USBM Contract G1115262

THE DEVELOPMENT OF GUIDELINES FOR CLOSING UNDERGROUND MINES EXECUTIVE SUMMARY

For

U.S. Department of Interior
Bureau of Mines
2401 E. Street, NW
Washington, D.C. 20241

under
State Mining and Mineral Resources and Research Institutes Program

by

Institute of Mineral Research
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December, 1983

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(Revised November 1982)
(460 EBM 7.1)

Date prepared June 28, 1984

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF MINES

APPROVAL AND DISTRIBUTION OF GRANT REPORTS

Title: "The Development of Guidelines for Closing Underground Mines. Executive Summary" 35 pp

Authors: Allan M. Johnson; Linneas Laage; Donald Butler

Report Date: December 1983   Type of Report (Final/Interim): FINAL

Sponsoring Organization: OSM/Bureau of Mines

Value/Impact of results: Improved closing procedures for underground mines.

Users/Audience: Mining engineers, regulators, legislative officials

grantee Name: Michigan Technological University

grant Number: G1115262, G1105033   Total grant Funding: 131,265

TPO: Program Manager:

Has grantee filed a Patent Form DI 1217? ☐ Yes ☒ No   If yes, attach Solicitor's approval to make public.

Press Release Recommendation: ☐ Yes ☒ No
Recommended for Open File: ☒ Yes ☐ No
Recommended for NTIS: ☐ Yes ☒ No

If no, explain: Does not meet NTIS standards

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Date Rec'd
OFR # 138(1)-84
NTIS # NA
# of pages
Price $

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Approved by GAO
B-190462 (RO697)
Expires October 31, 1983

☐ Program Narrative Statement ☐ Performance Report **SMMRRI Reports**

1. Grant Recipient	Type of Report	Reporting Period	Control Number(s)
Michigan Technological University Houghton, Michigan 49931 Dr. Lloyd Heldt, Director	Research	December 31, 1983 Final	G1115262

2. Project Title/Program

"The Development of Guidelines for Closing Underground Mines"

3. Investigator(s)/Fellowships Recipients

Johnson, Allan M., P.I.
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4. Performing Organization:

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5. Summary: Case histories were used to document and evaluate deficiencies in underground mine closures which have resulted in post-operation problems such as subsidence shaft failures, acid or toxic water drainage and others. Three different underground mining districts in the United States were investigated; 1) an iron mining district in Michigan 2) coal mining districts in eastern Ohio and southern Illinois and 3) three metal mining districts in central Colorado.

Previous work in the Michigan district on problems with subsidence and acid water drainage provided the background from which the concept for this project was developed. Student investigators working towards their MS degrees in Mining Engineering did the work on the eastern coal and western metal districts.

The combined studies show that problems from acid water drainage, subsidence and inadequately protected mine shafts are the most severe and widespread. Suggestions of a technical nature are presented as partial solutions to some of these problems. It was determined that pre-closure evaluations could result in the identification of some potential problems that may occur after the mine is closed. Early recognition of these problems would be an advantage for at this time more options are available to the mine operator to either prevent them or to plan for their occurrence. Mine closure and reclamation should be considered as a part of mining and be incorporated in the mining plan. This would result in reduced environmental impact and would be achieved at a lower overall cost to the mining companies and to society.

The role of water in the occurrence of several types of subsidence during mine flooding was significant at some mines in the Michigan district. These mechanisms which involve, friction reduction, gravity loading, overburden transport and hydraulic forces in a flooded mine probably have a broader effect than is currently recognized. Control of these processes may offer some interesting options during mine closure.

It is recognized that technical solutions alone cannot provide all of the answers to problems associated with underground mines. Education, modified attitudes on the part of regulators and operators, and a more realistic perception of the importance and value of mining by the general public are also needed.

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INTRODUCTION

Production of minerals from underground mines has been important to the industrial economy of the United States. The availability of abundant minerals at low cost has helped to make the United States a world power and at the same time provided an unparalleled standard of living for its citizens. Underground coal mining, for example, provided virtually all of our nation's coal until 1910 and currently contributes about half. This multibillion dollar industry currently provides about 20% of our energy needs and about 70 to 80% of our fossil fuel reserves.

Unfortunately, past mining practices have resulted in a variety of environmental problems such as subsidence, acid water drainage and inadequately protected mine shafts.

Recent studies performed by Michigan Technological University documented similar problems occurring in an underground iron mining district in northern Michigan. These studies revealed that simple steps taken at the time of mine closure could have reduced the environmental impact caused by problems at some mines.

This concept was presented in a proposal to the Office of Surface Mining in 1980, entitled "The Development of Guidelines For Closing Underground Mines". It was proposed that in addition to performing a more detailed evaluation of the iron mining district on the Menominee Range that two other underground mining districts would be examined; 1) an eastern coal district and 2) a western metal mining district. These two districts were to be studied by Mining Engineering students.

The proposal was funded and two students were selected for the project: 1) Linneas Laage who worked on problems with coal mines in Ohio and Illinois and 2) Donald Bulter who examined mine related problems in three metal mining districts in central Colorado (Leadville, Silvercliffe-Westcliffe and Cripple Creek-Victor). Both of these students received support from the project and have obtained Master of Science Degrees in Mining Engineering by preparing their reports as theses for graduate credit.

The results of the three studies are summarized in this report and an overall evaluation is made concerning suggestions for improved mine closure techniques and methods. Although the approach involved technical evaluations of mine-related problems in the various districts, each of the investigators recognized the importance of improvements in the non-technical areas; i.e., education, public image, regulations and enforcement.

Project Organization

Initially the responsibilities of the project were shared between Dr. Allan Johnson and Dr. S. Paul Sundeen as co-principal investigators. Dr. Johnson was responsible for overall project management. The two investigators were to share the research and report preparation and were to jointly serve as advisors to the two student investigators. However, Dr. Sundeen left the Institute of Mineral Research in June of 1982 and Dr. Johnson assumed full responsibility for the project at that time.

