7th Annual Technical Forum

**GEOHAZARDS IN TRANSPORTATION IN THE APPALACHIAN REGION**

Hosted by:

Association of Environmental and Engineering Geologists
North Carolina DOT
North Carolina Geological Survey

**August 1-2, 2007**
**Asheville, NC**

Sponsored by:

Nick J. Rahall, II Appalachian Transportation Institute

MARSHALL UNIVERSITY
Center for Environmental, Geotechnical and Applied Sciences

*Appalachian Coalition*
*Chair: Dr. Tony Szwilski, P.E.*
*Co-Chair: Kirk Beach*

# 2D MASW SURVEYS TO EVALUATE SUBSURFACE STIFFNESS

## Investigations of the 2004 I-40 Landslide and Other Projects


**Ned Billington, L.G., Jeremy Strohmeyer, L.G., and Alex Rutledge, E.I.T., G.I.T.**

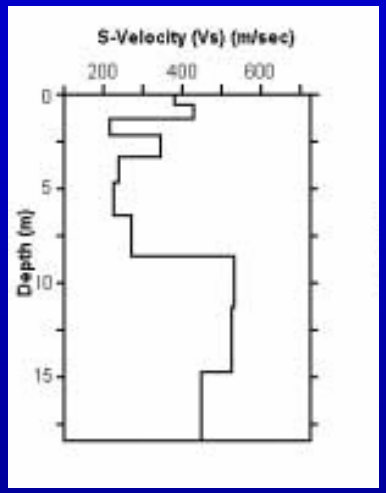
**Schnabel Engineering**
**11-A Oak Branch Drive, Greensboro, NC 27407**

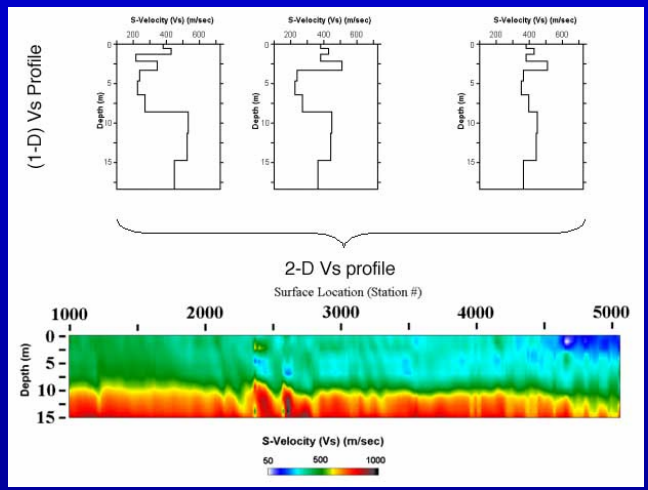
# Outline

- **What is MASW?**
- **Quick Primer on Surface Waves**
  - Raleigh wave motion, Dispersion, SASW
- **MASW Methodology**
  - Data Acquisition and Processing
- **2D MASW Applications**
  - Sinkhole Investigations
  - Abandoned Mine Survey
  - I-40 Landslide Investigation
  - Big Slow Movef Study

# What is MASW?

- Multi-channel Analysis of Surface Waves
- The generation, recording, and analysis of seismic surface waves (Raleigh waves) to determine subsurface shear wave velocities.
- Shear wave velocity is a direct indication of the stiffness of subsurface materials.

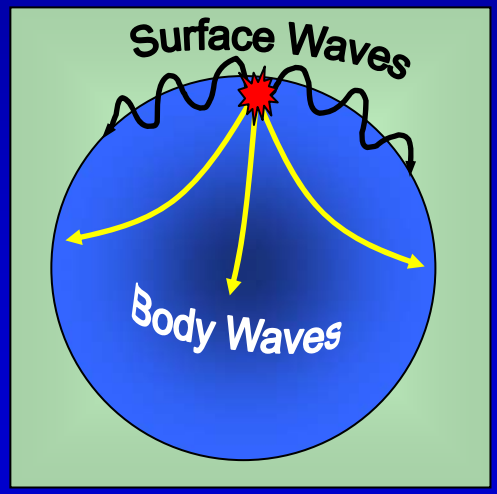


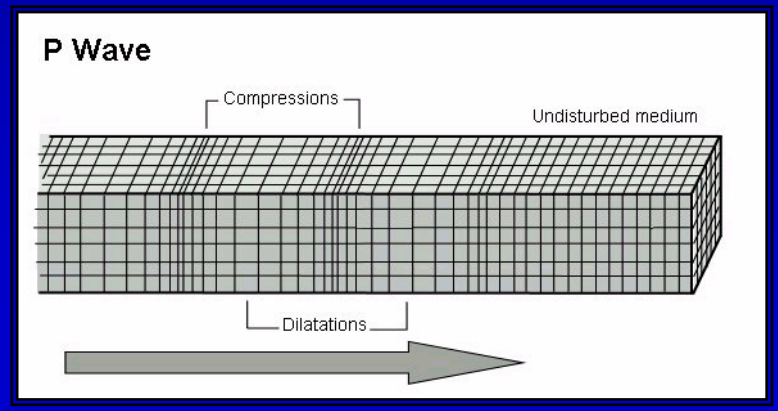



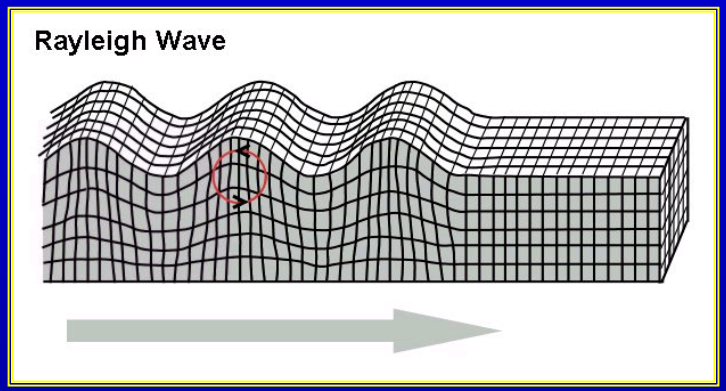
# What is it good for?

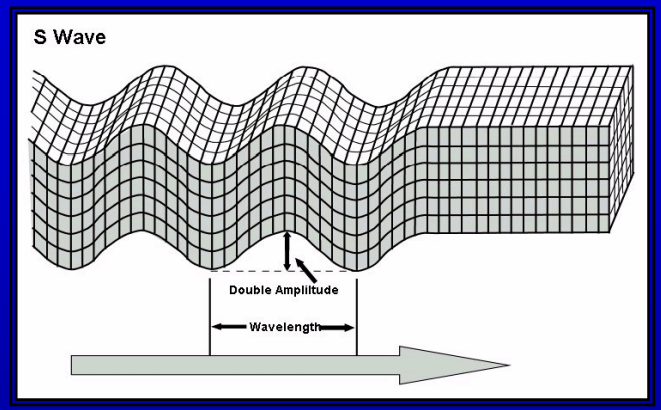
- **1D Shear wave velocity profiles**
  - Site-specific seismic analyses
  - IBC Site Class designation
- **2D Shear wave velocity cross-sections**
  - Investigating Karst and Sinkhole Features
  - Mapping Abandoned Mines
  - Determining Depth to Rock and Rock Quality
  - Mapping Weak Soil Zones
  - Locating Fracture Zones
  - More!

# Seismic Waves



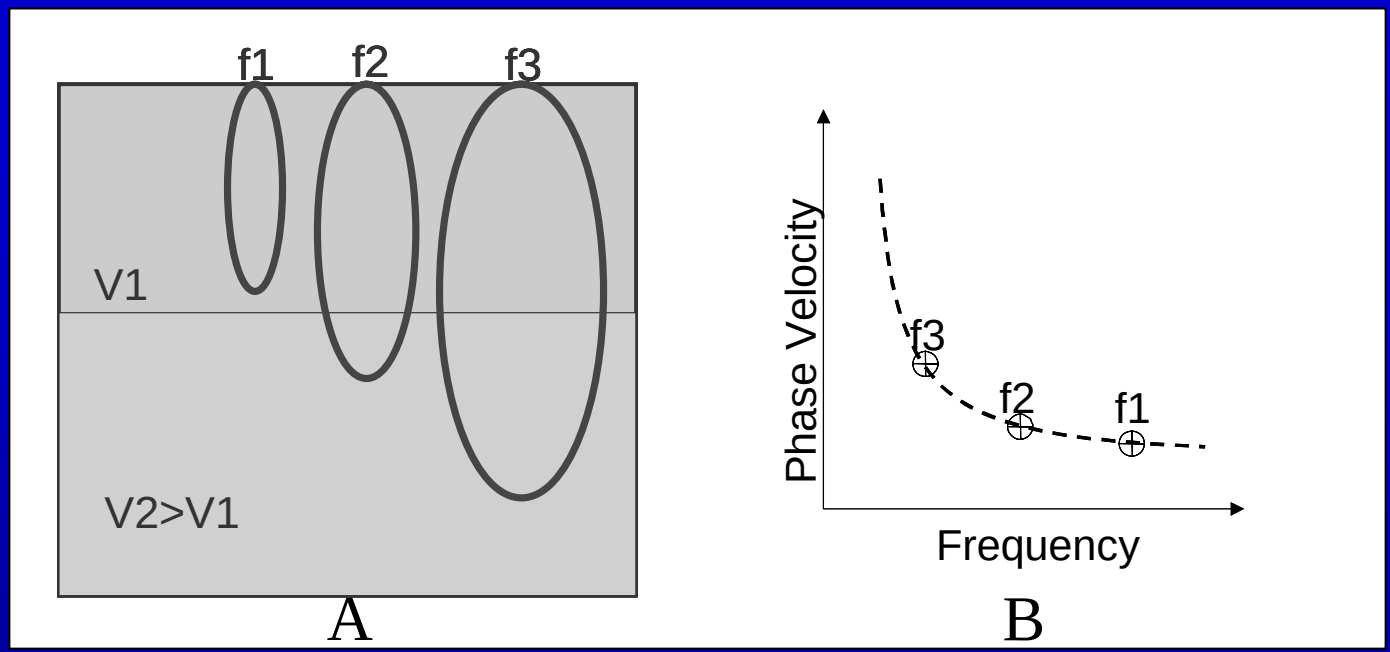



# Surface Wave Velocity and Dispersion

- **Lower frequency components of the surface wave have longer wavelengths and travel deeper in the subsurface, producing "dispersion" or variation of velocity with frequency.**



