillus thiooxidans* were isolated from acid mine water.

Temple and Koehler[632] studied acid formation by *Thiobacillus thiooxidans* and *Thiobacillus* (T.) *ferrooxidans* in the laboratory. Acid formation was enhanced by the action of *T. thiooxidans* on sulfur, sulfur ball, and marcasite. No acid was formed with bacteria on pyrite. *T. ferrooxidans* oxidized ferrous iron formed from pyrite and increased the acid formation from sulfur ball and pyrite.

About the same time, Braley, Leathen, and associates[136,404,406,407] at Mellon Institute studied the effect of bacteria on pyritic materials. They also isolated *Thiobacillus thiooxidans* and iron-oxidizing bacteria from mine waters. Laboratory investigations demonstrated that *T. thiooxidans* increased acid production from marcasite and sulfur but not from pyrite or sulfur ball. The iron-oxidizing bacteria was shown to have an augmentative effect on acid formation from sulfur ball and marcasite but not from pyrite. The iron-oxidizing bacteria also oxidized ferrous sulfate. Leathen and Braley[748] completely described the iron-oxidizing bacterium and proposed the generic name *Ferrobacillus* (F.) *ferrooxidans*.

A third group of investigators at Brigham Young University[147] in Utah isolated, characterized, and determined the nutrient requirements of two chemosynthetic autotrophic bacteria found in effluent streams. Both ferrous iron and sulfur were used as oxidizable substrates in the isolation of the bacteria. The culture grown on sulfur failed to oxidize ferrous iron; however, the culture isolated on ferrous iron was able to oxidize pyrite and sulfur. Since the bacteria corresponded most closely to the genus *Thiobacillus*, it was assumed that they were *T. thiooxidans* and *T. ferrooxidans* as reported by Leathen *et al.*[408] and Temple and Colmer.[628]

A table summarizing the activities of the organisms studied by the three groups (Mellon Institute, West Virginia University, and the Utah group) was presented by Smith *et al.*[331] and is shown as Table 1 of this report.

TABLE 1. ACTIVITIES OF VARIOUS ORGANISMS ISOLATED FROM ACID MINE WATERS

| | *T. thiooxidans* | | | *F. ferrooxidans* | *T. ferrooxidans* | |
|---|---|---|---|---|---|---|
| Substrates | Mellon Group | W. Va. Group | Utah Group | Mellon Group | W. Va. Group | Utah Group |
| Thiosulfate | | + | | - | +* | |
| Sulfur | + | + | + | (+; Silverman 1959) | | + |
| $Fe^{++}$ | - | - | - | + | + | + |
| Sulfur Ball | - | + | | + | + | |
| Pyrite | - | - | - | - | + | + |
| Marcasite | + | + | | + | | |
| Chalcopyrite | | | - | | | + |
| Molybdenite | | | - | | | + |

+ = activity shown

- = no activity

Blank = not done

*Later, lost activity

Silverman *et al.*[579,580] found that a significant oxidation of sulfur occurred by the bacterial action of *F. ferrooxidans* which were supplied to him by Leathen. Temple *et al.*[632] noted a difference in reactivities of different sulfur balls with *Thiobacillus thiooxidans*. He explained the disagreement with the results reported by Leathen in terms of a difference in the type of sulfuritic material used. Temple also found that *Thiobacillus ferrooxidans* enhanced acid formation from pyrite when the particle size was small enough. Since Leathen used coarse pyrite (between 1.0 and 2.4 millimeters or 0.04 and 0.095 of an inch) and Temple used a ball mill-grind pyrite, the reported results of the activity of *F. ferrooxidans* on pyrite may not be in disagreement.

A bacterium capable of oxidizing both sulfur and ferrous iron, Ferrobacillus sulfooxidans, was reported by Kinsel.[744] However, since Silverman showed that F. ferrooxidans oxidized sulfur, the difference between the two bacteria was not apparent.

Walsh[672] reported the isolation from acidic iron-bearing streams of a stalked iron bacterium which belongs to the genus Metallogenium. The new bacterium catalyzed iron oxidation only in the pH range 3.5 to 5.0. Since Thiobacillus ferrooxidans were shown to catalyze ferrous iron oxidation below pH 3.5, Walsh hypothesized that stalked iron bacteria may be one of the major causes of the initial production of acidity and of the lowering of the pH in mine water.

Bacteria have been isolated consistently from acid mine drainage. Their role in acid formation will be discussed in the following section.

### 3. Chemical Versus Biological Acid Formation

a. Laboratory Studies: That bacteria are an integral part of the coal mine environment has been well established. The exact mechanism by which these organisms aid in acid formation is inconclusive. Various investigators have attempted to resolve the chemical and biological components of acid formation.

Leathen[404] used substrates of sulfuritic materials which were prepared aseptically. The role of sulfur- and iron-oxidizing bacteria in the formation of acid was determined by examining inoculated and uninoculated substrates. He determined that Thiobacillus thiooxidans did not enhance the acid formation of sulfur ball or pyrite. A considerable increase in the amount of acid formed was noted in samples inoculated with iron-oxidizing bacteria as compared to uninoculated samples. A five-fold increase in acidity was reported with "sulfur ball" material, a four-fold increase with marcasite, and no increase with pyrite.

The influence of bacteria on acid formation was studied by Ashmead.[73] Iron disulfide and demineralized water were placed in a flask; the flask and contents were autoclaved. Natural mine water and sterile mine water were added to iron-disulfide suspension in order to ascertain the bacteriological extent of acid formation. Natural mine water, which was filtered through a bacterial filter, was also tested. Ashmead concluded that for every ton of sulfuric acid produced by chemical means, approximately four tons were produced by bacteriological means.

A Percolation Leaching Process was employed at Ohio State University[491] to resolve the acid-forming process into its fundamental components. The sulfuritic materials used were pyrite and marcasite. Samples were inoculated with acid mine water and sterile autoclaved water. The samples were then leached with tap water which was neutralized to pH of 7. The difference in acid production between inoculated and sterile samples was assumed to be indicative of biological activity. Both daily and cumulative acidities were recorded for a period of 22 days. A small amount of acid was produced initially in both inoculated and sterile samples. Then there was a lag time, after which the inoculated samples produced about twice as much acid as the sterile samples. Fifty percent of the acid formed was attributed to bacterial activity. Marcasite produced approximately 17 times more acid than did pyrite. No special precautions were taken to maintain "sterile" conditions after the initial inoculations.

The standard Warburg manometric method was used by Silverman[580] to study the oxidation of pyrites in the presence and absence of bacteria. Neither *T. thiooxidans* nor *F. ferrooxidans* enhanced the oxidation of crystalline pyrite. Both organisms accelerated the oxidation of marcasite, but *T. thiooxidans* did so only to a slight extent. The highest oxidation rates occurred with sulfur ball. Silverman demonstrated that sulfur-ball material which was inoculated with *F. ferrooxidans* underwent significantly greater oxidation than did sulfur-ball material with no bacteria present.

Smirnov[586] attempted to determine whether the chemical or biological theory of acid formation was correct. He used natural, sterile, and disinfected mine waters and inoculated sterile water for his experiments. The type of sterile water and the method used for sterilization were not stated; however, sterile waters had significantly higher initial acidities than the natural waters used.

A flow of water was maintained through crushed pyrite for a period of 30 days. Smirnov reported that *Thiobacillus thiooxidans* and *Thiobacillus ferrooxidans* increased the rate of oxidation of pyrite to sulfuric acid by 11 to 13 times compared with oxidation under sterile conditions. He noted that when furacillin or formaldehyde was added to the water to achieve complete sterility, no acid was formed. Again, the acidities of these waters were high initially. Any increase, therefore, would have been small compared to the original acidity of the water.

Shearer *et al.*[571] were not specifically trying to resolve the chemical and biochemical theories of acid formation. However, their experiments resulted in some indication of how bacteria affect acid production. Separate coal piles were inoculated with *F. ferrooxidans* and with *F. sulfooxidans*. An uninoculated coal pile was used as a control. The coal piles were continuously leached with tap water over a six-month period. A significant increase in acid production from the inoculated piles compared to that from the uninoculated pile was reported.

Caruccio[158] conducted leaching studies to evaluate the acid potential of coal and coal-related materials. Unweathered coal and rock samples were taken from active and abandoned mines. The samples were ground to 1-2 mm in size and placed in leaching chambers. A continuous flow of humidified air was maintained over the samples. Twice a week the chambers were flushed and the acidities of the effluents were determined. Twenty days after the acid-generation trends were established, three samples were inoculated with bacteria from acid mine drainage pools. The acid-generation rate of one sample increased six-fold; the other two samples showed no increase in the rate of acid formation.

Silverman et al.[581] tested the effect of bacteria on coals of different rank. Distilled water acidified to pH 2.6 was used to leach bituminous, subbituminous, and lignite coal samples. Experiments were conducted in the presence and absence of F. ferrooxidans. All bituminous coals tested showed a considerable increase in pyrite oxidation in inoculated compared to uninoculated samples. The pyrites associated with subbituminous coals and lignites seemed to resist bacterial attack.

A study of the oxidizing characteristics of pyritic materials from various coal mines was conducted by Lorenz and Tarpley.[426] The effect of F. ferrooxidans was determined by using inoculated and sterile samples. The type of drainage from the mine where each pyrite sample was collected was noted. Of the eleven pyritic materials tested, eight samples showed at least a 17-fold increase in oxidation due to bacterial activity. Four of the eight samples were associated with alkaline drainage areas. Two samples, one from an acid-drainage area and the other from a section which had both acid and alkaline waters, were not affected by bacterial activity.

Work conducted by Lazaroff[402] suggested that the growth of T. ferrooxidans required a high proportion of sulfate ions to other anions. Schnaitman et al.[560] corroborated this finding.

Walker and Randles[658] postulated that iron bacteria catalyze the initial removal of electrons from the iron of the pyrite surface, thereby initiating the acid-formation process. They pointed out that the microorganisms that were associated with acid mine drainage formation grew only in the presence of oxygen, although they did not dismiss the idea that other oxidizing agents may substitute for oxygen.

Lundgren and Schnaitman[434] suggested that iron-oxidizing bacteria catalyze the oxidation of ferrous iron by atmospheric oxygen by using the energy released by the reaction:

$$Fe^{++} \rightarrow Fe^{+++} + e^{-}$$

They postulated that a rate-limiting step in pyrite oxidation may be ferric ion formation.

Duncan, Landesman and Walden[257] proposed that ferric ion was of minor importance in the oxidation of sulfide minerals and demonstrated that direct bacterial action on iron and sulfide was the mode by which acid was produced.

Baker and Wilshire[80-83] demonstrated that F. ferrooxidans and T. thiooxidans accelerated oxidation of ferrous iron and $S_2^{2-}$ but did not alter the pyritic dissolution rate.

Stumm-Zollinger[614] suggested that the rate of oxidation appeared to be proportional to the quantity of bacteria present.

b. Discussion: Large increases in pyritic oxidation rates have been observed in microbially catalyzed reactions in the laboratory. However, the environment at the pyritic-reaction site in these laboratory oxidations is not representative of conditions in natural pyritic systems. An artificially high ferric-ferrous ratio is generated in a large quantity of water solution that is in contact with a relatively small surface area of exposed pyrite. In natural pyritic systems, pyrite in contact with this much water would be "flooded," with negligible oxygen in the vicinity of the pyrite surface.

It has been shown experimentally that both low water-to-pyrite ratios and a high concentration of acid and salts in solution reduce the number and activity of bacteria to the point that the ferric ion oxidation of pyrite is insignificant compared to oxygenation. Both of these conditions pertain to reaction sites in underground mines where vapor phase oxidation must be involved.

Ample evidence shows the existence of bacteria and their effectiveness in increasing the ferric-ferrous ratio in effluent water. However, the question remains as to whether microorganisms have a significant influence on the rate of acid production in natural pyritic systems. The key question is where do the microbially catalyzed reactions occur; in ponded water after contacting pyrite, or at the reaction site. If in ponded water, there would be no significant change in acid production due to the presence of bacteria simply because there is no further contact between the water and the pyrite. If bacteria are sufficiently active at reaction sites to generate a ferric-ferrous ratio greater than 5 to 1, then bacteria have a significant effect on acid production. In view of the nature of the environment at the reaction site, as determined in many previous Ohio State University studies, it does not seem likely that bacteria are capable of generating a ferric-ferrous ratio approaching 5 to 1.

Although effluent water from a pyritic system may have a high ferric-ferrous ratio, this does not imply a similar situation at reaction sites since effluent water is not representative of the water in contact with reaction sites.

Mathematical simulation models of pyritic systems such as that suggested by Morth[486] indicated the acid production observed in the field could be explained solely by the oxygenation rate of pyritic materials. Microbially-enhanced reaction rates were not needed to account for the rate at which acid was produced. It should be pointed out that utilization of the model requires physical information such as the porosity of the pyrite-containing strata and chemical data including pyrite reactivity. Good methods for determining these parameters are not available.

The bacterial role in acid formation is not well defined. Further research to determine the relative importance of biological processes in pyrite oxidation would contribute to a better understanding of acid formation but would not advance "at-source" abatement technology. Even if abatement measures based on inhibiting bacteria could be developed, chemical oxidation would still continue and acid would still be formed. In addition, the application of an effective bacterial inhibitor would present insurmountable problems.

4. Pyrite Reactivity: Laboratory studies demonstrated that pyrite in finer sizes was oxidized at a faster rate than coarser pyritic material. Braley[119] determined that marcasite reacted ten times faster than yellow pyrite and that black amorphous pyrite reacted eighty times faster than yellow pyrite.

X-ray diffraction analyses were made on field samples collected from coal mines in Ohio, Pennsylvania, and West Virginia.[426] The coal seams represented were the Pittsburgh, Lower Freeport, and Lower Kittanning seams. The only iron sulfide identified was pyrite. Marcasite was not found in any of the samples. This observation has been confirmed by many investigators.

Caruccio[723] indicated that the occurrence of acid mine drainage can be directly related to the occurrence of framboidal pyrite within a coal seam and associated strata. Framboidal pyrite was described as a fine-grained, highly-reactive form of pyrite. High percentages of framboidal pyrite were associated with the marine-brackish water coals and a paucity of framboidal pyrite was related statistically to fresh water coals.

Caruccio[158] compared two areas of strip mining: one area underlain by rocks of the "marine-brackish water," Lower and Middle Kittanning formations; and the other area underlain by the "fresh water" Freeport strata. He found that the occurrence of acid mine drainage could not be related to the sulfur content of the coals since one area produced acid waters and the other area produced non-acid discharges, but the sulfur content of the coals was similar. A microscopic examination of the coal samples revealed that in coals from the acid-producing area, a major portion of the pyrite occurred as clusters of spheres approximately 25 microns in diameter, while in samples from the non-acid-producing area, the pyrite commonly had a massive form with grains greater than 400 microns.

According to Renton and Hidalgo,[544] "there is no correlation between the amount of acid produced and the abundance of pyrite in coal." The only quarrel with this statement is that it presumes that a minimum level of pyrite is always present. As can be seen by Tables 2 and 3, coal seams with low (less than 1 percent) sulfur values, and correspondingly lower pyrite values, rarely produce acid mine drainage. These tables are based on a 1972 BCR survey and include data from both surface and underground mines. Table 2 shows the mine-drainage quality of coal seams in the Northern Appalachian region and the average sulfur content of the mines working the seam. Table 3 shows, on a nationwide basis, mine-drainage quality by mine compared to the average sulfur content of the coal being mined. These data tend to corroborate Caruccio's conclusion that the occurrence of acid mine drainage cannot be related to the sulfur content of the coal.

TABLE 2. RELATIONSHIP OF SULFUR IN COAL TO MINE WATER QUALITY
(by Coal Seams in Northern Appalachia)

| Coal Seams | Coal Sulfur Content in Percent | | | | | Total |
|---|---|---|---|---|---|---|
| | < 1.0 | 1.1-2.0 | 2.1-3.0 | 3.1-4.0 | > 4.1 | Mines |
| Lower Kittanning | | | | | | |
| pH < 4.0 | -- | 1 | 1 | 4 | -- | 6 |
| pH 4-6 | -- | -- | -- | -- | 1 | 1 |
| pH > 6.0 | -- | -- | -- | -- | -- | -- |
| Middle Kittanning | | | | | | |
| pH < 4.0 | -- | -- | 2 | -- | -- | 2 |
| pH 4-6 | -- | -- | 1 | -- | 2 | 3 |
| pH > 6.0 | -- | 1 | 2 | 1 | 1 | 5 |
| Lower Freeport | | | | | | |
| pH < 4.0 | -- | 1 | 1 | -- | -- | 2 |
| pH 4-6 | -- | -- | -- | -- | -- | -- |
| pH > 6.0 | -- | -- | 4 | 2 | -- | 6 |
| Upper Freeport | | | | | | |
| pH < 4.0 | -- | 2 | -- | -- | -- | 2 |
| pH 4-6 | -- | -- | 1 | -- | -- | 1 |
| pH > 6.0 | -- | 4 | 4 | -- | -- | 8 |
| Pittsburgh | | | | | | |
| pH < 4.0 | -- | 3 | 4 | 8 | 2 | 17 |
| pH 4-6 | -- | 2 | -- | -- | -- | 2 |
| pH > 6.0 | -- | 3 | 5 | 6 | 5 | 19 |
| Meigs Creek | | | | | | |
| pH < 4.0 | -- | -- | -- | -- | -- | -- |
| pH 4-6 | -- | -- | -- | -- | -- | -- |
| pH > 6.0 | -- | -- | -- | 2 | -- | 2 |
| Total | | | | | | |
| pH < 4.0 | -- | 7 | 8 | 12 | 2 | 29 |
| pH 4-6 | -- | 2 | 2 | -- | 3 | 7 |
| pH > 6.0 | -- | 8 | 15 | 11 | 6 | 40 |

## TABLE 3. RELATIONSHIP OF SULFUR IN COAL TO MINE WATER QUALITY

| Geographical Regions | Coal Sulfur Content in Percent | | | | | Total Mines |
|---|---|---|---|---|---|---|
| | < 1.0 | 1.1-2.0 | 2.1-3.0 | 3.1-4.0 | > 4.1 | |
| Northern Appalachia | | | | | | |
| pH < 4.0 | -- | 7 | 8 | 12 | 2 | 29 |
| pH 4-6 | -- | 2 | 2 | -- | 3 | 7 |
| pH > 6.0 | -- | 8 | 16 | 11 | 6 | 41 |
| Southern Appalachia | | | | | | |
| pH < 4.0 | 2 | 2 | 1 | -- | -- | 5 |
| pH 4-6 | 10 | 4 | -- | -- | -- | 14 |
| pH > 6.0 | 70 | 12 | -- | -- | -- | 82 |
| Illinois Basin | | | | | | |
| pH < 4.0 | -- | -- | -- | 2 | 2 | 4 |
| pH 4-6 | -- | -- | -- | 3 | 2 | 5 |
| pH > 6.0 | -- | 2 | 7 | 12 | 7 | 28 |
| Western Interior Province | | | | | | |
| pH < 4.0 | -- | -- | -- | -- | -- | -- |
| pH 4-6 | -- | -- | -- | -- | 1 | 1 |
| pH > 6.0 | 1 | -- | -- | 3 | 3 | 7 |
| Western Provinces | | | | | | |
| pH < 4.0 | -- | -- | -- | -- | -- | -- |
| pH 4-6 | -- | -- | -- | -- | -- | -- |
| pH > 6.0 | 7 | -- | -- | -- | -- | 7 |
| Total | | | | | | |
| pH < 4.0 | 2 | 9 | 9 | 14 | 4 | 38 |
| pH 4-6 | 10 | 6 | 2 | 3 | 6 | 27 |
| pH > 6.0 | 78 | 22 | 23 | 26 | 16 | 165 |

It can be concluded from these data that coal seams containing less than 1 percent sulfur rarely produce acid mine drainage. On the other hand, those coals containing greater than 1 percent sulfur, and therefore probably containing a significant amount of pyrite, may or may not produce acid mine water. It cannot be concluded that a seam containing 4 percent sulfur will produce acid drainage on more occasions, or will have greater acidity, than a seam containing only 1 to 2 percent sulfur. It is generally accepted that only the inorganic fraction (normally pyrite) of the sulfur present in coal contributes to acid formation. In addition, it is apparent that other factors, including pyrite reactivity, control the rate of acid formation.

The reactivity of pyrite has been experimentally measured and the effect of mineralogical properties on the reactivity semi-quantitatively described. However, a method for determining the reactivity of the pyrite associated with coal and adjacent rock measures that make up the natural mine environment is not available. A quantitative determination of the acid-producing potential of a particular coal or shale strata should be developed and would aid in predicting the probability and extent of acid mine drainage in a specific area.

There is also a need to develop, for use in the laboratory, a procedure for producing acid under all of the various conditions which exist in the underground mine. This procedure must accurately simulate such variables as oxygen concentration, character of infiltrating water, moisture content, and product-removal processes. Although numerous past laboratory studies have been based on the utilization of such a procedure, a reliable method does not exist. The development of this procedure would bridge the gap between laboratory and field work and may lead to a better understanding of the chemical processes involved in acid formation in the natural mine environment.

5. Predicting Mine-water Quality: Numerous factors have been shown to contribute to the quality and quantity of the mine-water discharge. Since the underground mine environment is a dynamic heterogeneous system, making predictions relative to the characteristics of the mine drainage to be formed is a complex task. Mathematical models may be the answer, and several have been developed to predict water discharge quantity and acid load from existing underground mines. These models, if perfected, are expected to accurately predict the environmental response to imposed changes in order (a) to determine the long-term effects of proposed mining operations, (b) to evaluate the effectiveness of abatement measures, and (c) to plan optimum treatment facilities.

The Water Generation Model (WATGEN) developed at Pennsylvania State University[509] required input parameters such as soil and rock properties, meteorologic data, fluid properties, and aquifer characteristics. Using these data, the water-discharge quantity from an active mine was simulated for one year. The simulated flows were generally higher than actual pumpages, but the predicted and the actual mine-water discharges did not differ by more than 22.5 percent.

The Acid Mine Drainage Quantity and Quality Generation Model developed at the Ohio State University[547] was based on two models: a modified version of the Stanford Watershed Model (SWM), to calculate the amount of moisture reaching the mine aquifer; and the Acid Mine Drainage Model (AMD) described by Morth *et al.*,[490] to simulate pyrite oxidation kinetics and oxidation product removal. The major inputs to the total model are: climatological, watershed characteristics, and mine characteristics data. The inputs are represented by 64 parameters as listed below. The outputs from the total model include: average daily mine water discharge, the associated acid concentration or load, plus the average daily flow in the receiving streams or at basin outlets. In using the Ohio State Model to simulate acid loads and water quantity from the McDaniel's Mine, the actual and predicted values were in fair agreement.

## LIST OF INPUT PARAMETERS FOR OHIO STATE UNIVERSITY ACID MINE DRAINAGE QUANTITY AND QUALITY GENERATION MODEL

### SWM Parameters

#### Measurable Parameters

- Impervious area that drains directly into the stream channel
- Watershed drainage area in square miles
- Index capacity of the existing channel in cubic feet per second
- Empirical constant for convection
- Estimate of the stream and lake surface area as a fraction of AREA
- Daily interflow recession constant
- Long term ratio of averate basin rainfall to average watershed ppt.
- Daily baseflow recession constant
- Streamflow routing parameter for low flows
- Stream routing parameter for flood flows
- Mean overland flow path length in feet
- Average ground slope in feet/foot of the overland flow surfaces

#### Trial and Adjustment Parameters

- Index controlling the rate of infiltration
- Index to estimate interception, depression storage capacity of the soil surface
- Index to controlling time distribution, quantities of moisture entering interflow
- Index for estimating soil surface moisture storage capacity
- Factor relating infiltration rates to evaporation rates for seasonal adjustment
- Minimum value of EN
- Current value of groundwater slope index in inches
- Daily baseflow recession adjustment factor
- Current soil moisture storage, in inches
- Soil profile moisture storage index, in inches
- Groundwater storage increment, in inches

Assigned or Selected Parameters

- Maximum interception rate for dry watershed
- Soil evaporation parameter
- Index for groundwater flow leaving basin
- Groundwater evaporation parameter
- Manning's n for overland flow on soil area
- Manning's n for overland flow on impervious area
- Index for routing
- Current soil moisture storage

AMD Parameters

Mine System

- Watershed area of mine in square miles
- Number of air-solid waterface increments
- Number of layers in coal seam
- Number of depth increments in model
- Length of depth increments in feet
- Length of air-solid interface increments in feet
- Datum plane for top of coal seam in feet
- Literal description of stratums
- Elevation of stratum relative to datum plane in feet

Pyrite Oxidation Kinetics

- Oxygen consumption rate of pyrite
- Void fraction of the stratum
- Mine temperature correction factor
- Volume occupied by gram mole gas in cubic feet
- Constant for calculating rate constant

Oxidation Product Removal

- Aquifer storage in inches
- Constant relating mine water flow and aquifer storage
- Alkalinity conversion factor
- Minimum flow rate to cause acid removal by flooding
- Minimum flow rate to cause acid removal by leaching
- Constant to determine the inundated distance
- Hypothetical slope of the water level
- Fraction of stored products removed daily by inundation
- Base gravity diffusion constant

Basin and Mine Characteristics

Basin Characteristics

- Drainage area, sq miles
- Length of principal water course, feet

Average slope percent
Peak discharge of record, cfs
Land use

Mine Characteristics

Area, sq ft
Average height, ft
Peak minewater flow recorded, gallons per day
Peak acid load recorded, lb per day
Principal materials in coal seam

Thirty-three watersheds were evaluated[101] to determine data availability to apply the SWM-AMD model. Data on acid-production parameters and mine conditions were generally lacking. These parameters, which are perhaps the most critical input data for accurate modeling, must be estimated.

Mathematical modeling was successful as far as predicting flow and acid load from several existing underground mines for which extensive field data were available. These mines were relatively small and well-defined compared to many underground mines, yet the input data were voluminous both in terms of the number of parameters and the number of determinations that had to be made to assign values for each of the parameters. In order to develop a more generally applicable model, a wide range of underground mine systems must be simulated and the results checked with field data.

The idea of a generalized model to predict acid formation from proposed and existing mines is intriguing, but the difficulties of modeling such complex and dynamic systems may be insurmountable. The completed model may be so complex that only the few who developed the model, and not coal-industry personnel in general, could actually apply it. The need, therefore, is to develop a simple model that would require input of only a few critical variables to estimate potential acid production.

## B. SCOPE OF ACID MINE DRAINAGE PROBLEM

1. Data Base: A considerable volume of information and data was evaluated to determine the present and probable future extent of the acid mine drainage problem. Such information included:

a. Water-quality information available in the publications in the BCR mine drainage library;

b. Water-quality data for specific mine sites that were generated by the 1974-75 study by the Environmental Protection Agency to develop Effluent Limitation Guidelines for the coal industry;

c. BCR file data relating mine-water quality to coal seams and to the specific sulfur content of the mines sampled;

d. U.S. Bureau of Mines data on underground mining reserves;

e. Reports on the geologic and hydrologic variables that influence mine drainage formation and discharge;

f. Descriptions of various mining systems and their effect on mine drainage formation and discharge; and

g. Discussion with mining experts.

In reviewing both the technical and non-technical literature, it became apparent that at present there exists a general misconception concerning the extent of the acid mine drainage problem. To most people, and this includes some who have worked on the problem for years, acid mine drainage is a normal result of mining, no matter what type of mining is undertaken or where the mining is located. In reality, the reports specifically referencing the occurrence of acid mine drainage and the data collected during BCR and Environmental Protection Agency (EPA) surveys of the coal industry, as presented in Tables 4 and 5, indicate that most drainage from coal mines is alkaline. Acid mine water is a problem that is limited to a relatively small percentage of coal seams and mines.

In 1972, BCR surveyed the coal industry to determine the extent of environmental problems on a mine-to-mine basis. Mine water quality data developed through the survey can be found in Tables 2 to 8 of this report. Most of these tables also include mine water quality information determined by Skelly and Loy Engineers, Harrisburg, Pennsylvania, as part of their 1975 study of the coal industry for EPA. The purpose of this study was to develop a data base to be used by EPA to establish Effluent Limitation Guidelines for the coal industry. It is noted that approximately 30 percent of the mines included in the EPA study were also covered by the BCR survey. In the tables, the mines are categorized on the basis of the worst (most acid) discharge from the mine. For example, if a mine had multiple discharges and only one was acid, the mine is included in the category reflecting the lowest pH. Three categories of pH ranges < 4, 4-6, and > 6 are used, with all discharges having a pH less than 6 being considered acid. It is recognized that pH is, at best, only a partial indicator of mine-water quality. Nevertheless, it is the parameter which is normally available for most discharges and, therefore, the one used in describing the extent of the mine drainage problem.

The general mine-water quality, on a nationwide basis, of all mines included in the surveys is presented in Table 4. Of the 248 mines responding to the BCR survey, 65, or 26 percent of the mines reporting, produced acid water. In the EPA study, only 41 of 163 mines, or 25 percent of the mines for which data were avaliable, had acid discharges or had discharges that required neutralization.

Included in the 248 mines responding to the BCR survey were 170 underground mines which represented more than 40 percent of the 1972 underground production. As shown in Table 5, only 49 of these 170 mines, or 29 percent of the active underground mines, produced acid discharges.

2. Regional Diversification of Acid Mine Drainage Formation: Obviously, numerous factors influence both the quality and the quantity of mine drainage that is produced at any given mining site. In all cases, these factors are variables which are dependent on either or both the geologic and geographic location of the mine and the total mining system employed. The most important factors, as discussed elsewhere, are: (a) pyrite presence, mode of occurrence (reactivity), and availability; (b) oxygen level; (c) bacteria; (d) quantity of water entering the mine; (e) quality of water entering the mine; and (f) water-flow pattern within the mine.

The coal industry's experience is that, geographically, the country can be divided into five separate mining regions and that the mines within each region display similar mine-water quality problems. These are: Region 1--Northern Appalachia which includes Pennsylvania, Ohio, Maryland, and Northern West Virginia; Region 2--Southern Appalachia which includes Southern West Virginia, Eastern Kentucky, Virginia, North Carolina, Tennessee, and Alabama; Region 3--Illinois Basin which includes Indiana, Illinois, Michigan, and Western Kentucky; Region 4--Western Interior Province which includes Iowa, Nebraska, Missouri, Kansas, Oklahoma, Arkansas, and Texas; and Region 5--the Western Provinces which include North Dakota, South Dakota, Montana, Idaho, Wyoming, Colorado, Utah, New Mexico, Arizona, Oregon, and Washington. This same regional breakdown is used in the following discussion.

## TABLE 4. GENERAL NATIONWIDE MINE WATER QUALITY

| Data on Mine Water Quality | Number of Mines Reporting | |
|---|---|---|
| | BCR Survey | EPA Effluent Guideline Study |
| Mine water quality pH < 4 | 37 | 31 |
| Mine water quality pH 4-6 | 25 | 5 |
| Mine water quality pH > 6 | 147 | 86 |
| Dry or no data available | 18 | 6 |
| No mine water data but survey forms indicate: | | |
| (a) neutralization provided | 3 | 5 |
| (b) no neutralization required | 18 | 30 |
| Total Mines in Data Base | 248 | 163 |

## TABLE 5. NATIONWIDE MINE WATER QUALITY FOR UNDERGROUND MINES

| Data on Mine Water Quality | Number of Mines Reporting |
|---|---|
| Mine water quality pH < 4 | 31 |
| Mine water quality pH 4-6 | 15 |
| Mine water quality pH > 6 | 93 |
| Dry or no data available | 11 |
| No water quality data but survey forms indicate: | |
| (a) neutralization provided | 3 |
| (b) no neutralization required | 17 |
| Total Underground Mines | 170 |

With the exception of the Appalachian Basin, the literature that has specifically been devoted to identifying the extent of the acid mine drainage problem is limited. In the Appalachian Basin, particularly Northern Appalachia, the Appalachian Regional Commission, the U.S. Environmental Protection Agency, the USGS, and the states of Pennsylvania, Ohio, West Virginia, and Maryland have devoted considerable effort to delineating the effects of mine drainage.

The relative intensification of activity in Appalachia is due not only to the concentration of mining in the East but also to the limited existence of a general acid mine drainage problem in the other regions.[724] As can be seen from the data in Table 6, presenting the results of the BCR and EPA surveys on the regional basis, the majority of mines with highly acid ($pH < 4$) discharges are located in Northern Appalachia.

Table 7 shows the same categories of data for the regions as Table 6 but includes underground mines only. It can be seen, by comparing these two sets of data, that acid mine drainage is generated by approximately the same percentage of underground mines as surface mines.

During discussions of this project with coal industry representatives and mine drainage experts, it was emphasized that the similarity ends there. In surface mining, mine drainage abatement including reclamation technology is sufficiently developed to minimize the problem when the mine is operating and to eliminate it when the mine is abandoned. In underground mining, abatement principles are well defined but are difficult or impossible to implement.

The basic principles are: (1) placement of acid-forming materials to eliminate or minimize contact with mine water; (2) inundation of acid-forming materials to eliminate contact with air; and (3) careful handling of water that does gain entrance to the mine to minimize contact with acid-forming materials and to expedite the water flow from the mine. A second reason why surface mining results in fewer mine-drainage problems is that underground mine sealing technology is not sufficiently developed to guarantee that the problem will be eliminated when the mine is abandoned.

It is recommended, therefore, that, wherever possible, surface mining should be encouraged for those coal seams located above drainage; and the thrust of the Bureau of Mines future research efforts in acid mine drainage abatement should focus on developing mine closure (sealing) technology.

## TABLE 6. MINE EFFLUENT DATA BY REGIONS

| | Number of Mines Reporting | | | | | | Total Mines in Survey | Percent of Mines Acid or Requiring Neutralization |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| | Mine Water Quality | | | Dry or No Data Available | No Mine Water Data but Survey Forms Indicate: | | | |
| Regions | pH < 4 | pH 4-6 | pH > 6 | | Neutralization Provided | No Neutralization Required | | |
| Northern Appalachia | | | | | | | | |
| BCR Survey | 28 | 7 | 41 | 5 | 1 | 0 | 82 | 44 |
| EPA Survey | 24 | 5 | 25 | 0 | 5 | 6 | 65 | 52 |
| Southern Appalachia | | | | | | | | |
| BCR Survey | 5 | 12 | 68 | 8 | 2 | 14 | 109 | 17 |
| EPA Survey | 2 | 0 | 25 | 2 | 0 | 10 | 39 | 5 |
| Illinois Basin | | | | | | | | |
| BCR Survey | 4 | 5 | 24 | 2 | 0 | 4 | 39 | 23 |
| EPA Survey | 4 | 0 | 14 | 0 | 0 | 2 | 20 | 20 |
| Western Interior Province | | | | | | | | |
| BCR Survey | 0 | 1 | 7 | 0 | 0 | 0 | 8 | 12 |
| EPA Survey | 1 | 0 | 5 | 2 | 0 | 3 | 11 | 9 |
| Western Provinces | | | | | | | | |
| BCR Survey | 0 | 0 | 7 | 3 | 0 | 0 | 10 | 0 |
| EPA Survey | 0 | 0 | 17 | 2 | 0 | 9 | 28 | 0 |
| Total | | | | | | | | |
| BCR Survey | 37 | 25 | 147 | 18 | 3 | 18 | 248 | 26 |
| EPA Survey | 31 | 5 | 86 | 6 | 5 | 30 | 163 | 26 |

TABLE 7. UNDERGROUND MINE EFFLUENT DATA (BCR SURVEY)

| | Number of Mines Reporting | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Mine Water Quality | | | | No Mine Water Data but Survey Forms Indicate: | | | |
| Regions | pH < 4 | pH 4-6 | pH > 6 | Dry or No Data Available | Neutralization Provided | No Neutralization Required | Total Mines in Survey | Percent of Mines Acid or Requiring Neutralization |
| Northern Appalachia | 26 | 4 | 29 | 3 | 1 | 0 | 63 | 49 |
| Southern Appalachia | 4 | 9 | 57 | 5 | 2 | 13 | 90 | 17 |
| Illinois Basin | 1 | 2 | 6 | 2 | 0 | 4 | 15 | 20 |
| Western Interior Province | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Western Provinces | 0 | 0 | 1 | 1 | 0 | 0 | 2 | 0 |
| Total | 31 | 15 | 93 | 11 | 3 | 17 | 170 | 29 |

Another approach to specifically delineating potential acid-problem areas was to attempt to identify the acid-producing seams. Again, much more information was available for the two Appalachian regions than for any other region.

According to the Appalachian Regional Commission Report <u>Acid Mine Drainage in Appalachia</u>, "In Pennsylvania, Ohio, and northern West Virginia, the Monongahela Group is responsible for acid mine water pollution in varying degrees. The Sewickley and the Redstone seams produce a slight acid to acid discharge in some localities, while at others the water discharge may remain non-acid. The Pittsburgh seam sometimes produces acid water in underground mines. This varies from locality to locality, and the water discharge varies from non-acid to acid depending upon the mine location in the coal basin. The Allegheny Group, also, is responsible for acid mine water pollution in northern Appalachia. The Upper and Lower Freeport seams produce slight acid to acid water discharges in some localities, while at others the water may remain non-acid. The Upper, Middle, and Lower Kittanning seams produce slight acid to acid water discharges in many localities, while at others the water discharges may remain non-acid. The Lower Kittanning seam often discharges acid water from both strip and underground mines."

"In southern West Virginia, western Virginia, eastern Kentucky and Tennessee, and northern Alabama, the Pottsville Groups of bituminous coal seams produce occasional slight acid water discharges, though the mine drainage pollution problem in the southern part of Appalachia is less severe when compared with the same problem in the northern part of Appalachia. The Island Creek coal seam in Logan County, West Virginia occasionally produces slight acid water discharges. The Pocahontas coal seams apparently produce little or no acid water discharges. The coal seams in eastern Kentucky and Tennessee and in northern Alabama produce occasional acid water discharges in some localities, while in others the water discharge may remain non-acid."[7]

Other work in Appalachia included that conducted by the West Virginia Geologic Survey, who sampled and determined the relative acid-producing potential of 19 coal seams in West Virginia.[544,545] The 19 coal samples represented the oldest through the youngest seams from the coal measures (Pennsylvanian and Dunkard strata). The greatest amount of acid was produced by the Pittsburgh and Upper Freeport coals, which exceeded the next highest acid produced, the Bakerstown coal, by a factor of 10. However, the acid-producing values of the Pittsburgh coal showed less variation than did those for the Upper Freeport, which indicates that estimating the relative acid-producing potential of the Upper Freeport coal would be more of a problem than estimating that of the Pittsburgh seam. Of all the coals tested, only the Pittsburgh, Upper Freeport, and Bakerstown were determined to be major acid producers. The Waynesburg coal yielded relatively low acid-production values, averaging five times less than those of the Bakerstown. Coal samples from the following seams showed extremely low acid-production values: Washington, Uniontown, Redstone, Elk Lick, Harlem, Brush Creek, Kittanning, Lower Mercer, Cedar Grove, No. 2 Gas, Sewell, Pocahontas No. 3, and Peacock.

These reports, as can be seen from Table 8, are in agreement with the data from the mines sampled during the BCR and EPA surveys.

TABLE 8. MINE-DRAINAGE QUALITY OF COAL SEAMS IN NORTHERN APPALACHIA

| | Number of Mines Reporting Effluent Water Quality | | | | | |
|---|---|---|---|---|---|---|
| | pH < 4 | | pH 4-6 | | pH > 6 | |
| Coal Seams | BCR | EPA | BCR | EPA | BCR | EPA |
| Meigs Creek | 0 | 0 | 0 | 0 | 2 | 0 |
| Pittsburgh | 17 | 11 | 2 | 3 | 19 | 9 |
| Upper Freeport | 2 | 4 | 1 | 0 | 8 | 8 |
| Lower Freeport | 2 | 1 | 0 | 0 | 6 | 3 |
| Upper Kittanning | 0 | 0 | 0 | 0 | 1 | 0 |
| Middle Kittanning | 2 | 3 | 3 | 2 | 5 | 5 |
| Lower Kittanning | 6 | 5 | 1 | 0 | 0 | 0 |

It is recognized and is demonstrated by the available data that there are significant differences in the mine-water quality produced by the various coal seams. Using the BCR survey, the EPA survey, and by searching the BCR mine drainage library, it was determined that, at least on occasion, the coal seams listed in Table 9 produce acid mine drainage.

