

*Update on the WV
Miner Location
Seismic System*

By

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Disclaimer

- There were a lot of people contributing to this work.
- I AM NOT A SEISMOLOGIST
- The results from the field test are very preliminary.

Scenario

- **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 – ten strikes, pause for a count of ten and then ten more strikes, then wait for a half-hour.**

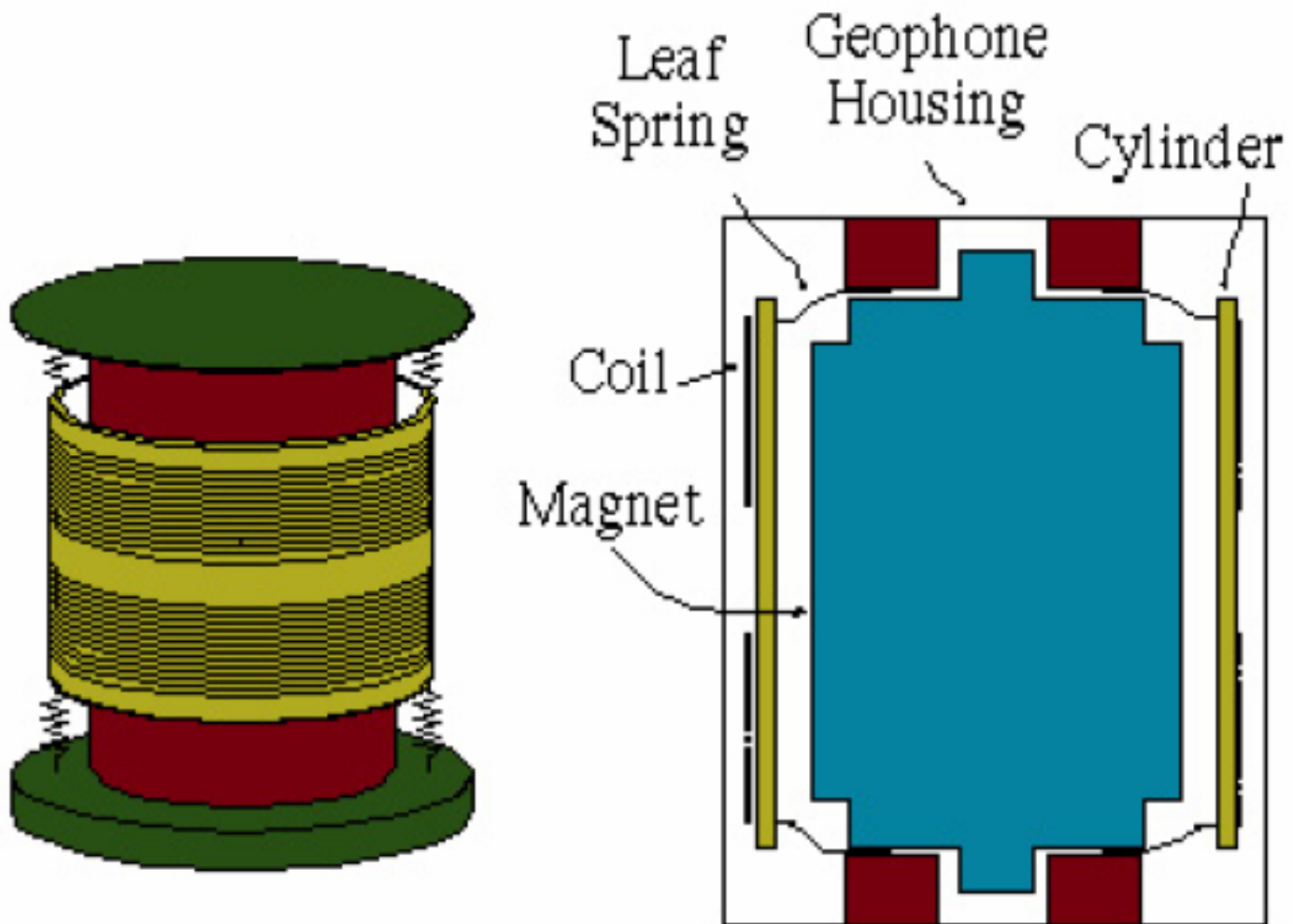
Seismic Location System

A blue horizontal brushstroke graphic, resembling a paintbrush stroke, extending across the middle of the slide. It has a soft, feathered edge and a slight gradient from left to right.

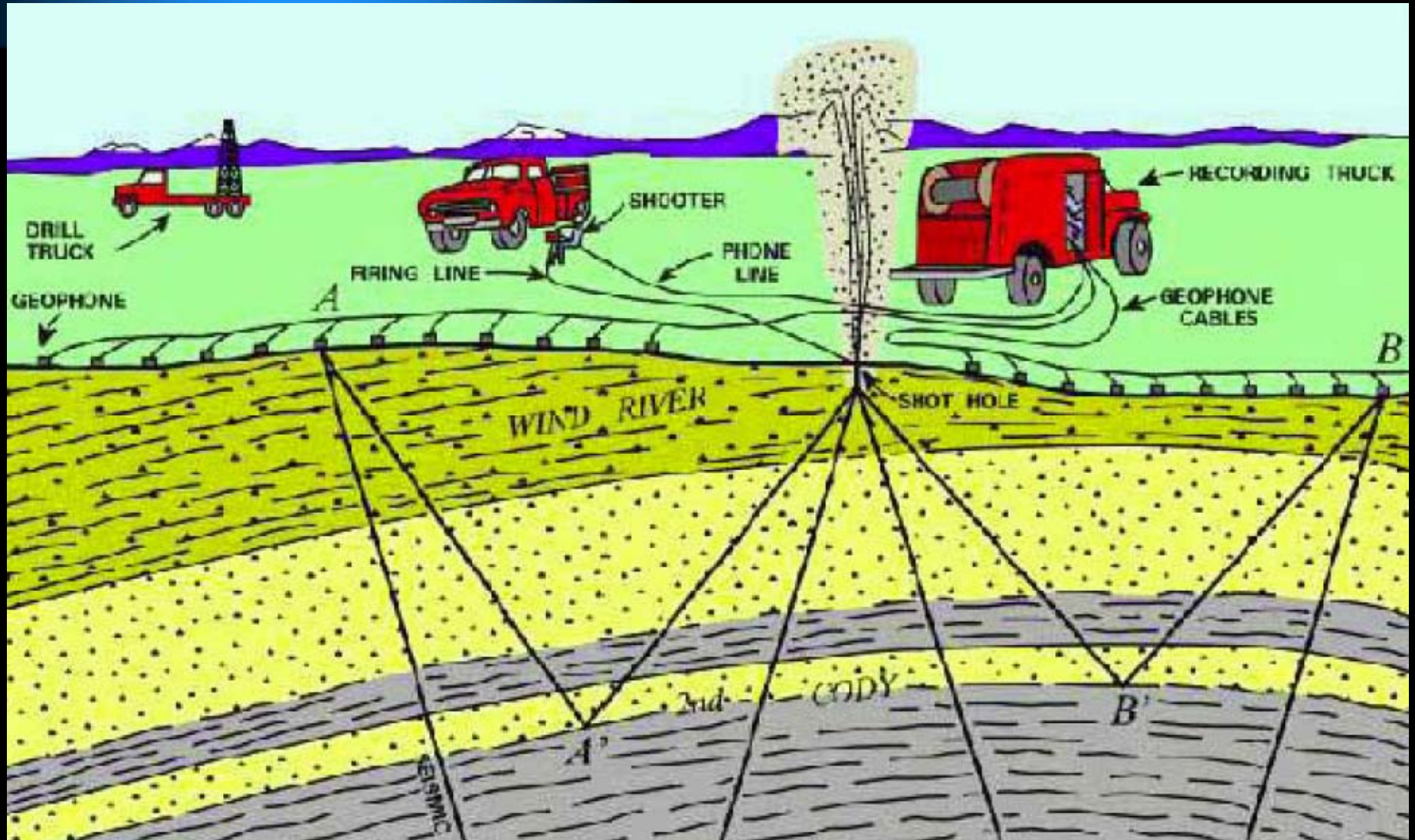
Seismicity

- The waves consists of 2 types:
 - P waves – **primary, compression waves**
 - S Waves – **secondary, shear waves**
 - **Larger amplitude**
 - **Slower (60% of P wave velocity)**
- Seismic waves travel through the ground (5000 m/s), water (1450 m/s), and air (330 m/s).