# Surface Wave Velocity

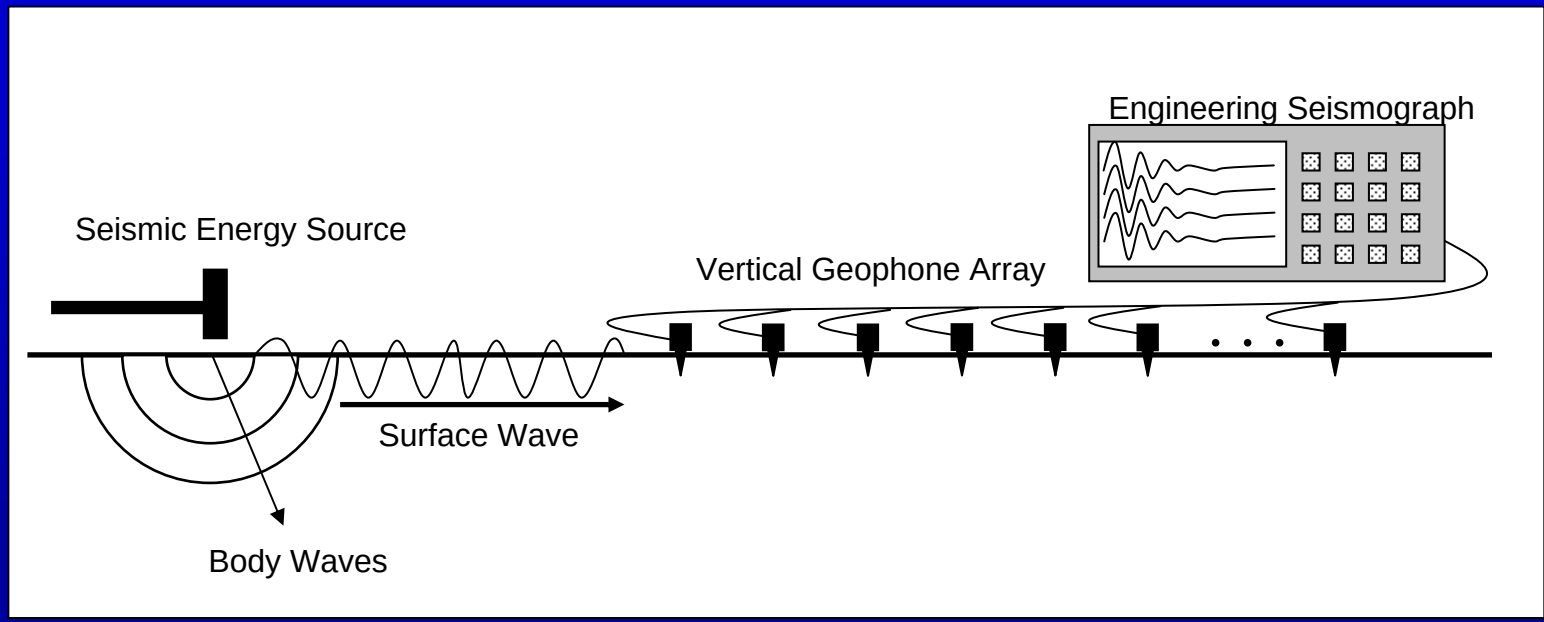
- The surface wave velocity ranges from 87% to 96% of the shear wave velocity.
- Variation is dependent on Poisson's Ratio.
- By determining the surface wave velocities, and by estimating Poisson's ratio, we can calculate the shear wave velocity.

**Relationship between S & Rayleigh Wave Velocities**

$$V_R = KV_s = \left( \frac{0.87 + 1.12\nu}{1 + \nu} \right) V_s$$

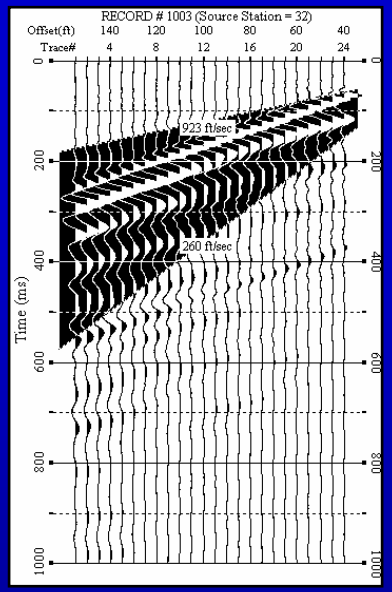
# MASW Data Aquisition

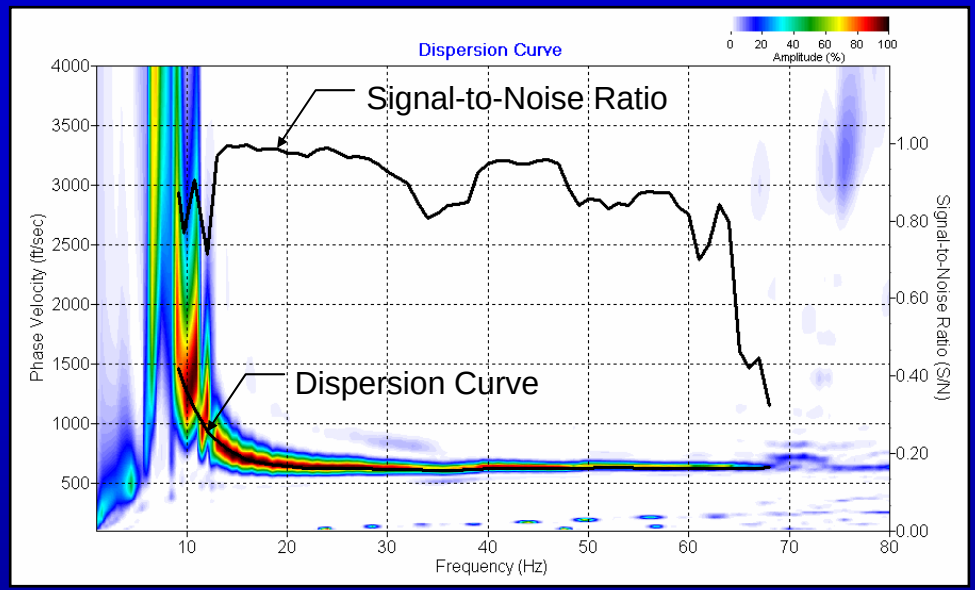
- Weight drop energy sources: sledgehammer, AWD, etc.
- Engineering seismograph and geophone array
- Energy source and  array moved along ground surface to collect additional data



# MASW Data Analysis

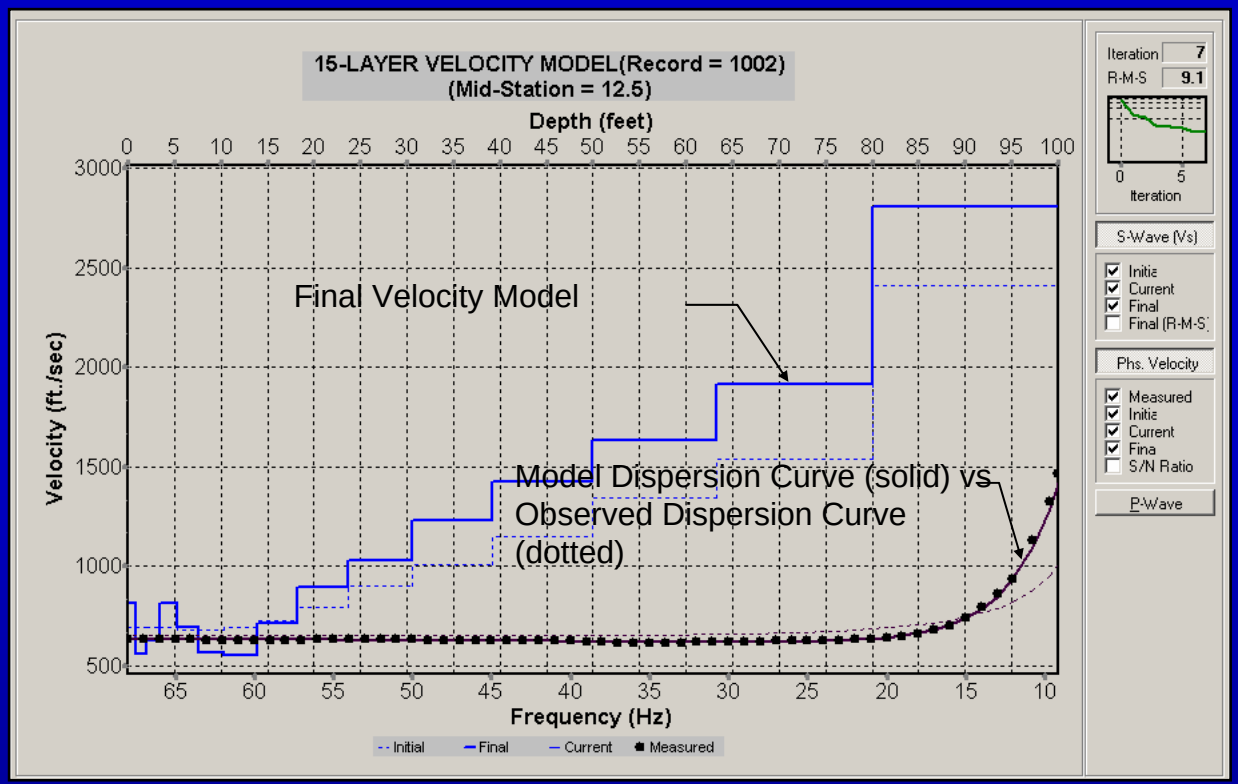
- Recognize surface wave energy
- Convert data to frequency domain
- Plot surface wave velocity versus frequency
- Select representative dispersion curve



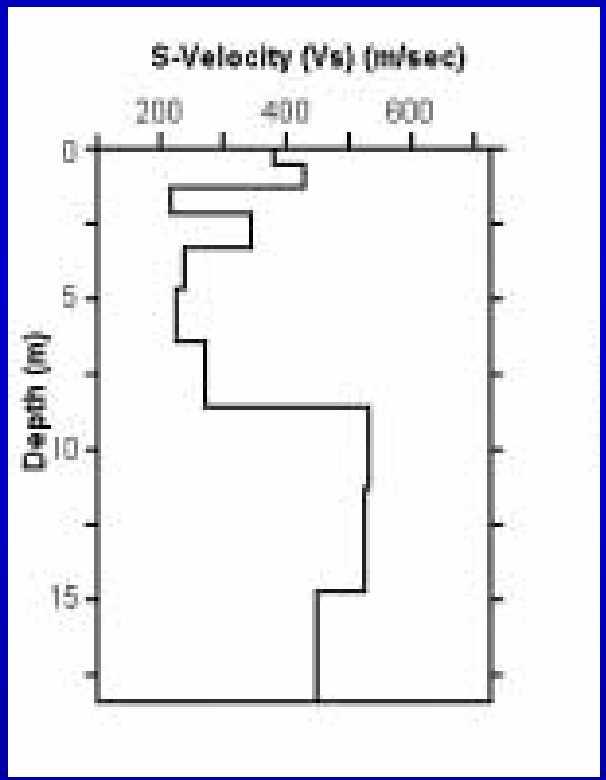



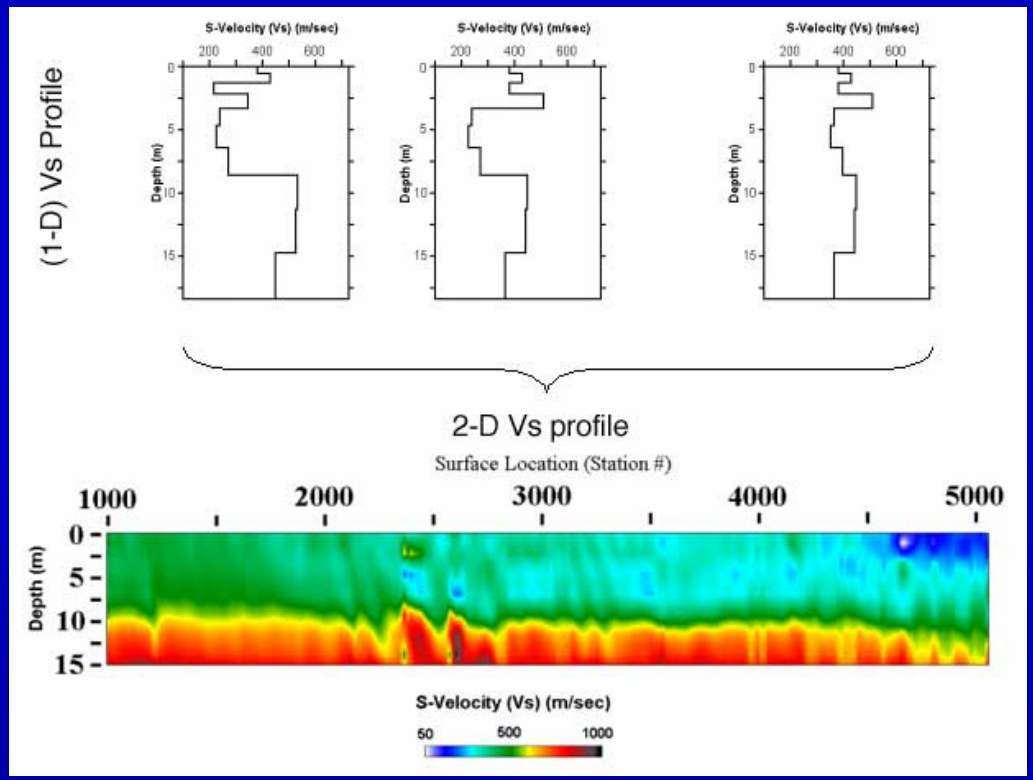
# MASW Inversion Modeling

- **An earth model of shear wave velocity with depth is generated to match the observed data.**



