ARM Group Inc.

Engineers and Scientists

PENNSYLVANIA PUC

PUBLIC UTILITY COMMISSION

PIPELINE AND ELECTRIC SAFETY SEMINAR

Geo-Hazards and Pipeline Safety

Presented By:

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Hershey, PA

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Pipelines Are in the Public Interest

PA PUC Mission Statement:

The Pennsylvania Public Utility Commission balances the needs of consumers and utilities; ensures safe and reliable utility service at reasonable rates; protects the public interest; educates consumers to make independent and informed utility choices; furthers economic development; and fosters new technologies and competitive markets in an environmentally sound manner.

Pipelines Are Safe

American Petroleum Institute:

Pipelines are an extremely safe way to transport energy across the country. A barrel of crude oil or petroleum product shipped by pipeline reaches its destination safely more than 99.999% of the time. The number of releases greater than 500 barrels is down 32% since 2011.

Agenda

Geo-Hazards & Pipeline Safety
What Are Geo-Hazards?
How Can Geo-Hazards Impact Pipelines?
What Can We Do to Evaluate Geo-Hazards?
Project Examples

What Are Geo-Hazards?

Steep Slopes / Landslides
Karst / Sinkholes / Subsidence
Radioactive / Arsenic Bearing Formations
Mining Related Surface Coal Mines Deep Coal Mines Acid-producing Rocks Mine Spoils Dumps Abandoned Mines / Drainage

How Can Geo-Hazards Impact Pipelines?

"Landslide caused West Virginia pipeline explosion, TransCanada reports"
Pittsburgh Post Gazette, July 2018

How Can Geo-Hazards Impact Pipelines?

"Officials believe landslide may have triggered massive gas pipeline explosion in Beaver County " Pittsburgh Post Gazette, September 2018

How Can Geo-Hazards Impact Pipelines?

"Another sinkhole appears in Chester County neighborhood, exposing pipeline "
Philadelphia Inquirer, January 2019

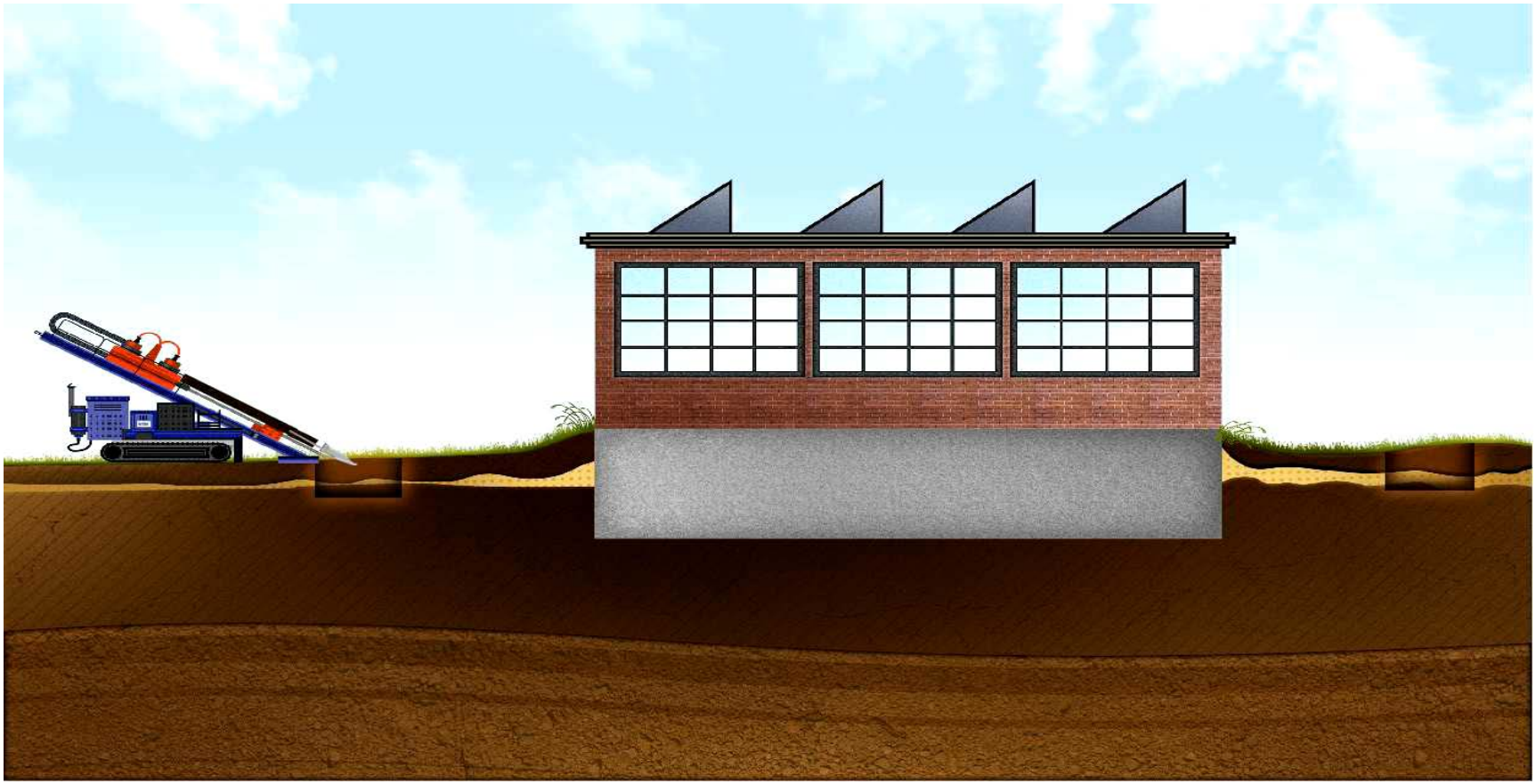
How Can Geo-Hazards Impact Pipelines?

"Neighbors concerned after latest sinkhole..."
WPVI TV Philadelphia, January 2019

What Can We Do to Evaluate Geo-Hazards?

Geotechnical Evaluations Desktop Field Investigations Laboratory Analyses
Soils Mapping
Geologic Mapping
Geophysical Investigations (focus of this presentation)

Geo-Hazards May be Dictated by Construction Technique



Potential Issues with Improper HDD Practices

- Inadvertent Returns (IRs)
- Ground surface heaving/subsiding
- Lost borehole (borehole collapse)
- Pullback failure
- Impacts to sensitive areas (water)

Inadvertent Return (IR)

