Development and Field Testing of a Seismic System for Locating Trapped Miners
- Progress Report

Yi Luo, Keith A. Heasley and Syd S. Peng
Department of Mining Engineering
West Virginia University

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Presentation Outline

- Introduction
- Seismic Methods
- Proposed WV Seismic Location Systems
- Field Tests
- Summary
- Future Research Works

Introduction

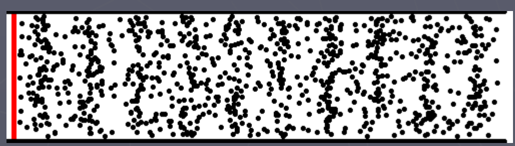
- An underground coal mine accident left miners trapped
- All communications systems compromised - no way to determine the locations of the survivors
- As instructed, the trapped to signal on the half-hour by pounding
- How to determine the their locations?
- A special seismic location system seems to be an answer.
- Issues to study
  - Hardware capabilities and limitations
  - Specialized software
  - Special conditions

Seismic Methods

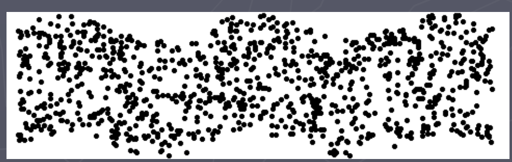
- Major components of a seismic system
  - Vibration inducer to generate unique and powerful seismic signals to travel the desired distances in the ground
  - Signal receivers (geophones) – motion detectors to detect the arrival time and intensity of the ground motion
  - Interpretation software
    - Filtering useful signal from noises
    - Determining locations of the desired features

Seismic Methods

- Seismic signals propagate in rock in 2 main forms:
  - P waves – primary, compression waves
  - S Waves – secondary, shear waves
- Typical P wave velocities
  - Sedimentary rocks, 600 – 6,700 m/s
  - Water, 1450 m/s
  - Air, 330 m/s
  - Signal attenuation rate (frequency dependent)?



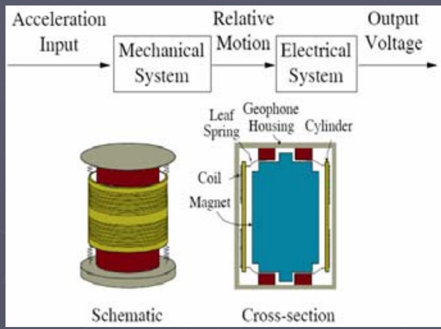
P Wave Propagation

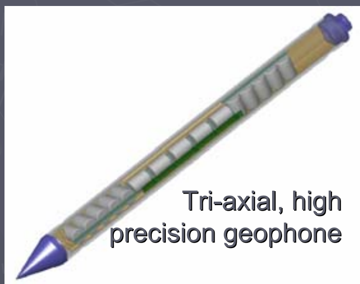


S Wave Propagation

Seismic Methods

- Geophones
  - Ground motion –> Housing motion
  - Differential movement between coil and magnet
  - Electrical current inducted
  - Output electric voltage depends acceleration



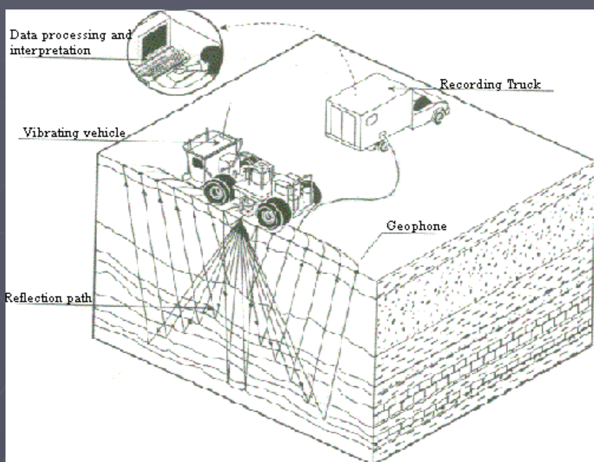


Tri-axial, high precision geophone

- Deserve most considerations for our system
  - Sensitivity for weak signals
  - Directional (unidirectional vs tri-axial geophones)?