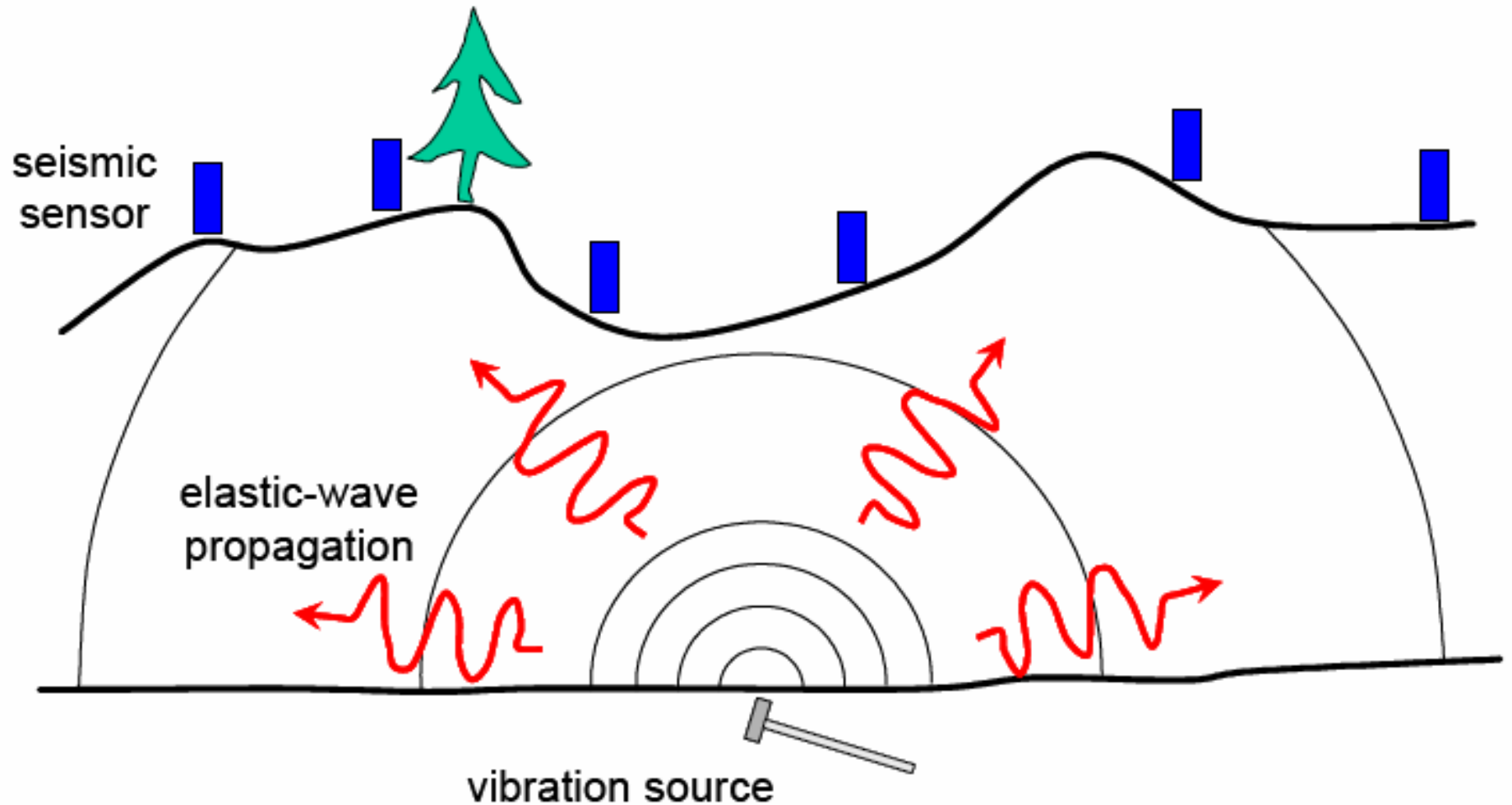
Geophone



Active Seismics



Passive Seismics



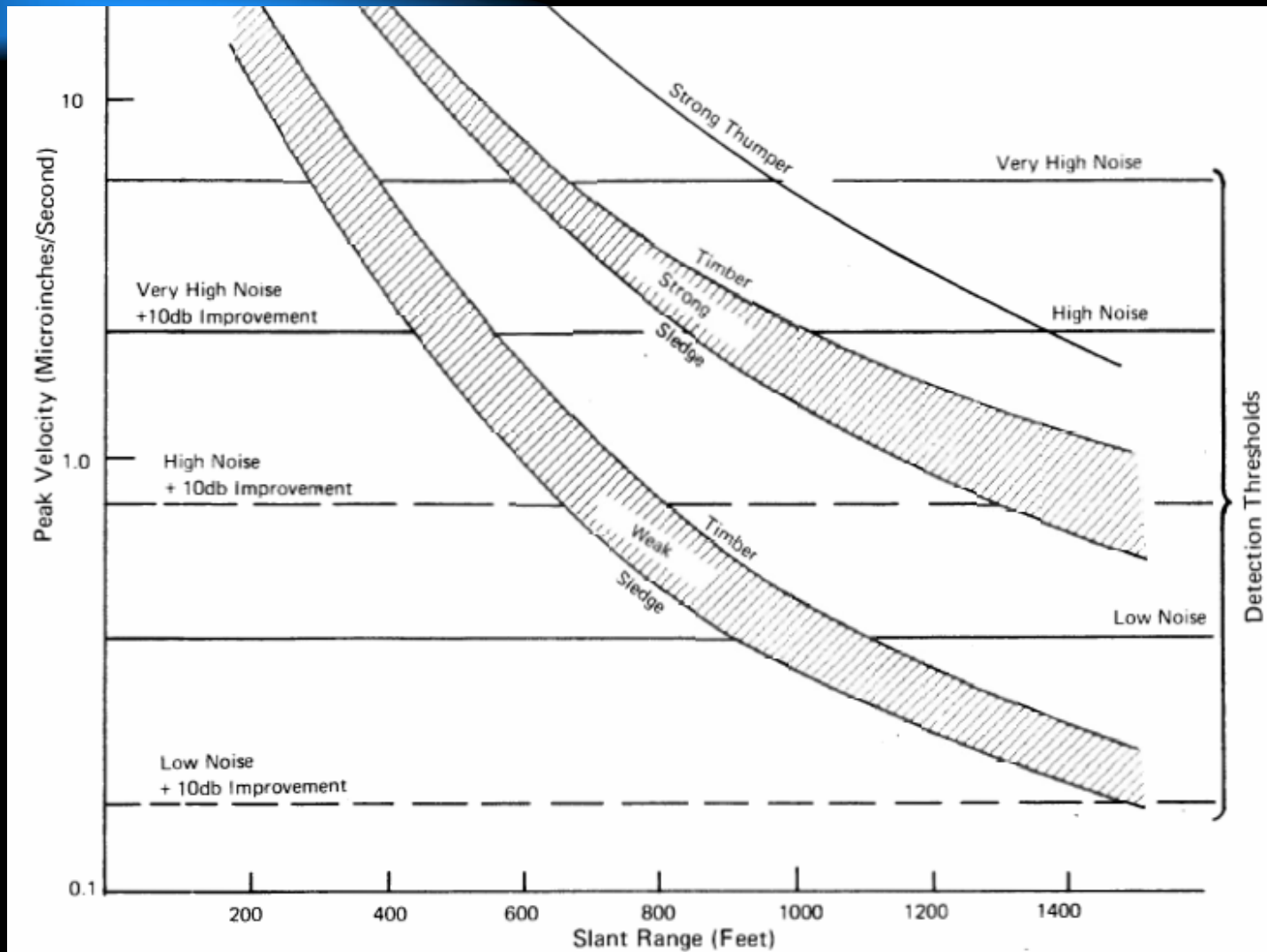
Background

- In 1970, the National Academy of Engineering (NAE) reported that a seismic system might be capable of detecting and locating trapped miners.
 - The miners would strike the roof
 - The ground vibrations would be recorded by surface geophones
 - Difference in arrival times at different geophones would be used to locate the miners

Background

- In 1971 and 1972, Westinghouse Electric Co. built and tested such a system.
 - Under favorable conditions, the system worked.
 - At actual disaster sites, the background noise generated by surface rescue operations masked any miner generated signals.
 - Thus a time specifically designated for seismic “listening” must be allocated and enforced.

Detection Distances



MSHA Seismic Location System

- **Developed in the 70's**
- **Uses 7 sub-arrays of 7 geophones each.**
- **Capable of detecting miners up to 1500 ft deep**

Equipment Truck



Generator Truck & Equipment Trailer



MSHA Seismic Location System

- **Older electronic technology – 70's**
- **“There have been some modifications over the years, but it is generally agreed that it is in need of replacement”**

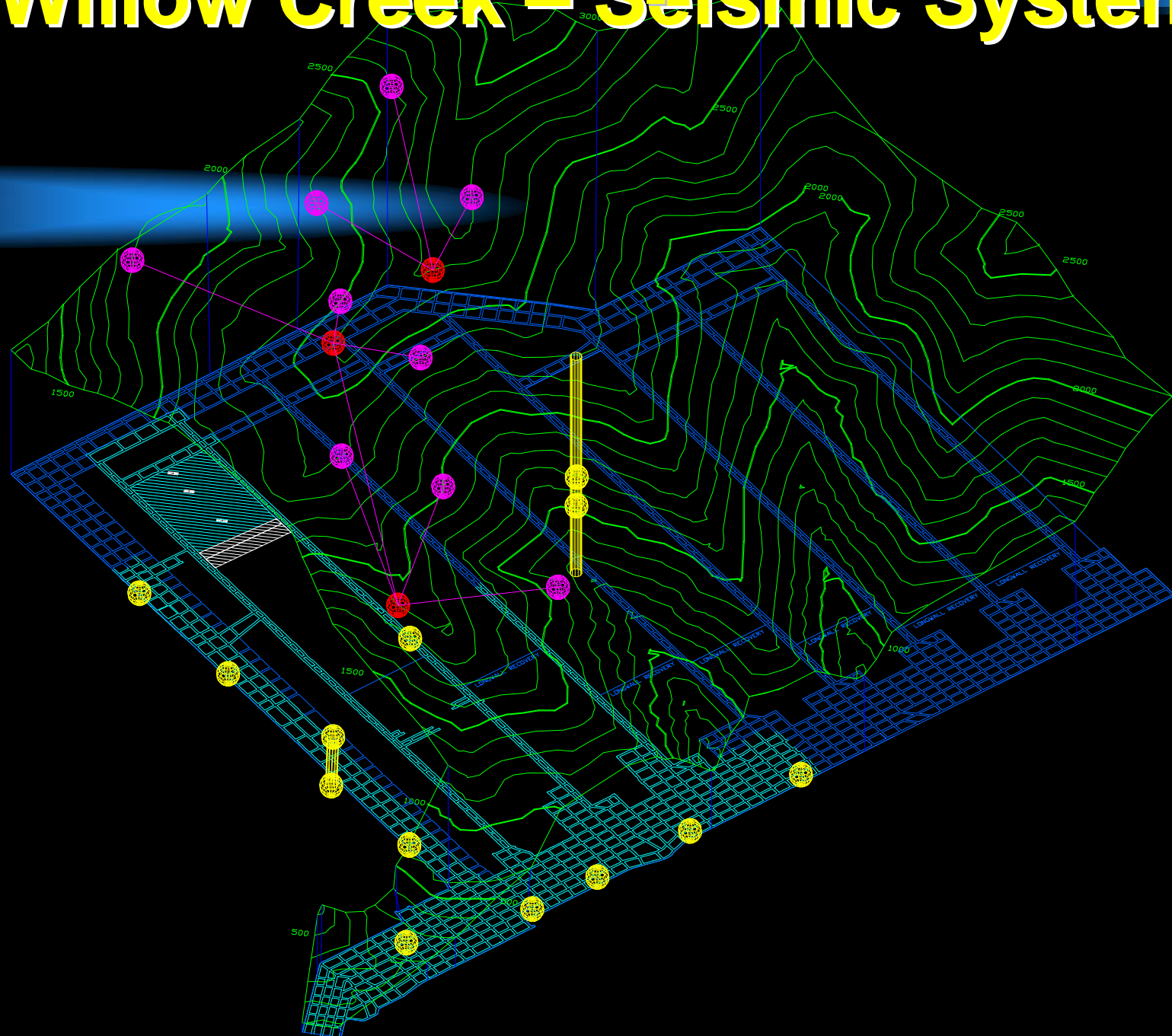
Since the 70's

- **Greatly Enhanced Computer Technology**
 - Digital transmission and storage **of seismic signals**
 - Digital filtering and triggering **for enhanced resolution.**