It is important to note that, although these coal seams are listed as potential acid producers, in many instances only a single reference could be found indicating that the seam produced acid. In most cases, there are significant differences in the quality of water produced by mines in the same seam but at different locations. When opening a new mine in one of these seams, the industry anticipates that the water quality will be the same as adjacent mines in the same seam. Nevertheless, if the seam produces acid at other locations, the rule of thumb is to be alert to the possibility that acid problems might develop at any given site even though nearby mines may have alkaline discharges.

## TABLE 9. LIST OF COAL SEAMS* THAT ON OCCASION HAVE BEEN KNOWN TO PRODUCE ACID MINE DRAINAGE

| | | | |
|---|---|---|---|
| 029 | Meigs Creek, Sewickley | 135 | Chilton |
| 033 | Redstone | 151 | Cedar Grove, Elkhorn No. 3 |
| 036 | Pittsburgh | 154 | Lower Cedar Grove, Up. Elkhorn No. 2 |
| 055 | Barton | 157 | Alma, Blue Gem |
| 063 | L. Bakerstown | 168 | No. 2 Gas, Eagle No. 2 Gas |
| 067 | Bakerstown, Brush Cr. | 174 | Upper Eagle |
| 070 | Mahoning | 176 | Eagle |
| 071 | Upper Freeport | 195 | Hagy |
| 073 | Lower Freeport | 207 | Clements, Gwin |
| 076 | Upper Kittanning | 212 | Lily |
| 077 | Princess No. 7 | 285 | Lower Seaboard |
| 080 | Middle Kittanning | 294 | Stearns |
| 084 | Lower Kittanning | 334 | Pocahontas No. 6 |
| 087 | Clarion | 484 | Kentucky No. 11 |
| 090 | Princess No. 5 | 489 | Kentucky No. 9, Springfield No. 5 |
| 095 | Brookville | 492 | Bevier |
| 103 | Stockton, Lewiston | 502 | Seelyville III |
| 111 | Coalburg | 506 | Davis |
| 121 | Winifrede | 906 | Rowe |

*The three-digit numbers refer to the coal bed numbers used by the Bureau of Mines IC 8680 "The Reserve Base of U.S. Coals by Sulfur Content."

Differences in water quality also often occur within the same mine. For instance, 26 of the 63 mines included in the BCR survey of Northern Appalachia had multiple discharges. Sixteen of these mines are shown in the acid category ($pH < 6$) in Table 7, although at least 50 percent of the discharges from 11 of these 16 mines were alkaline. The general reasons given by industry experts for the differences in mine-water quality include:

(1) During mine or panel development, the mine-water quality is usually alkaline and is similar to the quality of the local ground water;

(2) The corollary to this is that during development the mine water may be acid, as sumps and effective water-handling procedures have not been established;

(3) The effectiveness of abatement procedures, such as water handling, may differ within the mine with the result that some discharges are acid;

(4) In some instances it is suspected, but not documented, that rock dusting has a positive effect on the quality of some discharges;

(5) The quality of the water draining from abandoned areas of the mine will be influenced by the type of material that is present in the roof. As the roof collapses, this material becomes a significantly more important factor in affecting water quality than does the coal. If it contains reactive pyrites, an acid mine water will be formed. If limestone or calcareous shales are present, the water will be alkaline.

Due to the lack of complete data, it is impossible to reliably map those areas where acid mine drainage can be expected to be formed as a result of underground mining of bituminous coal. Mine-drainage maps that are presently available generally reference stream water quality and do not differentiate between the effects of surface mining and underground mining.

Tables 10-14 do provide some insight into the possible extent of the underground acid mine drainage problem on a state and county basis for each of the coal regions. Extreme caution is urged in using these data as they are based on several tenuous assumptions, and the resulting tables reflect a "worst case" situation. These assumptions include:

(1) Each coal seam included in Table 8 is a potential acid producer if the coal-bed sulfur content exceeds one percent. This ignores the effect of differences in pyrite reactivity which has been demonstrated to exist;

(2) Each numbered coal seam is considered a potential acid producer no matter where it exists, even if there is only a single reference available indicating it produces acid. This assumes that coal-bed characteristics are inter- and intra-regionally translatable;

(3) Local geographical and hydrologic conditions are the same throughout the country. This assumption ignores the fact that many mid-western and western mines are essentially dry or that in all regions influent ground water, or other materials available in the coal or roof rock, may contribute sufficient alkalinity to provide neutralization of any mildly-acid water that may be formed during mining.

Table 15 provides a summary of Tables 10-14 and indicates the percentage of the total underground bituminous coal reserve base that, assuming the worst-case situation, could have an acid mine drainage problem when mined. These percentages are understandably higher than those found in Table 6, which lists the percentage of mines found by ground surveys to have acid discharges. They do follow the same regional trends, however, in that Region 1 has the highest acid mine-water incidence and production potential, followed by Regions 3, 2, 4, and 5.

## TABLE 10. REGION 1 UNDERGROUND BITUMINOUS COAL RESERVE BASE BY STATE AND COUNTY KNOWN TO FORM ACID MINE WATER ON OCCASION
(million short tons)

| State and County | Total Underground Bituminous Coal Reserves | Reserves of Listed Coal Seams (Table 9) Potentially Acid Forming | | |
|---|---|---|---|---|
| | | < 1% Sulfur | Sulfur Value Unknown | > 1% Sulfur |
| Maryland | | | | |
| Allegany | 378.6 | 1.5 | 0.0 | 377.0 |
| Garrett | 523.3 | 89.5 | 0.0 | 429.4 |
| Maryland Total | 901.9 | 91.0 | 0.0 | 806.4 |
| Ohio | | | | |
| Athens | 1,327.0 | 68.3 | 12.9 | 1,245.8 |
| Belmont | 3,927.1 | 0.0 | 76.0 | 3,513.2 |
| Carroll | 757.7 | 0.0 | 36.3 | 721.4 |
| Columbiana | 747.9 | 17.7 | 0.0 | 706.5 |
| Coshocton | 127.3 | 0.0 | 3.5 | 123.9 |
| Gallia | 339.6 | 0.0 | 10.7 | 328.9 |
| Guernsey | 1,184.4 | 0.0 | 517.3 | 667.1 |
| Harrison | 1,523.3 | 0.0 | 507.9 | 624.3 |
| Hocking | 205.7 | 1.9 | 9.3 | 196.3 |
| Holmes | 28.5 | 0.0 | 1.1 | 27.3 |
| Jackson | 154.7 | 0.0 | 16.2 | 138.4 |
| Jefferson | 1,356.2 | 3.3 | 0.0 | 455.7 |
| Lawrence | 477.0 | 5.0 | 0.0 | 472.0 |
| Mahoning | 308.2 | 0.0 | 0.0 | 308.2 |
| Meigs | 396.3 | 0.7 | 0.0 | 395.6 |
| Monroe | 468.4 | 0.0 | 468.4 | 0.0 |
| Morgan | 435.1 | 0.0 | 29.9 | 405.2 |
| Muskingum | 720.8 | 0.0 | 1.1 | 719.7 |
| Noble | 570.0 | 0.0 | 14.6 | 555.4 |
| Perry | 645.0 | 17.5 | 0.0 | 627.5 |
| Scioto | 4.8 | 0.0 | 1.3 | 3.5 |
| Stark | 376.6 | 0.0 | 5.5 | 371.1 |
| Tuscarawas | 841.2 | 0.0 | 21.3 | 813.0 |
| Vinton | 301.2 | 0.0 | 10.8 | 290.4 |
| Washington | 196.0 | 0.0 | 0.0 | 196.0 |
| Wayne | 3.3 | 0.0 | 2.9 | 0.4 |
| Ohio Total | 17,423.3 | 109.4 | 1,747.0 | 13,906.8 |

## TABLE 10. REGION 1 UNDERGROUND BITUMINOUS COAL RESERVE BASE BY STATE AND COUNTY KNOWN TO FORM ACID MINE WATER ON OCCASION (Continued)
(million short tons)

| State and County | Total Underground Bituminous Coal Reserves | Reserves of Listed Coal Seams (Table 9) Potentially Acid Forming < 1% Sulfur | Sulfur Value Unknown | > 1% Sulfur |
|---|---|---|---|---|
| Pennsylvania | | | | |
| Allegheny | 881.4 | 27.8 | 455.0 | 398.6 |
| Armstrong | 1,092.9 | 16.7 | 62.7 | 1,013.5 |
| Beaver | 435.3 | 36.2 | 59.1 | 340.0 |
| Bedford | 89.5 | 2.5 | 0.2 | 86.8 |
| Blair | 18.7 | 1.9 | 1.6 | 15.2 |
| Bradford | 12.8 | 0.0 | 12.8 | 0.0 |
| Butler | 863.8 | 6.4 | 0.0 | 853.4 |
| Cambria | 1,454.2 | 272.4 | 0.0 | 1,181.8 |
| Cameron | 25.4 | 0.0 | 25.4 | 0.0 |
| Centre | 228.3 | 12.1 | 0.8 | 215.4 |
| Clarion | 640.1 | 11.7 | 69.9 | 558.5 |
| Clearfield | 1,102.5 | 93.5 | 0.0 | 1,008.9 |
| Clinton | 40.8 | 0.0 | 25.6 | 15.1 |
| Elk | 86.1 | 2.3 | 0.0 | 83.8 |
| Fayette | 1,023.7 | 19.6 | 0.0 | 814.6 |
| Fulton | 10.8 | 0.0 | 10.8 | 0.0 |
| Greene | 6,515.7 | 42.4 | 1,011.9 | 4,283.1 |
| Huntingdon | 36.3 | 1.9 | 0.0 | 34.3 |
| Indiana | 1,716.9 | 126.8 | 25.3 | 1,564.8 |
| Jefferson | 407.4 | 57.1 | 1.6 | 348.7 |
| Lawrence | 136.9 | 0.0 | 63.5 | 73.3 |
| Lycoming | 11.4 | 0.0 | 1.4 | 10.0 |
| McKean | 146.4 | 0.0 | 0.0 | 146.4 |
| Mercer | 128.0 | 0.7 | 86.4 | 40.9 |
| Somerset | 1,240.6 | 56.7 | 0.0 | 1,175.7 |
| Tioga | 36.5 | 2.2 | 0.0 | 20.9 |
| Venango | 55.0 | 0.0 | 0.4 | 54.5 |
| Washington | 3,604.2 | 143.8 | 187.2 | 2,904.2 |
| Westmoreland | 747.5 | 33.9 | 22.9 | 686.3 |
| Pennsylvania Total | 22,788.9 | 968.6 | 2,124.5 | 17,928.7 |

TABLE 10. REGION 1 UNDERGROUND BITUMINOUS COAL RESERVE BASE BY STATE AND COUNTY KNOWN TO FORM ACID MINE WATER ON OCCASION (Concluded)
(million short tons)

| State and County | Total Underground Bituminous Coal Reserves | Reserves of Listed Coal Seams (Table 9) Potentially Acid Forming | | |
|---|---|---|---|---|
| | | < 1% Sulfur | Sulfur Value Unknown | > 1% Sulfur |
| Northern West Virginia | | | | |
| Barbour | 948.8 | 0.0 | 43.0 | 398.7 |
| Braxton | 467.7 | 183.0 | 90.4 | 194.4 |
| Brooke | 169.3 | 0.0 | 38.1 | 131.1 |
| Calhoun | 0.3 | 0.0 | 0.0 | 0.0 |
| Clay | 695.0 | 460.1 | 135.2 | 99.7 |
| Doddridge | 248.4 | 0.0 | 239.2 | 0.0 |
| Gilmer | 154.1 | 0.0 | 0.0 | 154.1 |
| Grant | 313.2 | 81.6 | 0.0 | 231.6 |
| Hancock | 132.4 | 0.0 | 18.3 | 114.1 |
| Harrison | 380.9 | 0.0 | 0.0 | 380.6 |
| Kanawha | 1,120.6 | 238.9 | 0.0 | 199.7 |
| Lewis | 730.3 | 57.3 | 0.0 | 669.8 |
| Marion | 2,599.5 | 104.3 | 54.3 | 2,102.5 |
| Marshall | 3,043.8 | 0.0 | 0.0 | 2,840.7 |
| Mason | 116.7 | 0.0 | 0.0 | 115.4 |
| Mineral | 218.5 | 49.0 | 0.9 | 115.0 |
| Monongalia | 3,008.8 | 47.4 | 0.0 | 2,371.5 |
| Ohio | 379.0 | 0.0 | 79.9 | 291.0 |
| Preston | 837.5 | 34.8 | 2.9 | 799.8 |
| Putnam | 142.5 | 0.0 | 0.0 | 141.4 |
| Roane | 19.4 | 1.9 | 0.0 | 17.5 |
| Taylor | 388.2 | 0.0 | 0.0 | 388.2 |
| Tyler | 79.6 | 0.0 | 0.0 | 0.0 |
| Upshur | 876.9 | 42.3 | 112.5 | 224.9 |
| Wayne | 403.6 | 71.0 | 261.6 | 71.0 |
| Wetzel | 846.1 | 0.0 | 743.8 | 0.0 |
| Northern West Virginia Total | 18,321.1 | 1,371.6 | 1,820.1 | 12,052.7 |

TABLE 11. REGION 2 UNDERGROUND BITUMINOUS COAL RESERVE BASE BY STATE AND COUNTY KNOWN TO FORM ACID MINE WATER ON OCCASION
(million short tons)

| State and County | Total Underground Bituminous Coal Reserves | Reserves of Listed Coal Seams (Table 9) Potentially Acid Forming | | |
|---|---|---|---|---|
| | | < 1% Sulfur | Sulfur Value Unknown | > 1% Sulfur |
| Alabama | | | | |
| Blount | 0.7 | 0.0 | 0.0 | 0.0 |
| Cullman | 28.1 | 0.0 | 0.0 | 0.0 |
| DeKalb | 1.3 | 0.0 | 0.0 | 0.0 |
| Fayette | 93.7 | 0.0 | 0.0 | 0.0 |
| Jackson | 13.2 | 0.0 | 0.0 | 0.0 |
| Jefferson | 757.9 | 0.0 | 0.0 | 66.0 |
| Marion | 118.4 | 0.0 | 0.0 | 0.0 |
| St. Clair | 1.9 | 0.0 | 0.0 | 0.0 |
| Shelby | 3.8 | 0.0 | 0.0 | 0.0 |
| Tuscaloosa | 143.7 | 0.0 | 0.0 | 0.0 |
| Walker | 630.0 | 0.0 | 0.0 | 0.0 |
| Winston | 5.3 | 0.0 | 0.0 | 0.0 |
| Alabama Total | 1,798.1 | 0.0 | 0.0 | 66.0 |
| Eastern Kentucky | | | | |
| Bell | 106.4 | 26.0 | 40.0 | 3.0 |
| Boyd | 51.1 | 0.0 | 20.0 | 0.0 |
| Breathitt | 410.6 | 17.5 | 0.0 | 84.0 |
| Carter | 33.2 | 0.0 | 6.5 | 17.0 |
| Clay | 138.8 | 28.0 | 6.4 | 72.0 |
| Clinton | 0.5 | 0.0 | 0.5 | 0.0 |
| Elliott | 33.6 | 0.0 | 33.5 | 0.0 |
| Floyd | 952.6 | 489.0 | 77.4 | 369.0 |
| Greenup | 24.9 | 0.0 | 17.0 | 0.0 |
| Harlan | 1,408.5 | 722.0 | 133.0 | 299.0 |
| Jackson | 48.0 | 0.0 | 13.4 | 0.0 |
| Johnson | 78.0 | 11.5 | 24.0 | 35.0 |
| Knott | 1,248.4 | 531.0 | 146.0 | 218.0 |
| Knox | 50.0 | 21.0 | 0.0 | 5.0 |
| Laurel | 5.4 | 0.0 | 0.0 | 3.0 |

## TABLE 11. REGION 2 UNDERGROUND BITUMINOUS COAL RESERVE BASE BY STATE AND COUNTY KNOWN TO FORM ACID MINE WATER ON OCCASION (Continued)

(million short tons)

| State and County | Total Underground Bituminous Coal Reserves | Reserves of Listed Coal Seams (Table 9) Potentially Acid Forming: < 1% Sulfur | Sulfur Value Unknown | > 1% Sulfur |
|---|---|---|---|---|
| Eastern Kentucky (continued) | | | | |
| Lawrence | 56.5 | 111.0 | 18.0 | 0.0 |
| Lee | 25.2 | 0.0 | 1.6 | 16.3 |
| Leslie | 620.0 | 312.0 | 5.0 | 78.6 |
| Letcher | 730.4 | 318.0 | 0.0 | 247.0 |
| McCreary | 146.1 | 0.0 | 0.0 | 78.0 |
| Magoffin | 214.4 | 38.0 | 0.0 | 94.0 |
| Martin | 249.6 | 12.0 | 145.0 | 0.0 |
| Menifee | 3.7 | 0.0 | 3.7 | 0.0 |
| Morgan | 29.0 | 0.0 | 14.2 | 0.0 |
| Owsley | 2.0 | 0.0 | 2.0 | 0.0 |
| Perry | 560.2 | 8.0 | 21.4 | 40.1 |
| Pike | 2,170.0 | 1,341.1 | 65.7 | 380.4 |
| Powell | 0.8 | 0.0 | 0.8 | 0.0 |
| Pulaski | 28.2 | 0.0 | 21.4 | 0.0 |
| Rockcastle | 1.6 | 0.0 | 1.1 | 0.0 |
| Wayne | 1.6 | 0.0 | 1.6 | 0.0 |
| Whitley | 15.6 | 2.7 | 0.0 | 12.2 |
| Wolfe | 22.1 | 0.0 | 14.4 | 0.0 |
| Eastern Kentucky Total | 9,466.5 | 3,988.8 | 833.6 | 2,051.6 |
| North Carolina | | | | |
| Chatham | 12.2 | 0.0 | 0.0 | 0.0 |
| Lee | 19.1 | 0.0 | 0.0 | 0.0 |
| North Carolina Total | 31.2 | 0.0 | 0.0 | 0.0 |

## TABLE 11. REGION 2 UNDERGROUND BITUMINOUS COAL RESERVE BASE BY STATE AND COUNTY KNOWN TO FORM ACID MINE WATER ON OCCASION (Continued)

(million short tons)

| State and County | Total Underground Bituminous Coal Reserves | Reserves of Listed Coal Seams (Table 9) Potentially Acid Forming: < 1% Sulfur | Sulfur Value Unknown | > 1% Sulfur |
|---|---|---|---|---|
| Tennessee | | | | |
| Anderson | 89.3 | 7.9 | 0.0 | 50.4 |
| Bledsoe | 15.1 | 0.0 | 0.0 | 0.0 |
| Campbell | 194.7 | 48.5 | 0.0 | 98.4 |
| Claiborne | 35.9 | 1.4 | 22.1 | 4.5 |
| Cumberland | 21.2 | 0.0 | 0.0 | 0.0 |
| Fentress | 39.8 | 0.0 | 0.0 | 0.0 |
| Grundy | 8.9 | 0.0 | 0.0 | 0.0 |
| Hamilton | 36.5 | 0.0 | 0.0 | 0.0 |
| Marion | 26.5 | 0.0 | 0.0 | 0.0 |
| Morgan | 56.7 | 0.2 | 0.0 | 18.5 |
| Overton | 4.2 | 0.0 | 0.0 | 0.0 |
| Pickett | 0.2 | 0.0 | 0.0 | 0.0 |
| Putnam | 17.8 | 0.0 | 0.0 | 0.0 |
| Rhea | 7.6 | 0.0 | 0.0 | 0.0 |
| Roane | 1.3 | 0.0 | 0.0 | 0.0 |
| Scott | 58.8 | 9.0 | 0.0 | 14.0 |
| Sequatchie | 44.7 | 0.0 | 0.0 | 0.0 |
| Van Buren | 0.2 | 0.0 | 0.0 | 0.0 |
| White | 7.8 | 0.0 | 0.0 | 0.0 |
| Tennessee Total | 667.1 | 67.0 | 22.1 | 185.8 |
| Virginia | | | | |
| Buchanan | 820.0 | 73.9 | 0.0 | 194.1 |
| Dickenson | 515.5 | 0.8 | 0.0 | 2.5 |
| Lee | 167.4 | 31.4 | 0.0 | 136.3 |
| Russell | 403.0 | 0.0 | 0.0 | 0.0 |
| Scott | 44.6 | 0.0 | 0.0 | 0.0 |
| Tazewell | 166.0 | 3.9 | 0.0 | 16.0 |
| Wise | 716.6 | 101.2 | 10.4 | 32.8 |
| Virginia Total | 2,833.2 | 211.2 | 10.4 | 381.7 |

## TABLE 11. REGION 2 UNDERGROUND BITUMINOUS COAL RESERVE BASE BY STATE AND COUNTY KNOWN TO FORM ACID MINE WATER ON OCCASION (Concluded)
(million short tons)

| State and County | Total Underground Bituminous Coal Reserves | Reserves of Listed Coal Seams (Table 9) Potentially Acid Forming | | |
|---|---|---|---|---|
| | | < 1% Sulfur | Sulfur Value Unknown | > 1% Sulfur |
| Southern West Virginia | | | | |
| Boone | 1,868.8 | 712.6 | 0.0 | 845.1 |
| Fayette | 796.3 | 484.9 | 34.3 | 56.9 |
| Greenbrier | 269.7 | 77.3 | 0.0 | 45.1 |
| Lincoln | 360.4 | 113.4 | 118.0 | 129.0 |
| Logan | 3,076.3 | 1,121.9 | 0.0 | 1,501.8 |
| McDowell | 912.4 | 63.9 | 19.4 | 11.7 |
| Mercer | 38.6 | 5.6 | 0.5 | 2.2 |
| Mingo | 1,887.4 | 875.3 | 0.7 | 654.2 |
| Nicholas | 1,433.7 | 746.3 | 63.8 | 232.5 |
| Pocahontas | 131.6 | 73.4 | 0.0 | 0.0 |
| Raleigh | 1,656.3 | 328.7 | 96.5 | 252.4 |
| Randolph | 757.2 | 317.2 | 16.3 | 75.9 |
| Summers | 5.9 | 5.9 | 0.0 | 0.0 |
| Tucker | 121.0 | 34.2 | 0.0 | 86.7 |
| Webster | 1,098.9 | 242.2 | 129.8 | 355.4 |
| Wyoming | 1,642.0 | 274.6 | 78.8 | 77.2 |
| Southern West Virginia Total | 16,056.5 | 5,477.4 | 558.1 | 4,326.1 |

## TABLE 12. REGION 3 UNDERGROUND BITUMINOUS COAL RESERVE BASE BY STATE AND COUNTY KNOWN TO FORM ACID MINE WATER ON OCCASION
(million short tons)

| | Total Underground Bituminous Coal Reserves | Reserves of Listed Coal Seams (Table 9) Potentially Acid Forming | | |
|---|---|---|---|---|
| State and County | | < 1% Sulfur | Sulfur Value Unknown | > 1% Sulfur |
| Illinois | | | | |
| Adams | 0.02 | 0.0 | 0.0 | 0.0 |
| Bond | 1,831.4 | 0.0 | 79.4 | 1,752.1 |
| Bureau | 1,029.4 | 0.0 | 0.0 | 250.2 |
| Cass | 13.1 | 0.0 | 3.4 | 0.0 |
| Christian | 3,347.4 | 0.0 | 617.2 | 2,651.3 |
| Clark | 168.5 | 0.0 | 103.2 | 0.0 |
| Clinton | 1,322.5 | 0.0 | 2.1 | 1,320.0 |
| Coles | 80.7 | 0.0 | 44.0 | 0.0 |
| Crawford | 442.6 | 0.0 | 291.0 | 0.0 |
| Douglas | 411.7 | 0.0 | 11.0 | 390.6 |
| Edgar | 1,749.9 | 0.0 | 906.0 | 332.0 |
| Edwards | 54.0 | 0.0 | 54.0 | 0.0 |
| Fayette | 1,173.7 | 0.0 | 877.7 | 0.0 |
| Franklin | 3,038.4 | 802.0 | 168.0 | 1,905.0 |
| Fulton | 220.5 | 0.0 | 0.0 | 77.6 |
| Gallatin | 1,761.1 | 0.0 | 0.0 | 1,139.0 |
| Greene | 52.1 | 0.0 | 0.0 | 0.0 |
| Grundy | 246.0 | 0.0 | 0.0 | 32.5 |
| Hamilton | 2,440.2 | 0.0 | 2,440.0 | 0.0 |
| Henry | 28.3 | 0.0 | 0.0 | 2.6 |
| Jackson | 226.7 | 0.0 | 0.0 | 194.0 |
| Jefferson | 1,800.6 | 128.0 | 0.0 | 1,672.6 |
| Jersey | 42.0 | 0.0 | 8.3 | 0.0 |
| Kankakee | 79.9 | 0.0 | 0.0 | 0.0 |
| Knox | 68.0 | 0.0 | 16.6 | 0.0 |
| LaSalle | 1,083.0 | 0.0 | 0.0 | 92.0 |
| Lawrence | 893.6 | 0.0 | 527.7 | 0.0 |
| Livingston | 586.5 | 0.0 | 0.0 | 48.9 |
| Logan | 813.7 | 0.0 | 0.0 | 813.7 |
| McClean | 421.0 | 0.0 | 0.0 | 107.0 |
| Macon | 439.3 | 0.0 | 18.9 | 420.4 |
| Macoupin | 3,421.1 | 0.0 | 56.6 | 3,007.0 |
| Madison | 1,366.5 | 0.0 | 0.0 | 1,214.0 |
| Marion | 421.0 | 0.0 | 102.0 | 319.0 |
| Marshall | 358.0 | 0.0 | 9.8 | 0.0 |

## TABLE 12. REGION 3 UNDERGROUND BITUMINOUS COAL RESERVE BASE BY STATE AND COUNTY KNOWN TO FORM ACID MINE WATER ON OCCASION (Continued)

(million short tons)

| State and County | Total Underground Bituminous Coal Reserves | Reserves of Listed Coal Seams (Table 9) Potentially Acid Forming: < 1% Sulfur | Sulfur Value Unknown | > 1% Sulfur |
|---|---|---|---|---|
| Illinois (continued) | | | | |
| Menard | 1,460.0 | 0.0 | 0.0 | 1,460.0 |
| Mercer | 12.6 | 0.0 | 0.0 | 0.0 |
| Montgomery | 3,906.6 | 0.0 | 209.9 | 3,269.0 |
| Morgan | 144.8 | 0.0 | 0.0 | 43.4 |
| Moultrie | 123.1 | 0.0 | 0.0 | 123.1 |
| Peoria | 289.2 | 0.0 | 0.0 | 213.0 |
| Perry | 1,201.0 | 0.0 | 0.0 | 1,201.0 |
| Putnam | 588.9 | 0.0 | 78.9 | 0.0 |
| Randolph | 214.0 | 0.0 | 0.0 | 220.0 |
| Rock Island | 12.8 | 0.0 | 0.0 | 0.0 |
| St. Clair | 951.4 | 0.0 | 19.3 | 932.1 |
| Saline | 2,553.4 | 4.9 | 0.0 | 2,314.8 |
| Sangamon | 3,540.0 | 0.0 | 0.0 | 3,514.0 |
| Scott | 0.1 | 0.0 | 0.0 | 0.0 |
| Shelby | 712.5 | 0.0 | 534.1 | 53.1 |
| Tazewell | 69.3 | 0.0 | 0.0 | 34.2 |
| Vermilion | 1,544.3 | 0.0 | 44.5 | 537.0 |
| Wabash | 262.0 | 0.0 | 262.0 | 0.0 |
| Washington | 1,555.2 | 0.0 | 12.1 | 1,543.0 |
| Wayne | 89.0 | 0.0 | 89.0 | 0.0 |
| White | 992.5 | 0.0 | 628.6 | 360.0 |
| Williamson | 1,573.1 | 83.0 | 0.0 | 1,194.0 |
| Woodford | 213.9 | 0.0 | 42.3 | 0.0 |
| Illinois Total | 53,441.9 | 1,017.9 | 8,257.6 | 34,753.2 |

TABLE 12. REGION 3 UNDERGROUND BITUMINOUS COAL RESERVE BASE BY STATE AND COUNTY KNOWN TO FORM ACID MINE WATER ON OCCASION (Continued)
(million short tons)

| State and County | Total Underground Bituminous Coal Reserves | Reserves of Listed Coal Seams (Table 9) Potentially Acid Forming < 1% Sulfur | Sulfur Value Unknown | > 1% Sulfur |
|---|---|---|---|---|
| Indiana | | | | |
| Clay | 168.2 | 0.0 | 0.0 | 53.3 |
| Daviess | 109.3 | 0.0 | 18.7 | 0.0 |
| Dubois | 5.5 | 0.0 | 0.0 | 0.0 |
| Fountain | 7.0 | 0.0 | 0.0 | 0.0 |
| Gibson | 1,301.5 | 0.0 | 0.0 | 883.0 |
| Greene | 254.4 | 0.0 | 0.0 | 197.0 |
| Knox | 1,453.5 | 0.0 | 25.0 | 652.5 |
| Martin | 0.01 | 0.0 | 0.0 | 0.0 |
| Parke | 57.2 | 0.0 | 0.0 | 19.0 |
| Perry | 10.1 | 0.0 | 0.0 | 0.0 |
| Pike | 244.8 | 4.0 | 0.0 | 210.0 |
| Posey | 720.9 | 0.0 | 412.0 | 0.0 |
| Sullivan | 1,922.3 | 153.0 | 0.0 | 706.0 |
| Vanderburgh | 451.4 | 0.0 | 203.0 | 234.0 |
| Vermillion | 497.6 | 0.0 | 0.0 | 369.0 |
| Vigo | 1,212.1 | 0.0 | 0.0 | 721.0 |
| Warrick | 532.6 | 0.0 | 21.0 | 333.0 |
| Indiana Total | 8,948.5 | 157.0 | 679.7 | 4,377.8 |
| Western Kentucky | | | | |
| Butler | 20.2 | 0.0 | 0.0 | 0.0 |
| Christian | 2.5 | 0.0 | 0.0 | 0.0 |
| Crittendon | 11.6 | 0.0 | 0.0 | 0.0 |
| Daviess | 126.2 | 0.0 | 70.9 | 48.8 |
| Edmondson | 0.1 | 0.0 | 0.0 | 0.0 |
| Grayson | 0.2 | 0.0 | 0.0 | 0.0 |
| Hancock | 0.5 | 0.0 | 0.0 | 0.0 |
| Henderson | 1,503.6 | 0.0 | 17.4 | 1,411.2 |
| Hopkins | 1,805.7 | 0.0 | 0.0 | 1,300.0 |
| McClean | 723.6 | 0.0 | 96.4 | 627.2 |
| Muhlenberg | 898.4 | 0.0 | 0.0 | 711.9 |
| Ohio | 264.6 | 0.0 | 6.6 | 242.8 |
| Union | 1,926.3 | 0.0 | 0.0 | 1,807.7 |
| Webster | 1,436.4 | 0.0 | 15.9 | 1,216.2 |
| Western Kentucky Total | 8,719.9 | 0.0 | 207.2 | 7,365.8 |

## TABLE 12. REGION 3 UNDERGROUND BITUMINOUS COAL RESERVE BASE BY STATE AND COUNTY KNOWN TO FORM ACID MINE WATER ON OCCASION (Concluded)

(million short tons)

| State and County | Total Underground Bituminous Coal Reserves | Reserves of Listed Coal Seams (Table 9) Potentially Acid Forming | | |
|---|---|---|---|---|
| | | < 1% Sulfur | Sulfur Value Unknown | > 1% Sulfur |
| Michigan | | | | |
| Bay | 55.6 | 0.0 | 0.0 | 0.0 |
| Genesee | 7.0 | 0.0 | 0.0 | 0.0 |
| Huron | 6.5 | 0.0 | 0.0 | 0.0 |
| Saginaw | 27.0 | 0.0 | 0.0 | 0.0 |
| Shiawassee | 1.8 | 0.0 | 0.0 | 0.0 |
| Tuscola | 19.7 | 0.0 | 0.0 | 0.0 |
| Michigan Total | 117.6 | 0.0 | 0.0 | 0.0 |

## TABLE 13. REGION 4 UNDERGROUND BITUMINOUS COAL RESERVE BASE BY STATE AND COUNTY KNOWN TO FORM ACID MINE WATER ON OCCASION

(million short tons)

| State and County | Total Underground Bituminous Coal Reserves | Reserves of Listed Coal Seams (Table 9) Potentially Acid Forming | | |
|---|---|---|---|---|
| | | < 1% Sulfur | Sulfur Value Unknown | > 1% Sulfur |
| Arkansas | | | | |
| Crawford | 19.1 | 0.0 | 0.0 | 0.0 |
| Franklin | 6.1 | 0.0 | 0.0 | 0.0 |
| Scott | 12.5 | 0.0 | 0.0 | 0.0 |
| Sebastian | 268.3 | 0.0 | 0.0 | 0.0 |
| Arkansas Total | 306.0 | 0.0 | 0.0 | 0.0 |
| Iowa | | | | |
| Appanoose | 157.4 | 0.0 | 0.0 | 157.4 |
| Boone | 120.6 | 0.0 | 0.0 | 0.0 |
| Cass | 0.4 | 0.0 | 0.0 | 0.0 |
| Dallas | 50.4 | 0.0 | 0.0 | 0.9 |
| Davis | 37.6 | 0.0 | 0.0 | 0.0 |
| Decatur | 33.5 | 0.0 | 17.1 | 0.0 |
| Greene | 13.3 | 0.0 | 0.0 | 0.0 |
| Guthrie | 4.7 | 0.0 | 0.7 | 0.0 |
| Hamilton | 8.5 | 0.0 | 0.0 | 0.0 |
| Hardin | 4.6 | 0.0 | 0.0 | 0.0 |
| Henry | 1.2 | 0.0 | 0.0 | 0.0 |
| Jasper | 85.3 | 0.0 | 0.0 | 0.0 |
| Jefferson | 48.9 | 0.0 | 0.0 | 0.0 |
| Keokuk | 77.5 | 0.0 | 0.0 | 0.0 |
| Lee | 2.7 | 0.0 | 0.0 | 0.0 |
| Lucas | 134.4 | 0.0 | 1.9 | 0.0 |
| Mahaska | 325.3 | 0.0 | 0.0 | 0.0 |
| Marion | 398.3 | 0.0 | 0.0 | 0.0 |
| Marshall | 3.2 | 0.0 | 0.0 | 0.0 |
| Monroe | 518.7 | 0.0 | 0.0 | 0.0 |
| Muscatine | 0.1 | 0.0 | 0.0 | 0.0 |
| Polk | 492.7 | 0.0 | 0.0 | 0.0 |
| Scott | 2.2 | 0.0 | 0.0 | 0.0 |
| Story | 34.0 | 0.0 | 0.0 | 0.0 |
| Van Buren | 48.7 | 0.0 | 0.0 | 0.0 |
| Wapello | 148.9 | 0.0 | 0.0 | 0.0 |
| Warren | 87.5 | 0.0 | 1.0 | 0.0 |
| Webster | 43.9 | 0.0 | 0.0 | 0.0 |
| Iowa Total | 2,884.9 | 0.0 | 20.7 | 158.3 |

## TABLE 13. REGION 4 UNDERGROUND BITUMINOUS COAL RESERVE BASE BY STATE AND COUNTY KNOWN TO FORM ACID MINE WATER ON OCCASION (Continued)
(million short tons)

| | | Reserves of Listed Coal Seams (Table 9) Potentially Acid Forming | | |
|---|---|---|---|---|
| State and County | Total Underground Bituminous Coal Reserves | < 1% Sulfur | Sulfur Value Unknown | > 1% Sulfur |
| Missouri | | | | |
| Adair | 482.2 | 0.0 | 0.0 | 44.0 |
| Audrain | 469.7 | 0.0 | 0.0 | 0.0 |
| Barton | 109.4 | 0.0 | 0.0 | 0.0 |
| Bates | 292.3 | 0.0 | 0.0 | 0.0 |
| Boone | 60.7 | 0.0 | 60.7 | 0.0 |
| Caldwell | 128.6 | 0.0 | 128.6 | 0.0 |
| Callaway | 163.9 | 0.0 | 163.9 | 0.0 |
| Cass | 72.9 | 0.0 | 0.0 | 0.0 |
| Chariton | 63.8 | 0.0 | 0.0 | 3.7 |
| Clay | 32.4 | 0.0 | 0.0 | 32.4 |
| Daviess | 74.0 | 0.0 | 0.0 | 74.0 |
| Grundy | 31.0 | 0.0 | 0.0 | 31.0 |
| Harrison | 223.7 | 0.0 | 0.0 | 0.0 |
| Henry | 130.2 | 0.0 | 0.0 | 0.0 |
| Howard | 152.9 | 0.0 | 152.9 | 0.0 |
| Johnson | 67.5 | 0.0 | 0.0 | 0.0 |
| Linn | 564.7 | 0.0 | 0.0 | 0.0 |
| Macon | 370.5 | 0.0 | 0.0 | 225.3 |
| Mercer | 589.3 | 0.0 | 0.0 | 0.0 |
| Montgomery | 141.3 | 0.0 | 0.0 | 0.0 |
| Nodaway | 17.3 | 0.0 | 0.0 | 0.0 |
| Putnam | 384.7 | 0.0 | 0.0 | 384.7 |
| Randolph | 670.4 | 0.0 | 0.0 | 670.4 |
| Ray | 109.9 | 0.0 | 0.0 | 109.9 |
| St. Clair | 209.8 | 0.0 | 0.0 | 0.0 |
| Sullivan | 373.6 | 0.0 | 90.3 | 0.0 |
| Vernon | 67.4 | 0.0 | 0.0 | 0.0 |
| Worth | 19.4 | 0.0 | 0.0 | 0.0 |
| Missouri Total | 6,073.6 | 0.0 | 596.4 | 1,575.4 |

TABLE 13. REGION 4 UNDERGROUND BITUMINOUS COAL RESERVE BASE BY STATE AND COUNTY KNOWN TO FORM ACID MINE WATER ON OCCASION (Concluded)
(million short tons)

| State and County | Total Underground Bituminous Coal Reserves | Reserves of Listed Coal Seams (Table 9) Potentially Acid Forming | | |
|---|---|---|---|---|
| | | < 1% Sulfur | Sulfur Value Unknown | > 1% Sulfur |
| Oklahoma | | | | |
| Atoka | 3.3 | 0.0 | 0.0 | 0.0 |
| Coal | 36.8 | 0.0 | 0.0 | 0.0 |
| Craig | 156.3 | 0.0 | 0.0 | 0.0 |
| Haskell | 84.1 | 0.0 | 0.0 | 0.0 |
| Latimer | 63.0 | 0.0 | 0.0 | 0.0 |
| LeFlore | 269.7 | 0.0 | 0.0 | 0.0 |
| Okfuskee | 2.3 | 0.0 | 0.0 | 0.0 |
| Okmulgee | 106.2 | 0.0 | 0.0 | 0.0 |
| Pittsburg | 138.3 | 0.0 | 0.0 | 0.0 |
| Oklahoma Total | 860.1 | 0.0 | 0.0 | 0.0 |