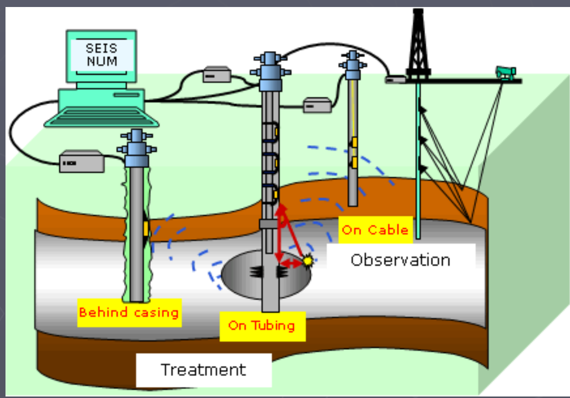
Reflective Seismic Methods

- Source and geophones located on surface
- Signals reflected from subsurface interface were received
- Common applications: oil or geological explorations, etc.



Penetrative Seismic Methods

- Seismic source located on the other side of the features to be investigated
- Applications: Downhole seismic geological explorations, etc.
- Principle similar to the seismic system for locating trapped miners



MSHA Seismic Location System


Equipment Truck


"Display" Unit

- Developed in the 70's
- Older electronic technology
- "There have been some modifications over the years, but it is generally agreed that it is in need of replacement"
- Three large vehicles


Generator Truck


Equipment Trailer

Proposed WV Seismic Location Systems

- WV State Mandate
  - **Portable seismic locating systems** at each of the four regional office for use in locating trapped miners
  - A trained staff at each regional office capable of delivering the portable system to the mine site and to deploy the system immediately and without delay
- Feasible because of Advancement in Electronic, Computer and Information Technologies
  - Small sized and feature rich geophones
  - Digital transmission and storage of seismic signals
  - Enormous computing power packed in a notebook PC
    - Digital filtering and triggering for enhanced resolution.
    - Data processing and interpretation

WV Seismic Location Systems

- Research Objectives
  - Determine and Acquire the "best available" seismic location system.
  - Conduct field tests to determine the capabilities and limitations of the system
    - Depths, Distances
    - Geology
    - Multiple seams, gob areas, etc.
  - Develop mathematical algorithm and user-friendly computer program for
    - Picking the event signals from noisy background
    - Pin-pointing the locations of the signal sources
  - Long Term: Help develop the hardware and software for a practical location system for trapped miners.

WV Seismic Location Systems

- Technology Requirements
  - Portable
    - Small enough to carry in regular vehicles
    - Require no power beyond portable batteries
  - Easily Deployed
    - Can be deployed in 60 minutes
    - Can be moved quickly
    - Can interconnect with additional units
    - Rugged enough to survive repeated use.

WV Seismic Location Systems

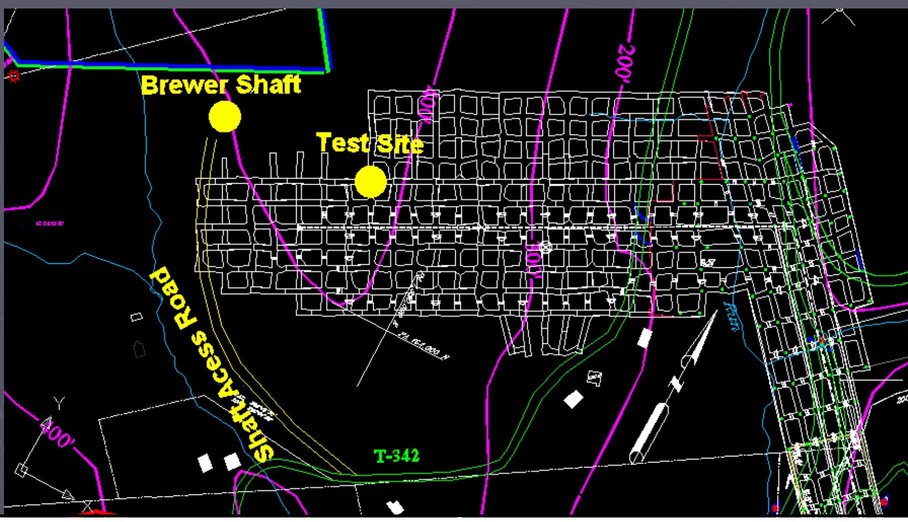
- Technology Requirements
  - Simple to Operate
    - Software should be automated enough for on-site technician
    - Produce accurate results in real-time
    - Ability to produce maps
    - Ability to save and transmit seismic data to consulting seismic experts to assist in interpretation
- Successful Location
  - **Within one or two coal pillars** for searching and rescuing operations
  - **Sub 10-ft accuracy** for drilling lifeline holes from surface