RECOMMENDATIONS

Based upon the combined results, conclusions and recommendations of the individual studies that comprise this report, two classes of recommendations concerning better procedures for closing underground mines are presented; 1) recommendations of a technical nature and 2) recommendations of a non-technical nature. They are presented separately.

Technical Recommendations

1. Mine closures should be considered as a part of mining and should receive as much attention as any other aspect of mining. Mine closure plans should be formulated and incorporated in the mining plan at the outset.
2. Prior to mine closure, a document should be prepared by the operator that includes all information relevant to subsidence potential, and any other problems which are anticipated or considered likely to occur following mine closure. The document should include all of the latest mine maps and detailed information on the shaft sealing and capping procedures to be employed. The document should become part of the title to the land and transfer with it. Copies should be made available to user groups. The preparation and distribution of the document by the operator should serve to limit his future liability.
3. A hydrologic evaluation should be made before the mine is closed to determine if a drainage problem is likely. If the evaluation indicates a likely problem, corrective steps can be taken prior to closure that would eliminate or reduce the drainage. These steps would include modifications to the "plumbing system" of the mine to alter or disrupt existing flow paths.

4. Special attention should be given to the design of mine shaft seals and caps. Shafts should be sealed with steel-reinforced concrete plugs which are keyed into the bedrock of the shaft. The shaft above the seal should be backfilled and a concrete surface cap should be added as a permanent marker. Both the seals and the cap should be vented to allow pressure equalization as the mine floods. The vent also allows water monitoring and helps to dissipate hydraulic forces that may be generated by post-flooding subsidence. Fencing should also be installed around the shaft area. If the shaft was sunk in poor ground, it should be backfilled.
5. Engineers responsible for developing closure plans should have a broad engineering background plus practical experience. Knowledge of mining, geology, chemistry, biology and civil engineering are desireable with special emphasis on rock and soil mechanics and surface, mine and groundwater hydrology. The training is necessary for them to have a good conceptual understanding of the mechanisms that operate in the regime of the closed mine. Their experience enables them to reliably design for and to accomodate these mechanisms.
6. Complete extraction of flat lying, bedded minerals such as coal is recommended. This would allow 100 percent recovery of a valuable resource and eliminate the effects of future subsidence.
7. The mechanisms which were operative during mine flooding in the Michigan case histories including water loading, friction reduction, sand washing, and piping should be investigated more fully. Some useful applications relating to mine stabilization during flooding may be developed from them.

Non-Technical Recommendations

1. Definitions of terms relating to mines that have ceased operation should be standardized. "Closed", "inactive" or "dormant" are terms that should be used as they apply. The term "abandoned" should receive little use as mines are no longer "abandoned". A great deal of preparation is required to properly close a mine and the use of the term "abandoned" is not an apt description. The use of the term "orphaned mine" should be discontinued.
2. Further and more extensive efforts should be made by the mineral industry, with the assistance of the federal government, to educate the general public concerning the need and the importance for a strong and viable domestic minerals industry.
3. Regulations governing the mineral industry should not be so specific that they do not allow innovative solutions. The regulations should be written to be goal-oriented.
4. Enforcement should be viewed as serving the intent of the law and not only the letter of the law.
5. Rather than having more and more regulations, a concept in which guidelines are put forth with rewards for compliance might be tried. This would require close cooperation between government and industry which is a desireable goal in itself.
6. Industry, in cooperation with government, should increase efforts to transfer technology and information relevant to improved mine closures and reduced environmental impact from mining activity.
7. A national minerals policy which recognizes the importance of a strong domestic minerals industry should be implemented. Of special importance would be efforts to devise methods, acceptable to the industry, that

would reduce the severe cyclicity inherent in the industry. The boom-bust cycles are deleterious to all aspects of industry including its economic well-being, ability to produce, national defense needs, retention of well-qualified people and consistent attention to reducing environmental problems resulting from mining.

SYNOPSIS OF RESULTS

Although case histories of problems resulting from past mining activity were investigated in three different and widely separated districts, the basic problems were found to be similar. In this section an attempt is made to combine the ideas and concepts of each of the investigators to address and find solutions to these problems with the hope that the whole shall add up to be more than its parts. The synopsis is divided into two parts, one on the technical aspects of the problems and the other on the non-technical --- both are important.

Technical Aspects

The goal of each of the three investigations was to identify problems resulting from past mining activity and, if possible, to suggest possible corrective solutions of a technical nature. These efforts were made by each investigator in his respective district or districts. Although it would be presumptuous to say, or to expect, that revolutionary methods and procedures have evolved, several good thoughts and ideas have resulted from this work. They are presented as follows.

Definitions. Mines that have ceased operations, whether permanently or temporarily, have been referred to variously as "closed", "shut-down", "defunct", "abandoned", "inactive" and most recently as "orphaned". There does not appear to be any uniformity of their use in the literature and, admittedly these terms were used indiscriminantly in the three reports from which this summary has been prepared. Yet, the various terms do have different meanings. For the sake of uniformity a mine that is permanently shut-down or closed should be referred to as a closed mine. A mine that is temporarily closed should be referred to as an inactive mine or perhaps a dormant operation (not mine). The use of the term abandoned carries with it a certain stigma that implies a lack of responsibility. For example, it would be accurate to say that a small mining operation was abandoned because the owners quit working and left the mine, never to return, without any preparation other than to pick up their tools and easily moved pieces of equipment. To apply the term abandoned to a mine at which an owner or company took the necessary or required steps to shut down the operation and leave the mine in a safe condition, is a grossly unfair use of the term. This practice should be discontinued. On the other hand, the recent use of the term orphaned mine is a thinly disguised attempt to provide a term with less stigma than the term abandoned. Supposedly, the term orphaned mine will be less offensive than the use of the term abandoned mine, and perhaps even generate sympathy for the mine. The use of the term orphaned should be discontinued.