TABLE 14. REGION 5 UNDERGROUND BITUMINOUS COAL RESERVE BASE BY STATE AND COUNTY KNOWN TO FORM ACID MINE WATER ON OCCASION
(million short tons)

| State and County | Total Underground Bituminous Coal Reserves | Reserves of Listed Coal Seams (Table 9) Potentially Acid Forming: < 1% Sulfur | Sulfur Value Unknown | > 1% Sulfur |
|---|---|---|---|---|
| Colorado | | | | |
| Archuleta | 92.1 | 0.0 | 0.0 | 0.0 |
| Delta | 65.8 | 0.0 | 0.0 | 0.0 |
| Fremont | 180.3 | 0.0 | 0.0 | 0.0 |
| Garfield | 553.0 | 78.2 | 0.0 | 0.0 |
| Gunnison | 696.6 | 0.0 | 0.0 | 6.5 |
| Huerfano | 278.3 | 8.7 | 0.0 | 0.0 |
| LaPlata | 322.1 | 0.0 | 0.0 | 0.0 |
| Las Animas | 832.0 | 0.0 | 13.7 | 0.0 |
| Mesa | 229.4 | 0.0 | 16.3 | 0.0 |
| Moffat | 1,994.8 | 0.0 | 202.1 | 0.0 |
| Montezuma | 19.1 | 0.0 | 0.0 | 0.0 |
| Montrose | 42.8 | 0.0 | 17.1 | 0.0 |
| Park | 25.3 | 0.0 | 0.0 | 0.0 |
| Pitkins | 88.6 | 0.0 | 0.0 | 0.0 |
| Rio Blanco | 1,067.4 | 0.0 | 175.4 | 0.0 |
| Routt | 2,738.7 | 0.0 | 0.0 | 0.0 |
| Colorado Total | 9,226.2 | 86.9 | 424.6 | 6.5 |
| Montana | | | | |
| Broadwater | 5.7 | 0.0 | 0.0 | 0.0 |
| Carbon | 735.0 | 0.0 | 0.0 | 0.0 |
| Cascade | 308.8 | 0.0 | 0.0 | 0.0 |
| Fergus | 210.1 | 0.0 | 0.0 | 0.0 |
| Glacier | 25.4 | 0.0 | 0.0 | 0.0 |
| Judith Basin | 90.4 | 0.0 | 0.0 | 0.0 |
| Meagher | 0.5 | 0.0 | 0.0 | 0.0 |
| Stillwater | 7.9 | 0.0 | 0.0 | 0.0 |
| Montana Total | 1,348.0 | 0.0 | 0.0 | 0.0 |

## TABLE 14. REGION 5 UNDERGROUND BITUMINOUS COAL RESERVE BASE BY STATE AND COUNTY KNOWN TO FORM ACID MINE WATER ON OCCASION (Continued)
(million short tons)

| State and County | Total Underground Bituminous Coal Reserves | Reserves of Listed Coal Seams (Table 9) Potentially Acid Forming: < 1% Sulfur | Sulfur Value Unknown | > 1% Sulfur |
|---|---|---|---|---|
| New Mexico | | | | |
| McKinley | 113.5 | 0.0 | 0.0 | 0.0 |
| Rio Arriba | 3.0 | 0.0 | 0.0 | 0.0 |
| Sandoval | 48.2 | 0.0 | 0.0 | 0.0 |
| San Juan | 422.2 | 0.0 | 0.0 | 0.0 |
| Valencia | 0.1 | 0.0 | 0.0 | 0.0 |
| New Mexico Total | 1,527.2 | 0.0 | 0.0 | 0.0 |
| Oregon | | | | |
| Coos | 1.0 | 0.0 | 0.0 | 0.0 |
| Oregon Total | 1.0 | 0.0 | 0.0 | 0.0 |
| Utah | | | | |
| Carbon | 766.7 | 0.0 | 0.0 | 0.0 |
| Emery | 77.3 | 0.0 | 0.0 | 0.0 |
| Garfield | 1,011.2 | 0.0 | 0.0 | 0.0 |
| Iron | 5.4 | 0.0 | 0.0 | 0.0 |
| Kane | 1,714.5 | 0.0 | 0.0 | 0.0 |
| Sevier | 142.4 | 0.0 | 0.0 | 0.0 |
| Unitah | 40.3 | 0.0 | 0.0 | 0.0 |
| Wayne | 22.8 | 0.0 | 0.0 | 0.0 |
| Utah Total | 3,780.5 | 0.0 | 0.0 | 0.0 |
| Washington | | | | |
| King | 44.3 | 0.0 | 0.0 | 0.0 |
| Kittitas | 64.4 | 0.0 | 0.0 | 0.0 |
| Lewis | 7.0 | 0.0 | 0.0 | 0.0 |
| Pierce | 65.1 | 0.0 | 0.0 | 0.0 |
| Whatcom | 70.4 | 0.0 | 0.0 | 0.0 |
| Washington Total | 251.2 | 0.0 | 0.0 | 0.0 |

## TABLE 14. REGION 5 UNDERGROUND BITUMINOUS COAL RESERVE BASE BY STATE AND COUNTY KNOWN TO FORM ACID MINE WATER ON OCCASION (Concluded)

(million short tons)

| State and County | Total Underground Bituminous Coal Reserves | Reserves of Listed Coal Seams (Table 9) Potentially Acid Forming: < 1% Sulfur | Sulfur Value Unknown | > 1% Sulfur |
|---|---|---|---|---|
| Wyoming | | | | |
| Carbon | 39.2 | 0.0 | 0.0 | 0.0 |
| Crook | 1.2 | 0.0 | 0.0 | 0.0 |
| Lincoln | 555.9 | 0.0 | 0.0 | 0.0 |
| Park | 8.3 | 0.0 | 0.0 | 0.0 |
| Sweetwater | 3,402.8 | 0.0 | 0.0 | 0.0 |
| Uinta | 494.7 | 0.0 | 0.0 | 0.0 |
| Weston | 22.0 | 0.0 | 0.0 | 0.0 |
| Wyoming Total | 30,817.7 | 0.0 | 0.0 | 0.0 |

## TABLE 15. NATIONWIDE UNDERGROUND BITUMINOUS COAL RESERVE BASE KNOWN TO FORM ACID MINE WATER ON OCCASION (by Region and State)

| Region | Total Underground Bituminous Coal Reserves (million short tons) | Sulfur Value of Potential Acid-Forming Seams as Listed in Table 8 | | | Percent of Total Underground Bituminous Reserves that on Occasion Have Been Known to Produce Acid Water* | |
|---|---|---|---|---|---|---|
| | | < 1% | Unknown | > 1% | Listed Coals with Sulfur Values > 1% | Listed Coals with Sulfur Values Unknown and > 1% |
| Region 1 | | | | | | |
| Maryland | 901.9 | 91.0 | 0.0 | 806.4 | 89 | 89 |
| Ohio | 17,423.3 | 109.4 | 1,747.0 | 13,906.8 | 80 | 90 |
| Pennsylvania | 22,788.9 | 968.6 | 2,124.5 | 17,928.7 | 79 | 88 |
| Northern West Virginia | 18,321.1 | 1,371.6 | 1,820.1 | 12,052.7 | 66 | 76 |
| Total | 59,435.2 | 2,540.6 | 5,691.6 | 44,694.6 | 75 | 85 |
| Region 2 | | | | | | |
| Alabama | 1,798.1 | 0.0 | 0.0 | 66.0 | 4 | 4 |
| Eastern Kentucky | 9,466.5 | 3,988.8 | 833.6 | 2,051.6 | 22 | 30 |
| North Carolina | 31.2 | 0.0 | 0.0 | 0.0 | 0 | 0 |
| Tennessee | 667.1 | 67.0 | 22.1 | 185.8 | 28 | 31 |
| Virginia | 2,833.2 | 211.2 | 10.4 | 381.7 | 13 | 14 |
| Southern West Virginia | 16,056.5 | 5,477.4 | 558.1 | 4,326.1 | 27 | 30 |
| Total | 30,852.6 | 9,744.4 | 1,424.2 | 7,011.2 | 23 | 27 |
| Region 3 | | | | | | |
| Illinois | 53,441.9 | 1,017.9 | 8,257.6 | 34,753.2 | 65 | 80 |
| Indiana | 8,948.5 | 157.0 | 679.7 | 4,377.8 | 49 | 57 |
| Western Kentucky | 8,719.9 | 0.0 | 207.2 | 7,365.8 | 84 | 87 |
| Michigan | 117.6 | 0.0 | 0.0 | 0.0 | 0 | 0 |
| Total | 71,227.9 | 1,174.9 | 9,144.5 | 46,496.8 | 65 | 78 |

*See footnote page 64

## TABLE 15. NATIONWIDE UNDERGROUND BITUMINOUS COAL RESERVE BASE KNOWN TO FORM ACID MINE WATER ON OCCASION (by Region and State) (Concluded)

| Region | Total Underground Bituminous Coal Reserves (million short tons) | Sulfur Value of Potential Acid-Forming Seams as Listed in Table 8 | | | Percent of Total Underground Bituminous Reserves that on Occasion Have Been Known to Produce Acid Water* | |
|---|---|---|---|---|---|---|
| | | < 1% | Unknown | > 1% | Listed Coals with Sulfur Values > 1% | Listed Coals with Sulfur Values Unknown and > 1% |
| Region 4 | | | | | | |
| Arkansas | 306.0 | 0.0 | 0.0 | 0.0 | 0 | 0 |
| Iowa | 2,884.9 | 0.0 | 20.7 | 158.3 | 5 | 6 |
| Missouri | 6,073.6 | 0.0 | 596.4 | 1,575.4 | 26 | 36 |
| Oklahoma | 860.1 | 0.0 | 0.0 | 0.0 | 0 | 0 |
| Total | 10,124.6 | 0.0 | 617.1 | 1,733.7 | 17 | 23 |
| Region 5 | | | | | | |
| Colorado | 9,226.2 | 86.9 | 424.6 | 6.5 | < 1 | 5 |
| Montana | 1,348.0 | 0.0 | 0.0 | 0.0 | 0 | 0 |
| New Mexico | 1,527.2 | 0.0 | 0.0 | 0.0 | 0 | 0 |
| Oregon | 1.0 | 0.0 | 0.0 | 0.0 | 0 | 0 |
| Utah | 3,780.5 | 0.0 | 0.0 | 0.0 | 0 | 0 |
| Washington | 251.2 | 0.0 | 0.0 | 0.0 | 0 | 0 |
| Wyoming | 30,817.7 | 0.0 | 0.0 | 0.0 | 0 | 0 |
| Total | 46,951.8 | 86.9 | 424.6 | 6.5 | < 1 | 1 |
| National Total | 218,592.1 | 13,546.8 | 17,302.0 | 99,942.8 | 46 | 54 |

*These percentages represent worst case situations as can be seen by the BCR survey, Table 7, which indicates that only about 44% of the mines in Region 1, 17% of the mines in Region 2, 23% of the mines in Region 3, 12% of the mines in Region 4, and none of the mines in Region 5 produce acid mine drainage.

## C. UNDERGROUND MINE DRAINAGE ABATEMENT

1. Use of Acid-formation Inhibitors: Control measures, based on eliminating one or more of the factors which influence pyrite oxidation, have been proposed to abate the formation of acid mine drainage.

a. Biological Control: As discussed in Section III A, numerous researchers have attributed increases in acid production from 2- to 17-fold to bacterial activity. The control of acid formation by applying inhibitors or biocides to retard the action of bacteria is based on reducing or eliminating this biological contribution to acid formation. Although biological control has frequently been discussed, the published experience in this area has been sparse and inconclusive. Several attempts have been made to apply inhibitors to underground mines but have met with little or no success.

As early as 1950, an experiment was conducted at West Virginia University[625] to test the effect of acriflavine on acid formation. The Weirton mine in the Upper Freeport coal seam was selected as the test site. This mine had the advantages of an isolated location and of being a new mine where no previous acid accumulation existed. The effluent from the mine had an acidity of 400 mg/l as $CaCO_3$ and a pH of 4. Sulfur-oxidizing bacteria were present in the water.

In the experiment, exposed coal faces in an acid-producing section of the mine were sprayed daily for one week, then at two- to three-day intervals for two weeks with a 1:1000 solution of acriflavine, an antiseptic which was reported to prevent the growth of sulfur-oxidizing bacteria. The faces remained neutral for two weeks but, after that period, the section was again found to be producing acid. The section was cleaned and the faces sprayed again for one week. Acid production was again noted the second day following cessation of spraying. With no further explanation, the authors concluded that the bulk of acid was formed in the strata immediately overlying the coal, since the wet shale above the coal was found to be acidic. The impracticality of applying an inhibitor was demonstrated by the authors as they were unable to find even a suitable test site in a mine in the Pittsburgh seam due to the extent and complexity of the workings.

Shearer and Everson[265,570] presented apparent evidence of the existence of bacteriophages, found in soil or compost, which dissolve (lyse) bacteria. Bacteria were inoculated with the phages under laboratory conditions and bacterial growth was inhibited for up to 7 days. Concentrated growths of bacteriophages were then isolated from neutral mine water and used to inoculate coal piles. The acid-production rate was reduced for 5 months, and further reinoculation restored inhibition. The anti-bacterial agent was later identified[569,572] as Caulobacter. It was believed that Caulobacter may compete for the food supply and reduce the number of iron bacteria or they may attack the iron bacteria directly.

The inhibitory effect of bacteriophages was subsequently field tested at the Robena No. 2 mine by injecting 51,100 litres (13,500 gallons) of water collected from another mine into the Robena mine. The inhibitory effectiveness of the injected water was previously demonstrated in laboratory experiments. No inhibition of acid production from the Robena mine was noted. Shearer *et al*. suggested that the topography prevented access of the inhibitor to some acid-producing regions. However, subsequent laboratory tests indicated that inhibitory effectiveness was absent at the time the water was collected. A second inoculation at the Robena mine was made but no change was noted in the acidity of the drainage from the test site over a period of several months. The injection of laboratory-prepared concentrates of the anti-bacterial agent into underground test mines was planned but apparently not carried out.

The work by Shearer *et al*. and by West Virginia University indicates the difficulty that many researchers have found in duplicating laboratory results in underground mines. Unless the exact points of acid formation are known and accessible, application of inhibitors is a fruitless endeavor. The Weirton mine used by the West Virginia University group was an ideal site--isolated and containing no previous acid accumulation. Yet the application of acriflavine to abate acid formation was not successful. Either the biocide itself was ineffective or acid may have been formed at a location remote from the test site and transported into the test area. Even under what appear to be ideal conditions, all of the parameters which affect acid formation are difficult to define.

Unresolved controversies, such as the role of sulfur-oxidizing bacteria in acid formation and the acid-forming potential of the various pyritic materials associated with coal and the surrounding strata, further complicate the problem.

The inhibitory properties of Caulobacter, which were used by Shearer for his studies, were questioned by Baker and Wilshire[79] who also conducted inhibition studies with the microorganisms. In a pilot-plant study, they found that Caulobacter had no effect on AMD production rates and were not parasitic to chemoautotrophic (those organisms able to use the energy from chemical reactions to produce nutritive substances from carbon dioxide and water) organisms.

*Streptomyces aureofaciens*, an antibiotic-producing bacteria, was found by Shearer *et al*.[569] to be effective against acid-producing bacteria in test-tube cultures and on solid media.

Charnego[167] reported that quaternary ammonium compounds inhibited acid formation by reducing the oxygen uptake of *F. ferrooxidans*, based on laboratory tests. Charnego's results corroborated the findings of Ashmead,[73] who demonstrated that certain quaternary ammonium compounds in the concentration range of 5 to 6 mg/l were lethal to bacteria associated with AMD formation. The biocides were not field tested.

Walsh and Mitchell[671] demonstrated that ferrous ion concentrations of 100 mg/l inhibited iron-oxidizing *Metallogenium*. When *Metallogenium* was inhibited, the rate of pH decrease from iron oxidation was slowed.

In the view of the authors of this report, the use of this inhibitor, however, would increase the amount of pollutants in the water since the additional ferrous ions in mine water would create more of a problem to the coal industry than the natural situation. In addition to the ferrous iron being difficult and costly to remove from mine effluents, it can be oxidized to ferric iron, which can oxidize even more pyrite.

The reported experience with "at-source" abatement by means of biological control of acid formation has been scanty. This control technique presents several problems, and the reasons why more researchers are not pursuing this area of investigation include:

(1) The production and use of biocides may be prohibitive as to cost of production and toxicity;

(2) The actual points of acid formation, especially in an abandoned mine, will probably not be accessible and perhaps not even known. Therefore, the real effectiveness of any inhibitor is questionable;

(3) Complete bacterial control would necessitate inoculating all of the infiltrating water--an impossible task;

(4) Due to the dilution effect, periodic inoculations would have to be made to maintain or re-establish the effectiveness of the inhibitor;

(5) Since the formation of acid mine drainage from the oxidation of pyrite is a slow, continuing process, occurring over long periods of time, any inhibitors or coatings applied for the purpose of abatement must be kept in place for equally long time periods;

(6) Proposed methods of chemical inhibition of bacteria would result in additional pollutants which would have to be removed from the effluent;

(7) The major problem with this control technique is that the chemical oxidation and leaching process would continue, regardless of bacterial inhibition.

In summary, the feasibility of successfully applying biological inhibitors to control acid formation is very low, and the costs would be prohibitive.

b. Coating of Pyritic Surfaces: Acid mine water is formed by the reaction of pyrite with oxidants such as oxygen and ferric ion. Whether or not water enters into the reaction is uncertain, but it is the transporting agent for the products of pyrite oxidation. "At-source" abatement of acid formation, by applying chemical coatings directly to the pyrite surface, is based on eliminating oxygen and water contact with pyrite. Very few efforts to actually utilize this abatement method are recorded in the literature.

Braley[136] reasoned that ammonia would react with iron sulfate to produce a protective coating on all oxidizable surfaces by precipitating iron as gelatinous ferric hydroxide. To test this theory, an abandoned mine was filled with ammonia gas. A slight increase, rather than the desired decrease in acidity of the mine water, was observed over the following 11 weeks.

Cotton[196] postulated that the oxidation of pyrite was electrolytic in nature and suggested the following: Hydrogen sulfide dissociates into sulfur, hydrogen and free electrons. The hydrogen combines with water and oxygen to form hydrogen peroxide which then combines with sulfur or pyrite to form ferrous or ferric salts or sulfuric acid. This reaction can be interrupted by electrical contact of metal salts which have a higher electrical potential than sulfur or iron. The metal salts suggested were zinc, chromium, aluminum, or phosphorus. Application difficulties were encountered, and the work was discontinued.

Phosphate, chromate, and alkali solutions and coatings were tested by Braley[137] to determine their effectiveness in preventing the reaction of sulfuritic material with oxygen. It was concluded that phosphates, chromates, and sodium hydroxide, either in solution or intimately dried on the pyritic surface, have little or no effect upon the rate of oxidation of pyrite.

Clark[174] also tested phosphates and chromates and reported that they did inhibit acid formation under laboratory conditions. However, he used more concentrated solutions than did Braley. Clark field-tested four chemical inhibitors: solutions of dibasic calcium phosphate, tribasic calcium phosphate, sodium pyrophosphate, and rock phosphate, which were sprayed or dusted on mine surfaces. He concluded that certain phosphates may be effective in retarding the decomposition of pyrite, but the amount of inhibiting substance needed for any particular area had not been determined.

Bloom et al.[111] reported on mono-, di- and tri-chloro derivatives of silane ($SiH_4$) for treatment of sulfide materials. The compounds reacted in the gaseous state with sulfides to form a hydrophobic surface. Bonding was stable in acid media. However, the gaseous substances also reacted with water. Field testing was not completed.

Tyco Laboratories[577,655] applied a silica- and aluminum/silica-gel treatment process to refuse piles. The silica gel endured for 305 centimeters (120 inches) of equivalent rainfall and the alumina/silica for 1,270 centimeters (500 inches). The gel was not tested in underground mines.

Peeler[519] discussed treatment of soil containing iron pyrites with an aqueous alkali metal silicate solution. The silicate solution reacted with sulfuric acid to form a silica gel.

Flynn[278] described a method of inhibiting the rate of pyrite oxidation by applying a mixture of pulverized phosphate and sulfuric acid. The phosphate rock reportedly converted any soluble iron compounds to non-acid forming phosphates which coated the unreacted iron sulfides, thereby eliminating air and water contact.

"At-source" abatement by coating acid-forming materials with an impervious shield to eliminate air and water contact with pyrite surfaces is not practical due to the inaccessibility of the enormous volumes of fractured coal and rock that contribute to acid formation. New pyritic surfaces are constantly being exposed as a result of roof falls and pillar collapse. This means periodic applications would have to be made to effect complete control. This would represent an impossible problem due to the inaccessibility of mined-out sections. The additional pollutants that may be formed from any inhibitor material would also compound the problem.

### 2. Hydrologic Controls

a. Water-infiltration Control: Water may enter the underground mine through surface fractures, permeable overburden, subsidence areas, bottom clay, adjacent non-regraded surface mines, and shaft, drift, slope, and borehole openings. To permit active mining, this water normally must be discharged from the mine via pumping or by gravity drainage. Since any available products of pyrite oxidation may also be transported from the mine, the mine water may require treatment before being discharged to the receiving stream.

Water-infiltration control techniques are designed to reduce the quantity of water that enters an underground mine, thereby reducing the volume of water that must be treated and discharged. If the volume of influent water can be substantially reduced, some savings in pumping and treatment costs would accrue to the coal industry.

Methods proposed, but not demonstrated,[460] for determining sources, paths, and quantities of water entering underground coal mines include:

(1) Photogeologic methods--most applicable to mining is small-scale and medium-scale aerial photography to map geological structures such as folding and fracturing of rock strata which are fundamental to (a) the occurrence of water in an underground mine, (b) the routes the water follows once it enters the subsurface, and (c) where the water will discharge.

(2) Field examination--to verify all structures previously inferred during the photogeologic studies. If conducted by an experienced hydrogeologist or engineering geologist, field examination can suggest many possibilities for avenues of water infiltration into an underground mine.

(3) Geophysical methods--the most applicable to coal mining are borehole techniques. Use of borehole methods facilitates quantitative measurement of material properties (density, porosity, permeability, and elasticity) and provides qualitative information such as zones of water influx, relative clay content, and lithology. Other less-applicable geophysical

methods include surface, airborne, and in-mine techniques. Geophysical methods can be used to locate geologic and man-made situations--joints, faults, sand intrusion into a coal seam, unconfined aquifers, abandoned mine openings and workings--all of which contribute to the problem of locating and quantifying potential sources of water entering underground coal mines.

(4) Subsurface geologic methods--measurements and observations of rock lithology; stratigraphy; gross structural geological characteristics of the overburden; and extent, thickness, and rank of coal are made by means of diamond core drilling, drilling and geologic logs, and laboratory testing. Individual geologic maps can be overlaid and used as a predictive tool to define slight to severe water inflow problem areas.

(5) Hydrogeologic methods--information about hydrogeological characteristics of rock units can be made by observations and measurements in existing wells, boreholes associated with coal exploration and development, and adjacent mines. Specific techniques include seepage tests, pressure tests, pump tests, and water analysis. The data obtained pertain to (a) the presence and extent of aquifers and aquicludes, (b) groundwater levels and pressures, (c) hydraulic parameters, and (d) water quality.

(6) Tracer methods--artificially-injected and naturally-occurring tracers such as organic dyes, inorganic substances, and radioactive isotopes have been used to physically trace movements of water which may enter an underground mine. No single tracer is ideal for all situations, and the applicability of this method is limited to small areas.

Control of surface-water infiltration into abandoned deep mines has been implemented in several "at-source" abatement programs under Operation Scarlift in Pennsylvania.

The Catawissa Creek Project[745] involved the reconstruction of a streambed to prevent the stream from entering the underground mine. With an average of 21.88 million litres (5.8 million gallons) of water per day prevented from passing through the mine, the load of acid to Catawissa Creek was reduced by an average of 830 kilograms (1,830 pounds) per day. However, the amount of iron discharged into the creek was approximately the same because the reduced volume of flow carried a higher concentration of iron.

Water-infiltration control was accomplished in the Beech Creek Stream Project[745] where a significant portion of the streamflow of Little Sandy Run was lost to deep mines through subsidence areas. A new channel was constructed and the subsidence areas filled to achieve positive drainage into the channel. An estimated 1.5 million litres (0.4 million gallons) per day of water was prevented from entering the mines. Thus, an average of

283 kilograms (624 pounds) of acid and 61 kilograms (156 pounds) of iron per day, which would have been carried by this amount of flow, were not discharged into the stream.

In the Tioga River area,[745] reconstruction of a streambed and restoration of strip mines prevented an estimated daily infiltration of 4.66 million litres (1.23 million gallons) per day of water into underlying mines. This reduction in flow was estimated to result in an average daily reduction in acid load to the stream of 3,850 kilograms (8,480 pounds).

Surface sealing of subsidence areas and water diversion were used in conjunction with deep-mine sealing at the Shaw Mines Complex to realize a 45-percent reduction in acidity. At Alder Run, a channel was relocated and diverted water away from deep-mine openings.[283]

Techniques to seal surface cracks, rechannel surface water, and seal boreholes and mine openings have been successfully demonstrated at numerous other sites than those listed above. These sites include many active mines.

Water-infiltration control might also be achieved by intercepting ground water before it enters the mine. This method of acid mine drainage abatement has been discussed extensively but is still in the theoretical stage. One such plan[15] was proposed to eliminate the acid discharge from the Todd mine into the Lake Hope drainage basin. An investigation of the area suggested that there were three main aquifers: a shallow water table above the coal; below the coal, a brackish aquifer between 300 and 400 feet; and a deeper fresh-water aquifer. In the proposed plan, the overlying aquifer would be connected to either of the lower aquifers by weeping wells so that water would bypass the coal and related strata instead of percolating through them to pick up pyrite oxidation products.

Loofbourow and Brittain,[422] in discussing the conditions favorable to dewatering, noted that: aquifers should be predictable as to position and productivity; ground should have some minimum coherence; comparatively shallow aquifers are developed more rapidly and are developed and pumped at less cost; ground should be easily bored; and water flows should not be extreme.

Considerable hydrogeological data is required to determine the feasibility of this approach to infiltration control. According to Parizek[753] these data include the spatial distribution, thickness, and geometry of aquifer and non-aquifer units; hydraulic boundaries that either restrict the flow of ground water (stratigraphic pinchouts, fault offsets, erosional unconformities) or serve as recharge sources (channel sandstones, flooded deep mines, fractured roof rock etc); permeability and storage distribution; infiltration capacity of streambed sediments; vertical permeability of confining beds; and hydraulic heads among and between various aquifer and non-aquifer units.

In some instances, and it is the opinion of the coal industry that such opportunities are limited, subsurface-infiltration control may reduce the volume of water entering the mine. Such instances could include all types of underground mines during development and deeper, below-drainage mines during the entire life of the mine. Normally, ground water that enters underground mines above drainage has not migrated through aquifers for any appreciable distance but has originated as precipitation or surface-water flow over the ground surface directly overlying the mine. As mining progresses, secondary fracturing of the overburden will result, which will enhance the flow of this water into the mine. It is difficult to believe that under normal circumstances it will be technically or economically possible to drill a sufficient number of wells to achieve any significant infiltration reduction. A pilot dewatering project to demonstrate the technical and economic feasibility of dewatering an active underground mine to control or prevent acid mine drainage is currently being conducted in central Pennsylvania by W. A. Wahler and Associates. The results of this demonstration project should be critically evaluated, particularly as they relate to developing mines and mines below drainage, to determine whether additional research on dewatering techniques is advisable.

b. Water Handling: The most effective abatement procedures that can be utilized in an operating mine involve the handling of water once it gains entrance to the mine. The principles involved, as described in Principles and Guide to Practices in the Control of Acid Mine Drainage (Attachment A), are minimizing the contact time between the water and acid-forming materials and removing the water as expeditiously as possible. Minimization of the contact time also assumes that care will be exercised in the placement of acid-forming materials.

(1) All gravity drains and sumps should be maintained in such a manner that they are kept free of acid-forming materials.

(2) If gravity drains are constructed in material that is acid producing, consideration should be given to enclosing the flow.

(3) Highly pyritic coal-cleaning refuse normally should not be returned underground but should be disposed of on the surface where positive action can be taken to eliminate any acid discharge. Underground stowage should only be considered at those locations where the mine is essentially dry or at those mines or sections of mines where such wastes will be completely inundated.

(4) Pumping schedules should be arranged to prevent large deviations in the water level within the mine. If acid-forming materials are exposed, the cyclic wetting and drying will result in an acceleration of the acid-formation process.

(5) Major sump locations should be determined prior to mining and consideration of procedures for accomplishing expeditious dewatering should be an integral part of the pre-mining planning.

(6) As mining progresses, secondary sumps should be constructed and positive pumping established to prevent uncontrolled water movement through the mine.

These procedures are fairly well known and have been put into practice by most major coal-producing companies. Comprehensive studies to evaluate these procedures have not been conducted, and it is difficult to accurately assess their effectiveness. However, it can be inferred, from the data from the BCR and EPA surveys, that the alkaline quality of many discharges originating from mines in acid-producing seams was due to implementation of these procedures. Coal-industry experts caution that, although acid production can often be significantly minimized by implementing these practices, it cannot always be eliminated.

Additional reductions in acid mine drainage pollution can be achieved through wider use of these practices. To identify and promote the use of such practices, it is recommended that the Bureau of Mines prepare a manual on control of acid mine drainage and develop a program that will result in the dissemination of this information throughout the coal industry. It would seem appropriate to utilize the Bureau of Mines State Liaison Officers in the dissemination effort. It would also seem appropriate to provide them with complete information concerning the mine-drainage problems in their respective states. By doing this, the coal industry in any given state would have a single source of complete information that they could utilize.

3. Mining Methods: The most common past practice has been to mine coal from the outcrop rather than driving slope or shaft entries. Such mines are usually driven up-dip wherever possible to, in part, facilitate gravity drainage and reduce pumping costs. When abandoned, it is extremely difficult to seal these mines and eliminate the discharges because of the large hydrostatic heads that will develop as the mine floods. Down-dip mining, which would eliminate all gravity discharges, therefore, has been suggested[512,536] as a viable method of guaranteeing the elimination of the mine discharge when the mine is abandoned and sealed.

An evaluation of up-dip versus down-dip mining was conducted for EPA by Skelly and Loy Engineers and Consultants.[457] Water quality was evaluated at a pair of abandoned mines--one developed up-dip and one developed down-dip. Since the mines were apparently similar in all other respects, the primary factor controlling water quality was the direction of mine development. It was determined that the acidity concentrations in the main discharge from the abandoned mine developed to the rise were consistently in excess of 2200 mg/l, while those of the discharge from the mine developed to the dip were generally less than 100 mg/l.

An active mine with units operating up-dip and down-dip was evaluated, as part of the same study, to ascertain major advantages and disadvantages of each method. The authors concluded: down-dip mining at the active site was no more or less productive than up-dip mining; pumping costs may be substantially increased by down-dip mining but they will probably not reach the point of adversely affecting production economics; despite extremely low conveyor-belt-haulage unit cost, percentage cost increases, incurred by haulage up-grade rather than down-grade, range from a few to several hundred percent; and effective sealing of mines in steeply dipping seams can only be assumed where mines have been developed to the dip and the lower outcrop or barrier integrity has been maintained.

In view of the prospect that mine operators might have to treat the mine discharge for many years after active mining has been completed, the additional costs incurred by mining down-dip may be offset by elimination of treatment costs through effective sealing upon abandonment. In acid-producing seams, down-dip rather than up-dip mining might be considered whenever the option exists of using either method. One technological limitation to the successful application of this method is the problem of estimating the required thicknesses of barrier pillar and coal outcrop so that coal recovery is maximized while outcrop or barrier failure is minimized.

Longwall mining has been suggested as a mining method that possibly will result in the inhibition of acid mine drainage formation.[566] It has been theorized that this acid reduction might result from several circumstances. First, if the acid condition normally experienced when mining a particular coal bed is due to pyrite found in the coal, the availability of such pyrite will be greatly reduced, since nearly 85 percent coal recovery is attained by longwall mining. The second circumstance concerns the effect of caving which would essentially be complete and uniform. It is theorized that caving would: (a) reduce the volume of water which would come in contact with oxidized materials; (b) restrict water flow through the mined-out area; and (c) limit the amount of air that would come in contact with any pyrite that is exposed or is available for oxidation.

The effect of longwall mining on water quality should be exhaustively studied as this method of mining has the appealing advantages of increasing production and of recovering a larger percentage of our valuable coal resource. The results of such a study might indicate that total roof collapse is the circumstance that results in improved water quality. If so, achieving roof collapse could be an abatement measure that would be recommended as an objective when using other mining systems.

### 4. Mine Closure

a. Air Sealing: The use of mine seals to exclude air from abandoned mines, thereby decreasing oxidation and the formation of acid mine drainage, has been the subject of many investigations since the early 1900's.

The initial research on sealing mines to reduce acidity was conducted in the 1920's and early 1930's by the Bureau of Mines.[413, 415, 416, 418] It was observed that the sealed mines were not as acid as adjacent mines which had not been sealed. As a result of these studies, a program to seal abandoned mines in ten states was initiated in 1933 under the Civil Works Administration (CWA). Pennsylvania, West Virginia, Alabama, Ohio, Kentucky, Maryland, Tennessee, Virginia, Illinois, and Indiana were involved in the program.

Three types of mine seals were employed in the sealing operations.[334] Dry seals, constructed of earth, brick, concrete, or stone, were used to exclude air from openings from which no drainage flowed. Openings from which drainage flowed were closed with air seals. This type of seal excluded air but permitted the normal outflow of water. In some cases, the only effective method of sealing was to flood the workings by building a concrete barrier to the full height of the drainage openings. The hydrostatic pressure developed by such a construction was normally relieved by removing the mine water at a point above the roof of the mine.

The CWA program was dissolved in March, 1934, but the mine sealing was continued as state projects in Ohio, West Virginia, and Pennsylvania.[518, 641, 642]

In 1935, a large-scale mine-sealing program was inaugurated under the direction of the Works Progress Administration (WPA).[477] The objective was to reduce the acid flowing into streams of Pennsylvania, Ohio, Kentucky, and West Virginia. This undertaking was a continuation of the work intitated by the CWA.

Several investigators[165, 329] have reported on the mine-sealing projects conducted during the 1930's. These reports indicate that the seals resulted in a reduction of acidity. Fellows,[276] for instance, noted reductions of 50 to well over 90 percent in the "sulfuric acid" flow from abandoned mines. However, the effectiveness of the mine-sealing programs was not long lasting as many of the seals either failed, due to lack of maintenance, or were broken in order to resume mining during the war years in the 1940's. Several more recent studies[9, 491, 722] were undertaken to assess the effectiveness of these projects but all concluded that such an assessment was impossible due to the lack of information.

It should be noted that most of the early mine-sealing projects were depression years "make work" projects. Although many highly qualified engineers and skilled artisans were involved, the work performed, using the limited technology and materials available, was not completely satisfactory in view of the demanding and thorough job that is required to air seal a mine. Any improvement in water quality, and there are many examples, probably was the result of mine flooding and inundation of acid-forming materials, and of reduction in discharge flow rates, rather than oxygen reduction, which was the objective of air sealing.

In a more recent study, Braley[126] evaluated the effectiveness of air sealing seven abandoned drift mines. In all cases, the mines had gravity drainage and the overburden thickness ranged from 15 to 61 meters (50 to 200 feet). Criteria for determining the effectiveness of air sealing were: (1) reduction in the amount of acid produced, and (2) decrease of oxygen concentration in the mine atmosphere. He concluded that sealing of abandoned drift mines, when the coal seam was above drainage level, was ineffective in reducing the quantity of acid which was discharged. There also was no evidence that sealing of the mine substantially reduced the oxygen content of the atmosphere inside the mine.

In order to evaluate the effectiveness of air sealing, the Bureau of Mines[483] sealed a 31-hectare (77-acre) above-drainage coal mine. One dry seal and seven wet seals were constructed. Mine-atmosphere samples were collected from five locations after sealing. A reduction in acidity of 150 mg/l shortly after sealing was directly attributed to the effects of sealing. The mean total acidity was 514 mg/l before sealing and 211 mg/l for almost 3 years after sealing. The oxygen level decreased from 20.9 to 17.0 percent following sealing. Five months later, the oxygen concentration began to fluctuate and did not decrease below 16 percent.

Better overall results would have been obtained had it been practical to find all permeable zones and, if suitable proven techniques were available, to seal them.

Several small underground mines, which were discharging acid mine drainage into Taylor Run, Red Run, and Fishing Hawk (all tributaries to Shavers Fork), were air sealed by the West Virginia Department of Mines. Evaluation of the effectiveness of the air sealing, which was conducted by EPA,[564] was limited because either insufficient or unreliable data were collected prior to sealing. However, the overall results indicated that the concentrations and load discharging into Shavers Fork did not change to a great extent in the two years following sealing.

Active research on acid mine drainage has been conducted at the McDaniels Test Mine since 1964. This pilot-scale facility is intermediate between laboratory scale and demonstration scale. The effect of oxygen concentration on acid production was studied[528] by maintaining the oxygen concentration of the McDaniels Test Mine at less than 1 percent for one year. Acid loads decreased to about 60 percent of the values for the previous year. This was approximately one-half of the expected decrease if steady-state conditions were reached.

It was estimated that if all oxygen could be excluded from the mine, 4-1/2 years would be required to remove 90 percent of the oxidation products present at the time oxygen was first eliminated from the mine. This indicates the care that must be exercised in interpreting mine-drainage field data because of the slow response of natural systems to imposed environmental changes and the erratic output due to hydrologic variations. Conclusions cannot be made on a single mine's discharge data over a 1- or 2-year period.

Both surface reclamation and underground mine sealing were carried out during the Elkins project.[356] Eleven "wet" seals (designed to allow water to leave the mine but prevent air from entering) were constructed in an 809-hectare (2000-acre) underground mine complex and one seal in a small, isolated mine. The sealing of the large mine was not completed and subsidence over large portions of the mine was not corrected. All known openings to the small, isolated mine were sealed.

The oxygen level inside the large mine was the same as the air outside the mine. The acid-load data showed little if any improvement.

The oxygen content of the small, isolated mine decreased to 11 percent during the first two years following sealing, and then increased to and remained at about 15 percent. The acidity, iron, and sulfate concentrations decreased but an increase in flow occurred so pollution loads showed little change.

Conclusions of the project were that air sealing of underground mines to eliminate oxygen could not be accomplished under the conditions encountered at Elkins. Even under the best conditions, oxygen was reduced to only 7 percent.

R. D. Hill,[355] when reviewing several mine-sealing projects, emphasized that in two projects, where extraordinary efforts to seal all known openings, subsidence, etc., were used, there was still an average of 15 to 17 percent oxygen in the mine atmosphere, indicating that air still had access to the mines. While the reduction of acidity was about 50 percent, part of that reduction could be attributed to preventing water from entering the mines. Hill's conclusions were: that 50 percent effectiveness was all that could be expected even from the best air-sealed mine and even then maintenance would be necessary to assure the integrity of the seal; and that mines with shallow cover, where outcrops were surface mined and which were highly subsided, would be even less conducive to air sealing.

In a survey conducted by Bucek *et al*.[722] pre- and post-closure water quality and quantity data were collected for 84 underground coal mines. They concluded that air sealing reduced acidity concentrations on the average by 50 percent. It was also pointed out in this study that air access was not eliminated even under the extraordinary measures that were taken during the sealing projects in Pennsylvania and West Virginia. All of these mines had shallow overburden (22-24 meters or 72-79 feet). A mine, having an overburden averaging 144 meters (472 feet), that was air sealed in West Virginia in 1972 was also evaluated. At this site, the pollutant concentrations increased considerably after sealing but have been diminishing at considerable rates since then. Based on this finding, they suggested that mines with thicker overburden should be more suitable for effective air sealing.

The major problem with air sealing underground mines is the elimination of air access through the fractured and porous overburden. With every change in atmospheric pressure, the mine "breathes," thereby replenishing the oxygen in the mine. As was previously noted in reviewing the mine-sealing work done by EPA at Elkins, West Virginia and by the Bureau of Mines, even when extreme precautions were taken to eliminate air access, the oxygen content of the mine did not drop below 7 percent. From research conducted at the McDaniels Test Mine on pyrite oxidation, it was estimated that the oxygen concentration would have to be less than 1 percent to effect a greater than 90 percent reduction in acidity.

The demonstrated effectiveness of air sealing in reducing acid loads is only about 50 percent. To ensure even this limited effectiveness, periodic maintenance of the seals is required. Additionally, subsidence and fracturing may open new air access routes which would mean additional surface sealing. Considering that air sealing has been demonstrated to be only moderately effective in reducing acidity, and that there are major limitations inherent to its successful application, further research in this area appears impractical.