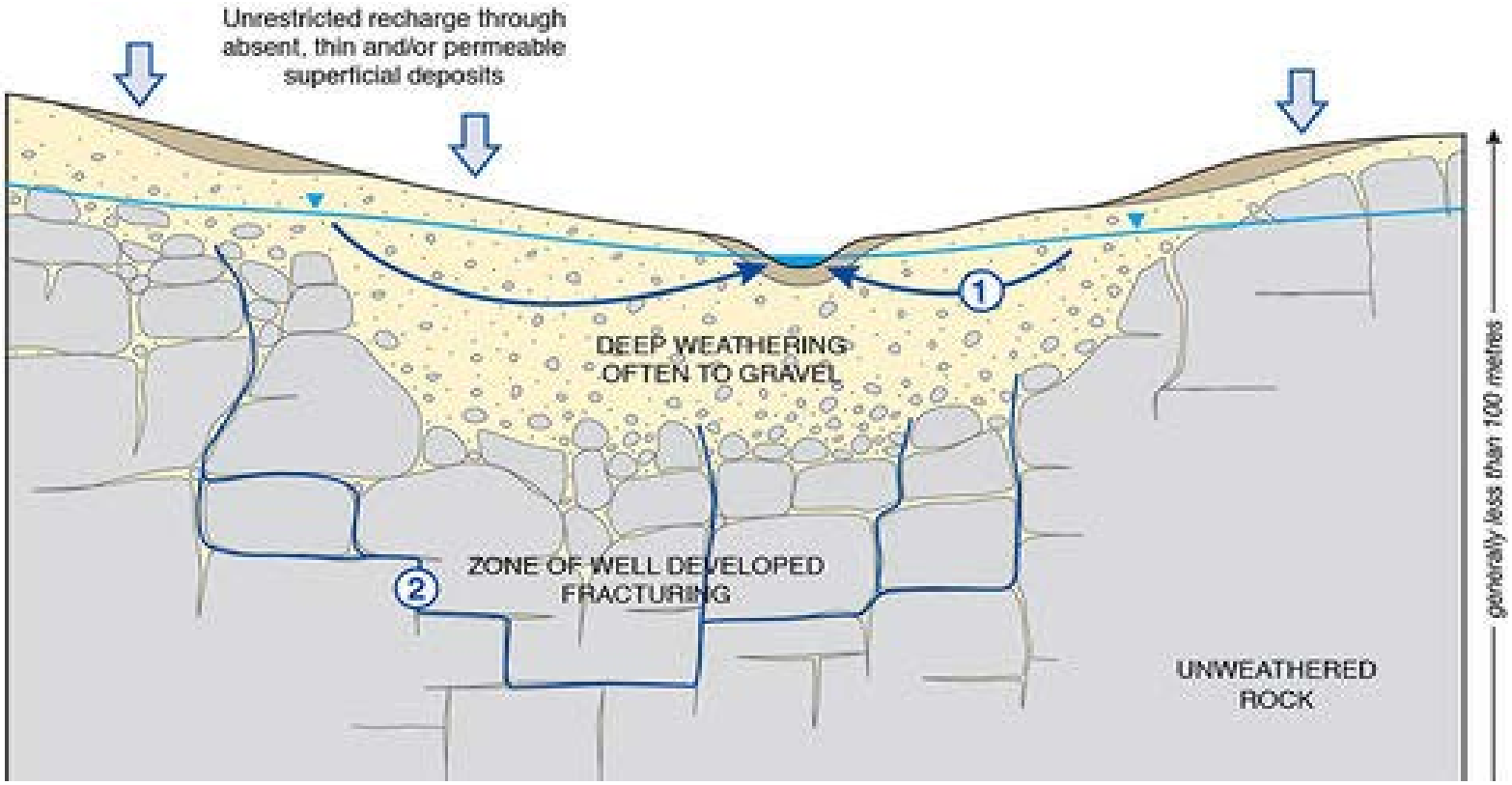
"Inadvertent Return" (IR) formerly known as "Frack Out"

Two primary causes:

1. Preferential Pathways
2. Improper Drilling Practices

Focus on IR's

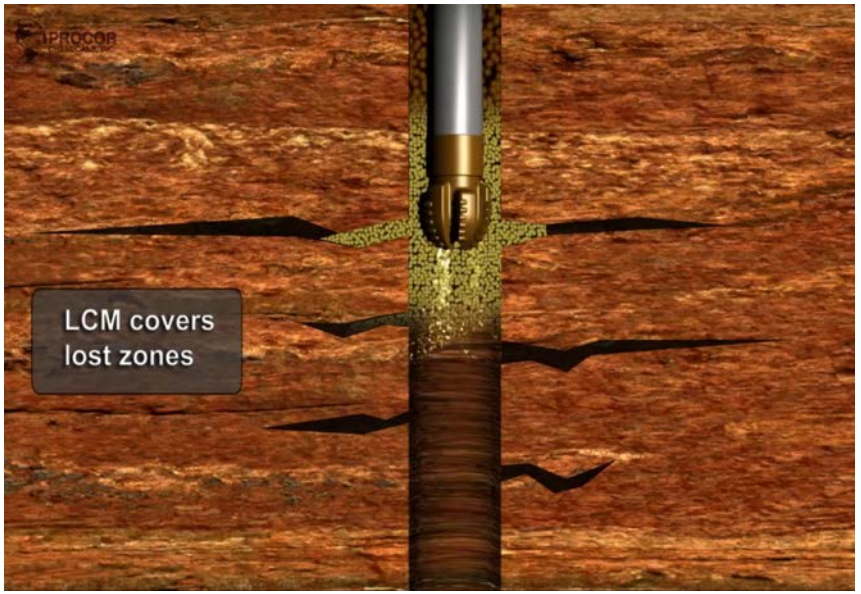
Cause #1 - Preferential Pathways



Focus on IR's

Eliminating IR via Preferential Pathways

1. Avoid them!
    1. Good geotechnical data, conservative bore planning
2. Drilling fluid additives (with small aperture openings)
    1. Thick bentonite drilling fluid can help, to a point
    2. LCM
3. Grout from Surface & Drill on



Focus on IR's

Eliminating IR via Preferential Pathways

4. Casing off the zone

Focus on IR's

Some IRs are expected

- When soil/rock pressures can't support the fluid pressure
  - Entry, Exit, Too thin of cover
- Managing the fluid return where it is occurring, by setting up the transfer of fluid via pumping or occasionally, trucking.
- Drilling may continue if IR is contained and managed
- Relief wells

Sinkholes & HDD

What is Karst?

Karst

Karst terrain is defined as a type of topography that is present in areas underlain by carbonate bedrock (limestone or dolomite). It is caused by dissolution and erosion and is characterized by surface depressions, sinkholes, caves, and subsurface drainage (Kochanov, 1990).

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Sinkhole Development

- During an IR, mud flow up and out of the bore can carry soil/sediment up and to the surface, leaving a preferential pathway for fluid flow, and potentially, a sinkhole.

Sinkholes May Be Karst-Related

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Sinkholes May Be Karst-Related

Not all Sinkholes are Karst-Related!

