MSHA Mine Safety and Health Administration
Department of Labor

Mine Mapping Benchmarking Workshop

"MSHA's Perspective"

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Pittsburgh Technical Support Center

Interstate Mining Compact Commission (IMCC)
In Cooperation with MSHA and OSM

February 15-16, 2012
Pittsburgh, Pennsylvania

Some High-Profile Incidents Related to Underground Mines

- Impoundment Breakthrough Incidents
  - Miller’s Cove, Lee Co. VA, August, 1996
  - Miller’s Cove, Lee Co. VA, October, 1996
  - Buchanan, Buchanan Co. VA, November, 1996
  - Big Branch, Martin Co., KY, October, 2000

- Mine Inundation
  - Quecreek No. 1 Mine Inundation and Rescue, July 2002

Other Inundations

- Quecreek is just a dramatic example of a relatively common scenario
- Between 1995 and 2002, mine operators reported 181 mine inundations. Of these, 107 were unplanned cut-throughs resulting in water inundations
- From 2002 to present, 179 inundations. Of these, 37 were cut-throughs into old mine workings, 20 of these had water.

Abandoned Coal Mines

State	No. of Abandoned Mines
Kentucky	150,000
West Virginia	100,000
Pennsylvania	40,000
Virginia	6,000

Inundation Hazards

- Water
- Slurry
- Methane
- Carbon Monoxide (CO)
- Low Oxygen

Sources of Inundation Hazards

- Abandoned gas & oil wells
- Exploration borings
- Horizontal de-gas holes
- Auger holes
- Old mine workings
- Known mine workings that are poorly mapped
- Paradise mine inundation – mine workings 1000 feet closer than expected

MSHA Regulations
30 CFR

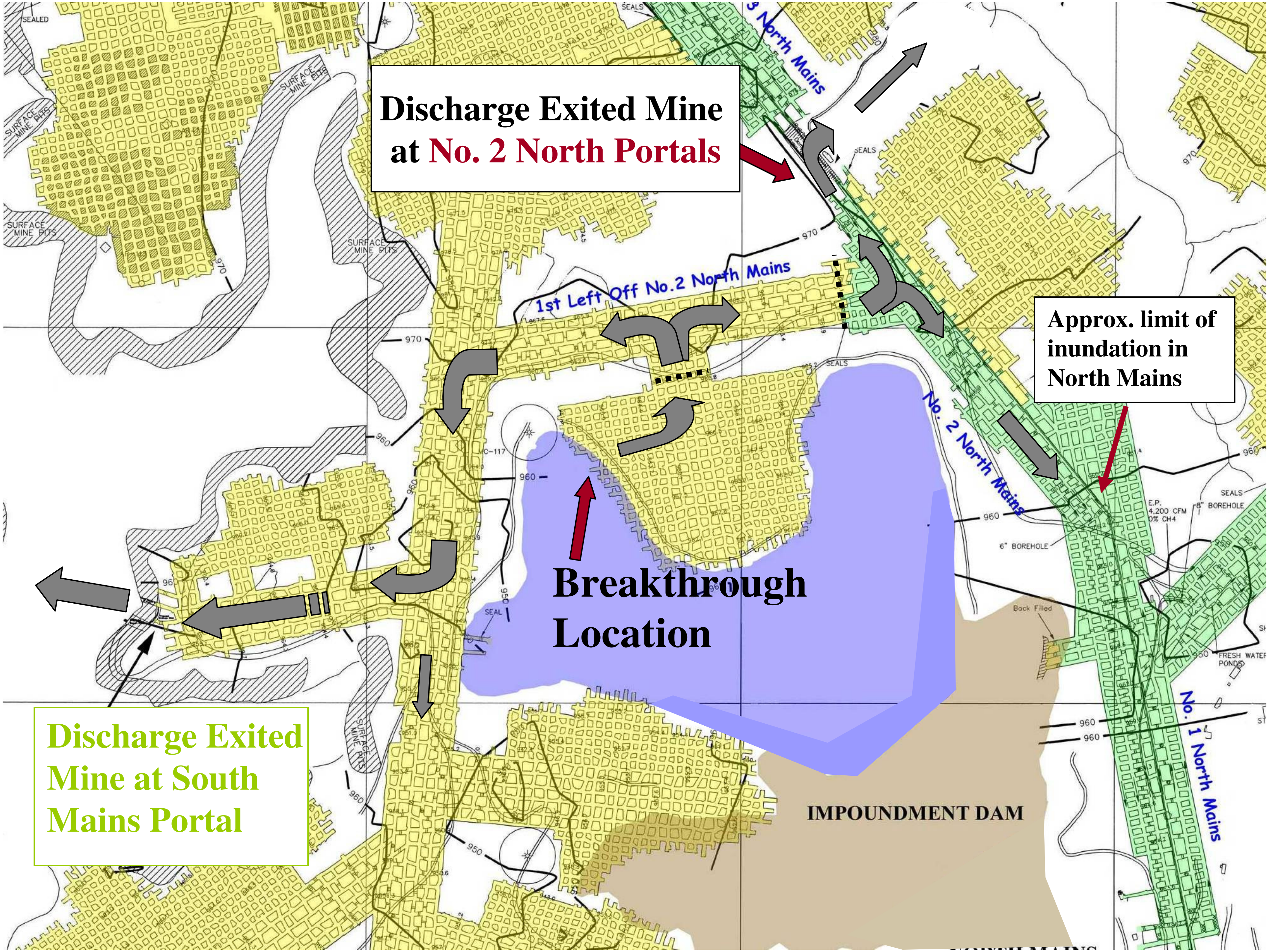
- §75.388
- Surveyed mine workings from same mine – pre-drill face when within 50 feet
- Mine workings from a different mine or the same mine that have not been surveyed – pre-drill face when within 200 feet
- §75.1700
- Maintain 300 diameter barrier around known oil and gas wells

Description of an Inundation Accident

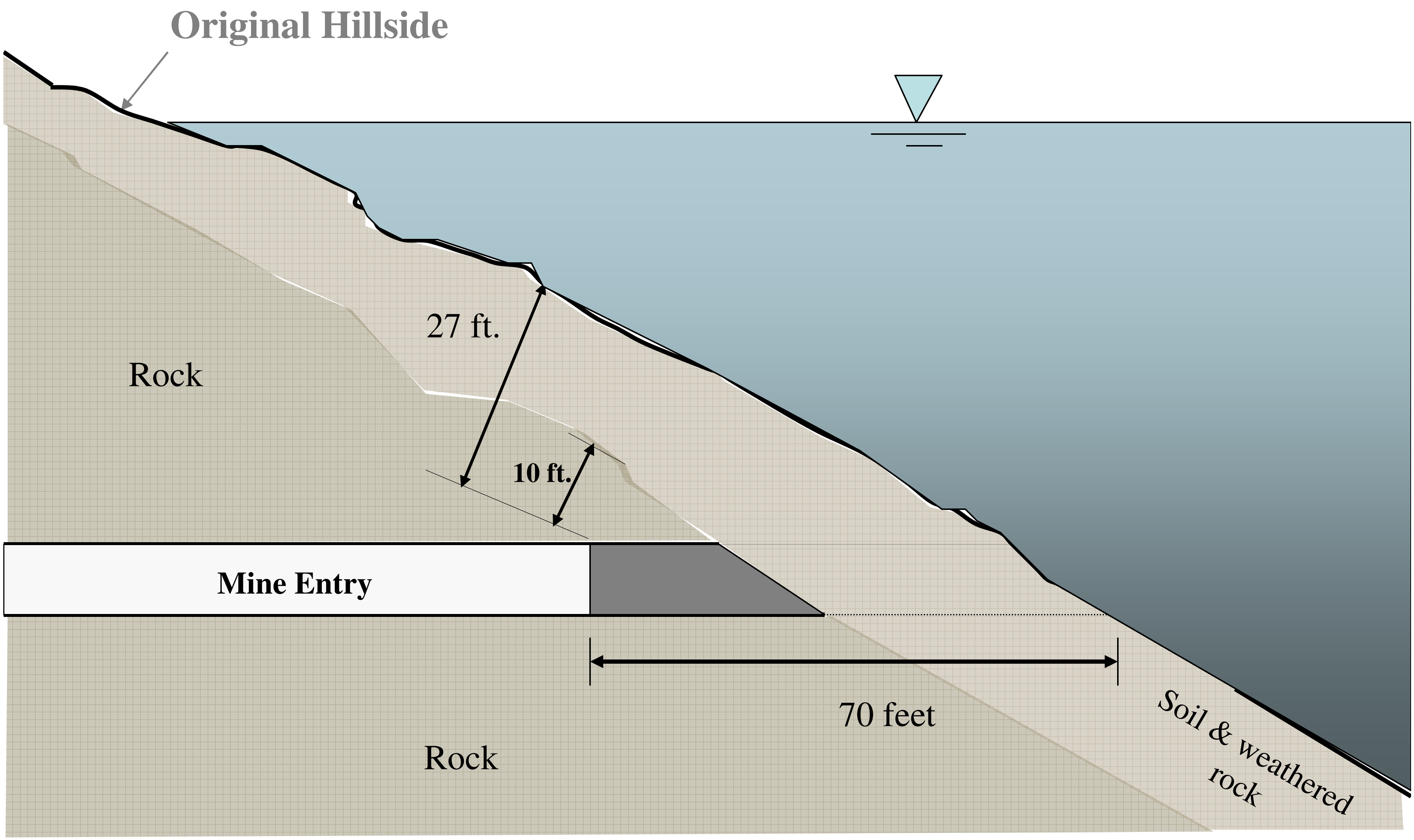
- He was operating a continuous miner cutting into a new return air shaft.
- A large amount of water broke through the coal face, washing him along the entry for approximately 220' .
- He struck a ram car that was positioned behind the continuous miner.
- He experienced contusions on his legs, arms, torso, and head.


Covington
Highland Heights
Ohio
Kentucky
Ashland
FRANKFORT
Georgetown
Big Sandy River
WEST VIRGINI
dge Park
Louisville
Lexington
Morehead
Lawrenceburg
Martin County
Inez
Tug Fork
Ohio
boro
Danville
Berea
Pikeville
Leitchfield
KENTUCKY
Jenkins
Mammoth Cave N.P.
CUMBERLAND PLATEAU
Bowling Green
VIRGINIA
Barbourville
Cumberland
Black Mt.
Middlesboro
Cumberland Gap N.H.P.

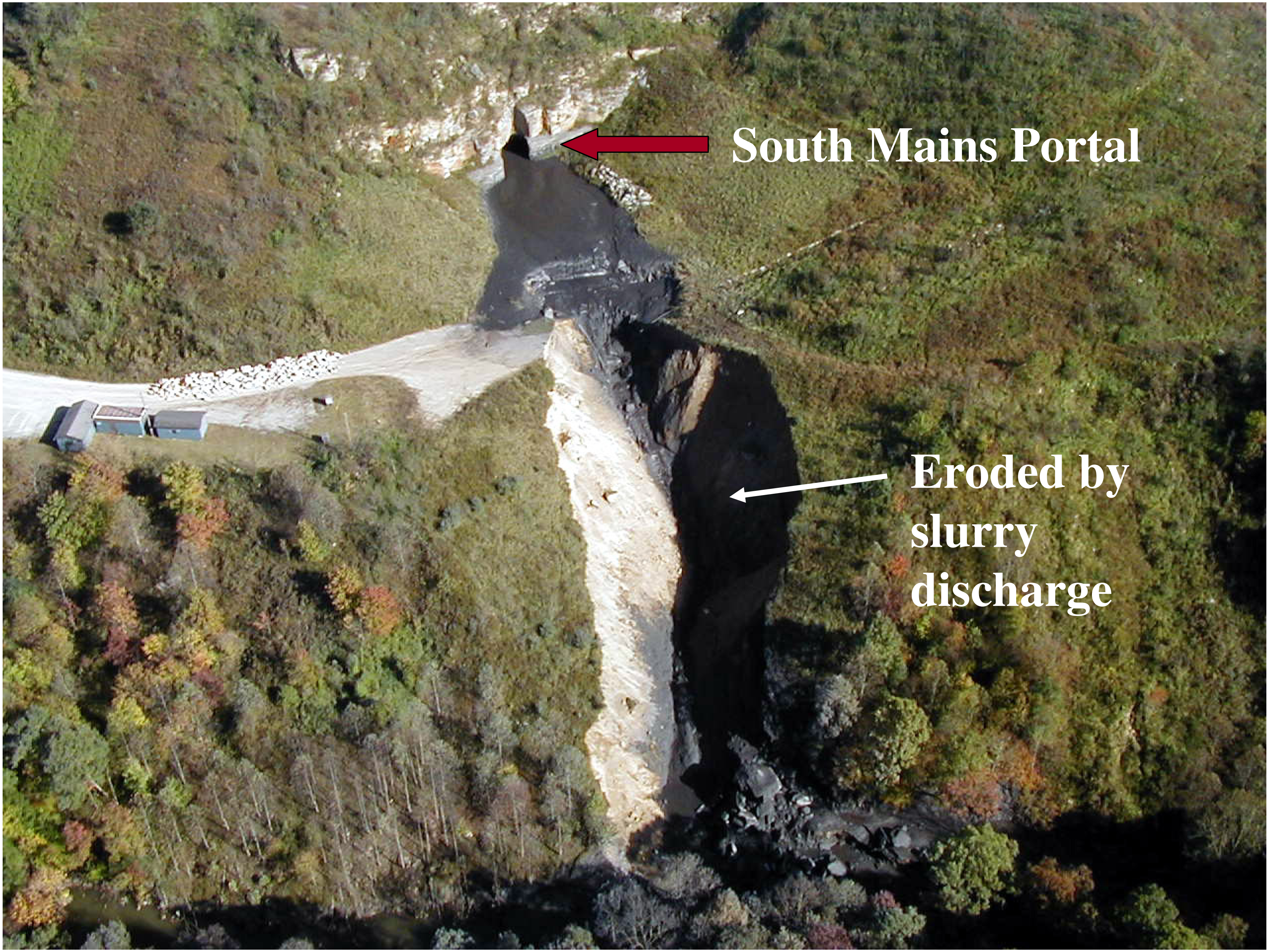

Martin County Coal Company
Big Branch Refuse Impoundment
October 2000
Approx 300 Million Gallons Released

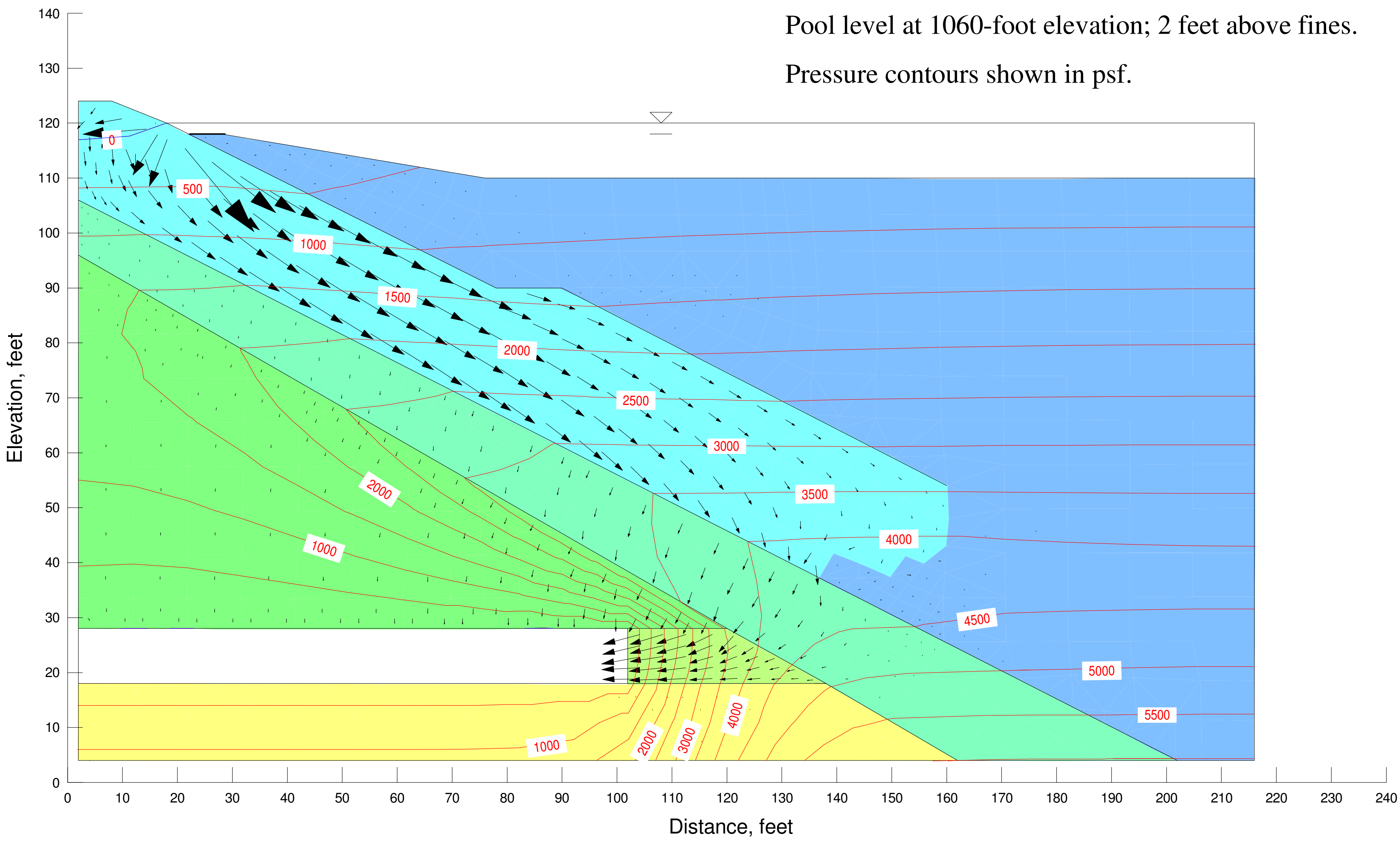

Discharge Exited Mine
at No. 2 North Portals
Approx. limit of
inundation in
North Mains
Breakthrough
Location
Discharge Exited
Mine at South
Mains Portal
IMPOUNDMENT DAM
1st Left Off No.2 North Mains
No. 2 North Mains
No. 1 North Mains
3 North Mains
SURFACE MINE PITS
SEALED
SEALS
SEAL
6" BOREHOLE
8" BOREHOLE
Back Filled
FRESH WATER PONDS
970
960
950

Example of potential for breakthrough created by mine workings located near an impoundment.




No. 2 North Belt Entry


South Mains Portal
Eroded by slurry discharge



Pool level at 1060-foot elevation; 2 feet above fines.
Pressure contours shown in psf.
Elevation, feet
Distance, feet
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
2000
1000
1000
2000
3000
4000

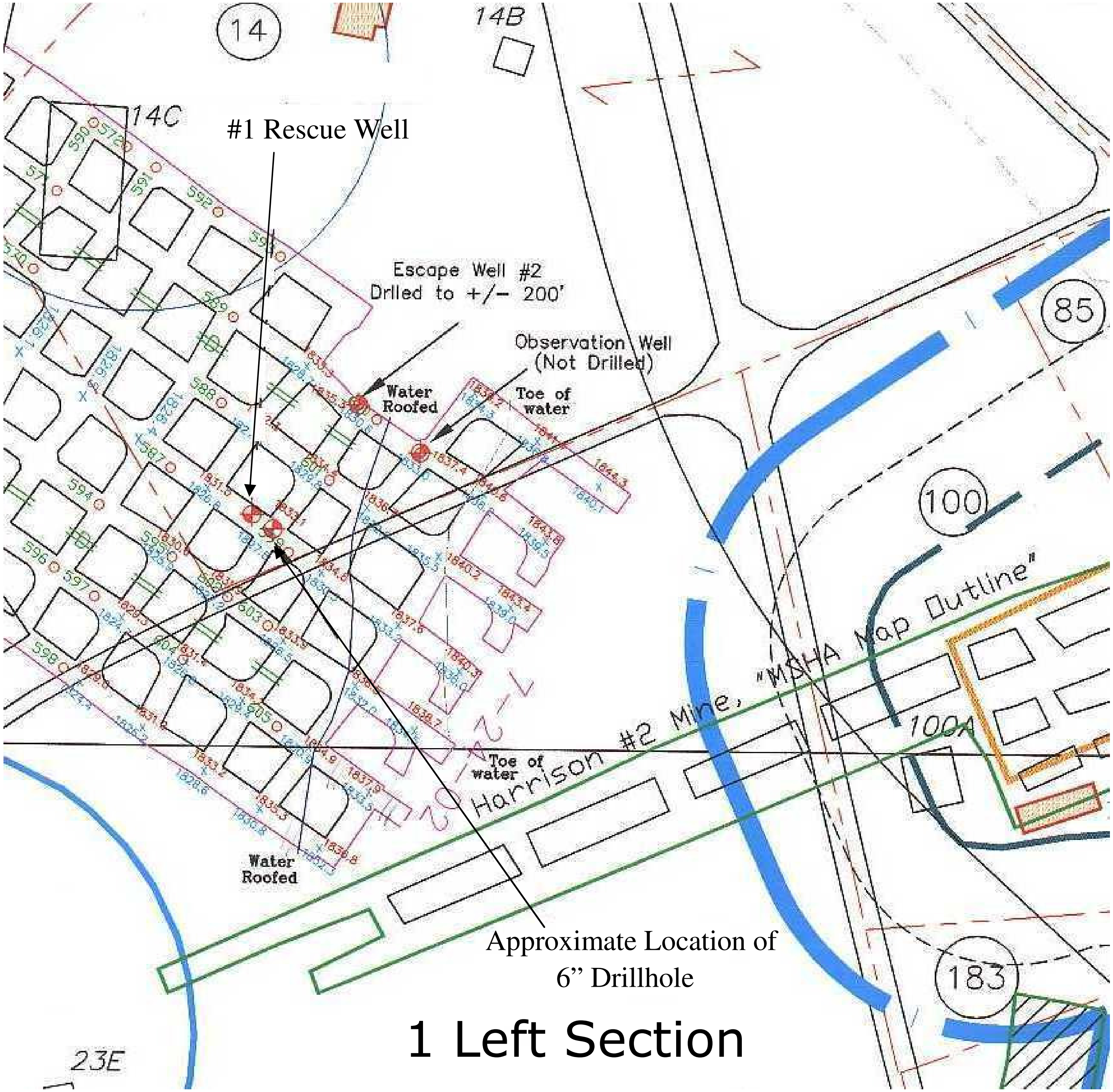
MSHA Mine Safety and Health Administration
Department of Labor

