The National Academies of
SCIENCES · ENGINEERING · MEDICINE

TRANSPORTATION RESEARCH BOARD

Geotechnical Responses to Extreme Events

May 24, 2021

@NASEMTRB
#TRBwebinar

PDH Certification Information:

- 1.5 Professional Development Hour (PDH) – see follow-up email for instructions
- You must attend the entire webinar to be eligible to receive PDH credits
- Questions? Contact Reggie Gillum at RGillum@nas.edu

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RCEP

REGISTERED CONTINUING EDUCATION PROGRAM

#TRBwebinar

Learning Objectives

1. Describe how geophysical data and testing tools help in extreme events

2. Identify opportunities and limitations of employing geotechnologies

Geotechnical and geophysical data collection in riverine and coastal environments during and after extreme events

Nina Stark (Virginia Tech)

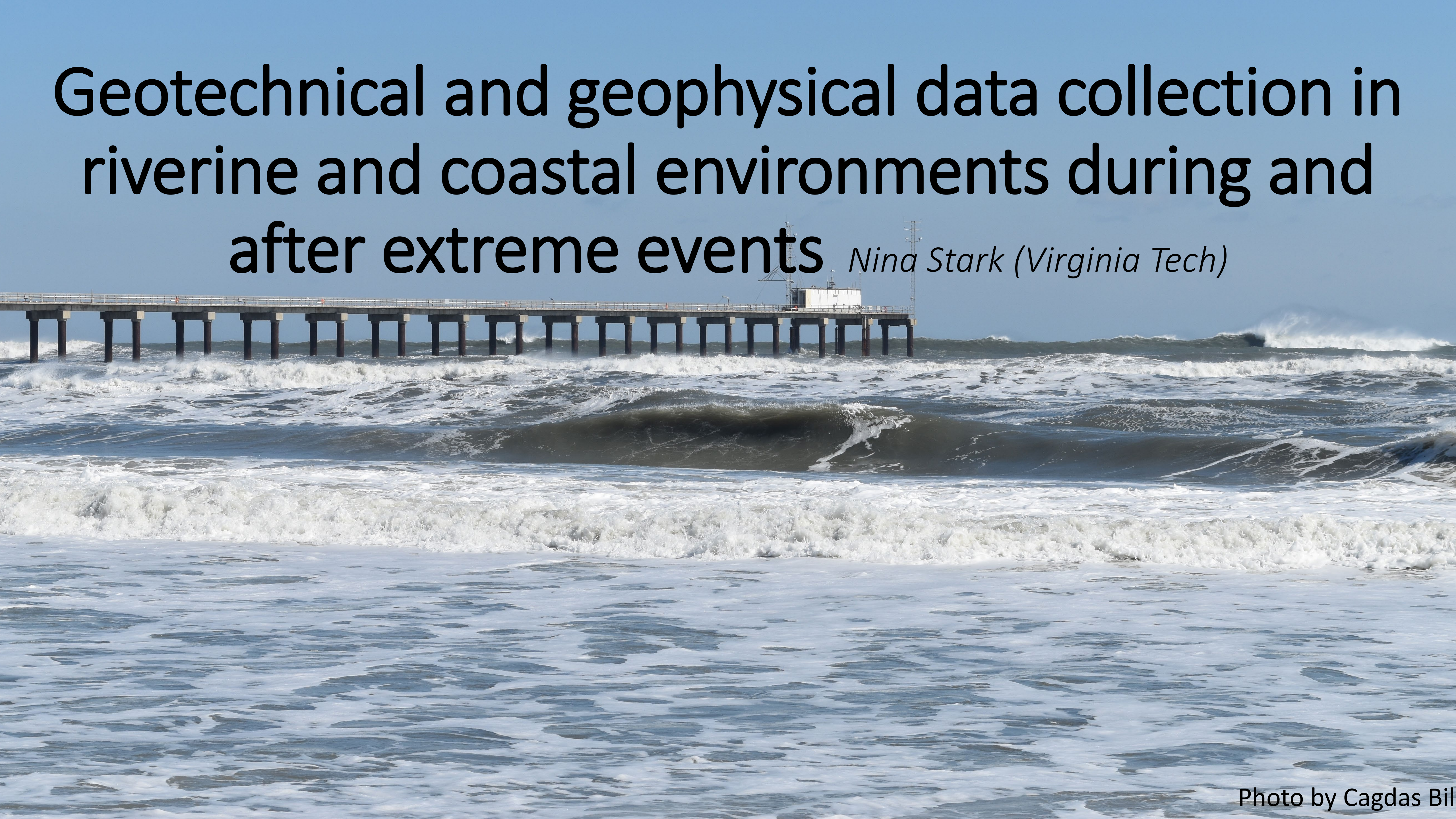
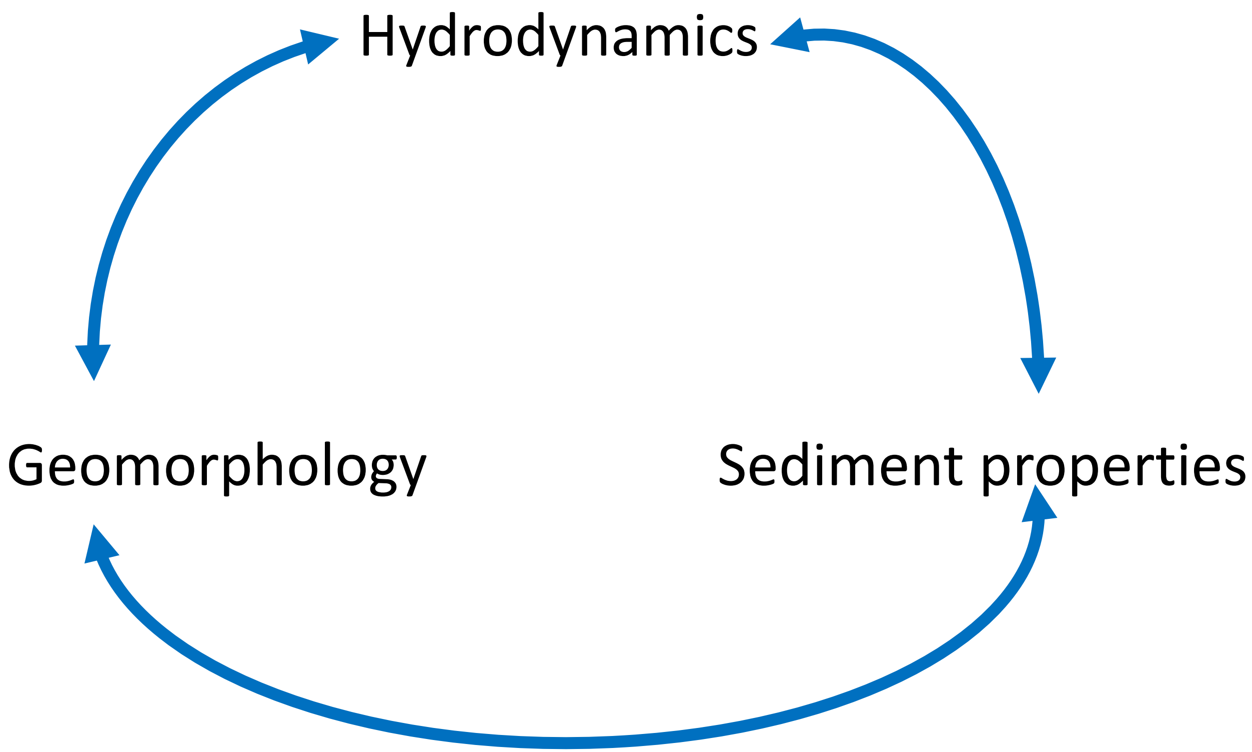


Photo by Cagdas Bil

Pre-deployment vs. reconnaissance:

Or how fast will essential data perish?