The feasibility of blanketing an abandoned deep mine with an inert gas in order to eliminate acid mine drainage formation was evaluated by Cyrus Wm. Rice Division, NUS Corporation.[552] The results of the study indicated that, although positive differential pressures could be maintained within the two mines investigated, continuous gas injection was necessary.

Mines with shallow overburden or with porous or fractured confining strata would not be suited to inert-gas injection since the gas would escape and, with each change in barometric pressure, oxygen could enter the mine. Periodic maintenance of the seals would be necessary, and fracturing and subsidence would open up new pathways through which gas could escape. This abatement method is not economically feasible since it requires continuous operation and, in this respect, is not a permanent solution to the acid mine drainage problem.

b. <u>Hydraulic Sealing</u>: Laboratory investigations and field studies have demonstrated that oxidation of pyrite can be eliminated by covering pyritic materials with water.

Braley[128] reported a significant improvement in water quality as a result of deep-mine flooding. He stipulated that the extent of beneficiation is dependent upon extent of total flooding as determined by coal and surface elevations.

The coal industry recognized the importance of mine flooding and, through the Coal Industry Advisory Committee (CIAC) to the Ohio River Valley Water Sanitation Commission (ORSANCO), published in 1964 the manual <u>Principles and Guide to Practices in the Control of Acid Mine-Drainage</u>.[534] One of these control measures called for effective planning of mine closing, including sealing, to minimize the formation and discharge of acid mine drainage.

Until the 1960's, most of the seals were constructed of cinder block and cement, which deteriorated in acid waters and, therefore, proved ineffective. As a result of the increased interest in environmental control, new mine-sealing techniques had to be developed. Today, hydraulic deep-mine seals are constructed of concrete and grout[639] and are designed to withstand water pressure, prevent inflow, and contain water.

From 1966 to 1969, the Halliburton Company[270-273, 499] conducted a study to develop and field test new methods for watertight seals and bulkhead construction. Based on the results of field tests, they concluded that a mine seal, composed of front and rear bulkheads of a quick-setting slurry with expansive-type cement filler between, would be satisfactory to seal a mine drift to hold the resultant head of impounded water.

In the last ten years, source-abatement methods have been employed in a number of government-sponsored programs. In the Moraine State Park[284] watershed area, 22 abandoned deep mines were sealed by installing 69 hydraulic mine seals of double-bulkhead construction, grouting, and surface sealing. Prior to the abatement, over 85 percent of the acidity, draining to what is now Lake Arthur, came from these 22 mines. The deep-mine sealing and grouting work resulted in 68-percent reduction in net acidity. Water quality has remained constant since construction was completed in 1971.

Mine-drainage abatement projects[283] also have been completed in the Argentine and Whiskerville mines, in the Shaw Mines Complex, and in the Ernest Complex in Pennsylvania. The Argentine and Whiskerville project consisted of installing 32 hydraulic deep-mine seals. Six deep-mine observation holes were installed to monitor the effect of sealing on water quality. As a result of the sealing operation, the flow was reduced by 70 percent and the net acidity decreased by 85 percent. Abatement work in the Shaw Mines Complex included installing five deep-mine hydraulic seals and grout curtains. Although the effect of deep-mine sealing could not be directly evaluated, the completed work resulted in a 45-percent reduction in acidity. Mine sealing completed in the Ernest Complex resulted in a 78-percent reduction in acidity. Based on these three projects, it was concluded that deep-mine sealing projects were the most effective of all abatement methods in reducing acidity.

The environmental effectiveness of close-down procedures at 84 sites throughout the eastern United States was evaluated by Bucek _et al_.[722] They reported that double-bulkhead sealing resulted in 45- to 99-percent reductions in acidity at 80 percent of the sites visited.

Klingensmith[745] reported on the results of using clay seals to achieve inundation of an abandoned deep mine. Prior to sealing, the discharge amounted to 354,276 litres (93,600 gallons) per day and contributed 246 kilograms (543 pounds) per day of acid to the stream. Several months after construction was completed, only a small trickle was found in the area of the former discharge.

Mine flooding has been demonstrated to be the only viable method of minimizing or eliminating acid discharges from underground mines following abandonment. Since such flooding will occur naturally in those mines that are situated below drainage, the concern for developing abatement procedures must be concentrated on those mines located above drainage. Flooding will also occur naturally in drift mines that are worked down-dip if there are no unsealed openings to the surface at elevations that are lower than that of the portal. Flooding of those mines having gravity discharges is the most difficult to achieve although some success has been reported.

Successful flooding of any above-drainage mine depends on: (1) having and maintaining a stable and impermeable outcrop and/or property barrier; (2) constructing durable and impermeable seals; (3) maintaining the long-time integrity of the seals; and (4) locating and sealing all openings to the surface that have resulted from mining. For instance, it can be theorized that, if there is sufficient hydrostatic head, in shallow-cover mines, discharges could be anticipated through the overburden cover at those points where major subsidence has occurred.

It is apparent that mine closure must be considered when planning and developing a mine. The width of the barriers to be left in place must be determined, portals must be planned and developed in such a way that successful sealing can be achieved, down-dip mining should be considered if the option exists, interior section- or panel-sealing should be considered, openings to the surface should be limited, and programs to record subsidence areas should be initiated.

Flooding appears to be the best method of abating acid mine drainage formation and discharge. However, before mine flooding can be unequivocally recommended, several problems must be addressed and additional research must be conducted.

First, tremendous volumes of water will be contained and, inadvertently, by man's activities, such as highway construction, or through natural deterioration of seals and outcrop, may be released with catastrophic results. If mine-flooding becomes widespread, the Bureau of Mines should accept the responsibility of mapping these mines and monitoring all surface activities that might interfere with the integrity of the system.

Second, the quality of overburden ground water may be affected at those sites where a large hydrostatic head results from mining. Future Bureau research should determine whether or not ground-water pollution might result from sealing.

Third, a considerable quantity of coal will be wasted when leaving outcrop and barrier pillars. At present, there are no valid specifications for determining the minimum pillar size required. There is a legitimate need for the Bureau of Mines to conduct research in this area. The pillar size requirements to provide adequate support for surface water bodies should also be investigated. Such research is needed since currently proposed requirements for support pillars are so stringent that longwall mining will be precluded in many areas in order that complete support be provided for even those streams that are classified as only wet weather tributaries.

Fourth, most mine-sealing programs have been conducted at abandoned mines and the conclusions drawn have been based on incomplete information concerning the mines and premining and presealing conditions. Restrictions in the location, type, and construction of the seals have been imposed by the conditions found at the site. There is also no assurance that all openings have been located and that all barriers are competent. The Bureau of Mines should undertake a mine-sealing research program in conjunction with the closure of a limited number of operating mines to determine the true effectiveness of sealing. There are, however, several recently completed, abandoned-mine-sealing programs for which adequate background information is available. There appears to be a lack of funds to continue monitoring these sites and, as much information can be gained from these experiences, the Bureau of Mines should sponsor a project to provide the required monitoring, maintenance, and evaluation.

Fifth, in certain states, section sealing of abandoned portions of active mines may be a problem due to conflicting regulations. For instance, Section 247 of the Mining Laws of Pennsylvania requires that "in a gassy mine all workings which are abandoned after the effective date of this act, or the dates such mine became a gassy mine, whichever is later, shall be ventilated." Section 291 states that "the superintendent shall not permit the mining of coal within fifty feet of an abandoned mine or any abandoned portion of any mine containing a dangerous accumulation of water, until said danger has been removed by driving a passageway to tap and drain off said water." Performance of either of these safety requirements would prevent section sealing or would eliminate its effectiveness. That section sealing is effective has been demonstrated at least at one site. At the Saginaw mine[266], as a result of sealing abandoned sections, only minimal amounts of water were found within the active sections of the mine. More extensive investigations into the effectiveness of section sealing should be conducted, and the conflict between existing mining laws and the requirements for section sealing should be resolved.

## IV. RESEARCH NEEDS AND PRIORITIES

A list of potential research projects, or lines of inquiries, that were suggested by this review can be found in Table 16. Each project has received a value judgment, using a scale of 0 to 10, with 10 being the highest mark given in each of four categories. These categories include: (1) Value of This Research Being Pursued--These ratings reflect the perceived overall value of the project without relating it directly to underground acid mine drainage abatement, or restricting future research to that to be conducted by the Bureau; (2) Probability of Leading to Development of Abatement Procedures--These ratings reflect the probability that the recommended project will result in the development of new mine-drainage procedures or will better define those procedures already available; (3) Value to the Coal Industry--These ratings are based on discussions with coal industry experts and reflect what they perceive to be their needs; and (4) Value of Bureau of Mines Pursuing This Research--These ratings are based on the ratings shown for the first three categories and, in addition, reflect both the need and the benefits to be derived from conducting the recommended project.

It is recommended that, to develop "at-source" abatement techniques, the Bureau of Mines actively pursue potential research projects (6) Development of Mine Closure Technology, (10) Development of Guidelines for Implementation of Surface Water Infiltration Control Procedures, (14) Study of the Effect of Roof Collapse on Mine Water Characteristics, (16) Evaluation of the Long-term Effects of Flooding Underground Mines Above Drainage, and (17) Investigate the Effectiveness of Section Sealing in Active Mines.

### A. PROJECT 6, DEVELOPMENT OF MINE CLOSURE TECHNOLOGY

Objective:

To provide the mining industry with the technology required to effectively seal a mine to ensure that all mine-water discharges are eliminated, or that flooding of a significant portion of the abandoned mine is achieved. Mine sealing must be considered an integral part of the active mining operation as the effectiveness of the sealing program will be dependent on the precautions taken during mining. Project 16 should be completed before work is initiated on this project.

Work Tasks:

(1) Determine the specifications for minimal size of all coal barriers, both internal and outcrop, to be left in place. These specifications should be dependent on projected hydrostatic head, structure of coal, competency of overburden, relationship of mine to adjacent mines in the same or other coal seams, and should ensure maximum coal recovery;

(2) Define the materials and procedures required for grouting less than minimal size barriers and fractured overburden to ensure their integrity; and

## TABLE 16. LIST OF PROJECTS THAT MIGHT BE CONSIDERED FOR FUTURE RESEARCH

| Potential Research Projects | Value Judgment 0-10 (10 is highest) | | | | Comments |
|---|---|---|---|---|---|
| | Value of this Research Being Pursued | Probability of Leading to Development of Abatement Procedures | Value to Industry | Value of BOM Pursuing this Research | |
| 1. Studies to Determine Exact Mechanisms by Which Chemical Oxidation of Pyrite Occurs | 1 | 1 | 0 | 0 | Information gaps exist that might be solved by further research. However, probability is remote that such research would lead to development of abatement procedures. |
| 2. Studies to Precisely Define the Role of Bacteria in the Formation of Acid Mine Water | 2 | 1 | 0 | 0 | Information gaps exist that might be solved by further research. However, probability is remote that such research would lead to development of abatement procedures. |
| 3. Develop a Method for Determining the Acid-forming Potential of Coal and Adjacent Stratigraphic Measures | 3 | 0 | 3 | 3 | Such a method might be valuable when preplanning a mine to determine the quality of water that will be generated, but research in this area will not lead to development of mine drainage abatement procedures. |

TABLE 16. LIST OF PROJECTS THAT MIGHT BE CONSIDERED FOR FUTURE RESEARCH (Continued)

| Potential Research Projects | Value Judgment 0-10 (10 is highest)<br>Value of this Research Being Pursued | Probability of Leading to Development of Abatement Procedures | Value to Industry | Value of BOM Pursuing this Research | Comments |
|---|---|---|---|---|---|
| 4. Development of a Laboratory Procedure, that Simulates the Conditions Which Exist in an Underground Mine, for Producing Acid Water | 3 | 1 | 0 | 1 | Reliable procedures for acid generation in the laboratory are not available. Such procedures should be developed before any laboratory studies involving mine acid formation are initiated. |
| 5. Develop a Simple Model for Predicting Mine Water Quality and Quantity | 5 | 1 | 5 | 5 | Such a model would be of value to the coal industry and would indicate the benefits to be derived from the implementation of "at-source" abatement procedures at a given site. |
| 6. Development of Mine-closure Technology | 10 | 10 | 10 | 10 | This assumes that the objective is partial or complete flooding of mines above drainage. Prior to conducting research in this area, thoughtful consideration should be given to the potential hazards of such flooding. |

TABLE 16. LIST OF PROJECTS THAT MIGHT BE CONSIDERED FOR FUTURE RESEARCH (Continued)

| | Value Judgment 0-10 (10 is highest) | | | | |
|---|---|---|---|---|---|
| Potential Research Projects | Value of this Research Being Pursued | Probability of Leading to Development of Abatement Procedures | Value to Industry | Value of BOM Pursuing this Research | Comments |
| 7. Studies to Determine Effect of Rock Dusting on Mine Water Quality | 2 | 2 | 3 | 3 | It is speculatively concluded that rock dusting will have a positive effect on mine water quality. This effect should be considered when evaluating abatement procedures. |
| 8. Evaluation of Materials to Inhibit Biological Oxidation of Pyrite | 0 | 0 | 0 | 0 | Applying and maintaining the effectiveness of these materials appear to be impossible tasks, and additional research is not recommended. |
| 9. Development of Materials to Inhibit Chemical Oxidation of Pyrite | 2 | 1 | 3 | 2 | Results of this research would be applicable to surface disposal of coal-cleaning refuse. Indirectly, this could be considered "at-source" abatement as this refuse would not be returned underground. |

TABLE 16. LIST OF PROJECTS THAT MIGHT BE CONSIDERED FOR FUTURE RESEARCH (Continued)

| | Value Judgment 0-10 (10 is highest) | | | | |
|---|---|---|---|---|---|
| Potential Research Projects | Value of this Research Being Pursued | Probability of Leading to Development of Abatement Procedures | Value to Industry | Value of BOM Pursuing this Research | Comments |
| 10. Development of Guidelines for Implementation of Surface Water Infiltration Control Procedures | 5 | 5 | 7 | 5 | Many such methods have been demonstrated, primarily at abandoned mine sites, but need to be presented in manual form that can be used by industry. New specifications are needed for support pillars that will permit greater coal recovery. |
| 11. Development of Methods for Reducing Ground Water Entry into Underground Mines | 1 | 1 | 1 | 0 | Research has been initiated by EPA. Follow-up research should be conducted by same agency to avoid duplication of effort. |
| 12. Prepare a Manual on Mine Drainage Abatement Procedures | 5 | 2 | 7 | 5 | Such a manual would benefit the many small operators. The value of the benefit would depend on the mechanism established by Bureau to disseminate information. |

TABLE 16. LIST OF PROJECTS THAT MIGHT BE CONSIDERED FOR FUTURE RESEARCH (Continued)

| | Value Judgment 0-10 (10 is highest) | | | | |
|---|---|---|---|---|---|
| Potential Research Projects | Value of this Research Being Pursued | Probability of Leading to Development of Abatement Procedures | Value to Industry | Value of BOM Pursuing this Research | Comments |
| 13. Develop a Program to Disseminate Information on Mine Drainage Control to Coal Industry | 5 | 2 | 7 | 5 | |
| 14. Study of the Effect of Roof Collapse on Mine Water Characteristics | 7 | 7 | 7 | 7 | |
| 15. Develop Methods of Air Sealing to Reduce Oxygen Content in Mine | 1 | 1 | 1 | 0 | Effective air sealing is not compatible with shallow-cover mines where maximum coal recovery has been achieved. Deeper mines, where oxygen cannot enter the mine via subsided areas or secondary overburden fractures, are normally below drainage and will naturally become flooded when the mine is abandoned. |

TABLE 16. LIST OF PROJECTS THAT MIGHT BE CONSIDERED FOR FUTURE RESEARCH (Concluded)

| | Value Judgment 0-10 (10 is highest) | | | | |
|---|---|---|---|---|---|
| Potential Research Projects | Value of this Research Being Pursued | Probability of Leading to Development of Abatement Procedures | Value to Industry | Value of BOM Pursuing this Research | Comments |
| 16. Evaluation of the Long-term Effects of Flooding Underground Mines Above Drainage | 10 | 10 | 10 | 10 | |
| 17. Investigate the Effectiveness of Section Sealing in Active Mines | 7 | 3 | 7 | 7 | |

(3) Develop design specifications for constructing a mine seal that will withstand the anticipated hydrostatic head; that can be effectively linked to the roof, rib, and bottom; and that will have maximum durability.

Applicability:

Results will be applicable to future underground mines to be opened in coal seams that represent approximately 25 percent of the reserves in the Northern Appalachian Region and 10 percent of the reserves in the Southern Appalachian Region.

Sequential Restraints:

Project 16 should be completed before work on this project is initiated. Project 16 must resolve the question of future responsibility and will provide guidance concerning the degree of flooding to be attained.

Duration and Cost:

See Table 17.

## B. PROJECT 10, DEVELOPMENT OF SURFACE WATER INFILTRATION CONTROL PROCEDURES

Objective:

To provide guidelines for minimizing the infiltration of surface water and design specifications for constructing surface-water diversion structures.

Work Tasks:

(1) Prepare a manual for use by the coal industry that provides guidelines for minimizing the creation of those conditions that result in infiltration of surface water. This manual should also contain design specifications for constructing surface-water diversion structures. The relative economics of water diversion control compared to the economics of pumping and treating acid mine water should be determined and included in the manual.

(2) A study should be undertaken to determine the need for and the minimum size requirements for pillars to provide adequate support for surface water bodies. These specifications are needed as current state requirements are so stringent that coal recovery is being minimized. For instance, currently proposed requirements in West Virginia will preclude the use of longwall mining at many mining sites.

Applicability:

Results of performing Task 1 will be applicable to all mines (see Table 15) where acid mine water may be generated and will require discharge to the surface.

Results of Task 2 will be applicable to all underground mining sites, whether or not acid water is formed, where the mine underlies any surface water body.

Duration and Cost:

See Table 17.

## C. PROJECT 14, STUDY THE EFFECT OF ROOF COLLAPSE ON MINE WATER CHARACTERISTICS

Objective:

To determine if essentially complete roof collapse will result in the reduced flow of mine water and/or will inhibit the formation of acid mine water. Such collapse will essentially be complete following longwall mining or pillaring. In effect, this may be found to be an abatement measure if compared to abandoned mines where coal recovery was limited.

Work Tasks:

(1) A study should be undertaken to evaluate the effect of roof collapse on mine water quality and quantity. To conduct this study, no less than ten sets of mines or sections of mines should be compared. Each set of mines should be in the same seam and be generally similar except that caving has occurred at only one site.

(2) Studies should also be undertaken to determine the effect of injecting highly-reactive alkaline material, or other potential inhibitors, into an abandoned, caved section. Since the collapsed section no longer represents a dynamic system, long-term inhibition of acid formation might result. These studies should also be conducted in conjunction with the section sealing studies (Project 17).

(3) If roof collapse is found to have a positive effect on mine water characteristics, mining procedures should be developed to optimize its use as an abatement procedure.

Applicability:

As an "at-source" abatement procedure, positive results of performing this project would be applicable to all mines where acid water may be formed and become a pollutional problem. As a technique that relates to mine closure, successful results would be applicable to new mines in 25 percent of the coal reserves in Northern Appalachia and 10 percent of the coal reserves in Southern Appalachia.

Sequential Restraints:

Performance of Task 3 will depend upon an evaluation of the results obtained from performing Tasks 1 and 2.

Duration and Cost:

See Table 17.

## D. PROJECT 16, EVALUATION OF THE LONG-TERM EFFECTS OF FLOODING UNDERGROUND MINES ABOVE DRAINAGE

Objective:

To determine under what conditions complete or partial mine flooding should be the objective of the mine-closure procedures. Flooding will be the result of mining on the dip or of construction of effective seals. Impounding of these vast quantities of water represents potential future hazards that must be considered when recommending that flooding be achieved. These hazards need to be more clearly defined and a program must be established by a responsible government agency to ensure that catastrophic events will not occur. Such events might include future construction projects that would break into a flooded mine, thereby releasing the impounded water, and possibly resulting in excessive stream pollution or even death and destruction.

Work Tasks:

(1) The Bureau of Mines should implement a continuing program to map those mines where flooding has occurred and as it occurs in the future. This program should include periodic monitoring of the sites to ensure that catastrophic events will not result from surface or underground activities that might interfere with the integrity of the system. If the Bureau or other government agency is unwilling to accept this responsibility, then flooding should be limited to small (to be defined by research) mines and/or mines with a relatively low (to be defined by research) hydrostatic head.

(2) Determine the effect of flooding on ground water quality and the general ground water hydrology.

(3) Establish a program to monitor several recently (within the last ten years) completed mine-sealing projects. Funds to provide continuous or even periodic monitoring of many of these sites are not currently available. Such a study is necessary to reliably evaluate the sealing procedures used to determine their long-term effectiveness in minimizing acid mine drainage pollution and their durability. Funds should also be made available for maintenance of the structures during the study period.

(4) Evaluate and define the potential dangers that would result from the accidental release of water impounded in a flooded mine. Such a study should define the activities that would cause the release and should consider restrictions on the hydrostatic head and volumes of water impounded.

Applicability:

Results will be applicable to new mines opened in coal seams that represent approximately 25 percent of the reserves in Northern Appalachia and 10 percent of the reserves in Southern Appalachia.

Duration and Cost:

See Table 17.

## E. PROJECT 17. INVESTIGATE THE EFFECTIVENESS OF SECTION SEALING IN ACTIVE MINES

Objective:

To determine if section sealing is an effective "at-source" abatement technique.

Work Tasks:

(1) Evaluate the effects and cost effectiveness of partial or complete flooding of sections of mines on the quality and quantity of the mine water produced. Design criteria should be established for the construction of the various impoundment mechanisms used and the size of pillars that must be left in place. Such mechanisms would range from simple retention dams to hydraulic seals.

(2) Evaluate the effects of section air sealing on the quality of water produced. Since significant reduction in oxygen content has been shown to partially inhibit acid formation, this type of sealing might have application in deeper mines where the overburden is not fractured to the surface.

Applicability:

All mines in seams that produce acid mine water.

Sequential Restraints:

Work on developing design criteria should not begin until effectiveness of methodology is established. Variances to restrictions imposed by ventilation requirements must be obtained prior to initiation of all work.

Duration and Cost:

See Table 17.

It is also recommended that the Bureau actively pursue projects (5) Develop a Simple Model for Predicting Mine Water Quality and Quantity, (12) Prepare a Manual on Mine Drainage Abatement Procedures, and (13) Develop a Program to Disseminate Information on Mine Drainage Abatement to Coal Industry. These projects would not result in the development of "at-source" abatement techniques but they would be of immediate value to the industry in that wider application of available "at-source" techniques would result.

## F. PROJECT 5, DEVELOP A SIMPLE MODEL FOR PREDICTING MINE WATER QUALITY AND QUANTITY

### Objective:

To provide the coal industry with the technology that will enable them to fairly accurately forecast the quality and quantity of mine water that a planned mine will generate. As the technical and financial resources of most companies are limited, the model should be simple and should not require the use of a computer. Availability of the model will be cost effective as the size of required treatment plants can be more accurately determined and the need for planned "at-source" abatement procedures will be demonstrated.

### Applicability:

All new underground mines during the planning stages.

### Sequential Restraints:

Some difficulties will occur in demonstrating the reliability of such a model. If some degree of success cannot be obtained during the first two years of the project, it should be dropped.

### Duration and Cost:

See Table 17.

## G. PROJECT 12, PREPARE A MANUAL ON MINE DRAINAGE ABATEMENT PROCEDURES

### Objective:

To make the entire industry aware of the availability of abatement procedures and to provide sufficient design criteria that will permit their implementation. Most large companies employ an adequate staff of environmental personnel who are knowledgeable of such procedures. This information is not currently available in a concise, easily-understood form and, as a result, abatement procedures have not beem implemented by many of the smaller operators. Such a manual is necessary to enable the total industry to implement the presently-available technology and, through periodic updates, will provide information concerning new technology that will be developed by the Bureau and others.

### Applicability:

All presently active and future mines that have potential acid mine drainage problems or will benefit from reduced pumping requirements.

### Sequential Restraints:

The manual should be prepared upon completion of Project 10, Task 1, and should be updated as new or improved technology becomes available.

Duration and Cost:

See Table 17.

## H. PROJECT 13, DEVELOP A PROGRAM TO DISSEMINATE INFORMATION ON MINE DRAINAGE ABATEMENT TO COAL INDUSTRY

Objective:

To establish an information-transfer program that will result in the implementation of "at-source" abatement. It is envisaged that such a program could be conducted by the Bureau's State Liaison Officers. Whatever the designated office, it should actively interface with the industry and should be in the position of providing complete information concerning all aspects of the mine-drainage problem within the specified state or district. Such a program must be established as it is recognized that availability of technology does not ensure implementation.

Applicability:

This program eventually should address mine-water problems other than acid and should not be limited to underground mines. It would then be of value to the entire industry.

Sequential Restraints:

If some type of information-transfer program is not established, it is doubtful if widespread implementation of "at-source" controls will be established. The overall value of the Bureau of Mines' involvement in mine drainage abatement would be significantly reduced and, in this respect, all proposed projects should be critically reviewed before being pursued.

Duration and Cost:

See Table 17.

TABLE 17. PROJECT WORK SCHEDULE AND ANTICIPATED MINIMUM COSTS

| | 1st Year | 2nd Year | 3rd Year | 4th Year | 5th Year | Additional Time Needed | Cost |
|---|---|---|---|---|---|---|---|
| 6. Develop Mine Closure Technology | | | | | | | |
| 1. Coal Barrier Specifications | | ▬ | ▬ | ▬ | ▬ | | 200,000 |
| 2. Grouting Technology | | ▬ | ▬ | ▬ | ▬ | | 500,000 |
| 3. Mine Seal Design | | ▬ | ▬ | ▬ | ▬ | | 400,000 |
| 10. Develop Infiltration Controls | | | | | | | |
| 1. Guidelines and Design | ▬ | | | | | | 50,000 |
| 2. Pillar Size Specifications | ▬ | ▬ | | | | | 75,000 |
| 14. Effect of Roof Collapse | | | | | | | |
| 1. Effect on Mine Water Quality | ▬ | ▬ | ▬ | | | | 500,000 |
| 2. Examine Use of Inhibitors | | ▬ | ▬ | ▬ | | | 400,000 |
| 3. Mining Procedure Development | | | | ▬ | ▬ | | 100,000 |
| 16. Evaluation of Flooding | | | | | | | |
| 1. Maintenance and Monitoring | ▬ | ▬ | ▬ | ▬ | ▬ | 500 years | 250,000/yr |
| 2. Effect on Ground Water | ▬ | ▬ | | | | | 200,000 |
| 3. Evaluate Completed Projects | ▬ | ▬ | ▬ | ▬ | ▬ | 10 years | 250,000 |
| 4. Define Hazards | ▬ | | | | | | 75,000 |
| 17. Investigate Section Sealing | | | | | | | |
| 1. Evaluate Effects of Flooding | ▬ | ▬ | ▬ | | | | 450,000 |
| 2. Evaluate Air Sealing | | ▬ | ▬ | ▬ | ▬ | | 400,000 |
| 5. Develop Simple Predictive Model | ▬ | ▬ | ▬ | ▬ | | | 200,000 |
| 12. Prepare Procedure Manual | | ▬ | ▬ | ▬ | ▬ | | 50,000/update |
| 13. Maintain Information Transfer Program | ▬ | ▬ | ▬ | ▬ | ▬ | 20 years | 250,000/yr |

# V. References

1. "Abatement of pollution from abandoned mines in Pennsylvania: a progress report," Pa. Dept. Health, Sanit. Water Bd., Publ. No. 26 (Mar. 1, 1970). 33 pp. MD70-1

2. "Acid drainage," Business Week, No. 1364, 123 (Oct. 22, 1955). MD55-1

3. "Acid mine drainage," U.S. Public Health Serv., Rept. to U.S. House Representatives, Comm. Public Works, 87th Congr., 2nd Session, House Comm. Print No. 18 (1962). 32 pp. MD62-1

4. "Acid mine drainage abatement measures for selected areas within the Susquehanna River basin," Gannett Fleming Corddry & Carpenter, Inc., Engineers, Rept. to U.S. Dept. Int., Fed. Water Pollut. Contr. Admin. (1968). 99 pp.+ NTIS, PB-220 158/0. MD68-1

5. "Acid mine drainage formation and abatement," The Ohio State Univ. Res. Found., Rept. to U.S. EPA, WQO, Water Pollut. Contr. Res. Ser. 14010 FPR 04/71 (1971). 82 pp. NTIS, PB-199 835. MD71-3

6. "Acid mine drainage in Appalachia. Appendix B. Engineering economic study of mine drainage control techniques," Cyrus Wm. Rice and Co., Rept. to Appalachian Regional Comm. (1969). 281 pp. NTIS PB-243 098/1WN. MD69-28

7. "Acid mine drainage in Appalachia. Appendix C. The incidence and formation of mine drainage pollution," U.S. Army Corps Eng., U.S. Dept. Int., FWPCA, and Bur. Mines, Rept. to Appalachian Regional Comm. (1969). 411 pp. NTIS, PB-243 099/9WN. MD69-40

8. "Acid mine drainage: prevention, control, treatment; control case histories," Coal Age 74 (7), 183-194 (1969). MD69-3

9. "Acid mine drainage studies at Morgantown, West Virginia," U.S. Public Health Serv., Stream Pollution Invest. Sta., 1941. 52 pp.+ MD41-1

10. "Acid mine drainage survey - East Branch Clarion River watershed Elk and McKean Counties," Michael Baker, Jr., Inc., Rept. to Pa. Dept. Mines Miner. Ind., Proj. No. SL-108 (1970). 379 pp. MD70-2

11. "Acid mine water + limestone = clean stream," Coal Age 74 (2), 112-114 (1969). MD69-4

12. Agnew, A. F. and Corbett, D. M. (Ind. Univ.), "Hydrology and chemistry of coal-mine drainage in Indiana," ACS Div. Fuel Chem. Preprints 13 (2), 137-149 (1969). MD69-5

13. Ahmad, M. U. (Ohio Univ.), "Coal mining and its effect on water quality," Water Resour. Problems Related to Mining, Am. Water Resour. Assoc., Proc. No. 18, June 1974. pp 138-148. MD74-3

14. Ahmad, M. U. (Ohio Univ.), "A hydrological approach to control acid mine pollution," Acid Mine Drainage Workshop, Athens, Ohio, by Ohio Univ., 1971. 25 pp. MD71-8

15. Ahmad, M. U. (Ohio Univ.), "A hydrological approach to control acid mine pollution for Lake Hope," Ground Water 8 (6), 19-24 (1970). MD70-3

16. Akers, D. J., Jr. and Lawrence, W. F., "Acid mine drainage control methods," W. Va. Univ., Coal Res. Bur., Morgantown, W. Va., Rept. No. 86, 1973. 10 pp. (Presented SME of AIME, Chicago, Ill., Feb. 1973). MD73-2

17. "Alder Run watershed mine drainage study," Skelly & Loy, Engineers, Consultants, Rept. to Pa. Dept. Mines Miner. Ind., Proj. No. SL-143 (1970). 108 pp. MD70-5

18. Allgaier, G. J. and Hopkins, M. E., "Reserves of the Herrin (No. 6) coal in the Fairfield Basin in southeastern Illinois," Ill. State Geol. Surv., Circ. 489 (1975). 31 pp. 2 plates.

19. "Analyses of Alabama coals," U.S. Bur. Mines, Tech. Paper 347 (1925). 111 pp.

20. "Analyses of Arizona, California, Idaho, Nevada, and Oregon coals," U.S. Bur. Mines, Tech. Paper 696 (1947). 83 pp.

21. "Analyses of Arkansas coals," U.S. Bur. Mines, Tech. Paper 416 (1928). 26 pp.

22. "Analyses of Colorado coals," U.S. Bur. Mines, Tech. Paper 574 (1937). 327 pp.

23. "Analyses of Illinois coals," U.S. Bur. Mines, Tech. Paper 641 (1942). 245 pp.

24. "Analyses of Indiana coals," U.S. Bur. Mines, Tech. Paper 417 (1927). 50 pp.

25. "Analyses of Iowa coals," U.S. Bur. Mines, Tech. Paper 706 (1949). 65 pp.

26. "Analyses of Kansas coals," U.S. Bur. Mines, Tech. Paper 455 (1929). 52 pp.

27. "Analyses of Kentucky coals," U.S. Bur. Mines, Tech. Paper 652 (1944). 323 pp.

28. "Analyses of Maryland coals," U.S. Bur. Mines, Tech. Paper 465 (1930). 89 pp.

29. "Analyses of Michigan, North Dakota, South Dakota, and Texas coals," U.S. Bur. Mines, Tech. Paper 700 (1948). 106 pp.

30. "Analyses of Missouri coals," U.S. Bur. Mines, Tech. Paper 366 (1926). 41 pp.

31. "Analyses of Montana coals," U.S. Bur. Mines, Tech. Paper 529 (1932). 129 pp.

32. "Analyses of New Mexico coals," U.S. Bur. Mines, Tech. Paper 569 (1936). 112 pp.

33. "Analyses of Ohio coals," U.S. Bur. Mines, Tech. Paper 344 (1923). 40 pp.

34. "Analyses of Oklahoma coals," U.S. Bur. Mines, Tech. Paper 411 (1928). 62 pp.

35. "Analyses of Pennsylvania anthracitic coals," U.S. Bur. Mines, Tech. Paper 659 (1944). 271 pp.

36. "Analyses of Pennsylvania bituminous coals," U.S. Bur. Mines, Tech. Paper 590 (1939). 503 pp.

37. "Analyses of Tennessee coals," U.S. Bur. Mines, Tech. Paper 356 (1926). 94 pp.

38. "Analyses of Tennessee coals (including Georgia)," U.S. Bur. Mines, Tech. Paper 671 (1945). 243 pp.

39. "Analyses of tipple and delivered samples of coal: collected during fiscal year 1970," U.S. Bur. Mines, RI 7490 (1971). 20 pp.

40. "Analyses of tipple and delivered samples of coal: collected during fiscal year 1971," U.S. Bur. Mines, RI 7588 (1972). 20 pp.

41. "Analyses of Utah coals," U.S. Bur. Mines, Tech. Paper 345 (1924). 90 pp.

42. "Analyses of Virginia coals," U.S. Bur. Mines, Tech. Paper 365 (1926). 75 pp.

43. "Analyses of Virginia coals," U.S. Bur. Mines, Tech. Paper 656 (1944). 159 pp.

44. "Analyses of Washington coals," U.S. Bur. Mines, Tech. Paper 491 (1931). 203 pp.

45. "Analyses of Washington coals: supplement to Technical Paper 491," U.S. Bur. Mines, Tech. Paper 618 (1941). 81 pp.

46. "Analyses of West Virginia coals," U.S. Bur. Mines, Tech. Paper 405 (1928). 343 pp.

47. "Analyses of West Virginia coals," U.S. Bur. Mines, Tech. Paper 626 (1942). 341 pp.

48. "Analyses of Wyoming coals," U.S. Bur. Mines, Tech. Paper 484 (1931). 159 pp.

49. "Appalachia Program, water supply & water quality control needs, St. Petersburg Reservoir, Clarion River, Pennsylvania, Allegheny River basin," U.S. Dept. Int., FWPCA, Wheeling Field Station, Rept. to U.S. Dept. Army, Corps of Engineers--Appalachia Study, Pittsburgh, Pa., Dec. 1967. 57 pp. MD67-2

50. Aresco, S. J. and Haller, C. P., "Analyses of tipple and delivered samples of coal (collected during the fiscal year 1951)," U.S. Bur. Mines, RI 4934 (1953). 93 pp.

51. Aresco, S. J., Haller, C. P., and Abernethy, R. F., "Analyses of tipple and delivered samples of coal (collected during the fiscal year 1953)," U.S. Bur. Mines, RI 5085 (1955). 82 pp.

52. Aresco, S. J., Haller, C. P., and Abernethy, R. F., "Analyses of tipple and delivered samples of coal (collected during the fiscal year 1954)," U.S. Bur. Mines, RI 5221 (1956). 77 pp.

53. Aresco, S. J., Haller, C. P., and Abernethy, R. F., "Analyses of tipple and delivered samples of coal (collected during the fiscal year 1955)," U.S. Bur. Mines, RI 5270 (1956). 66 pp.

54. Aresco, S. J., Haller, C. P., and Abernethy, R. F., "Analyses of tipple and delivered samples of coal (collected during the fiscal year 1956)," U.S. Bur. Mines, RI 5332 (1957). 67 pp.

55. Aresco, S. J., Haller, C. P., and Abernethy, R. F., "Analyses of tipple and delivered samples of coal (collected during the fiscal year 1958)," U.S. Bur. Mines, RI 5489 (1959). 54 pp.

56. Aresco, S. J., Haller, C. P., and Abernethy, R. F., "Analyses of tipple and delivered samples of coal (collected during the fiscal year 1959)," U.S. Bur. Mines, RI 5615 (1960). 59 pp.

57. Aresco, S. J., Haller, C. P., and Abernethy, R. F., "Analyses of tipple and delivered samples of coal (collected during the fiscal year 1960)," U.S. Bur. Mines, RI 5792 (1961). 44 pp.

58. Aresco, S. J., Haller, C. P., and Abernethy, R. F., "Analyses of tipple and delivered samples of coal (collected during the fiscal year 1961)," U.S. Bur. Mines, RI 6086 (1962). 41 pp.

59. Aresco, S. J. and Janus, J. B., "Analyses of tipple and delivered samples of coal: collected during fiscal year 1966," U.S. Bur. Mines, RI 6904 (1967). 43 pp.

60. Aresco, S. J. and Janus, J. B., "Analyses of tipple and delivered samples of coal: collected during fiscal year 1967," U.S. Bur. Mines, RI 7104 (1968). 43 pp.

61. Aresco, S. J. and Janus, J. B., "Analyses of tipple and delivered samples of coal: collected during fiscal year 1968," U.S. Bur. Mines, RI 7219 (1969). 31 pp.

62. Aresco, S. J., Janus, J. B., and Walker, F. E., "Analyses of tipple and delivered samples of coal: collected during the fiscal year 1962," U.S. Bur. Mines, RI 6300 (1963). 46 pp.

63. Aresco, S. J., Janus, J. B., and Walker, F. E., "Analyses of tipple and delivered samples of coal: collected during the fiscal year 1963," U.S. Bur. Mines, RI 6461 (1964). 38 pp.

64. Aresco, S. J., Janus, J. B., and Walker, F. E., "Analyses of tipple and delivered samples of coal: collected during the fiscal year 1964," U.S. Bur. Mines, RI 6622 (1965). 38 pp.

65. Aresco, S. J., Janus, J. B., and Walker, F. E., "Analyses of tipple and delivered samples of coal: collected during the fiscal year 1965," U.S. Bur. Mines, RI 6792 (1966). 49 pp.

66. Arndt, H. H., Averitt, P., Dowd, J., Frendzel, D. J., and Gallo, P. A., "Coal," in "Mineral resources of the Appalachian region," U.S. Geol. Surv., Prof. Paper 580 (1968). pp. 102-133.

67. Ash, S. H., "Flood prevention and control in the anthracite region of Pennsylvania," Mining Congr. J. 32 (3), 32-34, 46 (1946). MD46-1

68. Ash, S. H., Cassap, W. E., Westfield, J., Eaton, W. L., Romischer, W. M., Podgorski, E. J., and Johnson, L. H., "Flood-prevention projects at Pennsylvania anthracite mines - progress report for 1945," U.S. Bur. Mines, RI 4109 (1947). 64 pp. MD47-1

69. Ash, S. H., Eaton, W. L., Hughes, K., Romischer, W. M., and Westfield, J., "Water pools in Pennsylvania anthracite mines," U.S. Bur. Mines, Tech. Paper 727 (1949). 78 pp. MD49-1

70. Ash, S.H., Felegy, E. W., Kennedy, D. O., and Miller, P. S., "Acid mine drainage problems, anthracite region of Pennsylvania," U.S. Bur. Mines, Bull. 508 (1951). 72 pp. MD51-1

71. Ash, S. H. and Westfield, J., "Flood-prevention projects at Pennsylvania anthracite mines - a preliminary study," U.S. Bur. Mines, RI 3868 (1946). 25 pp.+ MD46-3

72. Ashley, G. H., Toenges, A. L., Anderson, R. L., Rice, W. E., Stull, C. M., Snyder, N. H., Swingle, R. J., Cooper, H. M., and Abernethy, R. F., "Analyses of Pennsylvania bituminous coals," U.S. Bur. Mines, Tech. Paper 590 (1939). 503 pp.