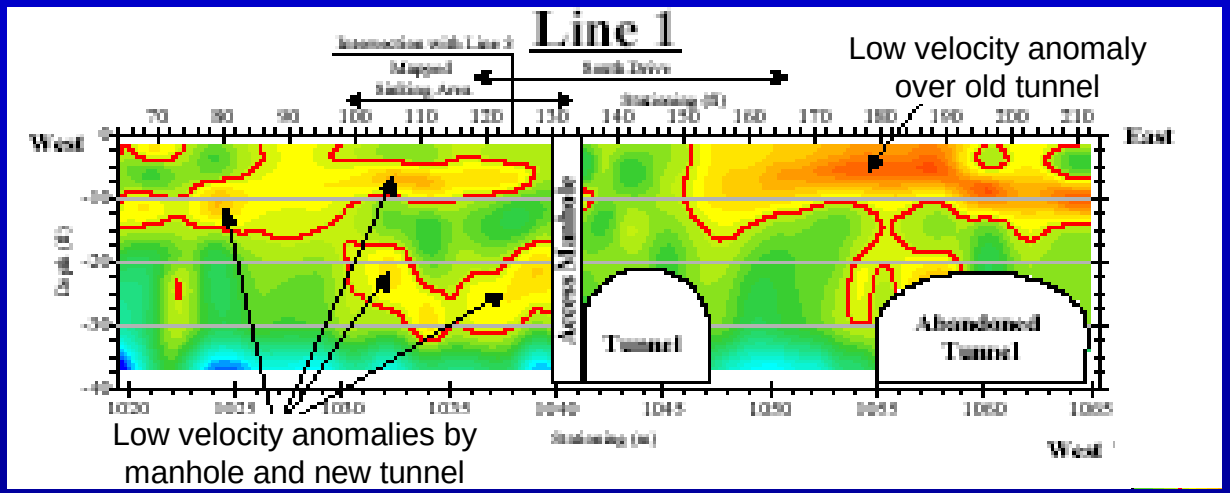
# 1D and 2D Models



# 2D MASW Applications

# Washington, DC
## Stream Tunnel Sinkhole Survey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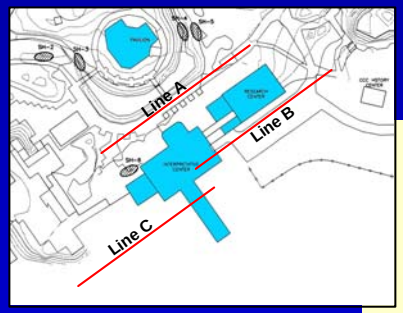
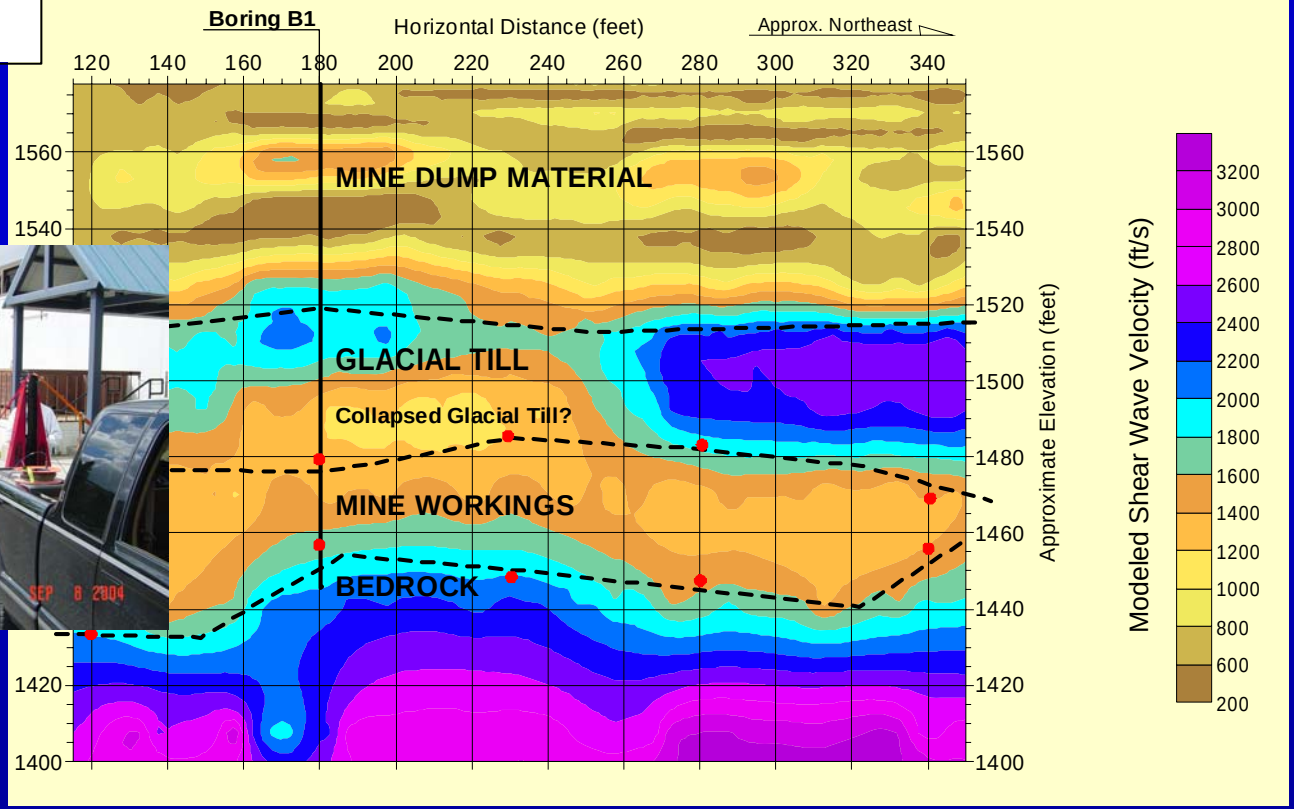
# Chisholm, MN

## Abandoned Iron Mine Survey




### Line A – Deep (48-channel data)





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# Chisholm, MN
## Drilling Results, B-1