Mine closure as an aspect of mining. Plans for closing should not be left until mining ceases. Mine closures should be an integral part of mining. They should receive the same emphasis as mine planning, production, and mine expansion. Many of the problems resulting from closed mines have arisen because so little attention was given to closure. The inadequate and poorly designed shaft cappings that were used as case history examples in all of the mining districts do generally go back to an earlier era. At that time it was common practice to leave the details of closing to a maintenance crew. They used materials available around the mine to cap the shafts as best they could. Consequently, many of the problems resulting from earlier closing procedures have occurred because mine closures were not given adequate thought or planning by qualified people. In many respects this problem is historic, although, all too often this concept of planned closures does not yet receive the attention that it merits. As the concept becomes accepted and practiced, these types of problems resulting from closed mines will occur less frequently and will become less severe.

Requirements of mine closure personnel. Ideally, those responsible for developing mine closure plans will have training in mining, rock and soil mechanics, groundwater and surface water hydrology, geology, rock alteration, water chemistry, biology, subsidence engineering, and civil engineering. Knowledge in these areas is needed in order to be familiar with the processes that take place in the various regimes of the closed mine. Moreover, the engineer(s) must be familiar with the forces operating within these regimes both qualitatively and quantitatively in order to design and specify the methods or structures that will accomodate these forces.

Obviously, a person with broad training and interests will be best suited to handle these many requirements. Ideally the person should have basic engineering expertise as a geological engineer, mining engineering or civil engineer with practical knowledge in the other areas. The background of the geological engineer with the proper options probably comes closest to meeting the overall educational requirements for this work.

In addition to education, the person responsible for this work should have a good basic grasp of engineering concepts, practical experience in applying them and the knack to rapidly reduce a complex problem to its basic essentials.

Subsidence

There are no easy answers or solutions to the problem of subsidence with underground mines. True, great strides have been made in ground control, roof support and rock mechanics, particularly in coal mining. These advances have enabled a better predictive capability of subsidence and its effects, but the best "solution" to the problem of subsidence is usually one of accomodation and not of prevention.

For underground mining of coal or of other minerals which occur in layered deposits that underlie large land areas, the best solution is to use mining methods that permit complete extraction of the mineral resource. Under these conditions the degree and extent of subsidence can be predicted and its effects planned for. As most of the damage to surface structures occurs in the compression zones in subsidence troughs or in tension zones on the flanks of the troughs, complete extraction would greatly reduce the numbers of these zones and thus some of the deleterious effects of subsidence.

Subsidence prediction and control in steeply dipping or vertical ore bodies is much more difficult. However, the area of land surface that is affected by any resulting subsidence is miniscule compared to coal mining activity, for example. More research should be done to learn more about subsidence over steep ore bodies so that it can be better controlled and predicted.

Complete extraction of ore in metal mines having ore with a cut-off grade is not a feasible concept. This cut-off grade is controlled by economics; the tenor of the ore must be such that the difference between the value of the metals and the cost of mining and extraction results in a profit. Thus, the determination of what is ore is subject to change. Although subsidence occurring at most metal mines can be extensive in terms of vertical displacement, its areal extent is greatly limited. Under these conditions, the best solution is to restrict the ultimate use of the undermined lands. They should be retained in singular ownership either by a mining company or held in ownership by a responsible governmental unit (local, state, or federal). If the mined land is sold or passed to other ownership the land should be retained as a block or unit (not subdivided), and certain restrictions concerning surface development should govern its use. Obviously, it would not be wise to allow construction of a housing development over the area, but it could be used for agriculture, forestry, grazing, or some other low intensity use.

Detailed records should be prepared by the mining company prior to mine closure, to document the extent of mining, the location and condition of the openings and supporting pillars and the information relavant to potential subsidence. Other information provided should include data on rock soundness, location of any previous subsidence areas, position and attitude of faults and shear zones, and the locations and conditions of all openings to the surface. This information should be prepared as a single document and be made available to various user-groups. The document should be part of the title of the property and transfer with it. The document should be updated as any new information becomes available; e.g., should any subsequent subsidence occur. The preparation of an adequate document should limit the liability to which the mining company or operator can be subjected to under law. This would help to insure both the accuracy of the document and cooperation from the owner or operator.

The only possible methods to eliminate any chance of subsidence above underground workings are to backfill the mine completely or to daylight the mine; i.e., cause the mine to cave completely. These methods are generally impractical except under unusual conditions. A less costly alternative is to monitor for subsidence activity by installing sensors. In this way the surface above mines could be safely used for some purposes.

The short term subsidence events that were documented in the Michigan case histories are of interest. The short term classification was defined as subsidence occurring during the time of mine flooding. In addition to rock mass adjustments caused by friction reduction and mass loading by flooding water, sand washing and piping mechanisms were also described. It was suggested that under the right conditions, these mechanisms could be employed to stabilize the mine openings against future subsidence. Moreover, the mechanisms could be enhanced to perform any desired degree of backfilling. The application of the piping mechanism for subsidence reduction offers an especially intriguing concept.

Mineralized Drainage

Mineralized drainage from underground mines and from surface sources (waste rock, tailings) is the most widespread and perplexing problem associated with mining activity. It includes not only acid drainage from the oxidation of sulfides, but also toxic metal drainage and the leaching of halides and other soluble minerals. The problem is persistent because it is a natural process. It is often severe when associated with mining activity because it has been enhanced by the exposure of new material to the enviroment.