73. Ashmead, D., "The influence of bacteria in the formation of acid mine waters," Part 1, Colliery Guardian 190, 694-698 (1955). Part 2, Colliery Guardian 192, 483-487 (1956). MD55-5, MD56-2

74. Averitt, P., "Coal resources of the United States, January 1, 1974," U.S. Geol. Surv., Bull. 1412 (1975). 131 pp.

75. Averitt, P., "Coking-coal deposits of the western United States," U.S. Geol. Surv., Bull. 1222-G (1966). 48 pp.

76. Averitt, P. and Lopez, L., "Bibliography and index of U.S. Geological Survey publications relating to coal, 1882-1970," U.S. Geol. Surv., Bull. 1377 (1972). 173 pp.

77. Baker, R. A., "Evaluation of pyritic oxidation by nuclear methods," Carnegie-Mellon Univ., Rept. to EPA, WQO, Water Pollut. Contr. Res. Ser. 14010 FII 03/71 (1971). 31 pp. NTIS, PB-198 523. MD71-11

78. Baker, R. A. and Wilshire, A. G., "Acid-mine drainage - pilot plant," Carnegie-Mellon Univ., Mellon Inst., Final Rept., Proj. 4447, to Appalachian Regional Comm. (Aug. 1, 1967 to Nov. 30, 1968). 59 pp. MD68-2

79. Baker, R. A. and Wilshire, A. G. (Carnegie-Mellon Univ.), "Evaluation of caulobacter as an inhibitor of acid mine drainage formation," Rept. to U.S. Dept. Interior, FWQA, Res. Grant 14010 DKN (July 1970). 13 pp. MD70-6

80. Baker, R. A. and Wilshire, A. G. (Carnegie-Mellon Univ.), "Evaluation of potential acid mine drainage," Water Sewage Works 117 (6), IW/10-16 (1970). MD70-7

81. Baker, R. A. and Wilshire, A. G., "Microbial factor in acid mine drainage formation: II further observations from a pilot plant study," Carnegie-Mellon Univ., Rept. to U.S. Dept. Int., FWQA, Water Pollut. Contr. Res. Ser. 14010 DKN 11/70 (1970). 68 pp. NTIS, PB-196 113. MD70-9

82. Baker, R. A. and Wilshire, A. G. (Carnegie-Mellon Univ.), "Microbiological factor in acid mine drainage formation: Part II - further observations from a pilot plant study," Sci. Total Environ. 1, 411-426 (1972/1973). MD73-7

83. Baker, R. A. and Wilshire, A. G. (Carnegie-Mellon Univ.), "Microbiological factor in acid mine drainage formation: a pilot plant study," Environ. Sci. Technol. 4 (5), 401-407 (1970). MD70-8

84. Barnes, H. L. (1) and Romberger, S. B. (2) [(1) Pa. State Univ. and (2) Mich. State Univ.], "Chemical aspects of acid mine drainage," J. Water Pollut. Contr. Fed. 40 (3-Pt. 1), 371-384 (1968). MD68-3

85. Barnes, I., "Selected properties of mine water and the chemical environment within some flooded anthracite mines," Symp. Acid Mine Drainage Res. Preprints, Pittsburgh, Pa., 1965. pp 1-9. MD65-1

86. Barnes, I. and Clarke, F. E., "Geochemistry of ground water in mine drainage problems," U.S. Geol. Surv., Prof. Paper 473-A (1964). 6 pp. MD64-1

87. Barnes, I., Stuart, W. T., and Fisher, D. W., "Field investigation of mine waters in the northern anthracite field, Pennsylvania," U.S. Geol. Surv., Prof. Paper 473-B (1964). 7 pp. MD64-2

88. Barry, A. J. and Wojciechowski, J. J., "Roof movement study of mechanized retreating longwall operation, Lanashire No. 15 Mine, Bakerton, Cambria County, Pa.," U.S. Bur. Mines, RI 5028 (1954). 13 pp.

89. Barthauer, G. L., "Practical aspects of mine drainage control and treatment," AIME Ann. Meet., Los Angeles, Calif., Feb. 1967. Preprint No. 67F72. 19 pp. MD67-6

90. Beafore, F. J. (Consolidation Coal Co.), "Tour of Mountaineer Division operations - August 4, 1971," Acid Mine Drainage Workshop, Athens, Ohio, by Ohio Univ., 1971. 7 pp. MD71-14

91. Beall, R. M., "Guide to the availability of hydrologic data, greater Pittsburgh region, Pennsylvania," U.S. Geol. Surv., open-file rept. 76-352 (1976). 12 pp.+

92. Beall, R. M., "Mean annual runoff in the upper Ohio River basin, 1941-70, and its historic variation," U.S. Geol. Surv., open-file rept. 76-384 (1976). 41 pp.+

93. Beall, R. M., "Selected streamflow experience graphs for southwestern Pennsylvania," U.S. Geol. Surv., open-file rept., Apr. 1976. 40 pp.

94. Beall, R. M., "Stream reconnaissance for nutrients and other water-quality parameters, greater Pittsburgh region, Pennsylvania," U.S. Geol. Surv., Water-Resour. Invest. 50-74 (1975). 47 pp.+

95. Bell, W. E., "Studies of the effect of gas atmospheres on pyrite oxidation," Cyrus Wm. Rice & Co., Rept. to U.S. Dept. Int., FWPCA, April 1969. 58 pp. MD69-7

96. Bell, W. E. and Escher, E. D. (Cyrus Wm. Rice & Co.), "A study of inert gas atmospheres on the oxidation of coal mine pyrites," ACS Div. Fuel Chem. Preprints 13 (2), 42-49 (1969). MD69-8

97. Bellano, W., "An operator looks at acid mine drainage," Mining Congr. J. 50 (8), 66-74 (1964). MD64-3

98. Berman, D. and Stratakis, N., "Auger mine drainage study," Green Eng. Co., Rept. to Pa. Dept. Mines Miner. Ind., Coal Res. Board, CR-97 (1969). 74 pp. MD69-10

99. Berryhill, H. L., Jr., "Coal reserves of the Pittsburgh (No. 8) bed in Belmont County, Ohio," U.S. Geol. Surv., Circ. 363 (1955). 11 pp.

100. Berryhill, H. L., Jr., Brown, D. M., Brown, A., and Taylor, D. A., "Coal resources of Wyoming," U.S. Geol. Surv., Circ. 81 (1950). 78 pp.

101. Biemel, G. D., "Watershed evaluation and data needs for hydrologic and acid mine drainage modeling," M. S. Thesis, Ohio State Univ., 1975. 98 pp. MD75-3

102. Biesecker, J. E. and George, J. R., "Stream quality in Appalachia as related to coal-mine drainage, 1965," U.S. Geol. Surv., Circ. 526, 1966. 27 pp.+ MD66-5

103. Biesecker, J. E., Lescinsky, J. B., and Wood, C. R., "Water resources of the Schuylkill River basin," Pa. Dept. Forests Waters, Water Resour. Bull. No. 3 (1968). 198 pp. MD68-5

104. Birch, J. J. (Barnes and Tucker Co.), "Application of mine drainage control methods," Second Symp. Coal Mine Drainage Res. Preprints, Pittsburgh, Pa., 1968. pp 372-375. MD68-6

105. Birch, J. J., "Pumping acid mine water from the West Branch of the Susquehanna River into an abandoned mine to improve the alkalinity content," Barnes and Tucker Co., Rept. to Pa. Coal Res. Bd., Dec. 11, 1967. 25 pp. MD67-7

106. "Bituminous coal mining laws of Pennsylvania for strip mines: including rules and regulations and procedures," with amendments through 1970, compiled by Pa. Dept. Mines Miner. Ind.

107. "Bituminous coal mining laws of Pennsylvania for underground mines," compiled by Pa. Dept. Mines Miner. Ind., 1961. 231 pp.

108. Blakeley, A. G., "Chemistry in coal mining," Coal Age 10 (8), 296-302 (1916). MD16-1

109. Blaylock, D. W., Dowd, J. J., Abernethy, R. F., and Reynolds, D. A., "Estimate of known recoverable reserves of coking coal in Clarion County, Pa.," U.S. Bur. Mines, RI 5231 (1956). 27 pp.

110. Blaylock, D. W., Dowd, J. J., Abernethy, R. F., and Reynolds, D. A., "Estimate of known recoverable reserves of coking coal in Clearfield County, Pa.," U.S. Bur. Mines, RI 5166 (1955). 36 pp.

111. Bloom, D. N. (1), Jennings, L. D. (1), and Bisque, R. E. (2) [(1) Earth Sciences, Inc., (2) Colo. School Mines], "In-situ treatment of sulfide minerals to reduce acid drainage," AIChE Meet., Houston, Tex., Apr. 24-25, 1969. 5 pp. MD69-11

112. Bohor, B. F. and Gluskoter, H. J., "Boron in illite as an indicator of paleosalinity of Illinois coals," J. Sed. Petrol. 43 (4), 945-956 (1973). Ill. State Geol. Surv., Reprint Ser. 1974D.

113. Bolstad, D. D., Allredge, J. R., and Mahtab, M. A., "Procedures used for sampling fracture orientations in an underground coal mine," U.S. Bur. Mines, RI 7763 (1973). 9 pp.

114. "Bond issue report," Land and Water Conservation and Reclamation Fund, Pa. Dept. Environ. Resour., Office Resour. Management, Period ending June 1976. 118 pp.

115. Boyer, J. F., Jr. (Bitum. Coal Res., Inc.), "Status of coal mine drainage control technology," Coal Mining & Process. 9 (1), 56-59 (1972). MD72-2

116. Brady, G. A. and Griffiths, H. H., "Properties of anthracite from the Bottom Ross bed," U.S. Bur. Mines, RI 7086 (1968). 29 pp.

117. Braley, S. A., "Acid drainage from coal mines," Trans. AIME 190, 703-708 (1951). MD51-2

118. Braley, S. A., "Acid mine drainage. I. The problem," Mechanization 18 (1), 87-89 (1954). MD54-3

119. Braley, S. A., "Acid mine drainage. II. Sources," Mechanization 18 (2), 113-115 (1954). MD54-4

120. Braley, S. A., "Acid mine drainage. III. Sampling and analysis," Mechanization 18 (3), 96-98 (1954). MD54-5

121. Braley, S. A., "Acid mine drainage. IV. Composition and flow," Mechanization 18 (4), 137-138 (1954). MD54-6

122. Braley, S. A., "Acid mine drainage. V. Control of mine acid," Mechanization 18 (5), 97-98 (1954). MD54-7

123. Braley, S. A., "Acid mine drainage. VI. Control of oxidation," Mechanization 18 (6), 105-107 (1954). MD54-8

124. Braley, S. A., "Annual Summary Report of Commonwealth of Pennsylvania Department of Health, Industrial Fellowship No. 4 (Aug. 20, 1949 to Aug. 20, 1950)," Mellon Inst., Fellowship No. 362B (1950). 57 pp. MD50-4

125. Braley, S. A., "Coal mine effluents," Symp. Fossil Fuels Environ. Pollut., ACS Div. Fuel Chem., Pittsburgh, 1966. 11 pp. MD66-6

126. Braley, S. A., "An evaluation of mine sealing," Mellon Inst., Spec. Rept. to Coal Ind. Advisory Comm. to Ohio River Valley Water Sanit. Comm., Res. Proj. No. 370-8, 1962. 33 pp.+ MD62-4

127. Braley, S. A., "Evaluation of mine drainage water," Trans. AIME 208, 76-78 (1957). MD57-3

128. Braley, S. A., "Flooding of a deep mine," Mellon Inst., Spec. Rept. to Coal Ind. Advisory Comm., Ohio River Valley Water Sanit. Comm., Res. Proj. No. 4370-8, 1962. 10 pp.+ MD62-5

129. Braley, S. A., "The Humphrey project," Symp. Acid Mine Drainage Res. Preprints, Pittsburgh, Pa., 1965. pp 167-173. MD65-4

130. Braley, S. A., "Mine acid control," Mellon Inst., Spec. Summary Rept., to Pa. Dept. Health, Ind. Fellowship No. 326B-6, 1952. 22 pp. MD52-3

131. Braley, S. A., "Mine acid control: a new approach," Coal Age 62 (3), 68-69 (1957). MD57-4

132. Braley, S. A., "Natural beneficiation of an abandoned mine," Mellon Inst., Spec. Rept. to Coal Ind. Advisory Comm., Ohio River Valley Water Sanit. Comm., Res. Proj. No. 4370-8, 1962. 5 pp. MD62-6

133. Braley, S. A., "The oxidation of pyritic conglomerates," Reprinted from Ind. Wastes, Aug. 1960. 3 pp. MD60-3

134. Braley, S. A., "Quarterly Reports of Coal Advisory Committee to the Ohio River Valley Water Sanitation Commission, Fellowship No. 370-4," Mellon Inst., 4 Quarterly Repts., 1958. MD58-1

135. Braley, S. A., "Quarterly Reports of Coal Advisory Committee to the Ohio River Valley Water Sanitation Commission, Fellowship No. 370-5," Mellon Inst., 4 Quarterly Repts., 1959. 16 pp. MD59-2

136. Braley, S. A., "Summary Report of Commonwealth of Pennsylvania (Department of Health) Industrial Fellowship Nos. 1 to 7 incl.," Mellon Inst. Fellowship No. 326B (1954). 279 pp. MD54-10

137. Braley, S. A., "Truth and fallacy about a serious problem: acid coal mine drainage," Trans. AIME 205, 314-318 (1956). MD56-4

138. Brant, R. A., "Coal resources of the upper part of the Allegheny formation in Ohio," Ohio Geol. Surv., RI No. 29 (1956). 68 pp.

139. Brant, R. A., "The Lower Kittanning No. 5 coal bed in Ohio," Ohio Geol. Surv., RI No. 21 (1954). 59 pp.

140. Brant, R. A. and DeLong, R. M., "Coal resources of Ohio," Ohio Geol. Surv., Bull. 58 (1960). 245 pp.

141. Brant, R. A. and Moulton, E. Q., "Acid mine drainage manual," Ohio State Univ., Eng. Expt. Sta., Bull. 179 (1960). 40 pp. MD 60-7

142. Briggs, R. P., "Guide to selected large-scale geologic maps of southwestern Pennsylvania," U.S. Geol. Surv., open file rept., 1973. 26 pp.+

143. Brown, A., Berryhill, H. L., Jr., Taylor, D. A., and Trumbull, J. V. A., "Coal resources of Virginia," U.S. Geol. Surv., Circ. 171 (1952). 57 pp. 3 plates.

144. Brown, R. L. and Parizek, R. R., "Shallow ground-water flow systems beneath strip and deep coal mines at two sites, Clearfield County, Pennsylvania," Pa. State Univ., Spec. Res. Rept. SR-84 to Pa. Dept. Environ. Resour. (May 1, 1971). 216 pp. MD71-21

145. Brown, T. S. and Long, B. W., "Neutralization and precoat filtration of concentrated sludge from acid mine water at the Rushton Mining Company in Osceola Mills, Pa. Project CR-82," Johns-Manville Prod. Corp., Res. Eng. Center, Rept. No. E412-8087-S1 to Pa. Coal Res. Bd. (Nov. 3, 1969). 16 pp. MD69-16

146. Brownocker, J. A., Lord, N. W., and Somermeier, E. E., "Coal: Part 1, Coals of the Monongahela formation or upper productive coal measures; Part 2, Chemical analyses and calorific tests of the Clarion, Lower Kittanning, Middle Kittanning and Upper Freeport coals," Ohio Geol. Surv., Fourth Ser., Bull. 9 (1908). 342 pp.

147. Bryner, L. C. and Jameson, A. K., "Micro-organisms in leaching sulfide minerals," Appl. Microbiol. 6 (4), 281-287 (1958).

148. Burke, S. P. and Downs, R., "Oxidation of pyritic sulfur in coal mines," Trans. AIME 130, 425-444 (1938). Also published as AIME Tech. Publ. 769 (1937). 20 pp. MD38-1

149. Bushnell, K., "Map showing areas that correlate with subsidence events due to underground mining of the Pittsburgh and Upper Freeport coal beds," U.S. Geol. Surv., Misc. Field Studies, Map MF693C (1975). 1 plate.

150. Bushnell, K., "Map showing depths to the Pittsburgh coal bed, mining activity, and related surface subsidence," U.S. Geol. Surv., Misc. Field Studies, Map MF693A (1975). 1 plate.

151. Bushnell, K. and Peak, R. J., "Map showing depths to the Upper Freeport coal bed, mining activity, and related surface subsidence and Redstone coal bed mines," U.S. Geol. Surv., Misc. Field Studies, Map MF693B (1975). 1 plate.

152. Cady, G. H., "Classification and selection of Illinois coals," Ill. State Geol. Surv., Bull. 62 (1935). 354 pp.

153. Cady, G. H. and Smith, G. E., "Petrographic constitution of the Meigs Creek No. 9 coal bed," Ohio Geol. Surv., RI No. 27 (1955). 97 pp.

154. Campbell, M. R., *et al*., "The Valley coal fields of Virginia," Va. Geol. Surv., Bull. No. XXV (1925). 322 pp. 1 plate in pocket.

155. Carpenter, L. V. and Davidson, A. H., "Developments in the treatment of acid mine drainage," Proc. Va. Acad. Sci. 4, 93-99 (1930). MD30-2

156. Carpenter, L. V. and Herndon, L. K., "Acid mine drainage from bituminous coal mines," W. Va. Univ., Eng. Expt. Stat., Res. Bull. 10, (1933). 38 pp. MD33-1

157. Caruccio, F. T., "Characterization of strip-mine drainage by pyrite grain size and chemical quality of existing groundwater," in "Ecology and Reclamation of Devastated Land," Vol. 1, R. J. Hutnik and G. Davis, Ed., New York: Gordon and Breach, 1973. pp 193-226. MD73-18

158. Caruccio, F. T. (Pa. State Univ.), "An evaluation of factors affecting acid mine drainage production and the ground water interactions in selected areas of western Pennsylvania," Second Symp. Coal Mine Drainage Res. Preprints, Pittsburgh, Pa., 1968. pp 107-151. MD68-13

159. Caruccio, F. T., "The quantification of reactive pyrite by grain size distribution," Third Symp. Coal Mine Drainage Res. Preprints, Pittsburgh, Pa. (1970). pp 123-131. MD70-15

160. Caruccio, F. T. (Univ. South Carolina), "Trace element distribution in reactive and inert pyrite," Fourth Symp. Coal Mine Drainage Res. Preprints, Pittsburgh, Pa. (1972). pp 48-54. MD72-5

161. Caruccio, F. T. and Ferm, J. C. (Univ. S.C.), "Paleoenvironment - predictor of acid mine drainage problems," Natl. Coal Assoc./Bitum. Coal Res., Inc., Fifth Symp. Coal Mine Drainage Res. Preprints, Louisville, Ky. (1974). pp. 5-10. MD74-12

162. Carruccio, F. T. and Parizek, R. R., "An evaluation of factors influencing acid mine drainage production from various strata of the Allegheny Group and the ground water interactions in selected areas of western Pennsylvania," Pa. State Univ., Dept. Geol. Geophysics, SR-65, Rept. to Pa. Coal Res. Bd. (1967). 213 pp.+ MD67-11

163. Cavallaro, J. A., Johnston, M. T., and Deurbrouck, A. W., "Sulfur reduction potential of the coals of the United States: a revision of Report of Investigations 7633," U.S. Bur. Mines, RI 8118 (1976). 323 pp.

164. Cavallaro, J. A. and Van Eck, O. J., "Preparation characteristics and desulfurization potential of Iowa coals," U.S. Bur. Mines, RI 7830 (1973). 32 pp.

165. Chapman, C. L., "Progress in mine sealing," W. Va. Univ., Eng. Expt. Sta., Tech. Bull. No. 11, 79-85 (1938). MD38-2

166. Charmbury, H. B., Buscavage, J. J., and Maneval, D. R. (Pa. Dept. Mines Miner. Ind.), "Pennsylvania's abandoned mine drainage pollution abatement program," Second Symp. Coal Mine Drainage Res. Preprints, Pittsburgh, Pa., 1968. 319-333. MD68-14

167. Charnego, M. R., "The use of biocides as inhibitors of the respiration rate of *Ferrobacillus ferrooxidans*," M.Ed. Thesis, Ind. Univ. of Pa., 1967. 57 pp.

168. "Chartiers Creek mine drainage pollution abatement project," Ackenheil & Assoc., Inc., SL-102 Phase III Rept. to Pa. Dept. Mines Miner. Ind. (1970). 272 pp. MD70-16

169. "Chemical grout prevents water inflow," reprinted from Coal Age, Sept. 1962. 1 pp.

170. "The Cherry Creek-Casselman River environmental improvement plan," Md. Dept. Natural Resour., Rept. to Appalachian Regional Comm., Jan. 1974. 62 pp. MD74-13

171. "Christopher attacks mine-drainage problem," Coal Age *74* (9), 80-82 (1969). MD69-18

172. Chung, N. K., "Investigation of use of gel material for mine sealing," Dravo Corp., Rept. to EPA, Environ. Protection Technol. Ser. EPA-R2-73-135 (Jan. 1973). 67 pp. NTIS, PB-221 247. MD73-19

173. "Clarion River acid mine drainage abatement program, Pennsylvania," U.S. Dept. Army, Washington, D.C., Draft Environ. Impact Statement, May 1972. 15 pp. NTIS, EIS-PA-72-4585-D. MD72-7

174. Clark, C. S., "A basic study of acid mine drainage formation," M.S. Thesis, Johns Hopkins Univ., 1962. 96 pp. MD62-7

175. Clark, C. S., "Mine acid formation and mine acid pollution control," Proc. 5th Ann. Symp. Ind. Waste Contr., by Frostburg State College and Md. Water Pollut. Contr. Comm., Frostburg, Md., 1964. pp 50-73. MD64-5

176. Clark, C. S., "The oxidation of coal mine pyrite," Ph.D. Thesis, Johns Hopkins Univ., 1965. 90 pp. MD65-9

177. Clark, C. S., "Oxidation of coal mine pyrite," J. Sanit. Eng. Div., Amer. Soc. Civil Eng. 92 (SA 2), 127-145 (1966). MD66-8

178. Clark, C. S., "Some factors involved in the oxidation of coal mine pyrite and water quality trends in the Monongahela River basin," Symp. Acid Mine Drainage Res. Preprints, Pittsburgh, Pa., 1965. pp 35-50. MD65-10

179. "Clear, alkaline run-off is J&L's goal in water-treatment plan," Coal Age 72 (8), 70-74 (1967). MD67-14

180. Clegg, K. E., "Subsurface geology and coal resources of the Pennsylvanian System in DeWitt, McLean and Platt Counties, Ill.," Ill. State Geol. Surv., Circ. 473 (1972). 25 pp. 4 plates.

181. Clifford, J. E. and Snavely, C. A., "Studies of acid mine waters with particular reference to the Raccoon Creek watershed," Battelle Memorial Inst., Rept. to Ohio Dept. Natural Resour., Div. Wildlife, 1954. 134 pp.+ MD54-11

182. "Coal data: 1975 edition," National Coal Assoc., Washington, D.C., 1976. 146 pp.

183. "Coal mine drainage," Pa. Dept. Health, Bur. Sanit. Eng., Bull. No. 104 (1951). 24 pp. MD51-4

184. "Coal mine drainage in the Susquehanna River basin," Skelly and Loy, Engineers, Consultants, Rept. to Susquehanna River Basin Comm., Sept. 1973. 297 pp. MD73-20

185. Cole, W. A., Grosh, W. A., and Stehlik, C. J., "Iowa coals as a source of sulfur," U.S. Bur. Mines, RI 5362 (1957). 23 pp.

186. Coll, M. B., Jr. and Beall, R. M., "Map showing selected extreme-streamflow statistics and drainage areas, greater Pittsburgh region, Pennsylvania," U.S. Geol. Surv., open-file map rept. 76-350 (1976). 1 plate.

187. Colmer, A. R. and Hinkle, M. E. (W. Va. Univ.), "The role of microorganisms in acid mine drainage: a preliminary report," Science 106, 253-256 (1947). MD47-2

188. Colmer, A. R., Temple, K. L., and Hinkle, M. E., "An iron oxidizing bacterium from the acid drainage of some bituminous coal mines," J. Bacteriol. 59, 317-328 (1950). MD50-6

189. Confer, D. S., Kestner, D. W., Jr., and Charmbury, H. B., "The preparation characteristics of the bituminous coal reserves in Pennsylvania with special emphasis on sulfur reduction," Pa. State Univ., Dept. Miner. Prep., Rept. SR-35 to Pa. Coal Res. Bd. (Oct. 31, 1962). 108 pp.

190. "Control of acid drainage from coal mines," Pa. Sanit. Water Bd., 1952. 28 pp. MD52-5

191. "Cooperative mine drainage study--selected areas in the Clarion River basin," EPA, Office of Water Programs, Wheeling, W. Va., June 1971. 144 pp. + app. MD71-29

192. "Cooperative mine drainage survey - Kiskiminetas River basin," U.S. EPA, Wheeling Field Office, Apr. 1972. 313 pp. + app. MD72-10

193. Corbett, D. M., "Acid mine-drainage problem of the Patoka River watershed, southwestern Indiana," Ind. Univ., Water Resour. Res. Cent., Rept. Invest. No. 4 (1969). 173 pp.+ MD69-22

194. Corbett, R. G. and Growitz, D. J. (W. Va. Univ.), "Composition of water discharged from bituminous coal mines in northern West Virginia," Econ. Geol. 62, 848-851 (1967). MD67-17

195. Cortis, S. E., Alexander, T. B., Edmunds, W. E., and Craft, J. L., "Greater Pittsburgh region maps of mined-out areas and thickness of rock over the Pittsburgh coal," Pa. Geol. Surv., Map 45 (1975). 2 plates.

196. Cotton, E. R., "A preliminary report on a process for prevention of acid mine waters," Interstate Comm. Potomac River Basin, 1954. Unpublished. MD54-12

197. Craft, J. L., Heyman, L., and Piotrowski, R. G., "Greater Pittsburgh region thickness of rock over the Upper Freeport coal," Pa. Geol. Surv., Map 49 (1976). 1 plate.

198. Crentz, W. L., "Preparation characteristics of Illinois coals," U.S. Bur. Mines Tech. Paper 724 (1949). 112 pp.

199. Crentz, W. L., Bailey, A. L., and Miller, J. W., "Preparation characteristics of coal from Clearfield County, Pa.," U.S. Bur. Mines, RI 4894 (1952). 27 pp.

200. Crentz, W. L., Bailey, A. L., and Miller, J. W., "Preparation characteristics of coal from Fayette County, Pa.," U.S. Bur. Mines, RI 4815 (1951). 16 pp.

201. Crentz, W. L., Bailey, A. L., and Miller, J. W., "Preparation characteristics of coal from Somerset County, Pa.," U.S. Bur. Mines, RI 4834 (1951). 23 pp.

202. Crentz, W. L., Bailey, A. L., and Miller, J. W., "Preparation characteristics of coal occurring in Westmoreland County, Pa.," U.S. Bur. Mines, RI 4823 (1951). 17 pp.

203. Crentz, W. L. and Fraser, T., "Preparation characteristics of Maryland coals," U.S. Bur. Mines, Tech. Paper 701 (1947). 65 pp.

204. Crentz, W. L. and Miller, J. W., "Preparation characteristics of coal from Floyd County, Ky.," U.S. Bur. Mines, RI 4920 (1952). 21 pp.

205. Crentz, W. L. and Miller, J. W., "Preparation characteristics of coal from Jefferson County, Pa.," U.S. Bur. Mines, RI 4941 (1953). 21 pp.

206. Crentz, W. L. and Miller, J. W., "Preparation characteristics of coal from Knott County, Ky.," U.S. Bur. Mines, RI 4993 (1953). 30 pp.

207. Crentz, W. L. and Miller, J. W., "Preparation characteristics of coal from Pike County, Ky.," U.S. Bur. Mines, RI 4910 (1952). 28 pp.

208. Crentz, W. L. and Steele, F., "Preparation characteristics of coal occurring in Cambria County, Pa.," U.S. Bur. Mines, RI 4747 (1950). 40 pp.

209. Crentz, W. L., Steele, F., and Bailey, A. L., "Preparation characteristics of coal occurring in Armstrong County, Pa.," U.S. Bur. Mines, RI 4788 (1951). 25 pp.

210. Crentz, W. L., Steele, F., and Bailey, A. L., "Preparation characteristics of coal occurring in Indiana County, Pa.," U.S. Bur. Mines, RI 4763 (1951). 33 pp.

211. Cross, A. T., "The geology of the Pittsburgh coal: stratigraphy, petrology, origin and composition, and geologic interpretation of mining problems," Proc. Second Conf. Origin and Constitution of Coal, Crystal Cliffs, N. S., by Nova Scotia Dept. Mines and Nova Scotia Res. Found., June 18-20, 1952. pp 32-111.

212. Cross, A. T., "Pennsylvanian stratigraphy and sedimentation of the northern Appalachian region," Proc. Conf. Origin and Constitution of Coal, Crystal Cliffs, N.S., by Nova Scotia Dept. Mines and Nova Scotia Res. Found., June 21-23, 1950. pp 142-155.

213. Cross, A. T. and Schemel, M. P., "Some geological interpretations and the significance of certain plant microfossils in Pennsylvanian strata of the Ohio valley in northern West Virginia," (abstract), Proc. Third Conf. Origin and Constitution of Coal, Crystal Cliffs, N.S., by Nova Scotia Dept. Mines and Nova Scotia Res. Found., June 20-22, 1956. (1961). pp 295-296.

214. Crouse, H. L. and Gormley, J. T. (D'Appolonia Consulting Engineers, Inc.), "Research needs related to mining methodology for prevention or reduction of acid mine water," Presented, Acid Mine Water Research Needs Workshop, Morgantown, W. Va., Nov. 10-12, 1976. 14 pp.+

215. Culbertson, W. C., "Geology and coal resources of the coal-bearing rocks of Alabama," U.S. Geol. Surv., Bull. 1182-B (1964). 79 pp. 4 plates.

216. Cunningham, L. J. (Heath & Sherwood Chemical Grouting Ltd.), "The use of chemicals in mine grouting," Presented, 63rd Ann. Meet. Canadian Inst. Mining Met., Quebec City, March 22, 1961. 8 pp.

217. Damberger, H. H., "Coalification pattern of the Illinois basin," Econ. Geol. 66, 488-494 (1971). Ill. State Geol. Surv., Reprint Set. 1971D.

218. Damberger, H. H., "Coalification patterns of Pennsylvanian coal basins of the eastern United States," Geol. Soc. Amer., Spec. Paper 153 (1974). pp 53-74. Ill. State Geol. Surv., Reprint Ser. 1974R.

219. Darkes, W. F., Jr., Charmbury, H. B., and Maneval, D. R., "Final report: experimental research project in the treatment of mine drainage - Harwick Mine of Duquesne Light Company Monarch Shaft - Indiana Township Allegheny County, Pennsylvania," Pa. Dept. Mines Miner. Ind., Jan. 1971. 20 pp. MD71-35

220. Davies, W. E., Pomeroy, J. S., and Kohl, W. R., "Map of coal-mining features, Allegheny County, Pennsylvania," U.S. Geol. Surv., Misc. Field Studies, Map MF-685C (1976). 2 plates.

221. Davis, D. H. and Griffin, J., "The Pittsburgh coal seam in Pennsylvania - its reserves, qualities and beneficiation," Trans. AIME 157, 22-66 (1944).

222. Davis, R. W., Plebuch, R. O., and Whitman, H. M., "Hydrology and geology of deep sandstone aquifers of Pennsylvanian age in part of the western coal field region, Kentucky," Ky. Geol. Surv., RI 15, Ser. X (1974). 26 pp. 11 plates.

223. DeBrosse, T. A., "Coal beds of the Conemaugh Formation in Ohio," Ohio Geol. Surv., RI No. 34 (1957). 33 pp.

224. DeCarlo, J. A., Sheridan, E. T., and Murphy, Z. E., "Sulfur content of United States coals," U.S. Bur. Mines, IC 8312 (1966). 44 pp.

225. "The deep-mining guidebook: mine-drainage methods and water handling equipment," Coal Age 71 (8), 214-217 (1966). MD66-15

226. "Deep-mining guidebook: mine drainage and pumping," Coal Age 66 (7), 211-213 (1961). MD61-6

227. DeLong, R. M., "Coal resources of the lower part of the Allegheny Formation in Ohio," Ohio Geol. Surv., RI No. 31 (1957). 43 pp.

228. DeLong, R. M., "The Pittsburgh No. 8 and Redstone No. 8A coal beds in Ohio," Ohio Geol. Surv., RI No. 26 (1955). 49 pp.

229. Denton, G. H., "Coal resources of the upper part of the Monongahela Formation and the Dunkard Group in Ohio," Ohio Geol. Surv., RI No. 38 (1960). 50 pp.

230. "Determination of estimated mean mine water quantity and quality from imperfect data and historical records," Vol I; "Results of standard mine data analyses," Vol. II; "Synthesized NSS (non-standard sources) time-load profiles," Vol. III; "Source rankings by acidity load," Vol. IV, Environ. Qual. Systems, Inc., Rept. to Appalachian Regional Comm., Jan. 1973. Vol. I, 166 pp.; Vol. II - IV, computer printouts. MD73-24

231. Deurbrouck, A. W., "Preparation characteristics of coal from Barbour County, W. Va.," U.S. Bur. Mines, RI 6707 (1965). 32 pp.

232. Deurbrouck, A. W., "Preparation characteristics of coal from Buchanan County, Va.," U.S. Bur. Mines, RI 6740 (1966). 49 pp.

233. Deurbrouck, A. W., "Preparation characteristics of coal from Fayette County, W. Va.," U.S. Bur. Mines, RI 6665 (1965). 52 pp.

234. Deurbrouck, A. W., "Preparation characteristics of coal from Hancock, Brooke, Ohio, and Marshall Counties, W. Va.," U.S. Bur. Mines, RI 6463 (1964). 34 pp.

235. Deurbrouck, A. W., "Preparation characteristics of coal from Mercer County, W. Va.," U.S. Bur. Mines, RI 6227 (1963). 23 pp.

236. Deurbrouck, A. W., "Preparation characteristics of coal from Randolph County, W. Va.," U.S. Bur. Mines, RI 6874 (1966). 30 pp.

237. Deurbrouck, A. W., "Preparation characteristics of coal from Russell County, Va.," U.S. Bur. Mines, RI 6342 (1963). 32 pp.

238. Deurbrouck, A. W., "Preparation characteristics of coal from Tazewell County, Va.," U.S. Bur. Mines, RI 6297 (1963). 31 pp.

239. Deurbrouck, A. W., "Preparation characteristics of coal from Upshur County, W. Va.," U.S. Bur. Mines, RI 7004 (1967). 32 pp.

240. Deurbrouck, A. W., "Preparation characteristics of coal from Webster County, W. Va.," U.S. Bur. Mines, RI 6825 (1966). 30 pp.

241. Deurbrouck, A. W., "Washability examinations of Colorado coals," U.S. Bur. Mines, RI 7467 (1970). 44 pp.

242. Deurbrouck, A. W., "Washability examinations of core samples of San Juan basin coals, New Mexico and Colorado," U.S. Bur. Mines, RI 7608 (1972). 26 pp.

243. Deurbrouck, A. W., "Washability examinations of Wyoming coals," U.S. Bur. Mines, RI 7525 (1971). 47 pp.

244. Diamond, W. P., McCulloch, C. M., and Bench, B. M., "Use of surface joint and photolinear data for predicting subsurface coal cleat orientation," U.S. Bur. Mines, RI 8120 (1976). 13 pp.

245. Dierks, H. A., Eaton, W. L., Whaite, R. H., and Moyer, F. T., "Mine water control program, anthracite region of Pennsylvania July, 1955 - December, 1961," U.S. Bur. Mines, IC 8115 (1962). 63 pp. MD62-11

246. Dougherty, M. T. (1), Moomau, H. F. (2), and Matis, J. R. (3) [(1) Ackenheil & Assoc. Geo Systems, Inc., (2) Potomac Eng. & Surveying, and (3) Md. Dept. Natur. Resour.], "Engineering and administrative problems--Deer Park day-lighting demonstration project," Natl. Coal Assoc./Bitum. Coal Res., Inc., Fifth Symp. Coal Mine Drainage Res. Preprints, Louisville, Ky. (1974). pp 70-87. MD74-20

247. Dowd, J. J., Provost, J. M., Abernethy, R. F., and Reynolds, D. A., "Estimate of known recoverable reserves of coking coal in Marshall, W. Va.," U.S. Bur. Mines, RI 5207 (1956). 21 pp.

248. Dowd, J. J., Provost, J. M., Abernethy, R. F., and Reynolds, D. A., "Estimate of known recoverable reserves of coking coal in Ohio County, W. Va.," U.S. Bur. Mines, RI 5171 (1955). 14 pp.

249. Dowd, J. J., Provost, J. M., Travis, R. G., Abernethy, R. F., and Reynolds, D. A., "Estimate of known recoverable reserves of coking coal in Brooke County, W. Va.," U.S. Bur. Mines, RI 5160 (1955). 17 pp.

250. Doyle, F. J. (Michael Baker, Jr., Inc.), "'Operation Scarlift' Project SL-108 AMD pollution of the East Branch of the Clarion River," Water Pollut. Contr. Assoc. Pa. Mag. 3 (1), 12-14 (1970). MD70-20

251. Doyle, F. J., Chen, C. Y., Malone, R. D., and Rapp, J. R., "Investigation of mining related pollution reduction activities and economic incentives in the Monongahela River basin," Michael Baker, Jr., Inc., Rept. to Appalachian Regional Comm., ARC-72-89/RPC-707 (1975). 416 pp. NTIS, PB-244 352-1WN. MD75-7

252. Doyle, R. W. S., "Eh and thermodynamic equilibrium in environments containing dissolved ferrous iron," Ph.D. Thesis, Yale Univ., 1968. 100 pp. University Microfilms, Inc. 68-11,175.

253. Drake, C. F., "Effect of acid mine drainage on river water supply," J. Amer. Water Works Assoc. 23, 1474-1494 (1931). MD31-1

254. Draper, J. C. (Duquesne Light Co.), "Mine drainage treatment experience," Fourth Symp. Coal Mine Drainage Res. Preprints, Pittsburgh, Pa. (1972). pp 415-422. MD72-17

255. Dugan, P. R., "The role of microorganisms in formation and abatement of acid mine drainage," Proc. Second Ann. Symp. Water Resour. Res., "Water Quality and Recreation in Ohio," Ohio State Univ., Columbus, Ohio, June 15-16, 1966. pp 209-226. MD66-16

256. Dugan, P. R., Randles, C. I., Tuttle, J. H., McCoy, B., and MacMillan, C. (Water Resour. Cent.), "The microbial flora of acid mine water and its relationship to formation and removal of acid," Ohio State Univ., Res. Proj. Completion Rept., Proj. No. A-002-OHIO U.S. Dept. Int., Office Water Resour. Res., Oct. 1968. 132 pp. MD68-25

257. Duncan, D. W., Landesman, J., and Walden, C. C. (British Columbia Res. Council), "Role of Thiobacillus ferrooxidans in the oxidation of sulfide minerals," Can. J. Microbiol. 13, 397-403 (1967). MD67-23

258. Dutcher, R. R., Jones, E. B., Lovell, H. L., Parizek, R., and Stefanko, R., "Mine drainage, Part 1: abatement, disposal, treatment," Mineral Ind., Pa. State Univ. 36 (3), 1-7 (1966). MD66-17

259. Elder, C. H. and Deul, M., "Hydraulic stimulation increases degasification rate of coalbeds," U.S. Bur. Mines, RI 8047 (1975). 17 pp.

260. Elder, C. H., Jeran, P. W., and Keck, D. A., "Geologic structure analysis using radar imagery of the coal mining area of Buchanan County, Va.," U.S. Bur. Mines, RI 7869 (1974). 29 pp.

