U.S. DEPARTMENT OF LABOR
MINE SAFETY AND HEALTH ADMINISTRATION

FINAL REPORTS ON GEOPHYSICAL VOID DETECTION DEMONSTRATION PROJECTS

Abandoned mines present a number of critical safety issues with respect to active mining operations as well as surface facilities at mines. A number of Void Detection Demonstration Projects were sponsored by MSHA in order to evaluate the ability of existing and emerging technologies to assist mine operators in locating abandoned mines to reduce risk to miners and the public.

Between 1997 and 2000, the mining industry experienced four notable incidents where large volumes of coal processing waste slurry retained in impoundments broke through inadequate barriers of soil and rock, passed through mines, and discharged into adjacent watersheds. The breakthrough which occurred at Martin County Coal in Kentucky, the largest of these incidents, resulted in the unplanned release of more than 300 million gallons of coal waste slurry and caused substantial environmental and property damage.

The Mine Safety and Health Administration is responsible for regulating 2,254 impoundments and dams associated with the mining industry. Immediately after the Martin County breakthrough it was determined that many existing coal-mining related impoundments had been built over or adjacent to coal mine workings. MSHA worked with the industry to find engineering solutions to the associated risks.

As a result of the Martin County breakthrough, the United States Congress funded a study through the National Academy of Science's National Research Council, which formed the Committee on Coal Waste Impoundments. The committee ultimately published a report in 2001 titled "Coal Waste Impoundments: Risks, Responses and Alternatives." Among various other things, the Council recommended *"that demonstration projects using modern geophysical techniques be funded and that results be widely conveyed to the mining industry and to government regulatory personnel through workshops and continuing education."*

On July 24, 2002, the mine inundation and dramatic rescue at the Quecreek #1 Mine in Pennsylvania drew worldwide attention to the problem of abandoned underground mines. In that instance, miners at the Quecreek Mine accidentally cut into flooded abandoned workings of an adjacent mine causing an inundation of the active mine. Nine miners narrowly escaped while nine others remained trapped underground for 77 hours before being rescued. The Quecreek accident was a dramatic example of an all-to-frequent problem. From 1995-2002, mine operators had reported 181 mine inundations, 107 of which were unplanned cut-throughs resulting in water inundation.

The mine inundation and impoundment breakthrough problems share one element in common. They were all the result of unavailable, incomplete, or inaccurate mine maps, and/or inadequate characterization of the subsurface conditions above or adjacent to the mines. Hence, the first step in preventing such problems is to accurately assess the location and extent of any abandoned underground mines in the area of interest.

There are approximately 300,000 abandoned mines located throughout the Appalachians. Other areas of the country have similar concerns. Primarily as a result of the era when these mines were abandoned, a high percentage are inaccurately or incompletely mapped. Old maps may be unavailable or illegible. In many instances, mine maps have also proven not to be accurate, particularly in the final cut near the outcrop. This area is generally not bolted, so it is not accessible for surveying. Therefore, the extents may only be estimated in these areas, and shown on the maps with dotted lines, indicating uncertainty. Therefore, mine operators and engineers must be diligent in searching for old maps and verifying their accuracy when any uncertainty exists which could adversely affect the safety of miners.

In recognition of the problems involving mine maps, the United States Congress appropriated $10M to MSHA for *"Digitizing mine maps and developing technologies to detect mine voids, through contracts, grants, or other arrangements."* Approximately $3.9M was allocated through state grants to establish programs for digitizing underground maps for abandoned mines and making them available digitally to the public. The funds were distributed as follows:

West Virginia	$1.2 Million
Kentucky	$1 Million
Pennsylvania	$1 Million
Virginia	$317,000
Ohio	$52,000
Utah	$52,000
Illinois	$52,000
Indiana	$52,000
Colorado	$51,000
Alabama	$51,000
Maryland	$50,000
New Mexico	$50,000
New York	$25,000

The states used this money to develop and enhance systems for collecting, digitizing, geo-referencing, archiving, ground-truthing, validating, and delivering mine maps, according to defined needs of each individual state. The progress of each state was presented during meetings on "Underground Mine Mapping" held in Louisville, Kentucky from October 15-16, 2003 and Pittsburgh, Pennsylvania, on June 1-2, 2005. The meetings were attended by representatives of various state and federal programs. Since that time, the states have continued to collect and digitize maps.