Quecreek Inundation and Rescue

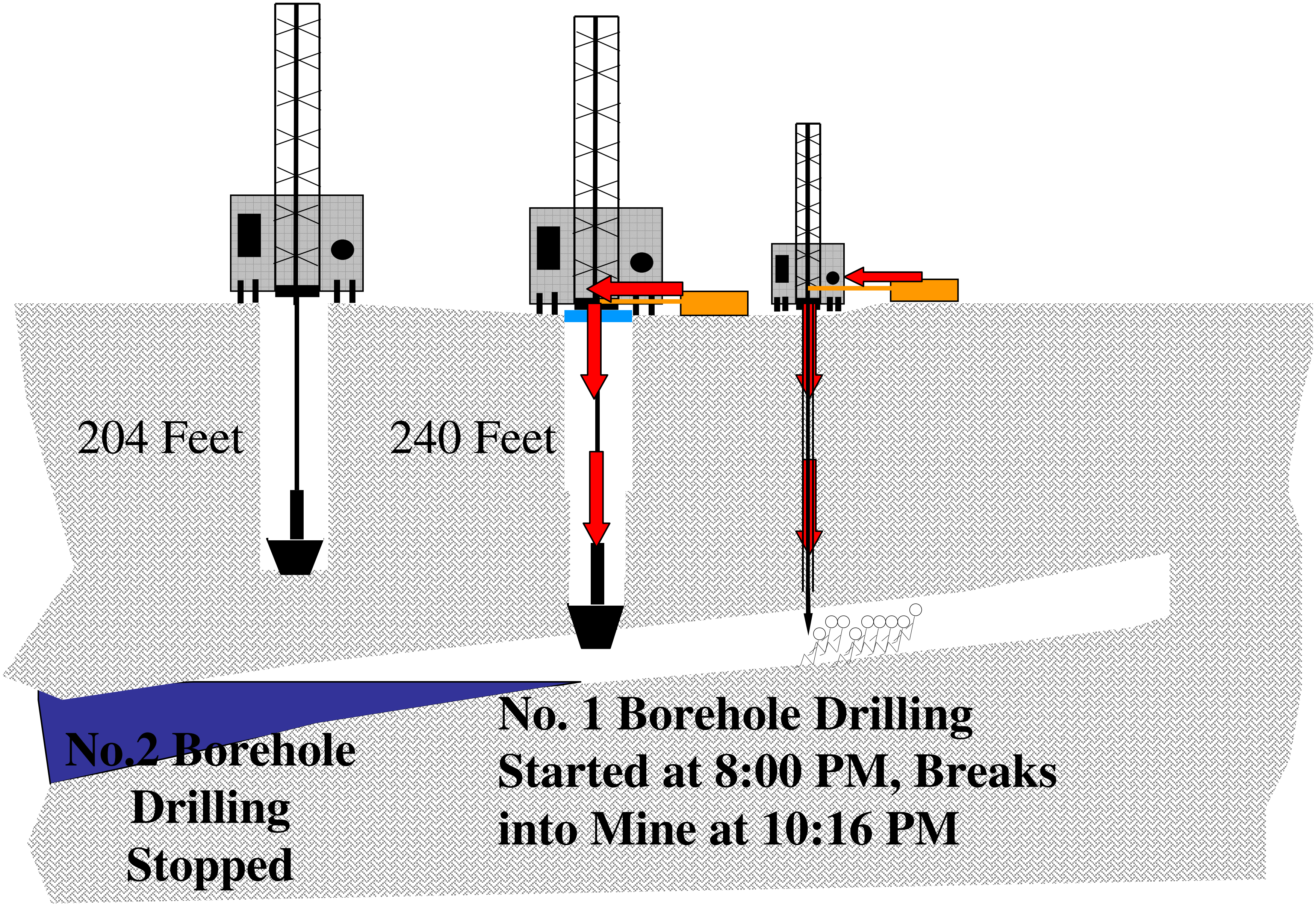
Accident Date: July 24, 2002

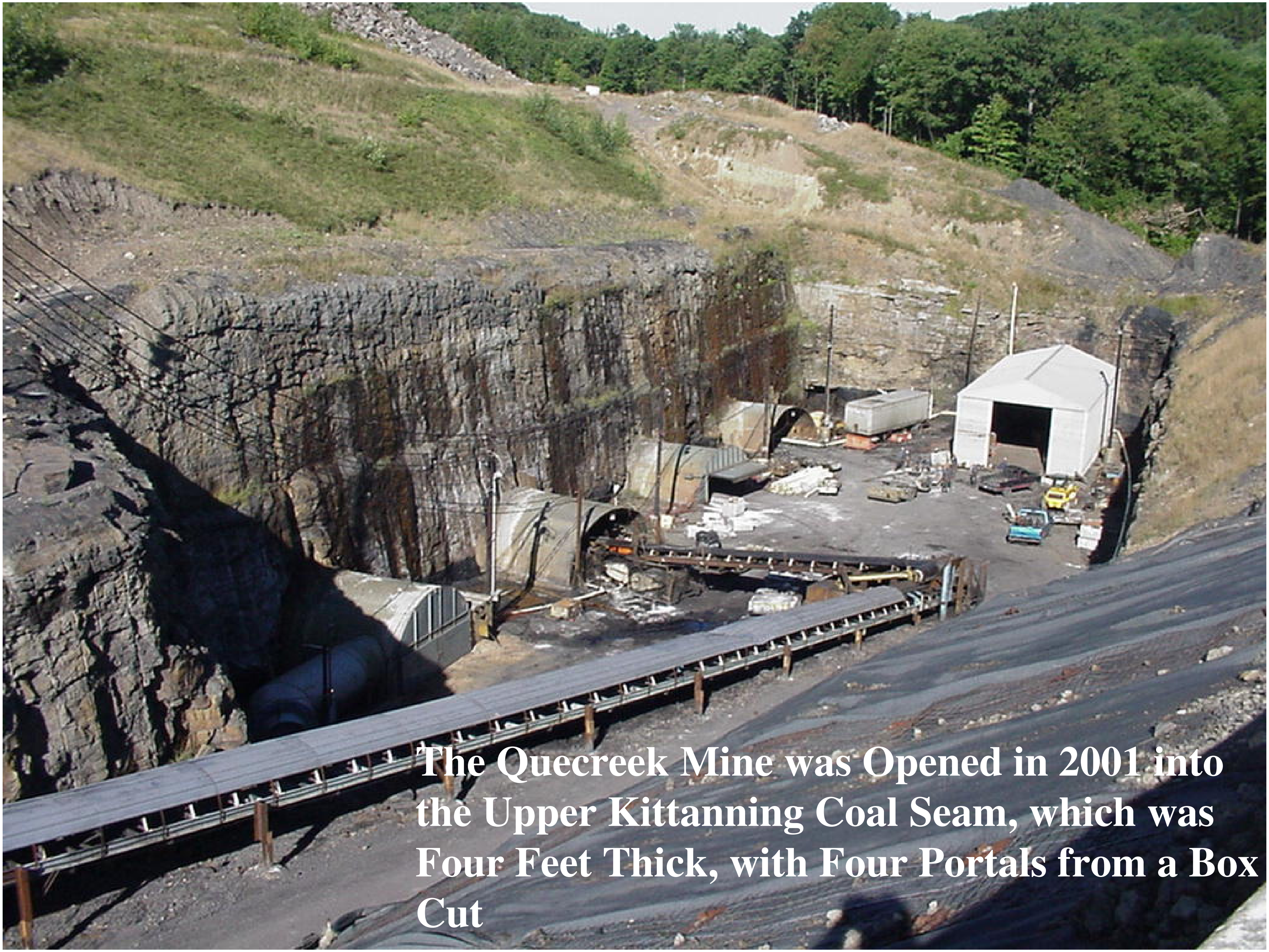
Black Wolf Coal Company
Quecreek No. 1 Mine
Somerset County, Pennsylvania

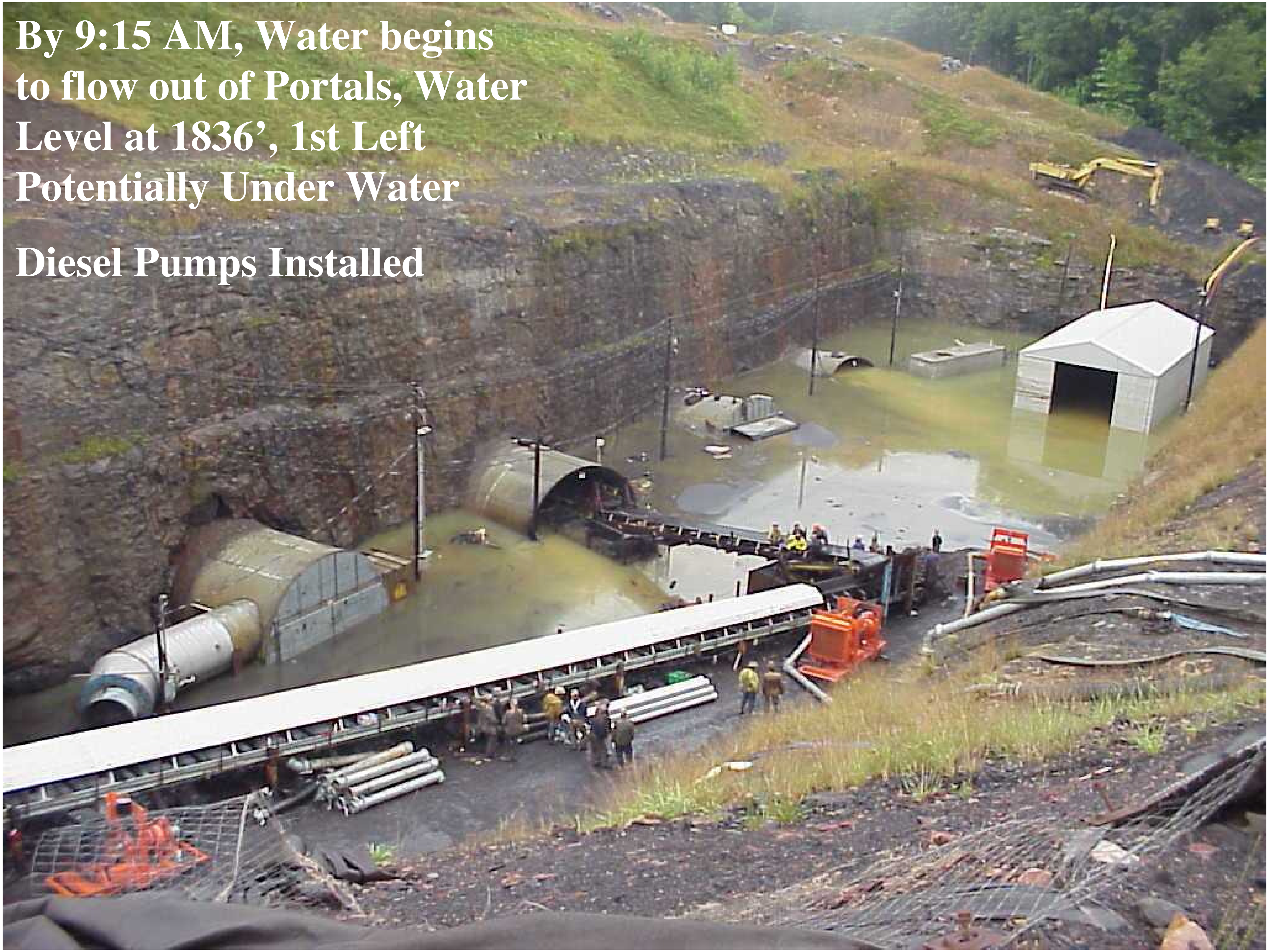
The Mine is located in Pennsylvania about 10 Miles from Shanksville, the Site of September 11 Flight 93 Crash

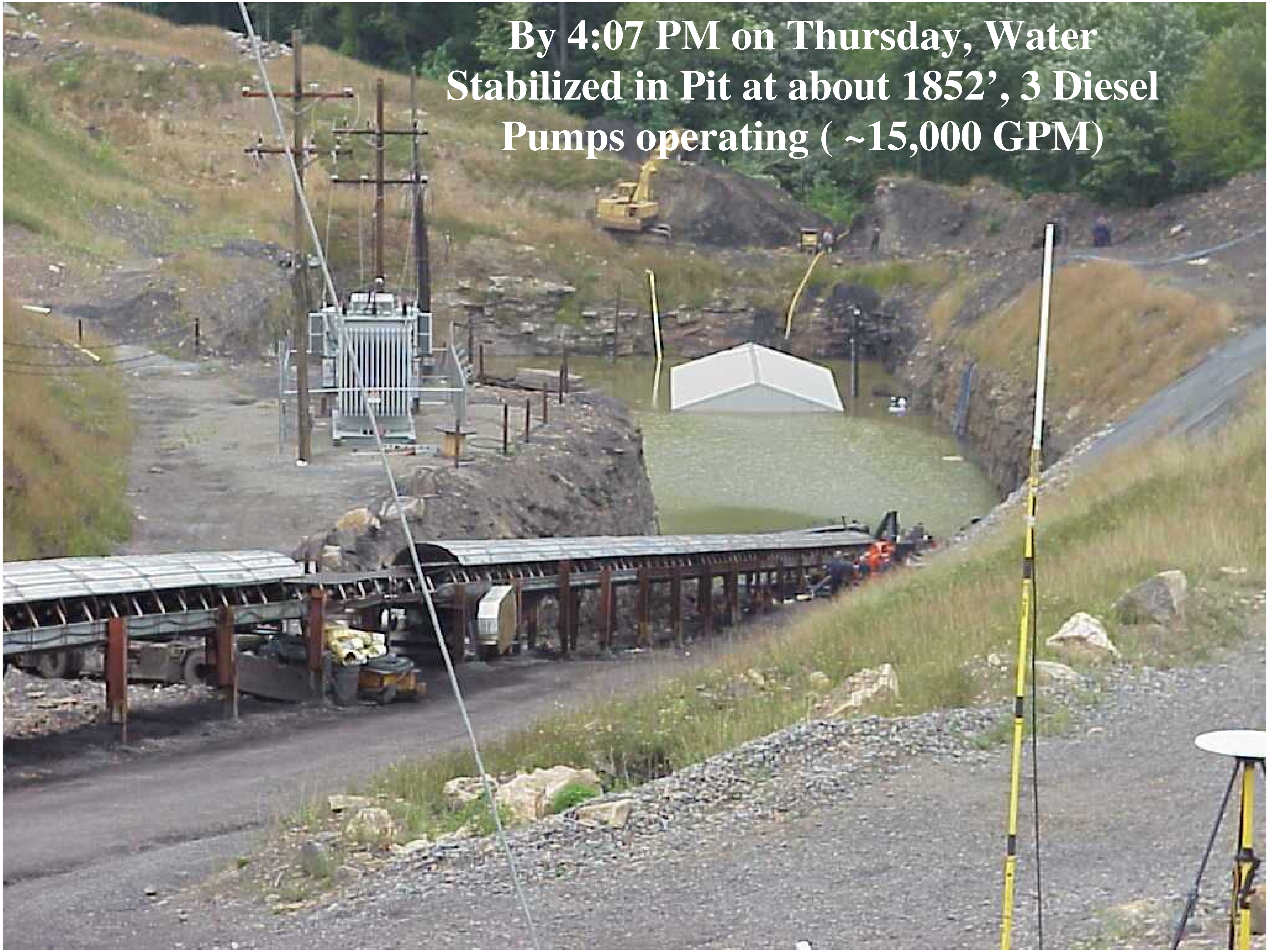


1 Left Section


204 Feet
240 Feet
No.2 Borehole Drilling Stopped
No. 1 Borehole Drilling Started at 8:00 PM, Breaks into Mine at 10:16 PM


The Quecreek Mine was Opened in 2001 into the Upper Kittanning Coal Seam, which was Four Feet Thick, with Four Portals from a Box Cut


By 9:15 AM, Water begins
to flow out of Portals, Water
Level at 1836’, 1st Left
Potentially Under Water
Diesel Pumps Installed


By 4:07 PM on Thursday, Water
Stabilized in Pit at about 1852’, 3 Diesel
Pumps operating (~15,000 GPM)


2KDKA-TV
HOMETOWN ADVANTAGE
2KDKA-TV
HOMETOWN ADVANTAGE

- *The Martin County Spill, the Quecreek Inundation, and all of the other inundations could have been easily prevented if accurate mine maps were available and thoroughly considered.*

House/Senate Conference Agreement

- "$10,000,000 for digitizing mine maps and developing technologies to detect mine voids, through contracts, grants, or other arrangements, to remain available until expended."
  - MSHA Allocation:
    - $3.9M to Mine Mapping – Disbursements to States
    - $6.1M to Void Detection – Funded Projects to Demonstrate available technologies for void detection.

Locating Abandoned Mines

- Better Surveying and Mapping practices during mining – permanent bench marks, common coordinate systems, closed loop surveys, mapping final cuts.
- Exploratory Borings
  - Conventional Drilling
  - Long-Hole Directional Drilling
- Indirect Methods - Geophysical
- Field Robotics

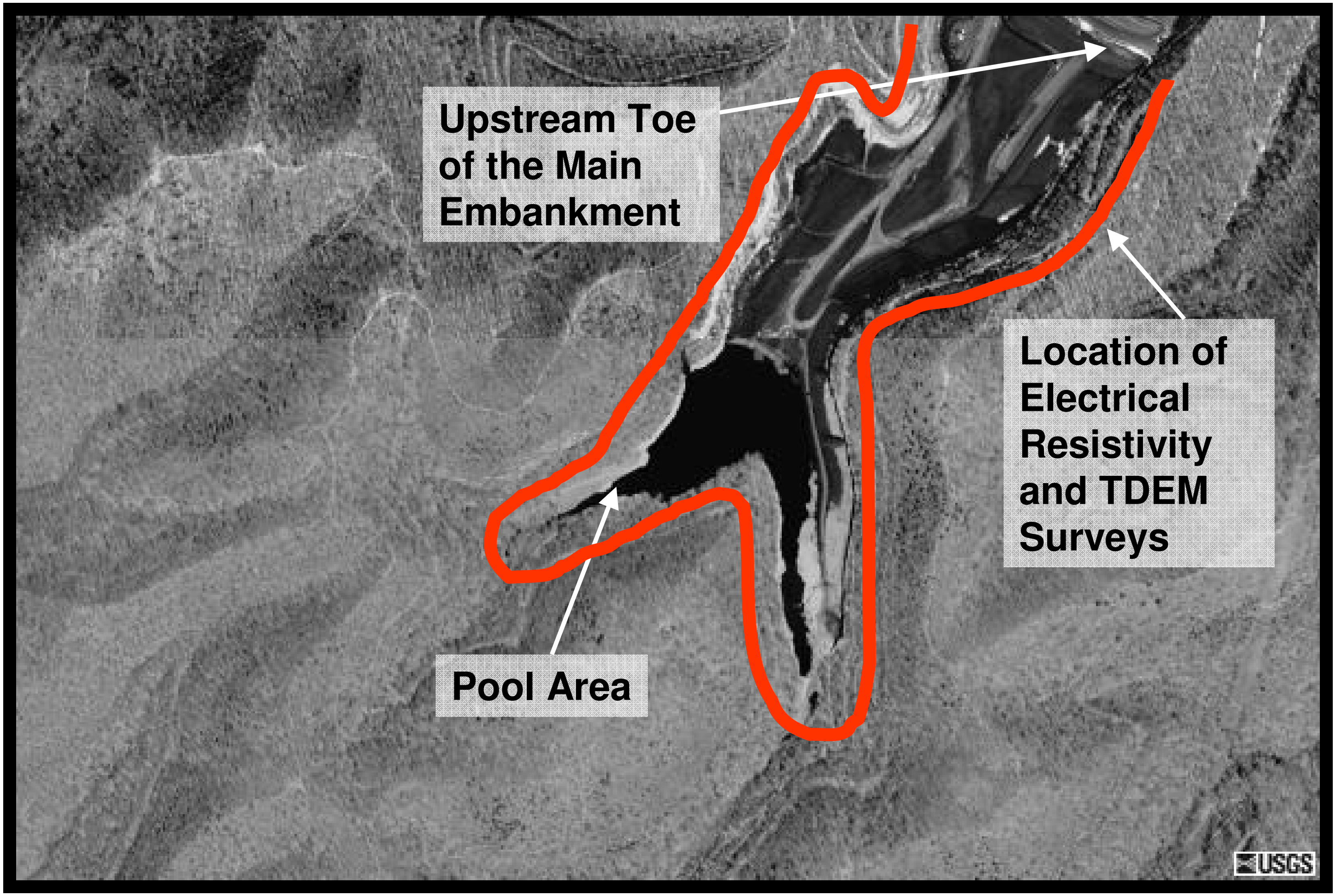
Void Detection Demonstration Projects (14)

- Surface Seismic Reflection (2)
- Borehole Seismic Tomography (2)
- Vertical Seismic Profiling (1)
- In-seam Seismic (ISS) (various sources) (4)
- Electrical Resistivity (1)
- Time Domain Electromagnetics (1)
- Look Ahead Radar (1)
- Borehole Radar Tomography (1)
- Delta EM Gradiometry (1)