- Caved mine workings 21 feet thick
- Timbers and partially filled voids


# Detroit, MI

## Combined Sewer Pipe Sinkhole Study


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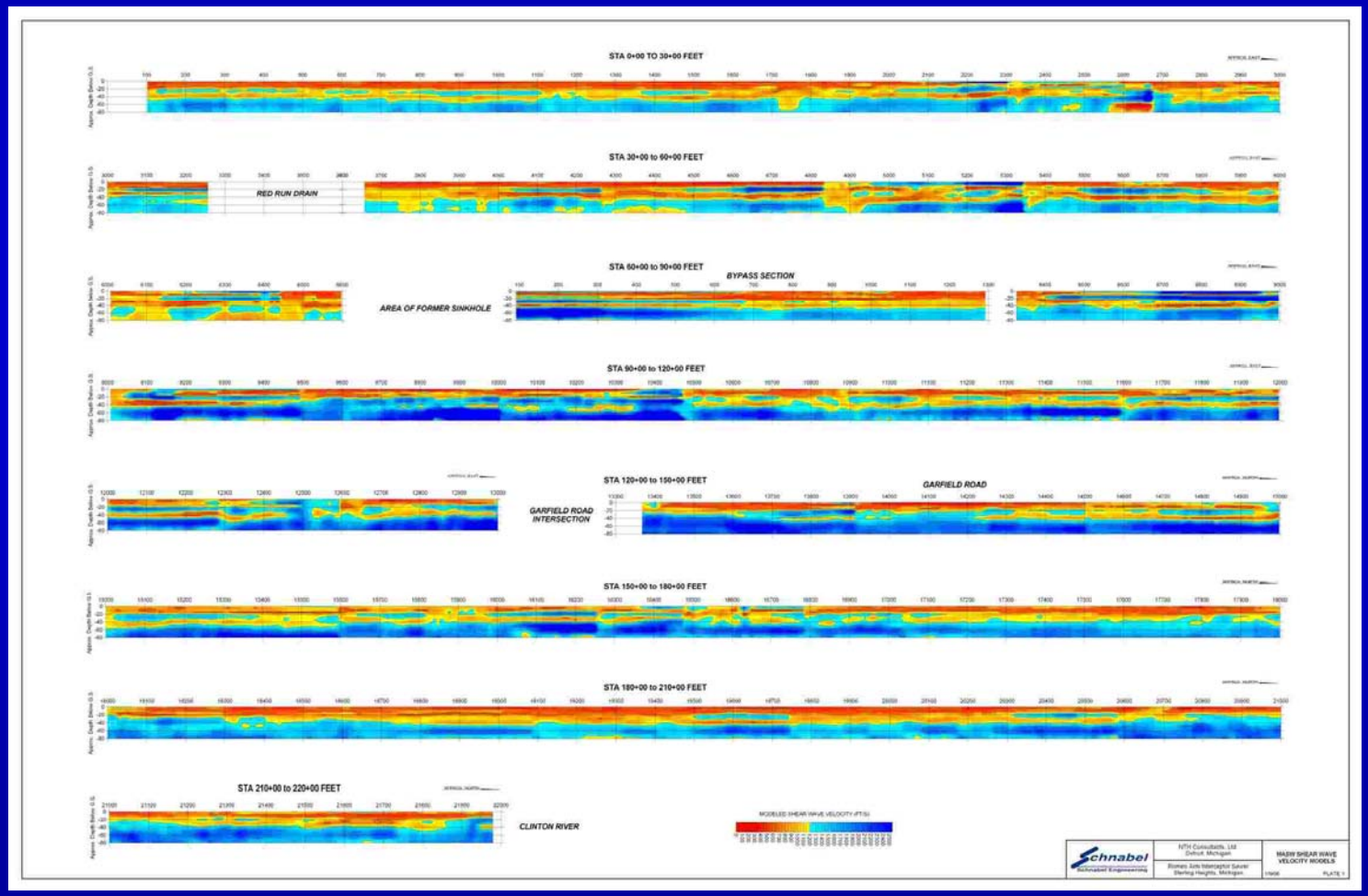
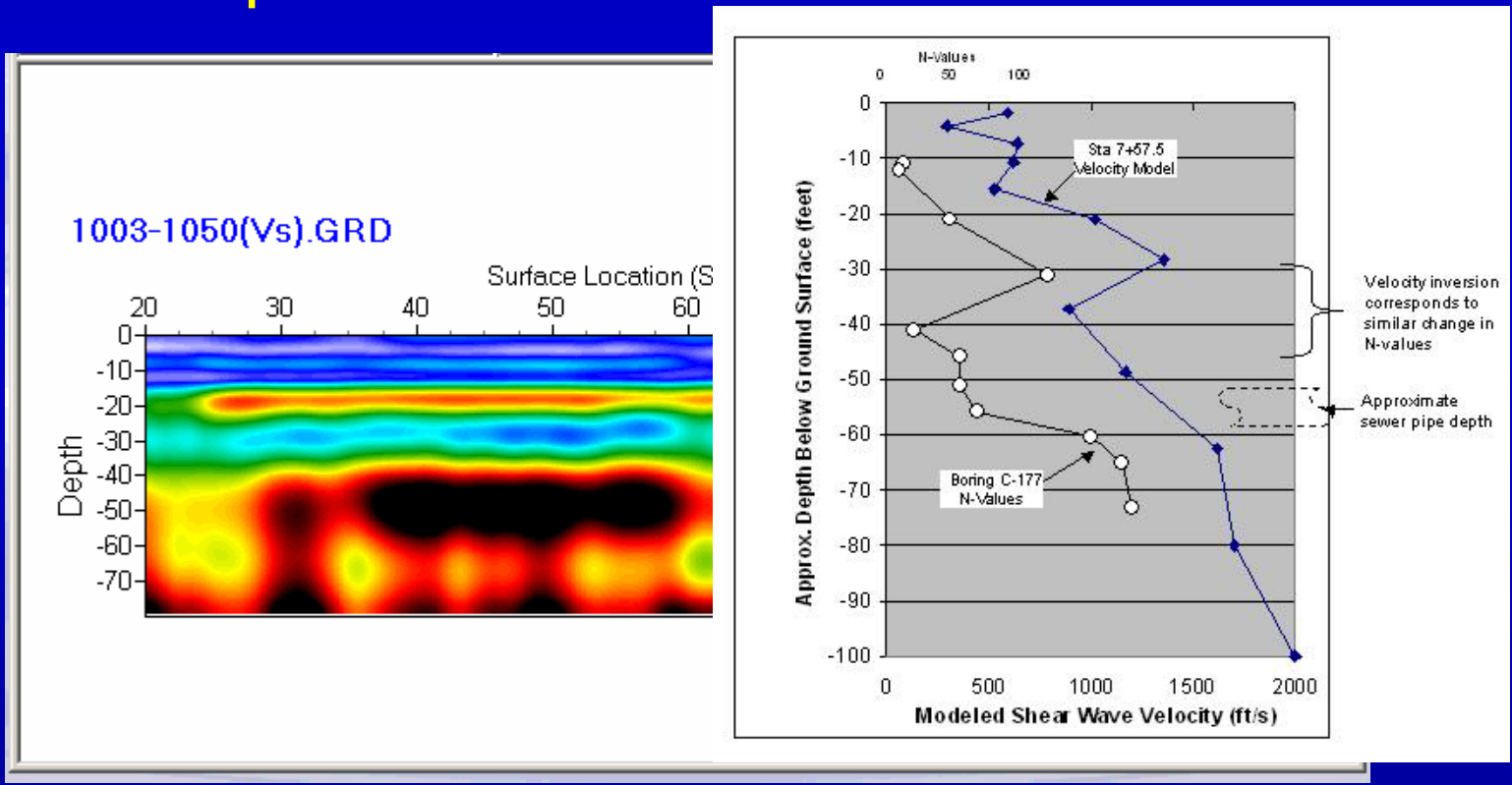
# Detroit, MI
## 2D MASW Results (3.3 miles)



# Detroit, MI
## Combined Sewer Pipe Sinkhole Study

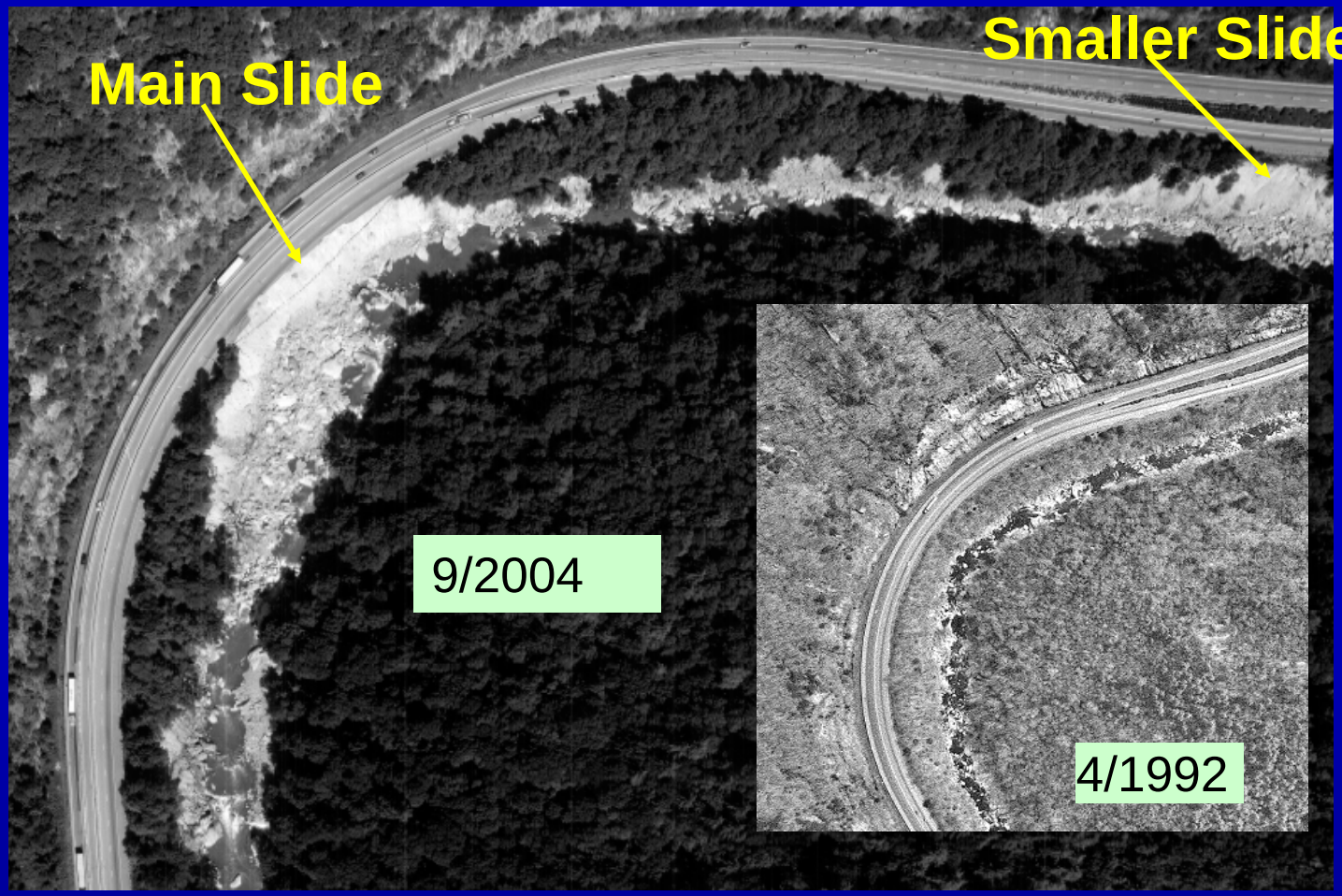
### Example 2D MASW Results



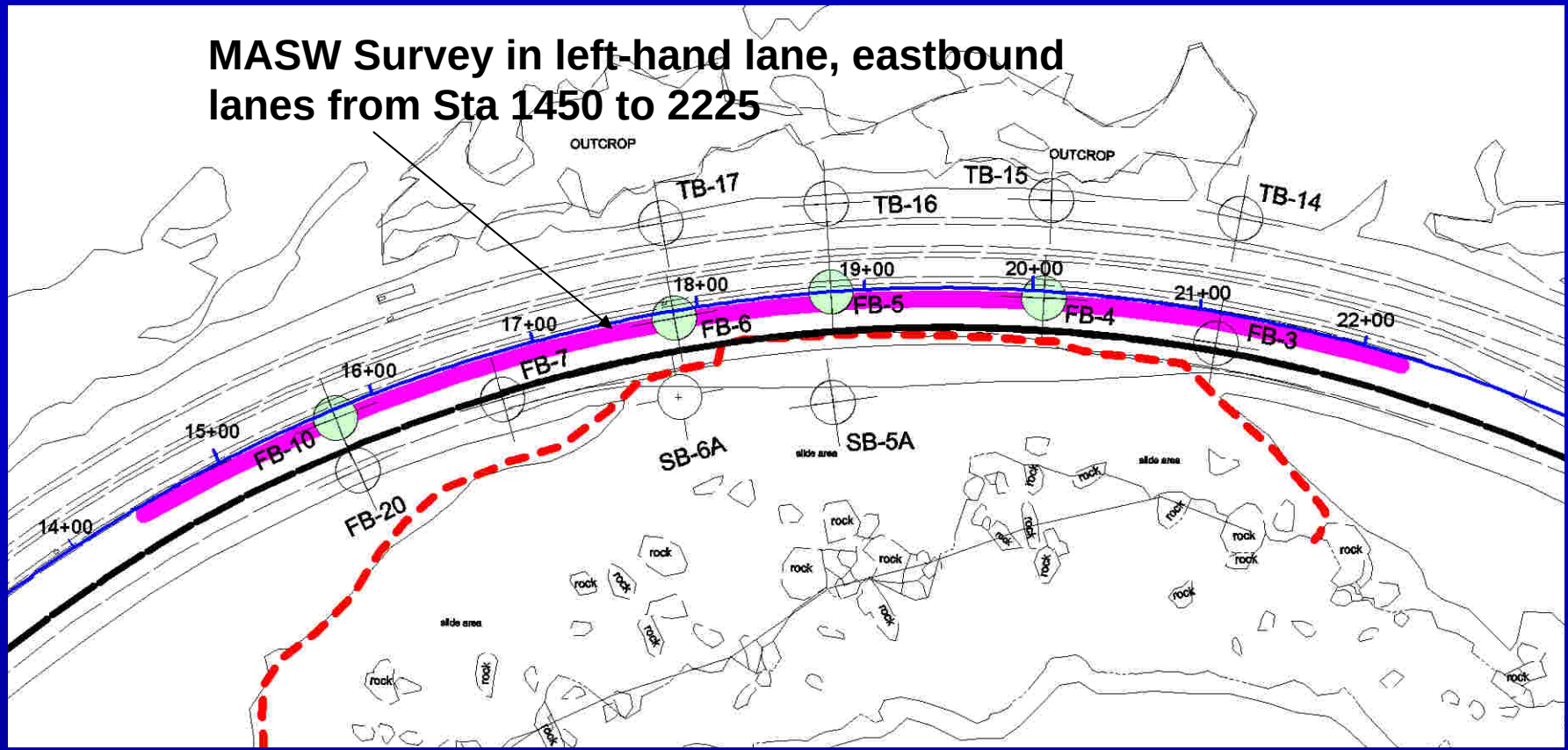
# 2D MASW to Assist in I-40 Landslide Investigation