Like subsidence, there are no easy solutions to this natural process. The solutions most often applied to solve a drainage problem originating from surface (above ground) sources usually only serve to reduce mineralized drainage. They seldom eliminate it. Treatment can be nearly 100 percent effective, but it is usually costly. Treatment is not a desireable solution for controlling mineralized drainage which occurs following mining, because of the costs.

Current efforts to reduce acid drainage involve steps that reduce the contact between oxygen, sulfide minerals and water. Drainage modification and reduction of permeability by compaction and soil coverings, the addition of neutralizers, water flooding to reduce contact with oxygen and similar methods are all in use. These methods are only partially successful.

Much research has been and is being done on the mineralized drainage problem. Recent work on the use of chemicals to inhibit the role of bacteria in acid formation offers some promise. Further research in this area is warranted. A low cost treatment process that effectively reduces or eliminates acid drainage would be a significant technological development.

A pre-closure hydrologic evaluation of underground mines may result in the identification of steps that can be taken to eliminate or reduce drainage when the mine is closed (Johnson, 1983). The steps would involve modifications to the "plumbing system" formed by the mine workings. Seals or bulkheads could be used to break the hydraulic continuity or to isolate mineralized zones in the mine from water flow. Selected drifting or drilling could also be considered as a means to provide optimum flow routes so mineralized drainage is less likely to occur. These preclosure evaluations are not, however, a substitute for long term hydrologic planning as recommended by Trexler et al (1982). With this planning, careful consideration can be given before taking any steps during mining that may profoundly affect or influence long term drainage from the mine.

Mine Shaft Protection

Safeguards to protect the surface openings of underground mines deserve special attention. Problems with inadequate seals and caps were observed in all of the mining districts which were investigated in this project. Although many of these problems are historic and have resulted from the use of inadequate materials and/or poor engineering design, disruptions can be caused by hydraulic forces in a flooded mine as illustrated by several

Michigan case histories.

At the time of mine closing, the shaft protection method that is chosen depends on whether the closure is permanent or temporary. When done properly, shaft backfilling is probably the best permanent solution especially if combined with a secure seal and cap. Shaft seals can be used for permanent or temporary closures. Seals should be reinforced concrete installed in sound bedrock in the shaft. The seal should be keyed into the shaft. The seal should be larger than the shaft so that it cannot fall into the shaft. A second reason to key it into the shaft is to prevent hydraulic forces from lifting the seal. The surface cap, in addition to offering some protection, serves to mark the shaft location. The void above the shaft seal should be backfilled if it is not securely lined with concrete. A steel vent pipe should be installed for pressure equalization and water level monitoring and sampling. If hydraulic surges are possible, the vent should be of larger diameter to allow more rapid pressure release.

Because of the great threat that inadequately protected shafts presents to the public, the shaft protection should be overdesigned with backup safety features. Fencing and signs posted around the cap are good safety features.

Butler (1983) in his assessment of mines in three Colorado mining districts suggested that the keyed area in the shaft seal could be cut in the shafts when the shaft is sunk. This is a good idea.

Non-Technical Aspects

Although the emphasis in this project was to develop procedures for closing underground mines that would solve technical problems, each investigator recognized that non-technical factors were also important. The non-technical aspects fell into two general areas; 1) legislation and enforcement and 2) education. Each is discussed separately.

Legislation/Enforcement. The mining industry has been subjected to a great deal of regulation in recent years. Recent legislation governing underground coal mining industry under Public Law 95-87 and subsequent revisions are quite explicit concerning the requirements for protection of the environment. Laage (1982) addressed the issue of the regulations and their impacts on the mining industry. He concluded that the federal regulations attempted to address all of the possible situations and mandate performance standards for them. He suggested that legislation oriented towards achieving goals rather than meeting rigid standards is a better concept which would allow creative engineering and the application of innovative techniques to solve problems. This would evolve into new technology, lower costs and the tailoring of methods to better solve local or regional problems. For example, it is not reasonable to require the effluent limits for some elements in water discharged from mining operations to be less than the levels that are found naturally in lakes and streams.

Another aspect of legislation is enforcement. Rigid enforcement of laws without concern for the intent of the law has occurred on occasion. Hostilities, often on a personal level, are the inevitable result. Hopefully these occurrences are rare, for they do nothing but undermine the merits of the system.

Laage concluded that although existing regulations governing underground coal mining appear to be adequate that modifications to existing legislation will probably be necessary as new knowledge and technology is developed. Furthermore, periodic review of any new legislation should be sought with input from the coal industry, especially on cost-benefit data during the review process.

Education. The term "education" is used in its broadest sense. Its use implies not only education of the public as to the importance and needs of the mineral industry but also the educational process that will shape the attitudes of both the operators and regulators of the mineral industry towards achievement of a common goal.

Ideally, the general public should be made aware of the importance of a viable mineral industry in the United States. They should understand that our national defense depends in part on a self sufficiency in mineral supply. They should be aware that, the high standard of living which is presently enjoyed in the United States is due in large part to the ready availability of large amounts of minerals, including fuels, at low cost. They should also understand that these resources come from the earth and that some environmental disruption is unavoidable during extraction. Moreover, they should be aware that although some of the impact of mining can be made more benign at reasonable costs that excessive demands will cripple the industry. These costs must be reflected in the price of the produce. If they are too high; i.e., not competitive in the world market, the domestic industry cannot long survive.

Those involved in formulating regulations that affect the mineral industry should also understand the importance of a viable domestic mineral industry. Those on the enforcement end should endeavor to understand the intent of the regulations and operate in that manner. Those that propose new regulations must recognize that their individual actions can profoundly affect the economics of a particular segment of the mineral industry and that collectively, the entire industry will be affected.