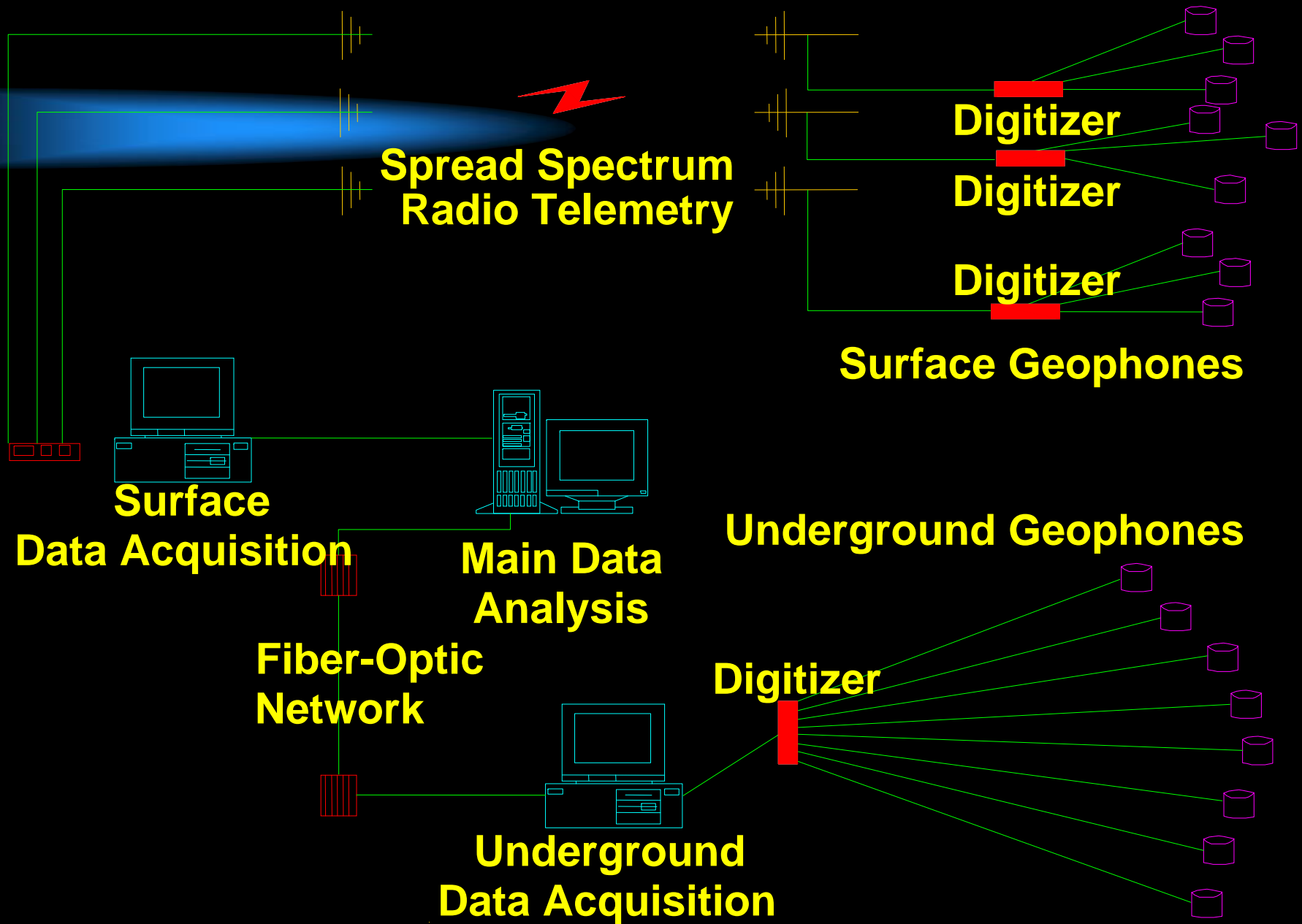
Seismic Monitoring Systems

- **Nickels mines in Sudbury Canada**
- **Deep Gold mines of South Africa**
- **Research Tool**
 - **Australian coal mines**
 - **US coal mines – NIOSH**
 - **US limestone mines - NIOSH**