- **September 18, 2004 - Floodwaters from Hurricane Ivan cause erosion and landslide of I-40 embankment near Tennessee border**


# Aerial Photographs



# MASW Survey - Main Slide

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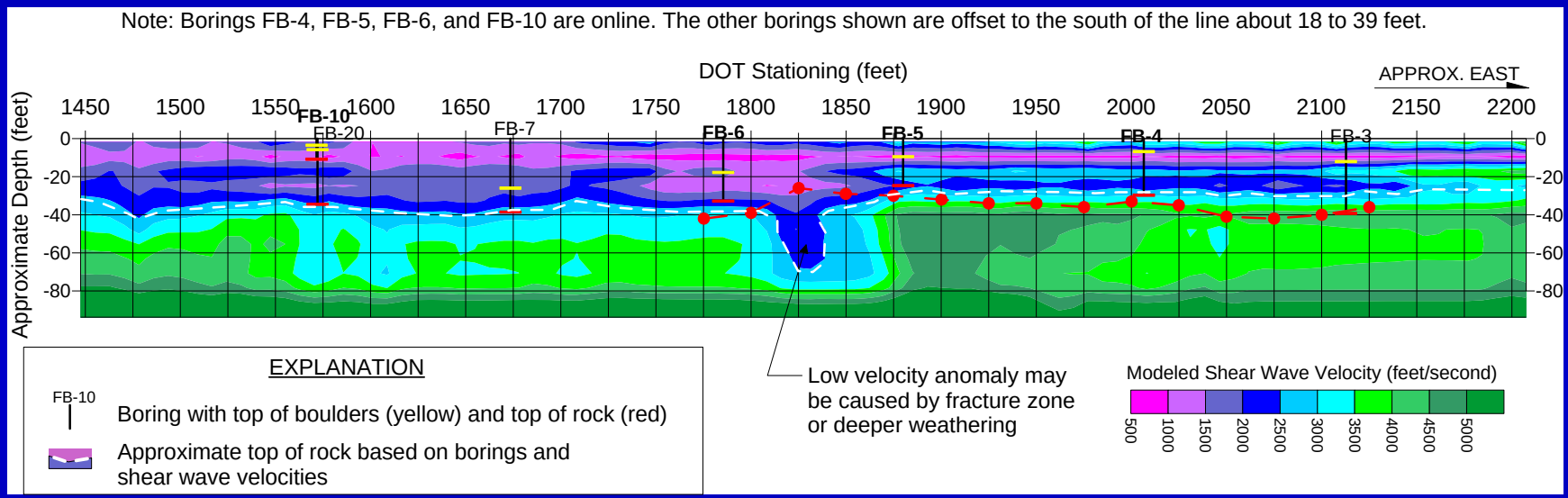
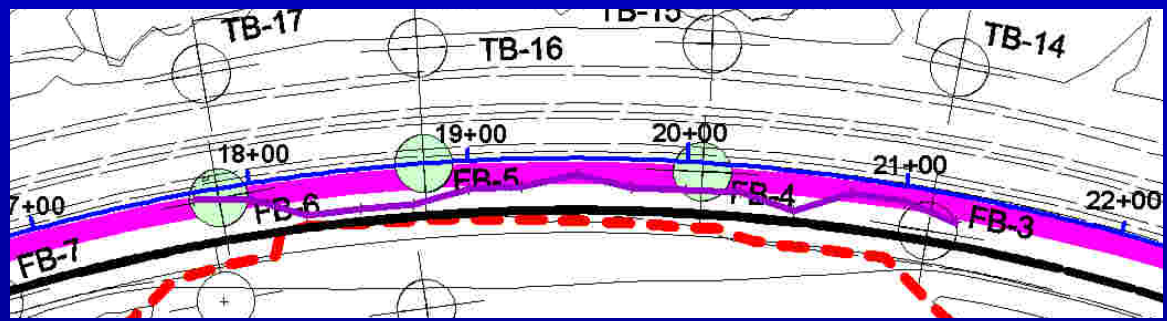
# MASW Data Acquisition

- 24-channel land streamer, 4.5 Hz phones
- 5-foot geophone spacing, 10-foot source spacing
- AWD energy source, 30-foot source offset

# Main Slide - comparison with boring and tieback data

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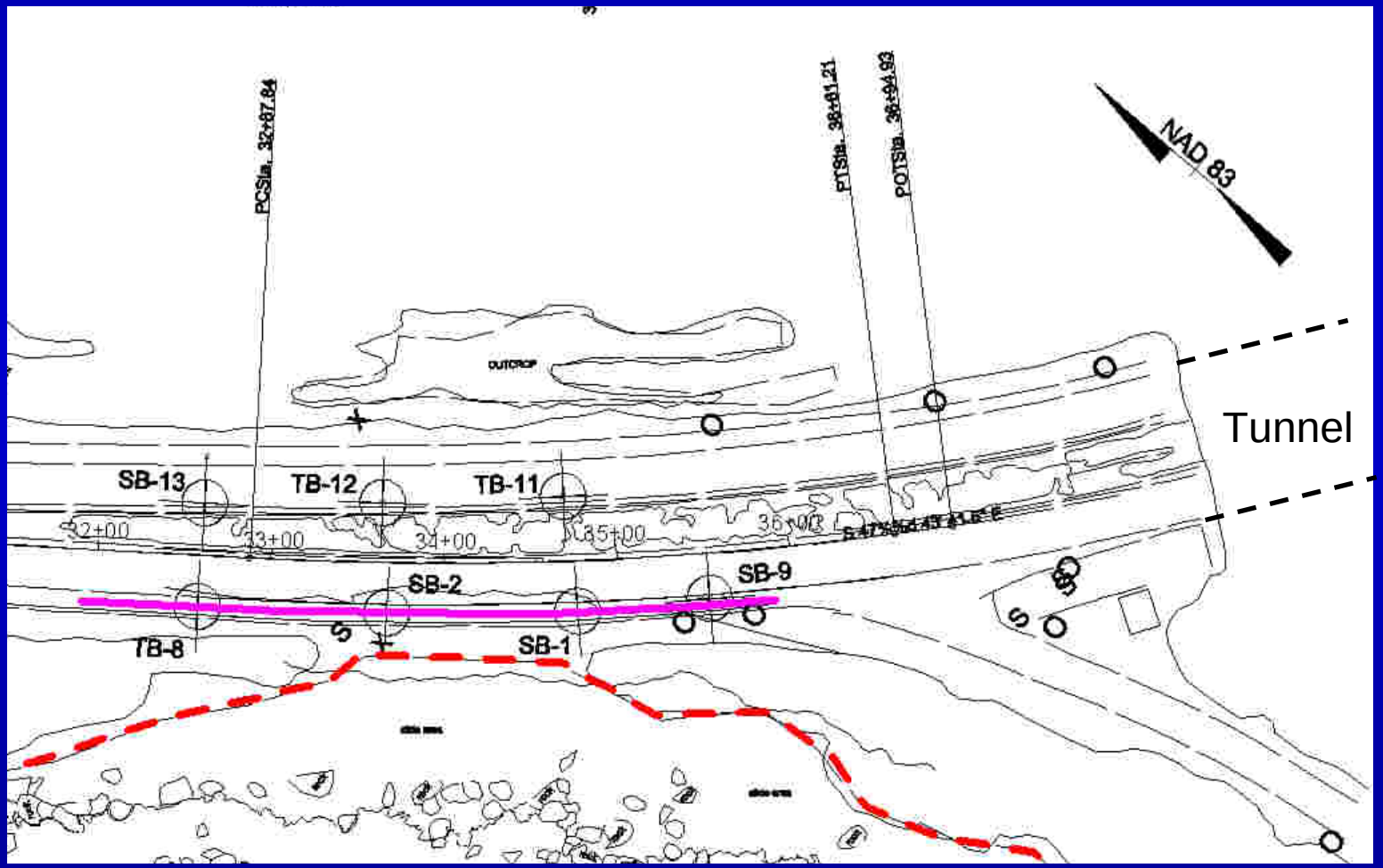
# MASW Survey
# Smaller Slide