- Geologic contacts
- Fractures
- Faults
- Mining Subsidence (i.e., Centralia)
- Utilities (i.e., City of Harrisburg)

Not all Sinkholes are Karst-Related

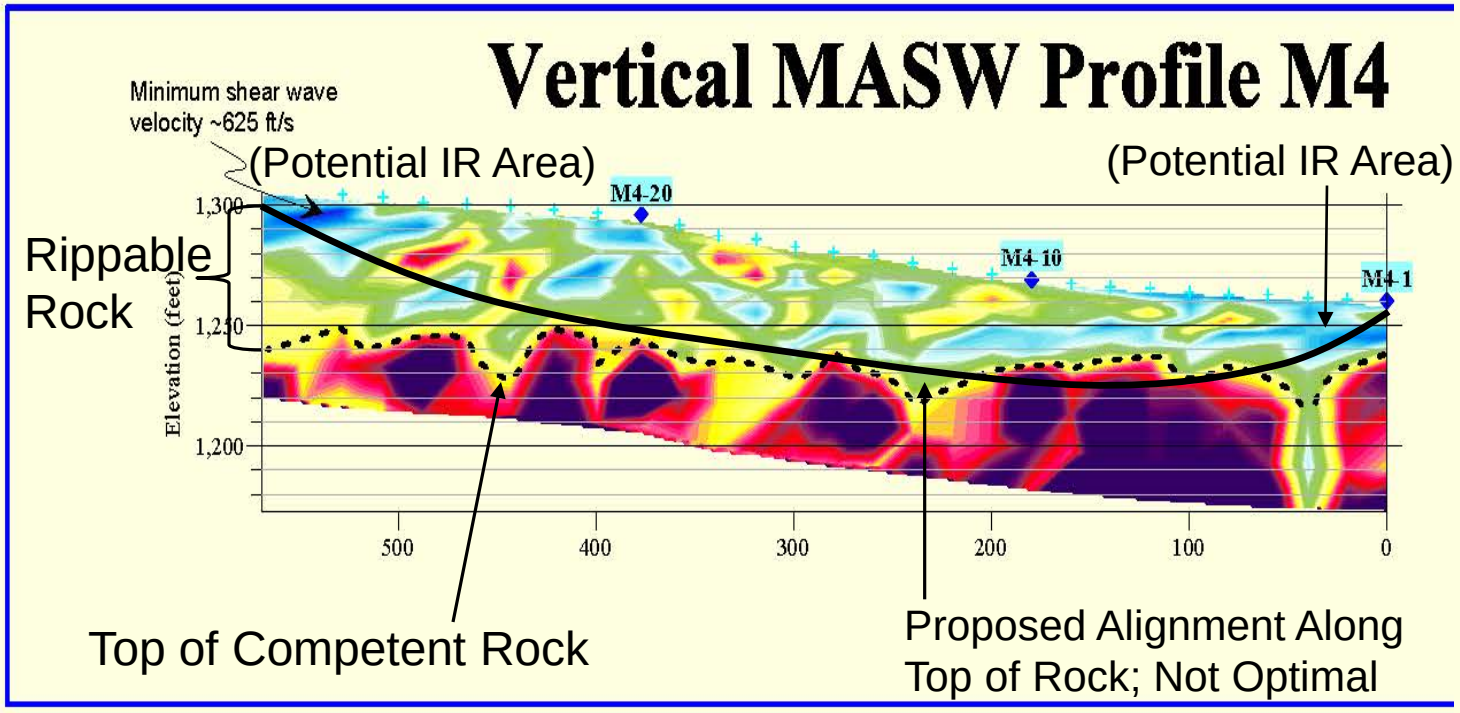
Not all Sinkholes are Karst-Related

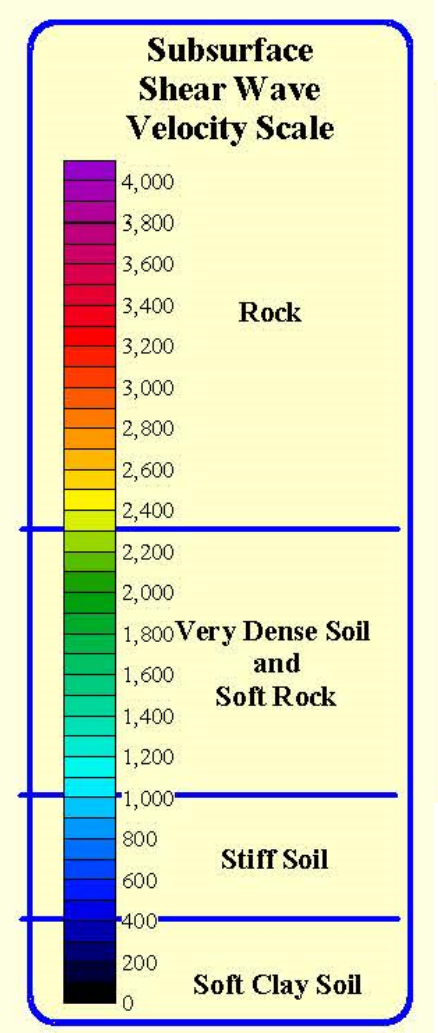
Not all Sinkholes are Karst-Related

What Can We Do to Evaluate Geo-Hazards?

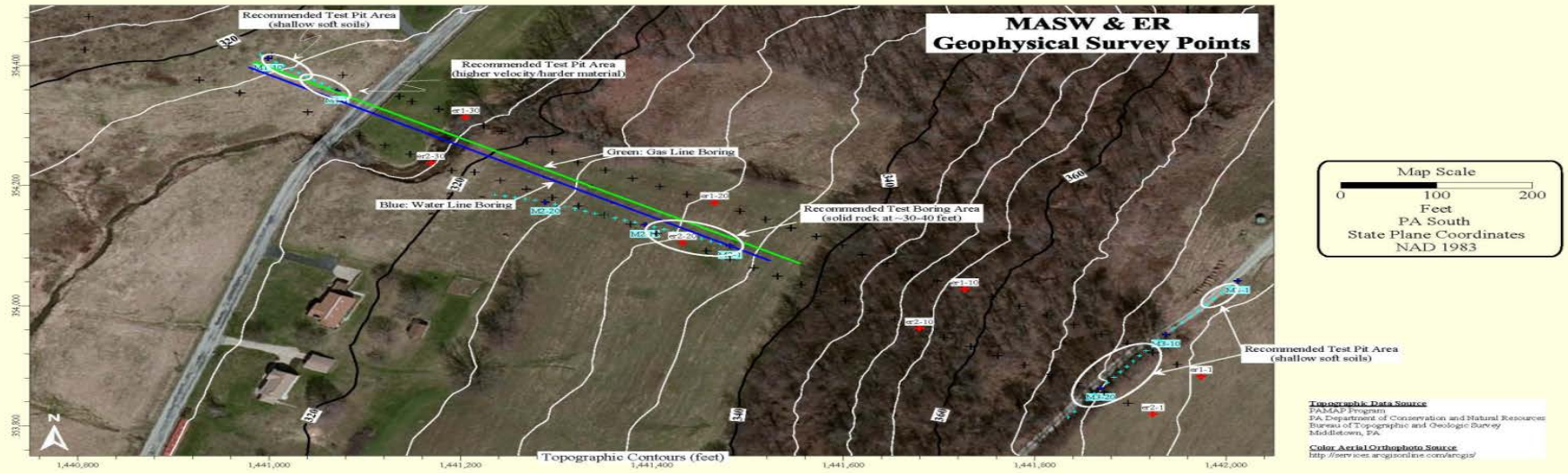
Geophysical & Geotechnical Investigations
Seismic (Refraction [limitations] & MASW)
Electrical Resistivity (ER)
Micro-Gravity
Electromagnetic (EM)
Borehole Logging