Electrical Resistivity Method

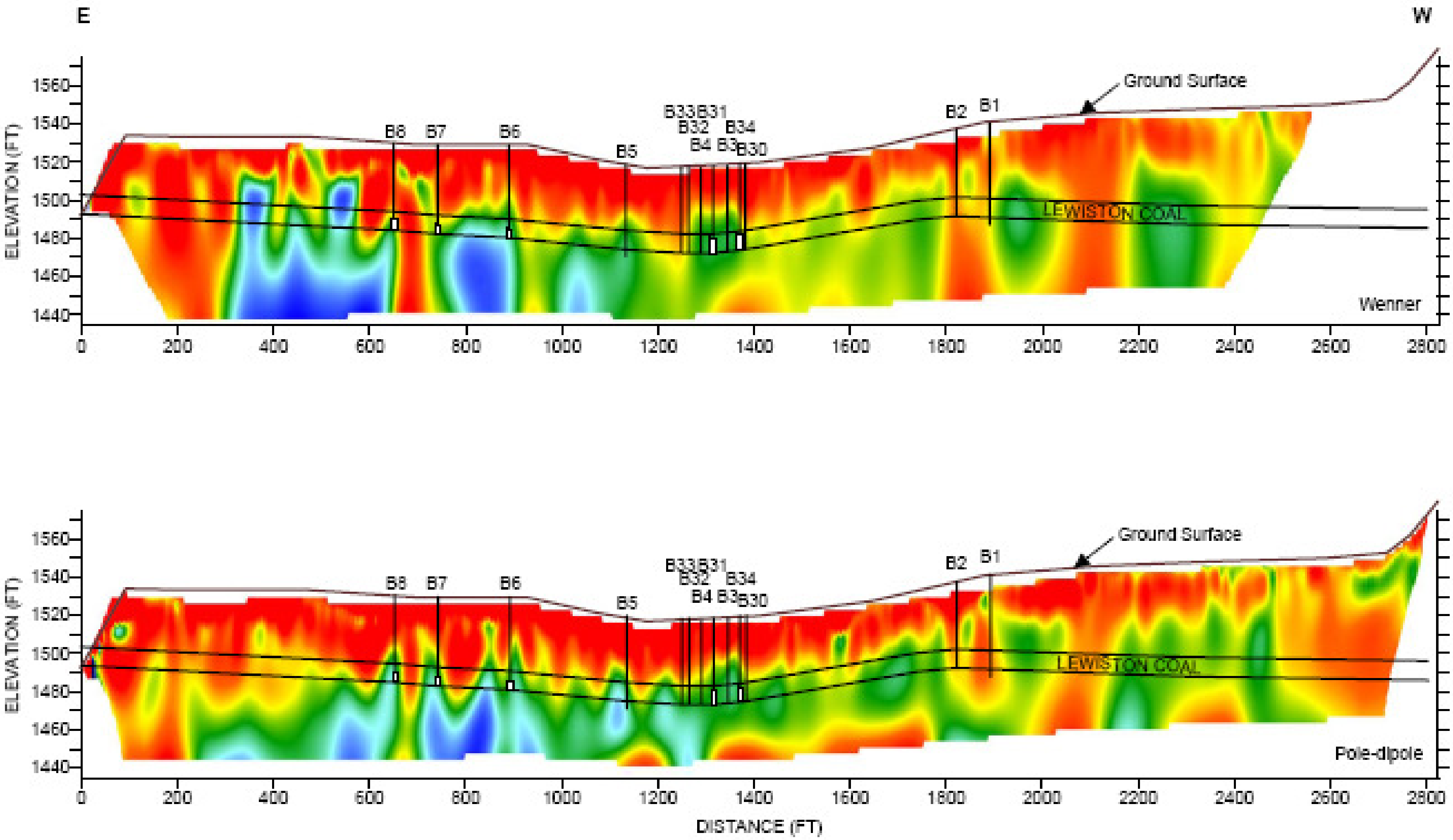
Time Domain Electromagnetics Method

Prenter, West Virginia

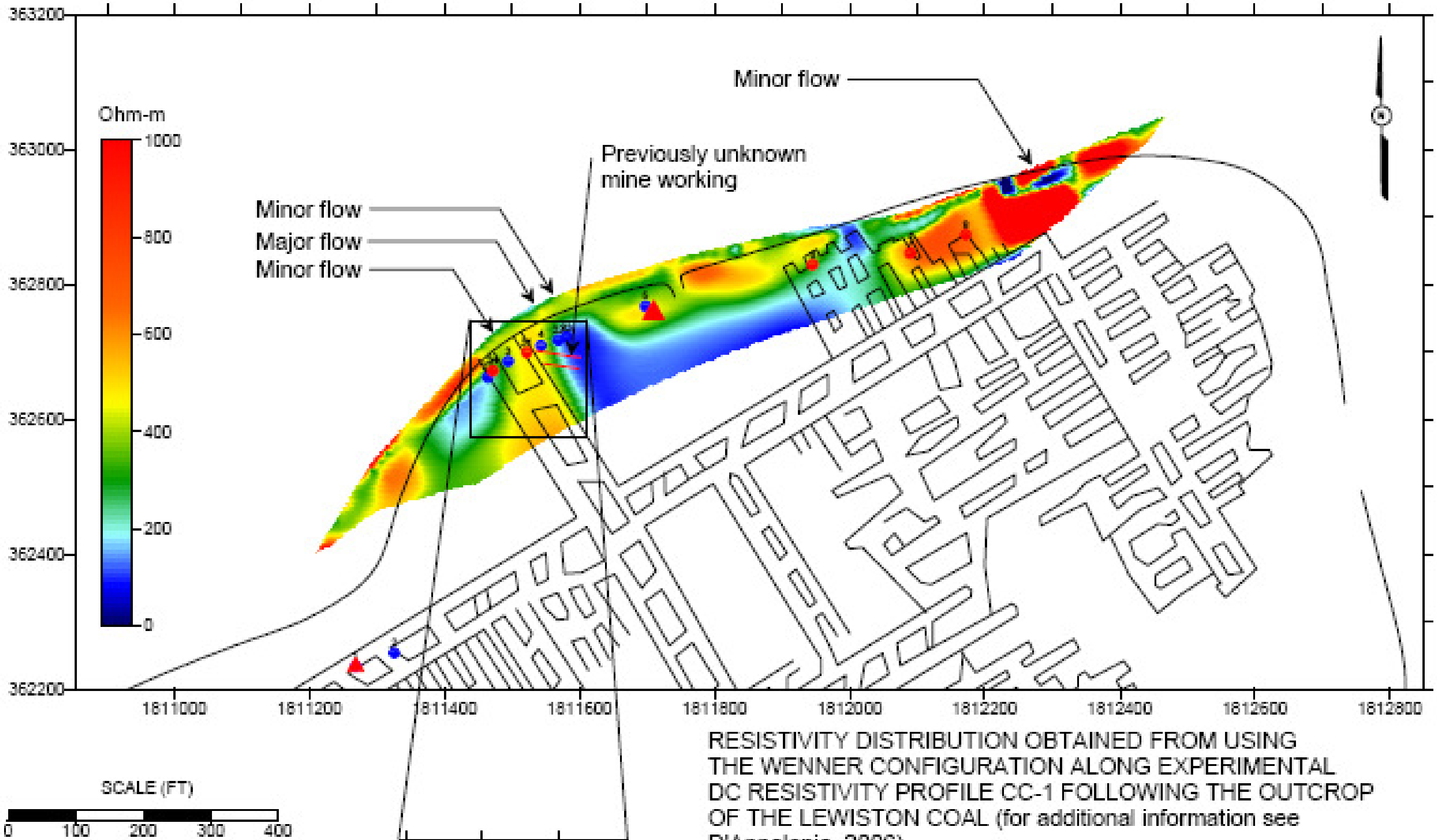


Lots Branch Impoundment Aerial Photo

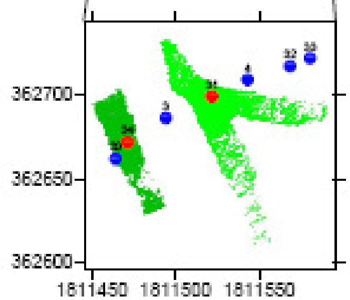
Abandoned Mine Workings at Lots Branch Impoundment



Partially flooded mine voids identified by electrical resistivity survey (shown as blue/green) and confirmed by drilling.



RESISTIVITY DISTRIBUTION OBTAINED FROM USING THE WENNER CONFIGURATION ALONG EXPERIMENTAL DC RESISTIVITY PROFILE CC-1 FOLLOWING THE OUTCROP OF THE LEWISTON COAL (for additional information see D'Appolonia, 2006)



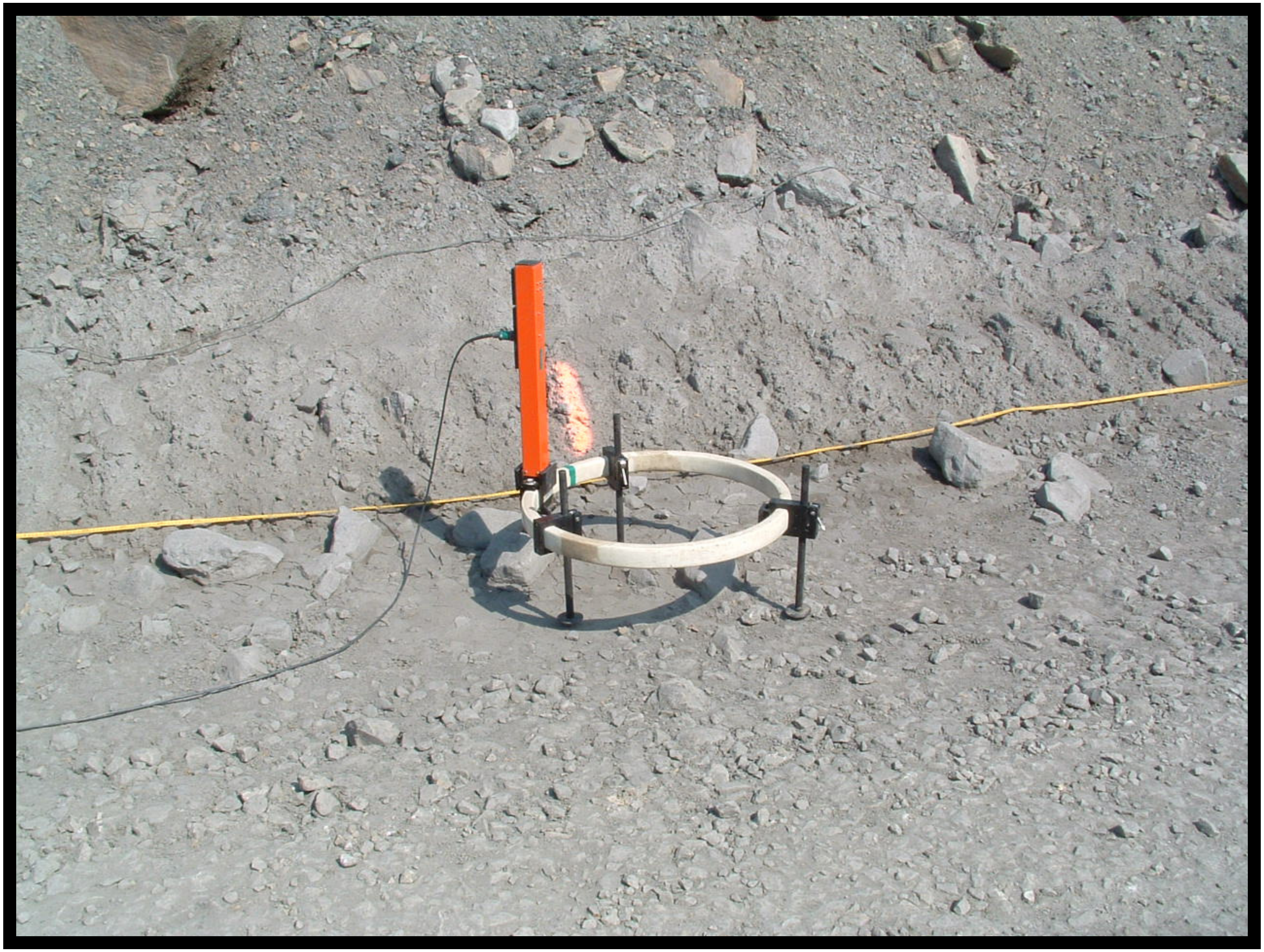
Layout of mine entry from laser imaging system surveyed by Workhorse Technologies - note that results identify a previously unknown tunnel extending into area of resistivity anomaly.

LEGEND

- Corehole
- Air rotary boring
- Air rotary boring with mine void

How The Time Domain Electromagnetic (TDEM) Method Works

- A transmitter induces an alternating current into a loop of insulated cable on the ground.
- The electrical current is gradually turned on and off (ramp time) which creates a changing magnetic field.
- The changing magnetic field induces electrical currents in subsurface materials that oppose the change.
- The diffusing, time-varying current produces time-varying secondary magnetic fields and the diffusion rate of the secondary EM fields is dependent on the conductivity of the material.
- The decaying magnetic fields produce time-varying voltage in the receiver coils that are located on the ground surface.
- It was anticipated that some of the mine voids at the Lots Branch Impoundment would be flooded (good electrical conductors).



TDEM Receiver

TDEM Data Collector

Results at the Southern Side of Lots Branch
(There was no measured water surface but the mine floor was characterized as moist to wet)

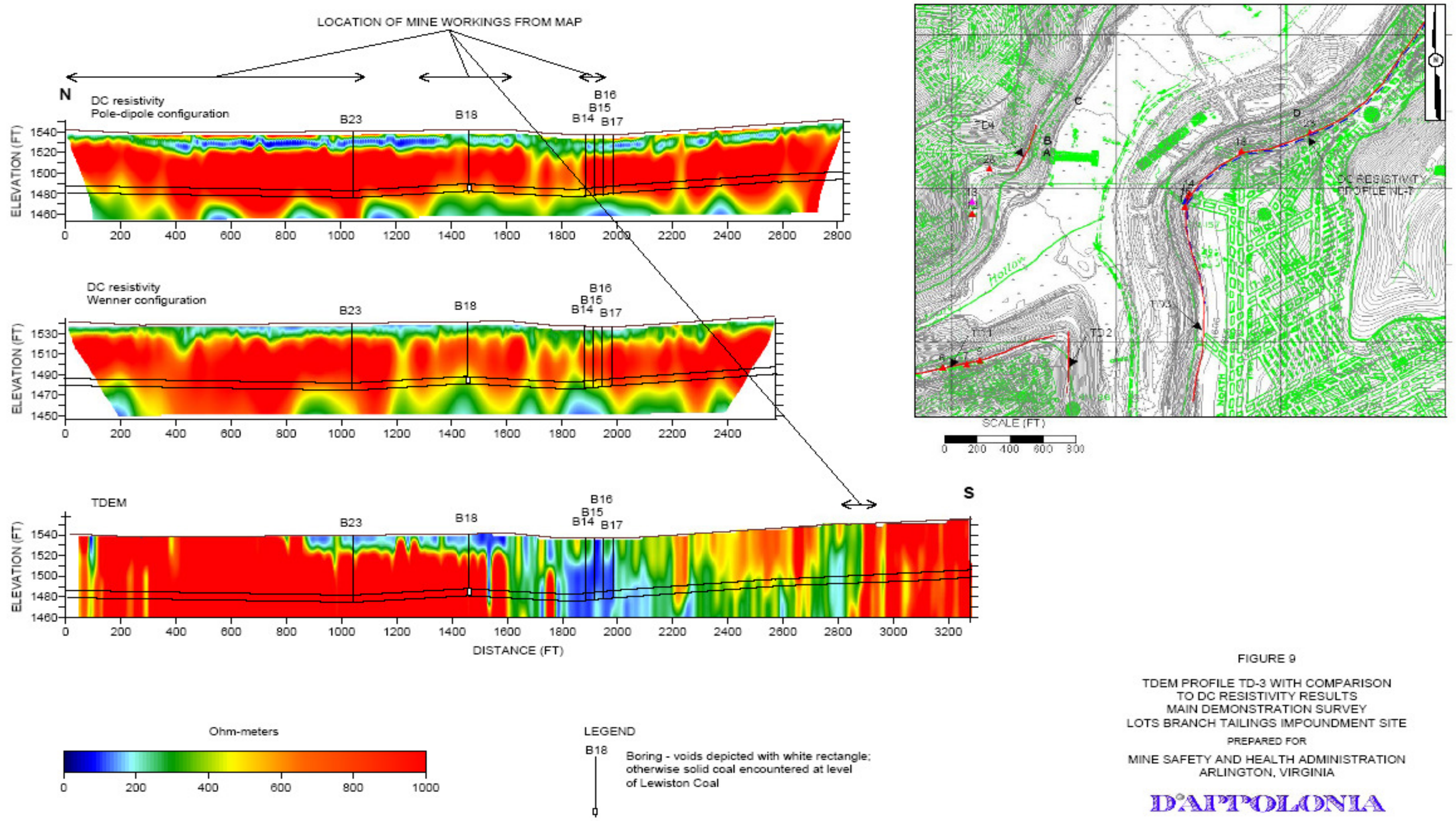


FIGURE 9

TDEM PROFILE TD-3 WITH COMPARISON TO DC RESISTIVITY RESULTS
MAIN DEMONSTRATION SURVEY
LOTS BRANCH TAILINGS IMPOUNDMENT SITE
PREPARED FOR
MINE SAFETY AND HEALTH ADMINISTRATION
ARLINGTON, VIRGINIA

D'APPOLONIA

Results at Northern Side of Lots Branch (Dry Mine Workings)

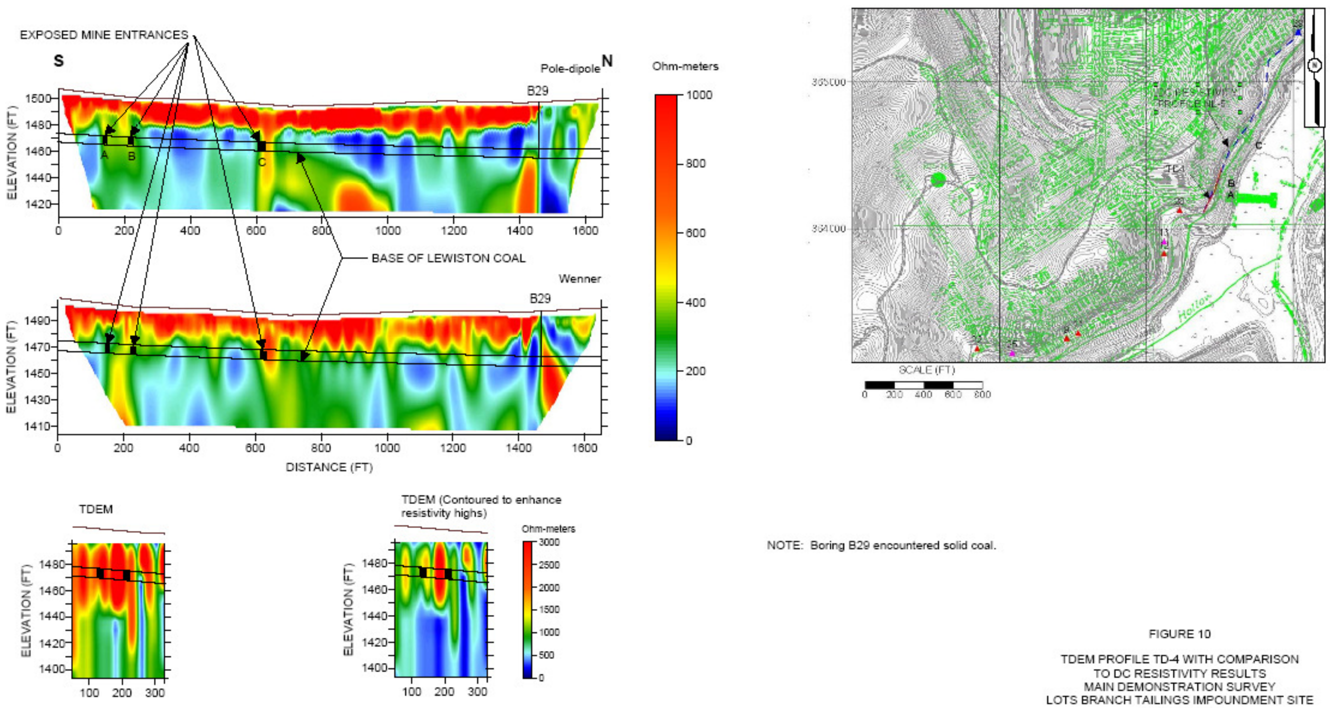


FIGURE 10

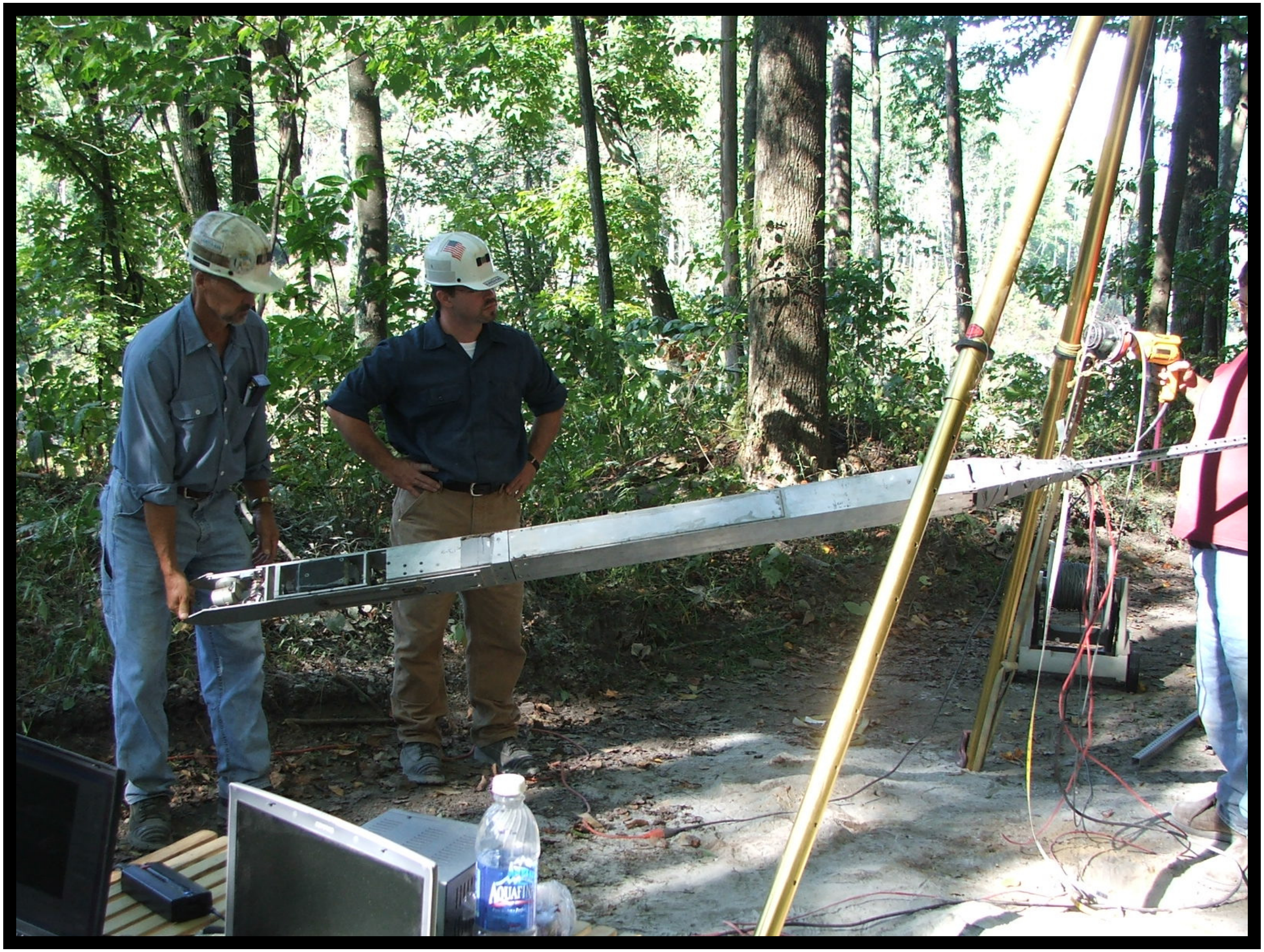
TDEM PROFILE TD-4 WITH COMPARISON
TO DC RESISTIVITY RESULTS
MAIN DEMONSTRATION SURVEY
LOTS BRANCH TAILINGS IMPOUNDMENT SITE