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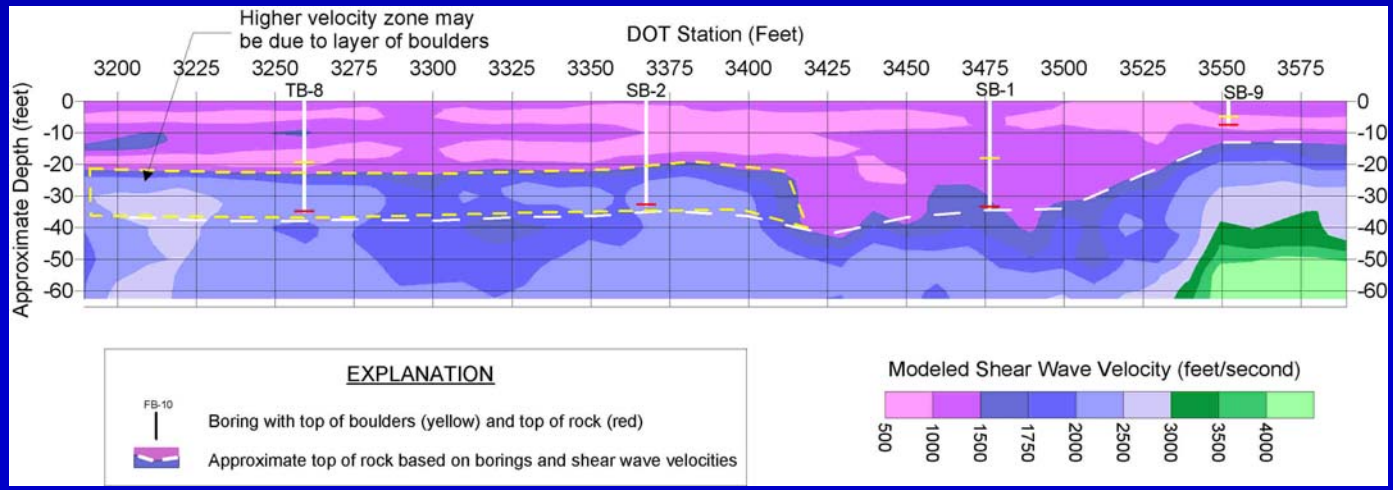
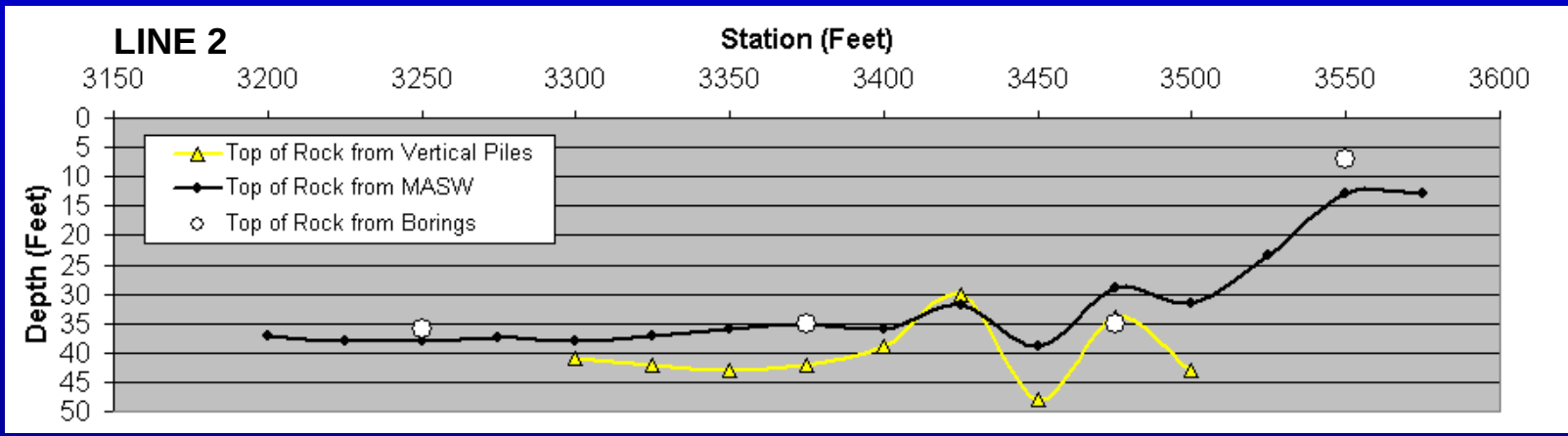
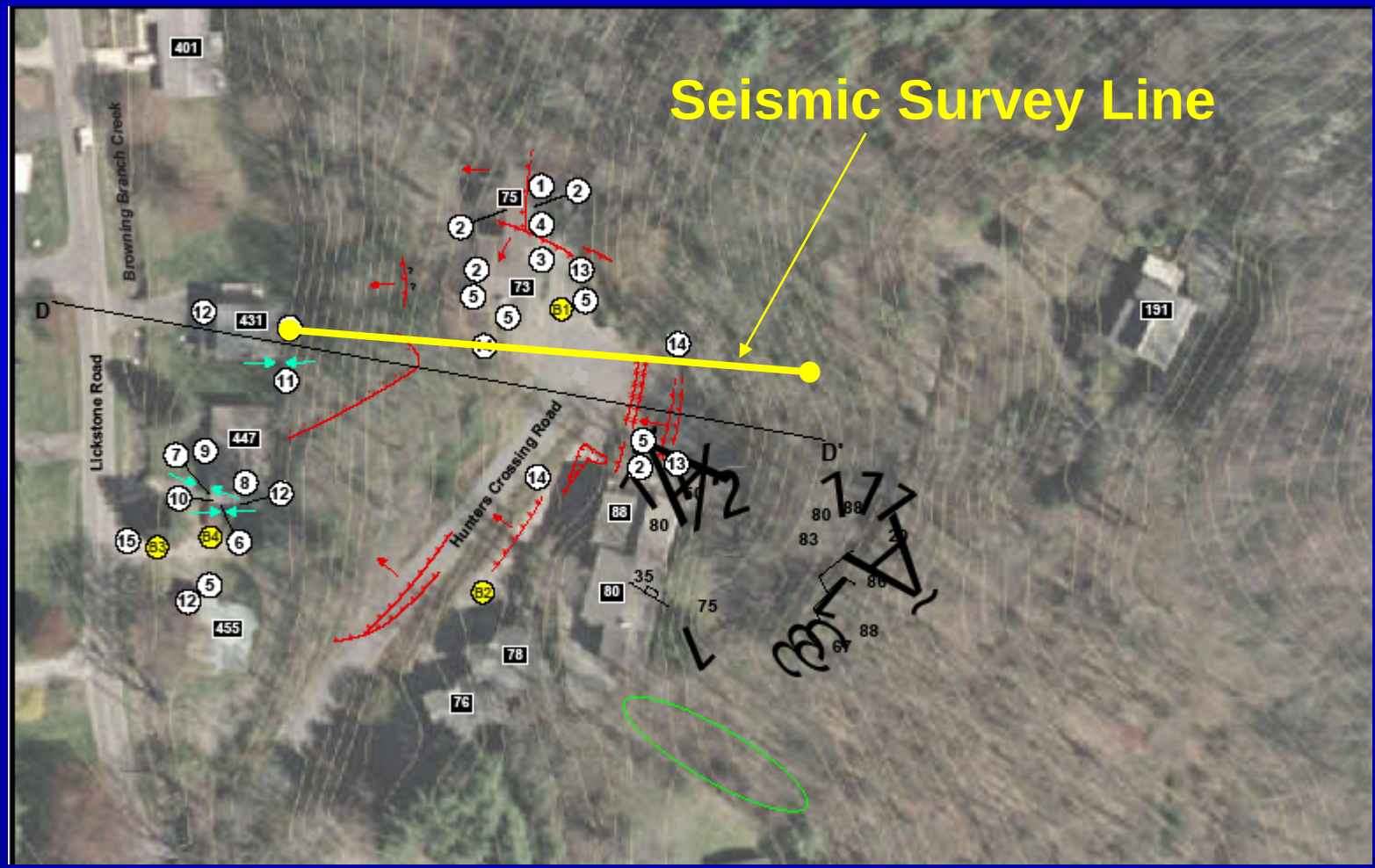
# MASW Results
# Smaller Slide



# Hunters Crossing BSM
# 2D MASW and Seismic Refraction

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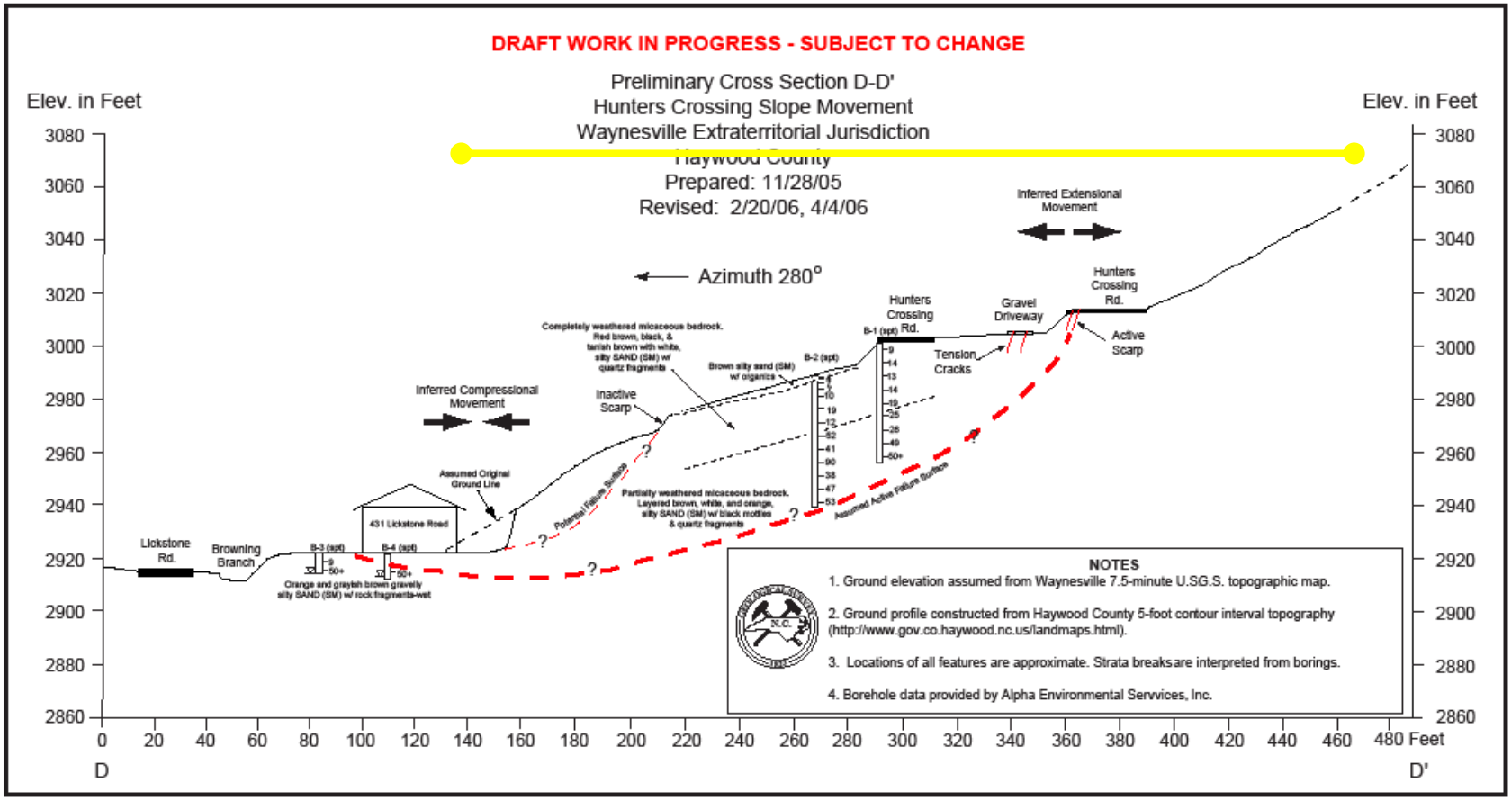
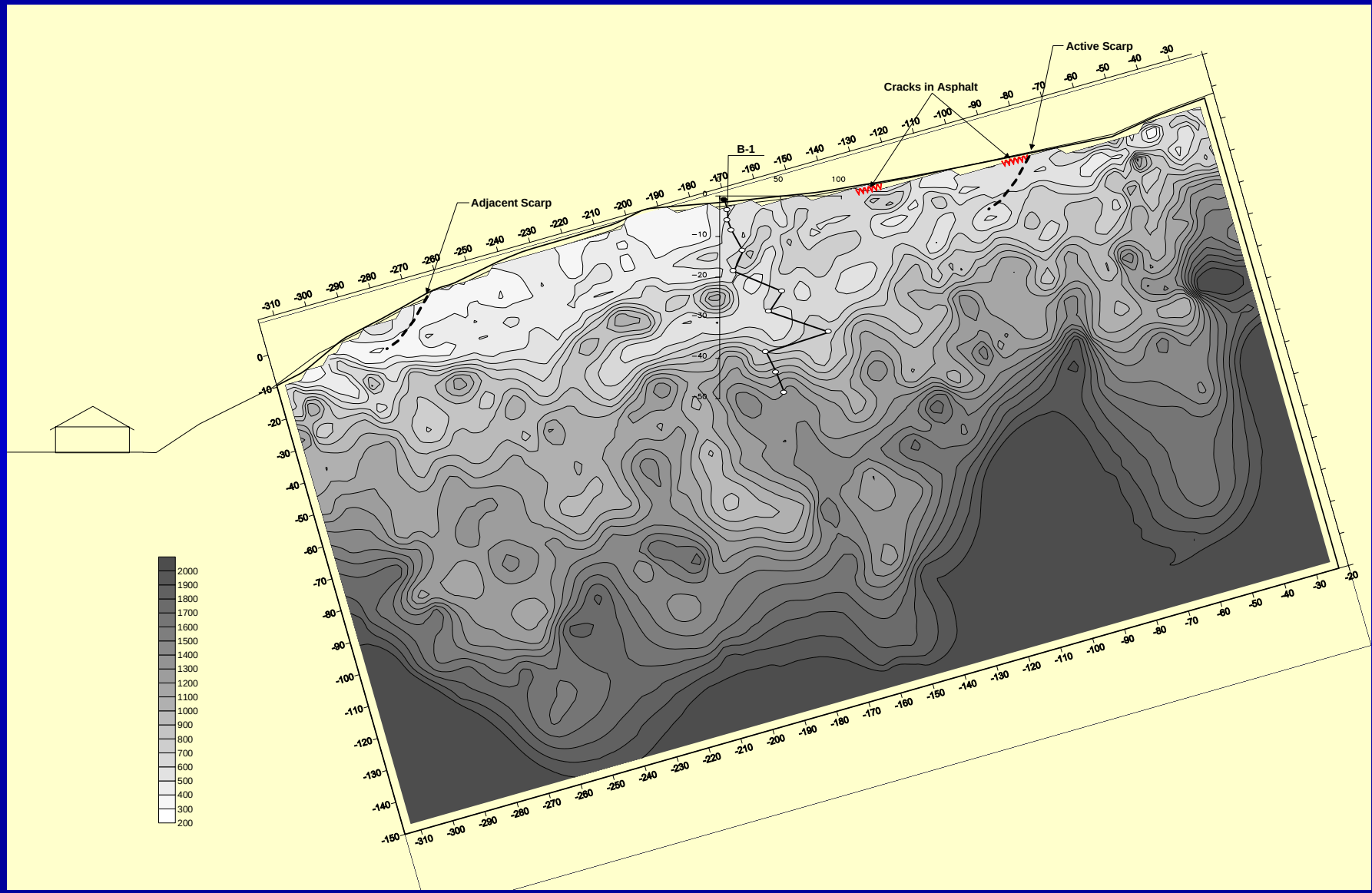
# Section D-D’