Education is also needed to secure a greater level of cooperation from the mineral industry. The industry should acknowledge that efforts to correct serious environmental problems resulting from past mining activity is their moral responsibility. They should also accept the responsibility of not only making reasonable and prudent efforts to correct these problems when they occur during mining, but also to avoiding them in the future.

If this level of cooperation could be achieved between government and industry, a better system for environmental protection would be possible. Instead of regulations enforced by frequent inspections and penalties, a better arrangement would be to have a system of mutually acceptable guidelines. Voluntary compliance to the guidelines could be rewarded through tax incentives and a relaxed permitting system.

The experience and information developed by various mining companies which would result in better environmental control should be made available to the industry as a whole. Perhaps this service could be provided through the Society of Mining Engineers of AIME or the American Mining Congress, or both.

Finally, the mineral industry and the public could benefit from the adoption of a national minerals policy that recognizes the need and the value of a strong domestic minerals industry. One of the goals of the National Minerals Policy board would be to devise methods, acceptable to the industry, that would reduce the severity of boom-bust cycles of the domestic mineral industry. This cyclicity reduces the ability of the industry to maintain its strength and vigor, to retain highly trained personnel and to support and pay for the needed environmental controls.

MICHIGAN MINING DISTRICT

Background

The report entitled "The Development of Guidelines For Closing Underground Mines: Michigan Case Histories" was prepared by Dr. Allan M. Johnson from work on the West Menominee Iron Range in northern Michigan. Previous work in the district, beginning in 1974, by Johnson and others (1976, 1978, 1982, 1983) had identified and quantified three basic problems associated with past mining activity; 1) subsidence, 2) acid water drainage and 3) inadequate mine shaft sealing procedures. As a result of this work it was recognized that some of the problems could have been avoided or their impact lessened if certain steps had been taken during or prior to mine closure. It was this idea that formed the concept for development of this project. Consequently, the Menominee Range was the first underground mining district selected for more detailed study in this project.

The Menominee Range of northern michigan was a major producer of direct shipping iron ore for nearly a century. When the last underground mine ceased operation in 1978, it marked the end of an era. For during this time the district has gone through a full cycle from the start-up of mining through close-down. During this period over 200 million long tons of iron ore were produced and shipped from nearly 100 mining operations.

The mines of the district extracted ore from vertical to steeply dipping tabular ore bodies using caving or stoping methods, sometimes in combination. The ore was mined from near the bedrock surface to depths in excess of 2000 feet, although most mines were shallower. The proximity of the large mine openings to the surface has resulted in extensive surface subsidence. Most of the subsidence was expected, and occurred during mining activity. However, unexpected subsidence has also occurred, sometimes many years later. At a number of locations, the threat of subsidence remains.

A thick glacial overburden, which is a prolific aquifer, has been the source of many problems in the district. The water saturated overburden caused problems in shaft sinking, mining and mine dewatering. Problems of mine drainage and subsidence have occurred following mining as a result of the abundant water.

Acid drainage was a problem in the western end of the district because of the close proximity of pyrite to the ore. Many mines in the district pumped acid water when they operated and several began draining acid again when they became flooded. Rapid oxidation of pyrite was sometimes the cause of mine and surface fires in the pyrite-rich slate.

Hundreds of vertical shafts are present in the district. Shafts capped with inadequate materials or those with poorly designed caps and seals create a problem.

Brief conclusions and results of the study are presented under each of the major headings.

Subsidence. Two types of subsidence were recognized; 1) short term subsidence and 2) long term subsidence. Short term subsidence was identified as subsidence which occurs during the period of mine flooding. Long term or delayed subsidence had no time limits. Five different occurrences of short term subsidence were documented by case histories at one mine complex. The mechanisms responsible for the subsidence were all related to mine flooding. They are listed as follows:

1. Rock mass movement occurred on a steeply dipping shear plane that intersected the mine workings. The movement is believed to have been caused by water loading of the upper block and friction reduction in the shear zone by inflowing water.

2. Broad surface subsidence affected an area of about 25 acres as a result of the rock mass movement described under item one.
3. A large, cone-shaped subsidence pit developed by shear failure in overburden when sand was washed into a stope as the mine flooded.
4. Piping activity caused a hemispherical-shaped cavity to develop in the thick glacial overburden above bedrock. Groundwater transport of the overburden into the mine via a fracture opening (i.e., piping) caused the cavity to develop. The eventual collapse of the soil capping above the cavity resulted in a vertical-walled subsidence pit that was about 50 feet in both depth and diameter. This is a newly recognized mine subsidence mechanism which was first documented from this case study.
5. Water surges within the nearly flooded mine complex disrupted shaft seals and cappings and caused the surface cap over the piping cavity, described in item four, to collapse. It was concluded that the surges were caused by an initial subsidence event.

Obviously, a special set of conditions was required for the mechanisms described above to occur. However, when conditions do favor piping activity at a flooding mine it was recognized that it may be possible to utilize this natural mechanism to sand fill the mine stopes. Ground preparation involving drilling and blasting could enhance the conditions favoring piping by channeling the water/sediment flow into the desired area of the mine. This would be, in essence, a controlled sand filling similar to hydraulic backfilling.

Long term or delayed subsidence was recognized as the greatest threat in this and other old mining districts. The many variables which are responsible for mine subsidence make it impossible to predict when subsidence may occur.

In the Iron River district, it was observed that subsidence was often more likely to occur at property boundries. Unless the mine operators coordinated their mining plans, the boundry pillars were often less substantial. In some of the earlier workings, the ore was often mined up to the property boundry (and in some cases, beyond). The only recorded death occurring from mine subsidence in the district occurred at a property boundry. A shallow stope under a county road caved to the surface one night and several cars drove into the 30 foot deep pit, resulting in a fatality.

It was concluded that, although long term subsidence poses a threat in many old mining districts this should not occur with newer mines. As long as mined areas are not developed, subsidence cannot pose a serious threat. To avoid this problem in the future it was recommended that the mined lands should be held in single ownership either by the mining company or by government that recognizes this responsibility.