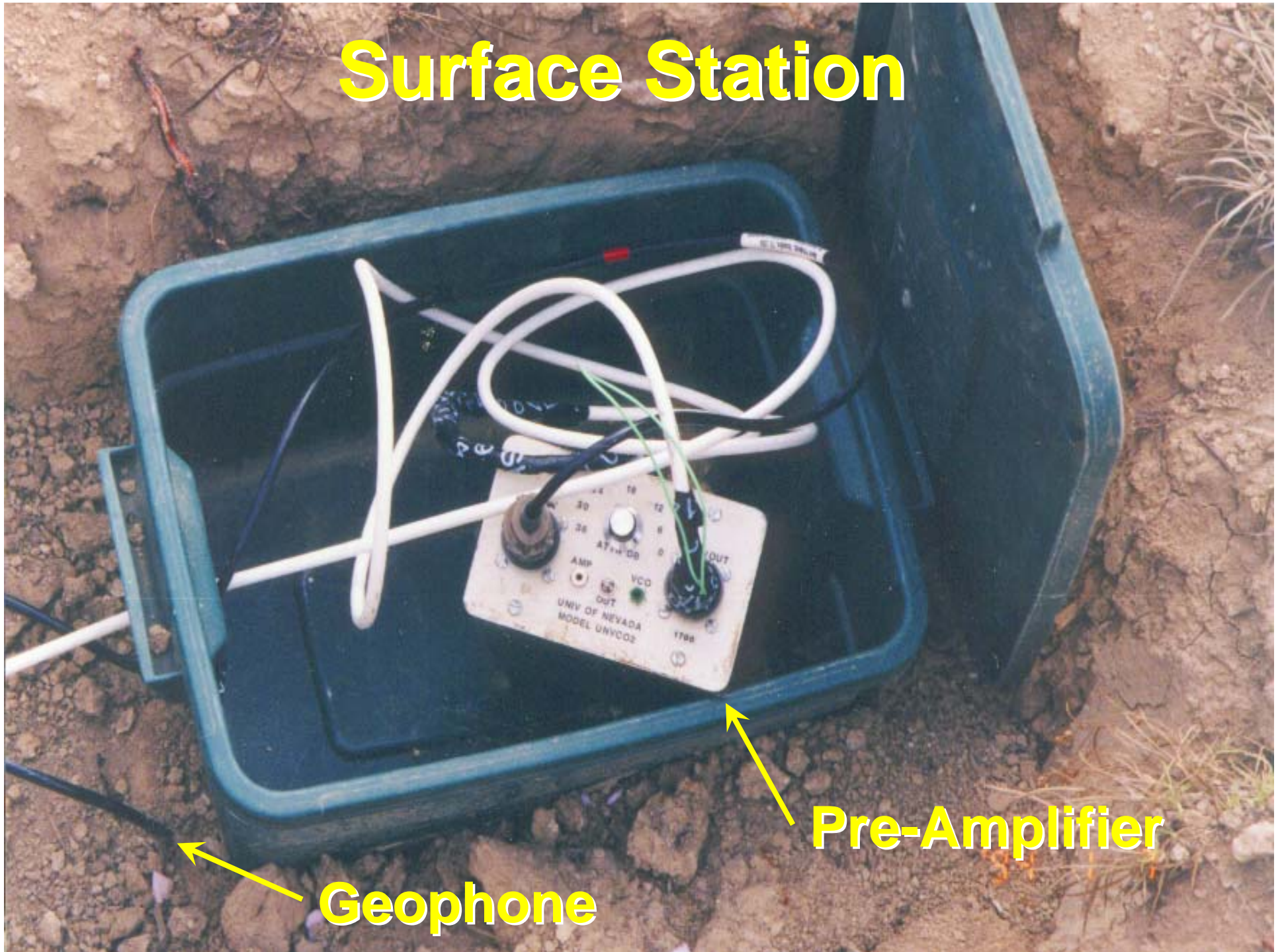
Willow Creek – Seismic System



Schematic of Seismic System



Surface Station



Geophone

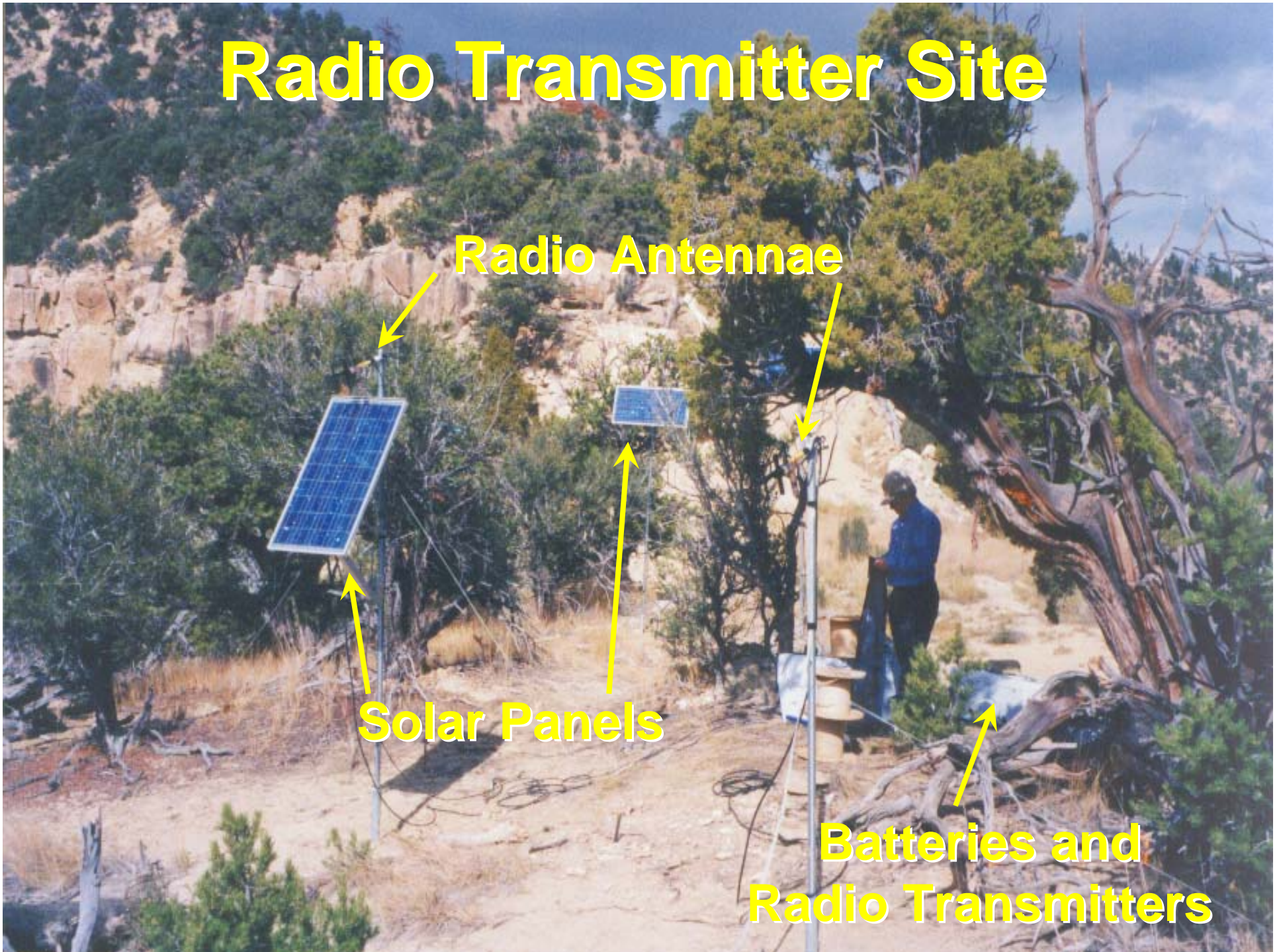
Pre-Amplifier

Radio Transmitter Site

Radio Antennae

Solar Panels

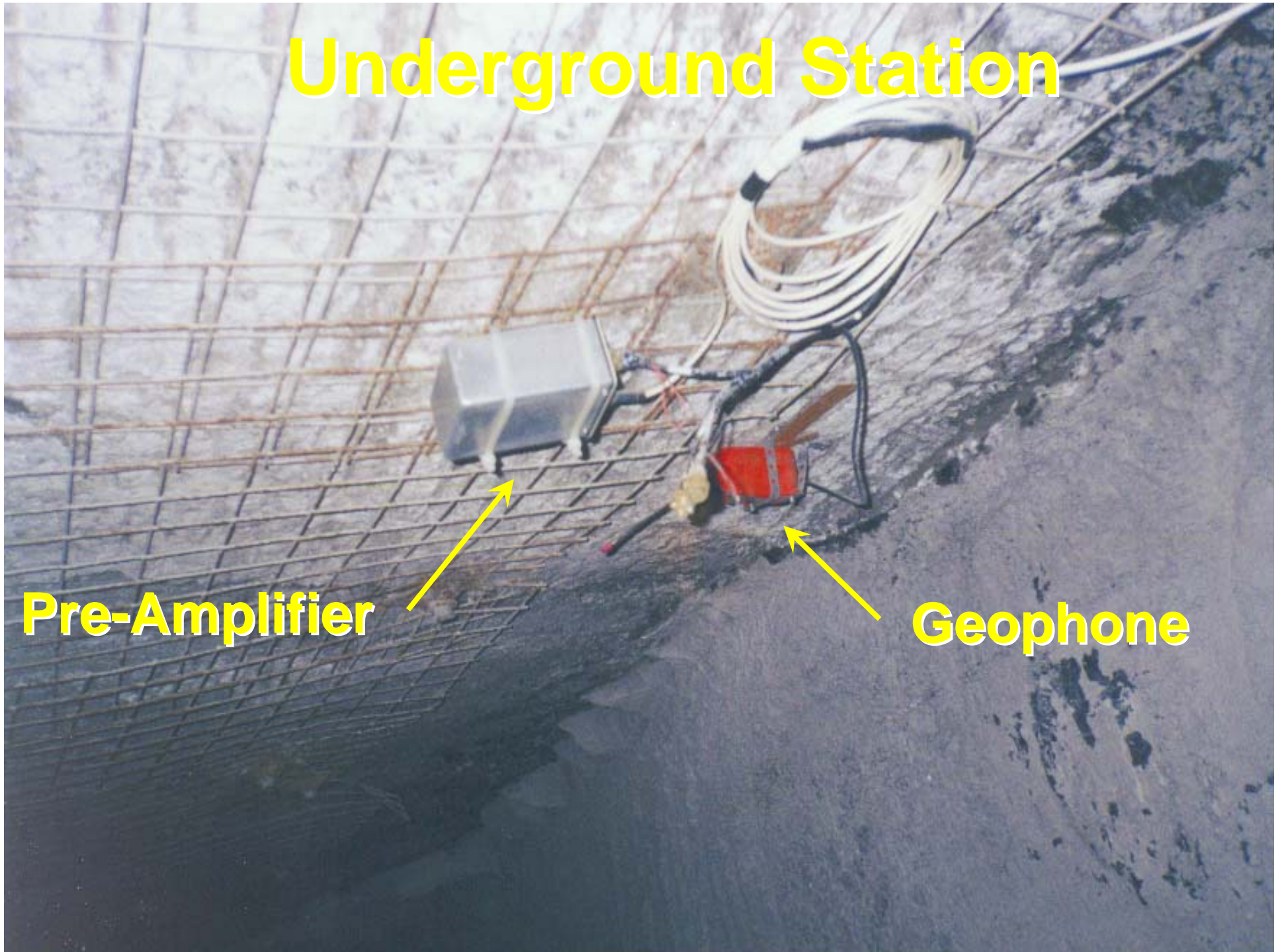
Batteries and
Radio Transmitters



Underground Station

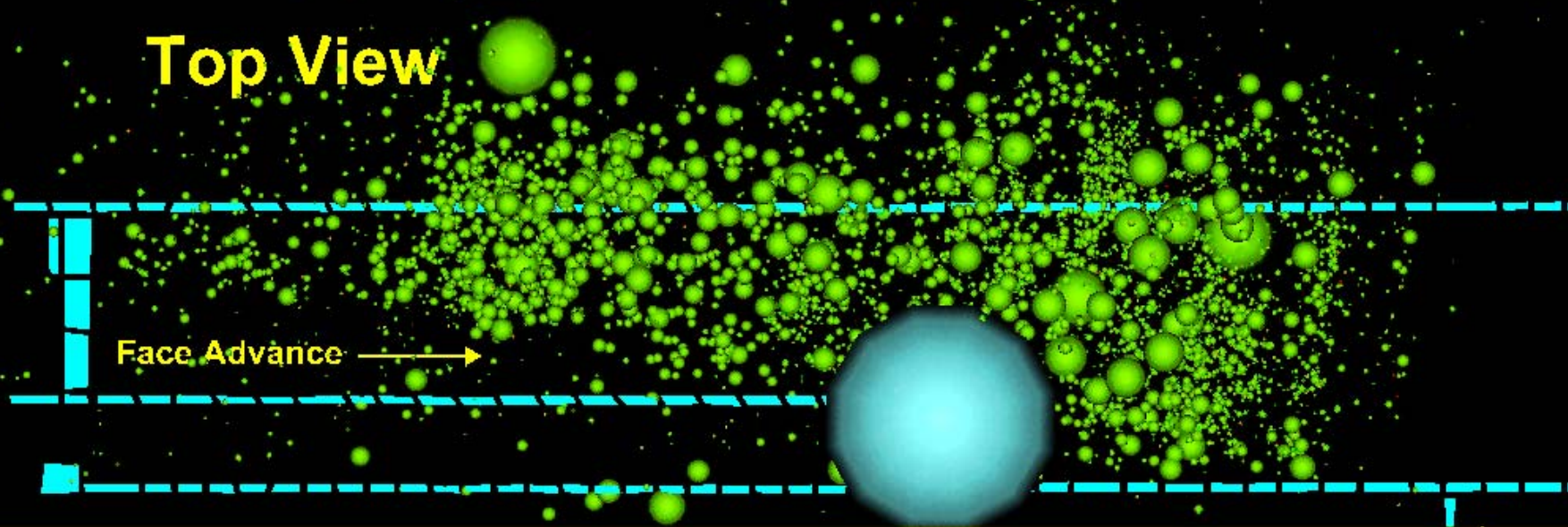
Pre-Amplifier

Geophone



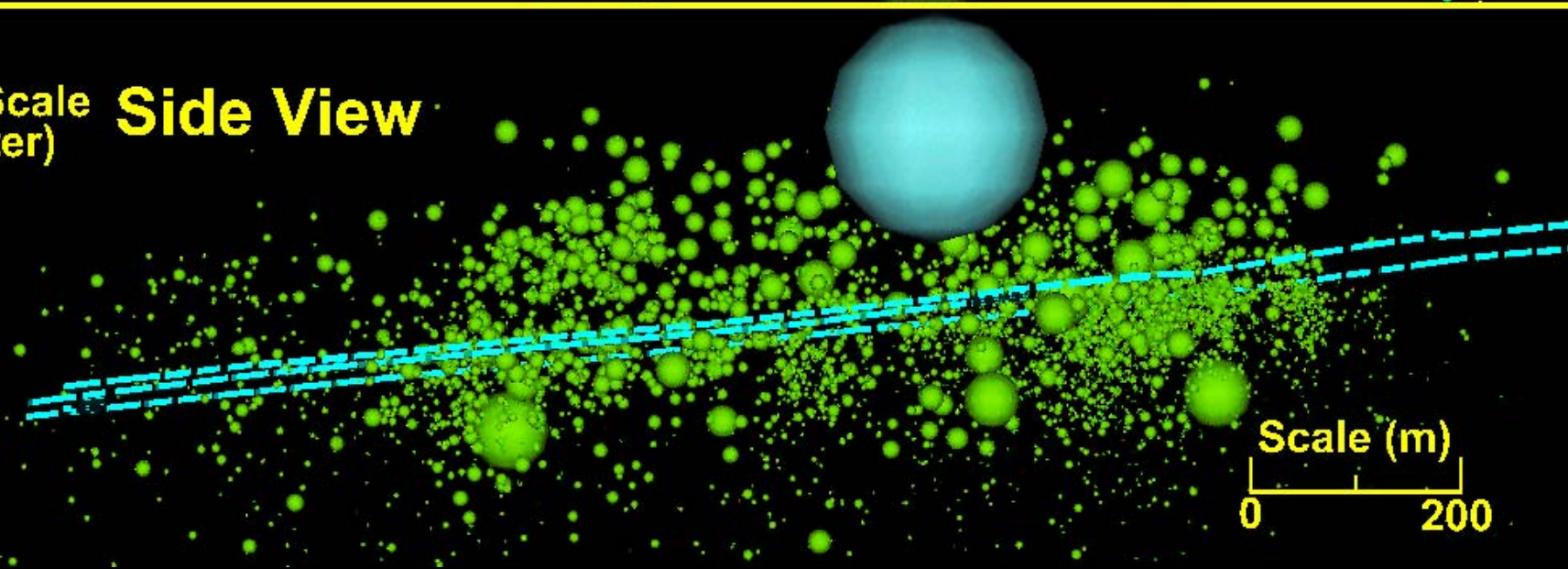
Seismic Events at Willow Creek Mine

Top View



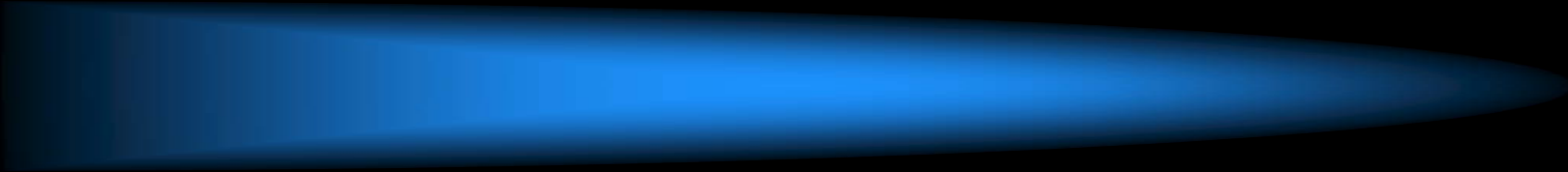
Event Scale (Richter) Side View

- 0
- 1
- 2



Scale (m)
0 200

Present Research



Mandate

- West Virginia Mine Safety Technology Task Force report (May 29th ,2006):
- “The director shall provide portable seismic locating systems at each regional office (4) for use in locating trapped miners.”
- “Each office will maintain a trained staff that shall, upon notification from Homeland Security Office, be capable of delivering the system to the mine site and to deploy the system immediately and without delay.”
- “These persons shall practice with the said systems at least annually at different mine sites.”