Field Tests

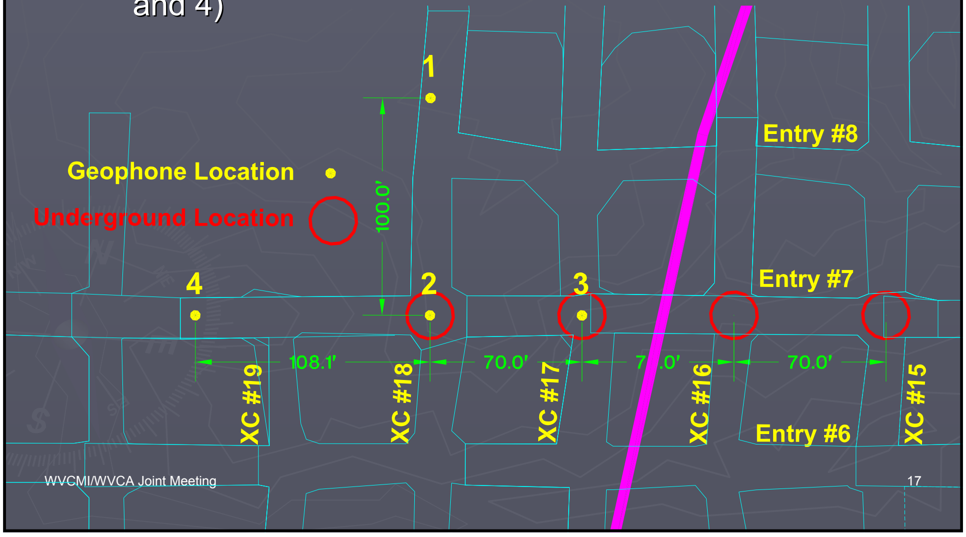
- Two Field Tests Performed
- Test Site No. 1
  - 4 West Mine, Dana Mining Co., Southwest PA
    - Room and Pillar coal mine
    - Depth: ~ 420 ft
    - Participants: Weir Jones, Hilti Mining
    - Success: Yes
- Test Site No. 2
  - Federal No. 2 Mine, Peabody Energy, North WV
    - Longwall coal mine
    - Depth: 800 – 1,000 ft
    - Participants: Weir Jones and ESG
    - Success: Unsure

Field Tests

- Test Site No. 1



- Test Setup at Site No. 1
  - Four underground signaling sites spaced 70 ft apart
  - Four surface geophone locations, two buried in drilled holes (1 and 2) and two just simply buried in the soil (3 and 4)



