Draft Summary of First Workshop on Trapped Miner Loaction using Siesmic Listening Devices

Report to the Director of the
Office of Miners' Health, Safety and Training

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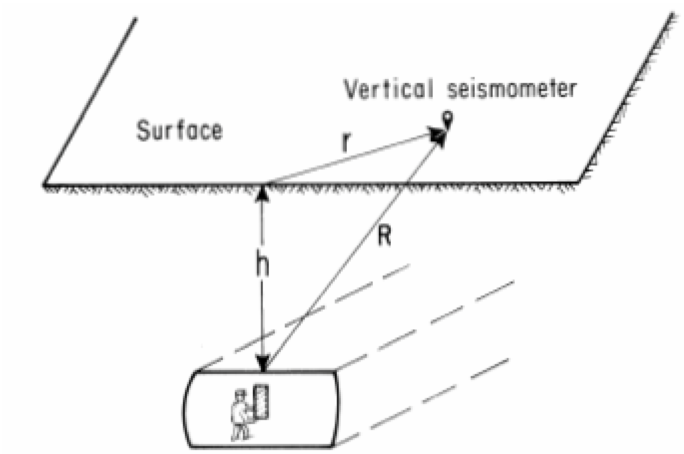
June 28, 2006



This is our worst nightmare. No matter how hard we try or how much our technology has evolved the miners and those wanting to help them are cut-off from each other.

> *An accident has happened in an underground coal mine that has left some number of miners trapped.*
>
> *All communications systems have been compromised and there is no way to determine if there are survivors or exactly where they are.*
>
> *All operations other than ventilation and rescue have ceased at the mine.*
>
> *The trapped miners have begun signaling on the half-hour by pounding on a roof bolt, other metal structure or cribbing timbers – ten strikes pause for count of ten and ten more strikes then wait for next half-hour.*

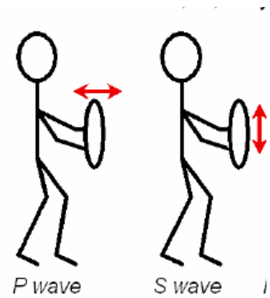
On June 28, 2006 the West Virginia Office of Miners Health Safety and Training in conjunction with the United Miner Workers, the West Virginia Coal Association, West Virginia University, Marshall University, and Southern West Virginia Community and Technical College hosted a roundtable to explore options for just such a scenario.

The roundtable was attended by approximately 40 experts from the mine rescue, geophysics, and state and federal regulatory communities. The group grappled with the challenges and current state of technology in order to determine what could be done now and what had yet to be done. This document summarizes the wisdom they shared.

WHAT IS MEANT BY SEISMIC LOCATION?

Seismic sound waves travel through the Earth. They follow paths bent by the varying density and composition of the earth's geology. This effect is similar to the refraction of light waves. There are two kinds of body waves: primary (P-waves) and secondary (S-waves).

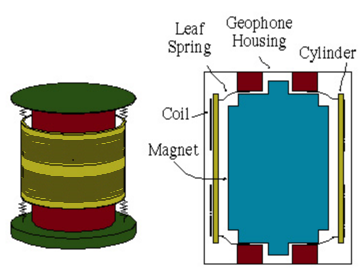
P waves are longitudinal or compression waves, which means that the ground is alternately compressed and dilated in the direction of propagation.



These waves generally travel slightly less than twice as fast as S waves and can travel through any type of material. In air, these pressure waves take the form of sound waves; hence they travel at the speed of sound. Typical speeds are 330 m/s in air, 1450 m/s in water and about 5000 m/s in granite. P waves are sometimes called "primary waves".

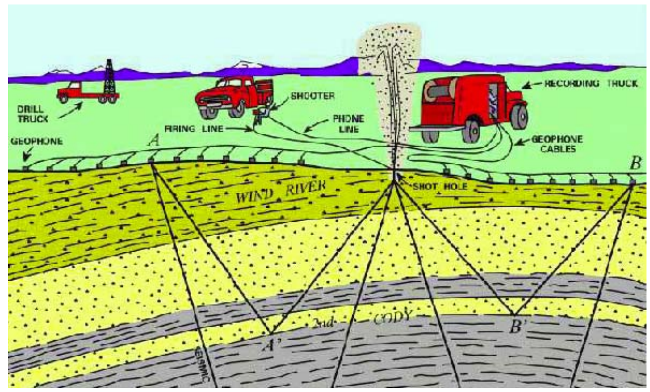
S waves are transverse or shear waves, which mean that the ground is displaced perpendicularly to the direction of propagation. In the case of horizontally polarized S waves, the ground moves alternately to one side and then the other. S waves can travel only through solids, as fluids (liquids and gases) do not support shear stresses. Their speed is about 60% of that of P waves in a given material. S waves are sometimes called "secondary waves", and are several times larger amplitude than the P waves.