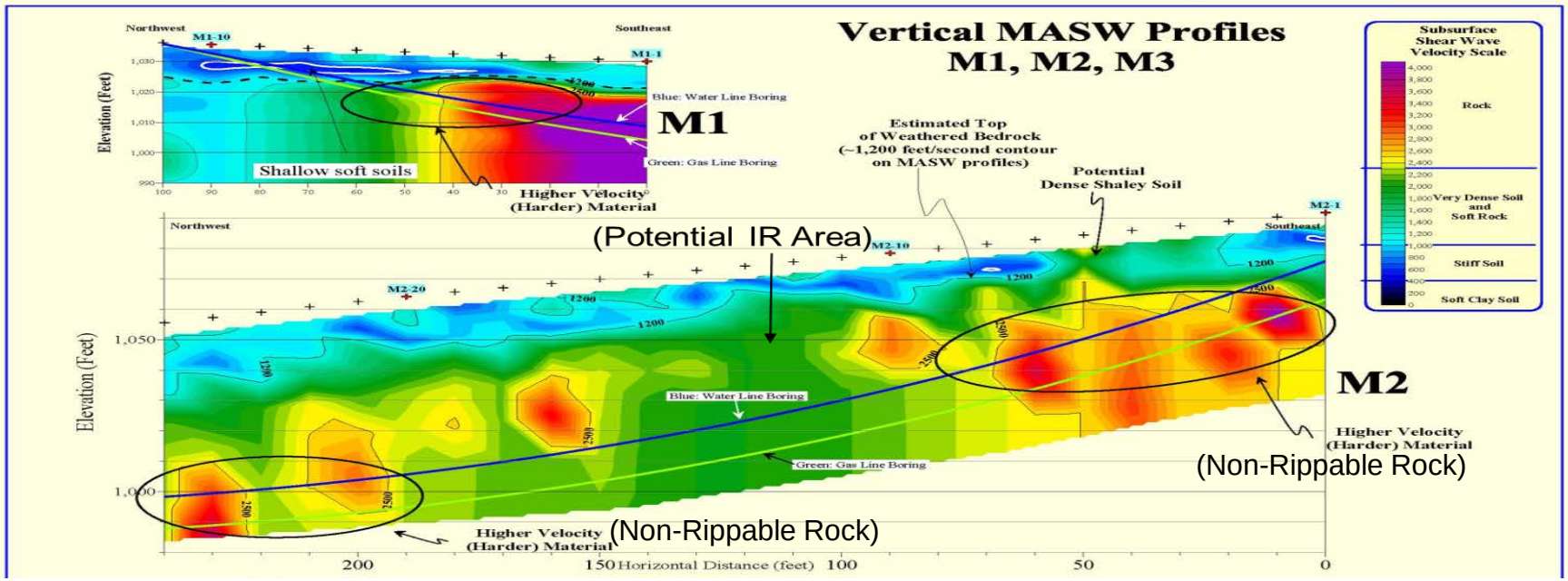
Seismic MASW for HDD



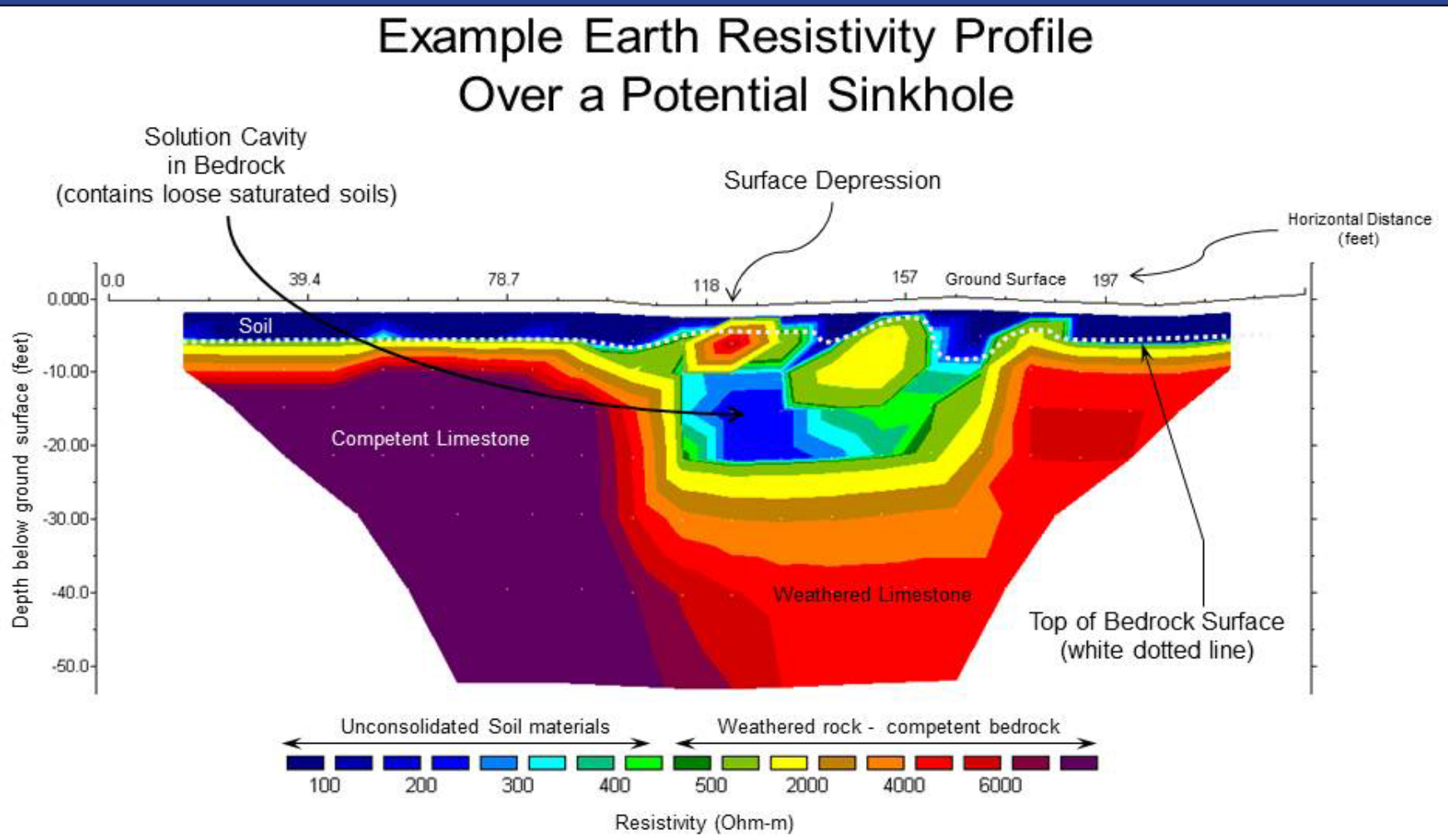


Seismic MASW for HDD Pipeline Investigation



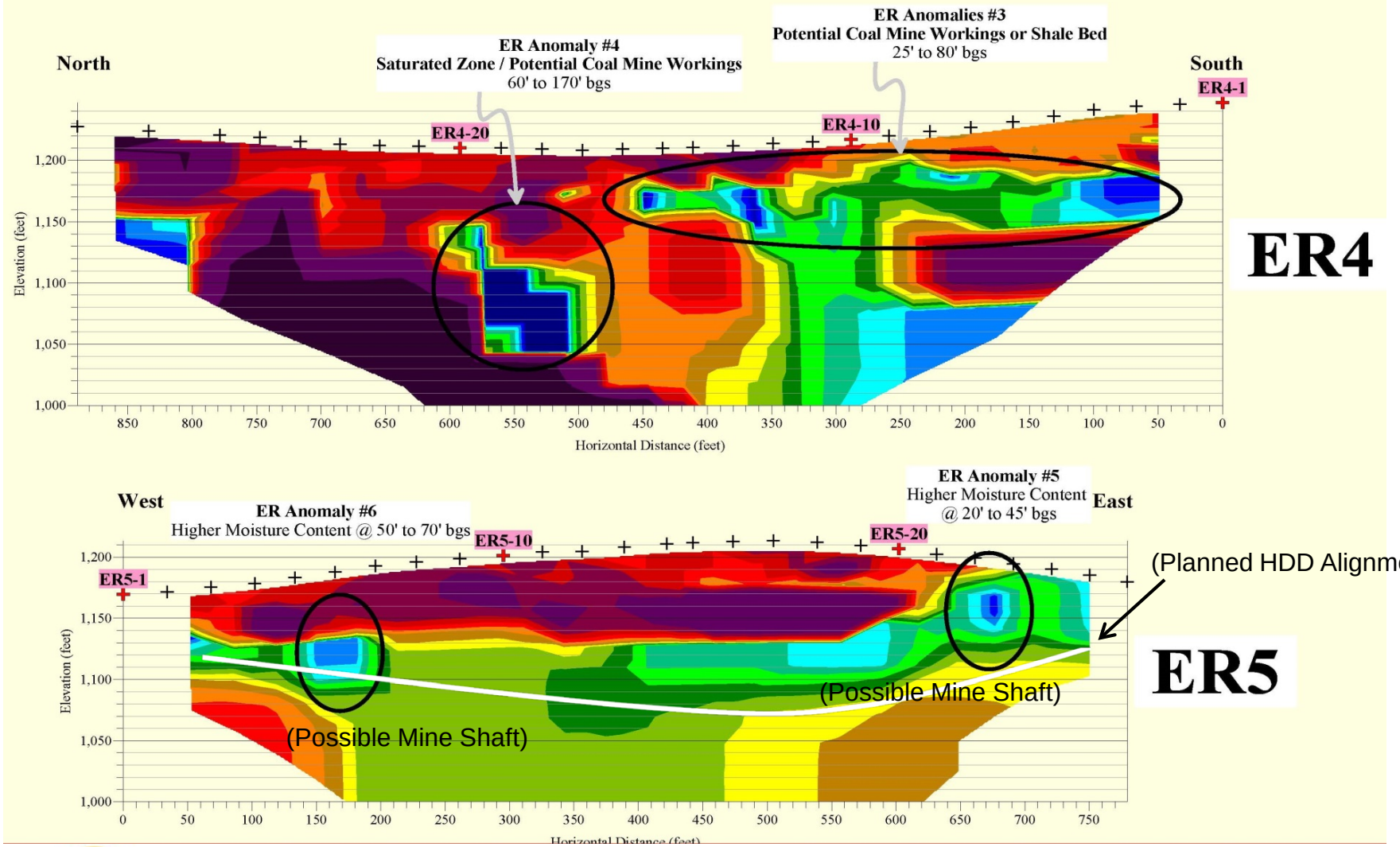


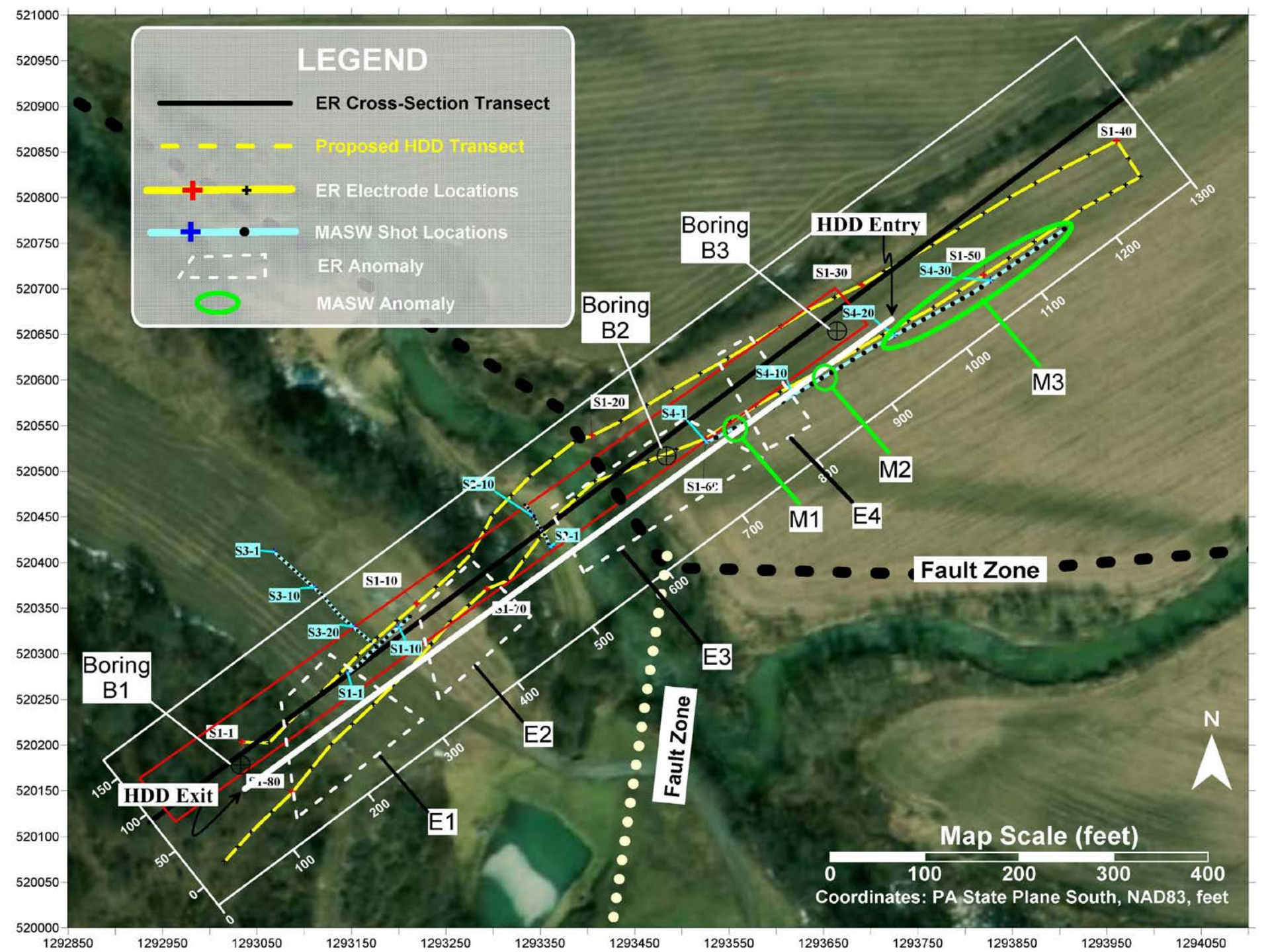
Electrical Imaging for Sinkhole



This earth resistivity profile was collected over a circular depression at the ground surface that was suspected to be a potential sinkhole. The profile indicates that a soil/water filled solution cavity had developed in the bedrock beneath the circular surface depression representing a hazardous condition for this site. Early detection of solution cavities allows for remediation and removal of these hazards prior to sinkhole formation.