- Local sediment dynamics in subaquatic environments change rapidly with changes in hydrodynamics.
- This means geotechnical properties (particularly of surficial sediments related to erosion and recent deposition) can change rapidly from pre-event conditions throughout the event and post-event.



Pre-deployment vs. reconnaissance:

Or how fast will essential data perish?

Surfside, Texas (Hurricane Harvey – landfall August 25, 2017)

Stark et al. (2020)

Pleiades (image resolution: 50 cm)

WorldView 3 (image resolution: 30 cm)

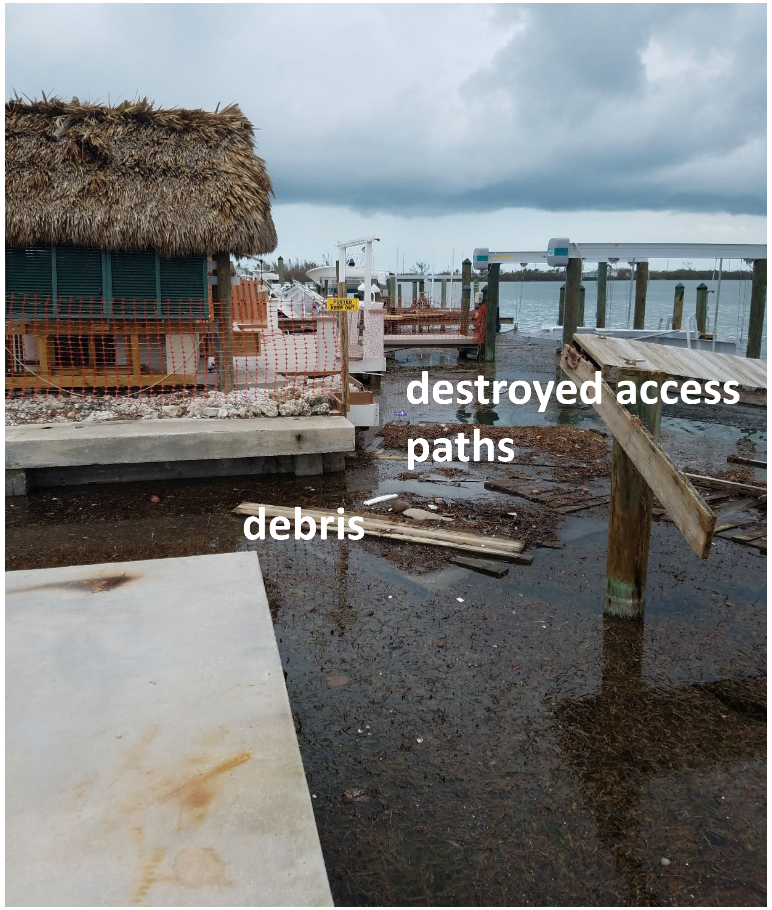
WorldView 2 (image resolution: 50 cm)

Challenges of conducting measurements in riverine and coastal environments post extreme events:

GEER – Hurricane Harvey 2017

Challenges of conducting measurements in riverine and coastal environments post extreme events:

GEER – Hurricane Irma 2017



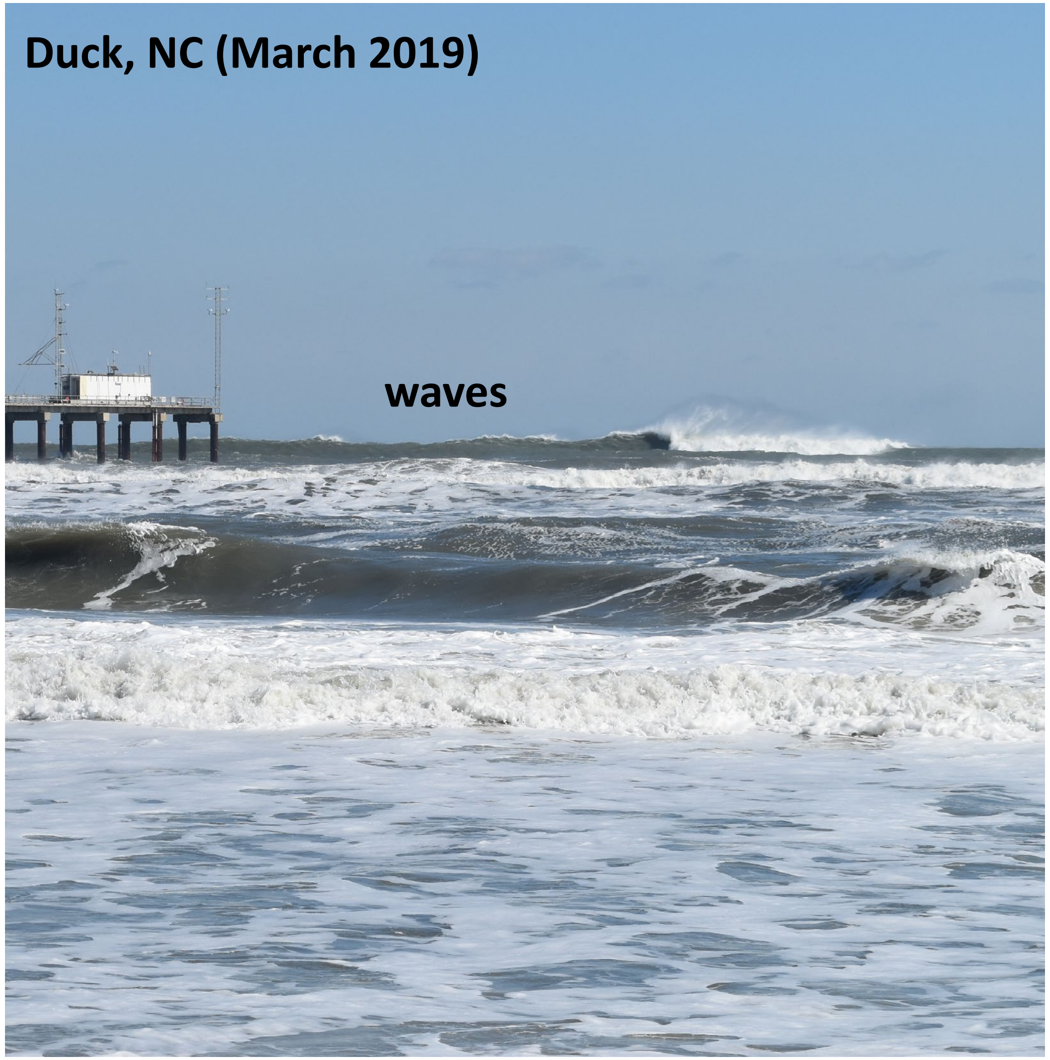
Challenges of conducting measurements in riverine and coastal environments post extreme events:

Other challenges include:

- Access to vessels or to water body
- Ongoing sediment dynamics
- ….