The difference in the arrival times of the P and S waves are used to determine the distance to the event that created the sound. The difference between multiple receiving locations allows the determination of the hypocenter (below the center) which is the location inside the earth where a sound originated. The information can be manipulated in several ways including creation of images as in ultrasound.



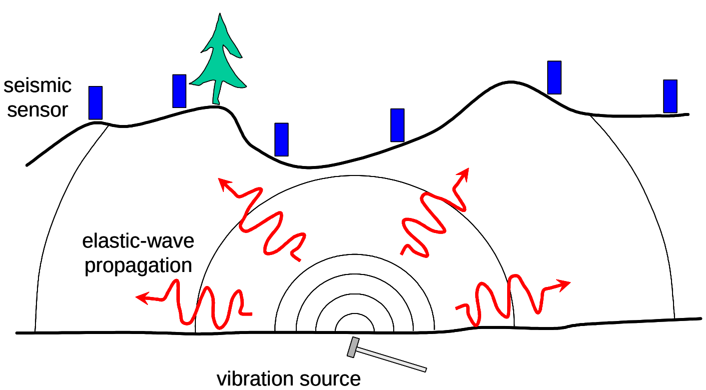
Sounds waves are traditionally collected from geophones, a device which converts ground movement (displacement) into voltage which is recorded much the same a a voice recorder. The figure to the right shows both an isometric and cross-sectional view of a geophone, which uses the motion of a spring supported coil in the field of a permanent magnet to generate an output signal.

Active seismic image mapping has changed radically over the last 30 years and become a billion dollar business. Seismic recording systems with thousands of channels, fleets of vibrators trucks operating in tandem and helicopter supported field operations are commonplace. A conventional seismic setup consisting of a dynamite source, an array of receivers (geophones) and a recording truck. The lines represent the path of the sound waves that travel down to the target and reflect back to the surface. Modern 3-D crews lay out thousands of geophones and miles of cable on the ground.

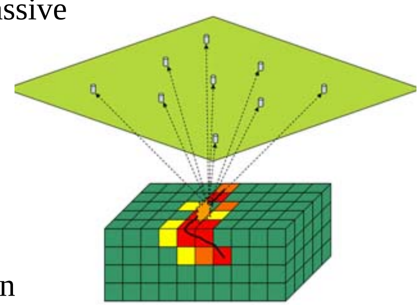


Passive seismic image mapping is done without an external source. A passive seismic crew merely lays out an array of receivers and…listens. They are listening for naturally produced sounds as well as the result of human activity.

With passive emission imaging the seismic activity becomes the imaging target. The common approach to emission mapping is to observe and record the direct arrivals of the seismic waves from these micro-events and to map the distribution of hypocenter locations. For the most part, the events being considered here are small, with local magnitudes in the -1 to -3 range, and rarely discernable as clean first breaks on surface recordings. Consequently, much of the previous work in this domain used borehole receivers.



One common application of passive emission immaging is hydraulic fracture monitoring in the oil and gas industry. Typically an array of 8 to 12, 3-component geophones is clamped at or just above the reservoir level. A mapping of the event locations over time mirrors the development of fracturing. This same process can be modified to address the trapped miner problem.



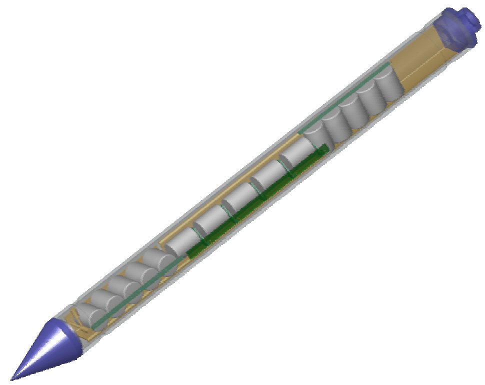
The illustration to the right shows a surface method of passive emission imaging. The signal from the miners would cause a seismic signal that is recorded on the surface array. As the sound is tracked the computer calculates the location based upon the time the signal arrives at each geophone. The seismic energy recorded by the array over a period of observation time is displayed as colors in the cube, hotter colors representing higher energy levels. The areas of high energy will delineate where the activity is taking place in the subsurface.