Research Objectives

- Determine and Acquire **the “best available” seismic location system for trapped miners.**
- Conduct field tests **to determine the capabilities and limitations of the system**
 - **Depths, Distances**
 - **Geology**
 - **Multiple seams, gob areas, etc.**
- Long Term: **Help develop the hardware and software for a practical location system for trapped miners.**

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.**

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**

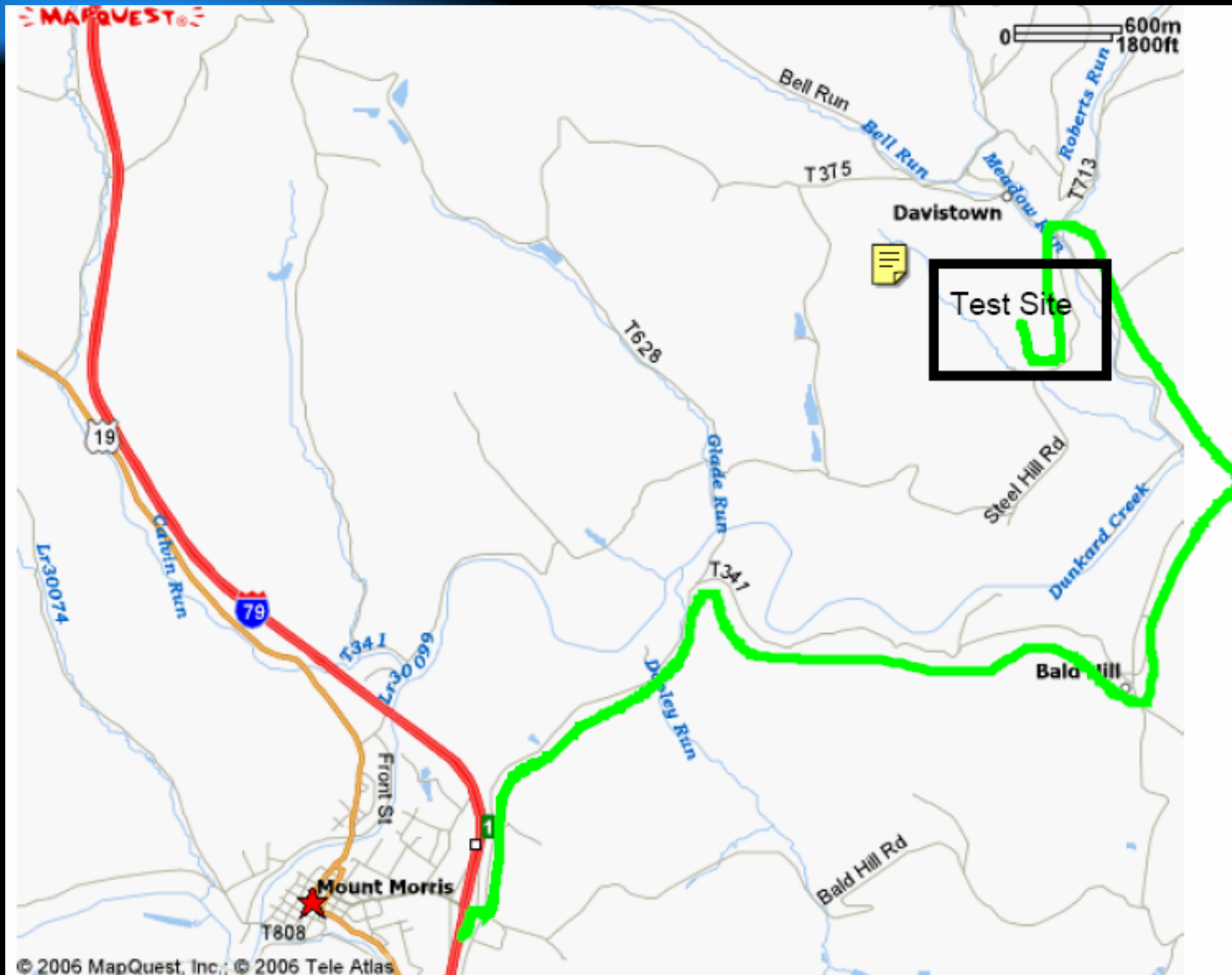
Successful Location

- **“Location accuracies to within one or two coal pillars, and even to within dimensions of a working section, when used in conjunction with a good mine map, will be extremely valuable and, in many cases, be more than sufficient to direct the efforts of both in-mine rescue crews and surface drilling crews.”**

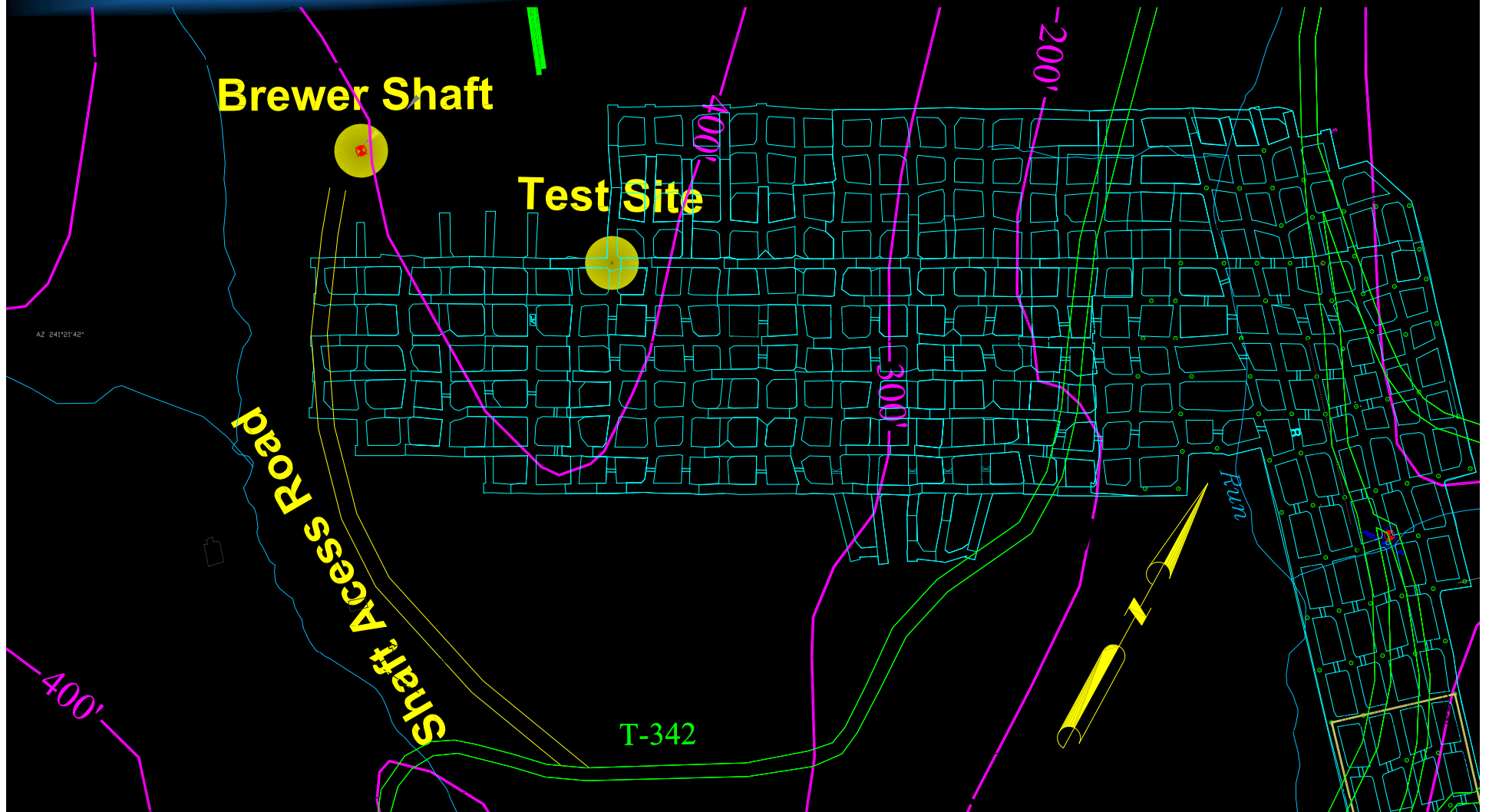
Field Test Site

- 4 West Mine, Dana Mining Co. of PA, Inc.
- North of Morgantown and the PA border
- Off the Mt Morris Exit (Exit #1) of interstate 79