Many challenges are related to:

- **Risk to personnel**
- **Risk to instrumentation**
- **Access**
- **Combinations of those**



Relevant measurement types

Pre-deployed sensors:

- Water level gages
- Current and flow meters
- Wave/pressure sensors
- Pore pressure sensors
- Acoustic or optic (sea)bed scanners
- …

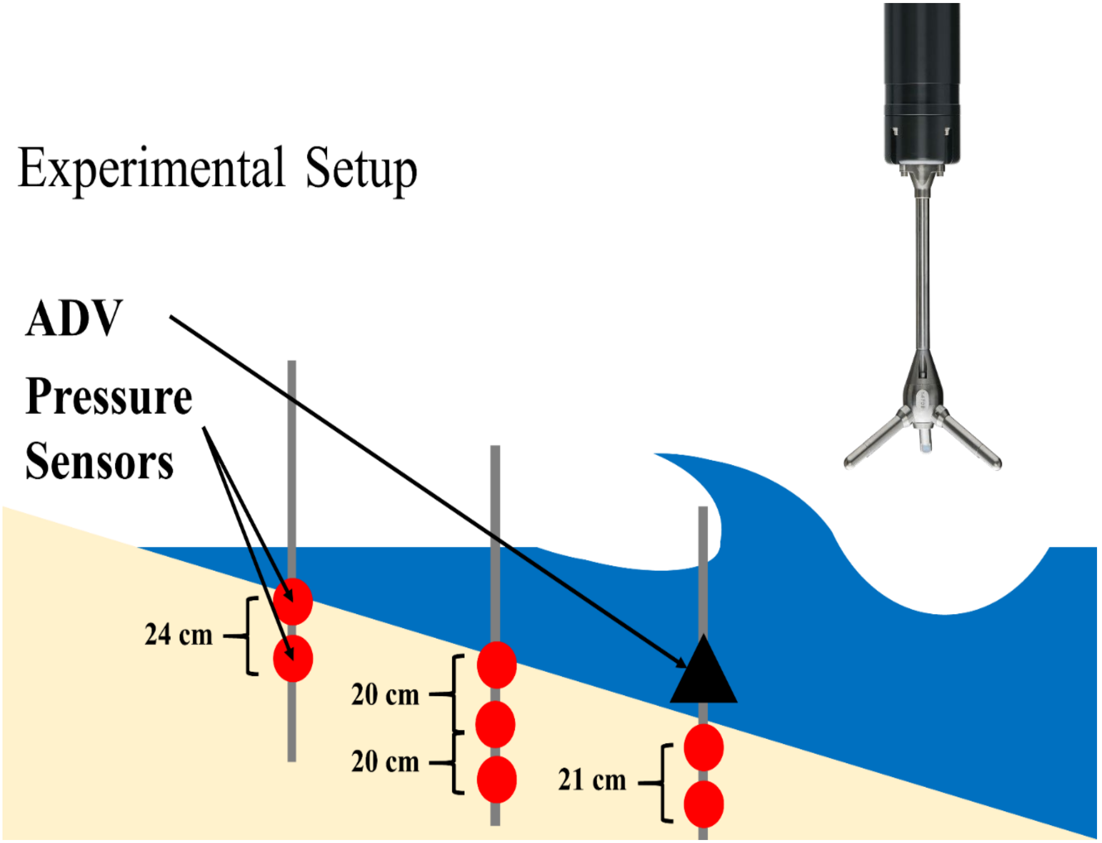
Post-event measurements:

- High water marks
- Topography/bathymetry (sediment erosion/deposition)
- Sediment strength
- Sediment sampling
- Sediment stratigraphy
- Seabed imaging
- Documentation of damage to earthen/hard structures
- …

Remote sensing (onshore):

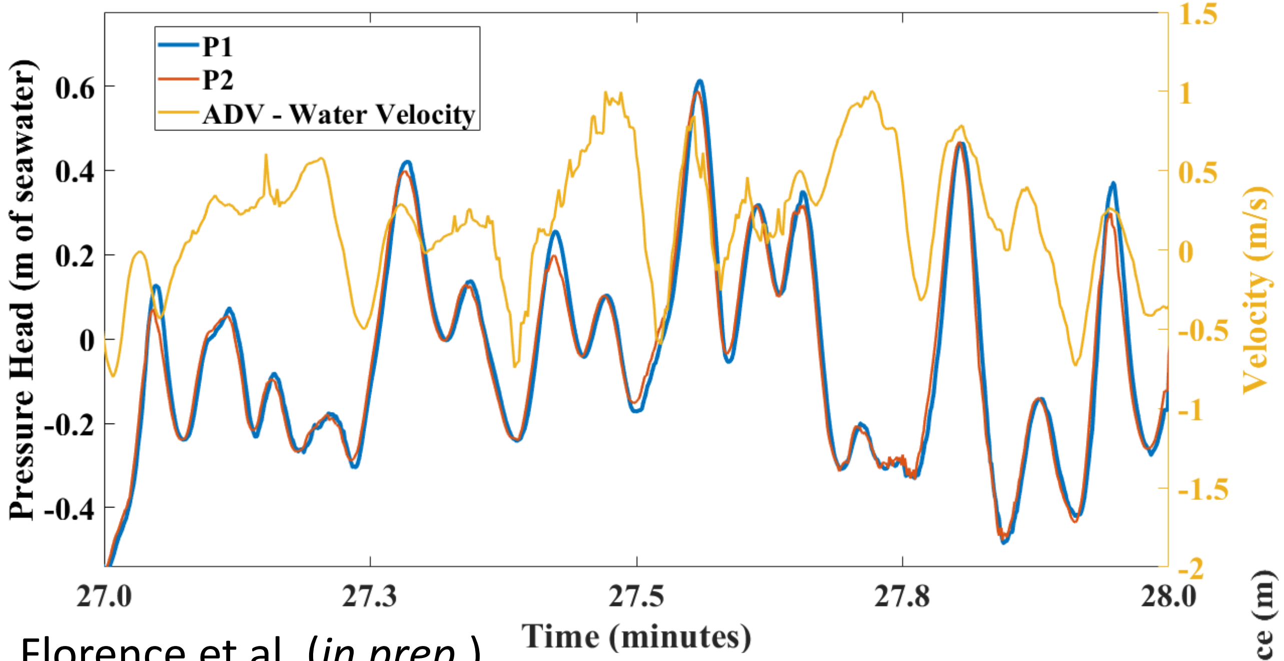
- Multi-/ Hyperspectral images
- Synthetic aperture radar (SAR, inSAR)
- Lidar
- Photogrammetry
- Aerial photos
- “CoastSnap”
- …