WHAT IS THE STATE OF THE TECHNOLOGY?

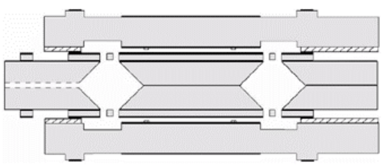
The currently available trapped miner seismic location equipment is owned by the US Mine Safety and Health Administration's Mine Emergency Operations branch and is located at the Pittsburgh facility. The rig is composed of three vehicles; an equipment truck that contains the records and filters, a generator truck to provide power and trailer which carries geophones, cables, and other supplies. While it was deployed during the Quecreek Number 1 Mine inundation in July 2002, it was not brought to the Sago explosion in January 2006. The system was built under contract with Westinghouse in the 1970's. There have been some moderations over the years but it is generally agreed that it is in need to replacement.

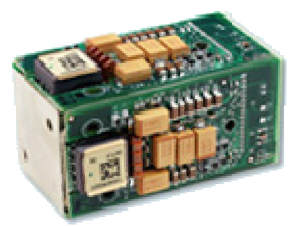
The biggest change in the technology since the 1970's has come with enhanced computer capability. The basic geophone has seen some improvements and there are new digital sensors that have been introduced but the ability to use software to recognize and filter the waveforms received has allowed for greatest advances in resolution.

Modern geophones have changed little from those of the 1970's. They are packaged in either individual cases with spikes that can be placed on the surface or in tubes with multiple geophones oriented to collect information from both horizontally oriented waves as well as vertically oriented waves. The voltage that results from a geophone converting seismic energy inputs (or vibrations) into electrical voltage provides the information needed to determine the direction and distance of the source. No power is necessary and amplification of the signal is not usually required.



The introduction of digital sensors and wireless communications is bringing a change in the way seismic information is collected. A digital sensor contains three identical, highly sensitive MEMS (micro-electro-mechanical systems) accelerometer chips. These sensors do not suffer the directional bias, signal smear and frequency loss effects of a geophone array and therefore more accurately sample the seismic wave. These devices are more complicated, require power and are considerably more expensive than geophone technology.





In addition to changes in the sensors the advances in the electronics for converting analog signals from traditional geophones into digital then moving the digital data using wireless technologies has brought significant changes to the deployment of sensors. While cable based systems are still utilized, where they can be they are being replaced with wireless systems. Geophones or digital sensors are now available that can be interconnected much as wireless computer networks are established. These approaches, while subject to some of the same interference issues as wireless computer

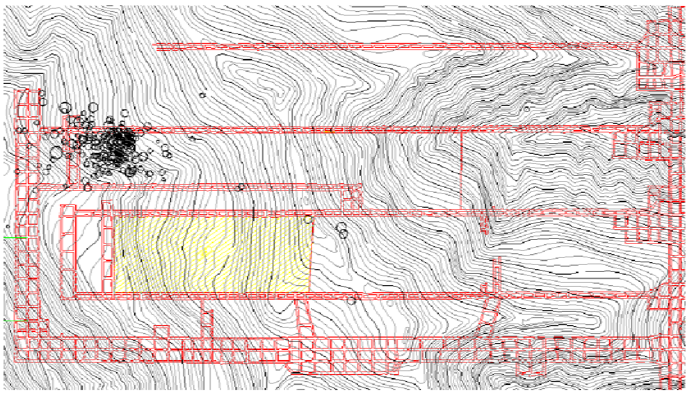
connections, provide a option for rapidly deploying arrays of geophones. These can also be supplemented with the use of UHF or microwave communications systems to interconnect individual arrays. This technique has been demonstrated by NIOSH in monitoring underground coal mines in the western United States with success.