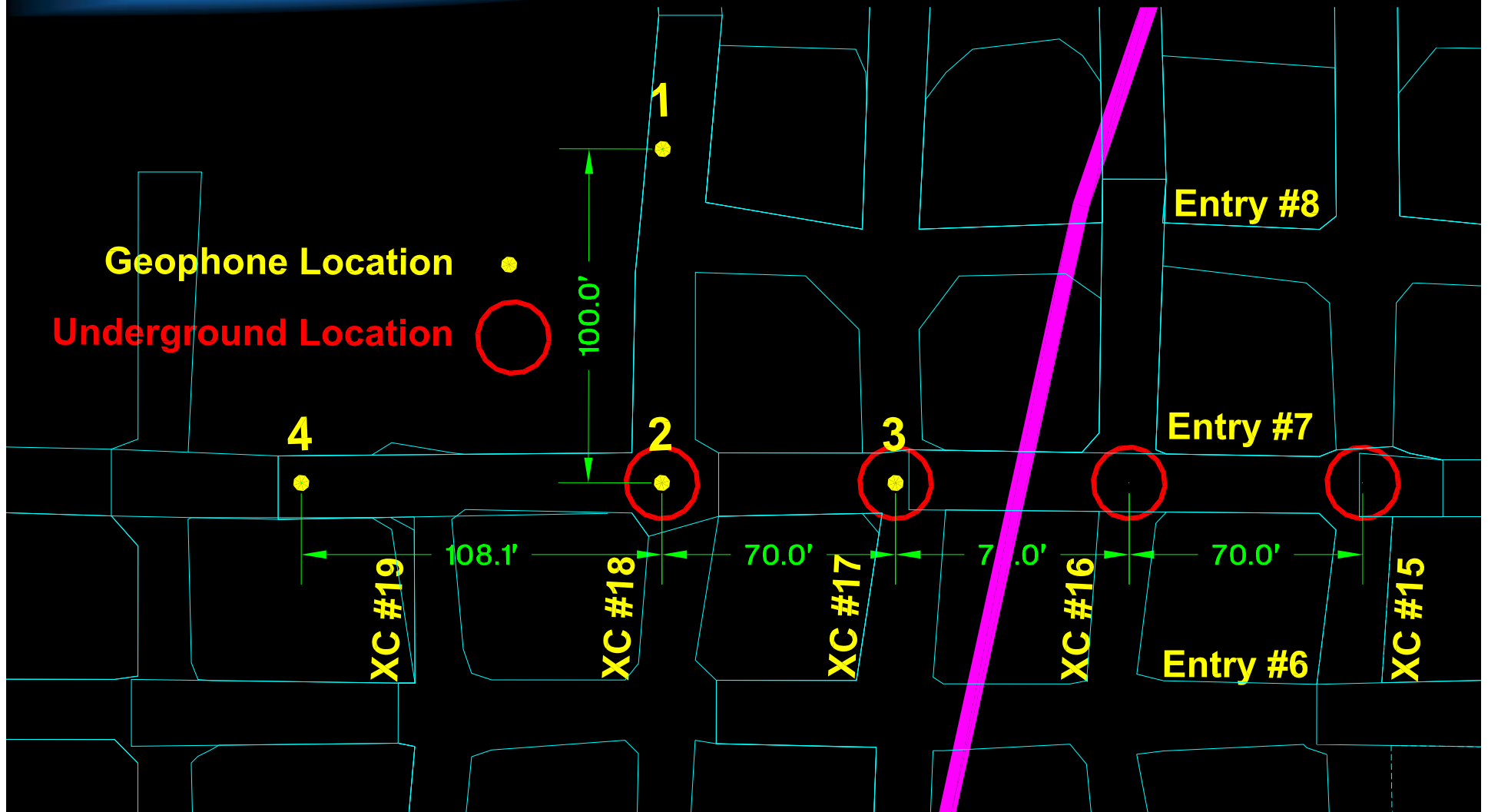
Field Test Site



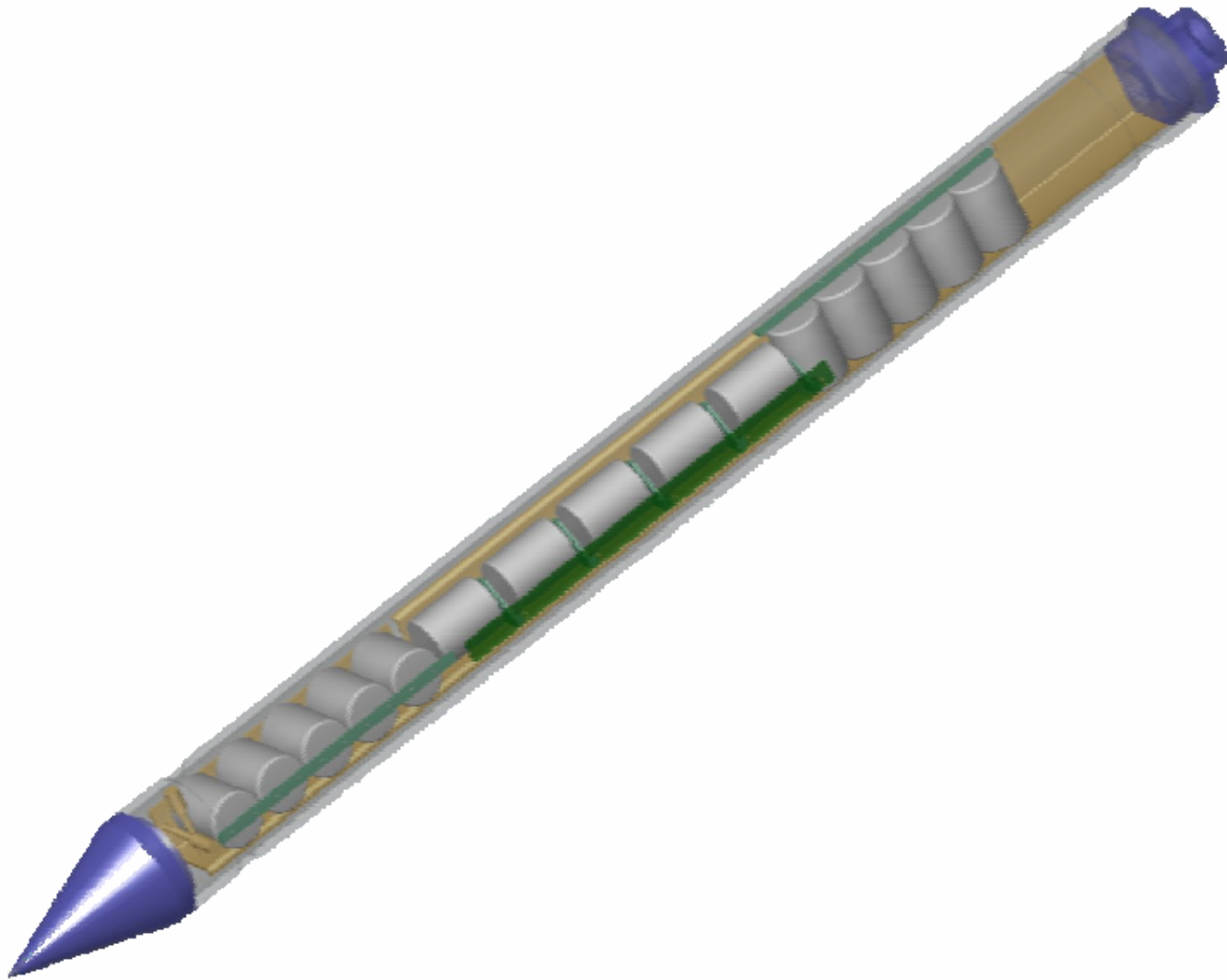
Field Test Site



Test Layout



Downhole Geophone



Seismic Equipment

- **Geospace 32CT geophones**
- **Terrasciences 24 channel, 24 bit digitizer sampling at 2 kHz**
- **Portable PC & car battery**

Test Protocol

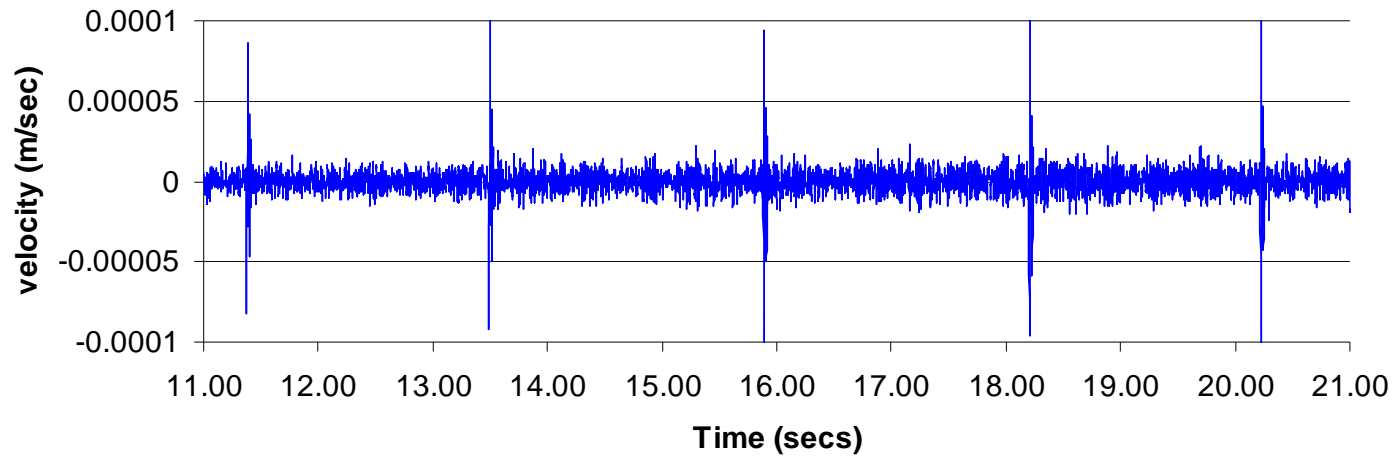
- **Signaling devices:**
 - **Hilti DX76, Hilti DX460, Hilti DX462, 8 lb sledge hammer, and crib block**
- **Signaling Locations:**
 - **Roof bolt, roof rock, and rib**
- **5 impacts, wait 30 seconds, next device**

Test Results

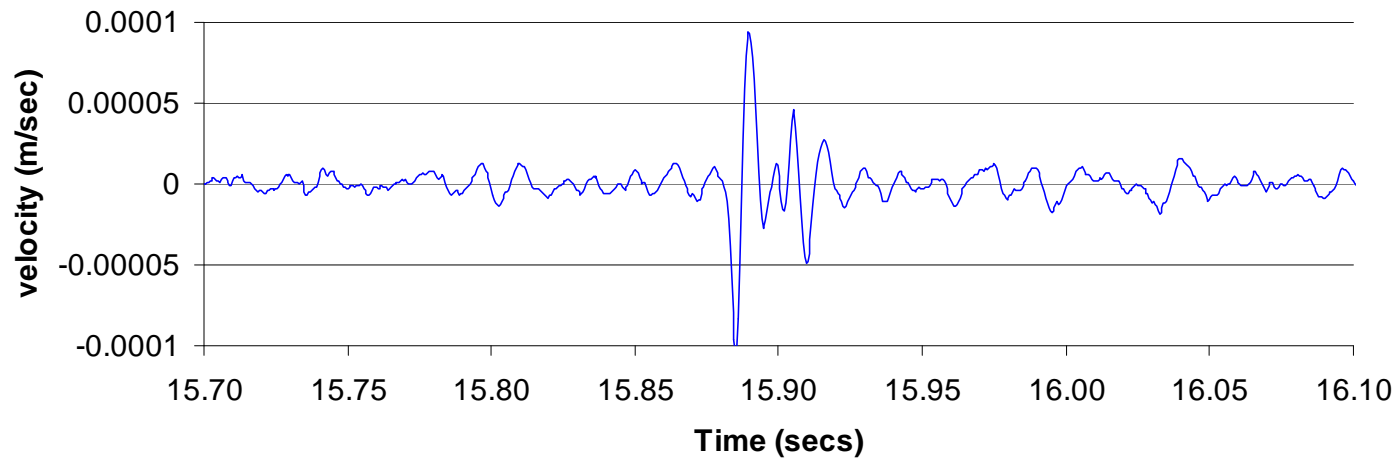
Device	Location	PPV (<i>um/s</i>)	Offset (ft)
Hammer	Roof Rock	60	0
Hammer	Roof Bolt	60	0
Crib Block	Roof Rock	100	0
Crib Block	Roof Bolt	80	0
Hammer	Roof Rock	45	70
Crib Block	Roof Rock	80	70
Crib Block	Roof Bolt	80	70
Hammer	Roof Rock	25	140
Block	Roof Rock	45	140

Seismic Signal

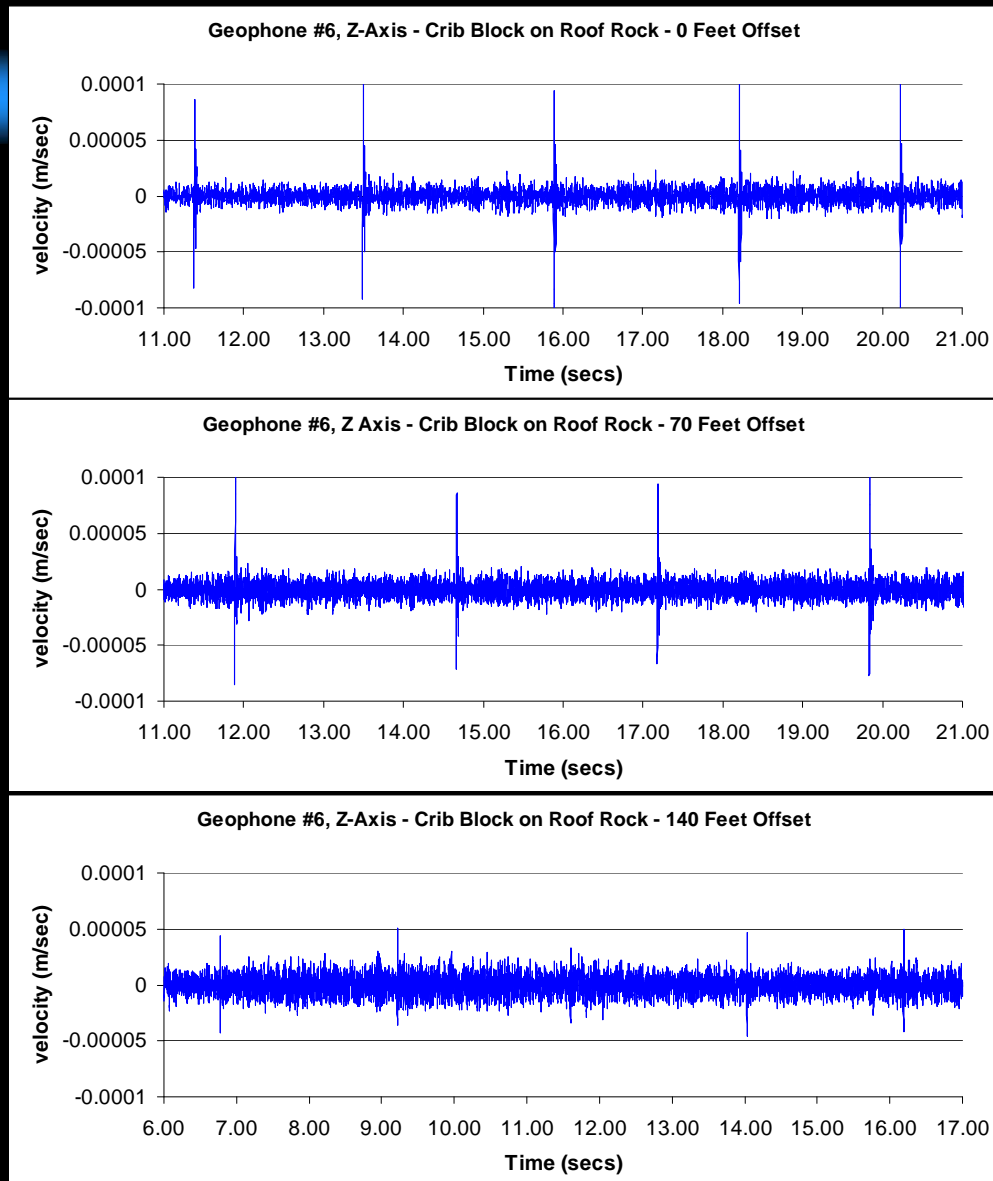
Geophone #6, Z-Axis - Crib Block on Roof Rock - 0 Feet Offset