ER Survey for Geo-Hazards




LEGEND
ER Cross-Section Transect
Proposed HDD Transect
ER Electrode Locations
MASW Shot Locations
ER Anomaly
MASW Anomaly
Boring B1
Boring B2
Boring B3
HDD Entry
HDD Exit
Fault Zone
Fault Zone
E1
E2
E3
E4
M1
M2
M3
S1-40
S1-50
S1-30
S4-30
S4-20
S4-10
S1-20
S4-1
S2-10
S2-1
S1-60
S3-1
S3-10
S1-10
S3-20
S1-70
S1-10
S1-1
S1-1
S1-80
N
Map Scale (feet)
0 100 200 300 400
Coordinates: PA State Plane South, NAD83, feet
521000
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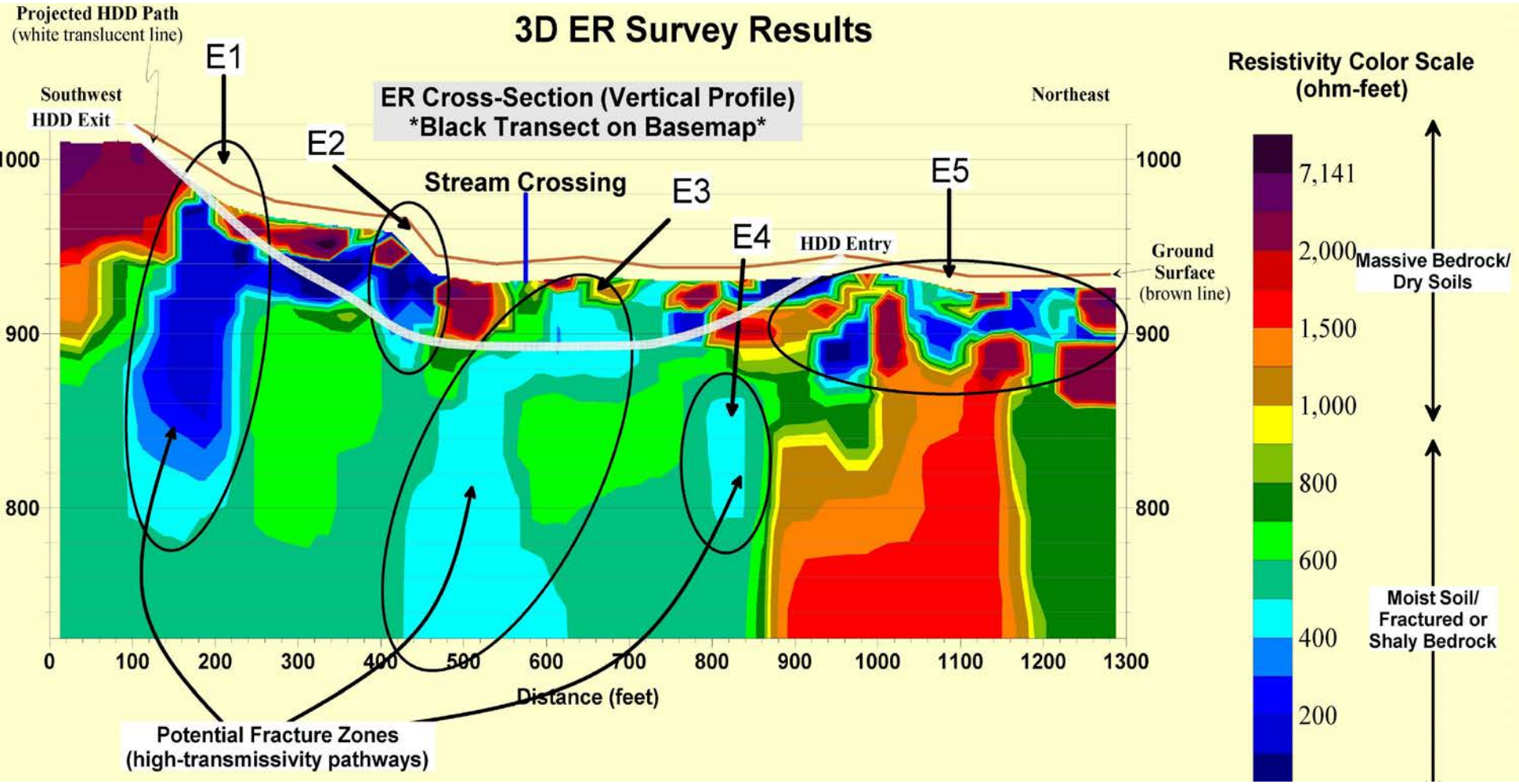
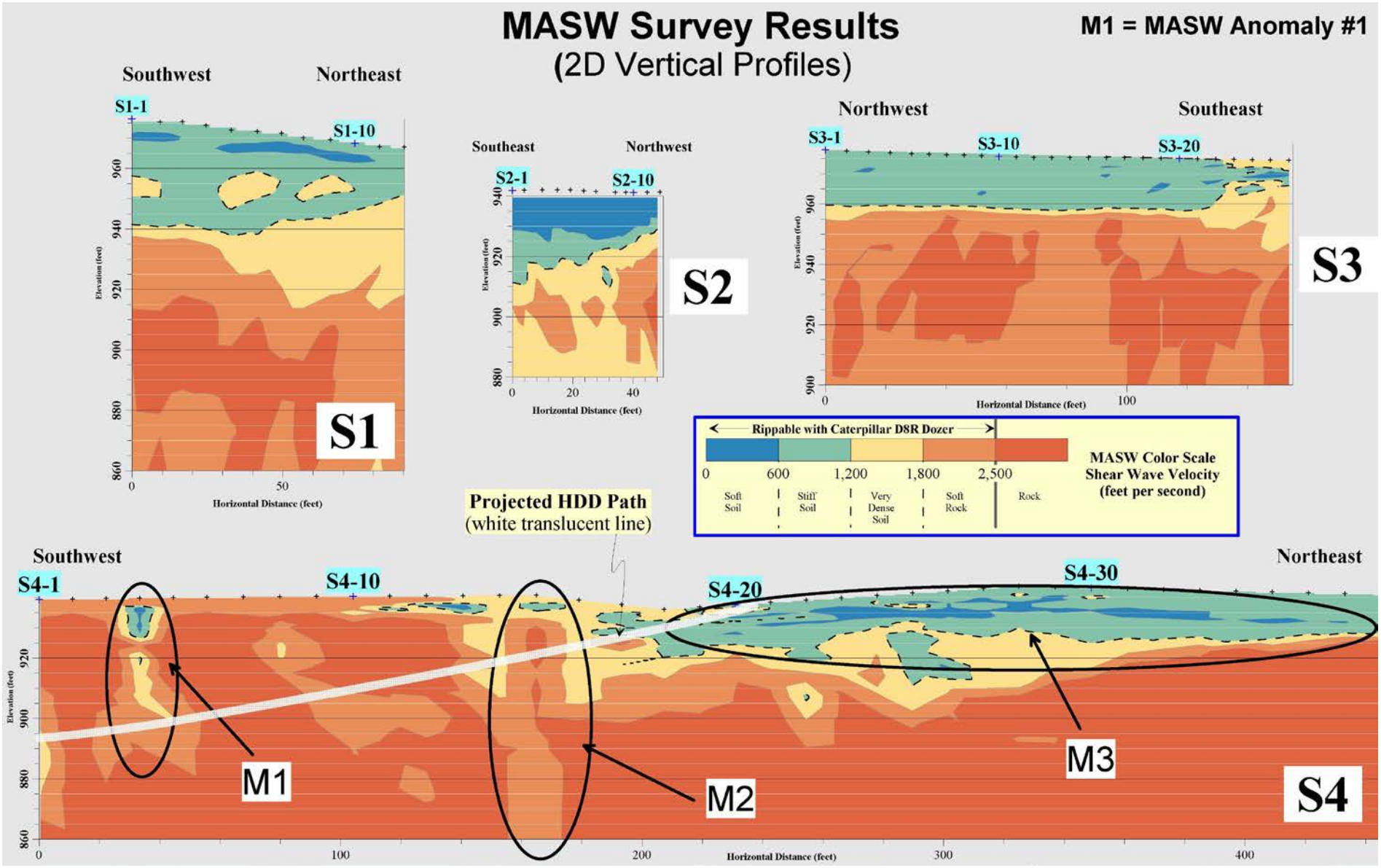
ER Survey for HDD Pipeline