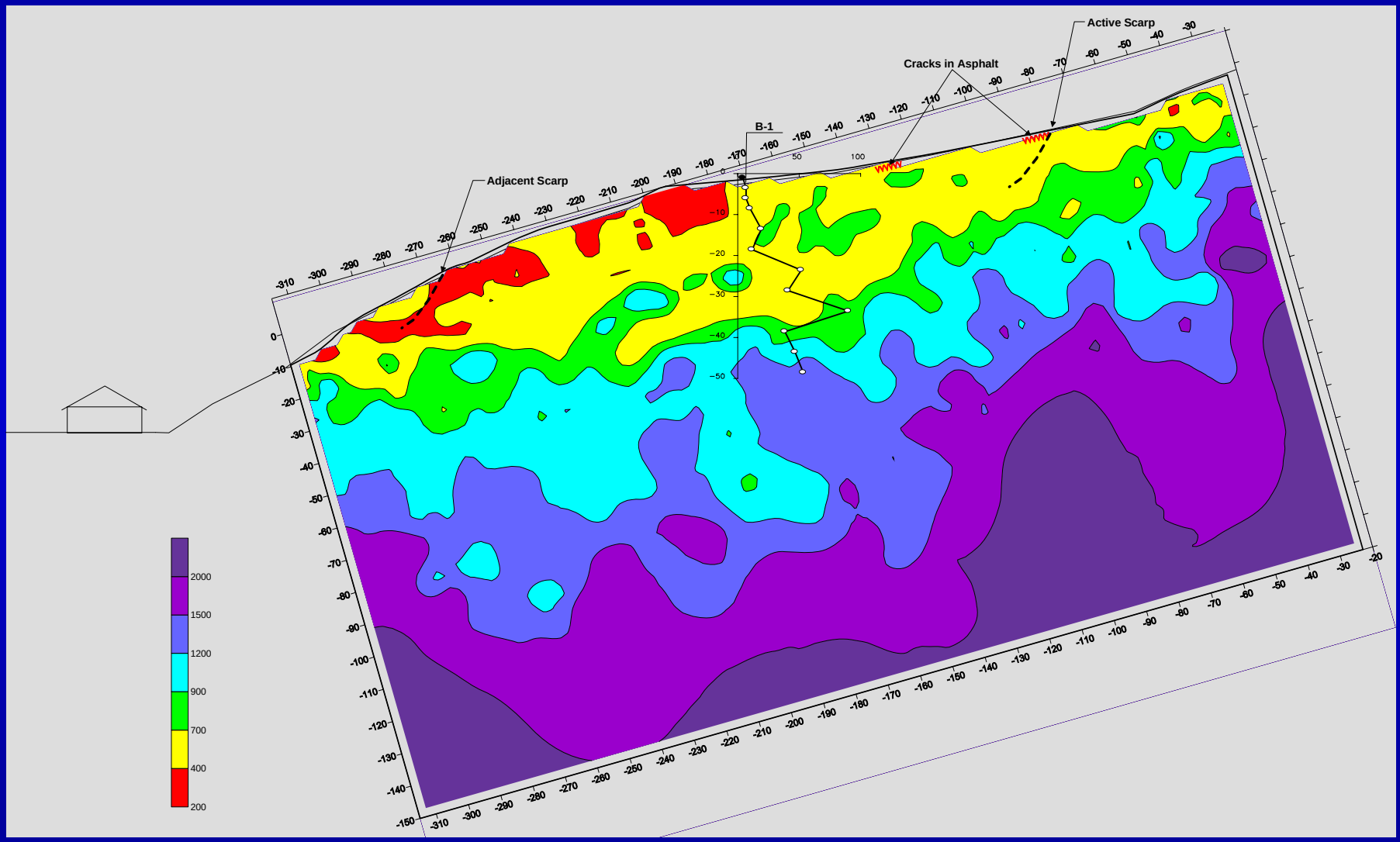

DRAFT WORK IN PROGRESS - SUBJECT TO CHANGE
Preliminary Cross Section D-D'
Hunters Crossing Slope Movement
Waynesville Extraterritorial Jurisdiction
Haywood County
Prepared: 11/28/05
Revised: 2/20/06, 4/4/06
Elev. in Feet
Elev. in Feet
Azimuth 280°
Inferred Extensional Movement
Inferred Compressional Movement
Inactive Scarp
Active Scarp
Tension Cracks
Gravel Driveway
Hunters Crossing Rd.
Lickstone Rd.
Browning Branch
431 Lickstone Road
Assumed Original Ground Line
Completely weathered micaceous bedrock. Red brown, black, & tanish brown with white, silty SAND (SM) w/ quartz fragments
Brown silty sand (SM) w/ organics
Partially weathered micaceous bedrock. Layered brown, white, and orange, silty SAND (SM) w/ black mottles & quartz fragments
Orange and grayish brown gravelly silty SAND (SM) w/ rock fragments-wet
Potential Failure Surface
Assumed Active Failure Surface
B-1 (apt)
B-2 (apt)
B-3 (apt)
B-4 (apt)
NOTES
1. Ground elevation assumed from Waynesville 7.5-minute U.SG.S. topographic map.
2. Ground profile constructed from Haywood County 5-foot contour interval topography (http://www.gov.co.haywood.nc.us/landmaps.html).
3. Locations of all features are approximate. Strata breaks are interpreted from borings.
4. Borehole data provided by Alpha Environmental Services, Inc.
3080
3060
3040
3020
3000
2980
2960
2940
2920
2900
2880
2860
0 20 40 60 80 100 120 140 160 180 200 220 240 260 280 300 320 340 360 380 400 420 440 460 480 Feet
D
D'

# Data Acquistion

# 2D Vs Model (MASW)



# 2D Vs Model (MASW)

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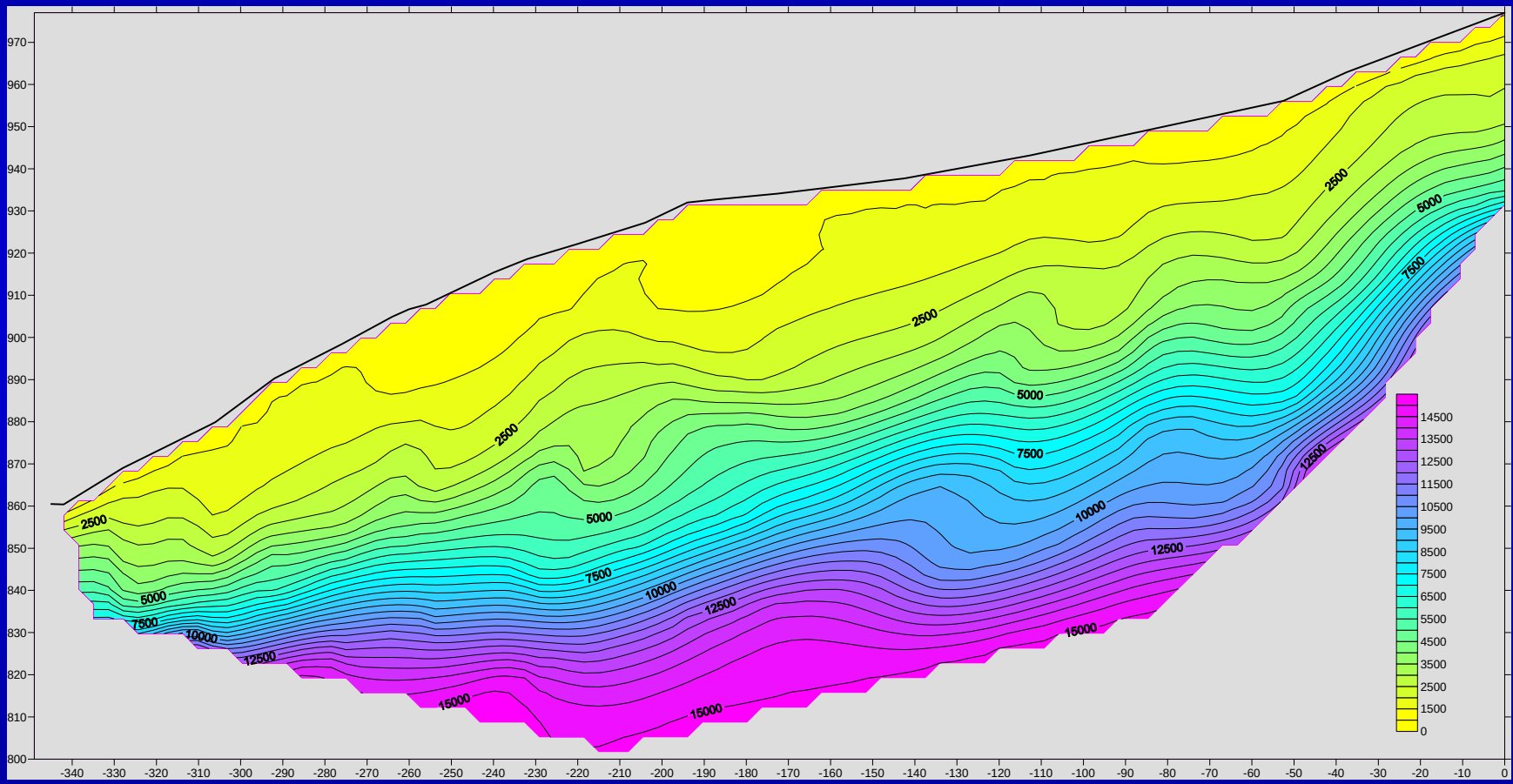
# 2D Vp Model (Refraction)