Field Tests

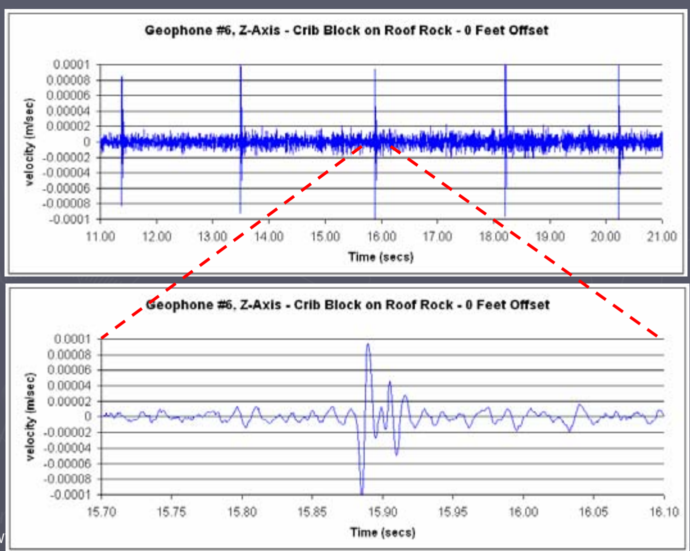
- Seismic Equipment
  - Geospace 32CT geophones
  - Terrasciences 24 channel, 24 bit digitizer sampling at 2 kHz
  - Notebook PC & car battery

Test Protocol

- ►Signaling devices
  - Hilti mining tools: DX76, Hilti DX460, Hilti DX462
  - 8 lb sledge hammer
  - Crib block

- ►Signaling Locations
  - Roof bolt
  - Roof rock
  - Pillar rib
- ►5 impacts, wait 30 seconds, next device
- ►Underground events precisely timed and recorded

