Geophysical technologies for detecting underground coal mine voids—An interactive forum

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Since 1995, U.S. coal miners have often inadvertently broken into abandoned underground coal mines in the Appalachian coal basin. Unavailable, inaccurate, or incomplete mine maps were typically blamed. However, two recent troubling occurrences have caused the U.S. Congress to authorize the Mine Safety and Health Administration (MSHA), Department of Labor, to refocus efforts to develop and employ remote-sensing technologies to detect and map abandoned and flooded mine works. These two events were (1) the breakthrough of a tailings impoundment through old mine works in Inez, Kentucky, releasing millions of gallons of mine wastewater and slurry on 11 October 2000, and (2) the breakthrough from a flooded mine works that trapped nine miners for nearly 77 hours at the Quecreek Mine, Pennsylvania, on 24 July 2002. Fortunately, there were no fatalities in these two incidents.

Rescue operations at Quecreek received international coverage. On the anniversary of the accident, a U.S. television network (ABC) aired a two-hour movie recreating the events, clearly depicting underground mining conditions at Quecreek Mine, and the subsequent logistics and rescue efforts. And *The New Yorker* (18 November 2002) magazine published an article by Peter Boyer, about the rich history and culture of coal mining in Pennsylvania, events leading to the accident, mobilization of rescue teams and drillers, on-site decisions made by key technical personnel, and the eventual rescue of the trapped miners.

The rescue capsule used to retrieve the miners was displayed at the Geophysical Technology Symposium, 28-30 July 2003 in Lexington, Kentucky. The diameter of the capsule was originally designed at 21.5 inches to allow the capsule to be used in 24-inch casing holes. The diameter was selected to be compatible with large diameter drilling rigs at that time and at a height of about 9 ft it allowed enough space to lower safety equipment, communication links, etc. downhole. It was previously tested in a hole drilled by MSHA in 1974 at the Latrobe Limestone Quarry in Pennsylvania. The only time the capsule has been used for a rescue operation was in the Quecreek incident.

Kelvin Wu, chief of the Mine Waste and Geotechnical Engineering Division of MSHA, was the key advisor of the rescue team. Because the miners were trapped in an air pocket that kept them alive, the water had to be pumped out first to a safe elevation level before a second attempt to drill through a 30-inch rescue hole. Drilling was stopped at 1860 ft above sea level, which was 30 ft above the mine roof, waiting for the water level to be lowered by large capacity surface pumps to the recommended level that came to be called "Dr. Wu's magic number"—1829 ft.

The objectives of the symposium organized by the Office of Surface Mining (OSM) and MSHA were to evaluate the applicability and effectiveness of various geophysical methods that can be used to locate, image, and delineate active or inactive underground coal mines. Industry experts, company managers, and government officials participated in this interactive forum.

Invited speakers, moderators, and panelists were: William Kovacic, John Craynon, and Jeffrey Jarrett (OSM); Kelvin Wu and Mark Skiles (MSHA); Richard Sweigard (University of Kentucky); Roy Tiley (DOE); Don Steeples (University of Kansas); Neil Anderson (University of Missouri-Rolla); Gary Olhoeft (Colorado School of Mines); Doug Conaway (West Virginia Health & Safety); Lawrence Gochioco (GX Technology); William Johnson (D'Appolonia Engineering); William Monaghan (NIOSH); Gary Slagel (Consol Energy); Ernest Majer (Lawrence Berkeley National Lab); Larry Stolarcyzk (Stolar Horizon Research); Syd Peng (West Virginia University); Richard Hammack (NETL); Benny Wampler (Virginia Dept. of Mines Mineral & Energy); Richard Benson (Technos); John Wood (Target Drilling); James Acker (Seis Pros); James Cobb (Kentucky Geological Survey); and Dwain Butler (retired, US Army Engineering R&D Center).

Escape capsule used to retrieve the nine trapped coal miners at the Quecreek Mine. Left to right, Lawrence Gochioco and symposium organizers Kelvin Wu, George Gardner, and William Kovacic.

An overview of the capabilities and limitations of various geophysical methods was followed by examples of geophysical techniques that could be used to detect mine voids; i.e., surface seismic methods, electrical resistivity, ground penetrating radar, tomography, electromagnetics, radio imaging, airborne electromagnetic surveying, microgravity, and directional drilling. Out of this array of methods and depending on ground conditions, only half is likely to be effective in detecting mine voids. Panel discussions were held on each day of the meeting to provide an interactive forum.

The use of geophysical technologies in the U.S. coal industry has been sporadic when compared to other nations, despite recent advances and innovations. A robust multifaceted coal geophysics program was fully utilized by a U.S. coal company from 1985 to 2000 to detect and map prospective coal areas as well as various geologic anomalies and man-made voids ahead of mining. At that time, this coal geophysics program represented nearly the entire geophysical work being conducted in the U.S. coal industry.

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Several original mine plans were changed as a result of findings from seismic data that indicated the presence of potentially hazardous geologic anomalies for future mine development and longwall production. By combining surface seismic and exploratory drilling methods, the coal company was able to properly leverage its risk by gathering useful subsurface information ahead of mine development. Unfortunately, when all of the former oil company executives at this coal company retired and were replaced by an external management team in 1999, the coal geophysics program received no support in 2000. With no geophysical technology in place, the coal company reverted back to its old traditional drilling method of evaluating reserves, and with great hope (and luck) that drilling would be able to help them detect geologic and man-made anomalies that could create adverse mining conditions.

At the end of the symposium, Dwain Butler provided a summary of all available geophysical technologies that could be used to address the challenges of detecting mine voids. He qualified his talk by suggesting that it is important to understand the capabilities and limitations of each method in order to properly design the most appropriate solution.

This interactive forum may well provide the proper venue to raise the awareness of coal industry professionals, engineers, and management that proven geophysical technologies are already available and need to be implemented properly by qualified and experienced geophysicists. Coal geophysics was once the exclusive domain of a local coal company that learned how to utilize its power to better manage its risks and was one of their best kept technology secrets in U.S. coal mining history. The symposium revealed its former existence and successful applications. One speaker eloquantly closed his talk with a provocative statement: "The *genie* is now out of the bottle. Let us all work together to bring about redeploying and employing geophysical technologies that not only can improve a coal company's bottom line, but can also potentially save lives by minimizing the risk factor." TLE

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