The receivers (geophones or digital sensors) are placed in the earth as close as possible to the area of interest. In the case of trapped miners that would be determined by the mine maps and their last known location. All WV mines must maintain accurate maps of their workings. These can be overlaid with topographic maps of the surface to best position arrays. Using these maps and with knowledge of the subsurface geology provided by local mining engineers the seismic operators will place the individual receivers in the ground and obtain their coordinates using GPS units. Receivers are placed in such a manner that they are physically connected to solid earth. This can be accomplished in several ways. If the rock strata are exposed they can be placed on it and held in place using a heavy weight. If there is surface soil a handheld augers can be used to place them a distance below the surface where they are packed in mud to maximize coupling to the earth. Various vendors offer tools that assist with the placement and recovery of seismic receivers.

Data from the array or arrays are routed to a computer for analysis. With the advent of powerful portable computers this can now be accomplished in the field in real time. The computer can be one of the powerful laptops or a specially configured CPU. Either way the data is processed using one of several commercially available software packages that use the timing of the wave and its intensity at the various seismic receivers to calculate the probable location of the source. These are then plotted on the mine map to provide information to the mine rescue teams.

Because of uncertainty about the geologic composition of the subsurface between the seismic receivers and the source of the sound there will be error in the location calculations. The result will be a cluster of possible locations being plotted. Using their knowledge of the mine the operators will be able interpret the cluster results and provide the rescue team with the most probable location of the sound source.

This has been demonstrated recently by NIOSH as they were monitoring coal mines for the sounds of microseismic activity indicating pending roof falls. By plotting the location and



magnitude of the sounds they were able to identify the portion of the mine where the sounds originated. From a mine rescue stand point this would in invaluable information for rapidly deploying rescuers to the most likely location. Studies done during by the former Bureau of Mines indicated an accuracy of 200 feet at depths of 1000 feet with 1970's technology. It is anticipated that current technology will be able to accomplish at least this precision in less time than the older technology.

Currently no vendor offer systems configured specifically to locate trapped miners. The last one purchased was MSHA in the 1970's so there has been no market for over three decades. Inquires from the W.Va. Mine Safety Technology Task Force and new rules promulgated by the State to place units with each of its four mine rescue teams along with renewed interest from MSHA to purchase two units have been greeted enthusiastically by vendors. While the market for mine rescue will likely remain limited the seismic industry has stepped forward to provide assistance anyway. They are to be complimented.

WHAT NEEDS TO BE DONE?

Scenario for solution design

It is not possible to know every possible combination of events that might occur, therefore the roundtable members debated a most likely case scenario for use in developing designs. The group concluded that as the technology and techniques are refined the elements may need tio be modified but for the initial design basis a reasonable starting point is:

- An accident has happened in an underground coal mine that has left some number of miners trapped

- All operations other than ventilation and rescue have ceased at the mine
  - Evacuate mine and determine who is missing and where they were last
  - Determine likely problem – explosion, fire, gas, water, etc
  - Terminate power
  - Establish gas monitoring

- The miners begin signaling by thumping a roof bolt with a timber or hammer. On each half hour they thump ten times followed by delay of a ten count and another ten thumps. Then they rest until the next half hour.

- Mine Rescue Teams supported by seismic location equipment and operators have been deployed

- The seismic operators need to determine:
  - If the miners are trying to communicate seismically
  - Where on the mine map miners are with as much accuracy as possible

- The seismic operators have:
  - An accurate surface and mine maps with escape-ways, SCSR storage caches and emergency shelter/chamber locations noted
  - An understanding of the geological conditions and access to the mine engineer/geophysicist
  - Access to consulting seismic experts via phone and internet
  - An understanding of the last known location of the miners
  - Unrestricted access to the surface over the mine
  - GPS capability to locate their geophones
  - Ability to silence extraneous noise (i.e., stop traffic, drilling, etc) on the half hours
  - Experience in listening to mines so as to distinguish common extraneous noises such as pumps, fans, etc from miner signals

Technology Requirements

The roundtable developed some general requirements based upon experience in mine rescue and applied geophysics. These will need to be reviewed as the technology and techniques are further refined to correct any shortcomings and take advantage of new capabilities.