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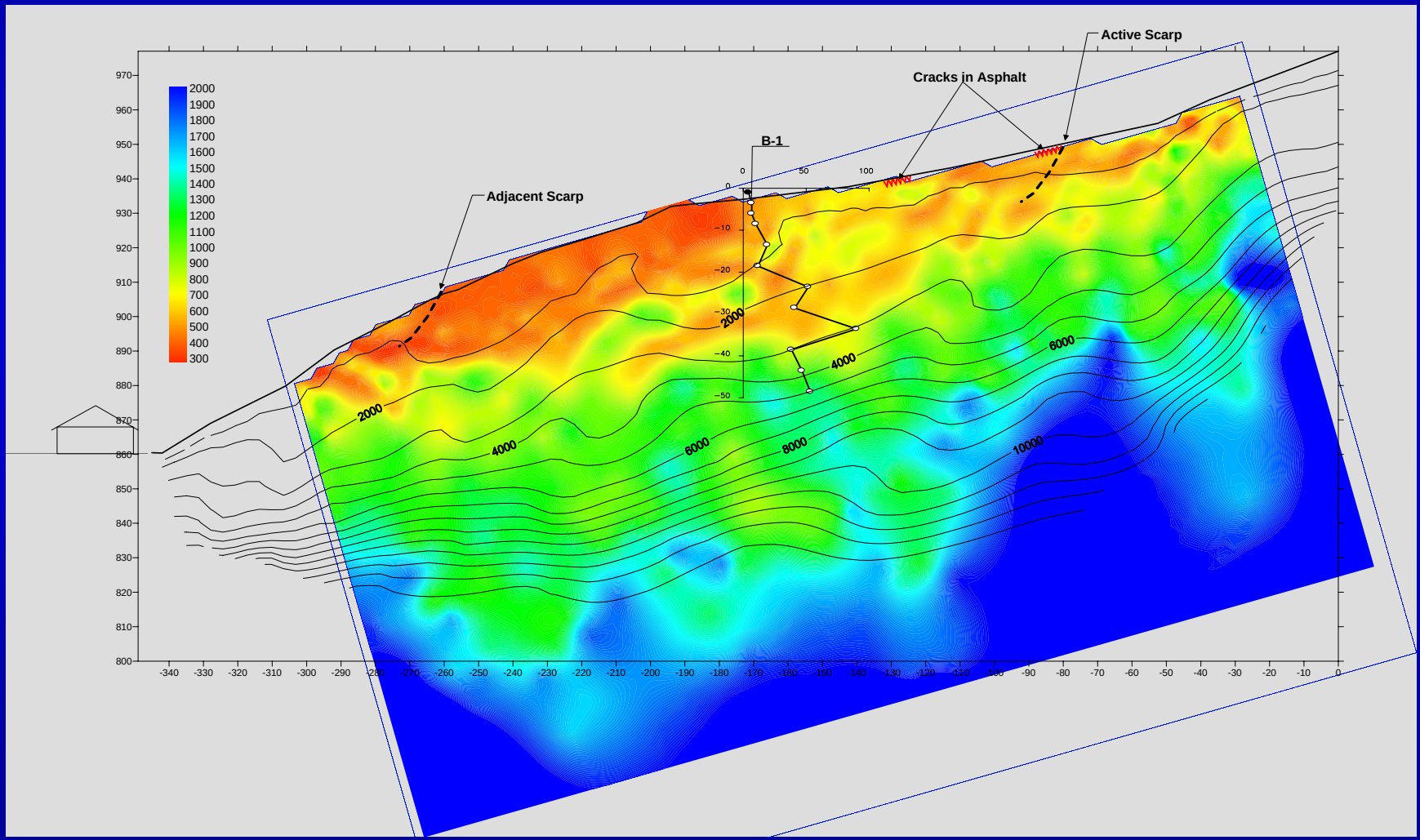
# Vs and Vp Models



# Closing Remarks

- **MASW is well suited to highway investigations**
  - **Can be collected next to traffic**
  - **Acquisition relatively quick on pavement**
  - **Not affected by buried, overhead utilities**
  - **Provides a physical property useful for design (shear wave velocity – stiffness)**

# Thank you !

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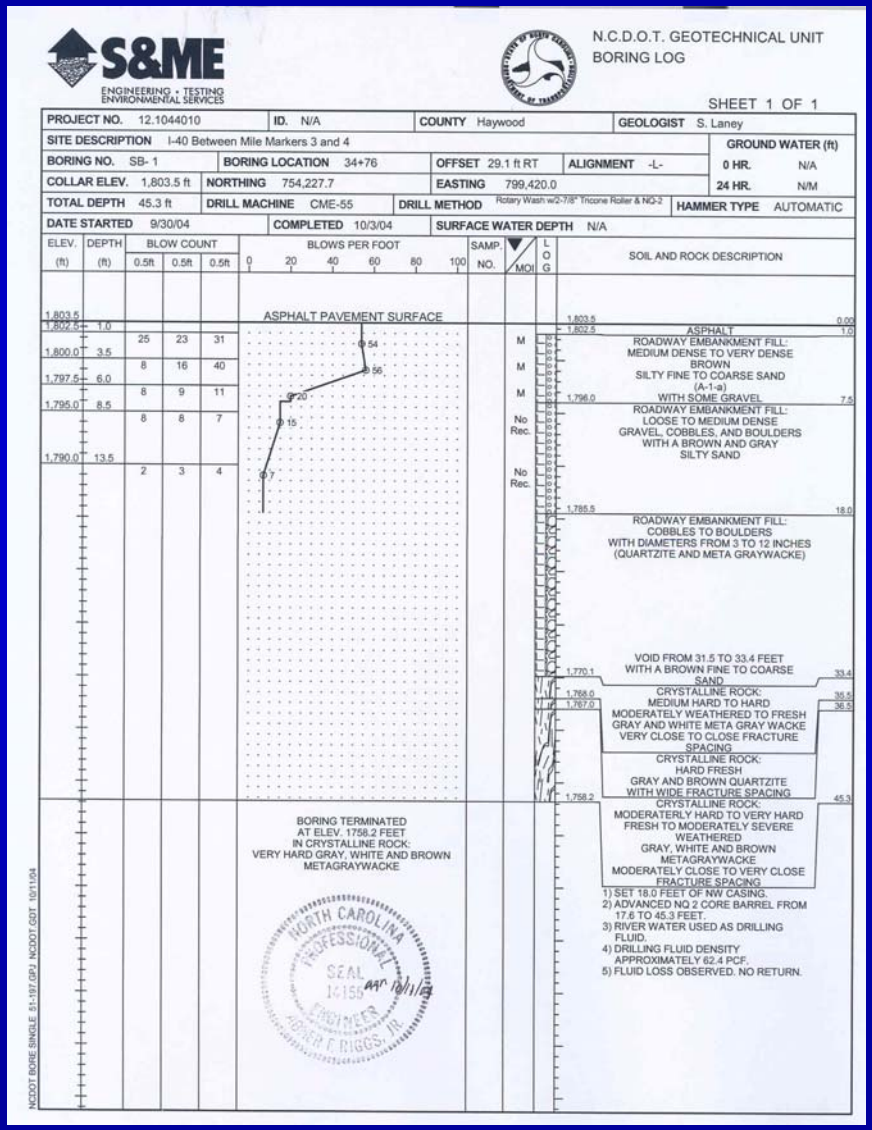
# Example Soil Boring



S&ME
ENGINEERING • TESTING
ENVIRONMENTAL SERVICES

N.C.D.O.T. GEOTECHNICAL UNIT
BORING LOG

SHEET 1 OF 1

| | | | |
|---|---|---|---|
| PROJECT NO. 12.1044010 | ID. N/A | COUNTY Haywood | GEOLOGIST S. Laney |
| SITE DESCRIPTION I-40 Between Mile Markers 3 and 4 | | | GROUND WATER (ft) |
| BORING NO. SB- 1 | BORING LOCATION 34+76 | OFFSET 29.1 ft RT | ALIGNMENT -L- | 0 HR. N/A |
| COLLAR ELEV. 1,803.5 ft | NORTHING 754,227.7 | EASTING 799,420.0 | 24 HR. N/M |
| TOTAL DEPTH 45.3 ft | DRILL MACHINE CME-55 | DRILL METHOD Rotary Wash w/2-7/8" Tricone Roller & NQ-2 | HAMMER TYPE AUTOMATIC |
| DATE STARTED 9/30/04 | COMPLETED 10/3/04 | SURFACE WATER DEPTH N/A | |

| ELEV. (ft) | DEPTH (ft) | BLOW COUNT 0.5ft | 0.5ft | 0.5ft | BLOWS PER FOOT 0 20 40 60 80 100 | SAMP. NO. | MOI | LOG | SOIL AND ROCK DESCRIPTION |
|---|---|---|---|---|---|---|---|---|---|
| 1,803.5 | | | | | ASPHALT PAVEMENT SURFACE | | | | |
| 1,802.5 | 1.0 | | | | | | | 1,803.5 | 0.00 |
| | | | | | | | | 1,802.5 | ASPHALT 1.0 |
| 1,800.0 | 3.5 | 25 | 23 | 31 | 54 | | M | | ROADWAY EMBANKMENT FILL: MEDIUM DENSE TO VERY DENSE BROWN SILTY FINE TO COARSE SAND (A-1-a) |
| 1,797.5 | 6.0 | 8 | 16 | 40 | 56 | | M | | |
| 1,795.0 | 8.5 | 8 | 9 | 11 | 20 | | M | 1,796.0 | WITH SOME GRAVEL 7.5 |
| | | 8 | 8 | 7 | 15 | | No Rec. | | ROADWAY EMBANKMENT FILL: LOOSE TO MEDIUM DENSE GRAVEL, COBBLES, AND BOULDERS WITH A BROWN AND GRAY SILTY SAND |
| 1,790.0 | 13.5 | 2 | 3 | 4 | 7 | | No Rec. | | |
| | | | | | | | | 1,785.5 | 18.0 |
| | | | | | | | | | ROADWAY EMBANKMENT FILL: COBBLES TO BOULDERS WITH DIAMETERS FROM 3 TO 12 INCHES (QUARTZITE AND META GRAYWACKE) |
| | | | | | | | | 1,770.1 | VOID FROM 31.5 TO 33.4 FEET WITH A BROWN FINE TO COARSE SAND 33.4 |
| | | | | | | | | 1,768.0 | CRYSTALLINE ROCK: MEDIUM HARD TO HARD MODERATELY WEATHERED TO FRESH GRAY AND WHITE META GRAY WACKE VERY CLOSE TO CLOSE FRACTURE SPACING 35.5 |
| | | | | | | | | 1,767.0 | CRYSTALLINE ROCK: HARD FRESH GRAY AND BROWN QUARTZITE WITH WIDE FRACTURE SPACING 36.5 |
| | | | | | | | | 1,758.2 | CRYSTALLINE ROCK: MODERATELY HARD TO VERY HARD FRESH TO MODERATELY SEVERE WEATHERED GRAY, WHITE AND BROWN METAGRAYWACKE MODERATELY CLOSE TO VERY CLOSE FRACTURE SPACING 45.3 |
| | | | | | BORING TERMINATED AT ELEV. 1758.2 FEET IN CRYSTALLINE ROCK: VERY HARD GRAY, WHITE AND BROWN METAGRAYWACKE | | | | 1) SET 18.0 FEET OF NW CASING. 2) ADVANCED NQ 2 CORE BARREL FROM 17.6 TO 45.3 FEET. 3) RIVER WATER USED AS DRILLING FLUID. 4) DRILLING FLUID DENSITY APPROXIMATELY 62.4 PCF. 5) FLUID LOSS OBSERVED. NO RETURN. |

NORTH CAROLINA PROFESSIONAL SEAL 14159 ENGINEER JOHN F. RIGGS, JR. 10/11/04

NCDOT BORE SINGLE 51-197.GPJ NCDOT.GDT 10/11/04

**<u>Roadway Embankment Fill</u>:**
**Silty Sand**

**<u>Roadway Embankment Fill</u>:**
**Gravel, Cobbles, and Boulders**

**<u>Crystalline Rock</u>:**
**Quarzite and Meta Graywacke**