261. Emrich, G. H. and Thompson, D. R., "Some characteristics of drainage from deep bituminous mines in western Pennsylvania," Second Symp. Coal Mine Drainage Res. Preprints, Pittsburgh, Pa., 1968. pp 190-222. MD68-27

262. Englund, K. J., "Geology and coal resources of the Elk Valley area Tennessee and Kentucky," U.S. Geol. Surv., Prof. Paper 572 (1968). 59 pp. 11 plates.

263. "Environmental protection--a Consol objective since 1948," Coal Age 77 (10), 122-138 (1972). MD72-19

264. "Evaluation of pollution abatement techniques applicable to Lost Creek and Brown's Creek watershed, West Virginia," Ackenheil & Associates Geo Systems, Inc., Pittsburgh, Pa., Rept. to Appalachian Regional Commission, Washington, D.C., (undated). 71 pp.+ MD73-28

265. Everson, W. A. and Shearer, R. E., "Elimination of pollution in mine drainage," MSA Res. Corp., MSAR 67-111, Progr. Rept. No. 6, to Pa. Dept. Mines Miner. Ind., 1967. 30 pp. MD67-25

266. "Extent of coal mine drainage pollution: McMahon Creek watershed, Ohio," U.S. Dept. Int., FWQA, Upper Ohio Basin Office, Work Document No. 34 (1970). 38 pp. MD70-28

267. "Feasibility study Lake Hope mine drainage demonstration project," Ohio Dept. Natural Resour., Rept. to EPA, Environ. Protection Technol. Ser. EPA-R2-73-151 (March 1973). 97 pp. NTIS, PB-227 343. MD73-29

268. "Feasibility study manual - mine water pollution control demonstrations," Rept. by U.S. Dept. Int., FWQA, Water Pollut. Contr. Res. Ser. 14010 FLW 07/70 (1970). 65 pp. NTIS, PB-197 594. MD70-29

269. "Feasibility study of mining coal in an oxygen free atmosphere - a demonstration of a new mining technique to prevent the formation of mine acid in an active deep mine - Phase I," Island Creek Coal Co. and Cyrus Wm. Rice Div., NUS Corp., Rept. to U.S. Dept. Int., FWQA, Water Pollut. Contr. Res. Ser. 14010 DZM 08/70 (1970). 163 pp. NTIS, PB-197 446. MD70-30

270. "Feasibility study on the application of various grouting agents, techniques and methods to the abatement of mine drainage pollution. Part I. Exploration of mine sites and feasibility study on techniques of materials application," Halliburton Co., A. A. Baker, Project Manager, Rept. to U.S. Dept. Int., FWPCA, Monongahela River Mine Drainage Remedial Project, Aug. 9, 1967. 297 pp. MD67-3

271. "Feasibility study on the application of various grouting agents, techniques and methods to the abatement of mine drainage pollution. Part II. Selection and recommendation of twenty mine sites," Halliburton Co., A. A. Baker, Project Manager, Rept. to U.S. Dept. Int., FWPCA, Monongahela River Mine Drainage Remedial Project, Aug. 23, 1967. 286 pp. MD67-4

272. "Feasibility study on the application of various grouting agents, techniques and methods to the abatement of mine drainage pollution. Part III. Plans, specifications and schedules for remedial construction," Halliburton Co., A. A. Baker, Project Manager, Rept. to U.S. Dept. Int., FWPCA, Monongahela River Mine Drainage Remedial Project, Nov. 30, 1967. (323 pp.) MD67-5

273. "Feasibility study on the application of various grouting agents, techniques and methods to the abatement of mine drainage pollution. Part IV. Additional laboratory and field tests for evaluating and improving methods for abating mine drainage pollution," Halliburton Co., R. W. Wenzel, Project Manager, Final Rept. to U.S. Dept. Int., FWPCA, Monongahela River Mine Drainage Remedial Project, April 15, 1968. 236 pp. MD68-98

274. "Federal and state efforts to control water pollution caused by acid drainage from mines," Rept. by the Comptroller General of the United States, to the Conservation and Natural Resources Subcomm., Comm. Govern. Operations, U.S. House Representatives, B-177011 (Aug. 14, 1973). 61 pp. MD73-30

275. Felegy, E. W., Johnson, L. H., and Westfield, J., "Acid mine water in the anthracite region of Pennsylvania," U.S. Bur. Mines, Tech. Paper 710 (1948). 49 pp. MD48-2

276. Fellows, P. A., "Sealing projects - sharply reduce stream pollution from abandoned mines," Coal Age 42 (4), 158-161 (1937). MD37-1

277. Fisher, W., Jr. (HRB-Singer, Inc.), "Airborne infrared detection and mapping of coal mine drainage," Fourth Symp. Coal Mine Drainage Res. Preprints, Pittsburgh, Pa. (1972). pp 331-339. MD72-20

278. Flynn, J. P. (to Dow Chemical Co.), "Treatment of earth surface and subsurface for prevention of acidic drainage from the soil," U.S. Pat. 3,443,882 (May 13, 1969). 3 pp. MD69-29

279. Foreman, J. W. (Gwin, Dobson & Foreman, Inc.), "Deep mine sealing," Presented, Acid Mine Drainage Workshop, Athens, Ohio, by Ohio Univ., 1971. 27 pp. MD71-43

280. Foreman, J. W. (Gwin, Dobson & Foreman, Inc.), "Evaluation of mine sealing in Butler County, Pennsylvania," Fourth Symp. Coal Mine Drainage Res. Preprints, Pittsburgh, Pa. (1972). pp 83-95. MD72-22

281. Foreman, J. W. (Gwin Engineers, Inc.), "Evaluation of pollution abatement procedures in Moraine State Park," Third Symp. Coal Mine Drainage Res. Preprints, Pittsburgh, Pa. (1970). pp 304-333. MD70-32

282. Foreman, J. W. (Gwin, Dobson, Foreman, Inc.), "Mine sealing as a control method," Interstate Mining Compact Comm., Spring Meet., Pipestem, W. Va., by U.S. EPA, May 16, 1974. 12 pp. MD74-24

283. Foreman, J. W. (Gwin, Dobson & Foreman, Inc.), "A progress report--Evaluation of mine drainage abatement projects in western Pennsylvania," Natl. Coal Assoc./Bitum. Coal Res., Inc., Fifth Symp. Coal Mine Drainage Res. Preprints, Louisville, Ky. (1974). pp 128-132. MD74-25

284. Foreman, J. W. and McLean, D. C., "Evaluation of pollution abatement procedures, Moraine State Park," Gwin, Dobson & Foreman, Inc., Rept. to U.S. EPA, Environ. Protection Technol. Ser. EPA-R2-73-140 (Jan. 1973). 71 pp. NTIS, PB-221 337. MD73-32

285. Foreman, J. W. (1) and Tarr, E. G. (2) [(1) Gwin Engineers, Inc. and (2) Pa. Dept. Forest. Waters], "Moraine State Park mine drainage project," Second Symp. Coal Mine Drainage Res. Preprints, Pittsburgh, Pa., 1968. pp 246-254. MD68-29

286. Fraley, J. E. and Simpson, R. E., "Magnesium oxysulfate cement sealant in coal mines," U.S. Bur. Mines, RI 8150 (1976). 17 pp.

287. Francis, W., "Coal Its Formation and Composition," London: Edward Arnold (Publishers) Ltd., 2nd Ed., 1961. 806 pp.

288. Fraser, T. and Crentz, W. L., "Washing characteristics of the Pittsburgh coal in a high-sulfur area in Greene County, Pa.," U.S. Bur. Mines, Tech. Paper 689 (1946). 85 pp.

289. Fraser, T., Crentz, W. L., and Bailey, A. L., "High-sulfur Pittsburgh coal: upgrading in southwestern Pennsylvania and northern West Virginia," U.S. Bur. Mines, Bull. 483 (1950). 70 pp.

290. Fraser, T. and Yancey, H. F., "Cleaning tests of central Illinois coal," U.S. Bur. Mines, Tech. Paper 361 (1925). 23 pp.

291. Gallaher, J. T., "Summary ground-water resources of Allegheny County, Pennsylvania," Pa. Geol. Surv., Bull. W-35 (1973). 71 pp.+

292. Gandrud, B. W. and Riley, H. L., "Washability study of Upper Hartshorne bed at the Quality Mine, Hackett, Ark.," U.S. Bur. Mines, RI 4964 (1953). 17 pp.

293. Gandrud, B. W., Riley, H. L., and Sutton, P., "Washability study of the Pratt bed at the Davidson Mine, Graysville, Ala.," U.S. Bur. Mines, RI 5128 (1955). 21 pp.

294. Garrels, R. M. and Thompson, M. E. (Harvard Univ.), "Oxidation of pyrite by iron sulfate solutions," Am. J. Sci. 258A, 57-67 (1960). MD60-9

295. Gazdik, G. C. and Tagg, K. M., "Annotated bibliography of high-calcium limestone deposits in the United States including Alaska, to April 1956," U.S. Geol. Surv., Bull. 1019-I (1957). Chapter I in "Contributions to bibliography of mineral resources," U.S. Geol. Surv., Bull. 1019, pp 675-713.

296. Geer, M. R. and Yancey, H. F., "Cleaning characteristics and cleaning tests of Montana coal," U.S. Bur. Mines, RI 5103 (1955). 47 pp.

297. Geer, M. R. and Yancey, H. F., "Washability examinations of coals from the Rocky Mountain and Pacific coast states," U.S. Bur. Mines, RI 5905 (1961). 34 pp.

298. Godard, R. R. (U.S. Steel Corp.), "Mine water treatment-Frick District," Mining Congr. J. 56 (3), 36-40 (1970). MD70-35

299. Gomez, M. and Donaven, D. J., "Forecasting the properties of coal seams in place," U.S. Bur. Mines, RI 7680 (1972). 53 pp.

300. Gomez, M. and Donaven, D. J., "Forecasts of chemical, physical, and utilization properties of coal for technical and economic evaluation of coal seams," U.S. Bur. Mines, RI 7842 (1974). 127 pp.

301. Gomez, M., Donaven, D. J., and Hazen, K., "The statistical and spatial evaluation of sulfur and ash in coal seams," U.S. Bur. Mines, RI 7679 (1972). 46 pp.

302. Gomez, M., Donaven, D. J., and Kent, B. H., "Distribution of sulfur and ash in part of the Pittsburgh seam and probable mode of deposition," U.S. Bur. Mines, RI 7827 (1974). 44 pp.

303. Gomez, M. and Hazen, K., "Evaluating sulfur and ash distribution in coal seams by statistical response surface regression analysis," U.S. Bur. Mines, RI 7377 (1970). 120 pp.

304. Granchi, J. A., "Coal resources of the Pottsville Formation," Ohio Geol. Surv., RI No. 36 (1958). 53 pp.

305. Gray, R. E., "Mine drainage pollution abatement survey, Piersons Run watershed - Allegheny County, Pennsylvania," General Analytics, Inc., Rept. to Pa. Dept. Environ. Resour., Proj. SL-157 (Sept. 20, 1971). 20 pp. + app. MD71-47

306. Gray, T. E., "Preparation characteristics of coal from Nicholas County, W. Va.," U.S. Bur. Mines, RI 6136 (1962). 32 pp.

307. Gray, T. E. and Boley, C. C., "Preparation characteristics of coal from Dickenson County, Va.," U.S. Bur. Mines, RI 5405 (1958). 31 pp.

308. Gray, T. E. and Boley, C. C., "Preparation characteristics of coal from Wise County, Va.," U.S. Bur. Mines, RI 5391 (1958). 50 pp.

309. Gray, T. E. and Deurbrouck, A. W., "Preparation characteristics of coal from Kanawha County, W. Va.," U.S. Bur. Mines, RI 6296 (1963). 53 pp.

310. Gray, T. E. and Palowitch, E. R., "Preparation characteristics of coal from Allegheny County, Pa.," U.S. Bur. Mines, RI 5492 (1959). 34 pp.

311. Gray, T. E. and Palowitch, E. R., "Preparation characteristics of coal from Boone County, W. Va.," U.S. Bur. Mines, RI 5909 (1961). 39 pp.

312. Gray, T. E. and Palowitch, E. R., "Preparation characteristics of coal from Butler County, Pa.," U.S. Bur. Mines, RI 5609 (1960). 49 pp.

313. Gray, T. E. and Palowitch, E. R., "Preparation characteristics of coal from Greene County, Pa.," U.S. Bur. Mines, RI 5434 (1958). 31 pp.

314. Gray, T. E. and Palowitch, E. R., "Preparation characteristics of coal from Harrison County, W. Va.," U.S. Bur. Mines, RI 5818 (1961). 31 pp.

315. Gray, T. E. and Palowitch, E. R., "Preparation characteristics of coal from Marion County, W. Va.," U.S. Bur. Mines, RI 5653 (1960). 29 pp.

316. Gray, T. E. and Palowitch, E. R., "Preparation characteristics of coal from Monongalia County, W. Va.," U.S. Bur. Mines, RI 5572 (1960). 42 pp.

317. Gray, T. E. and Palowitch, E. R., "Preparation characteristics of coal from Preston County, W. Va.," U.S. Bur. Mines, RI 5721 (1961). 37 pp.

318. Gray, T. E. and Palowitch, E. R., "Preparation characteristics of coal from Washington County, Pa.," U.S. Bur. Mines, RI 5475 (1959). 27 pp.

319. Griffith, E., "Mine-drainage practice in the anthracite region of Pennsylvania," AIME, Tech. Publ. No. 1907 (1945). 18 pp. MD45-1

320. "Grouting for control of ground water." "Systematic approach to grouting," by J. J. Reed; "Grouting by cementation," by L. A. York; "Chemical grouting," by V. L. Stevens, reprinted from Mining Congr. J., Jan. 1962. 9 pp.

321. Grove, D. R., "Ferric ion oxidation of pyrite," M.S. Thesis, The Ohio State Univ., 1970. 56 pp. MD70-37

322. Gunnett, J. W., "Hydrological influences in preventive control of mine drainage from deep coal mining," M.S. Thesis, Pa. State Univ., Dept. Miner. Eng., 1974. 89 pp.+ MD74-29

323. Haley, B. R., "Coal resources of Arkansas, 1954," U.S. Geol. Surv., Bull. 1072-P (1960). Chapter P in "Contributions to economic geology," U.S. Geol. Surv., Bull. 1072, pp 795-831. 7 plates in pocket.

324. Halko, E. M. (Dept. Chem. Eng.), "Aerobic-Anaerobic oxidation of pyrites," M.S. Thesis, Ohio State Univ., 1968. 67 pp. MD68-30

325. Hall, E. P., "Coal mining," in "Industrial Wastewater Control," C. F. Gurnham, Ed., New York: Academic Press, 1965. pp 169-181. MD65-17

326. Hall, E. P., Cook, L., Braley, S. A., Brant, R. A., Riley, C. V., Fisher, E. H., and Williams, N. E., "The Sheban Project," Unpublished Progress Report to October, 1960. 20 pp. MD60-11

327. Hall, E. P. and Hebley, H. F., "Some considerations in water pollution from bituminous coal," Unpublished report, 1958. 7 pp. MD58-3

328. Hall, E. P. and Rozance, J. L., "Hutchison Mine - a problem in coal mine-drainage," AIME Joint Meet. Coal Div., Ind. Miner. Div., Bedford Springs, Pa., Sept. 1959. Preprint No. 59F309. 7 pp. MD59-5

329. Hall, G. L., "Mine sealing in Maryland," Eng. News-Record 120, 713-715 (1938). MD38-3

330. Hanna, G. P., Jr. (1) and Brant, R. A. (2) [(1) Ohio State Univ., Water Resour. Cent. and (2) Ohio Geol. Surv.], "Stratigraphic relations to acid mine water production," Eng. Ext. Ser. No. 112, Purdue Univ., Proc. 17th Ind. Waste Conf., May 1-3, 1962. pp 476-492. MD62-12

331. Hanna, G. P., Jr., Brant, R. A., Lucas, J. R., Randles, C. I., and Smith, E. E., "Analysis of fundamentals of acid mine drainage: a basis for future investigation," The Ohio State Univ. Eng. Expt. Sta., Final Rept., Proj. EES-175, to Ohio River Valley Water Sanit. Comm., 1961. 76 pp. MD61-9

332. Hanna, G. P., Jr. (1), Lucas, J. R. (1), Randles, C. I. (1), Smith, E. E. (1), and Brant, R. A. (2) [(1) Ohio State Univ. and (2) Ohio Geol. Surv.], "Acid mine drainage research potentialities," J. Water Pollut. Contr. Fed. 35 (3), 275-296 (1963). MD63-7

333. Hartford, W. H., "Control of acidic mine drainage," Science 169, 504 (1970). MD70-40

334. Hatch, B. F., "Sealing abandoned coal mines: a federal project to protect public water supplies," Water Works and Sewerage 81 (3), 99-100 (1934). MD34-2

335. Hatch, J. R., Gluskoter, H. J., and Lindahl, P. C., "Sphalerite in coals from the Illinois basin," Econ. Geol. 71 (3), 613-624 (1976). Ill. State Geol. Surv., Reprint Ser. 1976E.

336. Headlee, A. J. W., McClelland, R. E., Hoskins, H. A., and Hunter, R. G., "Characteristics of minable coals of West Virginia," W. Va. Geol. Surv. Vol. XIII A, Parts III-VII, 1955. 166 pp.

337. Headlee, A. J. and Nolting, J. P., "Characteristics of minable coals of West Virginia," W. Va. Geol. Surv., Vol. XIII, Parts I and II, 1940. 272 pp.

338. Heine, W. N. (Dir., Div. Mine Drainage, Pa. Dept. Health), "Control of pollution from active mines in Pennsylvania," Presented, ORSANCO Eng. Comm., Sept. 12, 1968. 3 pp. MD68-31

339. Heine, W. N. and Giovannitti, E. F. (Pa. Dept. Health, Div. Mine Drainage), "Treatment of mine drainage by industry in Pennsylvania," 2nd Mid-Atlantic Ind. Waste Conf., Philadelphia, Pa., Nov. 19, 1968. 18 pp. MD68-32

340. Helfinstine, R. J., Shimp, N. F., and Simon, J. A., "Sulfur varieties in Illinois coals: float-sink tests," Ill. State Geol. Surv., Phase I Rept. to U.S. Public Health Serv., 1969. 97 pp.

341. Helfinstine, R. J., Shimp, N. F., Simon, J. A., and Hopkins, M. E., "Sulfur reduction of Illinois coals - washability studies," Ill. State Geol. Surv., Phase II Rept. to U.S. Public Health Serv., 1971. 28 pp.

342. Helfinstine, R. J., Simon, J. A., Shimp, N. F., and Hopkins, M. E., "Sulfur reduction of Illinois coals: washability tests," Ill. State Geol. Surv., Environ. Geol. Notes No. 34 (Apr. 1970). 12 pp.

343. Hendricks, E. L., "Water and coal," Presented, National Coal Assoc. Conv., June 14, 1965. 8 pp. MD65-20

344. Herndon, L. K., "Survey of the mine drainage in the West Fork River basin," W. Va. Univ., Eng. Expt. Sta., Tech. Bull. No. 4, 115-142 (1931). MD31-3

345. Herndon, L. K. and Hodge, W. W., "West Virginia coal seams and their drainage," W. Va. Univ., Eng. Expt. Sta., Res. Bull. No. 14 (1936). 25 pp. MD36-1

346. Herricks, E. E. (1), Cairns, J., Jr. (2), and Shanholtz, V. O. (2) [(1) Union Carbide Corp. and (2) VPI & SU], "Preplanning mining operations to reduce the environmental impact of mine drainage on streams," Water Resour. Problems Related to Mining, Am. Water Resour. Assoc., Proc. No. 18, June 1974. pp 1-11. MD74-35

347. Hershey, R. E., Williams, L., Crentz, W. L., and Miller, J. W., "Estimate of known recoverable reserves and the preparation characteristics of coking coal in Hamilton County, Tenn.," U.S. Bur. Mines, RI 5263 (1956). 27 pp.

348. Hershey, R. E., Williams, L., Crentz, W. L., and Miller, J. W., "Estimate of known recoverable reserves and preparation characteristics of coking coal in Van Buren County, Tenn.," U.S. Bur. Mines, RI 5208 (1956). 25 pp.

349. Hershey, R. E., Williams, L., Crentz, W. L., Miller, J. W., and Reynolds, D. A., "Estimate of known recoverable reserves and preparation and carbonizing properties of coking coal in Claiborne County, Tenn.," U.S. Bur. Mines, RI 5229 (1956). 44 pp.

350. Hershey, R. E., Williams, L., and Gundrud, B. W., "Estimate of known recoverable reserves of coking coal in Grundy County, Tenn.," U.S. Bur. Mines, RI 5148 (1955). 16 pp.

351. Hill, R. D. (Chief, Mine Drainage Pollut. Contr. Act., Cincinnati, Ohio), "Control and prevention of mine drainage," Presented, Battelle Conf., Columbus, Ohio, Nov. 1972. 12 pp. Also in Cycling and Control of Metals, Proceed. Environ. Resour. Conf., Oct. 31-Nov. 2, 1972 (1973). pp 91-94. NTIS, PB-216 184. MD72-31

352. Hill, R. D. (U.S. Dept. Int., FWPCA), "The effectiveness of mine drainage pollution control measures, Elkins, West Virginia," ACS Div. Fuel Chem. Preprints 13 (2), 103-115 (1969). MD69-34

353. Hill, R. D. (U.S. Dept. Int., FWQA, Cincinnati, Ohio), "Elkins mine drainage pollution control demonstration project," Third Symp. Coal Mine Drainage Res. Preprints, Pittsburgh, Pa. (1970). pp 284-303. MD70-43

354. Hill, R. D., "Mine Drainage treatment: state of the art and research needs," U.S. Dept. Int., FWPCA, Cincinnati, Ohio (1968). 101 pp. MD68-33

355. Hill, R. D. (U.S. EPA, Mine Drainage Control Branch), "Underground mine drainage pollution control," Interstate Mining Compact Comm., Spring Meet., Pipestem, W. Va., by U.S. EPA, May 16, 1974. 14 pp. MD74-37

356. Hill, R. D. and Martin, J. F. (EPA, Cincinnati, Ohio), "Elkins Mine Drainage Pollution Control Demonstration Project--an update," Fourth Symp. Coal Mine Drainage Res. Preprints, Pittsburgh, Pa. (1972). pp 96-104. MD72-32

357. Hinkle, M. E. and Koehler, W. A., "The action of certain microorganisms in acid mine drainage," AIME, Coal Div., Tech. Publ. 2381 (1948). 5 pp. MD48-4

358. Hinkle, M. E. and Koehler, W. A., "Investigations on coal mine drainage - 1944 Annual Report," W. Va. Univ., Eng. Expt. Sta., Ind. Res. Fellowship No. 11, May 1946. 100 pp.+ MD46-5

359. Hinkle, M. E. and Koehler, W. A., "Investigations on coal mine drainage - Annual Report for 1945," W. Va. Univ., Eng. Expt. Sta., Ind. Res. Fellowship No. 11, June 1946. 29 pp. MD46-6

360. Hinkle, M. E. and Koehler, W. A., "Investigations on coal mine drainage - 1946 Annual Report," W. Va. Univ., Eng. Expt. Sta., Ind. Res. Fellowship No. 11, Jan. 1947. 20 pp. MD47-3

361. Hinkle, M. E. and Koehler, W. A., "Investigations on coal mine drainage - Quarterly Report, July 1, to September 30, 1946," W. Va. Univ., Eng. Expt. Sta., Ind. Res. Fellowship No. 11, Nov. 1946. 14 pp. MD46-7

362. Hinkle, M. E. and Koehler, W. A., "Investigations on coal mine drainage - Semi-annual Report for the first half of 1946," W. Va. Univ., Eng. Expt. Sta., Ind. Res. Fellowship No. 11, July 1946. 13 pp.+ MD46-8

363. Hinkle, M. E. and Koehler, W. A., "Investigations on coal mine drainage - Summary Report, January 1944 to June 1, 1947," W. Va. Univ., Eng. Expt. Sta., Ind. Res. Fellowship No. 11, May 1947. 32 pp. MD47-4

364. Hodge, W. W., "The effect of coal-mine drainage on West Virginia rivers and water supplies," W. Va. Univ., Eng. Expt. Sta., Res. Bull. No. 18 (1938). 30 pp. MD38-5

365. Hodge, W. W., "Pollution of streams by coal-mine drainage - beneficial effects of sealing abandoned mines," Ind. Eng. Chem. 29, 1048-1055 (1937). MD37-3

366. Hodge, W. W. and Hinkle, M. E., "Investigations on coal mine drainage - Interim Report, January 1944 to July 1945," W. Va. Univ., Ind. Res. Fellowship No. 11, Interim Rept. to Bituminous Coal Research, Inc., Aug. 15, 1945. 15 pp. MD45-2

367. Hollyday, E. F. and McKenzie, S. W., "Hydrogeology of the formation and neutralization of acid waters draining from underground coal mines of western Maryland," Md. Geol. Surv., Rept. Invest. No. 20 (1973). 50 pp. MD73-35

368. Hopkins, M. E. and Simon, J. A., "Coal resources of Illinois," Ill. State Geol. Surv., Miner. Note 53 (Jan. 1974). 24 pp.

369. Hopkins, T. C., Jr., "Physical and chemical water quality from the effects of mine drainage in western Maryland," Md. Dept. Water Resour., Aug. 1967. 19 pp. MD67-36

370. Hopkins, T. C., Jr., "Western Maryland mine drainage survey 1962-1965," Md. Dept. Water Resour., Water Qual. Div., 1965. Vol. I, Savage River Watershed, Deep Creek Lake Watershed, Youghiogheny River Watershed, Casselman River Watershed, Willis Creek Watershed; Vol. II, Georges Creek Watershed; Vol. III, North Branch Potomac River Watershed. MD65-21

371. Hosterman, J. W., Wood, G. H., Jr., and Bergin, M. J., "Mineralogy of underclays in the Pennsylvania Anthracite region," in "Geological Survey Research 1970, Chapter C," U.S. Geol. Surv. Prof. Paper 700-C (1970). pp 89-97.

372. Huddle, J. W., Lyons, E. J., Smith, H. L., and Ferm, J. C., "Coal reserves of eastern Kentucky," U.S. Geol. Surv., Bull. 1120 (1963). 247 pp. 15 plates.

373. Hutchison, H. C., "Geology and coal deposits of the Brazil quadrangles, Indiana," Ind. Geol. Surv., Bull. No. 16 (1960). 50 pp. 2 plates.

374. "Inert atmosphere in mines could abate acid drainage," Chem. Eng. News 48 (21), 33-35 (1970). MD70-50

375. Ingersoll, D. E. and Eckerd, J. W., "Washability characteristics of Mammoth and Holmes vein anthracites," U.S. Bur. Mines, RI 5569 (1960). 12 pp.

376. "Inventory of coal mine drainage sources, selected areas, upper Ohio River basin," U.S. Dept. Int., FWPCA, Ohio Basin Region, Work Document No. 32 (1969). 110 pp. MD69-41

377. "Investigation of coal deposits in the Fairview and Coal City basins of Coosa field, St. Clair County, Ala.: reserves, petrography, and chemical properties of coals; washability characteristics of coal from Fairview bed; and geology of area," U.S. Bur. Mines, Tech. Paper 719 (1949). 104 pp.

378. "Investigative mine survey of a small watershed," Halliburton Co., Rept. to U.S. Dept. Int., FWQA, Water Pollut. Contr. Res. Ser. 14010 DMO 03/70-A (1970). 89 pp. NTIS, PB-196 110. MD70-51

379. Janus, J. B., "Analyses of tipple and delivered samples of coal: collected during fiscal year 1974," U.S. Bur. Mines, RI 7997 (1975). 13 pp.

380. Janus, J. B. and Shirley, B. S., "Analyses of tipple and delivered samples of coal: collected during fiscal year 1972," U.S. Bur. Mines, RI 7712 (1973). 17 pp.

381. Janus, J. B. and Shirley, B. S., "Analyses of tipple and delivered samples of coal: collected during fiscal year 1973," U.S. Bur. Mines, RI 7848 (1973). 15 pp.

382. Janus, Z. L., "Chemical grouting cuts water flow in colliery drift," Reprinted from Mine & Quarry Mechanisation, 1963. 5 pp. MD63-10

383. Jenkins, C. R. (1) and Carroll, H. C. (2) [(1) W. Va. Univ. and (2) N.Y. State Dept. Conserv.], "Mine acid drainage and associated flow fluctuations," Proc. W. Va. Acad. Sci. (1969). pp 286-293. MD69-42

384. Jolley, T. R. and Miller, J. W., "Preparation characteristics of coal from Bell County, Ky.," U.S. Bur. Mines, RI 5357 (1957). 30 pp.

385. Jones, D. C., "Getting the facts at Hollywood (Pa.)," Coal Mining Process. 7 (8), 28-33 (1970). MD70-52

386. Jones, J. B. and Ruggeri, S. (Parsons-Jurden Corp.), "Abatement of pollution from abandoned coal mines by means of in-situ precipitation techniques," ACS Div. Fuel Chem. Preprints 13 (2), 116-119 (1969). MD69-43

387. Kehn, T. M., Palmer, J. E., and Franklin, G. J., "Revised correlation of the No. 4 (Dawson Springs No. 6) coal bed, western Kentucky coal field," in "Geological Survey Research 1967, Chapter C," U.S. Geol. Surv. Prof. Paper 575-C (1967). pp 160-164.

388. Kent, B. H. and Gomez, M., "Geologic factors that control thickness and composition of the upper Pennsylvanian coals in Appalachian basin," Amer. Assoc. Petrol. Geol. Bull. 56 (3), 631-632 (1972).

389. Koehrsen, L. G., "Lake Hope acid mine drainage abatement program," Stanley Consultants, Rept. to Ohio Dept. Natural Resour., 1969. 38 pp. MD69-45

390. Kohl, W. R. and Briggs, R. P., "Summary map of mined areas and areas of potential coal mining, southwestern Pennsylvania," U.S. Geol. Surv., Misc. Field Studies, Map MF-729 (1976). 1 plate

391. Koppe, E. F., "Some geological factors affecting the Upper Freeport coal and its quality," Trans. AIME 217, 185-189 (1960).

392. Koppe, E. F. (1) and Thompson, D. R. (2) [(1) E. F. Koppe & Associates and (2) Pa. Dept. Environ. Resour.], "Progress in the recognition of fractured rock zones in prevention and abatement of mine drainage," Fourth Symp. Coal Mine Drainage Res. Preprints, Pittsburgh, Pa. (1972). pp 41-47. MD72-37

393. Krickovic, S., "Acid mine drainage: mine sealing," U.S. Bur. Mines, Pittsburgh Mining Res. Cent., Progr. Rept., 2nd Quarter, FY 1965. 3 pp. MD65-25

394. Krickovic, S., "Acid mine drainage pollution control--approach to solution," Mining Cong. J. 52 (12), 64-68 (Dec. 1966). MD66-23

395. Krickovic, S., "U.S. Bureau of Mines acid mine drainage control program and joint Interior-HEW Departments acid mine drainage control program," Symp. Acid Mine Drainage Res. Preprints, Pittsburgh, Pa., 1965. pp 111-126. MD65-26

396. Kunin, R. (1) and Demchalk, J. J. (2) [(1) Rohm and Haas Co. and (2) Pa. Dept. Environ. Resour.], "The use of AMBERLITE® ion exchange resins in treating acid mine waters at Philipsburg, Pennsylvania," Natl. Coal Assoc./ Bitum. Coal Res., Inc., Fifth Symp. Coal Mine Drainage Res. Preprints, Louisville, Ky. (1974). pp 302-311. MD74-43

397. Kyle, G. E. (Pa. Dept. Environ. Resour.), "Mine drainage pollution control - a state viewpoint," Interstate Mining Compact Comm. Spring Meet., Pipestem, W. Va., by U.S. EPA, May 16, 1974. 6 pp. MD74-44

398. "Lackawanna Valley mine drainage pollution abatement project," Gannett Fleming Corddry & Carpenter, Inc., Rept. to Pa. Dept. Health, Div. Sanit. Eng., Publ. No. 19 (1967). 47 pp. MD67-40

399. Landis, E. R., "Coal resources of Colorado," U.S. Geol. Surv., Bull. 1072-C (1959). Chapter C in "Contributions to economic geology," U.S. Geol. Surv., Bull. 1072, pp 131-232. 2 plates in pocket

400. LaRosa, P. J., Karnavas, J. A., and Pelczarski, E. A., "Carbonate bonding of coal refuse," Black, Sivalls & Bryson, Inc., Rept. to U.S. EPA, Water Qual. Office, Water Pollut. Contr. Res. Ser. 14010 FOA 02/71 (1971). 44 pp. NTIS, PB-198 230. MD71-56

401. Lau, C. M., Shumate, K. S., and Smith, E. E. (Ohio State Univ.), "The role of bacteria in pyrite oxidation kinetics," Third Symp. Coal Mine Drainage Res. Preprints, Pittsburgh, Pa. (1970). pp 114-122. MD70-59

402. Lazaroff, N. (British Columbia Res. Council), "Sulfate requirement for iron oxidation by Thiobacillus ferrooxidans," J. Bacteriol. 85 (1), 78-83 (1963).

403. Leamon, A. R. and Maher, S. W., "Coal mining in Tennessee (as of November 1974)," Tenn. Dept. Conserv., Div. Geol., Inform. Circ. 17 (undated). 35 pp. 1 plate

404. Leathen, W. W. (Mellon Inst.), "Bacteriologic aspects of bituminous coal mine effluents," Proc. Pa. Acad. Sci. 27, 37-44 (1953). MD53-9

405. Leathen, W. W. (Mellon Inst.), "The influence of bacteria on the formation of acid mine drainage," AIME Joint Meet. Coal Div., Ind. Miner. Div., Bedford Springs, Pa., 1959. Preprint 59F305. 8 pp. MD59-10

406. Leathen, W. W., "Microbiological studies of bituminous coal mine drainage," Mellon Inst., Spec. Summary Rept., to Pa. Dept. Health, Ind. Fellowship No. 326B-6, 1952. 54 pp.+ MD52-8

407. Leathen, W. W. and Braley, S. A., "A study of the role of autotrophic bacteria in the formation of mine acid (July 1949 - July 1951)," Mellon Inst. Special Rept. to Pa. Dept. Health, Ind. Fellowship No. 326B, 1951. 211 pp. MD51-7

408. Leathen, W. W., Braley, S. A., Sr., and McIntyre, L. D. (Mellon Inst.), "The role of bacteria in the formation of acid from certain sulfuritic constituents associated with bituminous coal. I. Thiobacillus Thiooxidans; II. Ferrous iron oxidizing bacteria," Appl. Microbiol. 1 (2) (1953). I., pp 61-64; II., pp 65-68. MD53-10

409. Lees, J. H., "Iowa coal areas and characteristics of Iowa coal," in "Annual Reports, 1925, 1926 with Accompanying Papers," Iowa Geol. Surv. Vol. XXXII (1927). pp 65-81.

410. Leighton, H., "Pyrite from bituminous coal mines in Pennsylvania," Pa. Geol. Surv., Bull. 48 (1922). 19 pp.

411. Leitch, R. D., "Acidity of drainage from high pyritic coal areas in Pennsylvania," U.S. Bur. Mines, RI 3146 (1932). 15 pp. MD32-3

412. Leitch, R. D., "The acidity of several Pennsylvania streams during low water," U.S. Bur. Mines, RI 3119 (1931). 10 pp. MD31-6

413. Leitch, R. D., "Observations of acid mine drainage in western Pennsylvania," Mining Congr. J. 14, 835-839, 848 (1928). MD28-1

414. Leitch, R. D., "Sealing of coal mines - will reduce acidity of their effluent waters," Coal Age 40, 323-326 (1935). MD35-1

415. Leitch, R. D. and Yant, W. P., "A comparison of the acidity of waters from some active and abandoned mines," U.S. Bur. Mines, RI 2892 (1928). 8 pp. MD28-2

416. Leitch, R. D. and Yant, W. P., "Sealing old workings prevents acid formation and saves pipes and streams," Coal Age 35, 78-80 (1930). MD30-4

417. Leitch, R. D., Yant, W. P., and Sayers, R. R., "Character of drainage from mines in the Thick Freeport coal bed, Pennsylvania," U.S. Bur. Mines, RI 3193 (1932). 2 pp. MD32-4

418. Leitch, R. D., Yant, W. P., and Sayers, R. R., "Effect of sealing on acidity of mine drainage," U.S. Bur. Mines, RI 2994 (1930). 11 pp. MD30-5

419. Lesser, W. H., "Deep-well pumps and shaft pumps in anthracite mines of Pennsylvania," U.S. Bur. Mines, RI 4656 (1950). 52 pp.

420. Light, B. A. (Consolidation Coal Co.), "Dents Run watershed project," Natl. Coal Assoc./Bitum. Coal Res., Inc., Third Symp. Surface Mining and Reclamation Preprints, Vol. 1, Louisville, Ky. (1975). pp 148-151. MD75-20

421. Long, B. W., "Neutralization and precoat filtration of concentrated sludge from mine water at the Reading Anthracite Co. in St. Clair, Pa. Project CR-82," Johns-Manville Prod. Corp., Res. Eng. Center, Rept. No. E412-8087 to Pa. Coal Res. Bd., (Sept. 15, 1969). 12 pp. MD69-50

422. Loofbourow, R. L. and Brittain, R. L., "Dewatering through wells before mine development," Mining Congr. J. 50 (7), 43-50 (1964).

423. Lorenz, W. C., "Progress in controlling acid mine water: a literature review," U.S. Bur. Mines, IC 8080 (1962). 40 pp. MD62-15

424. Lorenz, W. C. and Stephan, R. W., "Factors that affect the formation of coal mine drainage pollution in Appalachia," U.S. Bur. Mines, Area I Mineral Resource Office, Pittsburgh, Pa., 1967. 17 pp. MD67-41

425. Lorenz, W. C. and Stephan, R. W., "The oxidation of pyrite associated with coal mines," U.S. Bur. Mines, Area I Miner. Resource Office, Pittsburgh, Pa., 1967. 21 pp. MD67-42

426. Lorenz, W. C. and Tarpley, E. C., "Oxidation of coal mine pyrites," U.S. Bur. Mines, RI 6247 (1963). 13 pp. MD63-14

427. Lovell, H. L. and Gunnett, J. W. (Dept. Miner. Eng.), "Hydrogeological influences in preventive control of mine drainage from deep coal mining," Pa. State Univ., Spec. Res. Rept. SR-100, to Pa. Dept. Environ. Resour. (1974). 89 pp. MD74-46

428. Lowe, R. W., Crentz, W. L., and Miller, J. W., "Estimate of known recoverable reserves and preparation characteristics of coking coal in Fentress County, Tenn.," U.S. Bur. Mines, RI 5235 (1956). 34 pp.

429. Lowrie, R. L., "Analysis of the coal industry in Boulder-Weld coalfield, Colorado," U.S. Bur. Mines, RI 6726 (1966). 79 pp.

430. Loy, L. D., Jr. (Skelly and Loy, Engineers-Consultants), "Deep mine pollution - solving the hole problem," Interstate Mining Compact Comm. Spring Meet., Pipestem, W. Va., by U.S. EPA, May 16, 1974. 8 pp. MD74-47

431. Loy, L. D., Jr. (Skelly and Loy, Engineers-Consultants), "Description of new, innovative and theoretical mine drainage abatement techniques," Natl. Coal Assoc./Bitum. Coal Res., Inc., Fifth Symp. Coal Mine Drainage Res. Preprints, Louisville, Ky. (1974). pp 146-159. MD74-48

432. Lucas, J. R. (Ohio State Univ.), "A field study in acid mine drainage," Ann. Meet. AIME, New York, N. Y., 1960. Preprint 60F35. 13 pp. MD60-15

433. Lundgren, D. G., "Inorganic sulfur oxidation by iron-oxidizing bacteria," Syracuse Univ., Rept. to EPA, WQO, Water Pollut. Contr. Res. Ser. 14010 DAY 06/71 (1971). 149 pp. NTIS, PB-213 006. MD71-60

434. Lundgren, D. G. and Schnaitman, C. A. (Syracuse Univ.), "The iron-oxidizing bacteria - culture and iron-oxidation," Symp. Acid Mine Drainage Res. Preprints, Pittsburgh, Pa., 1965. pp 14-22. MD65-30

435. Lundgren, D. G. and Tabita, F. R. (Syracuse Univ.), "Biochemical ecology of metal sulfide oxidizing bacteria," ACS Div. Fuel Chem. Preprints 13 (2), 60-67 (1969). MD69-52

436. Lyon, W. A. (Dir., Bur. Sanit, Eng., Pa. Dept. Environ. Resour.), "Water quality management in the Monongahela River basin," Conf. on Pollut. of Monongahela River & Its Tributaries, Pittsburgh, Pa., by EPA, 1971. 102 pp. MD71-61

437. Maize, E. R. and Wallace, J. J., "Cementation of bituminous-coal-mine roof strata: Part 1. - determining penetrability of mine roof by injecting oil and water," U.S. Bur. Mines, RI 5304 (1956). 17 pp.