PREPARED FOR

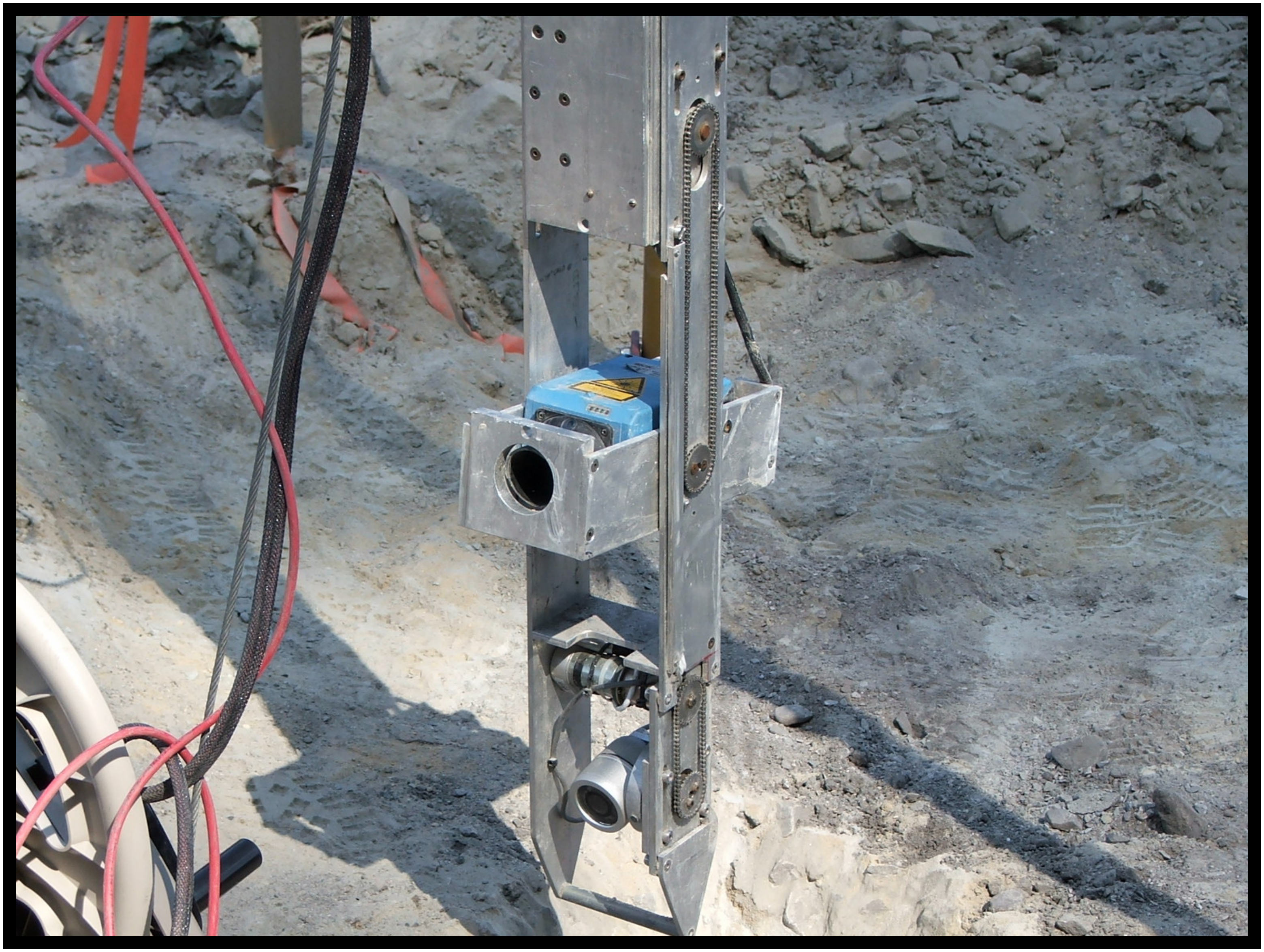
MINE SAFETY AND HEALTH ADMINISTRATION
ARLINGTON, VIRGINIA

D'APPOLONIA

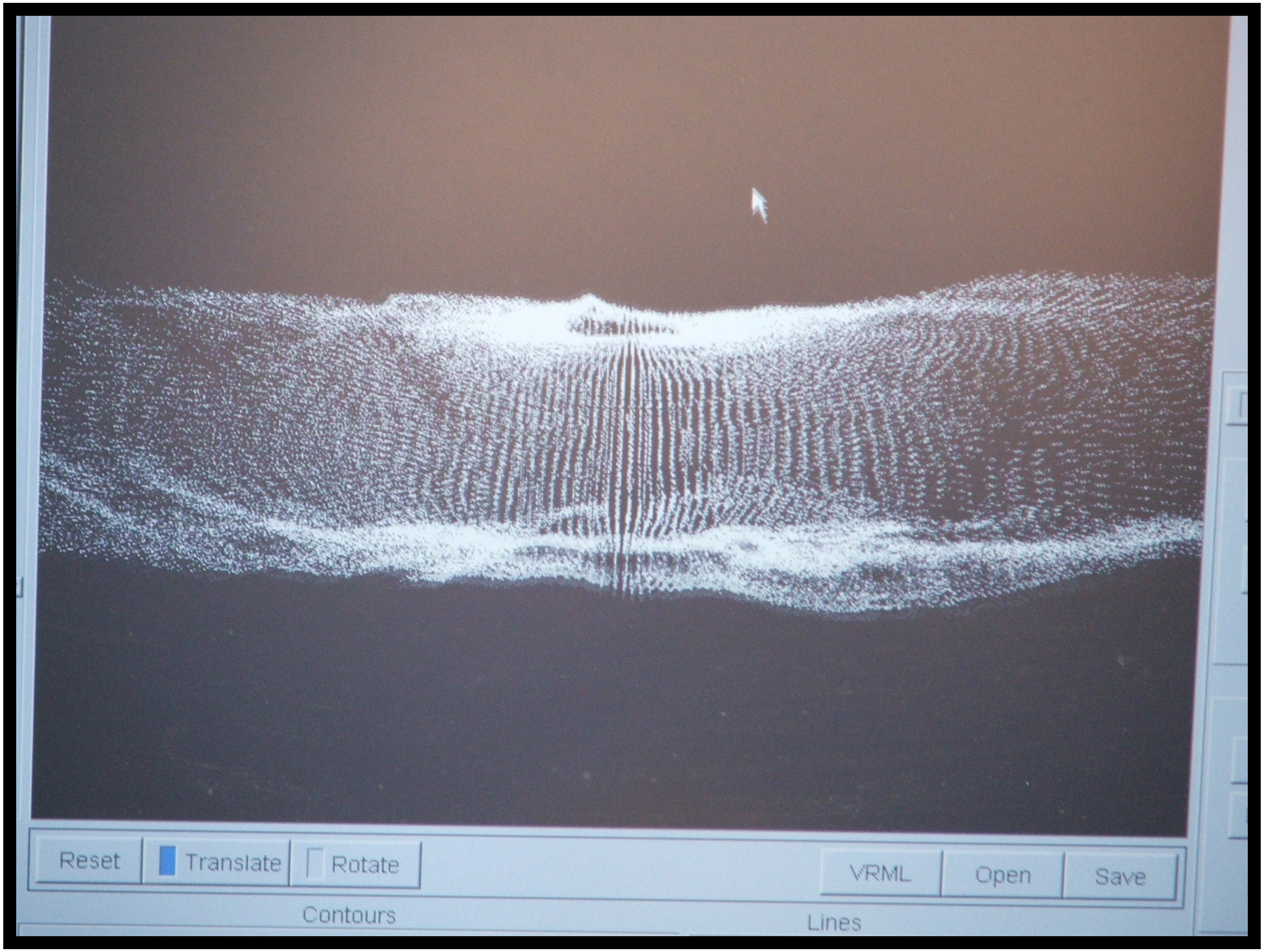
Confirmation Drilling



Downhole Laser Imaging by Workhorse Technologies, Inc.

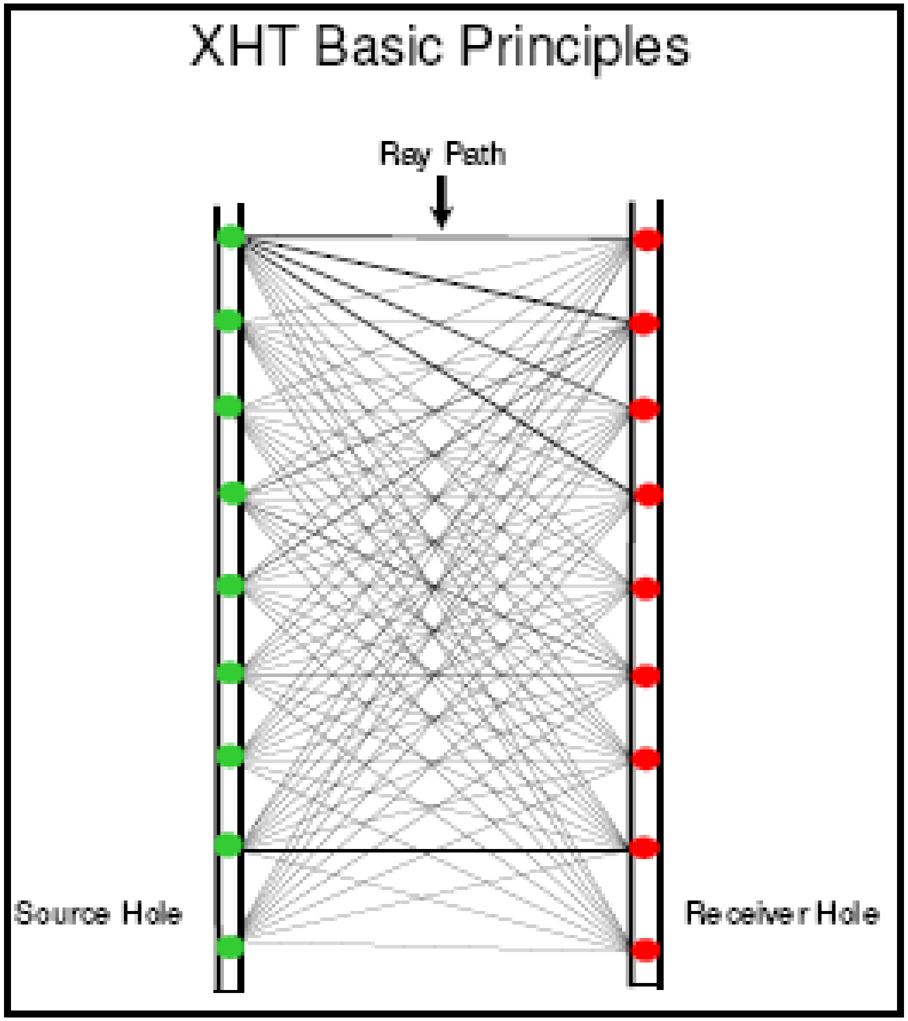


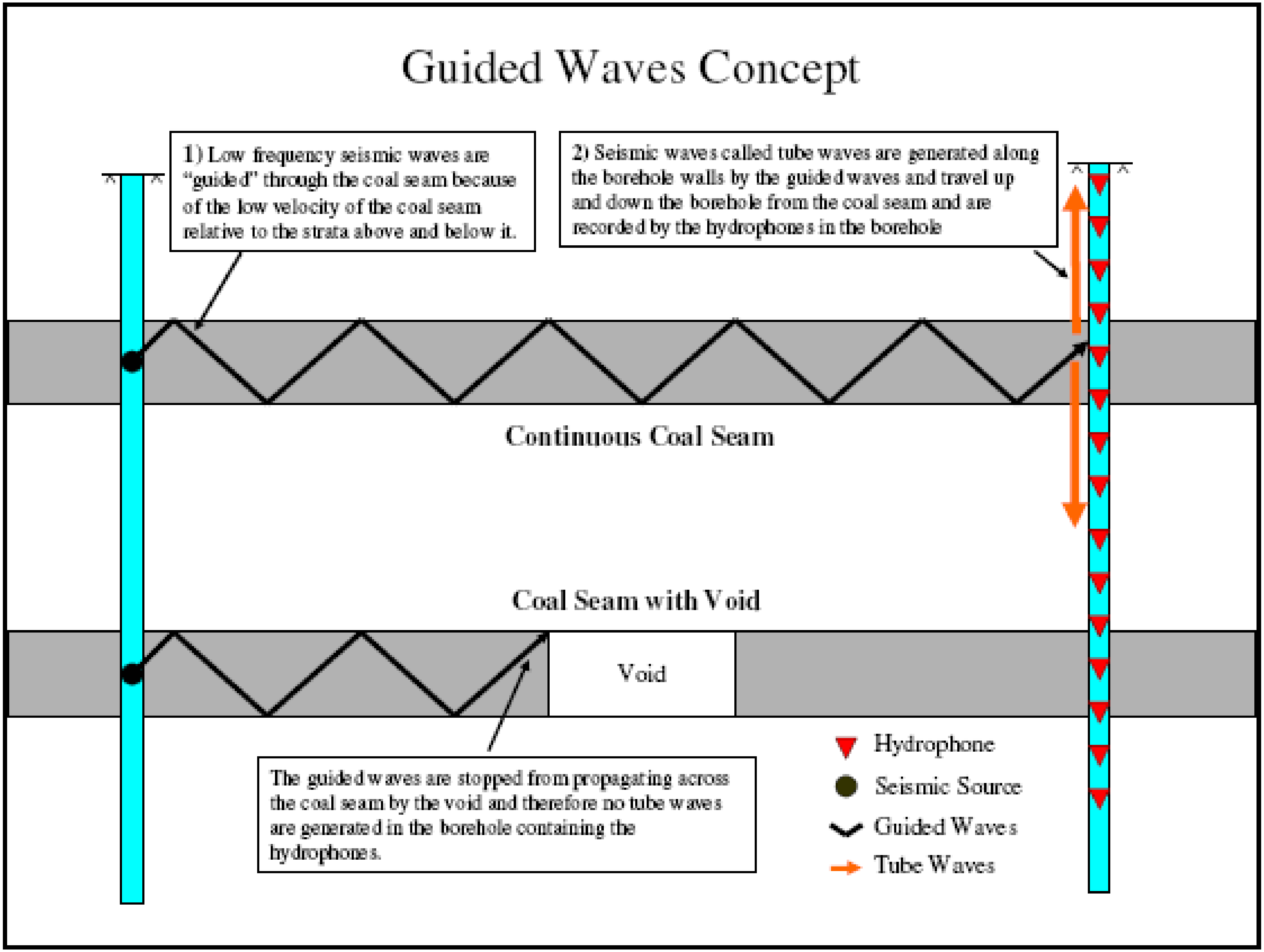
Downhole Laser and Video Camera



Point Cloud of Laser Shots

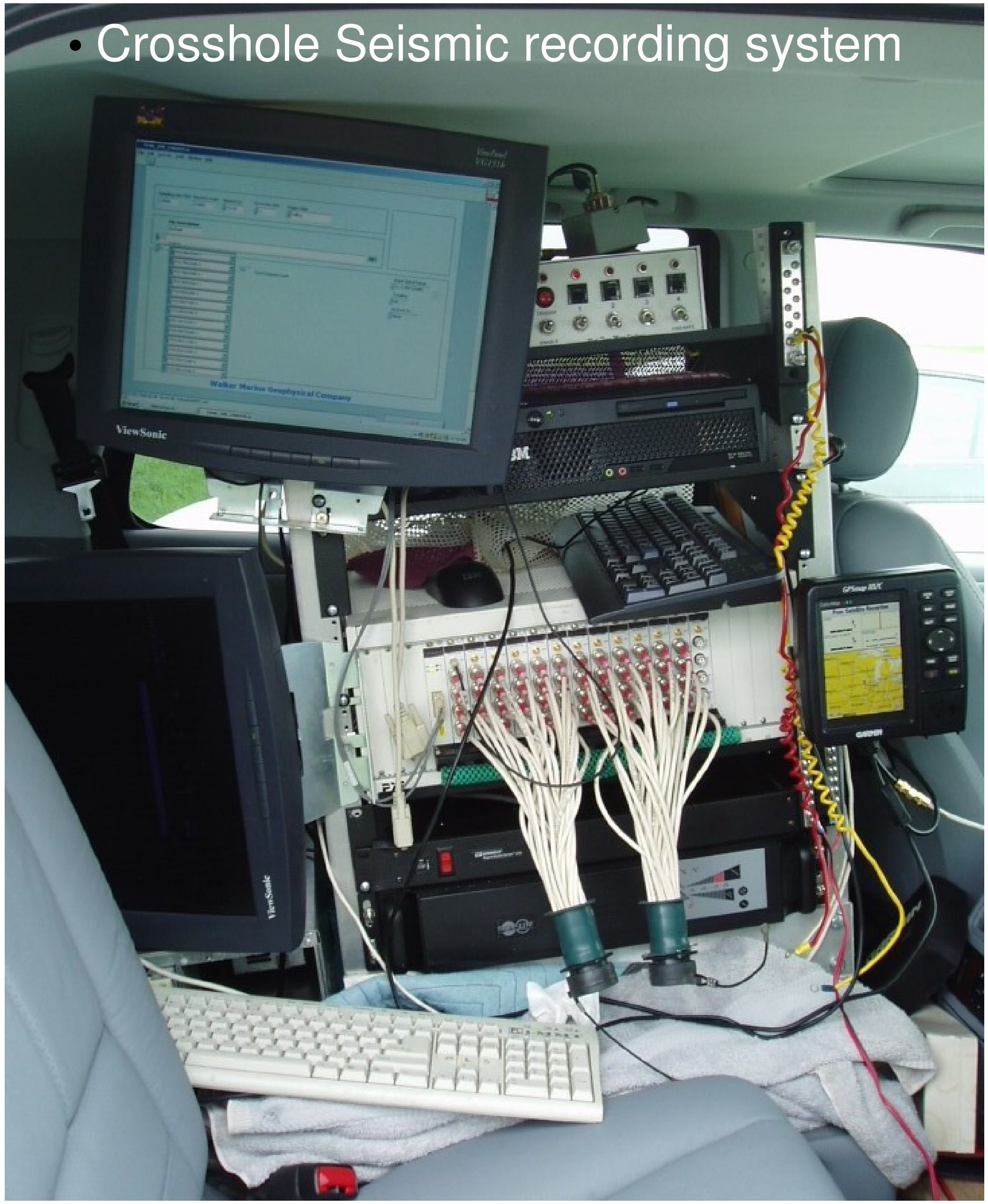
Crosshole Seismic Method (XHT)




Guided Waves Concept
1) Low frequency seismic waves are "guided" through the coal seam because of the low velocity of the coal seam relative to the strata above and below it.
2) Seismic waves called tube waves are generated along the borehole walls by the guided waves and travel up and down the borehole from the coal seam and are recorded by the hydrophones in the borehole
Continuous Coal Seam
Coal Seam with Void
Void
The guided waves are stopped from propagating across the coal seam by the void and therefore no tube waves are generated in the borehole containing the hydrophones.
Hydrophone
Seismic Source
Guided Waves
Tube Waves

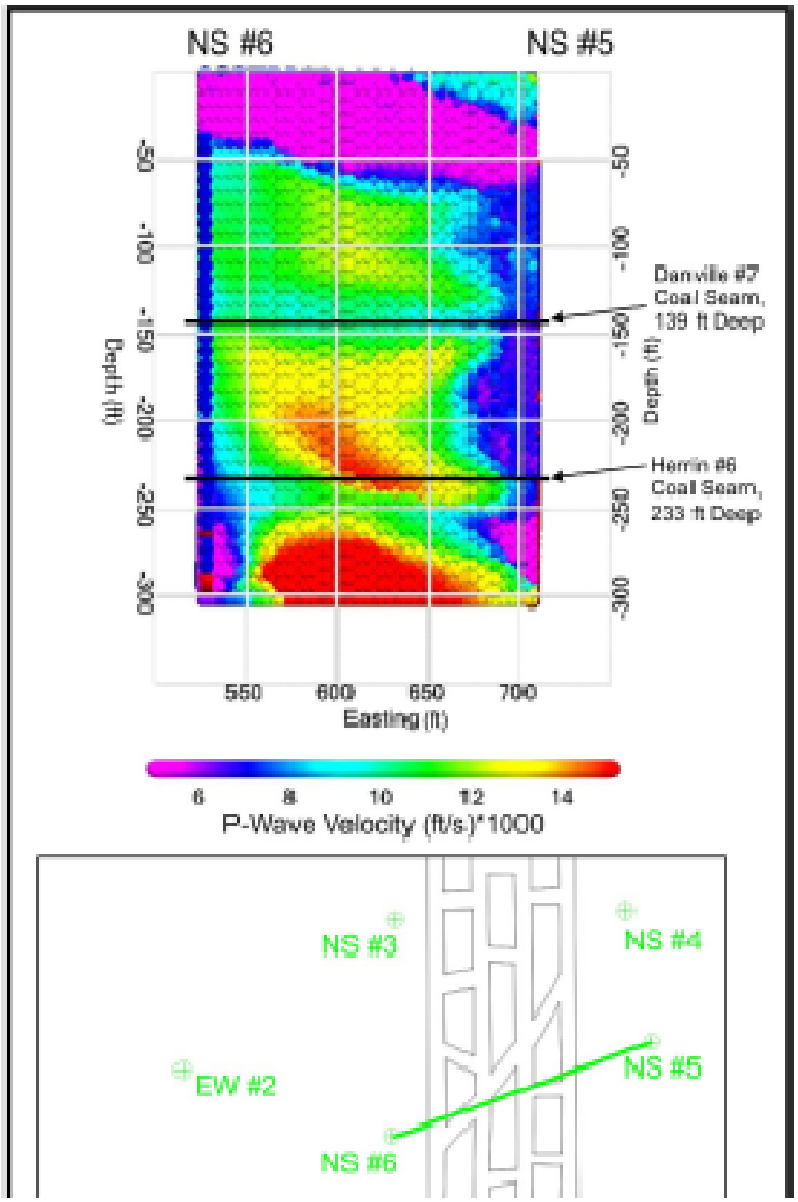
- Downhole source is a DHSS-5500 air gun, 2000 psi