The remaining $6.1M was allocated to contracts for demonstration projects *"for advancing the current state of technology in detecting underground mine voids."* In 2004, MSHA issued a "Request for Proposals" seeking sources to conduct demonstration projects involving methods to locate mine workings. MSHA subsequently received 58 proposals from 23 different sources including universities, government entities, and private contractors. The proposals were thoroughly reviewed by teams consisting of MSHA engineers, geophysicists from the U.S. Army Corps of Engineers' Geophysical Branch, consulting geophysicists, and university professors of geophysics with specific expertise in the methods that they were reviewing. The reviews focused on the technical feasibility of the proposed projects and the perceived value to the industry of conducting the demonstration. An objective rating system was developed. Due to the highly specialized nature of the work, MSHA relied heavily on the contracted expert reviewers and advisers to assist with project selection. The projects funded were those determined to show the most promise for accurately locating or detecting mine voids.

Fourteen proposals were ultimately selected for demonstration, covering a broad spectrum of available technologies. The methods funded are generally categorized as follows:

Surface Seismic Reflection (2 demonstrations)
Borehole Seismic Tomography (3 demonstrations)
In-Seam Seismic (with Various Sources) (4 demonstrations)
Electrical Resistivity (1 demonstration)
Time Domain Electromagnetics (1 demonstration)
Look Ahead Radar (1demonstration)
Borehole Radar Tomography (1 demonstration)
Delta Electromagnetic Gradiometry (1 demonstration)

Since it was clear that no individual technology could address the myriad of conditions and problems in the mining industry, MSHA and our contracted experts believed that it was prudent to sponsor a wide variety of techniques.

The specific contractors selected and their projects are listed below:

Colorado School of Mines, Borehole Seismic Tomography
Colorado School of Mines, Borehole Radar Tomography
D'Appolonia Engineering Division of Ground Technology Inc., Electrical Resistivity
D'Appolonia Engineering Division of Ground Technology Inc., TDEM
L.M. Gochioco Associates, Inseam Seismic
L.M. Gochioco Associates, Surface Seismic Reflection
L.M. Gochioco Associates, Vertical Seismic Profiling
Marshall Miller Associates, Inseam Seismic from Outcrop
Pennsylvania State University, Inseam Seismic
Stolar Research Corporation, Delta EM Gradiometer
Stolar Research Corporation, Look-Ahead Radar
Wright State University, Inseam-to-Surface Seismic with Miner Source
Zapata Engineering, Blackhawk Division: High Resolution Seismic Tomography
Zapata Engineering, Blackhawk Division: Crosshole Seismic

Field work began on the various projects in late 2004. MSHA has monitored the progress of these projects throughout their execution. Preliminary information concerning these projects has been conveyed to the industry in forums such as the National Mining Association MINExpo and the Society for Mining, Metallurgy, and Exploration (SME) Annual Meeting, The Interstate

Technical Group on Abandoned Underground Mines, and the National Research Council's Transportation Research Board.

At the conclusion of field work, draft reports were prepared and submitted to MSHA. These reports were again subjected to review by MSHA's contracted experts. Comments from the experts were forwarded to the contractors for consideration and incorporation into the final reports. Final reports have now been received and accepted for each of the projects. The one exception is the Pennsylvania State University project which is an ongoing multiple-year effort. In this case the enclosed report is for the initial phase.

The information on this site is the culmination of the program to explore the viability of using geophysical methods for locating mine voids. Since this is probably the first coordinated effort to systematically examine these various methods for this application, additional work remains. The projects met with varying degrees of success. Clearly, when applied under the correct conditions, geophysical techniques can provide valuable information which can assist in assessing a variety of site conditions, including the presence and location of abandoned underground mines. It is also clear that while they can effectively supplement a well designed and executed drilling program and assist in determining appropriate drilling locations, geophysical techniques can not substitute for drilling. A common element of all projects was that each of the projects required interpretation of the data by experienced geophysicists and all contained a degree of uncertainty and an element of professional judgment.

In addition to the direct benefits of demonstration of the geophysical methods, ancillary benefits included successful ground-truthing and mapping of conditions using downhole laser (for air filled voids) and downhole sonar (for water filled voids). Downhole sonar and radar methods offer significant advantages over borehole cameras for remotely measuring and mapping the conditions in underground mines. These tools can be used to remotely perform three-dimensional mapping of the conditions in inaccessible underground mines and, as such may have broad applications in exploration and mine emergency operations.

The reports contained on this website were prepared by the individual contractors. MSHA does not endorse or advocate use of any particular geophysical methods, and clearly no single method can be used under all circumstances. Nonetheless, MSHA hopes that the information contained herein is useful to the industry when they are considering both the benefits and limitations of using geophysical methods to identify and locate abandoned mines, and that this heightened awareness and continued development of modern geophysical techniques ultimately improves the safety of our Nation's miners. Additional information regarding the contracts can be obtained from the following:

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