MASW Survey for HDD Pipeline



Geophysical Results - HDD Pipeline

- No subsurface voids identified.
- Multiple near-vertical bedrock fracture zones in area of proposed HDD. Fractures correspond to fracture zones identified by ARM on aerial and LiDAR imagery, and to the mapped contact between geologic formations based on information from the Pennsylvania Geologic Survey.
- Potential for significant groundwater volumes to be present on both sides of the stream. The anomalies identified are representative of the types of zones ARM commonly seeks when exploring for commercially-viable groundwater resources (i.e., well yields >> 100 gallons per minute).
- Potential for a groundwater seep/spring on the hillside approximately 100- to 150-feet southwest of the stream along the proposed pipeline alignment.

Geophysical Results - HDD Pipeline

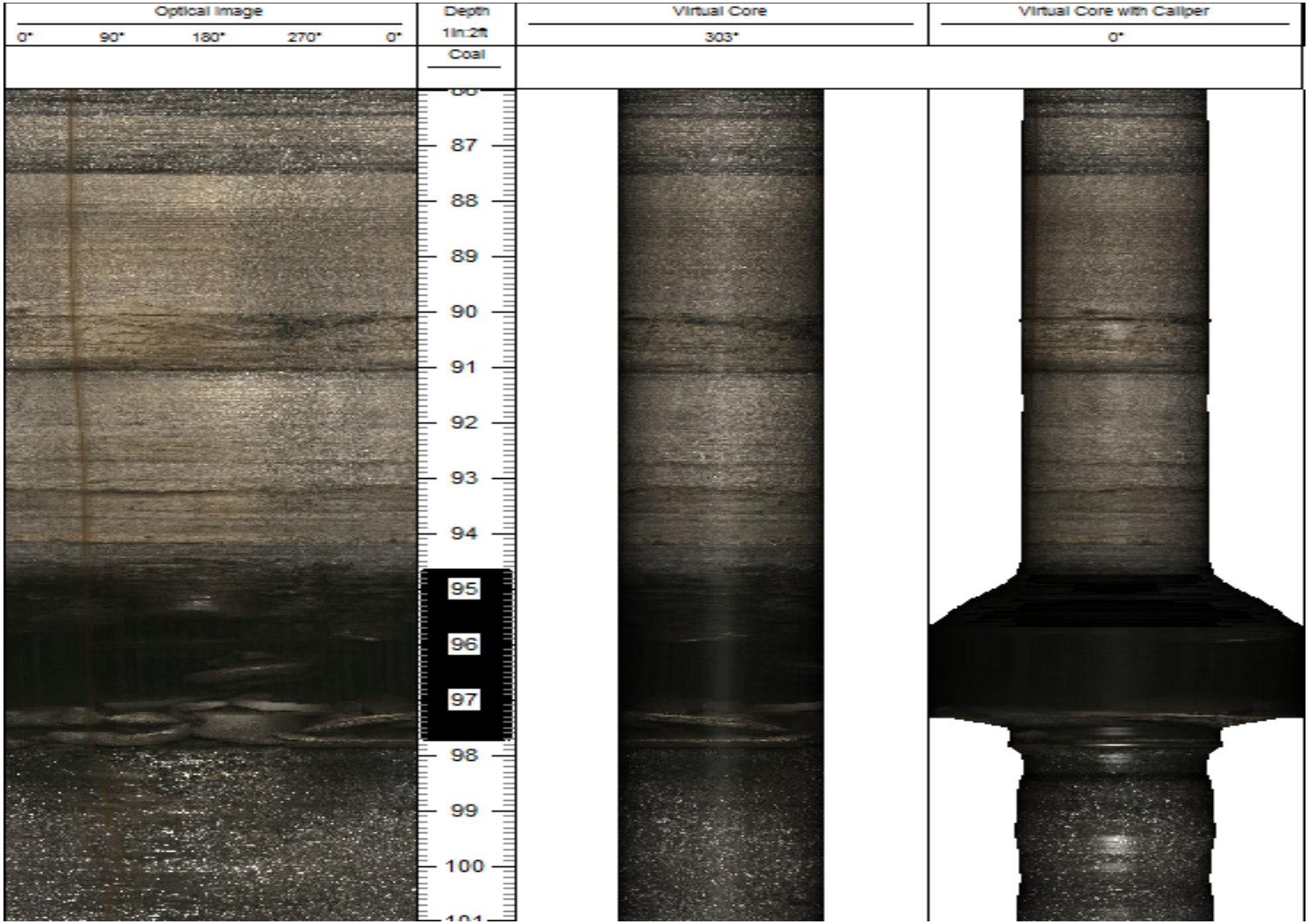
- Soft soils & apparent fracture zones appear to be associated with zones of structural weakness and are likely to be problem areas during an HDD construction project. For example, these zones of weakness are areas where inadvertent returns (IRs) may occur.

- Potential for significant groundwater volumes also poses a risk to proposed HDD construction. Significant groundwater volume at a higher elevation to the southwest of the stream could result in water flowing through the HDD bore and discharging to the surface at the proposed HDD entry point. The artesian conditions observed in test borings B-2 and B-3 support this conclusion.