Pre-deployed sensors: *Pore pressure sensors*

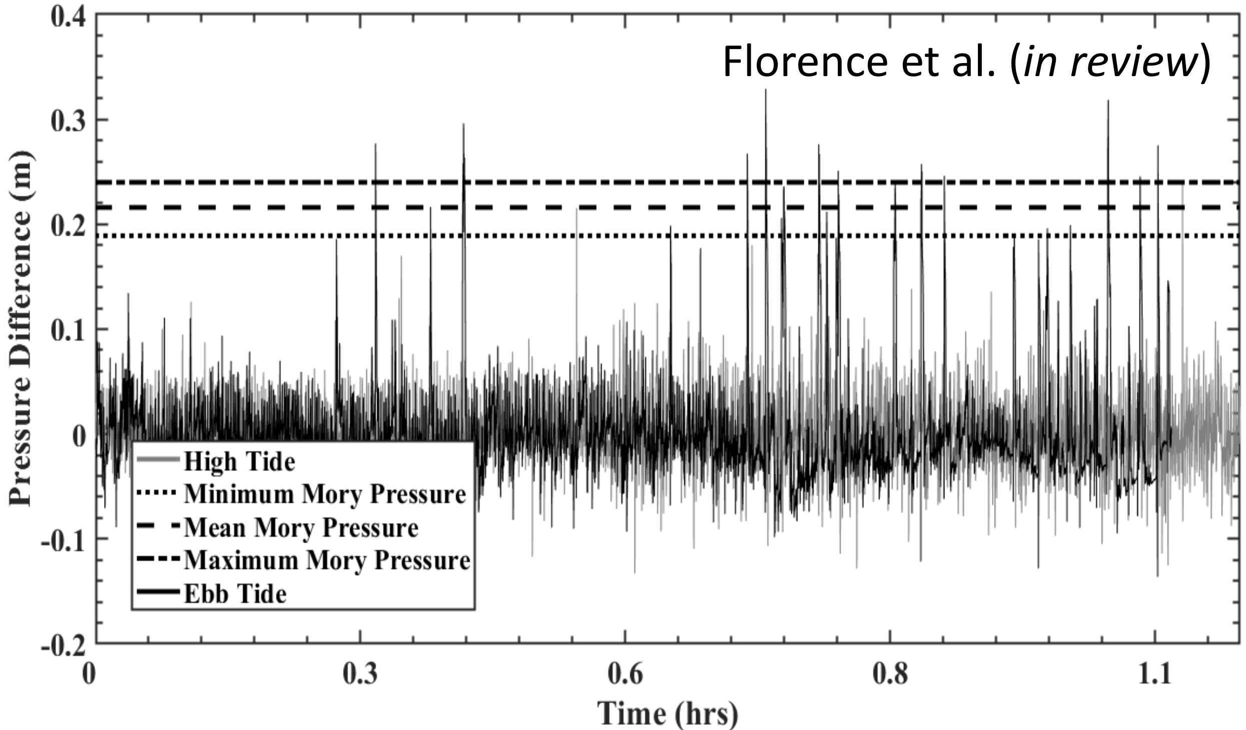


Stark et al. (2020)

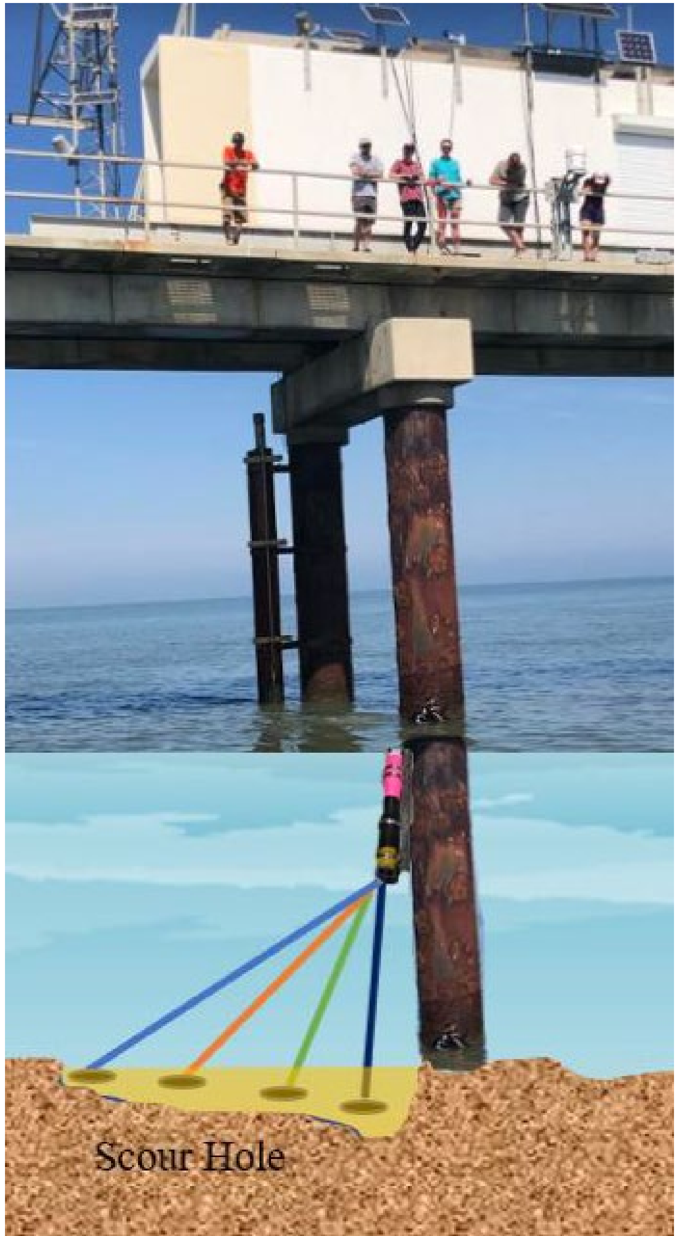
Pre-deployed sensors: *Pore pressure sensors*