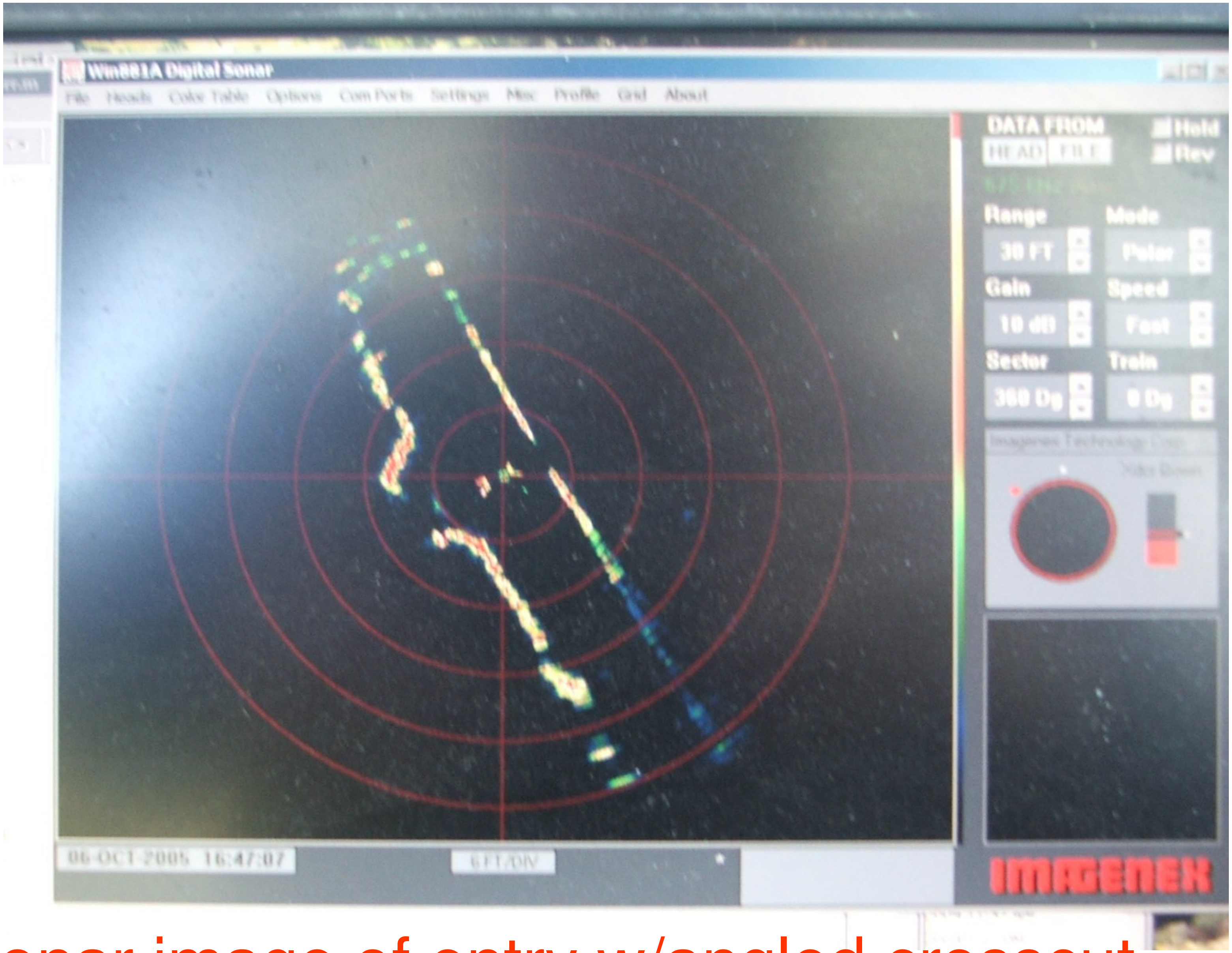
• Crosshole Seismic recording system



Borehole Locations for XHT

XHT Velocity Tomogram – no mine works imaged

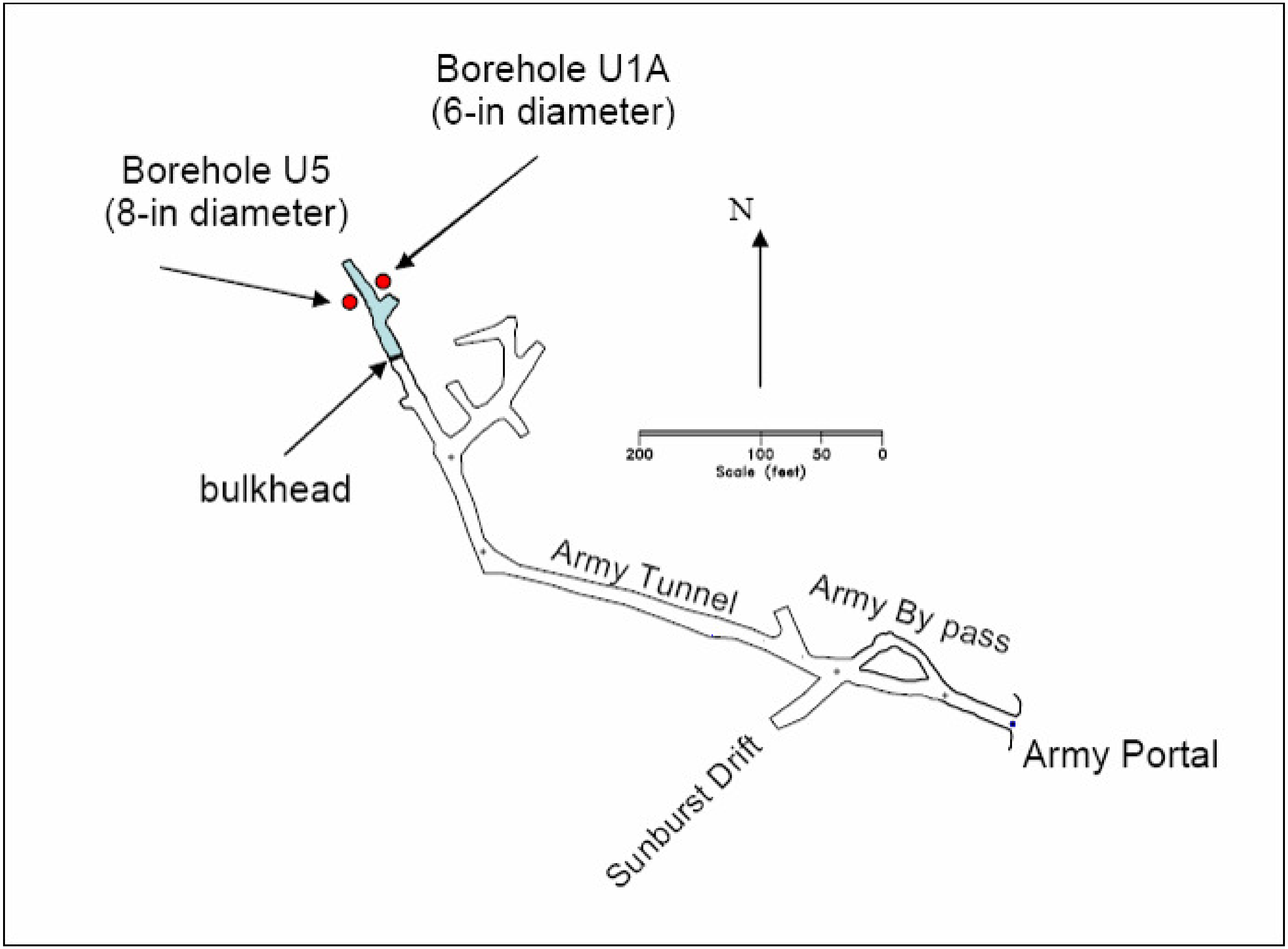




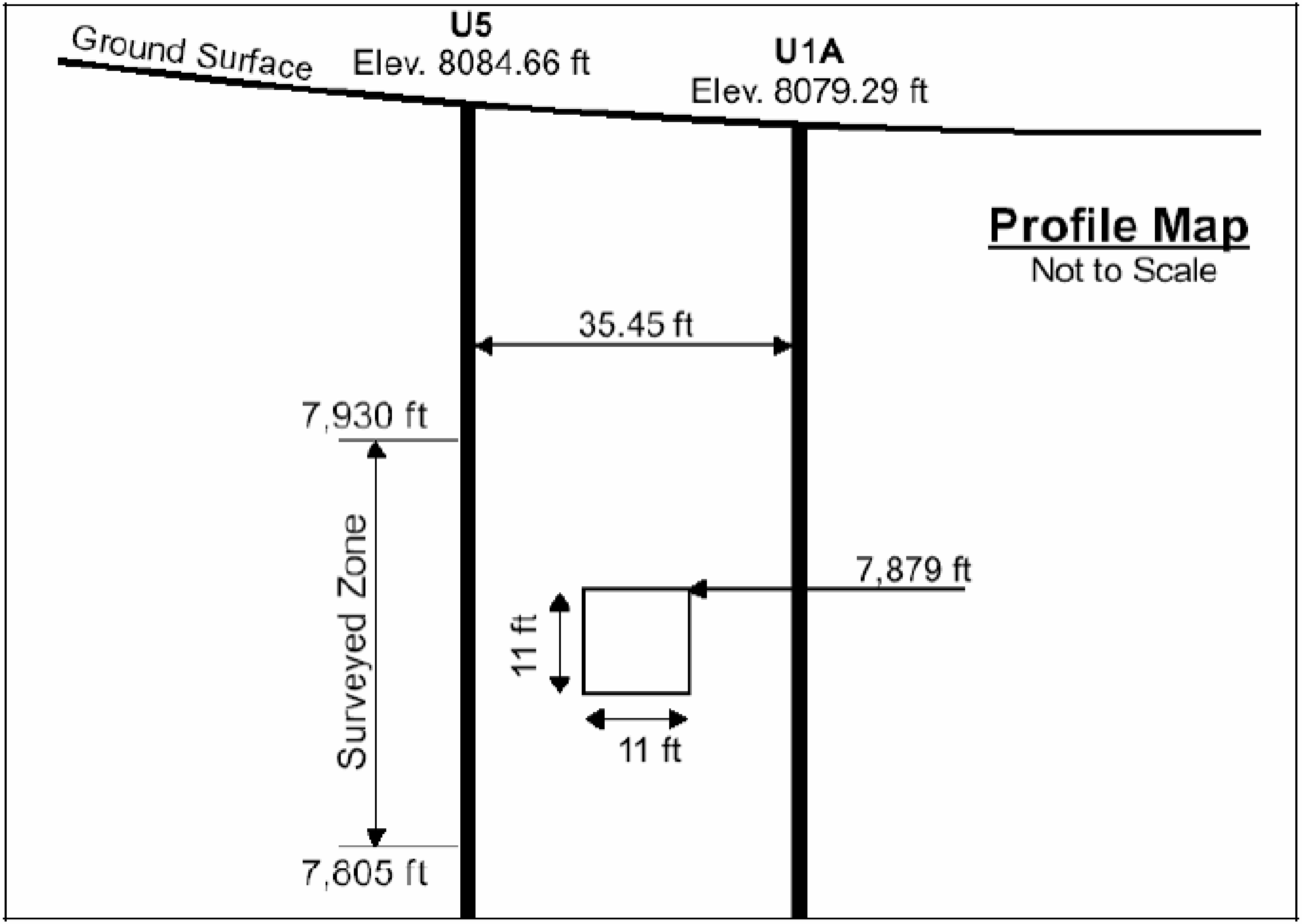
- Sonar image of entry w/angled crosscut

Cross-hole Seismic Tomography
Cross-hole Radar Tomography
Down-hole Radar

Performed by
Colorado School of Mines



Layout of Army Tunnel. Note borehole and bulkhead locations.


Ground Surface
U5
Elev. 8084.66 ft
U1A
Elev. 8079.29 ft
Profile Map
Not to Scale
35.45 ft
7,930 ft
Surveyed Zone
7,605 ft
7,879 ft
11 ft
11 ft

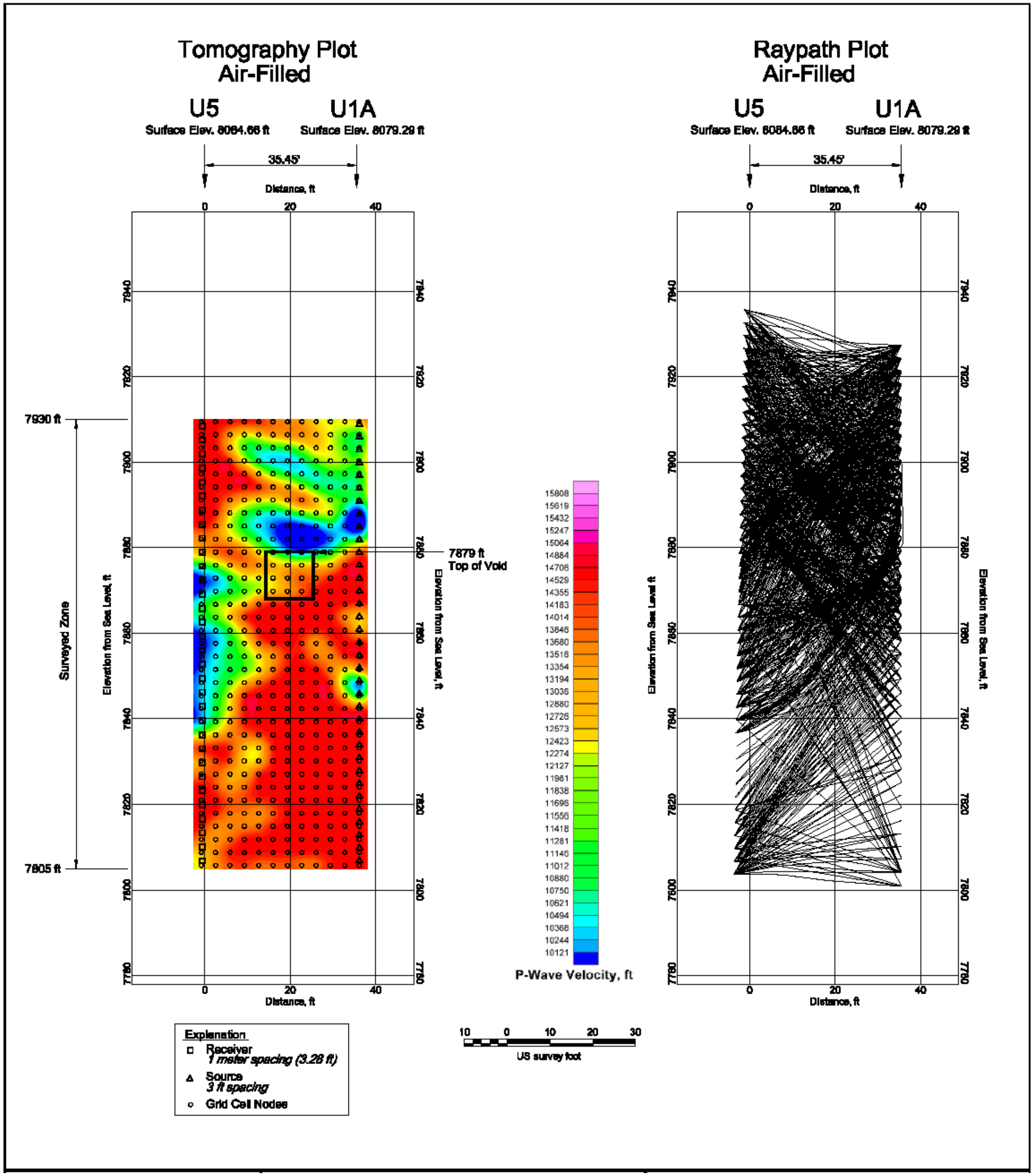
Tunnel conditions prior to bulkhead construction

Completed reinforced concrete bulkhead

Lowering hydrophones into Borehole U5 **9/22/05**

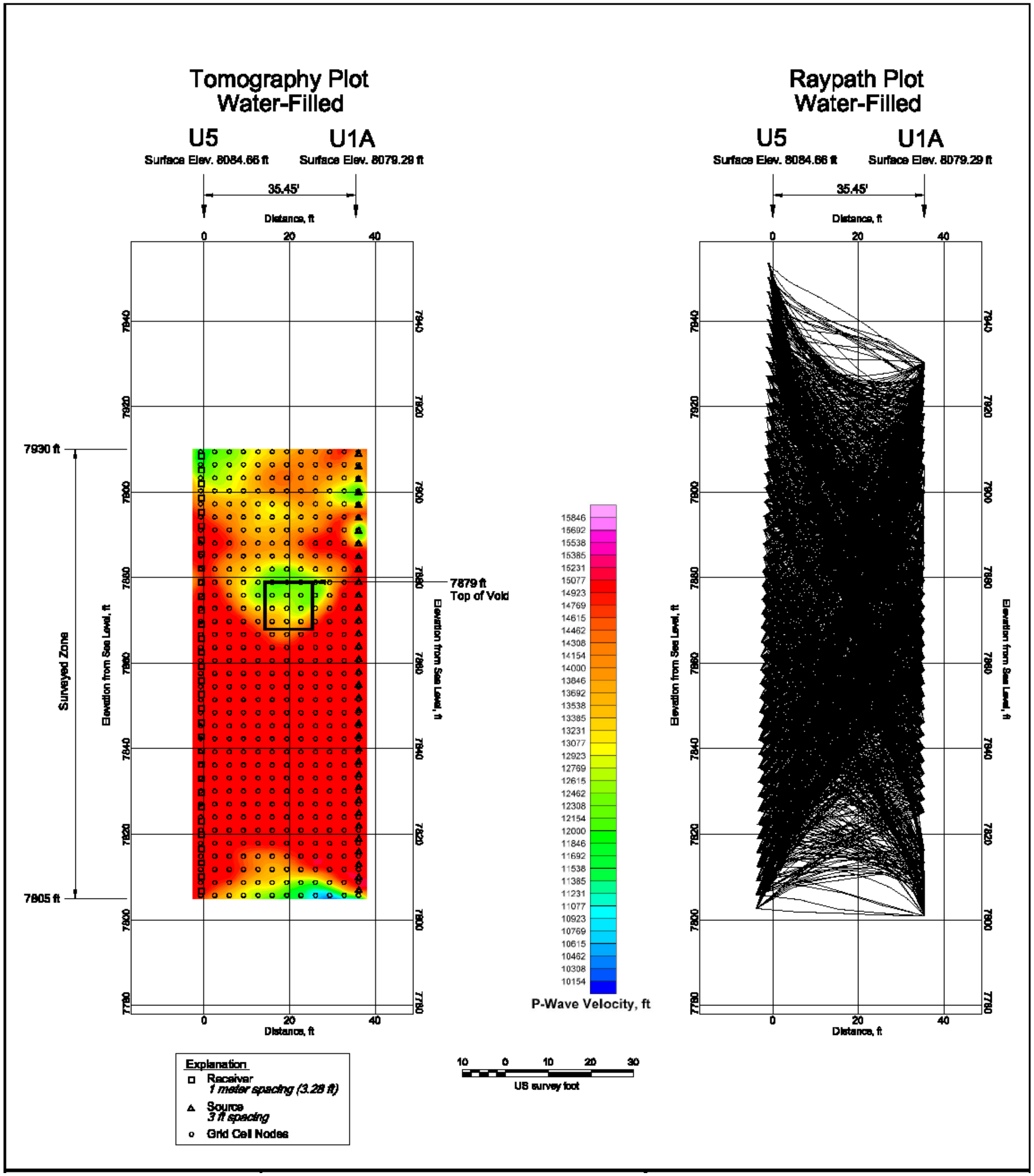
Etrema seismic source **9/22/05**

Lowering seismic source into Borehole U1. Note water hose used to fill borehole.



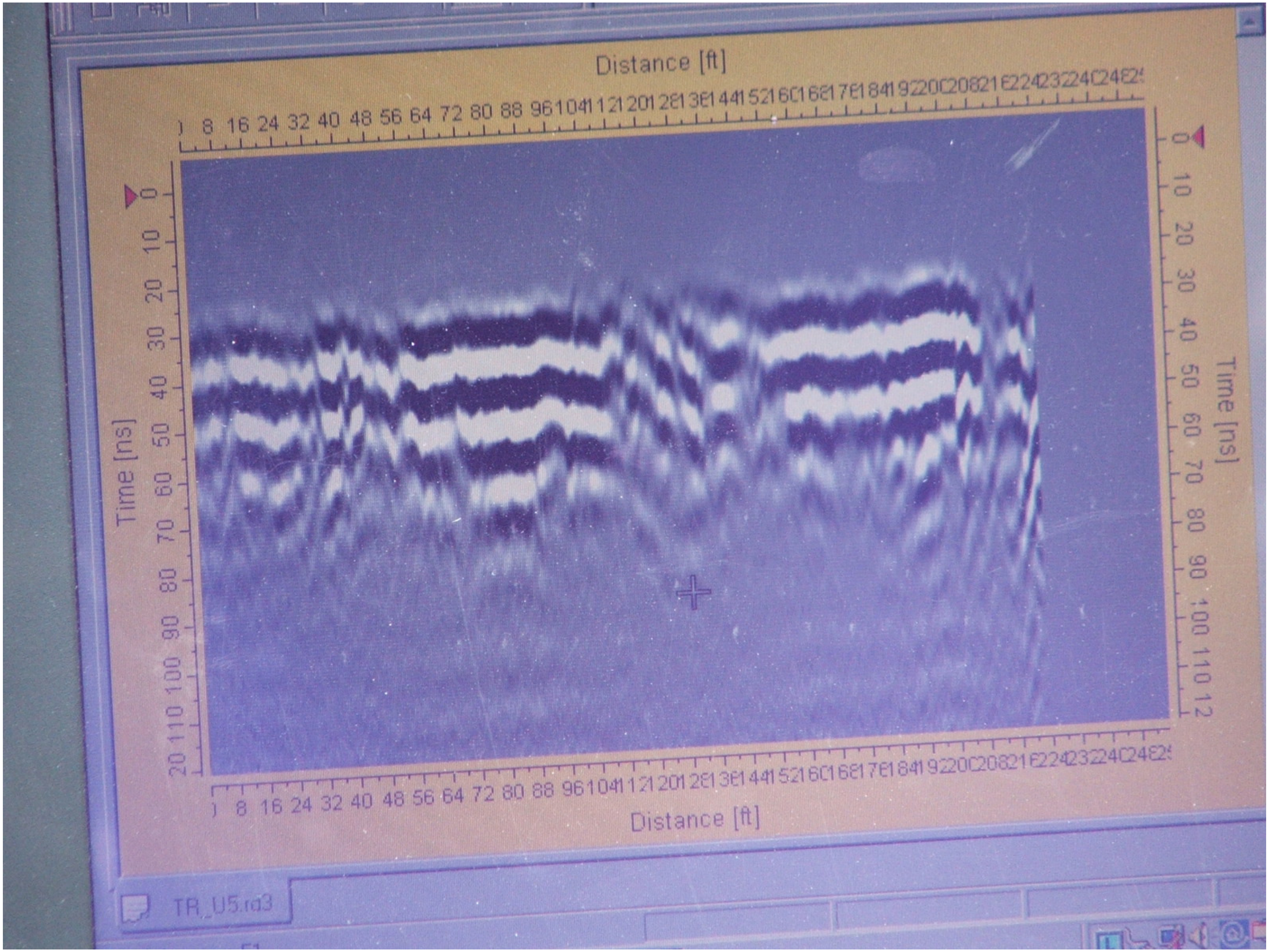
Crosshole Seismic

- Two-dimensional tomogram image for the air filled void condition
- Actual Void is 200 feet deep (elevation 7879)
- Void was imaged at elevation 7887