438. Maize, R., "History and progress made in mine sealing to reduce the flow of acid mine water into the streams of this Commonwealth," Presented, Coal Mining Inst., Pittsburgh, Pa., Dec. 1952. 23 pp. MD52-9

439. Malhotra, R., "Factors responsible for variation in productivity of Illinois coal mines," Ill. State Geol. Surv., Miner. Note 60 (Aug. 1975). 18 pp.

440. Malhotra, R. and Smith, P. A., "Directory of Illinois mineral producers, 1974," Ill. State Geol. Surv., Miner. Note 64 (1976). 119 pp.

441. Mansfield, S. P. and Spackman, W., "Petrographic composition and sulfur content of selected Pennsylvania bituminous coal seams," Pa. State Univ., Spec. Res. Rept. SR-50, to Pa. Coal Res. Bd. (1965). 178 pp.

442. Markley, R. W. and Perlee, H. E., "U.S. Bureau of Mines high-speed data acquisition system," 14th International APCOM Symp., Session on Information Systems for Mine Planning, Oct. 4-8, 1976. 12 pp.

443. Maser, K. R., Wallhagen, R. E., and Dieckmann, J., "Development of a fly ash-cement mine sealing system," Foster-Miller Associates, USBM Contract Rept. H0144061, Bur. Mines OFR 26-76, 1976. 113 pp. NTIS, PB-250 611.

444. Matson, T. K. and Doss, H. W., Jr., "The reserve base of coal for underground mining in the western United States," U.S. Bur. Mines, IC 8678 (1975). 238 pp.

445. McCarren, E. F., Wark, J. W., and George, J. R., "Hydrologic processes diluting and neutralizing acid streams of the Swatara Creek basin, Pennsylvania," U.S. Geol. Surv., Prof. Paper No. 424-D, Geol. Surv. Res., 1961. pp D-64--D-67. MD61-12

446. McCartney, J. T., O'Donnell, H. J., and Ergun, S., "Pyrite size distribution and coal-pyrite particle association in steam coals: correlation with pyrite removal by float-sink methods," U.S. Bur. Mines, RI 7231 (1969). 18 pp.

447. McCulloch, C. M., "Applying computer-drawn maps of geologic data to analysis of mining problems," U.S. Bur. Mines, RI 8151 (1976). 26 pp.

448. McCulloch, C. M. and Deul, M., "Geologic factors causing roof instability and methane emission problems," U.S. Bur. Mines, RI 7769 (1973). 25 pp.

449. McCulloch, C. M., Deul, M., and Jeran, P. W., "Cleat in bituminous coalbeds," U.S. Bur. Mines, RI 7910 (1974). 25 pp.

450. McCulloch, C. M., Diamond, W. P., Bench, B. M., and Deul, M., "Selected geologic factors affecting mining of the Pittsburgh coalbed," U.S. Bur. Mines, RI 8093 (1975). 72 pp.

451. McCulloch, C. M., Jeran, P. W., and Sullivan, C. D., "Geologic investigations of underground coal mining problems," U.S. Bur. Mines, RI 8022 (1975). 30 pp.

452. McCulloch, C. M., Lambert, S. W., and White, J. R., "Determining cleat orientation of deeper coalbeds from overlying coals," U.S. Bur. Mines, RI 8116 (1976). 19 pp.

453. McMillan, B. G., "Sulfur occurrence in coal and its relationship to acid water formation: literature review," W. Va. Univ., Coal Res. Bur., Tech. Rept. No. 110, Undated. 18 pp. MD75-24

454. McPhilliamy, S. C. and Green, J., "A chemical and biological evaluation of three mine drainage treatment plants," U.S. EPA, Region III, Wheeling Field Office, Surveillance Anal. Div., Work Document No. 47 (1973). 76 pp. MD73-49

455. McQuillin, K. B. (Anglo American Corp. of South Africa, Ltd.), "A computer based data storage and retrieval system for the evaluation of coal-field data," 14th International APCOM Symp., Session on Information Systems for Mine Planning, Oct. 4-8, 1976. 13 pp.

456. Melton, R. A., Ott, D. L., and Ferm, J. C. (Univ. South Carolina), "A computerized system for coal exploration and mine planning," 14th International APCOM Symp., Session on Information Systems for Mine Planning, Oct. 4-8, 1976. 12 pp.

457. Mentz, J. W. and Warg, J. B. (Skelly and Loy, Engineers-Consultants), "Up-dip versus down-dip mining: an evaluation," U.S. EPA Environ. Protection Technol. Ser. EPA-670/2-75-047 (June 1975). 74 pp. NTIS, PB-244 420/6WP. MD75-26

458. Merritt, G. L. (1) and Angerman, T. W. (2) [(1) Pa. Dept. Environ. Res. and (2) Huntley & Huntley, Inc.], "The use of ionic tracers in determining the subsurface flow of mine drainage. A case study," Fourth Symp. Coal Mine Drainage Res. Preprints, Pittsburgh, Pa. (1972). pp 340-343. MD72-50

459. Merritt, G. L. and Emrich, G. H. (Pa. Dept. Health), "The need for a hydrogeologic evaluation in a mine drainage abatement program: a case study: Toms Run, Clarion County, Pennsylvania," Third Symp. Coal Mine Drainage Res. Preprints, Pittsburgh, Pa. (1970). pp 334-364. MD70-67

460. "Methods for determining sources, paths & quantities of water entering underground coal mines in eastern United States," D'Appolonia Consulting Engineers, Inc., Phase 1 Rept. to U.S. EPA, Ind. Environ. Res. Lab., Cincinnati, Ohio, Proj. No. 75-633B, Apr. 1976. (416 pp.)

461. Mihok, E. A. and Moebs, N. N., "U.S. Bureau of Mines progress in mine water research," Fourth Symp. Coal Mine Drainage Res. Preprints, Pittsburgh, Pa. (1972). pp 33-40. MD72-51

462. Miller, J. T. (1) and Thompson, D. R. (2) [(1) Rummel, Klepper and Kahl, Consulting Engineers and (2) Pa. Dept. Environ. Resour.], "Seepage and mine barrier width," Natl. Coal Assoc./Bitum. Coal Res., Inc., Fifth Symp. Coal Mine Drainage Res. Preprints, Louisville, Ky. (1974). pp 103-127. MD74-53

463. Miller, J. W., "Preparation characteristics of coal from Lee County, Va.," U.S. Bur. Mines, RI 5358 (1957). 14 pp.

464. Miller, J. W. and Jolley, T. R., "Preparation characteristics of coal from Logan County, W. Va.," U.S. Bur. Mines, RI 5306 (1957). 48 pp.

465. Miller, J. W. and Jolley, T. R., "Preparation characteristics of coal from Mingo County, W. Va.," U.S. Bur. Mines, RI 5278 (1956). 35 pp.

466. Miller, J. W. and Jolley, T. R., "Preparation characteristics of coal from Perry County, Ky.," U.S. Bur. Mines, RI 5230 (1956). 28 pp.

467. Miller, J. W., Jolley, T. R., and Sokaski, M., "Preparation characteristics of coal from Harlan County, Ky.," U.S. Bur. Mines, RI 5140 (1955). 44 pp.

468. Miller, J. W., Jolley, T. R., and Sokaski, M., "Preparation characteristics of coal from Letcher County, Ky.," U.S. Bur. Mines, RI 5135 (1955). 43 pp.

469. Miller, J. W., Jolley, T. R., and Sokaski, M., "Preparation characteristics of coal from McDowell County, W. Va.," U.S. Bur. Mines, RI 5094 (1954). 41 pp.

470. Miller, J. W., Jolley, T. R., and Sokaski, M., "Preparation characteristics of coal from Raleigh County, W. Va.," U.S. Bur. Mines, RI 5070 (1954). 32 pp.

471. Miller, J. W., Jolley, T. R., and Sokaski, M., "Preparation characteristics of coal from Wyoming County, W. Va.," U.S. Bur. Mines, RI 5112 (1955). 26 pp.

472. Miller, M. S., "Stratigraphy and coal beds of Upper Mississippian and Lower Pennsylvanian rocks in southwestern Virginia," Va. Div. Miner. Resour., Bull. 84 (1974). 211 pp. 4 plates in pocket.

473. "Mine drainage manual," Pa. Dept. Health, Sanitary Water Bd., Publ. No. 12, 1966. (Including 1968 revisions). MD66-28

474. "Mine drainage pollution abatement measures for the Beech Creek watershed," Gannett Fleming Corddry and Carpenter, Inc., Rept. to Pa. Dept. Mines Miner. Ind., Proj. No. SL - 111 (Dec. 31, 1970). 57 pp.+ MD70-71

475. "Mine drainage pollution watershed survey, the northern Youghiogheny River complex: Cherry Creek, Casselman River watersheds, Garrett County, Maryland: Vol. I," Baker-Wibberley and Associates, Inc., Rept. to Md. Dept. Natural Resour., May 1973. 101 pp.+ MD73-51

476. "Mine drainage pollution watershed survey, the northern Youghiogheny River complex, Cherry Creek and Casselman River watersheds, Garrett County, Maryland: Vol II," Skelly and Loy, Engineers, Consultants, Rept. to Md. Dept. Natural Resour., May 1973. 368 pp. MD73-52

477. "Mine-sealing program to reduce acid pollution in streams," Eng. News-Record 116 (2), 42-43 (1936). MD36-5

478. "Mine sealing reduces acid pollution of streams in the Ohio basin," Coal Mining 14 (2), 6-7 (1937). MD37-4

479. Moebs, N. N., "Air sealing as a means of abating acid mine drainage pollution," Symp. Fossil Fuels Environ. Pollut., ACS Div. Fuel Chem. Preprints 10 (1), 93-100 (1966). MD66-29

480. Moebs, N. N. (U.S. Bur. Mines), "Mine air sealing: a progress report," Second Symp. Coal Mine Drainage Res. Preprints, Pittsburgh, Pa., 1968. pp 255-264. MD68-54

481. Moebs, N. N. and Chamberlain, C. E., "The effect of atmospheric pressures on the oxygen level in a sealed mine," U.S. Bur. Mines, RI 7606 (1972). 19 pp. MD72-53

482. Moebs, N. and Curth, E. A., "Geologic and ground-control aspects of an experimental shortwall operation in the upper Ohio valley," U.S. Bur. Mines, RI 8112 (1976). 30 pp.

483. Moebs, N. N. and Krickovic, S., "Air-sealing coal mines to reduce water pollution," U.S. Bur. Mines, RI 7354 (1970). 33 pp. MD70-72

484. Moore, T. L. and Turcotte, J. A., "Youghiogheny River basin mine drainage pollution abatement project," Gibbs & Hill, Inc., Rept. of Phase 1, to Pa. Dept. Mines Miner. Ind., 1969. (100 pp.) MD69-56

485. "Moraine State Park watershed area, Butler County," Gwin Engineers, Inc., Altoona, Pa., Rept. to Pa. Dept. Mines Miner. Ind., Mine Drainage Proj. MD-8A (1968). 109 pp. MD68-55

486. Morth, A. H., "Acid mine drainage: a mathematical model," Ph.D. Thesis, The Ohio State Univ., 1971. 165 pp. MD71-66

487. Morth, A. H. (1) and Smith, E. E. (2) [(1) Ohio Geol. Surv. and (2) Ohio State Univ.], "Acid mine drainage: a mathematical model," Fourth Symp. Coal Mine Drainage Res., Pittsburgh, Pa. by Coal Ind. Advisory Comm. to ORSANCO (1972). 11 pp. MD72-54

488. Morth, A. H. and Smith, E. E., "Kinetics of the sulfide-to-sulfate reaction," Symp. Fossil Fuels Environ. Pollut., ACS Div. Fuel Chem. Preprints 10 (1), 83-92 (1966). MD66-30

489. Morth, A. H., Smith, E. E., and Shumate, K. S. (Ohio State Univ.), "Pyrite systems: a mathematical model," Third Symp. Coal Mine Drainage Res. Preprints, Pittsburgh, Pa. (1970). pp 132-137. MD70-74

490. Morth, A. H., Smith, E. E., and Shumate, K. S., "Pyritic systems: a mathematical model," The Ohio State Univ. Res. Found., Rept. to EPA, Environ. Protection Technol. Ser. EPA-R2-72-002 (Nov. 1972). 171 pp. NTIS, PB-213 887. MD72-55

491. Moulton, E. Q., Ed., "The acid mine-drainage problem in Ohio," Ohio State Univ., Eng. Expt. Sta., Bull. 166 (1957). 158 pp. MD57-10

492. "Mountaineer water treatment plant highly efficient," Consol News 7 (6), 22-24 (1968). MD68-56

493. "Muddy Run mine drainage pollution abatement project: Operation Scarlift," Skelly and Loy, Engineers-Consultants, Rept. to Pa. Dept. Environ. Resour., Proj. No. SL-155 (Dec. 1971). 239 pp.+

494. Mull, D. S. and Pickering R. J. (U.S. Geol. Surv.), "Water resources of the Middlesboro area, Kentucky," Ky. Geol. Surv., Rept. Invest. No. 9, Series X, (1968). 51 pp. 7 plates. MD68-57

495. Murrie, G. W., Diamond, W. P., and Lambert, S. W., "Geology of the Mary Lee group of coalbeds, Black Warrior coal basin, Alabama," U.S. Bur. Mines, RI 8189 (1976). 49 pp.

496. Nelson, H. W., Snow, R. D., and Keyes, D. B. (Univ. Ill.), "Oxidation of pyritic sulfur in bituminous coal," Ind. Eng. Chem. 25, 1355-1358 (1933). MD33-2

497. Nelson, W. L. and Hall, E. P., "A proposed sealed circular coal-refuse pile," Mechanization 16 (12), 85-89 (1952). MD52-10

498. "Neutralized AMD overcomes plant water shortage," Coal Mining Process. 5 (2), 40-41 (1968). MD68-58

499. "New mine sealing techniques for water pollution abatement," Halliburton Co., Rept. to U.S. Dept. Int., FWQA, Water Pollut. Contr. Res. Ser. 14010 DMO 03/70 (1970). 163 pp. NTIS, PB-196 736. MD70-75

500. Newport, T. G., "Summary ground-water resources of Washington County, Pennsylvania," Pa. Geol. Surv., Bull. W-38 (1973). 32 pp.+

501. Newport, T. G., "Summary ground-water resources of Westmoreland County, Pennsylvania," Pa. Geol. Surv., Bull. W-37 (1973). 49 pp.+

502. "North Branch Potomac River Basin: mine drainage study," Skelly and Loy, Consultants-Engineers, Phase I, Task 1, Rept. to U.S. Army, Corps Engineers, Baltimore Dist., Feb. 13, 1976. 182 pp.

503. "Ohio River pollution survey - final report to the Ohio River Committee - Supplement 'C' - acid mine drainage studies," Office of Stream Sanitation, U.S. Public Health Serv., 1942. MD42-3

504. O'Melia, C. R. (Dept. Environ. Sci. Eng.), "Oxygenation of iron (II) in continuous reactions," Univ. N. C., Water Resour. Res. Inst., Rept. No. 23 (1969). 53 pp. MD69-57

505. O'Neill, B. J., Jr., "Limestones and dolomites of Pennsylvania," Part I. of "Atlas of Pennsylvania's Mineral Resources," Pa. Geol. Surv., Fourth Series, Bull. M 50 (1964). 83 pp.

506. "'Operation Yellowboy' - mine drainage plan, Bethlehem Mines Corporation Marianna Mine No. 58, Marianna, Pennsylvania," Dorr-Oliver Inc., Rept. to Pa. Coal Res. Bd., Jan. 1966. 48 pp.+ MD66-31

507. "Operation Yellowboy: mine drainage treatment plans and cost evaluation," Dorr-Oliver Inc., Rept. to Pa. Coal Res. Bd., June 1966. (79 pp.+) MD66-33

508. Overbey, W. K., Jr. (W. Va. Univ.), "Geologic evaluation of probable results of mining of Upper Freeport coal near Maple Run Monongalia County, West Virginia," Prepared for Cheat Lake Area Environmental Conservancy, Morgantown, W. Va., April 10, 1973. 17 pp.+ MD73-56

509. Owili-Eger, A.S.C. and Manula, C. B. (Pa. State Univ.), "Modeling and simulation of mine water drainage," 14th International APCOM Symp., Session on Environmental Planning for Underground Mines, Oct. 4-8, 1976. 21 pp.

510. Palowitch, E. R., "Materials handling and environmental control research," Mining Congr. J. 53 (4), 42-47 (1967). MD67-47

511. Palowitch, E. R. and Gray, T. E., "Washability characteristics of the Lower Hartshorne (Spadra) coalbed near Clarksville, Ark.," U.S. Bur. Mines, RI 6059 (1962). 13 pp.

512. Parizek, R. R. (1) and Tarr, E. G. (2) [(1) The Pa. State Univ. and (2) Knox, Bergman, Shearer Corp.], "Mine drainage pollution prevention and abatement using hydrogeological and geochemical systems," Fourth Symp. Coal Mine Drainage Res. Preprints, Pittsburgh, Pa. (1972). pp 56-82. MD72-59

513. Parks, B. C., "Mineral matter in coal," Proc. Second Conf. Origin and Constitution of Coal, Crystal Cliffs, N.S., by Nova Scotia Dept. Mines and Nova Scotia Res. Found., June 18-20, 1952. pp 272-292.

514. Parsons, J. D., "Literature pertaining to formation of acid-mine wastes and their effects on the chemistry and fauna of streams," Ill. Acad. Sci. Trans. 50, 49-59 (1957). MD57-12

515. Pash, E. A. (U.S. Dept. Int., FWQA, Wheeling, W. Va.), "The coal mine drainage problem in southwestern Pennsylvania," Spring Geography Conf. Environ. Pollut., Calif. State Coll., California, Pa., April 1970. 13 pp. MD70-79

516. Patterson, E. D. and VanLieu, J. A., "Coal resources of Butler County, Pennsylvania," U.S. Geol. Surv., Bull. 1143-C (1971). 43 pp.

517. Patterson, R. M. (The Don Chemical Company), "Stowing in abandoned mines for drainage control," Interstate Mining Compact Comm. Spring Meet., Pipestem, W. Va., by U.S. EPA, May 16, 1974. 7 pp. MD74-59

518. Paul, J. W., "Treating bituminous coal mines to reduce acid mine drainage," AIME Tech. Paper 628 (1935). 17 pp. MD35-2

519. Peeler, C. E., Jr. (to Diamond Alkali Company), "Treatment of earth strata containing acid forming chemicals," U.S. Pat. 3,094,846 (June 25, 1963). 6 pp. MD63-18

520. "Pennsylvania's ten year mine drainage pollution abatement program," Pa. Dept. Health, Sanit. Water Bd., Progr. Rept., April 1, 1966. (9 pp.) MD66-35

521. "Pennsylvania's ten year mine drainage pollution abatement program for abandoned mines," Pa. Dept. Health, Sanit. Water Bd., Progr. Rept., 2nd ed., March 1, 1967. 13 pp. MD67-48

522. "Pennsylvania's ten year mine drainage pollution abatement program for abandoned mines," Pa. Dept. Health, Sanit. Water Bd., Progr. Rept., 3rd ed., April 1, 1968. 11 pp. MD68-62

523. Penrose, R. G., Jr. (Cyrus Wm. Rice Div., NUS Corp.), "Limestone selection for permeable plug mine seals," Natl. Coal Assoc./Bitum. Coal Res., Inc., Fifth Symp. Coal Mine Drainage Res. Preprints, Louisville, Ky. (1974). pp 133-145. MD74-63

524. Penrose, R. G., Jr. and Holubec, I., "Laboratory study of self-sealing limestone plugs for mine openings," Cyrus Wm. Rice Div. - NUS Corp., and E. D'Appolonia Consulting Engineers, Inc., Rept. to EPA, Environ. Protection Technol. Ser. EPA-670/2-73-081 (Sept. 1973). 217 pp. NTIS, PB-228 586/AS. MD73-57

525. Perry, R. E., Gandrud, B. W., Riley, H. L., Gayle, J. B., and Eddy, W. H., "Laboratory and full-scale sulfur elimination tests on coal from Pratt bed, Alabama," U.S. Bur. Mines, RI 5397 (1958). 25 pp.

526. Phillips, T. L., Peppers, R. A., Avcin, M. J., and Laughman, P. F., "Fossil plants and coal: patterns of change in Pennsylvanian coal swamps of the Illinois basin," Science <u>187</u> (4144), 1367-1369 (June 28, 1974). Ill. State Geol. Surv., Reprint Ser. 1974M.

527. "Physical properties of mine rocks," U.S. Bur. Mines: Part I by S. L. Windes, RI 4459 (1949). 79 pp. Part II by S. L. Windes, RI 4727 (1950). 37 pp. Part III by B. E. Blair, RI 5130 (1955). 69 pp. Part IV, with Indexes, by B. E. Blair, RI 5244 (1956). 69 pp.

528. "Pilot scale study of acid mine drainage," The Ohio State Univ., Res. Found., Rept. to EPA, WQO, Water Pollut. Contr. Res. Ser. 14010 EXA 03/71 (1971). 84 pp. NTIS, PB-214 771 MD71-70

529. Poth, C. W., "Summary ground-water resources of Armstrong County, Pennsylvania," Pa. Geol. Surv., Bull. W-34 (1973). 38 pp.+

530. Poth, C. W., "Summary ground-water resources of Beaver County, Pennsylvania," Pa. Geol. Surv., Bull. W-39 (1973). 39 pp.+

531. Poth, C. W., "Summary ground-water resources of Butler County, Pennsylvania," Pa. Geol. Surv., Bull. W-36 (1973). 49 pp.+

532. Powell, A. R., "The analysis of sulfur forms in coal," U.S. Bur. Mines, Tech. Paper 254 (1921). 20 pp.

533. "Preparation of plans and specifications for pollution abatement activities in Cherry Creek watershed, Maryland," Skelly and Loy, Engineers-Consultants, and Zollman Associates, Rept. to Appalachian Regional Comm., ARC Contract #73-35/RPC 767, 1973. (109 pp.+) MD73-58

534. "Principles and guide to practices in the control of acid mine-drainage," Coal Industry Advisory Committee, Ohio River Valley Water Sanitation Commission, March 1964. MD64-12

535. "Proceedings of the National Symposium on the control of coal mine drainage," Pa. Dept. Health, Bur. Environ. Health, Publ. No. 4, 1962. 113 pp. MD62-19

536. "Processes, procedures, and methods to control pollution from mining activities," Skelly and Loy, Engineers-Consultants, and Penn Environmental Consultants, Inc., Rept. to U.S. EPA, Washington, D.C., EPA-430/9-73-011, Oct. 1973. 390 pp. MD73-60

537. "Progress report: mine sealing project: Decker No. 3 Mine," U.S. Bur. Mines, Pittsburgh Mining Res. Cent., Sept. 1963. 6 pp. MD63-20

538. Provost, J. M., Dowd, J. J., Abernethy, R. F., and Reynolds, D. A., "Estimate of known recoverable reserves of coking coal in Marion County, W. Va.," U.S. Bur. Mines, RI 5267 (1956). 30 pp.

539. Razzell, W. E. and Trussell, P. C. (Univ. British Columbia), "Isolation and properties of an iron-oxidizing Thiobacillus," J. Bacteriol. 85, 595-603 (1963).

540. Ream, V. H. (Christopher Coal Co.), "Lime slurry system at Pursglove No. 15 Mine," Mining Congr. J. 56 (1), 55-59 (1970). MD70-85

541. "Recommendations for water pollution control. Raccoon Creek basin, Ohio," U.S. Dept. Int., FWPCA, Wheeling Field Station, 1967. (81 pp.) MD67-50

542. Reidenouer, D., Williams, E. G., and Dutcher, R. R., "The relationship between paleotopography and sulfur distribution in some coals of western Pennsylvania," Econ. Geol. 62, 632-647 (1967).

543. Reinbold, R. H. (to Layne-New York Co., Inc.), "Mine water barrier," U.S. Pat. 3,469,405 (Sept. 30, 1969). 4 pp. MD69-65

544. Renton, J. J. and Hidalgo, R. V., "Some geochemical considerations of coal," W. Va. Geol. Ec. Surv., Coal-Geol. Bull. No. 4 (1975). 38 pp.+

545. Renton, J. J. (1), Hidalgo, R. V. (1), and Streib, D. L. (2) [(1) W. Va. Geol. Surv. and (2) Ohio Geol. Surv.], "Relative acid-producing potential of coal," W. Va. Geol. and Econ. Surv., Morgantown, W. Va., Environ. Geol. Bull. No. 11, (Aug. 1973). 7 pp. MD73-62

546. "The reserve base of bituminous coal and anthracite for underground mining in the eastern United States," U.S. Bur. Mines, IC 8655 (1974). 428 pp.

547. Ricca, V. T. and Chow, K. (Ohio State Univ.), "Acid mine drainage quantity and quality generation model," AIME 102nd Ann. Meet., Chicago, Ill., 1973. 38 pp. MD73-63

548. Rice, J. K. (Cyrus Wm. Rice Div., NUS Corp.), "Coal mining in an oxygen-free atmosphere," ASME Winter Ann. Meet., New York, N.Y., 1970. Preprint 70-WA/PID-4. 8 pp. MD70-87

549. Rice, J. K. (Cyrus Wm. Rice Div., NUS Corp.), "The use of inert gas to eliminate acid production by abandoned and active deep mines," Third Symp. Coal Mine Drainage Res. Preprints, Pittsburgh, Pa. (1970). pp 169-179. MD70-88

550. Riedinger, A. B., "Reverse osmosis field testing on acid mine waters at Norton, West Virginia," Gulf General Atomic, Inc., Final Rept. to U.S. Dept. Int., Office Saline Water, Jan. 17, 1969. 21 pp. MD69-67

551. Riley, H. L., Perry, R. E., and Gayle, J. B., "Washability study of coal from Mary Lee bed, Maben, Ala.," U.S. Bur. Mines, RI 5393 (1958). 14 pp.

552. Robins, J. D., "Gas requirements to pressurize abandoned deep mines," Cyrus Wm. Rice Div. - NUS Corp., Rept. to Pa. Dept. Environ. Resour. and U.S. EPA, Environ. Protection Technol. Ser. EPA-670/2-73-054 (Aug. 1973). 192 pp. NTIS, PB-224 831. MD73-65

553. Robins, J. D. and Hutchins, J. C., "Criteria for developing pollution abatement programs for inactive and abandoned mine site," Skelly and Loy, Engineers-Consultants, Rept. to U.S. EPA, Office Water Hazardous Materials, EPA-440/9-75-008, 1975. (510 pp.) MD75-35

554. Robins, J. D. and Troy, J. C., "The effects of various gas atmospheres on the oxidation of coal mine pyrites," Cyrus Wm. Rice Div., NUS Corp., Rept. to EPA, WQO, Water Pollut. Contr. Res. Ser. 14010 ECC 08/71 (1971). 140 pp. NTIS, PB-203 679. MD71-78

555. Roen, J. B., "A transcurrent structure in Fayette and Greene Counties, Pennsylvania," in "Geological Survey Research 1968, Chapter C," U.S. Geol. Surv., Prof. Paper 600-C (1960). pp 149-152.

556. Rogoff, M. H., Silverman, M. P., and Wender, I. (U.S. Bur. Mines), "The elimination of sulfur from coal by microbial action," ACS Div. Gas and Fuel Chem. Preprints, New York, N. Y., Sept. 1960. pp 25-36. MD60-20

557. Rozelle, R. B., "Studies on the kinetics of iron(II) oxidation in mine drainage," Wilkes College, Wilkes-Barre, Pa., Final Rept. to U.S. Dept. Int., Fed. Water Pollut. Contr. Admin., Sept. 25, 1968. 135 pp. MD68-65

558. Sanner, W. S., "Preparation characteristics of Pennsylvania anthracite from the Bottom Red Ash bed, northern field," U.S. Bur. Mines, RI 6989 (1967). 36 pp.

559. Sasmojo, S., "Oxidation kinetics of pyritic materials in aqueous media," Ph.D. Thesis, Ohio State Univ., 1969. 182 pp. MD69-69

560. Schnaitman, C. A., Korczynski, M. S., and Lundgren, D. G. (Syracuse Univ.), "Kinetic studies of iron oxidation by whole cells of *Ferrobacillus ferrooxidans*," J. Bacteriol. 99 (2), 552-557 (1969).

561. Schopf, J. M., "Field description and sampling of coal beds," U.S. Geol. Surv. Bull. 1111-B (1960). (109 pp.) 3 plates in pocket.

562. Schopf, J. M., Ehlers, E. G., Stiles, D. V., and Birle, J. D., "Fossil iron bacteria preserved in pyrite," Proc. Am. Philosophical Soc. 109 (5), 288-308 (1965).

563. Scott, R. B. (Crown Mine Drainage Control Field Site, Rivesville, W. Va.), "Evaluation of bulkhead seals," U.S. EPA, Office Res. Monitoring, Environ. Res. Center, Cincinnati, Ohio, Oct. 1972. 29 pp. MD72-67

564. Scott, R. B. (Norton Mine Drainage Field Site), "Evaluation of Shavers Fork Mine seals," EPA, WQO Publ. No. 14010--09/71 (1971). 14 pp.+ app. MD71-79

565. Scott, R. B. (1), Hill, R. D. (2), and Wilmoth, R. C. (1) [(1) U.S. Dept. Int., FWQA, Elkins, W. Va. and (2) U.S. Dept. Int., FWQA, Ohio Basin Region], "Cost of reclamation and mine drainage abatement - Elkins demonstration project," SME Fall Meet., St. Louis, Mo., 1970. Preprint 70AG349. 22 pp. (U.S. Dept. Int., FWQA Publ. No. 14010 --- 10/70) MD70-91

566. Scott, R. L. and Hays, R. M., "Inactive and abandoned underground mines - water pollution prevention & control," Michael Baker, Jr., Inc., Rept. to U.S. EPA Office Water Hazardous Materials, EPA-440/9-75-007 (1975). 338 pp. MD75-37

567. Selmeczi, J. G., "Evaluation of rate determining factors in the oxidation of sulfides in water," ACS Div. Water Air Waste Chem. Preprints 6 (1), 14-23 (1966).

568. "Sewickley Creek area, Pennsylvania," U.S. Dept. Int., Fed. Water Pollut. Contr. Admin., Monongahela River Mine Drainage Remedial Project 1966. 68 pp. MD66-42

569. Shearer, R. E. and Everson, W. A., "Effect of antibacterial agents on mine drainages. Use of viable antibacterial agents to reduce pollution by mine drainages," MSA Res. Corp., Rept. to U.S. Dept. Int., FWPCA, Water Pollut. Contr. Res. Ser., 14010EGJ 11/69 (1969). 138 pp. NTIS, PB-191 215. MD69-71

570. Shearer, R. E. and Everson, W. A., "Study of bacteriophages in controlling acid mine water," Symp. Acid Mine Drainage Res. Preprints, Pittsburgh, Pa. 1965. pp 23-34. MD65-42

571. Shearer, R. E., Everson, W. A., and Mausteller, J. W. (MSA Res. Corp.), "Reduction of acid production in coal mines with use of viable antibacterial agents," Second Symp. Coal Mine Drainage Res. Preprints, Pittsburgh, Pa., 1968. pp 98-106. MD68-68

572. Shearer, R. E. (1), Everson, W. A. (1), Mausteller, J. W. (1), and Zimmerer, R. P. (2) [(1) MSA Res. Corp. and (2) Juniata Coll.], "Characteristics of viable anti-bacterial agents used to inhibit acid-producing bacteria in mine waters," Third Symp. Coal Mine Drainage Res. Preprints, Pittsburgh, Pa. (1970). pp 188-199. MD70-92

573. Sholes, M. A. and Skema, V. W., "Bituminous coal resources in western Pennsylvania," Pa. Geol. Surv., Miner. Resour. Rept. 68 (1974). 13 plates.

574. Shotts, R. Q., "A summary of the composition and technology of the coals of Bibb County, Alabama: compiled from the published literature," Ala. Geol. Surv., Circ. 73 (1971). 72 pp.

575. Shumate, K. S. and Smith, E. E. (Ohio State Univ.), "Development of a natural laboratory for the study of acid mine drainage production," Second Symp. Coal Mine Drainage Res. Preprints, Pittsburgh, Pa., 1968. pp 223-235. MD68-69

576. Shumate, K. S. (1), Smith, E. E. (1), and Brant, R. A. (2)[(1) Ohio State Univ., and (2) ORSANCO], "A model for pyritic systems," ACS Div. Fuel Chem. Preprints 13 (2), 50-58 (1969). MD69-72

577. "Silicate treatment for acid mine drainage prevention," Tyco Lab., Inc., Rept. to EPA, WQO, Water Pollut. Contr. Res. Ser. 14010 DLI 02/71 (1971). 94 pp. MD71-80

578. Silverman, M. P. (U.S. Bur. Mines, Pittsburgh, Pa.), "Mechanism of bacterial pyrite oxidation," J. Bacteriol. 94 (4), 1046-1051 (1967). MD67-56

579. Silverman, M. P. and Lundgren, D. G. (Syracuse Univ.), "Studies on the chemoautotrophic iron bacterium *Ferrobacillus ferrooxidans*: I. An improved medium and a harvesting procedure for securing high cell yields," J. Bacteriol. 77 (5), 642-647 (1959). "II. Manometric studies," J. Bacteriol. 78 (3), 326-331 (1959). MD59-12, MD59-13

580. Silverman, M. P. Rogoff, M. H., and Wender, I., "Bacterial oxidation of pyritic materials in coal," Applied Microbiol. 9 (6), 491-496 (1961). MD61-18

581. Silverman, M. P., Rogoff, M. H., and Wender, I., "Removal of pyritic sulfur from coal by bacterial action," Fuel 42, 113-124 (1963).

582. Simon, J. A., "Slipping coal mines in Illinois," Ill. State Geol. Surv. Map, Scale 1-50,000, Jan. 1, 1966.

583. Singer, P. C. and Stumm, W. (Harvard Univ.), "Kinetics of the oxidation of ferrous ion," Second Symp. Coal Mine Drainage Res. Preprints, Pittsburgh, Pa., 1968. pp 12-34. MD68-70

584. Singer, P. C. and Stumm, W., "Oxygenation of ferrous iron: the rate-determining step in the formation of acidic mine drainage," Harvard Univ., Final Rept. to U.S. Dept. Int., FWPCA, Water Pollut. Contr. Res. Ser., 14010 ---06/69 (1969). 216 pp. NTIS, PB-189 223. MD69-73

585. Singer, P. C. and Stumm, W. (Harvard Univ.), "The rate-determining step in the production of acidic mine wastes," ACS Div. Fuel Chem. Preprints 13 (2), 80-87 (1969). MD69-74

586. Smirnov, V. V. (Perm Univ., USSR), "The role of the microbiological factor in increasing the corrosive aggressiveness of mine water of the Kizel coal basin," Mikrobiologiya 32 (4), 695-699 (1963). U.S. Dept. Comm., Clearinghouse Transl. No. TT63-41329. MD63-25

587. Smith, E. E., "Engineering aspects of acid mine drainage," Proc. Second Ann. Symp. Water Resour. Res., "Water Quality and Recreation in Ohio," Ohio State Univ., Columbus, Ohio, June 15-16, 1966. pp 187-203. MD66-45

588. Smith, E. E. (Ohio State Univ.), "Research needs related to chemical and physical aspects of acid mine waters," Presented, Acid Mine Water Research Needs Workshop, Morgantown, W. Va., Nov. 10-12, 1976. 12 pp.

589. Smith, E. E. and Shumate, K. S. (Ohio State Univ.), "Rate of pyrite oxidation and acid production rate in the field," Acid Mine Drainage Workshop, Athens, Ohio, by Ohio Univ., 1971. 11 pp. MD71-83

590. Smith, E. E. and Shumate, K. S., "Sulfide to sulfate reaction mechanism," Ohio State Univ., Rept. to U.S. Dept. Int., FWQA, 14010 FPS 02/70 (1970). 115 pp. NTIS, PB-199 835. MD70-96

591. Smith, E. E., Shumate, K. S., and Svanks, K. (Ohio State Univ.), "Sulfide to sulfate reaction studies," Second Symp. Coal Mine Drainage Res. Preprints, Pittsburgh, Pa., 1968. pp 1-11. MD68-73

592. Smith, E. E., Svanks, K., and Halko, E. (Ohio State Univ.), "Aerobic-anaerobic oxidation of pyrite," ACS Div. Fuel Chem. Preprints 13 (2), 68-78 (1969). MD69-75

593. Smith, G. E. (Pa. Dept. Mining Miner. Ind.), "Swatara Creek watershed abatement project," Second Symp. Coal Mine Drainage Res. Preprints, Pittsburgh, Pa., 1968. pp 236-245. MD68-74

594. Smith, W. H., Nance, R. B., Hopkins, M. E., Johnson, R. G., "Depositional environments in parts of the Carbondale formation, western and northern Illinois, Francis Creek shale and associated strata, and Mazon Creek biota," Ill. State Geol. Surv., Guidebook Ser. No. 8 (1970). 119 pp.

595. Smith, W. H. and Stall, J. B., "Coal and water resources for coal conversion in Illinois," Ill. State Geol. Surv. and Ill. State Water Surv., Coop. Resour. Rept. 4 (1975). 79 pp. 3 plates.

596. Snodgrass, J. J., "Calibration models for geophysical borehole logging," U.S. Bur. Mines, RI 8148 (1976). 21 pp.

597. Snyder, N. H. and Swingle, R. J., "Analyses of Pennsylvania bituminous coals from July 1, 1937, to June 30, 1941: supplement to Technical Paper 590," U.S. Bur. Mines, Tech. Paper 645 (1942). 19 pp.

598. "Sources of coal mine drainage pollution. Raccoon Creek watershed, Pennsylvania," U.S. Dept. Int. FWPCA, Wheeling Field Station, Work Document No. 28 (1968). 45 pp. MD68-77

599. "Sources of coal mine drainage pollution. Wheeling Creek watershed, Ohio," U.S. Dept. Int., FWPCA, Wheeling Field Station, Work Document No. 25 (1968). 22 pp.+ MD68-78

600. Spencer, F. D., "Coal resources of Indiana," U.S. Geol. Surv., Circ. 266 (1953). 42 pp.

601. Sponseller, R. D., "Analyses and measured sections of Pennsylvania bituminous coals," Pa. Geol. Surv., Fourth Ser., Miner. Resour. Rept. 66 (1973). 23 pp.+ data sheets.

602. Sprunk, G. C., Ode, W. H., Selvig, W. A., and O'Donnell, H. J., "Splint coals of the Appalachian region: their occurrence, petrography, and comparison of chemical and physical properties with associated bright coals," U.S. Bur. Mines, Tech. Paper 615 (1940). 59 pp.