Received Event Signal

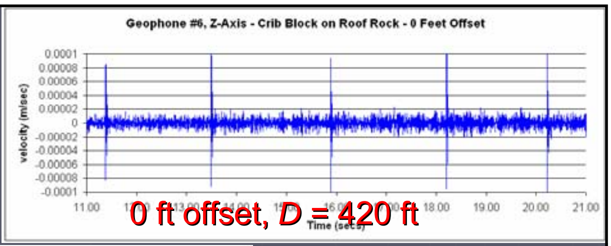


Received signal for vibration generated by crib block

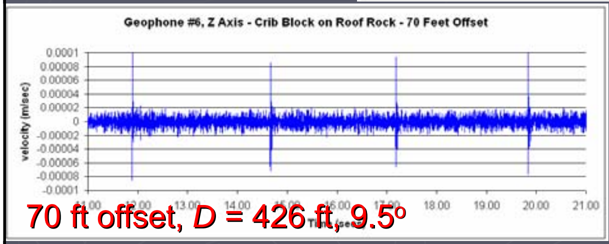
Expanded View

“Event” at frequency 50 -70 Hz

Effects of Offset Distance

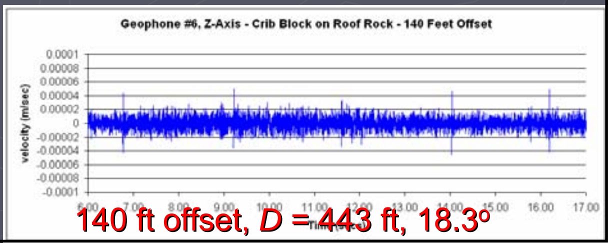


0 ft offset, *D* = 420 ft



70 ft offset, *D* = 426 ft, 9.5°

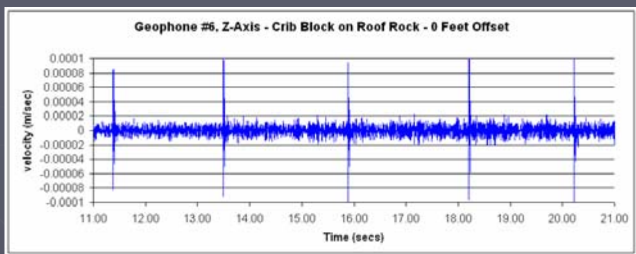
Geophone



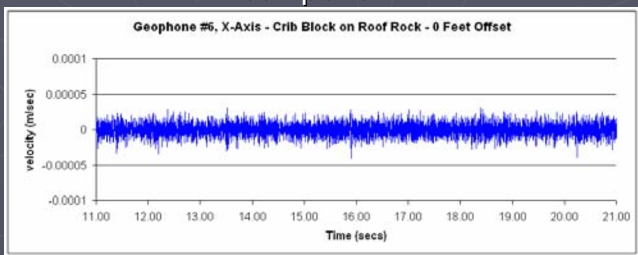
140 ft offset, *D* = 443 ft, 18.3°

- No detectable signal when offset is 210 ft, *D* = 470 ft, 26.6°

Directional Components



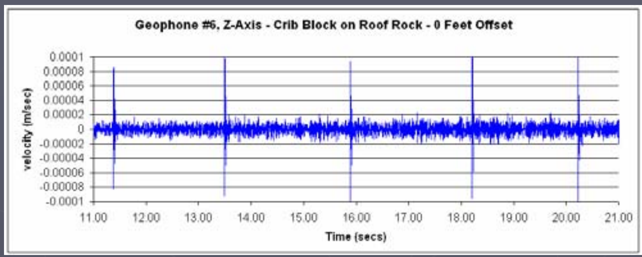
Z component



X component

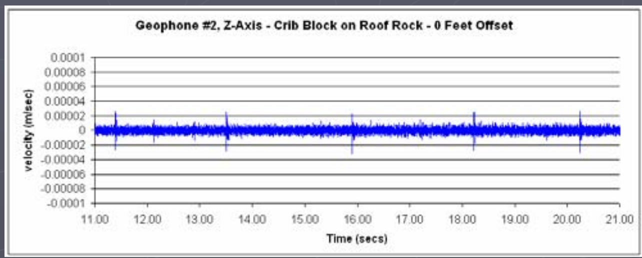
Need tri-axial geophones?

Effects of Geophone Installations



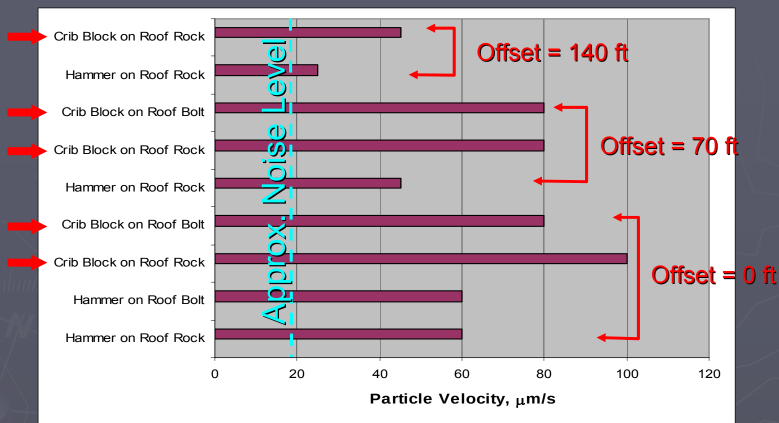
Buried in drilled hole about 2 ft deep

About 4 times stronger signal in drilled hole



Simply buried

Peak Particle Velocities



For different vibration inducers at field test site No. 1 (420 ft deep)

Received crib block signals (lower frequency) are 20-40% stronger than hammer signals – better choice!

Findings from Field Tests No. 1

- Crib Block on the Roof Rock appeared to be the strongest
  - Crib on Roof Bolt
  - Hammer on Roof Rock
  - Hammer on Roof Bolt
- Hilti tools, though very powerful, were hardly detected?
  - Higher Frequencies?
- Good detection out to 140 ft (18 degrees)
  - Not at 210 ft (26 degrees)

Findings from Field Tests No. 1

- Mostly Vertical Ground vibration
- Buried geophones provided about twice the peak particle velocity
  - Better connection?
  - Less soil?
- Increase in distance not totally responsible for signal attenuation
  - Polarized source?
  - Horizontal bedding?