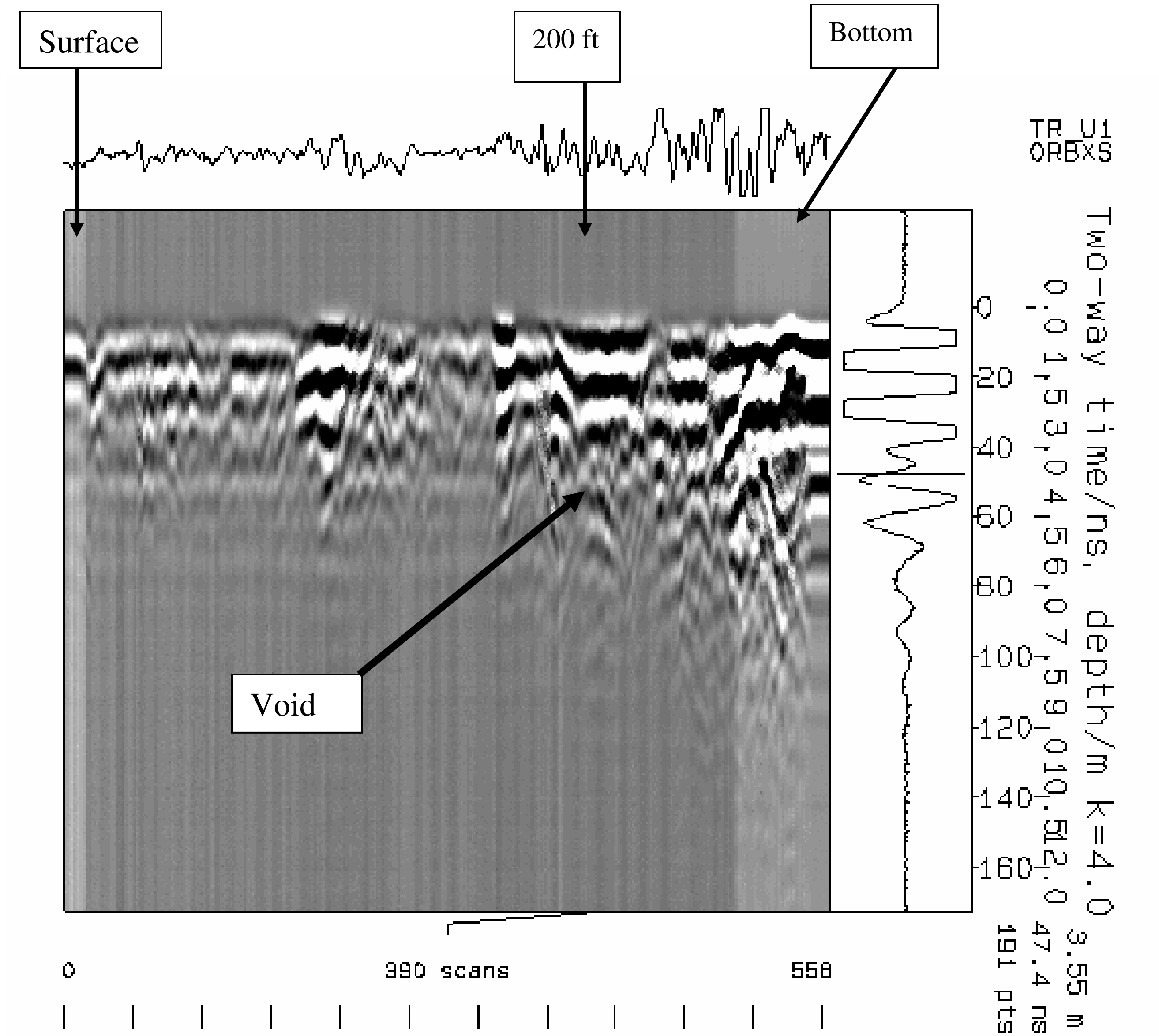


Crosshole Seismic

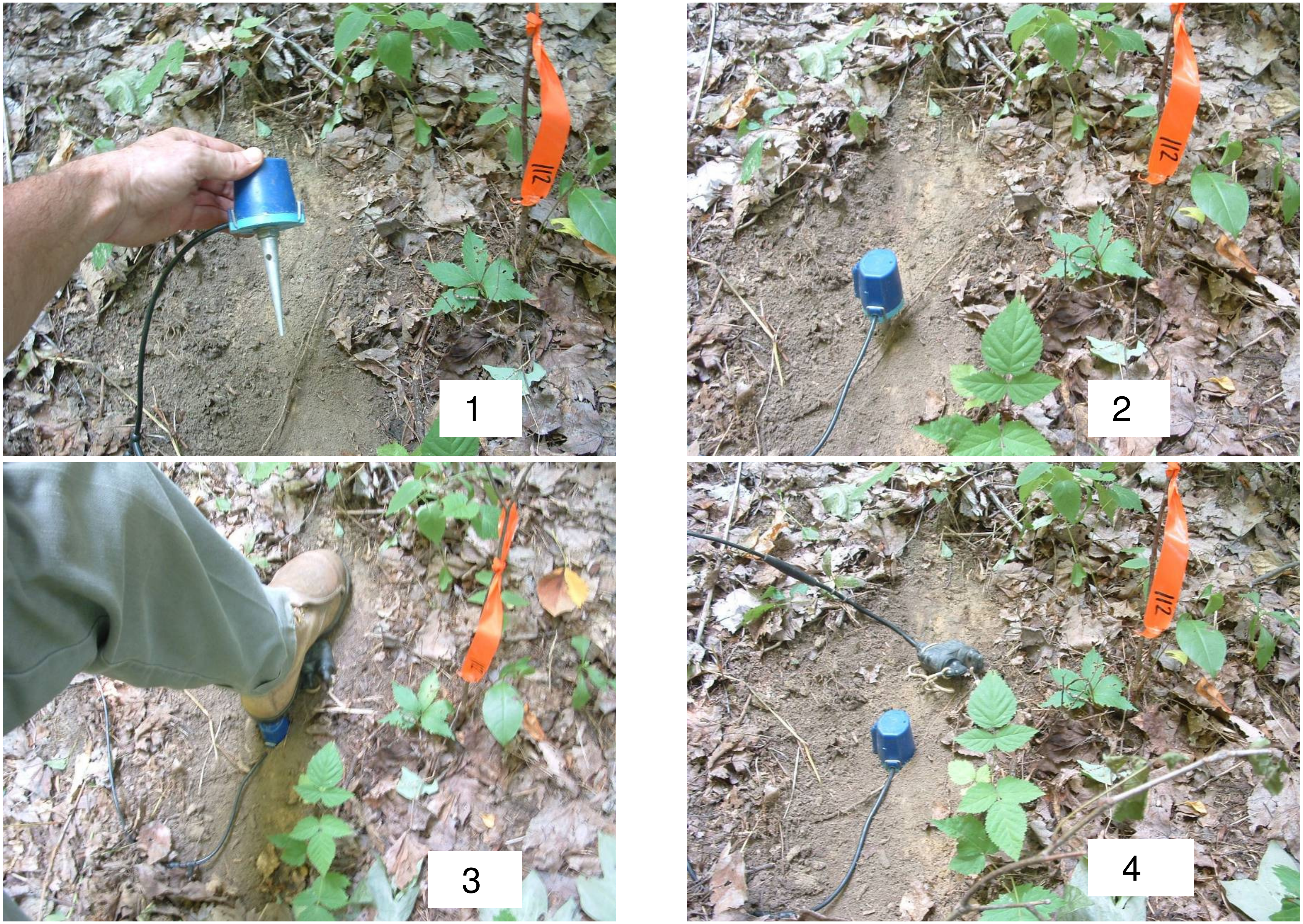
- **Two-dimensional tomogram image for the water filled void condition**
- **Actual Void is 200 feet deep (elevation 7879)**
- **Void was imaged at elevation 7882**



Raw data display on the Mala RAMAC recording equipment



Borehole radar data for the air filled void condition (transmitter and receiver placed in the same hole)

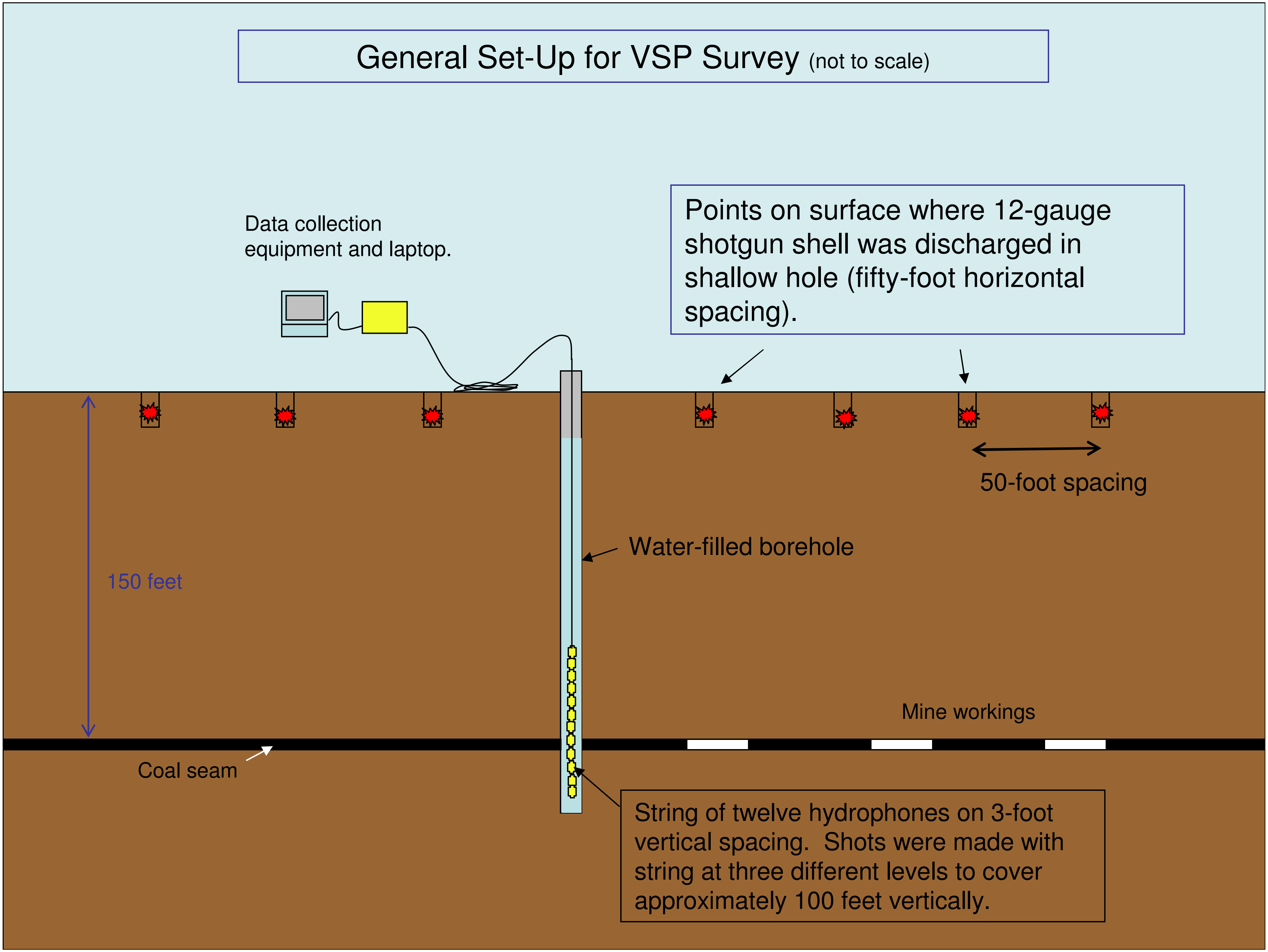


Installing a geophone is simply a matter of (1) clearing the ground of loose material; (2) pushing the geophone spike into the ground; and (3) ensuring good contact by striking the geophone with the heel of your boot. The geophone lead is now ready to be connected to the cable (4).

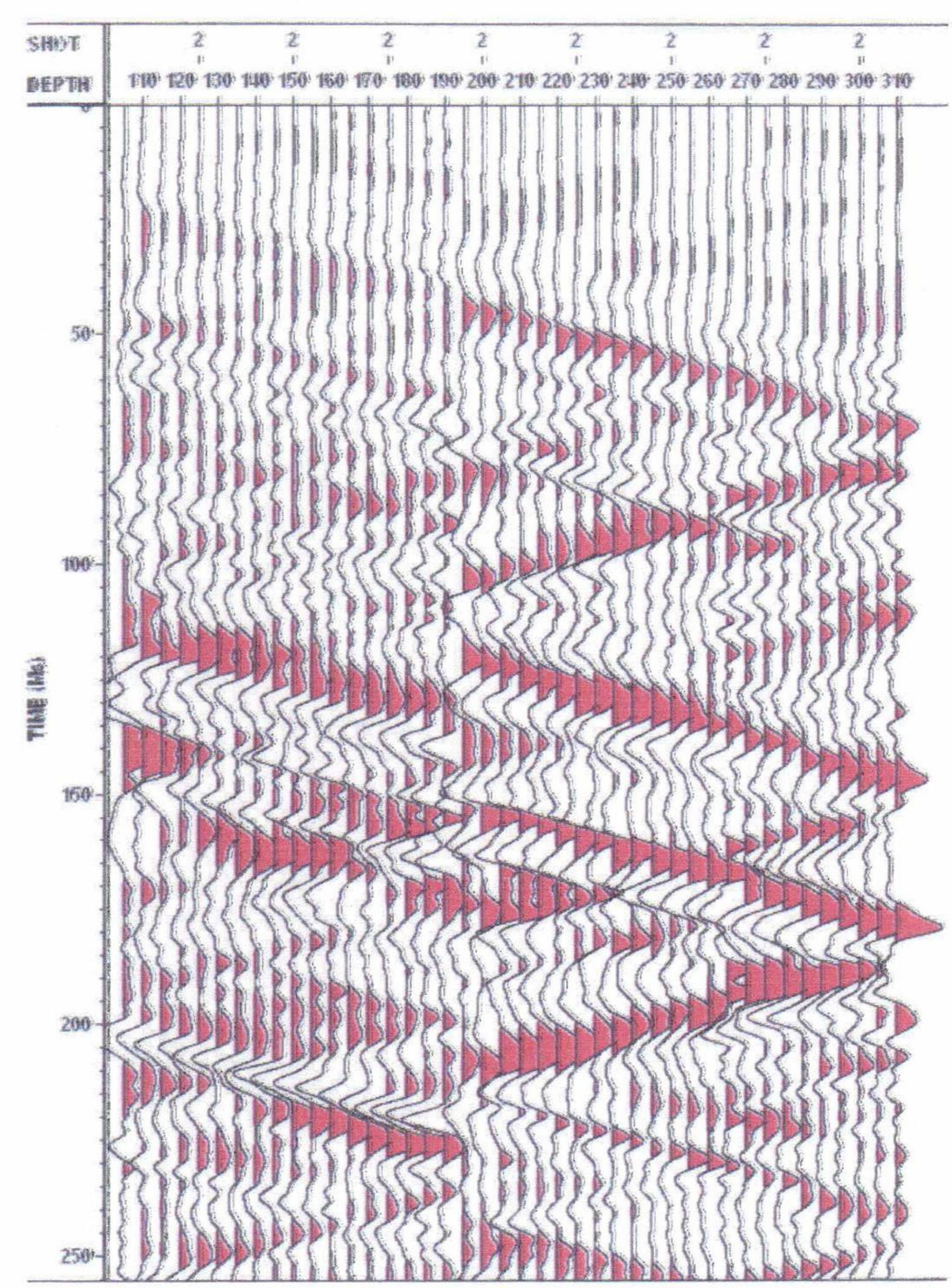
(1) Assistant puts shotgun shell in fitting and hands to firer; (2) firer screws fitting and shell onto end of pipe; (3) "seisgun" is lowered into hole; and (4) rod is placed in pipe. The "seisgun" is ready to be fired by striking the end of the rod with a hammer.

Firing the “seisgun” by striking the top of the rod with a hammer.

The shot from the 12-gauge shell was usually muffled and not very loud. The shot was louder (like a firecracker) in a few cases where the bottom of the hole was near rock.



General Set-Up for VSP Survey (not to scale)
Data collection equipment and laptop.
Points on surface where 12-gauge shotgun shell was discharged in shallow hole (fifty-foot horizontal spacing).
50-foot spacing
Water-filled borehole
150 feet
Mine workings
Coal seam
String of twelve hydrophones on 3-foot vertical spacing. Shots were made with string at three different levels to cover approximately 100 feet vertically.

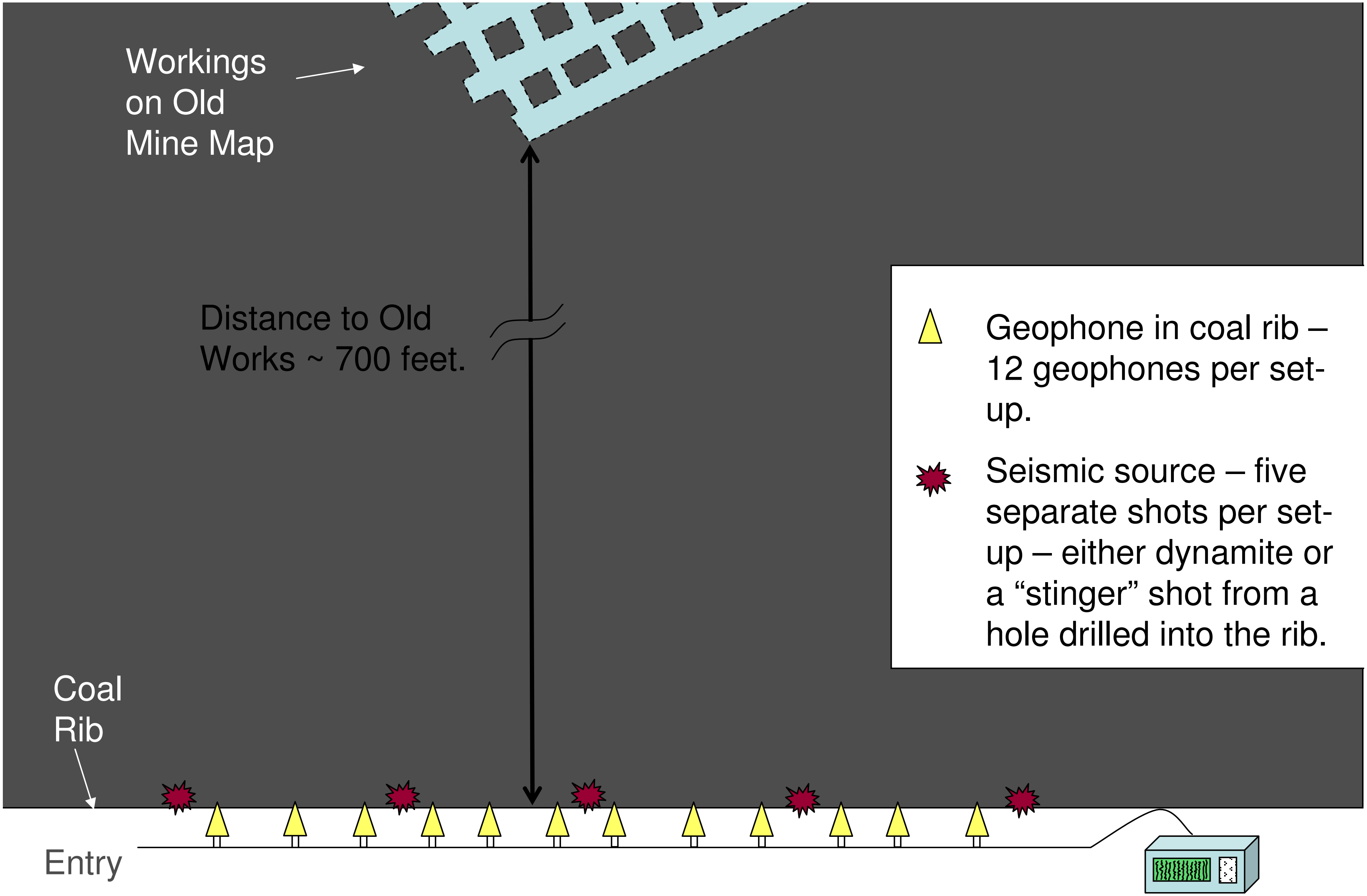


- Sample of raw VSP data with downgoing waves highlighted
- Poor signal-to-noise ratio
- First arrivals not apparent
- Data was also saturated by tubewaves within the borehole
- Unable to process/detect the mine works

In-seam Seismic Reflection

Surveys were conducted at five different mines:

- Sterling Mining Corporation’s Carroll Hollow Mine
- Buckeye Industrial Mining Corporation’s Deep Mine 10-6A
- Bell County Coal Corporation’s Cabin Hollow Mine
- Bluff Spur Coal Corporation’s Mine No. 1
- NIOSH Bruceton Safety Research Coal Mine



Simplified Plan-View Schematic for Layout of 12 Geophone Array per Set-up

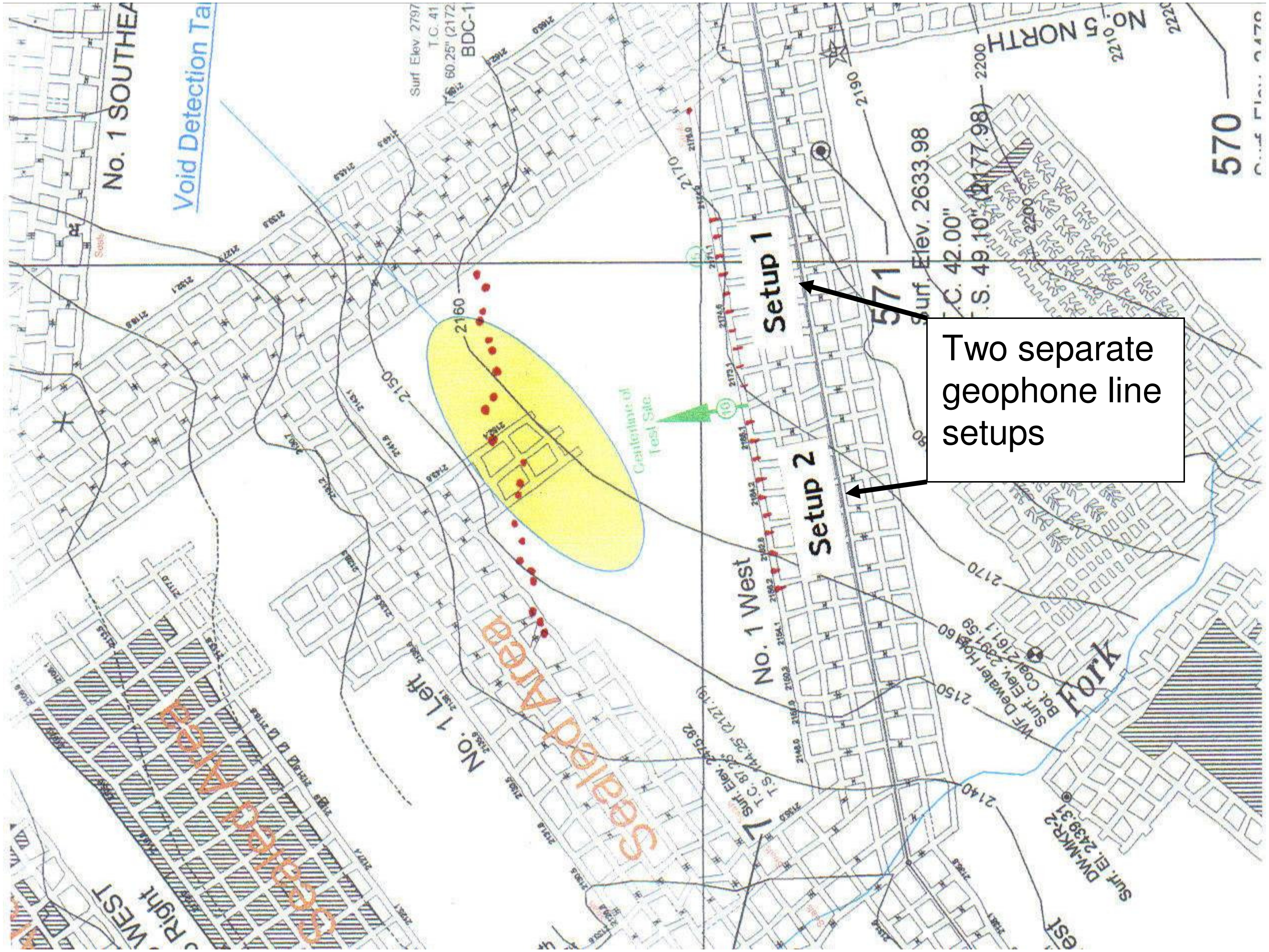
Typical geophone installation into coal rib using a cordless drill.

The geophone spike was simply pushed into the hole in the rib creating a snug fit. The geophone lead wires are attached to a cable that runs to the data-collection instrument.