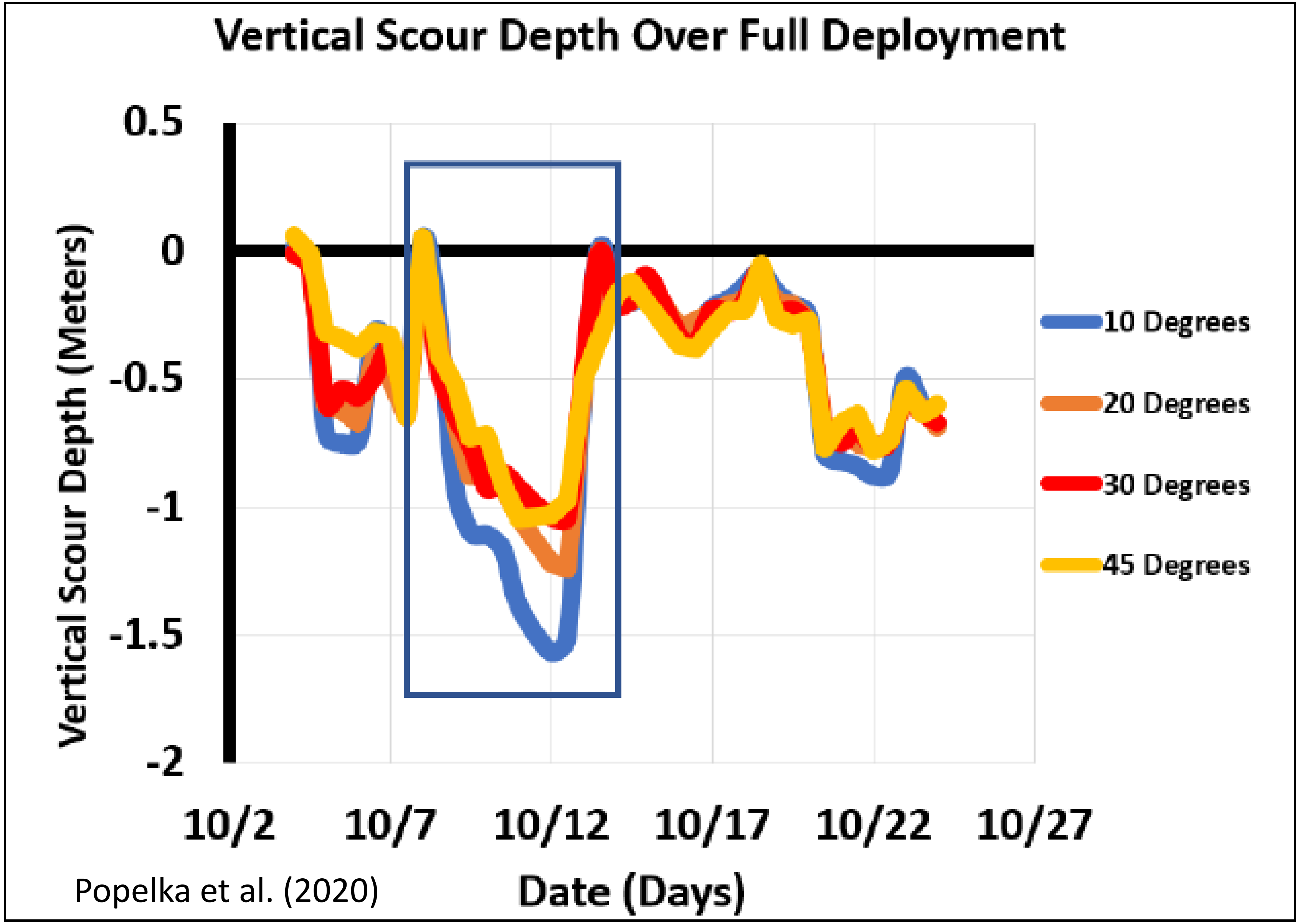


Florence et al. (*in prep.*)



Pre-deployed sensors: *Acoustic scour monitoring*





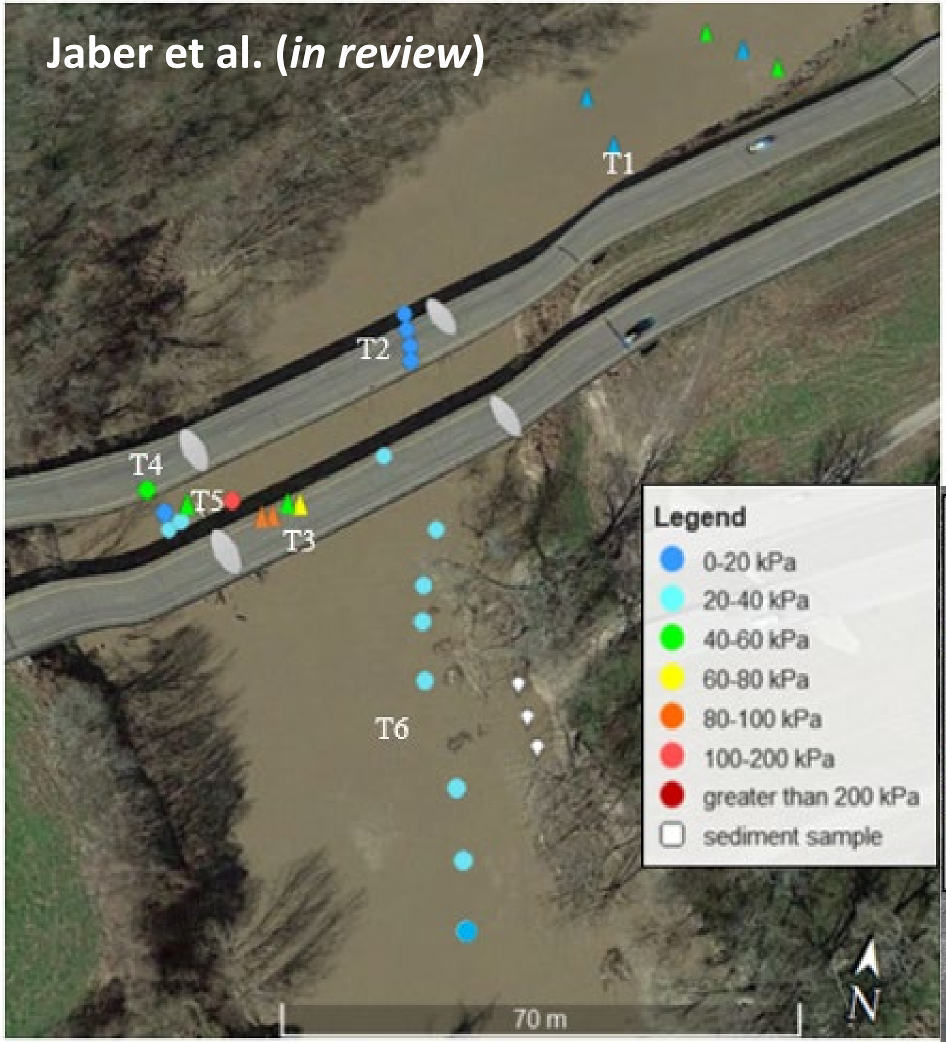
Post-event: *Sediment strength*

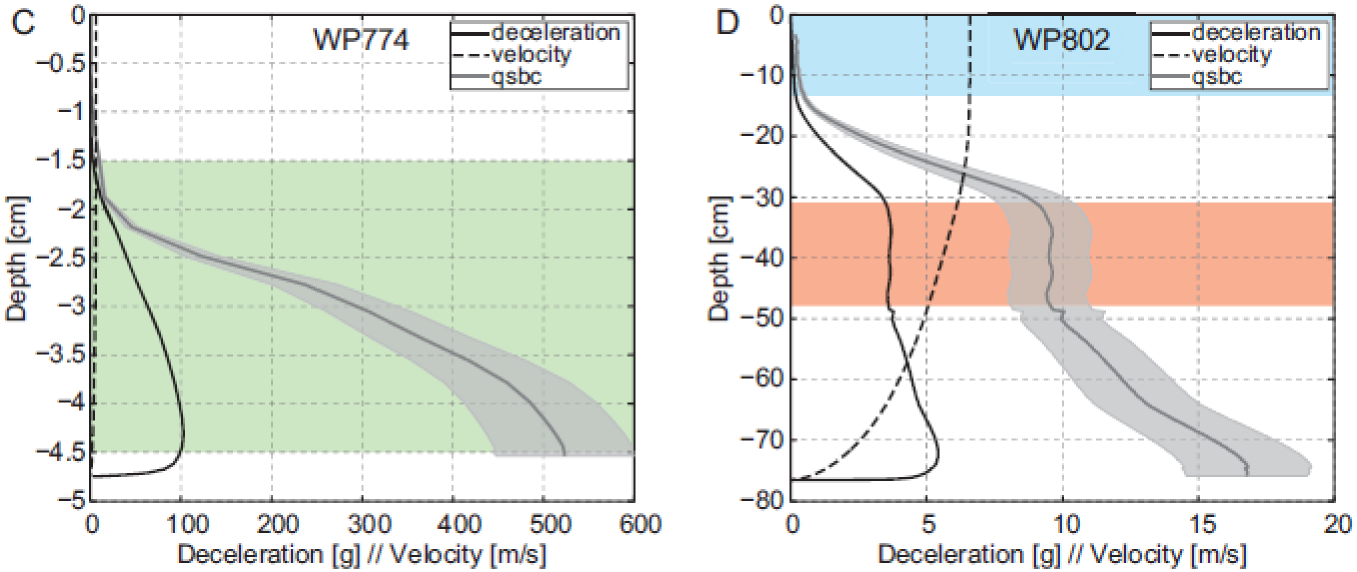
Portable free fall penetrometer

- Suitable for water depths < 200 m
- Suitable for deployment in waves and strong currents
- Robust against impact with debris
- Fast (no anchoring needed)
- Lightweight (no winch support needed)
- Penetration depths: lightweight probes typically: < 30 cm in sand; < 300 cm in mud
- Provides estimate of sediment strength in terms of undrained shear strength (muds) or friction angle and relative density (sands)