Algorithm to Detect Event Signals

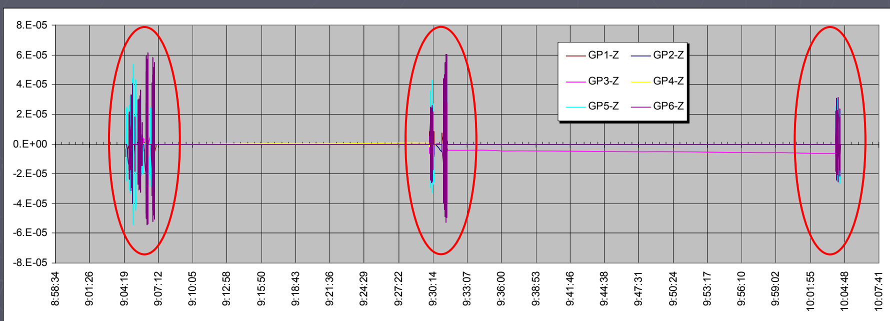
- Determine standard deviation from incoming data, σ
- Set an appropriate abnormality number, N
- Detections

Condition	Detection	Action Take
If $\|V\| > N\sigma$	Event signal	Record data for further analysis
If $\|V\| < N\sigma$	Noise	Delete data from the files

- Amount of data to be stored and analyzed will be greatly reduced
  - Before 21.45 MB zip files
  - After 4.77 MS Excel file or about 1 MB zip file

Algorithm to Detect Event Signals

- Before processing, data from every 30-second period occupies an entire Excel file (about 4.8 MB in size after compressed)
- After processing, all data fit in one Excel file and can be plotted together



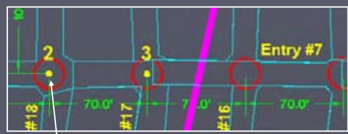
Signaling at 0 ft Offset

Signaling at 70 ft Offset

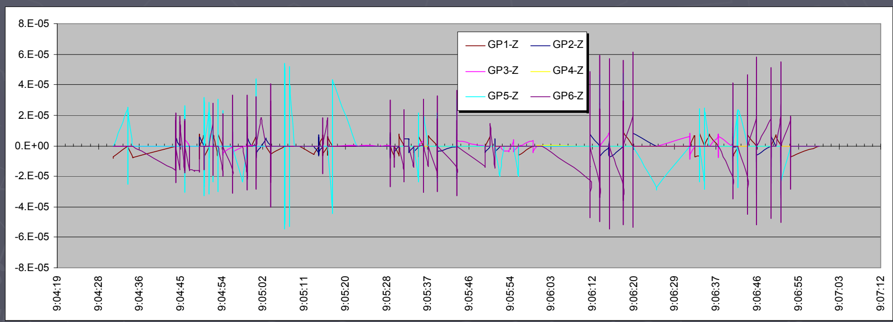
Signaling at 140 ft Offset

Algorithm to Detect Event Signals

- Expanded view of the detected “events” when signals were sent from 0 ft offset location
- Times and magnitudes of detected events clearly shown

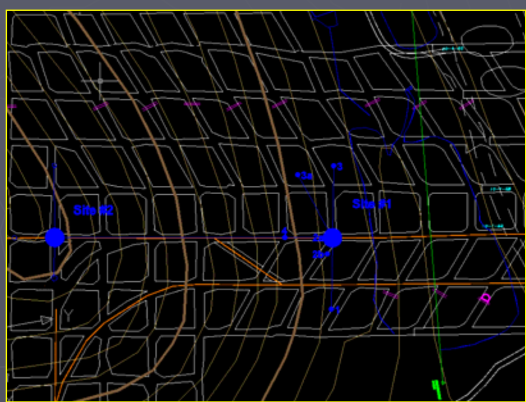


Signaling Location



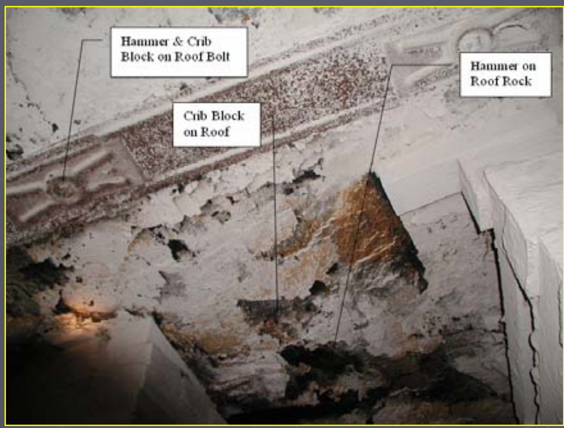
Field Test No. 2

- A longwall mine
- Two sets of seismic equipment deployed
- Two Sites Prepared
  - Site No. 1
    - At the toe area of a steep hill
    - Beside a large water pond
    - Depth: 780 – 820 ft
    - Tests conducted
  - Site No. 2
    - Top of the hill
    - Depth: ~ 1000
    - Tests not conducted