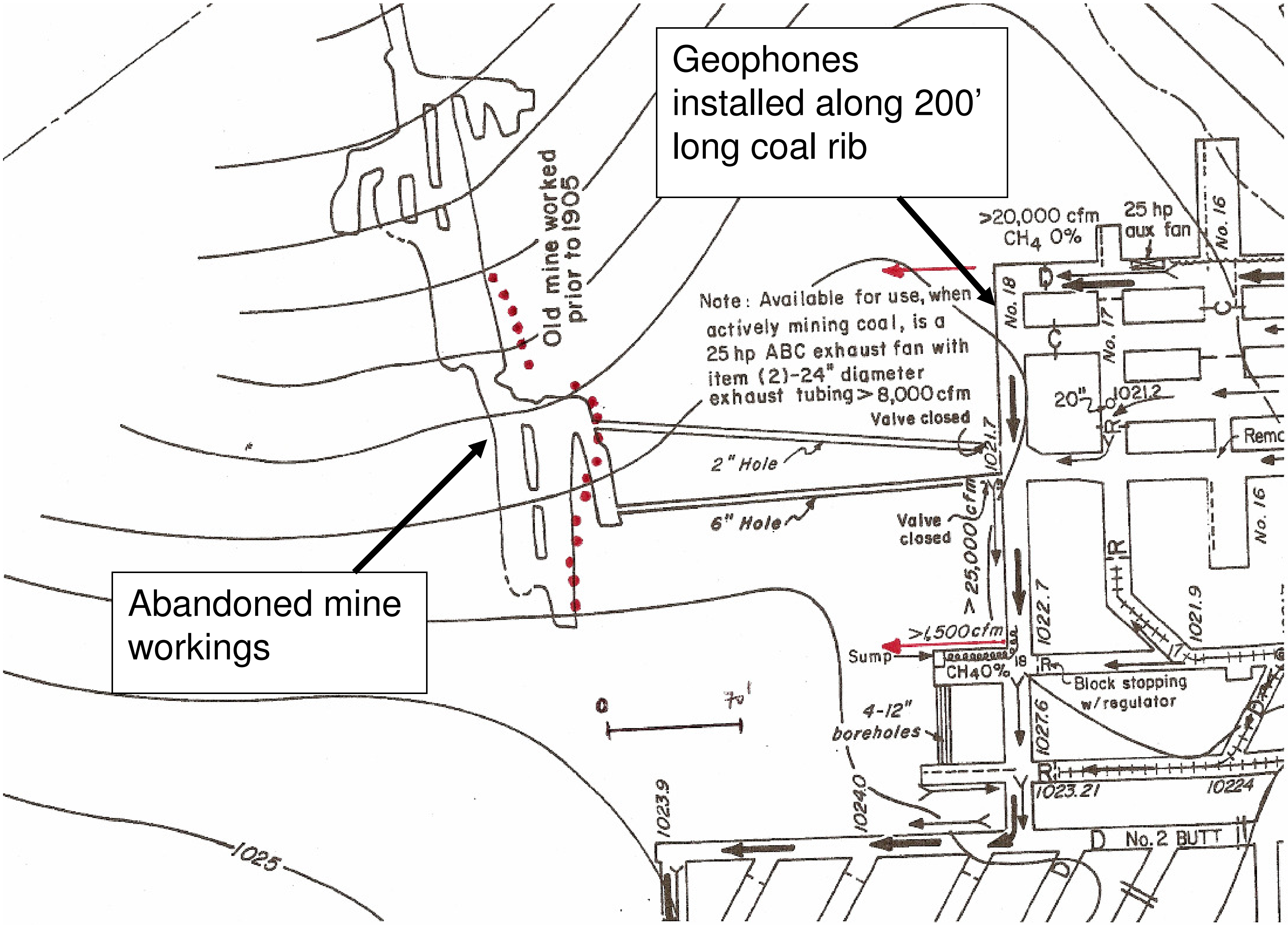
The seismic source was created by shooting either a ½-inch-long piece of a stick of dynamite, or using a “stinger” charge (shown above on the right). The explosive was detonated using an electric blasting cap (shown on the left). The explosives were loaded into holes drilled into the ribs.

A sledgehammer was also used to create the seismic source for some of the surveys. The hammer is struck against the coal rib.

Most of the surveys were conducted in low mining height which significantly increased the time and effort required to conduct the survey.

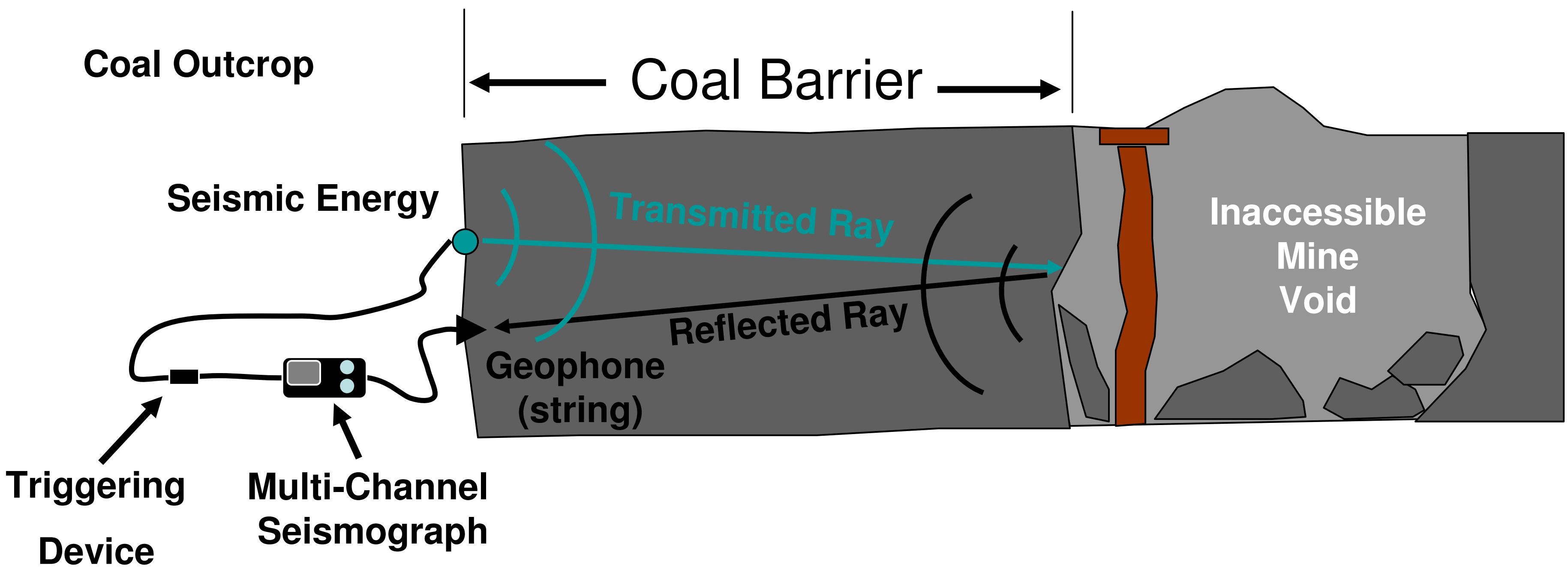


Reflection points plotted from Bluff Spur “blind” in-seam survey

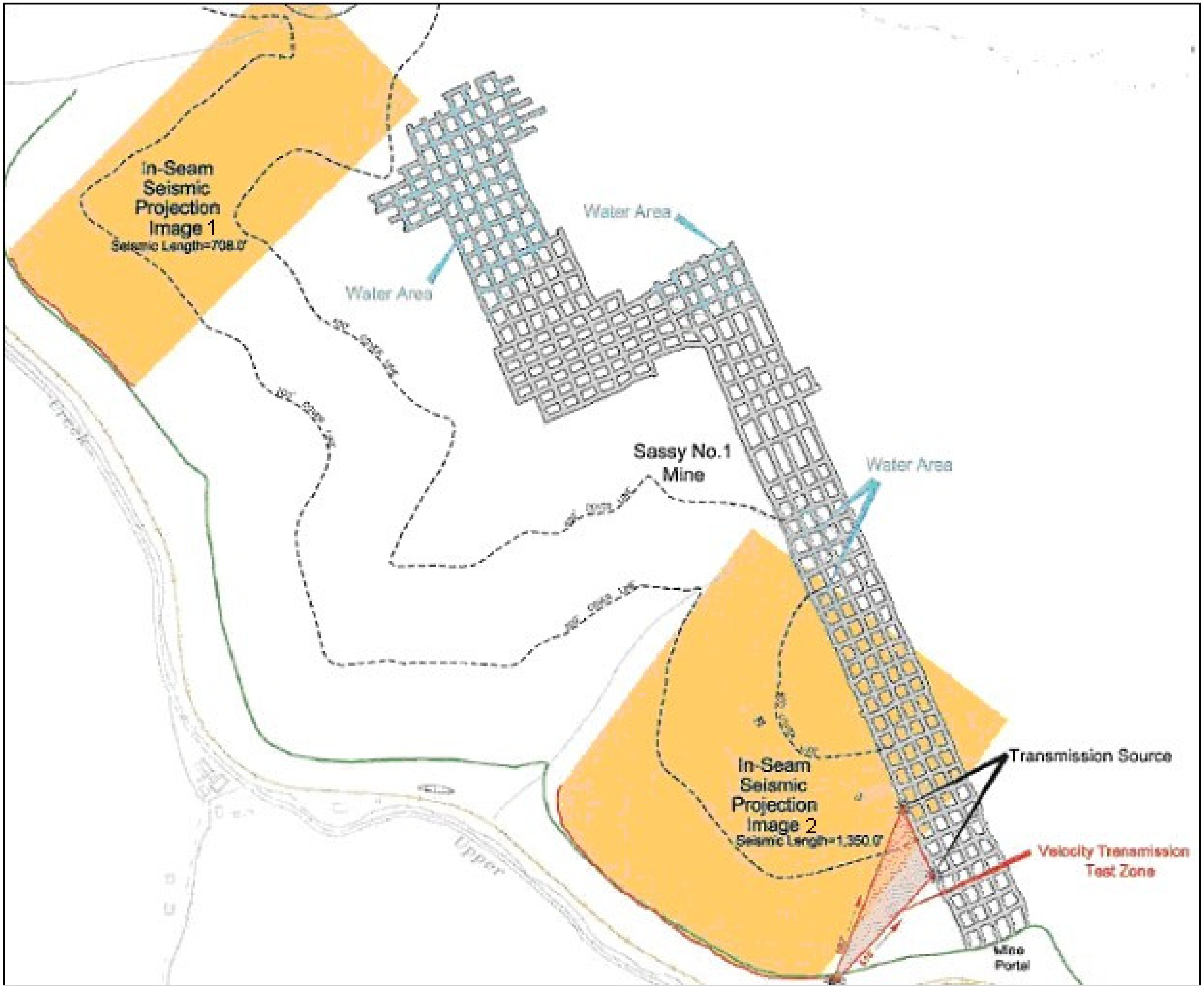


Reflection points plotted from NIOSH Bruceton "blind" in-seam survey. The results of this second "blind" test were fairly accurate.

In-seam Seismic Reflected Wave Principles (from surface outcrop)



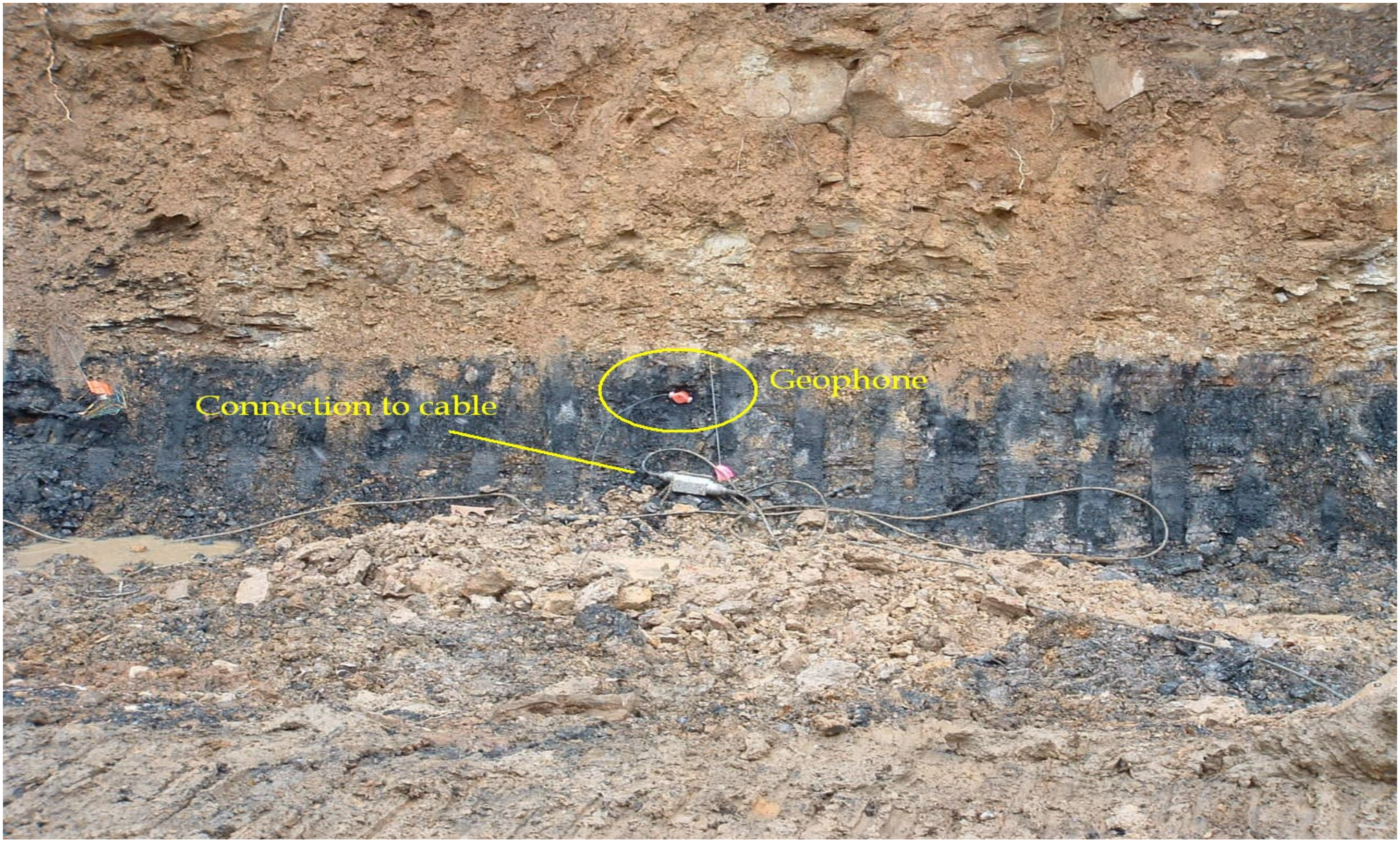
Test Layout


In-Seam
Seismic
Projection
Image 1
Seismic Length=708.0'
Water Area
Water Area
Sassy No.1
Mine
Water Area
In-Seam
Seismic
Projection
Image 2
Seismic Length=1,350.0'
Transmission Source
Velocity Transmission
Test Zone
Mine
Portal
Upper

Placement of explosives into blast holes. Blast holes were 4 feet deep, 1.75 inches in diameter, loaded with permissible powder, and detonated with electric caps.

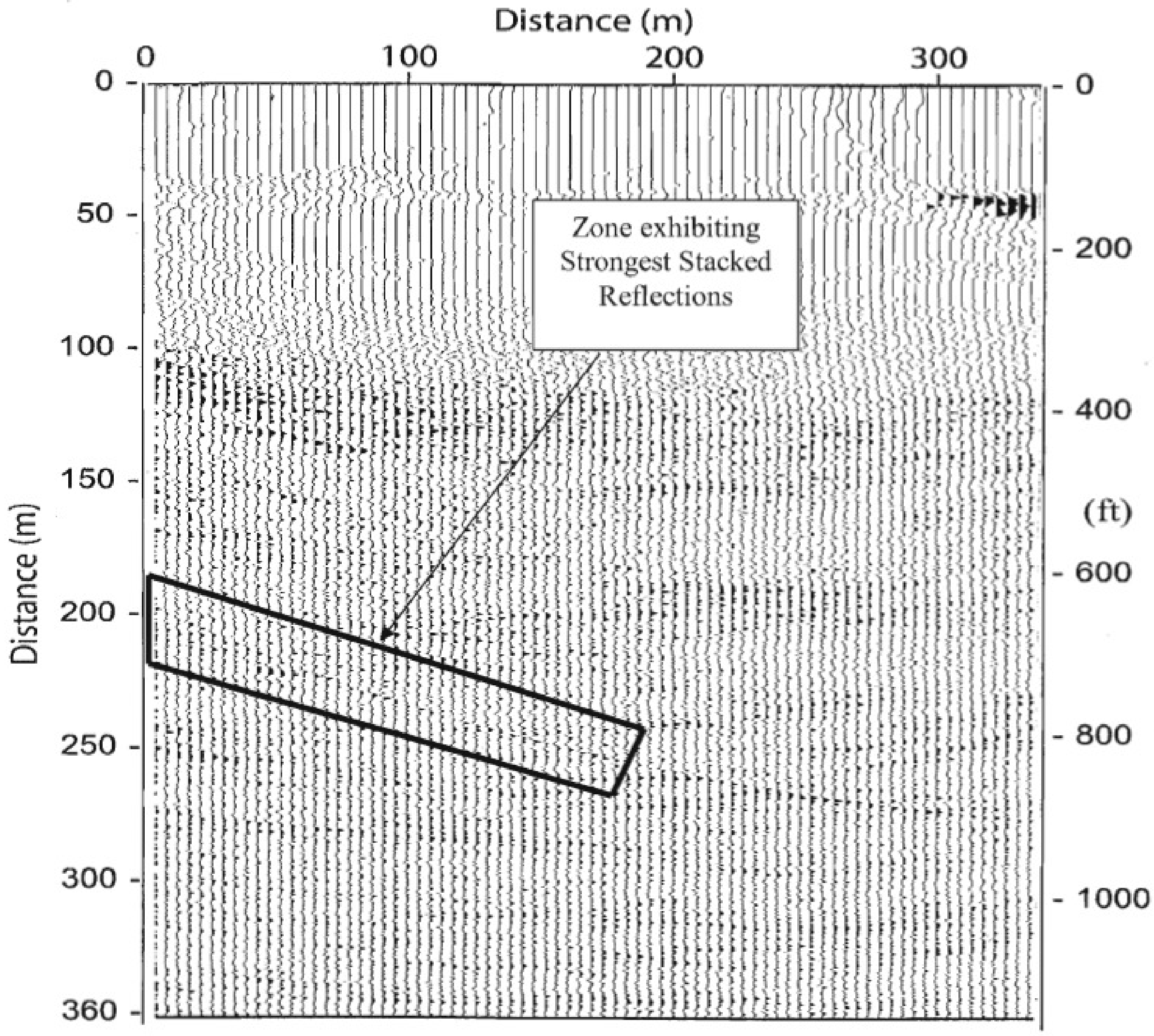
View of charged blast hole and geophones placed into the face of the coal outcrop.

View of geophone placed along the face of the coal outcrop.



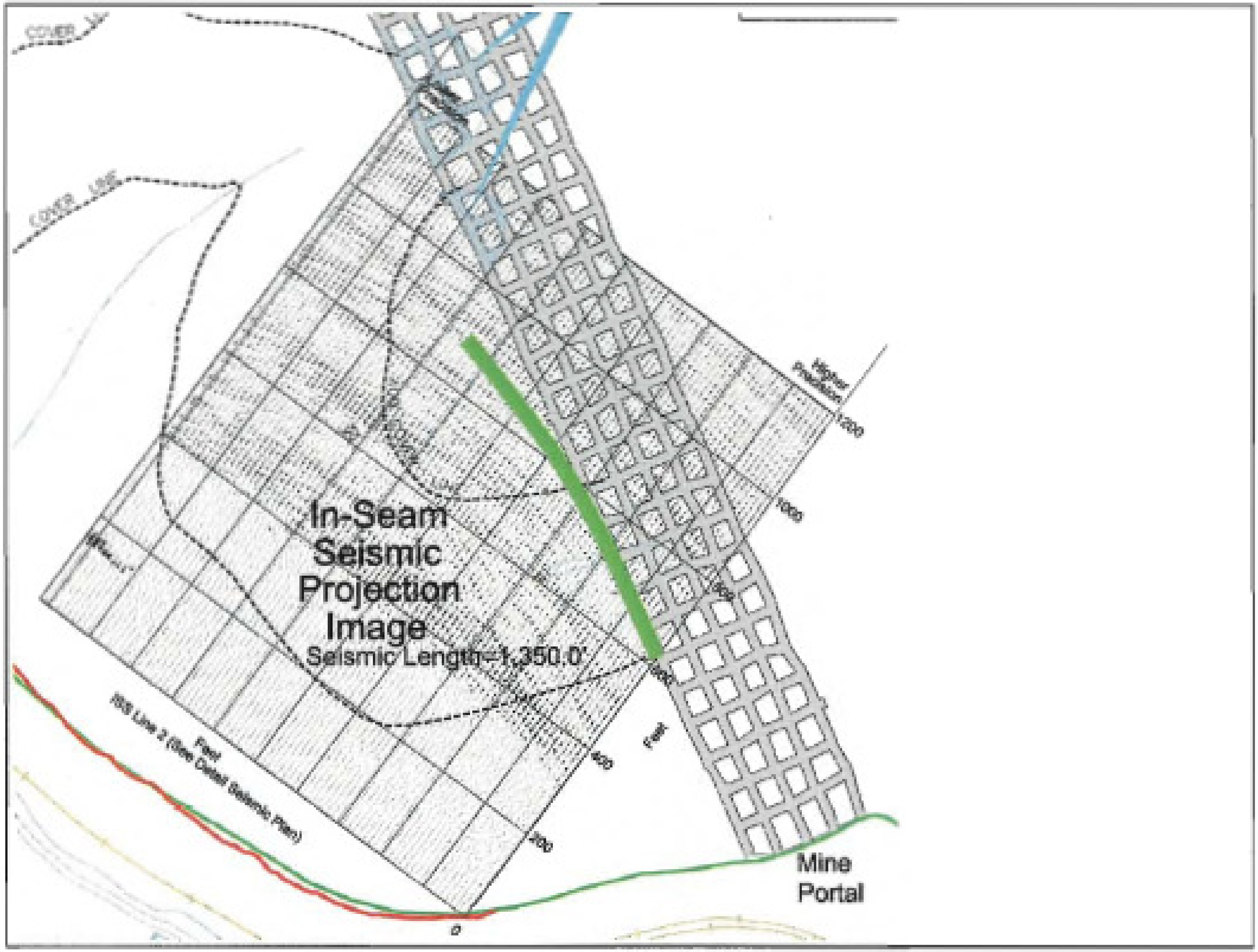
View of the seismic data acquisition system.