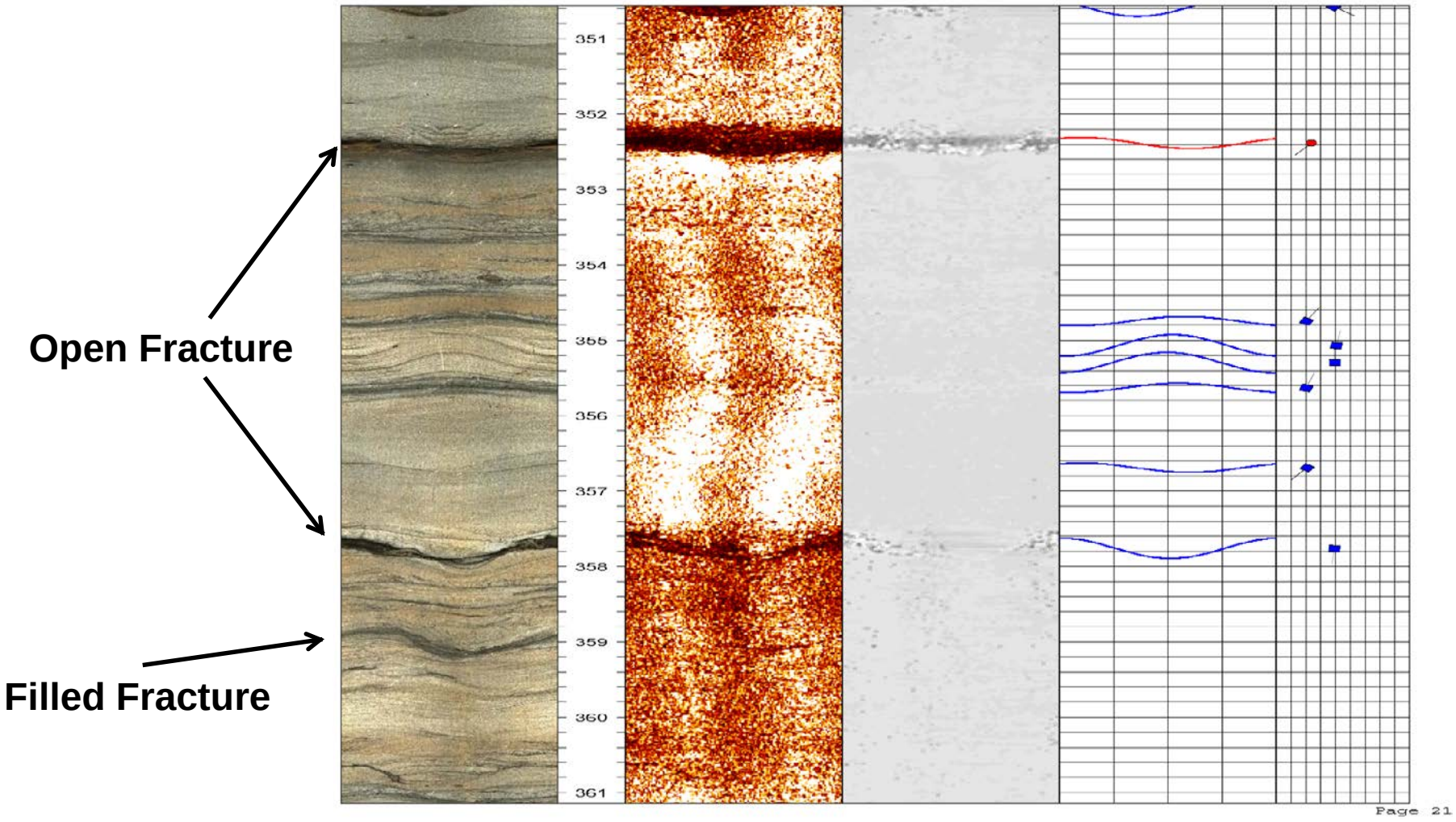
- The potential risks associated with HDD activities should be carefully considered when determining if HDD methods or open-cut trench methods are to be used to cross the stream.

Borehole Logging

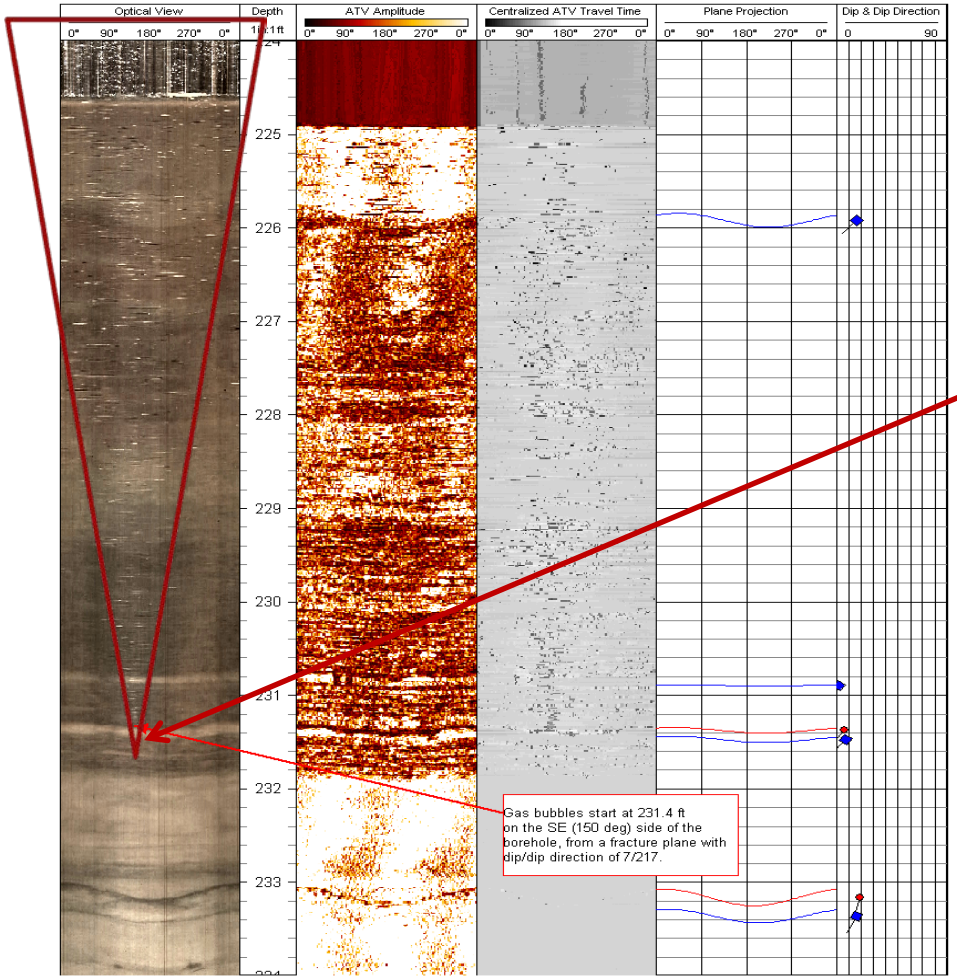
Evaluating Coal Seams



Televiewer Imaging



Methane Intrusion Investigation



Gas bubbles start @ 231.4' on the SE side (150 deg) of borehole, from a fracture with dip & dip direction of 7/217.

Geo-Hazards Can Be Managed

With proper planning and due diligence, geo-hazards may be identified and managed, allowing safe operation of pipelines.

Deploying the proper geophysical & geotechnical tools can be a cost-effective approach to managing risks associated with pipeline construction.

Thank You!

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