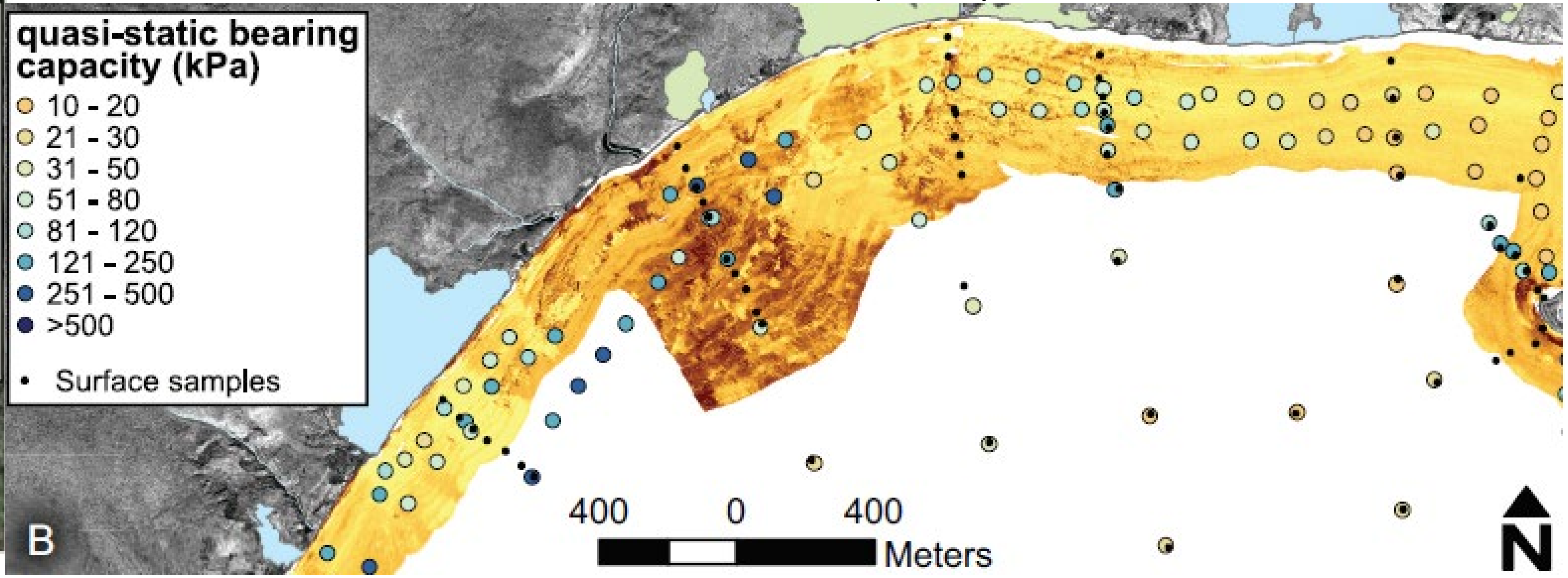
Post-event: *Sediment strength*

Portable free fall penetrometer



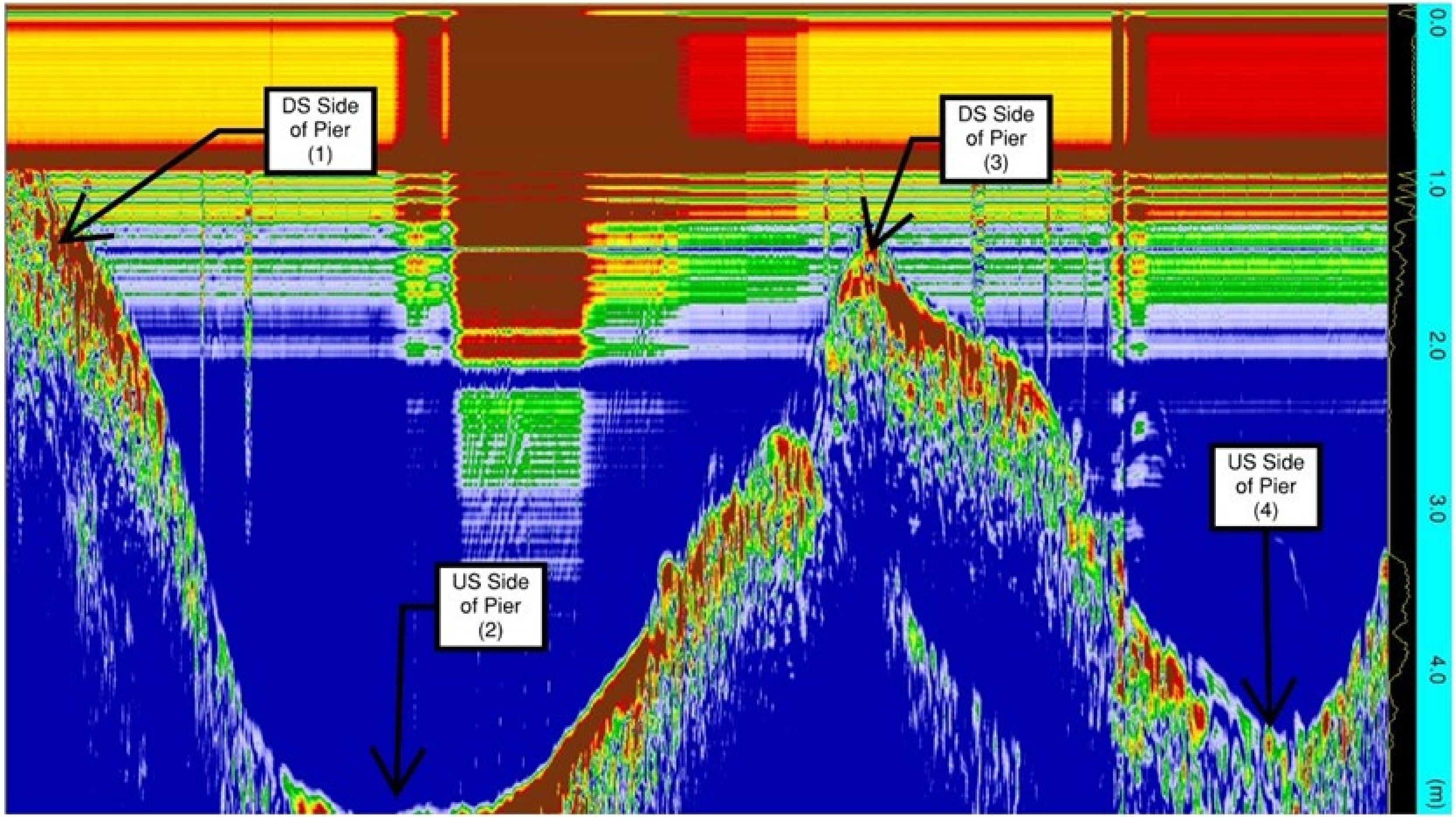


Stark et al. (2016)