Geophone #6, Z-Axis - Crib Block on Roof Rock - 0 Feet Offset

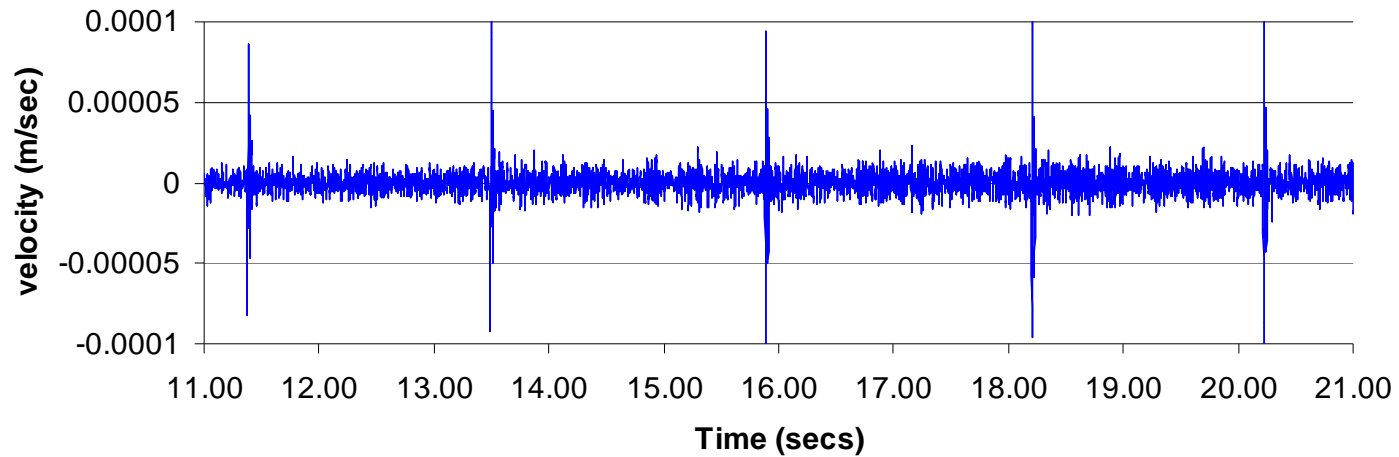


Distance

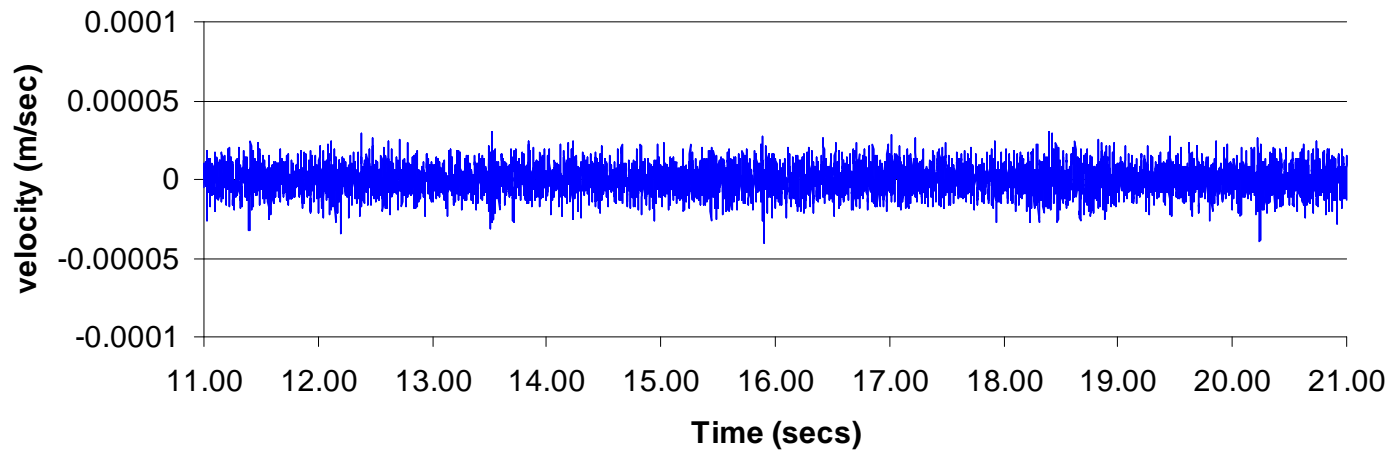


Z-Axis – X-Axis

Geophone #6, Z-Axis - Crib Block on Roof Rock - 0 Feet Offset

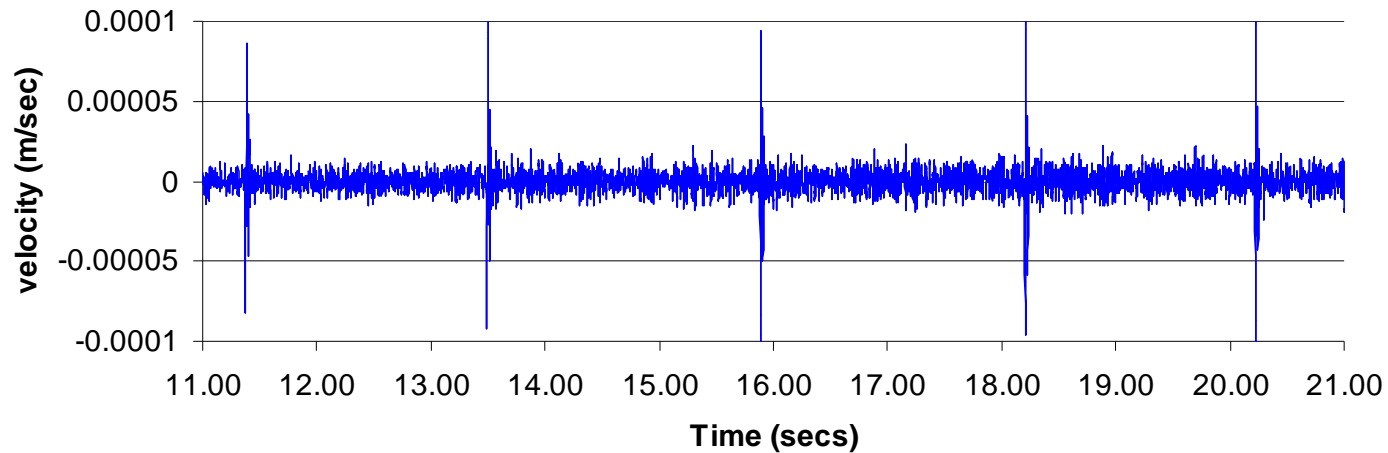


Geophone #6, X-Axis - Crib Block on Roof Rock - 0 Feet Offset

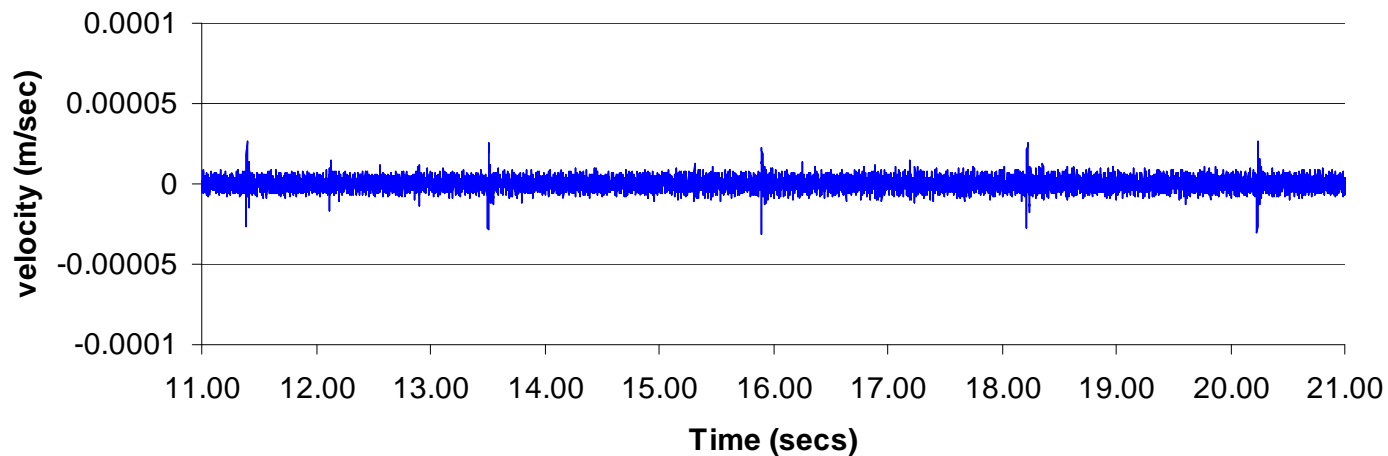


Buried - Surface

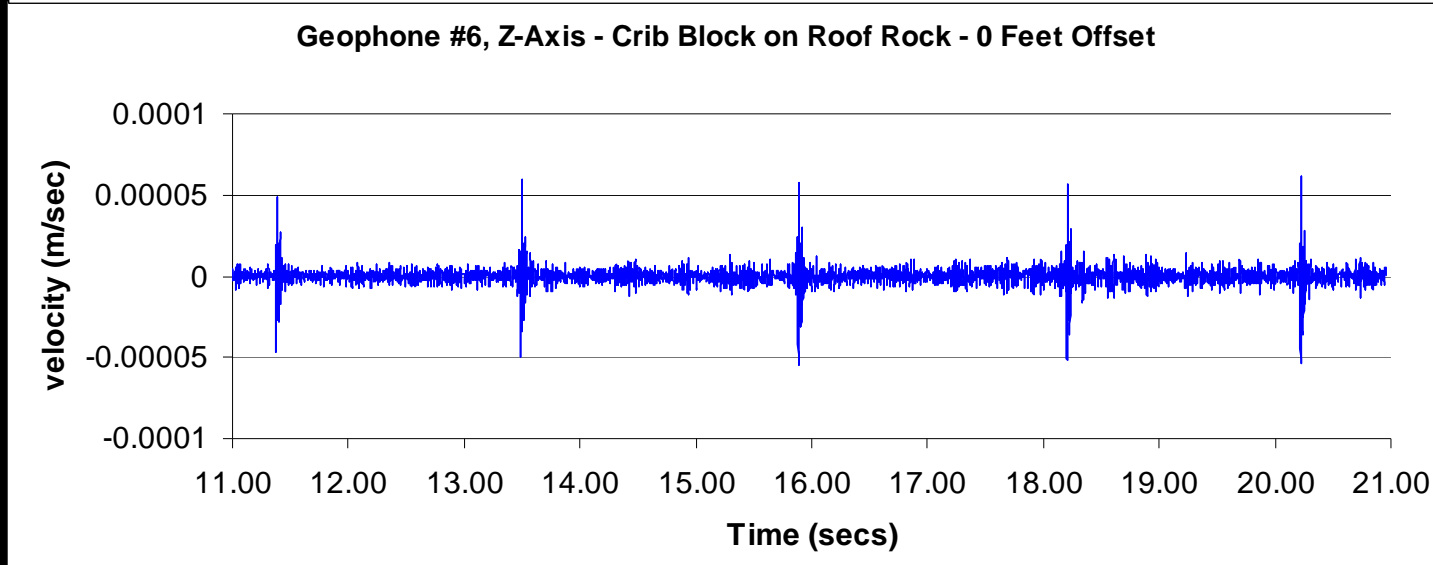
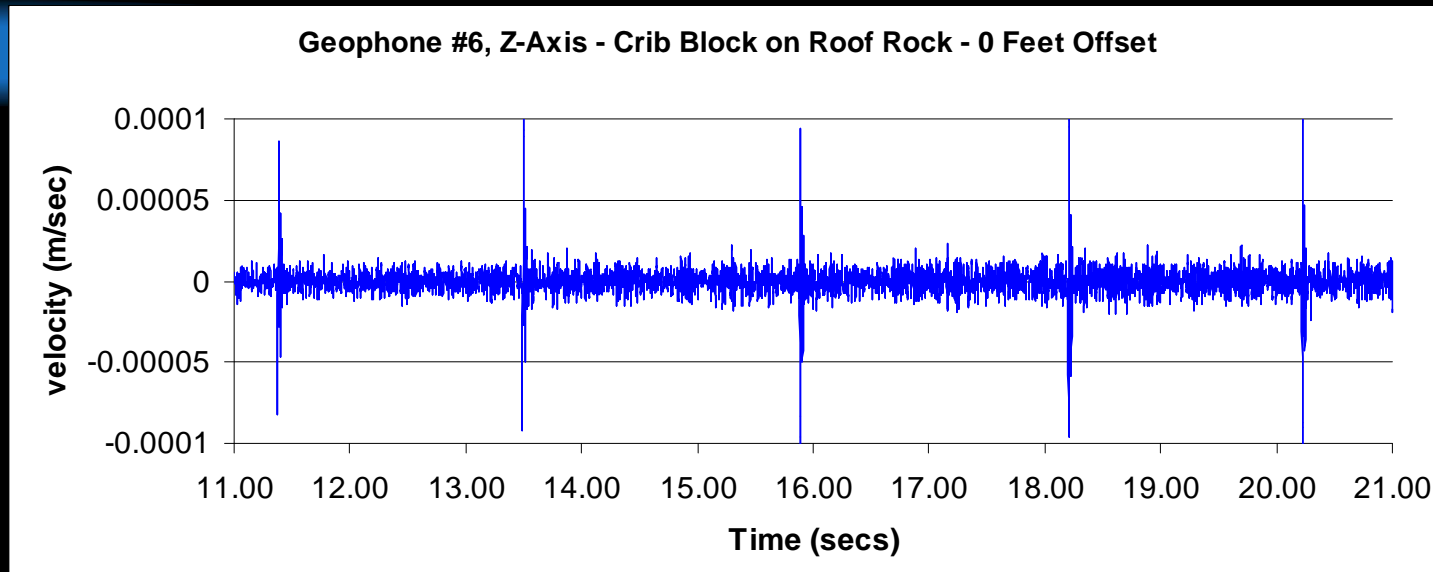
Geophone #6, Z-Axis - Crib Block on Roof Rock - 0 Feet Offset



Geophone #2, Z-Axis - Crib Block on Roof Rock - 0 Feet Offset



UnFiltered - Filtered



Test Results

- 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 were not very detectable?
 - Higher Frequencies?
- Good detection out to 140 ft
 - Not at 210 ft

Test Results

- **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?**

Conclusions

- **Use a crib block on the roof rock**
- **An effective trapped miner, seismic location system is achievable.**

Future Work

- **Thorough analyze data**
 - **Quantify detection strength**
 - **Apply filtering**
- **Test at “deep” mine**
 - **Multiple-seam**
 - **Gob areas**
- **Acquire “state-of-the-art” system**

Seismic Signaling

WHEN ESCAPE IS CUT OFF

1. **BARRICADE**



2. **LISTEN** for
3 shots, then ...



3. **SIGNAL** by
pounding hard
10 times



4. **REST** 15 minutes,
then **REPEAT** signal until ...

5. **YOU HEAR 5** shots, which
means you are located
and help is on the way.



Supporting Literature

- **“Mine Safety Recommendations,” Report to the Director of the Office of Miners Health, Safety and Training, West Virginia Mine Safety Technology Task Force, May 29th, 2006.**
- **WV Mine Safety Roundtable on Seismic Miner Location, June 28th, 2006**
- **“The Sago Mine Disaster,” A Preliminary Report to Governor Joe Manchin III, by J. Davitt McAteer and associates, July, 2006**

Ground Rules