FIGURE 10: STACKED IN-SEAM REFLECTION LINE 2 (COMBINATION OF 37 INDIVIDUAL EDITED REFLECTION GATHERS)



ISR Line 2 Stack

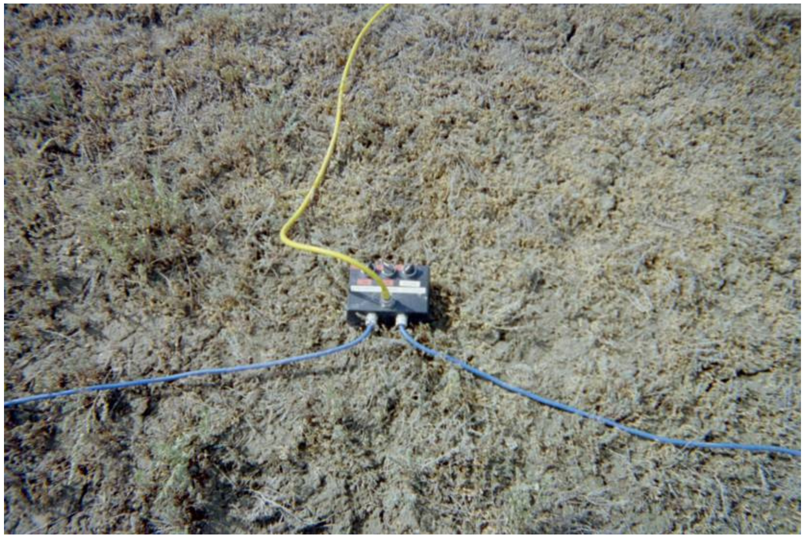
In seam seismic projection – line 2 results



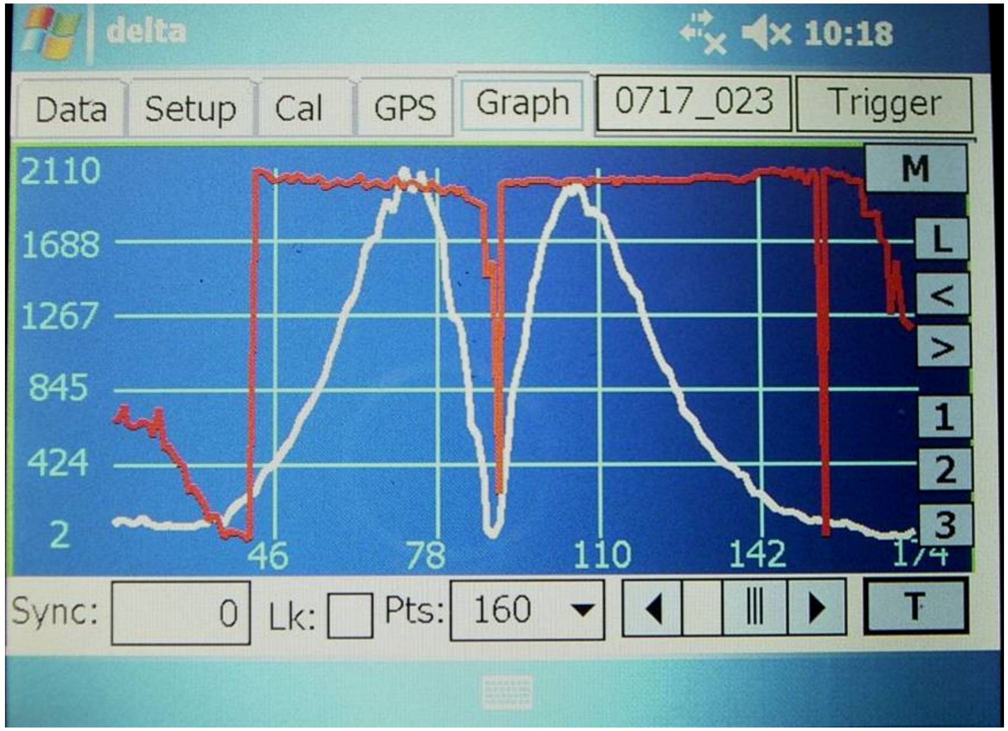
Delta Electromagnetic Gradiometer

How The Delta EM Gradiometer Works

- A transmitter (source) induces an electrical current into a loop of insulated cable on the ground.
- An electromagnetic field is created from the electrical current.
- The electromagnetic field creates and electrical current in subsurface conductors.
- The subsurface conductors create their own electromagnetic fields that radiate outwards (secondary EM waves).
- The EM Gradiometer rejects the primary EM wave (wave directly from source to receiver) and measures the gradient of the secondary EM waves between two receivers.
- A subsurface conductor (potential mine void) is identified when the gradient is zero.
- The data was collected (approximately 10 readings per second) at 2, 20, 80, and 200 kilohertz (kHz) operating frequencies and was automatically recorded by a PDA.
- The plotted data (signal magnitude, signal phase, and receiver synchronization) could be observed on the screen of the PDA during and after each survey.

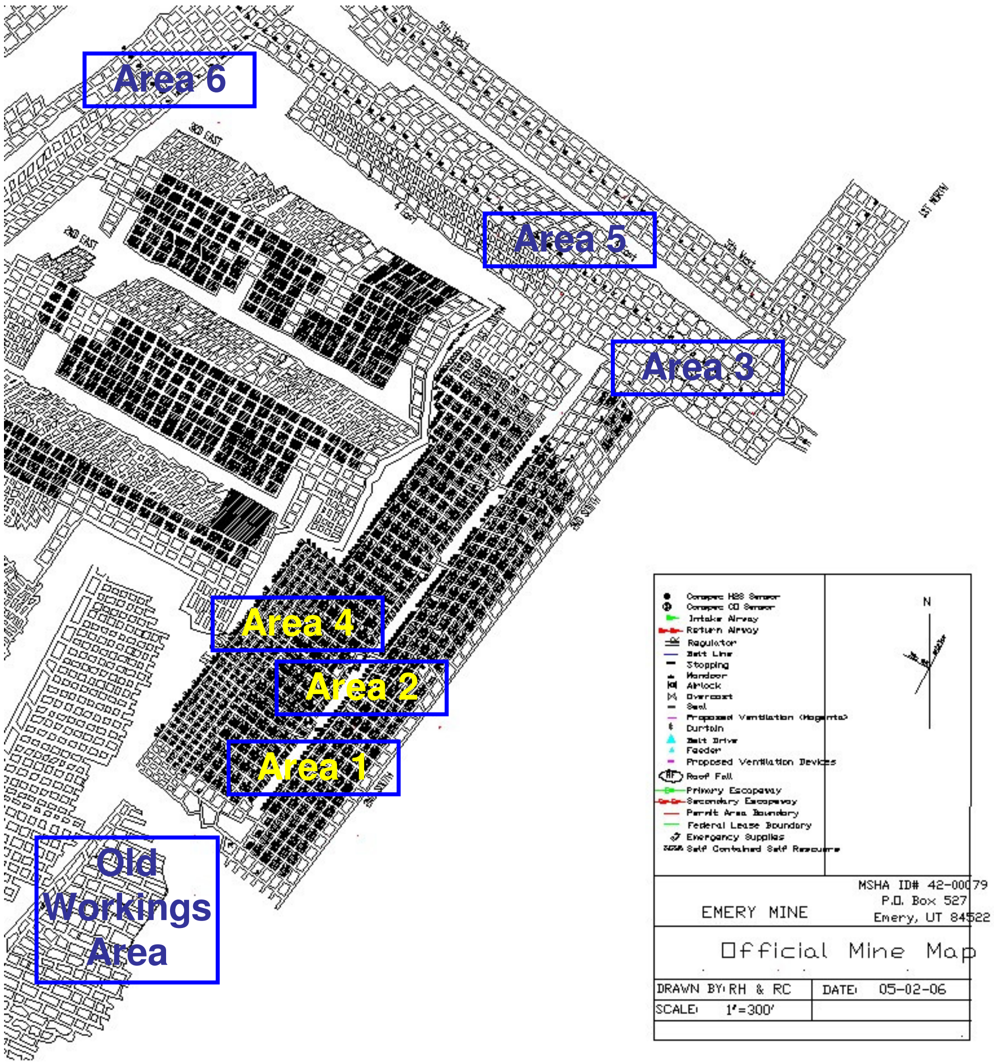


How The Delta EM Gradiometer Works



Optimally, an “M-curve” centered on a “null point” will be created when the EM Gradiometer passes over a mine void (white line). The null point is the lowest part of the dip between the two peaks. This is where each receiver is reading the same value and the gradient between the two measurements is zero. The criteria for selecting null points that correspond to mine voids were experimentally determined by Stolar. The null points from the field data that met the experimentally-determined criteria were manually selected by Stolar.

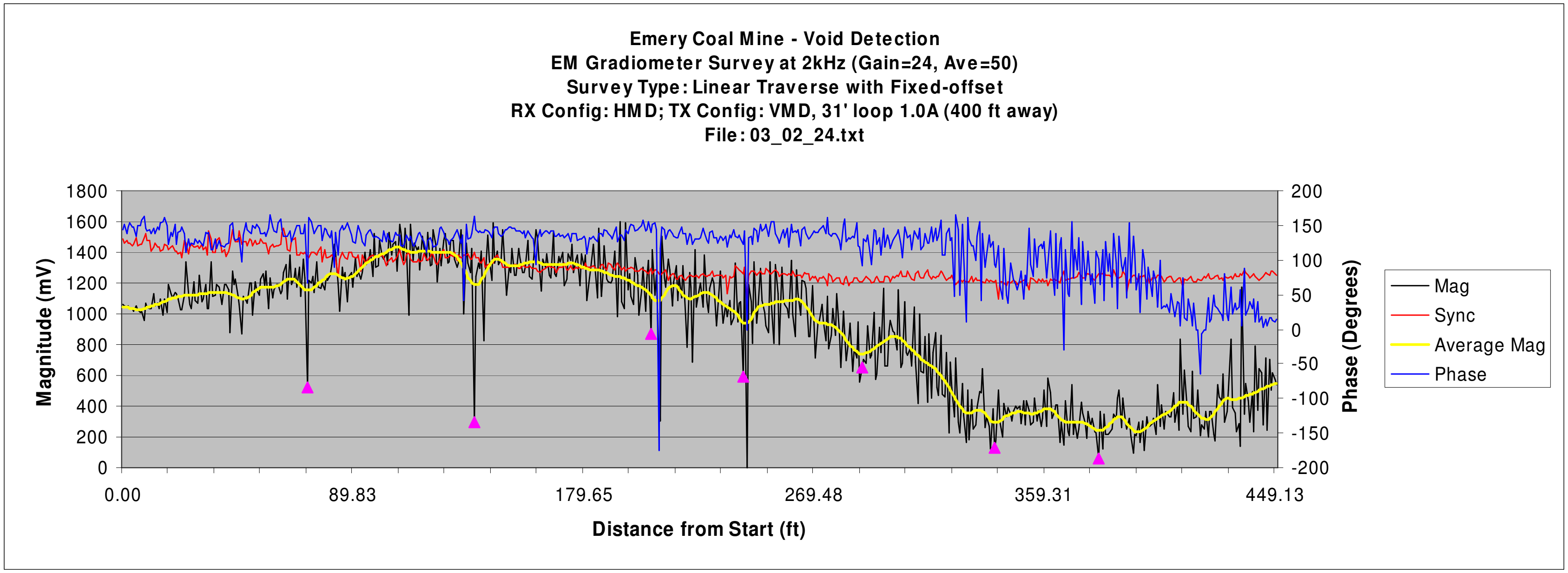
Data Collection Areas



Area on Mine	Approx. Depth
3	100'
2	130'
1	40'
5	200'
6	400'
4	200' (flooded)
Old Workings Area	185'

Photo of Area 1

One of the Response Plots in Area 5

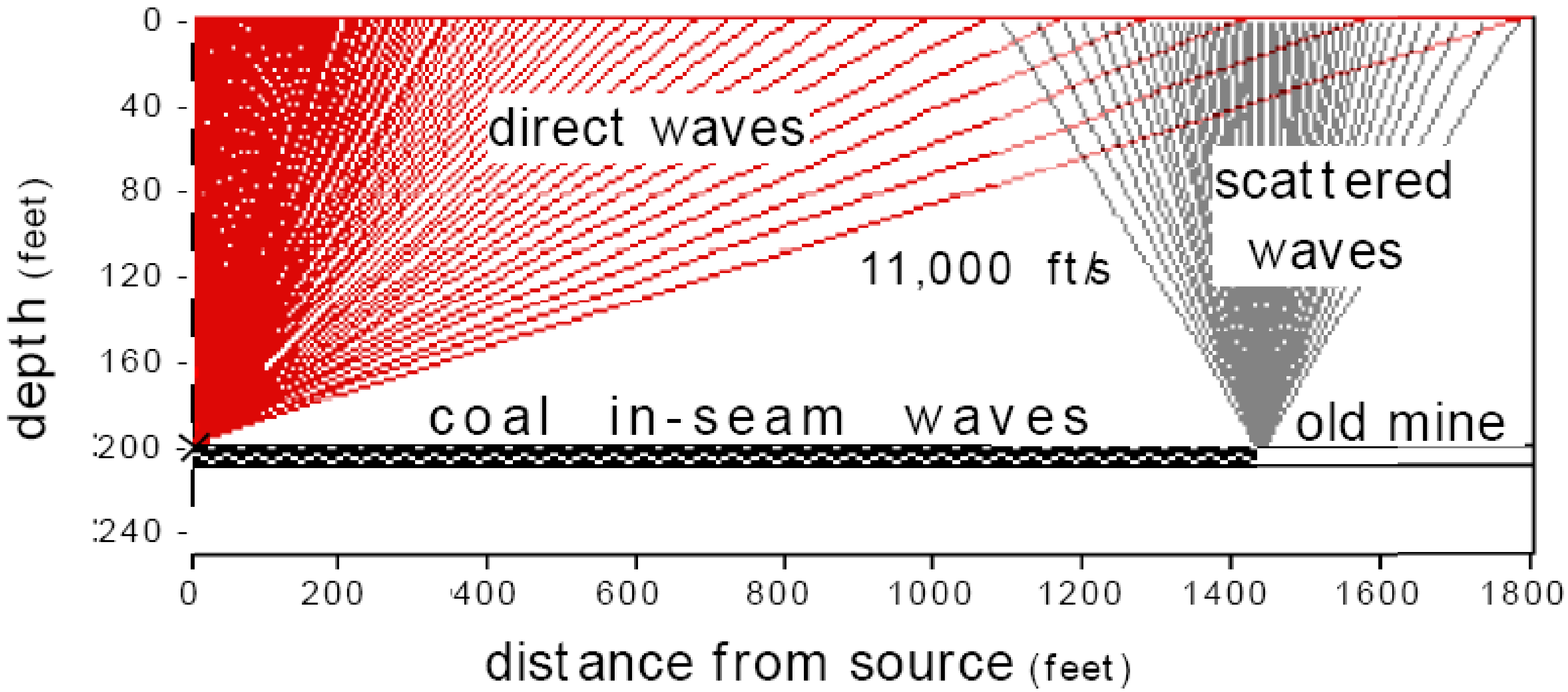


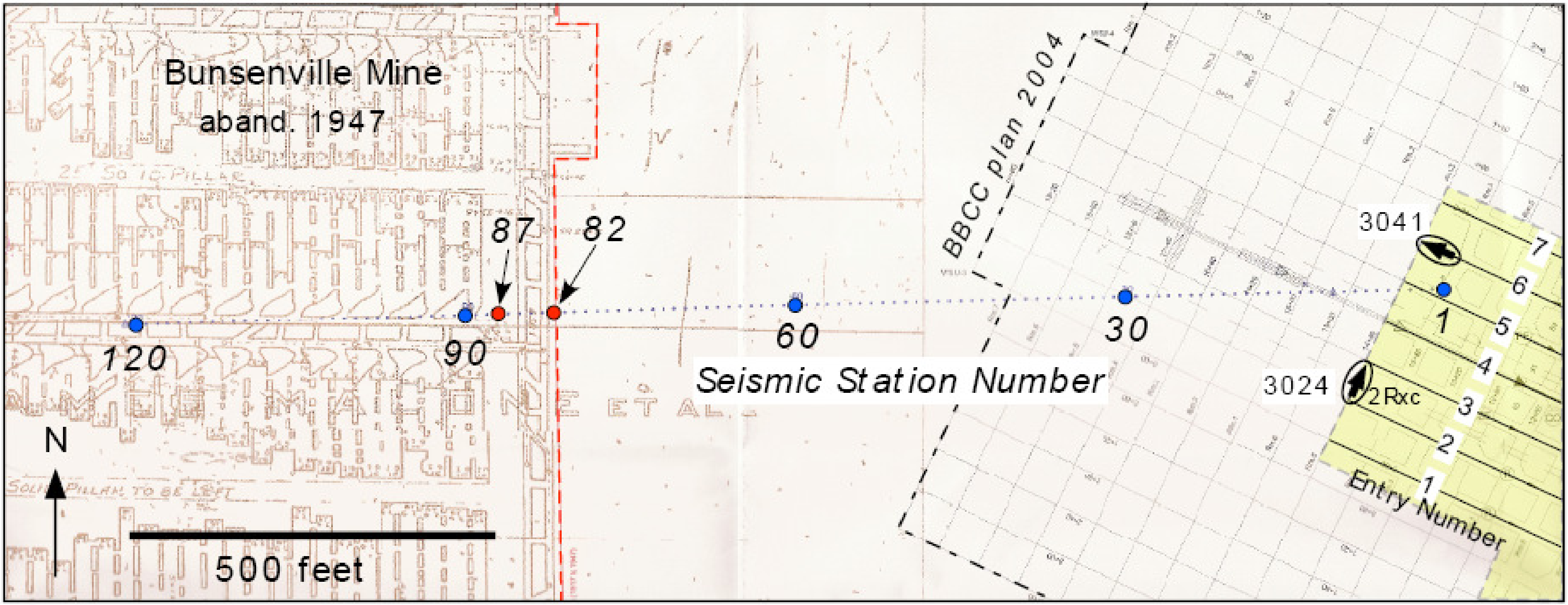
Forward Looking Seismic – with Continuous Mine Source

Performed by
Wright State University

Overview of project

- The project attempts to detect surface seismic signal scattered when in-seam seismic waves generated by the active mining operation encounter the disruption of the coal seam at the end of the barrier between the mines.
- This idea is an extension of seismic studies done during vertical boring/drilling and also surface seismic studies done ahead of a working tunnel boring machine (TBM).

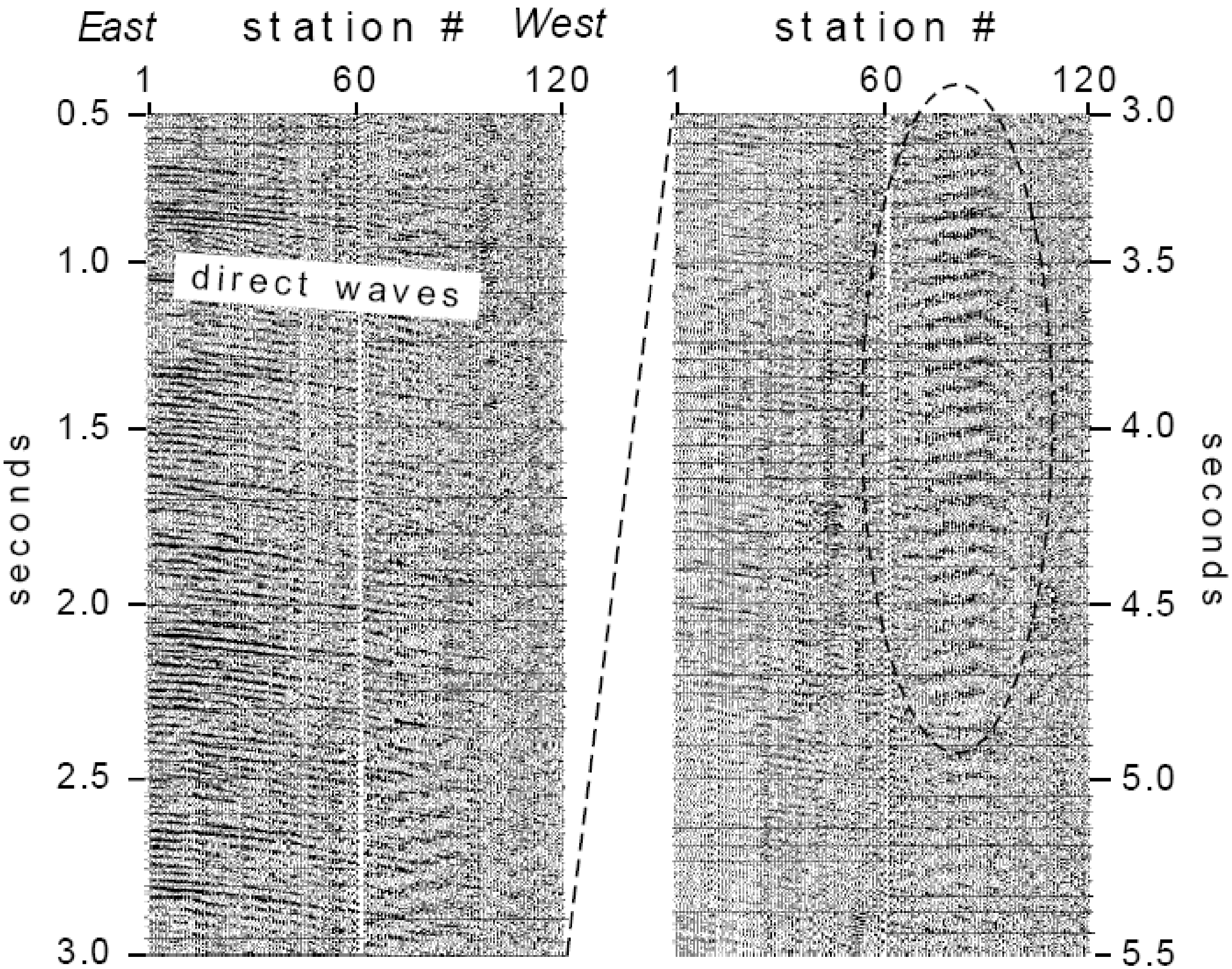




Plan view of wet mine project site

- The coal seam is generally 200 feet in depth and 8 feet in thickness.
- The blue dots represent the surface seismic line stretching 1800 feet across the coal barrier from the active underground mine to the “best estimate” of the abandoned mine. (120 geophones placed at 15 feet apart). The abandoned (Bunsenville) mine is known to be flooded in this location.
- Yellow area depicts the extent of mining that had been completed prior to the data retrieval part of the project. Broken black line depicts the future mining to complete work in this section.
- Heavy black arrows indicate the location and orientation of the continuous miner during data retrieval.


This is a surface view of geophones placed perpendicular to current mining, crossing the anticipated barrier to the abandoned mine.
Flags represent the location of 120 vertically mounted geophones.
Just to the right of the flags are the 10 (75 feet center-to-center) 3-component geophones.



This is a 5 second portion of a raw field record. Notice the angled direct arrivals (more prominent over the first 50 stations in the first 3 seconds) and the oscillatory signal (seen in the broken-line oval) at the anticipated location of the abandoned mine.

Conclusion

- Varying degrees of success.
- Most methods were able to detect mine voids under specific conditions, but none could precisely detect all known voids.
- Geophysics may be used to compliment a drilling program, allowing the engineer to select borehole locations, but geophysics alone should not be relied on to conclude the absence of voids.

MSHA Mine Safety and Health Administration
Department of Labor

End