It was also recommended that accurate mine maps and data relevant to subsidence potential should be prepared as a single document at the time of mine closure by the mining companies. It was proposed that this information should be made available to responsible user groups with the guarantee that it cannot be used as the basis for any future liability.

Acid drainage. Case histories were used to illustrate acid drainage problems originating from both underground and surface sources. Acid drainage from underground mines was observed to occur when a significant difference in elevation existed between the recharge areas and the spill point (the mine opening from which the water would flow). In all cases it was observed that flow issued from a mine shaft collared at lower elevation, usually in a river valley. Also, in every case the mine which was draining water was part of a mine complex. The mines of a complex were often developed independently and physically connected at a later date. It was determined that the deep interconnections between the mines were responsible for the large volumes of acid that would drain until the upper levels were flushed of acid.

It was concluded that a preclosure evaluation of mine hydrology can determine if mineralized drainage will occur, how severe it might be and what preventive steps are possible. Changes to the "plumbing system" of the mine including the installation of seals or bulkheads and/or providing supplementary water flow routes by drifting or drilling were suggested as possible methods to lessen or prevent acid or other mineralized drainage.

Acid drainge from surface piles of pyritic slate occurs at one mine complex in the Iron River district. Surface waters and near-surface groundwaters become acid as they pass through the slate. Treatment by neutralization and precipitation of metal compounds in holding ponds was recognized as probably the best solution to this persistent problem. This occurrence was considered to be largely a historic problem as current regulations would no longer permit dumping of acid generating waste rock in a flood plain nor allow the effluent allowed to drain into surface waters. It was concluded this type of problem will continue to receive much attention because it is so common.

Mine shaft protection. Deficiencies in mine shaft cappings were grouped into three separate areas; 1) inadequacies resulting from the use of unsuitable materials 2) problems resulting from poor design and 3) problems resulting from unexpected occurrences. In the first category problems resulted from the use of unsuitable materials to cap mine shafts. Wood planks and timber covered shafts, sometimes earth-covered, rot and collapse in a relatively short period of time because of the moist climatic conditions in Michigan. It was observed that although steel plates may last longer than wood, they will eventually rust away and that neither of these materials should be used for constructing permanent mine shaft caps, although they are both suitable for temporary protection.

Several case histories were presented which illustrated problems with the design of the cappings. In these cases, well-constructed, reinforced concrete caps had been placed over the shaft collar. Through time, the portion of the shaft liner through overburden had failed causing the unconsolidated ground to cave into the shaft and undermine the caps. It was determined that this problem could be avoided by installing steel-reinforced concrete seals in the shaft below the bedrock surface, backfilling to the surface and capping the shaft area. Vent pipe should also be provided to allow pressure equilibration and to permit water level monitoring and sampling. In addition, fencing and surveyed monuments were recommended so the area will always be recognized as a shaft location and can be relocated easily by survey if the surface presence of the shaft becomes obscured with time.

The category of unexpected problems originated as a result of the case histories of shaft capping and sealing failures resulting from water surges in flooded mines. The water surges were triggered by subsidence within the mine complex. The transmitted hydraulic forces caused water to surge through the "plumbing system" of the mine and to disrupt shaft caps and seals.

It was concluded that disruptions of this type can usually be designed for by installing sound shaft seals as previously described and by providing a vent pipe of sufficiently large diameter for pressure release. Backfilling of the shafts could also be done if hydraulic surges were anticipated.

COLORADO METAL MINING DISTRICTS

Background

Mr. Donald Butler authored the report "The Development of Guidelines For Closing Underground Mines: Colorado Districts". The case studies for this report came from three inactive or largely inactive districts in central Colorado, Leadville, Westcliffe and the Cripple Creek-Victor mining districts. Leadville is located about 70 miles southwest of Denver at an elevation of about 10,000 feet. The Cripple Creek-Victor district is located about 60 miles on a line SSW of Denver or about 20 miles west and a little south of Colorado Springs on the west side of Pikes Peak at an elevation of about 9,000 feet. Westcliffe is located about 200 miles SSW of Denver or about 50 miles SW of Pueblo, Colorado at an elevation of about 8,500 feet.

Mining in Leadville began in 1860 with the discovery of placer gold and mining of gold was followed by silver, lead, zinc and molybedenum which have all been produced in significant quantities. The camp is largely inactive today although several small mines have been rejuvenated. Most of the early mining was shallow and done by narrow vein stoping. Ony a few shafts were more than 1000 feet deep.

Gold was the principal metal of value in the Cripple Creek-Victor area being present as a telluride. Mining began in 1891 with production rising rapidly just prior to 1900 and continuing strong until World War I. From 1900 until 1903, 475 mines shipped gold ore with an average yearly value of $17 million. Production continued at a reduced level until 1934 when the price of gold was raised to $35/ounce. It dropped off again during World War II. After the war, reduced production was continued until 1962. The rise of gold prices in 1974 caused renewed interest in the area and several companies began developing them for small scale production. The Carlton Mill reopened in late 1981 and the leaching of old mine dump rock on constructed pads began the same year.

The mines were operated to relatively great depths; the Portland Mine which was a major producer had a 3200 foot deep shaft. Mining methods were open cuts varying from narrow vein stoping to room and pillar. This was a very rich district, producing nearly $500 million worth of gold at the earlier low values of $20 to $35/ounce. As in Leadville, drainage tunnels were constructed to allow deeper mining.