- **System hardware suitable for rapid field deployment**
- **System use present state-of-the-art equipment**
- **System operates from the surface.**
- **System is self-contained**
- **System is compatible with overall rescue effort**
- **Readily available signal sources**
- **Likely area of trapped miners is known**
- **Surface team will have mine maps.**

Field Test Site

- **Near the top of a ridge for maximum overburden (441 ft)**
- **Over the supply entry in an 11 entry main.**

Test Layout

- 4 geophone sites in a “T”
- A “surface” geophone at each site
- A “downhole” geophone at site 1 & 2

Successful Location

- **Within 100 ft**

- **Favorable, Controlled Situations**
- **Arrival times can be estimated within 1- 5 ms**
- **Layering and seismic velocities can be specified within 5%**

Signal Improvement

- **Bandpass Filtering**
- **Burial of Sensors**
- **Subarrays**
 - **Size Optimization**
 - **Delayed or Direct Sum**
 - **Weighted Sum**

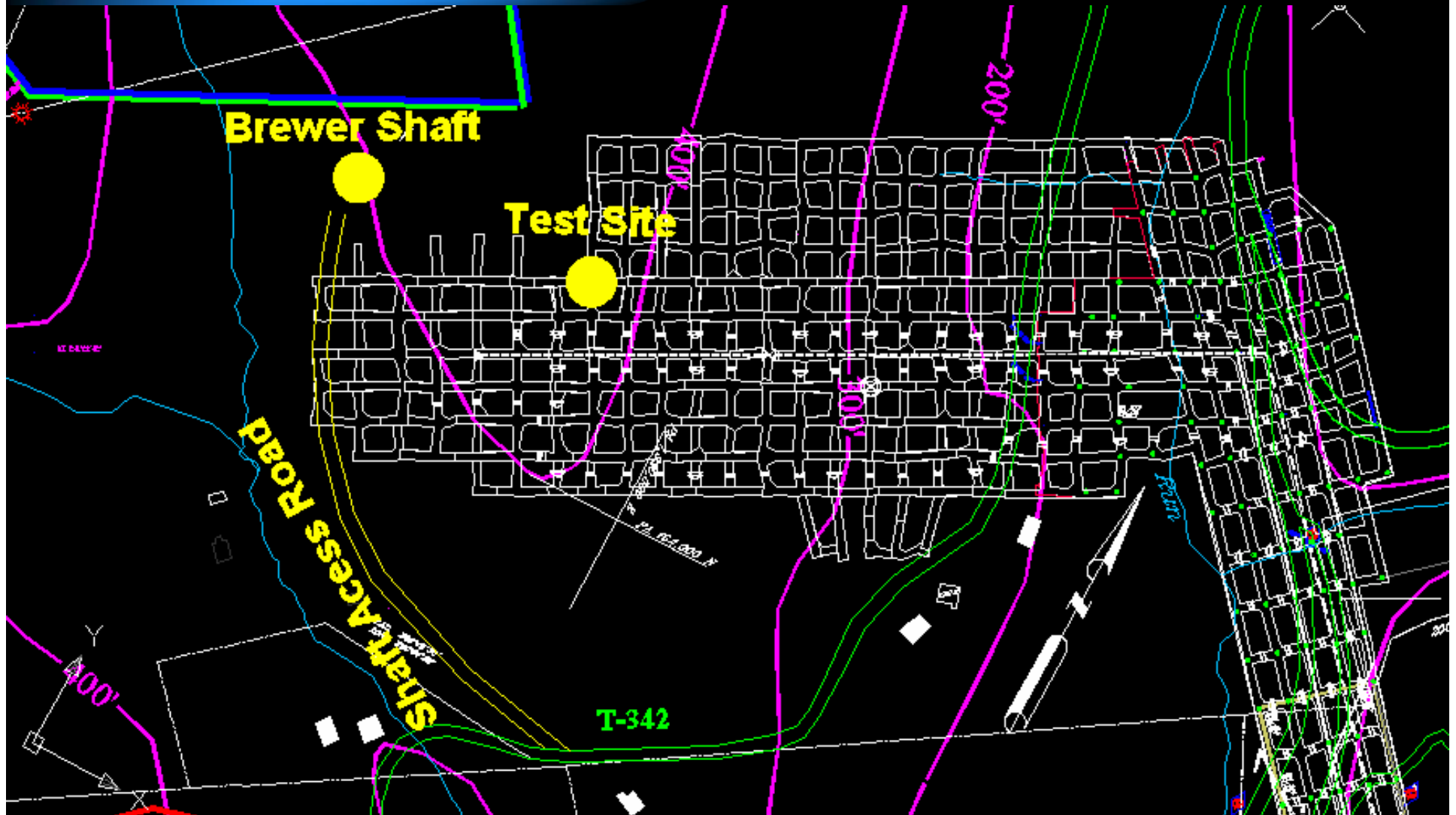
MSHA Seismic Location System

- **Consists of 3 trucks**
 - **Equipment truck – recorders and filters**
 - **Generator truck**
 - **Trailer – geophone, cables & supplies**

Areas for Development

- Pre-deployed systems
- Data format standardization
- Improved signaling methods
- Signaling from within shelters
- Ideal set of available of geologic information
- Options for remote analysis
- Preloaded mine maps
- Options for use in other emergencies.

Field Test Site



Background

- **Outcomes, Westinghouse Electric System tests.**
 - **System was all underground**
 - **Signals could be detected up to 1000 ft, but not 1500 ft, away.**
 - **Point-anchor bolts caused a 100 Hz resonance.**
 - **A band-pass filter range of 20-200 Hz worked best.**
 - **Velocities of 4,200-5,000 m/s were observed (with second arrivals at 1,700 m/s).**
 - **An array of 6 geophones did not work any better than a single phone.**