Post-event: *Bathymetry & sediment stratigraphy*

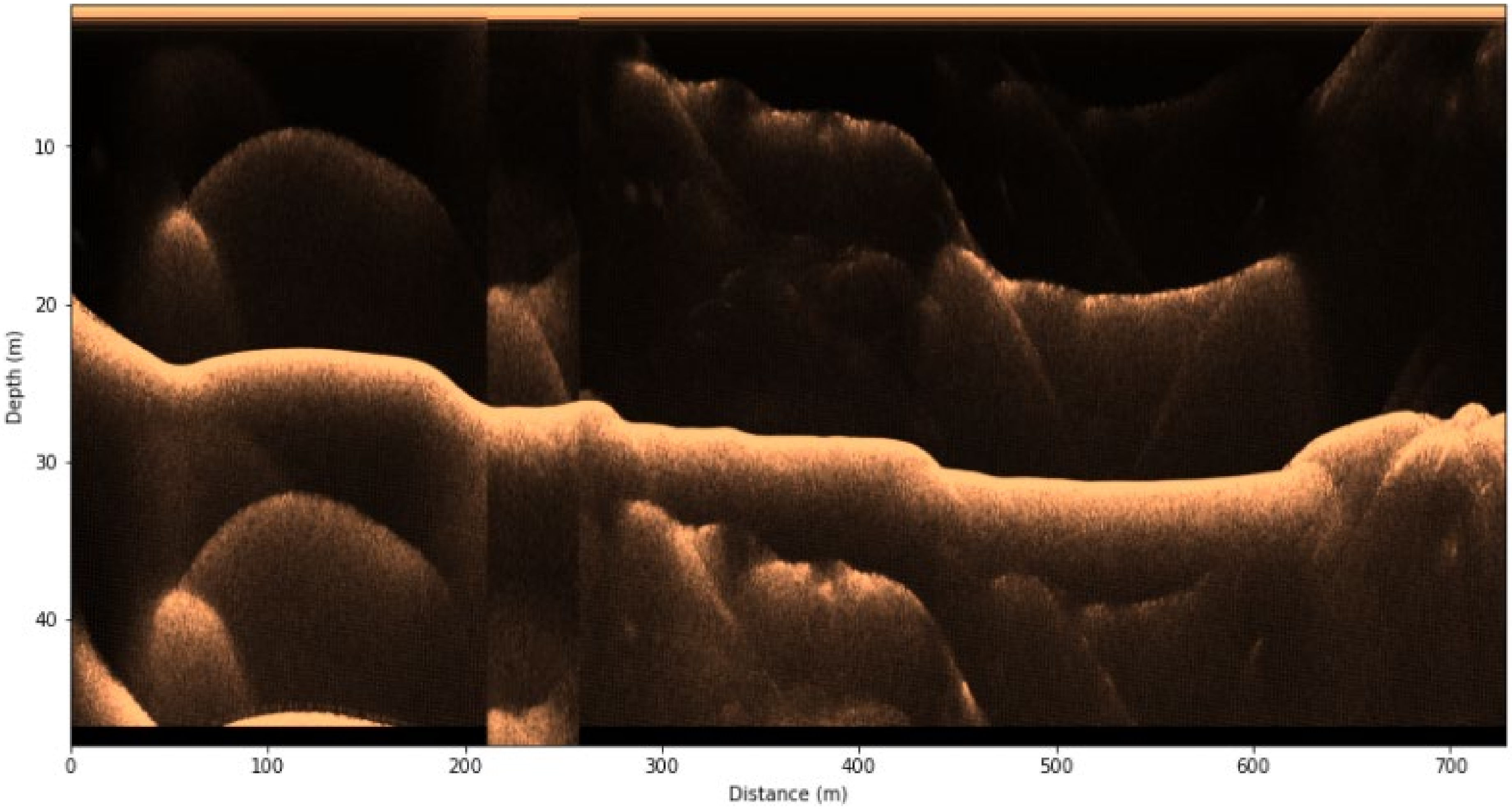
Chirp sonar



Stark et al. (2021a)