The Westcliffe district is actually better known as the Silvercliffe-Rosita mining district, however, Westcliffe is the only viable town in the area. Significant mining of silver and gold with minor lead, copper and zinc began in the mid 1870's and by 1945 11 important mines had produced about $10 million. Several of the mines were quite deep; the Bassick Mine was 1800 feet deep and the Geyser Mine was 2800 feet deep. However, many shallow workings were developed throughout the district to mine ore from near-surface, high-grade ore pockets. Most of these operations utilized narrow vein stoping methods.

Conclusions

The major problems resulting from past mining activity in the Colorado districts fall into two groups; 1) environmental problems and 2) problems resulting from hazardous conditions. The environmental problems result from acid and toxic drainage from mine drainage and leaching of surface waste rock and mill tailings. The hazardous conditions result from inadequate shaft or adit sealing or capping, mine subsidence and deteriorating mine buildings and related surface structures.

Each of these problems is discussed in greater detail under separate headings.

Acid and toxic drainage. Contamination of surface water resources by acid waters, some with high toxic metal levels is a severe problem in Colorado. Earlier work by Federal agencies determined that more than 675 kilometers of streams in Colorado have been polluted by active and inactive mining operations.

Most of the pollution originates from the oxidation of pyrite, but other sulfides are present and contribute (in addition to Fe) Mn, Zn, Cu, Pb, Cd and other metals to the drainages --- sometimes at elevated levels. The source of much of the acid drainage is from mines and mining districts at higher elevations. These streams join larger, greater river systems downstream, so many miles of river are affected. The metals eventually become oxidized in the streams and rivers and are precipitated as finely divided oxides and hydroxides. Thus, a sedimentation problem also exists.

Two basic sources of acid drainge are recognized in Colorado; 1) underground souces issuing from mine shafts, adits and drainage tunnels and 2) surface sources from waste mine rock and mill tailings. Each is described separately.

Mine drainage. One advantage of mining in mountainous areas with great variations in elevation has been the ability to dewater the mines by driving drainage tunnels into the workings. Although the initial expense is great, the mines can be drained by gravity. The high cost of pumping water to the surface was avoided. When many mines were operating in a district, the drainage tunnels could serve them all and the costs could be spread. The tunnels were also used for exploration, tramming ore and ventilation.

The Leadville district was served by three drainage tunnels, the Yak, Rosse and Leadville. The Cripple Creek-Victor district also has three the El Paso Tunnel, the Roosevelt Tunnel and the later and deeper Carlton

Tunnel. These tunnels made it possible for the mines to continue production to much greater depths and greatly extended the productivity of the mines and the lives of the districts.

Unfortunately, when the mining operations ceased, the drainage continued. These tunnels which were a boon to the operating mines now are the source of a serious and persistent acid drainage problem. Sealing the tunnels is not a good solution as they are still used by some active mines for drainage and ventilation. Moreover, caving limits the access in some tunnels and makes it impossible to effectively or economically seal the individual mines draining into the tunnel.

The use of settling ponds and water treatment offer the best solutions. Some pond installations have been attempted, but they have not been totally effective and acid and dissolved metals are still entering the river systems.

Surface souces of acid and toxic metal drainage. A characteristic of the older western precious metal mining districts is the great number of mines that were active at one time. Waste rock piles are found at each of these mines, the volume of the piles generally are a good indication of the size of the operation.

The sulfides in these waste rock piles represent a potential source of acid and toxic metal drainage. Based upon field evaluations, this problem was most severe in Leadville, less so in the Cripple Creek-Victor district and negligible in the Westcliffe area because it is so dry.

A second source of acid and toxic metal drainage is from tailings impoundments of old mills. This problem was most severe in the Leadville district because the mining and milling activities were situated in major drainage gulches that drain into the Arkansas Rivery valley.

Solutions to the existing problems would involve rerouting upstream drainage around the dumps or providing protected drainage channels through them, and treatment for any remaining acid drainage as needed. Some of the piles have recoverable grades of gold and silver and they coulds be hauled to prepared leaching pads for dump leach extraction of their values. High gold prices has prompted this activity in the Cripple Creek district.

These problems are largely historic, as it would no longer be acceptable to indiscriminately dump or dispose of acid generating mine and tailings wastes. However, the problem of protecting the environment against acid and toxic metal drainage will always require careful planning and extra effort and expense.

Hazardous conditions. Hazardous conditions were observed in each of the three mining districts. The conditions included subsidence, unsafe shaft and adit openings and deteriorating surface mining structures. Because these well-known mining district receive a great deal of tourist traffic, these hazardous conditions present a special problem. They may be considered as attractive hazards. On one hand, the dilapitated mining structures, pits and open shafts provide a flavor of the rich history and on the other they are an attractive hazard with potential for injury or a life hazard --- especially to the average tourist who is unaware of the danger present around the old mines. Each of these is discussed separately.

Subsidence. Stopes caved to the surface were observed in each of the three mining districts. The common methods of open vertical-vein stoping in the many small mines of these districts has resulted in elongated trench-like subsidence pits. These pits formed from the caving of shallow workings in fractured and oxidized zones. A total of 33 of these zones were observed, with the majority in the Cripple Creek district. There are probably many areas of near surface stopes that have not collapsed.

In a number of cases, timber lagging has been placed across these narrow trench-like openings to give some protection, and in some cases the lagging was covered with rock and surface debris. Covering the wood lagging has created a greater hazard, for when it deteriorates, the surface will cave into the stopes. These areas appear safe, but may cave with the slightest disturbance and no warning.

In the Westcliffe area two large subsidence caverns were observed. They resulted from caving of large near-surface stopes. Subsidence in these areas is also unpredictable and a potential hazard exists.

Shaft and adit conditions. The great number of open or inadequately protected shafts and adits in the three Colorado districts, makes this the most prevalent mine-related problem in terms of public safety.

Many of the old mines were abandoned without any effort to close, seal or protect the openings. Consequently, many of the mine openings are accessible to the public. Deterioration of timbered shafts, ladder-ways and adits make them very dangerous for anyone foolhardy enough to enter.