- Portable
  - Small enough to carry in regular vehicles from regional offices to the mine
  - Require no power beyond batteries that can be carried into the field

- Easily deployed
  - Ability to deploy in no more than 60 minutes once arriving at the mine
  - Ability to move quickly if need to refine location
  - Ability to interconnect with additional units as they arrive
  - Rugged enough to survive repeated use in training and still work when needed

- Simple to operate
  - As much as possible the software should be automated to provide the on-site technician the ability to operate
  - Ability to produce accurate results in real-time (estimates of location on mine maps) with sufficient precision to aid rescue team
  - Ability to produce maps to inform command staff and mine rescue teams
  - Ability to save and transmit collected seismic data to consulting seismic experts to assist in interpretation

Procedural Requirements

In addition to the technology there are several areas where procedures must be developed and implemented to ensure the seismic location system to function. Some of these relate to how the equipment is used others to how miners and rescuers must react.

- Mine Operators
  - Prepare and provide accurate mine and topographic maps in the same coordinate system in a format that will be accepted by the seismic software
  - Prepare and provide geologic information as needed by seismic team to calibrate the software (velocity constants, void recognition, loosely compacted areas, etc)
  - Secure necessary access to surface areas that are needed for seismic operations in the evident of an accident

- Seismic Operators
  - Review each mine in their region and plan through system setup and operation
  - Develop and maintain mine specific velocity and other variable values
  - Detailed setup and operational checklists that minimize possibility of operator error under stress
  - Practice transport, setup and operation and know how to make necessary corrections and repairs under field conditions
  - Maintain interactions with other operators and consulting seismic experts to minimize chance of miscommunications under stress

- Miners
  - Understand and know how to use the mine's escape plan, available escape aids and communications system
  - Understand how the seismic location system works
  - Understand the seismic thumping procedures
  - If trapped only thump on the half hour then rest

- Command Center
  - Provide all assistance seismic operators require
  - Enforce quite time on the half hour
  - Use the location information provided to aid rescue team deployment

- Rescue Teams
  - Understand how the seismic location systems works
  - Obey the half hour quite time
  - Utilize the information to speed advance

Technology Gaps

The Roundtable members identified many areas where requirements could be met by transferring technology from the oil and gas industry onto this problem. There were however several areas where those technologies required or would benefit from further development. The group was unanimous in recommending that federal, state and private funding be focused on those areas as quickly as possible and that funding for advancing the use of seismic systems in mining be maintained at a level such that the option never again falls off the table. Areas where additional capability should be developed included:

- Pre-deployed systems
  - Either pre-deployment for seismic receivers for connection during emergency or complete systems for continuous monitoring

- Data format standardization
  - International standardization of seismic data to ensure that as multiple systems arrive at the science of an accident that the results can be integrated

- Improved signaling methods
  - Investigation of ways that miners can increase the likelihood of their thumping being recognized over background noise

- Signaling from inside shelters
  - Investigation into a means for signaling from within an emergency shelter

- Ideal set of available geologic information
  - Investigate what is the minimal required geologic information required to calibrate a seismic location system to increase signal recognition and location precision
- Noise pattern library
  - Develop a library of typical noises that can be shared by seismic operators (pumps, fans, etc)

- Options for remote analysis
  - Develop options for use of a network of seismic experts that could assist operators in real-time analysis of data using the internet

- Preloaded mine maps
  - Explore options for maintaining accurate mine and topo maps such that teams can have them download for review on the way to the mine

- Options for use in other emergencies
  - Explore uses for trapped miner seismic location systems in support of other emergency operations

Actions

The roundtable members believe that there is sufficient information to move to begin implementing a seismic trapped miner location program now. While there are long term issues that could enhance such a system's performance, it should work now and there is no reason to wait. The following are actions recommended:

NOW – Develop configuration for deployable seismic units

- Utilizing the best available off-the-shelf technologies configure a system that will meet the requirements and be flexible enough to be updated as technology changes

NOW – Collect necessary mine specific information

- Start the process of determining the minimal set of information and the system for gathering and maintaining it

BY NOVEMBER – Test configuration

- As soon as possible begin testing the elements of the deployable configuration

BY DECEMBER – Acquire four units and train operators

- Acquire four seismic units that meet the States configuration requirements and begin training

NOW – Incorporate seismic options in tests of mine communications systems

- As communication testing is being done this summer identify opportunities for incorporating installed seismic elements into the integrated systems

NOW – Developing national workgroup on trapped miner seismic location

- Work with WVU and MSHA to establish a national forum for seismic professions focused upon mining applications with a special emphasis of trapped miner location

NOW – Begin working the State, Federal, non-profit groups and industry to establish the resources necessary to address the technology gaps identified above