603. "The status of active deep mines in the Monongahela River basin," U.S. EPA, Region III, Wheeling Field Office, Surveillance Anal. Div., Work Document No. 46 (1973). 129 pp. MD73-69

604. Stefanko, R. (Pa. State Univ.), "Subsurface disposal of mine water," AIME Preprint No. 69-AIME-10 (1969). 16 pp.+ ACS Div. Fuel Chem. Preprints 13 (2), 95-102 (1969). MD69-78

605. Steinberg, M., Pruzansky, J., Jefferson, L. R., and Manowitz, B., "Removal of iron from mine drainage waste with the aid of high-energy radiation. Part II," Brookhaven Natl. Lab., BNL 12114 (1967). 23 pp. MD67-61

606. Steinman, H. E., "Acid mine water neutralization," Presented, AMC Meet., Pittsburgh, Pa., May 1966. 11 pp.+ MD66-46

607. Steinman, H. E., "Controlled mine water drainage," Ind. Water and Wastes 5, 201-203 (1960). MD60-21

608. Stephan, R. W. and Lorenz, W. C., "A review of current research on coal mine drainage in Appalachia," U.S. Bur. Mines, Area I Miner. Resource Office, Pittsburgh, Pa. (1967). 26 pp. MD67-62

609. Stoddard, C. K., "Abatement of mine drainage pollution by underground precipitation," Parsons-Jurden Div., The Ralph M. Parsons Co., Rept. to EPA, Environ. Protection Technol. Ser. EPA-670/2-73-092 (Oct. 1973). 125 pp. NTIS, PB-229 407/AS. MD73-70

610. "Stream pollution by coal mine drainage, Captina Creek basin, Ohio," U.S. Dept. Int., FWPCA, Wheeling Field Station, Work Document No. 23 (1968). 14 pp. MD68-85

611. "Stream pollution by coal mine drainage in Appalachia," U.S. Dept. Int., FWPCA, Cincinnati, Ohio, 1967, Revised 1969. 270 pp. MD67-63, MD69-79

612. Stumm, W. (Harvard Univ.), "Oxygenation of ferrous iron - properties of aqueous iron as related to mine drainage pollution," Symp. Acid Mine Drainage Res. Preprints, Pittsburgh, Pa., 1965. pp 51-63. MD65-51

613. Stumm, W. and Lee, G. F., "Oxygenation of ferrous iron," Ind. Eng. Chem. 53 (2), 143-146 (1961). MD61-19

614. Stumm-Zollinger, E. (Harvard Univ.), "Die bakterielle Oxydation von Pyrit (Bacterial mediation in the oxidation of pyrite)," Arch. Mikrobiol. 83, 110-119 (1972). (In German with English summary). MD72-72

615. Stutzer, O., "Geology of coal," Translated and Revised by A. C. Noé, Chicago: Univ. Chicago Press, 1940. 461 pp.

616. Subitzky, S., "Hydrogeologic studies, Allegheny County, Pennsylvania," U.S. Geol. Surv., Misc. Field Studies, Maps MF-641A-MF641E (1976). 5 plates.

617. "Substantial progress reported in mine seal program," Coal Mining 15 (2), 8-10 (1938). MD38-8

618. "Susquehanna River basin study - Appendix F - water supply and water quality," Susquehanna River Basin Study Coordinating Comm., Rept. to Water Resour. Council (1970). 262 pp. MD70-104

619. "Susquehanna River basin study - Summary," Susquehanna River Basin Study Coordinating Comm., Rept. to Water Resour. Council (1970). 157 pp. MD70-105

620. Tabita, R., Kaplan, M., and Lundgren, D. G. (Syracuse Univ.), "Microbial ecology of mine drainage," Third Symp. Coal Mine Drainage Res. Preprints, Pittsburgh, Pa. (1970). pp 94-113. MD70-106

621. Tavenner, W. H., Dowd, J. J., Abernethy, R. F., and Reynolds, D. A., "Estimate of known recoverable reserves of coking coal in Logan County, W. Va.," U.S. Bur. Mines, RI 5259 (1956). 50 pp.

622. Temple, K. L., "Investigations on coal mine drainage - Annual Report, July, 1948 to July, 1949," W. Va. Univ., Eng. Expt. Sta., Ind. Res. Fellowship No. 11, July 1949. 17 pp.+ MD49-6

623. Temple, K. L., "Investigations on coal mine drainage - Annual Report, July 1950 - July 1951," W. Va. Univ., Eng. Expt. Sta., Ind. Res. Fellowship No. 11, July 1951. 8 pp. MD51-9

624. Temple, K. L., "Investigations on coal mine drainage - Interim Report No. 19," W. Va. Univ., Eng. Expt. Sta., Ind. Res. Fellowship No. 11, Nov. 1952. 13 pp. MD52-13

625. Temple, K. L., "Investigations on coal mine drainage - Quarterly Report, January - March 1950," W. Va. Univ., Eng. Expt. Sta., Ind. Res. Fellowship No. 11, Apr. 1950. 11 pp. MD50-17

626. Temple, K. L., "Investigations on coal mine drainage - Semi-annual Report, July 1951 to January 1952," W. Va. Univ., Eng. Expt. Sta., Ind. Res. Fellowship No. 11, March 1952. 8 pp.+ MD52-14

627. Temple, K. L., "Investigations on coal mine drainage - Semi-annual Report, January 1952 to July 1952," W. Va. Univ., Eng. Expt. Sta., Ind. Res. Fellowship No. 11, July 1952. 34 pp. MD52-15

628. Temple, K. L. and Colmer, A. R., "The autotrophic oxidation of iron by a new bacterium: Thiobacillus ferrooxidans," J. Bacteriol. 62 (5), 605-611 (1951). MD51-10

629. Temple, K. L. and Colmer, A. R., "The formation of acid mine drainage," Trans. AIME 190, 1090-1092 (1951). MD51-11

630. Temple, K. L. and Colmer, A. R. (W. Va. Univ.), "The formation of acid mine drainage," Eng. Ext. Ser. No. 76, Purdue Univ., Proc. 6th Ind. Waste Conf., Feb. 21-23, 1951. pp 285-291 MD51-12

631. Temple, K. L. and Colmer, A. R., "Investigations on coal mine drainage - Semi-annual Report, July 1950 - December 1950," W. Va. Univ., Eng. Expt. Sta., Ind. Res. Fellowship No. 11, Feb. 1951. 11 pp. MD51-13

632. Temple, K. L. and Koehler, W. A., "Drainage from bituminous coal mines," W. Va. Univ., Eng. Expt. Sta., Res. Bull. 25 (1954). 35 pp. MD54-20

633. Temple, K. L. and Koehler, W. A., "Investigations on coal mine drainage - Annual Report, July 1949 - July 1950," W. Va. Univ., Eng. Expt. Sta., Ind. Res. Fellowship No. 11, July 1950. 21 pp. MD50-19

634. Temple, K. L. and Koehler, W. A., "Investigations on coal mine drainage - Quarterly Report, July 1 to September 30, 1948," W. Va. Univ., Eng. Expt. Sta., Ind. Res. Fellowship No. 11, Oct. 1948. 8 pp. MD48-7

635. Temple, K. L. and Koehler, W. A., "Investigations on coal mine drainage - Quarterly Report, October 1 to December 31, 1948," W. Va. Univ., Eng. Expt. Sta., Ind. Res. Fellowship No. 11, Jan. 1949. 6 pp. MD49-7

636. Temple, K. L. and Koehler, W. A., "Investigations on coal mine drainage - Semi-annual Report, July 1 to December 31, 1949," W. Va. Univ., Eng. Expt. Sta., Ind. Res. Fellowship No. 11, Jan. 1950. 14 pp. MD50-18

637. Thiessen, R. and Sprunk, G. C., "Coal paleobotany," U.S. Bur. Mines, Tech. Paper 631 (1941). 56 pp.

638. Thomas, J., Jr. and Damberger, H. H., "Internal surface area, moisture content and porosity of Illinois coals: variations with coal rank," Ill. State Geol. Surv., Circ. 493 (1976). 38 pp.

639. Thompson. D. R. and Emrich, G. H. (Pa. Dept. Health, Div. Sanit. Eng.), "Hydrogeologic considerations for sealing coal mines," 40th Ann. Conf. Water Pollut. Contr. Assoc. Pa., University Park,Pa., 1968. 5 pp. MD68-87

640. Thomson, R. D. and York, H. F., "The reserve base of U.S. coals by sulfur content. 1. The eastern states," U.S. Bur. Mines, IC 8680 (1975). 537 pp.

641. Tisdale, E. S. and Lyons, E. W., "Acid mine-drainage control on upper Ohio River tributaries," J. Amer. Water Works Assoc. 27, 1186-1198 (1935). MD35-3

642. Tisdale, E. S. and Lyons, E. W., "The mine sealing program on the Ohio River watershed," J. Amer. Water Works Assoc. 26, 1843-1852 (1934). MD34-4

643. "Toby Creek mine drainage pollution abatement project," Lee-Simpson Associates, Inc., Rept. to Pa. Dept. Environ. Resour., Proj. SL-132 (undated). 33 pp.+ app. MD71-90

644. Toenges, A. L., Davis, J. D., Turnbull, L. A., and Schopf, J. M., "Reserves, bed characteristics, and coking properties of the Willow Creek coal bed, Kemmerer District, Lincoln County, Wyo.," U.S. Bur. Mines, Tech. Paper 673 (1945). 48 pp.

645. Toenges, A. L., Turnbull, L. A., Williams, L., Smith, H. L., O'Donnell, H. J., Cooper, H. M., Abernethy, R. F., and Waage, K., "Investigation of lower coal beds in Georges Creek and north part of upper Potomac basins, Allegany and Garrett Counties, MD.," U.S. Bur. Mines, Tech. Paper 725 (1949). 142 pp., with 11 accompanying maps.

646. Tolsma, J. and Johnson, A. N., "Use of latex as a soil sealant to control acid mine drainage," Uniroyal, Inc., Rept. to EPA, Office Res. Monit., and Pa. Dept. Environ. Resour., Water Pollut. Contr. Res. Ser. 14010 EFK 06/72 (1972). 84 pp. NTIS, PB-213 040. MD72-77

647. Travis, R. G., Dowd, J. J., Abernethy, R. F., and Reynolds, D. A., "Estimate of known recoverable reserves of coking coal in Monongalia County, W. Va.," U.S. Bur. Mines, RI 5233 (1956). 30 pp.

648. Tuttle, J. H., Dugan, P. R., MacMillan, C. B., and Randles, C. I. (Ohio State Univ.), "Microbial dissimilatory sulfur cycle in acid mine water," J. Bacteriol. 97 (2), 594-602 (1969). MD69-83

649. Tuttle, J. H., Dugan, P. R., and Randles, C. I. (Ohio State Univ.), "Microbial sulfate reduction and its potential utility as an acid mine water pollution abatement procedure," Appl. Microbiol. 17 (2), 297-302 (1969). MD69-84

650. "Two Lick Creek mine drainage pollution abatement project," L. Robert Kimball, Consulting Engr., Rept. to Pa. Dept. Mines Miner. Ind., Project No. SL-109 (1971). 265 pp. MD71-91

651. "U. S. coal mine production by seam - 1975," New York, New York: McGraw Hill, Inc., Keystone Coal Industry Manual, Mining Informational Services, 1976. 629 pp.

652. "Underground coal mining in the United States: research and development programs," TRW Systems Group, Rept. No. 13497-6001-RO-00, to Office Sci. Technol., June 1970. (291 pp.). U.S. Bur. Mines OFR 10-70.

653. Van Lieu, J. A. and Patterson, E. D., "Coal resources of Lawrence County, Pennsylvania," U.S. Geol. Surv., Bull. 1143-B (1964). 33 pp.

654. Wagner, W. R., Craft, J. L., Heyman, L., and Harper, J. A., "Greater Pittsburgh region geologic map and cross sections," Pa. Geol. Surv. Map 42 (1975). 4 plates

655. Walitt, A., Jasinski, R., Keilin, B., and Gruber, A. (Tyco Lab., Inc.), "Prevention of acid mine drainage: silicate treatment of coal mine refuse piles," Third Symp. Coal Mine Drainage Res., Pittsburgh, Pa., by Coal Ind. Advisory Comm. to ORSANCO, (1970). 17 pp. MD70-110

656. Walker, F. E. and Hartner, F. E., "Forms of sulfur in U.S. coals," U.S. Bur. Mines, IC 8301 (1966). 51 pp.

657. Walker, F. K., "Bibliography and index of U.S. Geological Survey publications relating to coal, January 1971 - June 1974," U.S. Geol. Surv., Circ. 709, Suppl. to Geol. Surv. Bull. 1377. (1975). 14 pp.

658. Walker, J. G. and Randles, C. I. (Ohio State Univ.), "Mechanism of pyrite oxidation," Symp. Acid Mine Drainage Res. Preprints, Pittsburgh, Pa., 1965. pp 10-13. MD65-54

659. Wallace, J. J., Dowd, J. J., Bowsher, J. A., Abernethy, R. F., and Reynolds, D. A., "Estimate of known recoverable reserves of coking coal in Somerset County, Pa.," U.S. Bur. Mines, RI 4998 (1953). 19 pp.

660. Wallace, J. J., Dowd, J. J., Provost, J. M., Abernethy, R. F., and Reynolds, D. A., "Estimate of known recoverable reserves of coking coal in Allegheny County, Pa.," U.S. Bur. Mines, RI 5003 (1953). 16 pp.

661. Wallace, J. J., Dowd, J. J., Provost, J. M., Abernethy, R. F., and Reynolds, D. A., "Estimate of known recoverable reserves of coking coal in Greene County, Pa.," U.S. Bur. Mines, RI 5143 (1955). 22 pp.

662. Wallace, J. J., Dowd, J. J., Provost, J. M., Abernethy, R. F., and Reynolds, D. A., "Estimate of known recoverable reserves of coking coal in Washington County, Pa.," U.S. Bur. Mines, RI 5109 (1955). 23 pp.

663. Wallace, J. J., Dowd, J. J., Tavenner, W. H., Abernethy, R. F., and Reynolds, D. A., Estimate of known recoverable reserves of coking coal in Mingo County, W. Va.," U.S. Bur. Mines, RI 5068 (1954). 57 pp.

664. Wallace, J. J., Dowd, J. J., Tavenner, W. H., Provost, J. M., Abernethy, R. F., and Reynolds, D. A., "Estimate of known recoverable reserves of coking coal in McDowell County, W. Va.," U.S. Bur. Mines, RI 4924 (1952). 26 pp.

665. Wallace, J. J., Dowd, J. J., Travis, R. G., Abernethy, R. F., and Reynolds, D. A., "Estimate of known recoverable reserves of coking coal in Harlan County, Ky.," U.S. Bur. Mines, RI 5037 (1954). 26 pp.

666. Wallace, J. J., Dowd, J. J., Travis, R. G., Abernethy, R. F., and Reynolds, D. A., "Estimate of known recoverable reserves of coking coal in Letcher County, Ky.," U.S. Bur. Mines, RI 5016 (1953). 26 pp.

667. Wallace, J. J., Dowd, J. J., Travis, R. G., Abernethy, R. F., and Reynolds, D. A., "Estimate of known recoverable reserves of coking coal in Perry County, Ky.," U.S. Bur. Mines, RI 5083 (1954). 26 pp.

668. Wallace, J. J., Dowd, J. J., Williams, L., Abernethy, R. F., and Reynolds, D. A., "Estimate of known recoverable reserves of coking coal in Allegany County, Md.," U.S. Bur. Mines, RI 4970 (1953). 18 pp.

669. Walsh, F. M., "An ecological approach to acid mine pollution control," Rept. by Eco-Control, Inc. (Nov. 1970). 21 pp. MD70-111

670. Walsh, F. and Mitchell, R. (Harvard Univ.), "Biological control of acid mine pollution," J. Water Pollut. Contr. Fed. 44 (5), 763-768 (1972). MD72-80

671. Walsh, F. and Mitchell, R. (Harvard Univ.), "Mine drainage pollution reduction by inhibition of iron bacteria," Water Res. 9, 525-528 (1975). MD75-45

672. Walsh, F. and Mitchell, R. (Harvard Univ.), "A pH-dependent succession of iron bacteria," Environ. Sci. Technol. 6 (9), 809-812 (1972). MD72-81

673. Wanless, H. R., "Depositional basins of some widespread Pennsylvanian coal beds in the United States," Proc, Third Conf. Origin and Constitution of Coal, Crystal Cliffs, N.S., by Nova Scotia Dept. Mines, and Nova Scotia Res. Found., June 20-22, 1956. (1961). pp 94-128.

674. Wanless, H. R., "Studies of field relations of coal beds: Part I. Studies on coalification; Part II. Widespread partings in coal beds," Proc. Second Conf. Origin and Constitution of Coal, Crystal Cliffs, N.S., by Nova Scotia Dept. Mines and Nova Scotia Res. Found., June 18-20, 1952. pp. 148-180.

675. "Water treatment plant attractive and efficient," Consol News 7 (4), 6-7 (1968). MD68-96

676. Wayman, C. H. (Colo. School Mines), "Abatement procedures related to acid mine drainage," AIChE, Proc. Ind. Water Design for Water Pollut. Contr., Vol. 2, pp 38-44 (1969). MD69-88

677. "We can control acid mine waters," Summary Proceed., Spring Meet., Interstate Comm. Potomac River Basin, Bedford, Pa., May 8-9, 1958. 41 pp. MD58-10

678. Weller, J. M., "Patterns in Pennsylvanian cyclothems," Proc. Third Conf. Origin and Constitution of Coal, Crystal Cliffs, N.S., by Nova Scotia Dept. Mines and Nova Scotia Res. Found., June 20-22, 1956. (1961). pp. 129-171.

679. "West Virginia acid mine drainage study in North Branch Potomac River basin," W. Va. Dept. Natural Resour., Div. Water Resour., 1974. 77 pp. MD74-84

680. White, D., Thiessen, R., and Davis, C. A., "The origin of coal," U.S. Bur. Mines, Bull. 38 (1913). 390 pp.

681. White, G. W., "Waynesburg coal in Harrison and northern Belmont Counties, Ohio, and revision of Dunkard (Permian) boundary," Ohio Geol. Surv., RI No. 1, reprinted from Ohio J. Sci. XLVII (2), 55-58 (1947).

682. Whitesell, L. B., Jr., Huddleston, R. L., and Allred, R. C. (Continental Oil Co.), "The microbiological oxidation of ferrous iron in mine drainage water," ACS Div. Fuel Chem., 157th Natl. Meeting, Minneapolis, Minn., Apr. 13-18, 1969. 19 pp. MD69-89

683. Whitesell, L. B., Jr. (1), Huddleston, R. L. (1), and Kosowski, Z. V. (2) [(1) Continental Oil Co. and (2) Consolidation Coal Co.], "The microbiological oxidation of ferrous iron in mine drainage water--pilot plant studies," Presented, ACS 162nd Natl. Meet., Washington, D. C., Sept. 12-17, 1971. 13 pp. MD71-97

684. Whitfield, E. J. and Zabban, W., "Saw Mill Run, Allegheny County, Pennsylvania, report on sources of acid mine drainage," Chester Engineers, Inc., Rept. to Pa. Dept. Mines Miner. Ind., 1969. 33 pp. MD69-90

685. Wilbar, C. L., Jr., "Water pollution control in the Monongahela River basin," Pa. Dept. Health, Div. Sanit. Eng., Publ. No. 6, 1963. 86 pp.+ MD63-27

686. Williams, E. G. and Keith, M. L., "Relationship between sulfur in coals and the occurrence of marine roof beds," Econ. Geol. 58, 720-729 (1963).

687. Williams, L., Abernethy, R. F., Gandrud, B. W., Reynolds, D. A., and Wolfson, D. E., "Estimate of known recoverable reserves and the preparation and carbonizing properties of coking coal in Overton County, Tenn.," U.S. Bur. Mines, RI 5131 (1955). 27 pp.

688. Williams, L., Gibbs, H. K., Crentz, W. L., and Miller, J. W., "Estimate of known recoverable reserves and preparation characteristics of coking coal in Scott County, Tenn.," U.S. Bur. Mines, RI 5232 (1956). 36 pp.

689. Williams, L., Gibbs, H. K., Crentz, W. L., Miller, J. W., and Reynolds, D. A., "Estimate of known recoverable reserves and preparation and carbonizing properties of coking coal in Campbell County, Tenn.," U.S. Bur. Mines, RI 5258 (1956). 78 pp.

690. Williams, L. and Hershey, R. E., "Estimate of known recoverable reserves of coking coal in Bledsoe County, Tenn.," U.S. Bur. Mines, RI 5234 (1956). 18 pp.

691. Williams, L., Hershey, R. E., Abernethy, R. F., Gandrud, B. W., and Reynolds, D. A., "Estimate of known recoverable reserves and the preparation and carbonizing properties of coking coal in Sequatchie County, Tenn.," U.S. Bur. Mines, RI 5136 (1955). 28 pp.

692. Williams, L., Hershey, R. E., and Gandrud, B. W., "Estimate of known recoverable reserves and the preparation and carbonizing properties of coking coal in Marion County, Tenn.," U.S. Bur. Mines, RI 5159 (1955). 30 pp.

693. Williams, L., James, C., Crentz, W. L., and Miller, J. W., "Estimate of known recoverable reserves and the preparation characteristics of coking coal in Morgan County, Tenn.," U.S. Bur. Mines RI 5266 (1956). 43 pp.

694. Williams, L., James, C., Gandrud, B. W., and Reynolds, D. A., "Estimate of known recoverable reserves and the preparation and carbonizing properties of coking coal in Anderson County, Tenn.," U.S. Bur. Mines, RI 5185 (1955). 52 pp.

695. Williams, L., Lowe, R., Turnbull, L. A., Carman, E. P., Crentz, W. L., Reynolds, D. A., and Abernethy, R. G., "Estimate of known recoverable reserves and the preparation and carbonizing properties of coking coal in Putnam County, Tenn.," U.S. Bur. Mines, RI 5029 (1954). 21 pp.

696. Willman, H. B., Atherton, E., Buschbach, T. C., Collinson, C., Frye, J. C., Hopkins, M. E., Lineback, J. A., and Simon, J. A., "Handbook of Illinois stratigraphy," Ill. State Geol. Surv., Bull. 95 (1957). 261 pp.

697. Wilson, L. W., Matthews, N. J., and Stump, J. L., "Underground coal mining methods to abate water pollution," W. Va. Univ., Coal Res. Bur., Rept. to EPA, Water Pollut. Contr. Res. Ser. 14010 FKK 12/70 (1970). 50 pp. NTIS, PB-214 697. MD70-116

698. "Wyoming Valley mine drainage pollution abatement project," Pa. Dept. Health, Bur. Sanit. Eng., Div. Mine Drainage, Publ. No. 25 (undated). 27 pp. MD69-93

699. Yancey, H. F. and Geer, M. R., "Cleaning trials on subbituminous coal containing bentonitic clay from Lewis and Thurston Counties, Wash.," U.S. Bur. Mines, RI 5794 (1961). 21 pp.

700. Young, C. M., "Pollution of river water in the Pittsburgh district," J. Amer. Water Works Assoc. 8, 201-217 (1921). MD21-2

701. Young, G. K. and Gitto, L. F. (U.S. Dept. Int., FWPCA), "Streamflow regulation for acid control," IBM Sci. Computing Symp., Water Air Resour. Management, 1967. 24 pp. MD67-70

702. Young, G. K., Taylor, R. S., and Selekof, J. S., "Simulation and optimization of acid mine drainage abatement alternatives," Water Resources Engineers, Inc., Springfield, Va., Rept. to U.S. Army Corps of Engineers, Baltimore, Md., Jan. 1973. 70 pp.+ NTIS, AD-757 782. MD73-82

703. Zaval, F. J. and Robins, J. D., "Water infiltration control to achieve mine water pollution control - a feasibility study," Cyrus Wm. Rice Div. - NUS Corp., Rept. to W. Va. Dept. Natural Resour. and U.S. EPA, Environ. Protection Technol. Ser. EPA-R2-73-142 (Jan. 1973). 185 pp. NTIS, PB-217 886. MD73-83

704. Zawadzki, E. A. (Bitum. Coal Res., Inc.), "Status of mine drainage technology," Attachment B to Boyer, J. F., Jr., Statement before Subcom. Air, Water Pollution, Comm. Public Works, U.S. Senate, July 13, 1967. 33 pp. MD67-73

705. Zeilinger, J. E., "Preparation characteristics of coal from Beaver and Lawrence Counties, Pa.," U.S. Bur. Mines, RI 7324 (1969). 23 pp.

706. Zeilinger, J. E., "Preparation characteristics of coal from Clay, Gilmer, and Lewis Counties, W. Va.," U.S. Bur. Mines, RI 7216 (1969). 40 pp.

707. Zeilinger, J. E., "Preparation characteristics of coal from the Ohio coalfield," U.S. Bur. Mines, RI 7616 (1972). 72 pp.

708. Zeilinger, J. E. and Deurbrouck, A. W., "Preparation characteristics of coal from Clarion County, Pennsylvania," U.S. Bur. Mines, RI 7174, 1968. 34 pp.

709. Zeilinger, J. E. and Deurbrouck, A. W., "Preparation characteristics of Pennsylvania anthracite from the Kidney seam, northern field," U.S. Bur. Mines, RI 7364 (1970). 19 pp.

710. "Acid mine drainage in Appalachia," Appalachian Regional Comm., Rept. to President of the U.S. (1969). 126 pp. NTIS, PB-243 096/5WP. MD69-2

711. "Analyses of Alaska coals," U.S. Bur. Mines, Tech. Paper 682 (1946). 114 pp.+

712. Anderson, R. H., "Feasibility study - upper Meander Creek mine drainage abatement project," Stanley Consultants, Cleveland, O., Rept. to EPA, Office Res. Monit., Water Pollut. Contr. Res. Ser. 14010 HBQ 09/71 (1971). 53 pp. NTIS, PB-206 232. MD71-10

713. Aresco, S. J. and Haller, C. P., "Analyses of tipple and delivered samples of coal (collected during the fiscal year 1952)," U.S. Bur. Mines, RI 4972 (1953). 84 pp.

714. Ash, S. H., "Barrier pillars in Wyoming Basin, Northern field anthracite region of Pennsylvania," U.S. Bur. Mines, Bull. 538 (1954). 251 pp. 8 plates in pocket.

715. Ash, S. H., Davies, B. S., Jenkins, H. E., and Romisher, W. M., "Barrier pillars in Lackawanna Basin, Northern field anthracite region of Pennsylvania," U.S. Bur. Mines, Bull. 517 (1952). 114 pp. 4 plates in pocket.

716. Ash, S. H. and Kynor, H. D., "Barrier pillars in the Southern field anthracite region of Pennsylvania," U.S. Bur. Mines, Bull. 526 (1953). 44 pp. 10 plates in pocket.

717. Baker, A. R. and Koehrsen, L. G., "Report on acid mine-drainage control for state reclamation lands, Perry County, Ohio," Stanley Eng. Co., Rept. to Ohio Dept. Natural Resour. (1966). 99 pp. MD66-3

718. Barnes, F. F., "Coal resources of Alaska," U.S. Geol. Surv., Bull. 1242-B (1967). 36 pp.+

719. Beers, W. F. (2), Ciolkosz, E. J. (1), and Kardos, L. T. (1) [(1) Pa. State Univ., Dept. Agronomy and (2) Roy F. Weston, Inc.], Natl. Coal Assoc./Bitum. Coal Res., Inc., Fifth Symp. Coal Mine Drainage Res. Preprints, Louisville, Ky. (1974). pp 160-171. Also published as Pa. State Univ., Inst. Res. Land Water Resour., Reprint Ser. No. 37 MD74-5

720. Brant, J. W., "Loyalhanna Creek watershed engineering survey," Buchart-Horn Consulting Eng. Planners, Progr. Rept. to Pa. Dept. Mines Miner. Ind., Project No. SL-122, July 31, 1969. 30 pp. MD69-15

721. Brezina, E. R. (1), Campbell, R. S. (2), and Whitley, J. R. (3) [(1) Pa. Dept. Health, (2) Univ. Mo., and (3) Mo. Dept. Conserv.], "Effects of acid mine drainage on water quality of a reservoir," J. Water Pollut. Contr. Fed. <u>42</u> (8, Pt. 1), 1429-1436 (1970). MD70-13

722. Bucek, M. F., Emel, J. L., Petrus, C. A., and Schad, J. A. (HRB - Singer Inc.), "Evaluation of the environmental effectiveness of close down procedures - eastern underground coal mines," Natl. Coal Assoc./Bitum. Coal Res., Inc., Sixth Symp. Coal Mine Drainage Res., Louisville, Ky. (1976). 5 pp. MD76-4

723. Caraccio, F. T., Geidel, G., and Sewell, J. M. (Univ. S.C.), "Character of drainage as a function of the occurrence of framboidal pyrite and ground water quality in eastern Kentucky," Natl. Coal Assoc./Bitum. Coal Res., Inc., Sixth Symp. Coal Mine Drainage Res., Louisville, Ky. (1976). 16 pp. MD76-5

724. Carter, R. P., Zimmerman, R. E., and Kennedy, A. S., "Strip mine reclamation in Illinois," Argonne National Laboratory, Energy and Environ. Studies Div., Rept. to Ill. Inst. Environ. Qual., Dec. 1973. 296 pp. MD73-17

725. Clark, C. S., "The oxidation of coal mine pyrite," presented, ASCE National Symp. on Sanitary Eng. Res., Dev. and Design. July 1965.

726. Clark, L. J., "Mine drainage in the North Branch Potomac River basin," U.S. Dept. Int., FWPCA, Chesapeake Tech. Support Lab., Tech. Rept. No. 13 (1969). 80 pp. MD69-20

727. Collier, C. R., Pickering, R. J., and Musser, J. J. (Editors), "Influences of strip mining on the hydrologic environment of parts of Beaver Creek basin, Kentucky, 1955-66," U.S. Geol. Surv. Prof. Paper 427-C (1970). 80 pp. MD70-17

728. Davis, R. S. (1) and Maneval, D. R. (2) [(1) U.S. EPA Phila., Pa., (2) Appalachian Regional Comm.], "An intergovernmental project to improve environmental quality in an area of abandoned mines," Natl. Coal Assoc./ Bitum. Coal Res., Inc., Sixth Symp. Coal Mine Drainage Res., Louisville, Ky. (1976). 16 pp. MD76-11

729. Deane, J. A. (Peabody Coal Company), "The abatement program of Peabody Coal Company," Second Symp. Coal Mine Drainage Res. Preprints, Pittsburgh, Pa., 1968. pp 392-395. MD68-20

730. Estep-Barnes, P. A. and Kovach, J. J., "Chemical and mineralogical characterization of core samples from underground coal gasification sites in Wyoming and West Virginia," U.S. ERDA, Morgantown, W. Va., MERC/RI-75/2 (1975). 16 pp.

731. Fieldner, A. C., Rice, W. E., Moran, H. E., "Typical analyses of coals of the United States," U.S. Bur. Mines, Bull. 446 (1942). 45 pp.

732. Fieldner, A. C., Selvig, W. A., and Paul, J. W., "Analyses of mine and car samples of coal collected in the fiscal years 1916 to 1919," U.S. Bur. Mines, Bull. 193 (1922). 391 pp.

733. Fieldner, A. C., Smith, H. I., Paul, J. W., and Sanford, S., "Analyses of mine and car samples of coal collected in the fiscal years 1913 to 1916," U.S. Bur. Mines, Bull. 123 (1918). 478 pp.

734. "Gas requirements to pressurize abandoneddeep mines," Cyrus Wm. Rice Co., Rept. to Pa. Dept. Mines Miner. Ind., Coal Res. Bd., and U.S. Dept. Int., FWPCA (1969). 89 pp. MD 69-30

735. Geer, M. R. and Fennessy, F. D., "Washability of coals from the Matanuska Valley and Beluga River fields, Alaska," U.S. Bur. Mines, RI 6017 (1962). 33 pp.

736. Giovannitti, E. F. (Pa. Dept. Environ. Resour., Div. Mine Drainage & Erosion Control), "Control of pollution from deep bituminous coal mines in Pennsylvania," AIME Ann. Meet., San Francisco, Calif., 1972. 72-F-85. 17 pp. MD72-24

737. Gluskoter, H. J., "Composition of ground water associated with coal in Illinois and Indiana," Econ. Geol. 60, 614-620 (1965). MD65-16

738. Grubb, H. F. and Ryder, P. D., "Effects of coal mining on the water resources of the Tradewater River basin, Kentucky," U.S. Geol. Survey, Water-Supply Paper 1940, (1972). 83 pp. MD72-26

739. Hamilton, P. A., White, D. H., Jr., and Matson, T. K., "The reserve base of U.S. coals by sulfur content (in two parts) 2. The western states," U.S. Bur. Mines, IC 8693 (1975). 322 pp.

740. "Handbook of pollution control costs in mine drainage management," U.S. Dept. Int., FWPCA, 1966. 54 pp. MD66-19

741. Holland C. T., Corsaro, J. L., McGlothlin, C. W., and Ladish, D. J. (W. Va. Univ.), "Research on acid mine drainage control," W. Va. Coal Mining Inst. Ann. Meet., White Sulphur Springs, W. Va., 1967 (1968). pp 115-148. MD68-35

742. Hyde, L. W., "Acid mine drainage in Cane Creek basin, near Oakman, Walker County, Alabama," Geol. Surv. of Ala., Circular 64 (1970). 19 pp. MD70-49

743. "Keystone Coal Industry Manual," New York; McGraw-Hill, Inc., published annually.

744. Kinsel, N. A. (Univ. Pittsburgh), "New sulfur oxidizing iron bacterium: *Ferrobacillus sulfooxidans* sp. n.," J. Bacteriol. 80, 628-632 (1960). MD60-14

745. Klingensmith, R. S., Miorin, A. F., and Saliunas, J. R. (Gannett Fleming Corddry and Carpenter, Inc.), "At-source control through the application of several abatement techniques," Natl. Coal Assoc./Bitum. Coal Res., Inc., Sixth Symp. Coal Mine Drainage Res., Louisville, Ky. (1976). 15 pp. MD76-18

746. Krieger, R. A., Cushman, R. V., and Thomas, N. O. (U.S. Geol. Surv.), "Water in Kentucky," Ky. Geol. Surv., Ser. X, Spec. Publ. 16 (1969). 51 pp. MD69-47

747. "Lackawanna River mine drainage pollution abatement project Part I," Albert E. Peters Associates, Rept. to Pa. Dept. Environ. Resour., Proj. SL-139 (Nov. 30, 1971). 37 pp. + app. MD71-55

748. Leathen, W. W. and Braley, S. A., "A new iron-oxidizing bacterium: Ferrobacillus ferrooxidans," Reprinted from Bacteriol. Proc., May 1954. 1 pp. MD54-15

749. Lord, N. W., Holmes, J. A., Stanton, F. M., Fieldner, A. C., and Sanford, S.," Analyses of coals in the United States with descriptions of mine and field samples collected between July 1, 1904 and June 30, 1910," Part I. Analyses, Part II. Descriptions of samples, U.S. Bur. Mines, Bull. 22 (1913). 1200 pp.

750. McWhorter, D. B., Skogerboe, R. K., and Skogerboe, G. V. (Colo. State Univ.), "Water quality control in mine spoils: upper Colorado River basin," U.S. EPA Environ. Protection Technol. Ser. EPA-670/2-75-048 (June 1975). 99 pp. NTIS, PB-242 908/AS. MD75-25

751. "Mining guidebook - mine drainage and acid water treatment," Coal Age 77 (7), 159-165 (1972). MD72-52

752. "Monongahela River Mine Drainage Remedial Project," U.S. EPA, Div. Field Invest., Cincinnati, Summary Rept. to Enforcement Conf., Monongahela River & Its Tributaries, 1971. 235 pp. MD71-65

753. Parizek, R. R., "Prevention of coal mine drainage formation by well dewatering," Pa. State Univ., Spec. Res. Rept. SR-82 to Pa. Dept. Environ. Resour., April 15, 1971. 73 pp. MD71-69

754. "Rausch Creek watershed mine drainage pollution abatement project," Anthracite Research and Development Co., Inc., Rept. to Pa. Dept. Mines Miner. Ind., Proj. No. SL-112 (undated). 86 pp.+ MD70-84

755. "The Rausch Creek watershed treatment plant," Anthracite Res. Develop. Co. Inc., Preliminary Design Rept., Project No. SL-112, for Pa. Dept. Mines Miner. Ind. (1969). 10 pp. MD69-62

756. "Report to the Sanitary Water Board on pollution of Slippery Rock Creek - Volume II," Pa. Dept. Health, Div. Sanit. Eng. Publ. No. 17, April 1967. 109 pp. MD67-51

757. Reyes-Navarro, J. and Davis, A., "Pyrite in coal; its forms and distribution as related to the environments of coal deposition in three selected coals from western Pennsylvania," The Pa. State Univ., Coal Res. Section., SR-110 (1976). 141 pp.

758. Selvig, W. A., Ode, W. H., and Davis, J. D., "Low-temperature carbonization of Alaskan coals," U.S. Bur. Mines, Tech. Paper 668 (1944). 16 pp.

759. Singer, P. C. (1) and Stumm, W. (2) [(1) Univ. Notre Dame and (2) Harvard Univ.], "Acidic mine drainage: the rate-determining step," Science <u>167</u>, 1121-1123 (1970). MD70-94

760. "Slippery Rock Creek mine drainage pollution abatement project," Gwin Engineers, Inc., Rept. to Pa. Dept. Mines Miner. Ind., Proj. No. SL-110 (1970). 163 pp. MD70-95

761. Smith, E. E. (1), Shumate, K. S. (1), Singer, P. C. (2), and Stumm, W. (3) [(1) Ohio State Univ., (2) Univ. Notre Dame, and (3) Harvard Univ.], Science <u>169</u>, 98 (1970). MD70-97

762. Snyder, N. H. and Aresco, S. J., "Analyses of tipple and delivered samples of coal (collected during the fiscal years 1948 to 1950 inclusive)," U.S. Bur. Mines, Bull. 516 (1953). 133 pp.

763. Trainer, F. W. and Watkins, F. A., Jr., "Geohydrologic reconnaisance of the upper Potomac River basin," U.S. Geol. Surv., Water-Supply Paper 2035, 1975. 68 pp. 1 plate in pocket. MD75-42

764. Tybout, R. A., "Alternative economic responses to the acid mine drainage problem in Appalachia," Ohio State Univ., Water Resour. Cent., Proj. Completion Rept. to U.S. Dept. Int., Office Water Resour. Res. (1968). 42 pp. MD68-90

765. Tybout, R. A. (Ohio State Univ.), "A cost-benefit analysis of mine drainage," Second Symp. Coal Mine Drainage Res. Preprints, Pittsburgh, Pa., 1968. pp 334-371. MD68-91

766. Vonder Linden, K. and Stefanko, R., "Subsurface disposal of acid mine water," Symp. Fossil Fuels Environ. Pollut., ACS Div. Fuel Chem. Preprints <u>10</u> (1), 101-106 (1966). MD66-50

767. "Water resources data for Kentucky, 1969. Part I. Surface water records. Part 2. Water quality records," U.S. Geol. Surv. in cooperation with Commonwealth Ky., Univ. Ky., Ky. Geol. Surv. and other Federal agencies, 1970.

768. "Water resources data for West Virginia, 1969. Part 1. Surface water records. Part 2. Water quality records," U.S. Geol. Surv. in cooperation with state of West Virginia and other agencies, 1970. 175 pp.

769. Young, E. F., Jr. and Steinman, H. E. (Jones & Laughlin Steel Corp.), "Coal mine drainage treatment," Eng. Ext. Ser. No. 129, Purdue Univ., Proc. 22nd Ind. Waste Conf., 1967. pp 477-491. MD67-71

770. Huffman, R. E. and Davidson, N., "Kinetics of the ferrous iron-oxygen reaction in sulfuric acid solution," J. Am. Chem. Soc. <u>78</u>, 4836-4842 (1956).

771. Warfield, R. S. and Bolez, C. C., "Sampling and coking studies of several coalbeds in the Kokolik River, Kakpowruk River, and Cape Beaufort areas of Artic Northwestern Alaska," U.S. Bur. Mines, RI 7321 (1969). 58 pp.

772. Smith, R. M., Sobek, A. A., Arkle, T., Jr., Sencindiver, J. C., and Freeman, J. R., "Extensive overburden potentials for soil and water quality," W. Va. Univ., Rept. to U.S. EPA Ind. Environ. Res. Lab., Cincinnati, Ohio, Environ. Protection Technol. Ser. EPA-600/2-76-184 (1976). 311 pp.

# INDEX TO REFERENCES