Of the shaft and adits that have protective caps or seals, many of them are inadequate. In many cases inferior materials used to restrict access to the mines and in other cases poor engineering design has resulted in unsafe conditions.

Surface structures. A common sight in many western mining districts are the old wooden head frames, shaft houses and other relics of past mining. These structures are enjoyable to look at, but many are unsafe to enter. Deterioration due to weathering and no maintenance has resulted in their present condition. It is recognized that this problem is largely historic, that is, it is not likely to occur again because of current regulations governing mine closures. However, the problems are real and the lessons to be learned from them are of value.

Vandalism. Although not a mine related problem, *per se*, vandalism does pose a problem at many inactive and abandoned mines. Premises that have been locked to protect equipment and safeguard the public are often broken into and sometimes vandalized. As many of the areas are somewhat remote, they are inspected infrequently and may remain open for long periods of time. Often fences, signs and gates that restrict access to mining properties have been defaced, broken, stolen or damaged to the point that the safeguards are no longer effective.

Better design of safeguards can make them more vandal proof. However, education to make the offending public more aware of the problems resulting from this type of behavior along with more frequent inspections and appropriate penalties are also needed to deal with this troublesome and persistent problem.

COAL DISTRICTS

Background

A report entitled "The Development of Guidelines for Closing Eastern Underground Coal Mines" was prepared by Mr. Linneas Laage (1982). The report is based upon selected field studies of closed coal mines in three coal mining districts, two in Eastern Ohio and one in Southern Illinois. The field study data was supplemented by case histories extracted from the literature. The types of problems identified in the study which originated from closed underground coal mines included: 1) acid drainage from mine and refuse pile sources, 2) mine and refuse pile fires, 3) mine gases, 4) inadequate entry sealing, 5) subsidence, 6) landslides and 7) abandoned equipment and structures. Each is reviewed separately.

Hydrological Problems. Acid water drainage was recognized as one of the most prevalent problems resulting from coal mining activity. Standard current methods used to control acid drainage involve control of oxygen, water or pyrite. Mine design and sealing are probably the most effective methods that offer hope of improvements in reduction of acid mine drainage. These steps can also reduce problems resulting from alteration of hydrology by mining activity which influence aquifer depletion/creation/relocation/ pollution, landslide initiation and alteration of soil and minerals.

It was suggested that the problems of refuse pile drainage is more appropriately addressed in pre-mining planning than when the mine is closed. In this way the spoil material is moved directly to its final disposal site as mining progresses. Costs are lowered because the material is handled only once. Drainage from the refuse can be controlled and supplementary measures such as neutralizing, sealing, and revegetation can be initiated earlier, thus minimizing environmental problems.

It was concluded that although the Federal Regulations (Title 30) should help to prevent drainage problems, that in many cases they were too stringent. In some cases the concentration of dissolved constituents in nearby lakes and rivers exceed the established effluent limitations.

Subsidence. Subsidence over a mine may occur immediately after mining or be delayed. Subsidence over old mines is difficult to predict because of incomplete information on the mine openings and geologic conditions. Many current problems from subsidence occur where development has taken place over older workings.

Current mining methods and techniques have resulted in greater control of subsidence. Accurate subsidence prediction and control has been improved by better knowledge of rock mechanics, roof support and ground control. Currently, the choices of subsidence control are largely economic. Whenever possible, complete extraction of coal should be achieved. In some cases it may be most economical for the mining company to purchase the surface structures to permit 100 percent extraction rather than leaving pillars to protect the structure.

Improvements in design that make structures less susceptible to subsidence damage in coal mining areas offer promise. Existing problems are sometimes solved by modifications to or around the structure (slurry trenches), or through the purchase of subsidence insurance.

Slope stability. Case histories of landslides related to past mining activity were found in three southeastern Ohio counties. Some of the slope failures are related to slope saturation from draining drift mines common in the area. However, future landslide problems from active mines are not as likely because up-dip mining with subsequent drainage and the disposal of spoil on the slopes is not generally permitted.

Mine gas. Mine gases in closed underground coal mines are rarely a problem because people do not enter the mines. However, methane release can result in an explosion hazard at some mines and venting is required. Current methods to drain and capture methane from developing mines should reduce this problem in the future.

Mine and refuse pile fires. The problems generally resulting from mine fires in closed workings are loss of coal resources, subsidence and noxious gases. In 1981 Illinois had 140 waste bank fires and Ohio had 20. In addition Ohio had 7 mine and outcrop fires.

Refuse pile fires can be prevented and extinguished by proper refuse pile construction which is correctly part of the pre-mining plan.

Mine fires can be prevented by properly sealing the mine at the time of closure. Current Federal Regulations address the topic of mine sealing and the recommended techniques should prevent fires after closure.

The U.S. Bureau of Mines has conducted much research pertaining to the prevention and extinguising of fires in active mines. Currently much research is being done on methods to extinguish fires in coal seams and closed mines. The coal fires are usually brought under control by removing coal, applying agents to the fire to lower temperature or limit oxygen or mine sealing.

Mine openings. Inadequate sealing of closed mines has, in the past, resulted in problems including subsidence of shaft fill, acid mine drainage, landslide initiation and unsafe conditions for people and animals. Current Federal Regulations are probably adequate to avert most of these problems in the future.

Abandoned equipment and structures. The major problem resulting from abandoned equipment and mine structures is their threat to safety especially after gradual deterioration due to neglect. Economic incentives to coal operators to remove equipment and structures is probably the best way to prevent future occurrences. The equipment may be used at another operation or may have salvage value. Also, the removal of equipment and structures can reduce liability and increase land value.

However, some structures may be better used for secondary purposes and in selected cases should be preserved for historic purposes and as a tourist attraction.

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