Field Test No. 2

- Unable to detect event signals by both sets of seismic equipment
  - Noisy background?
    - Sites close to mine shaft, refuse disposal area?
  - Depth too large (~ 800 ft) ?
- Efforts continue to find why's



Summary

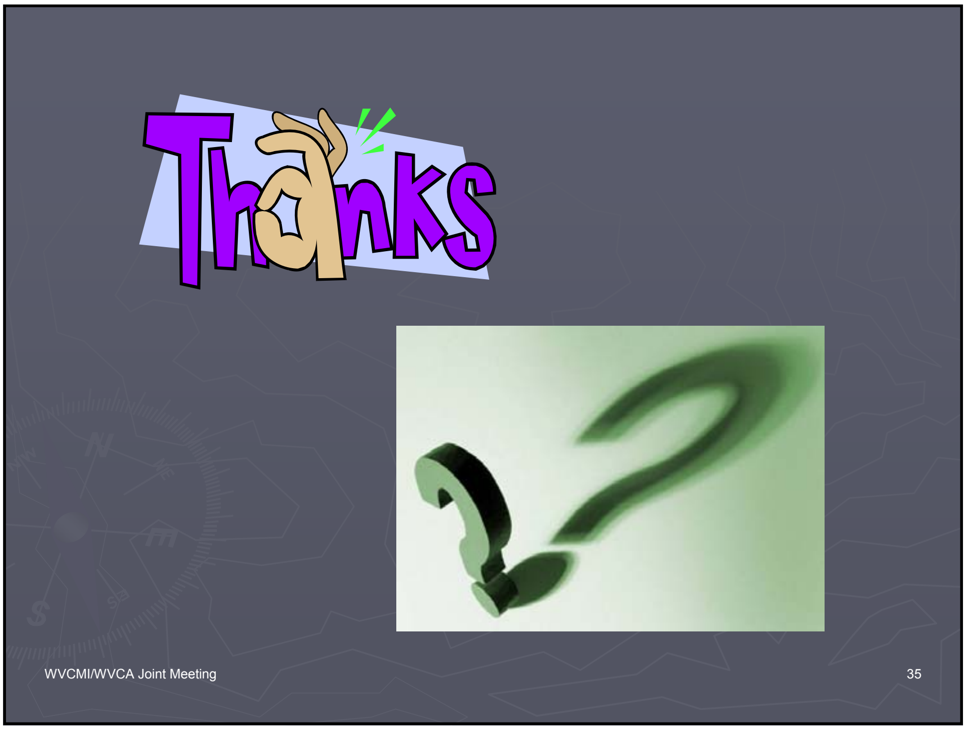
- Crib block and sledge hammer as more appropriate signaling tools to pound on the roof rock
- An effective and portable seismic system for locating trapped miner may be achievable for most West Virginian coal mines
- A simple algorithm can be used to automatically detect the event signals and to reduce data volume
- More research works needed to have better understanding of the capabilities, limitations and ways to improve the system, testing procedure, and data processing and interpretation

Future Research Works

- Purchase our own seismic system
  - To reduce dependence on equipment venders for future testing
  - To conduct tests more frequently and at varying conditions to fully understand its capabilities and limitations as well as ways to improve
- Develop the algorithm and computer program for locating the seismic source more accurately for drilling lifeline vertical holes
- Investigate effects of offset distance/angle
- Explore possibility of wireless seismic system in our applications

Future Research Works

Wireless Seismic System – www.wirelessseismic.com


Thanks
WVCMI/WVCA Joint Meeting
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