Post-event: *Bathymetry & sediment stratigraphy*

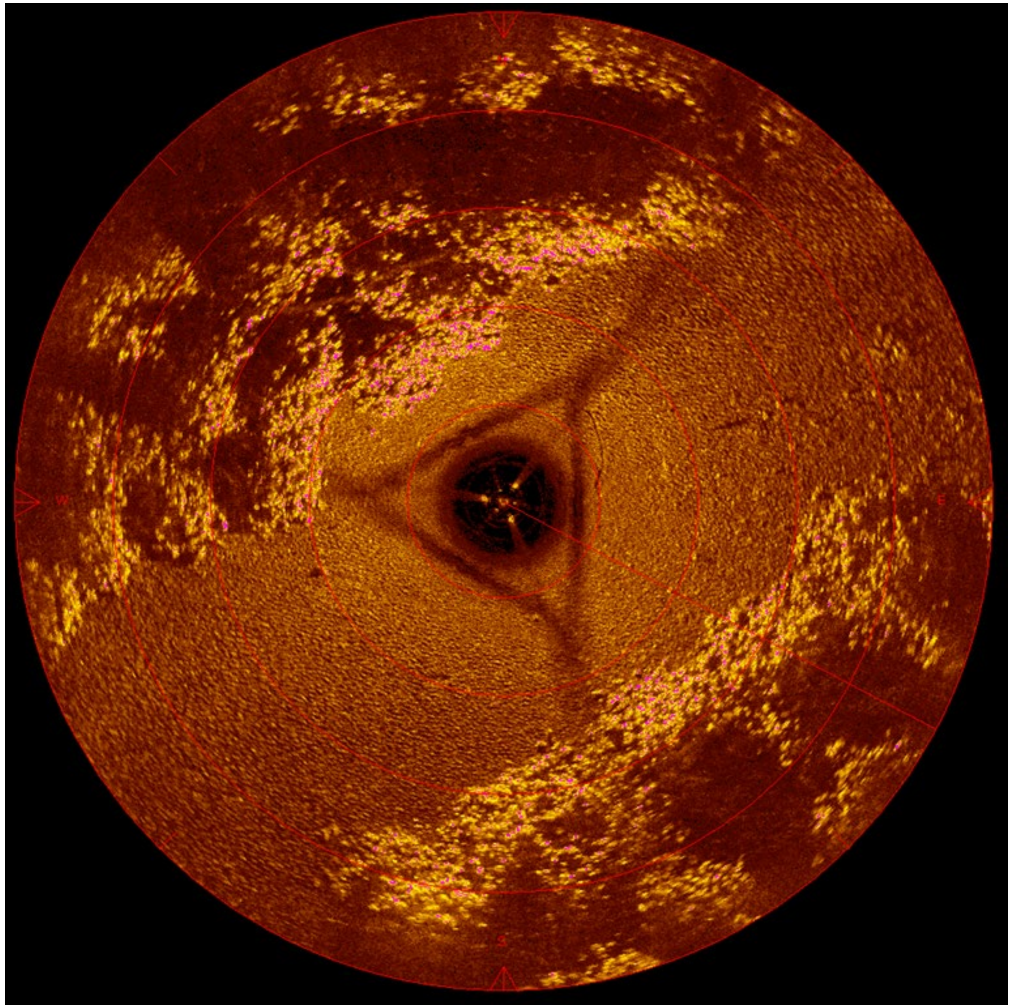
Chirp sonar

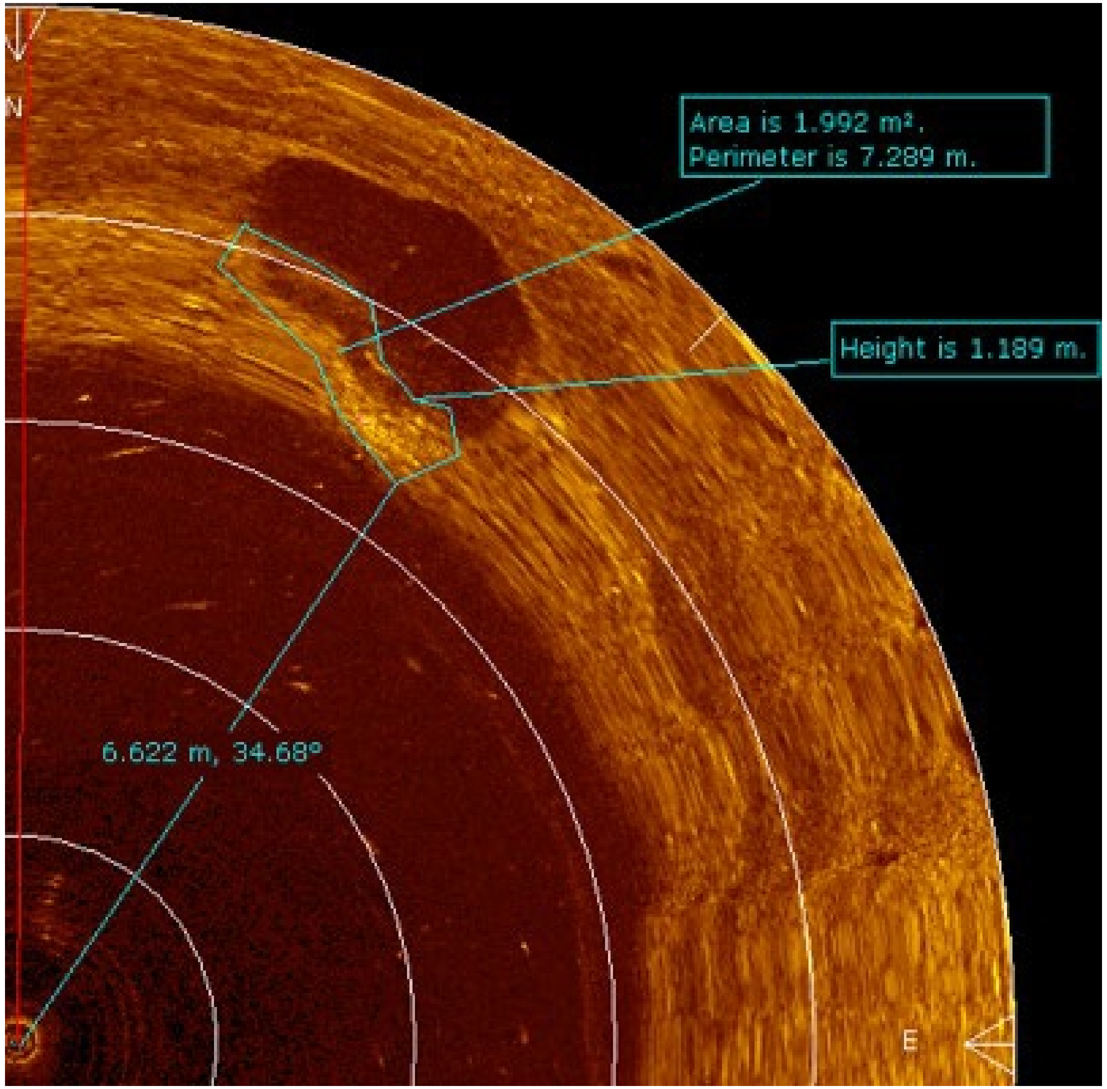


Stark et al. (2021b)

Post-event: *Seabed imaging*

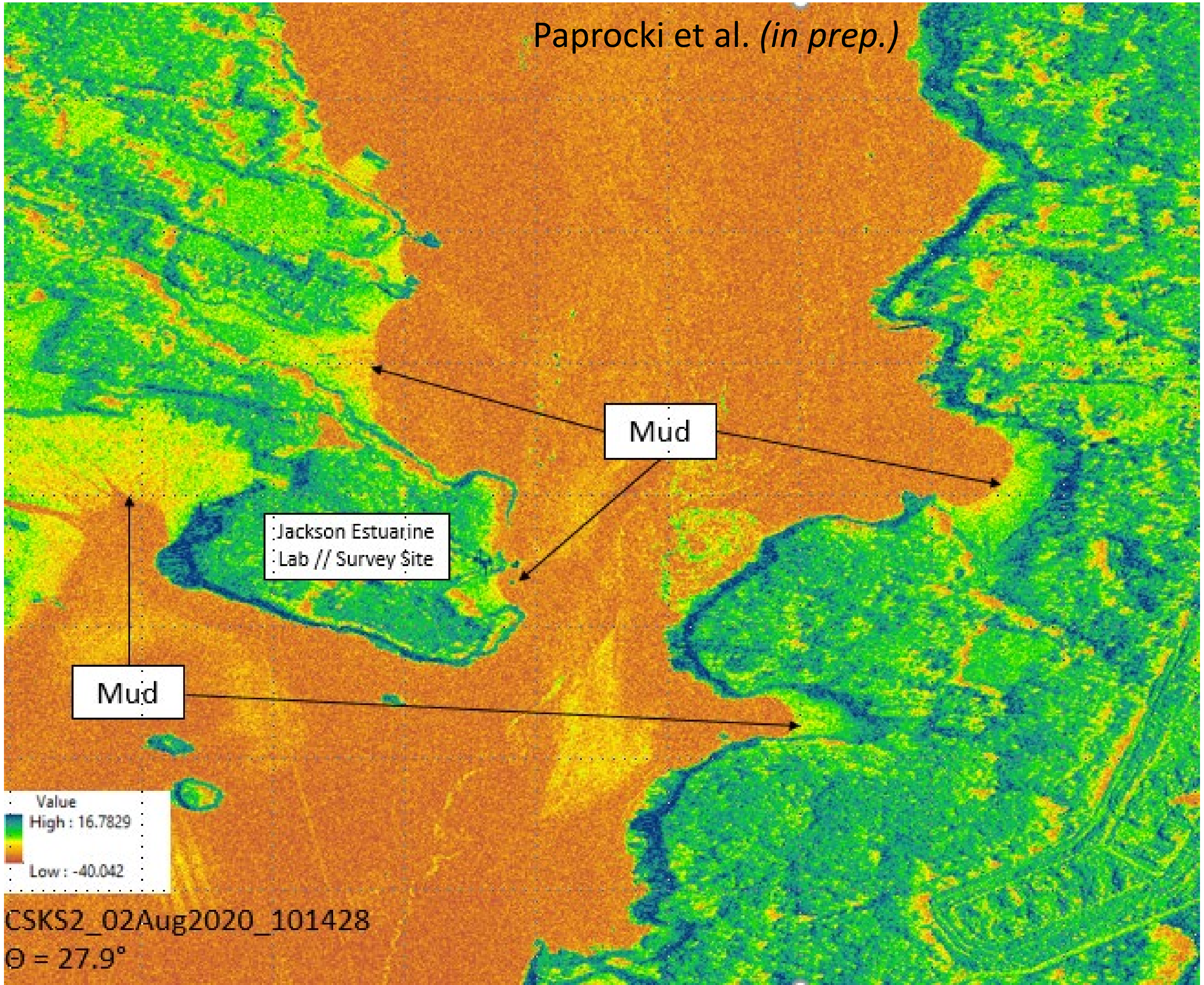
(Rotary) side scan sonar



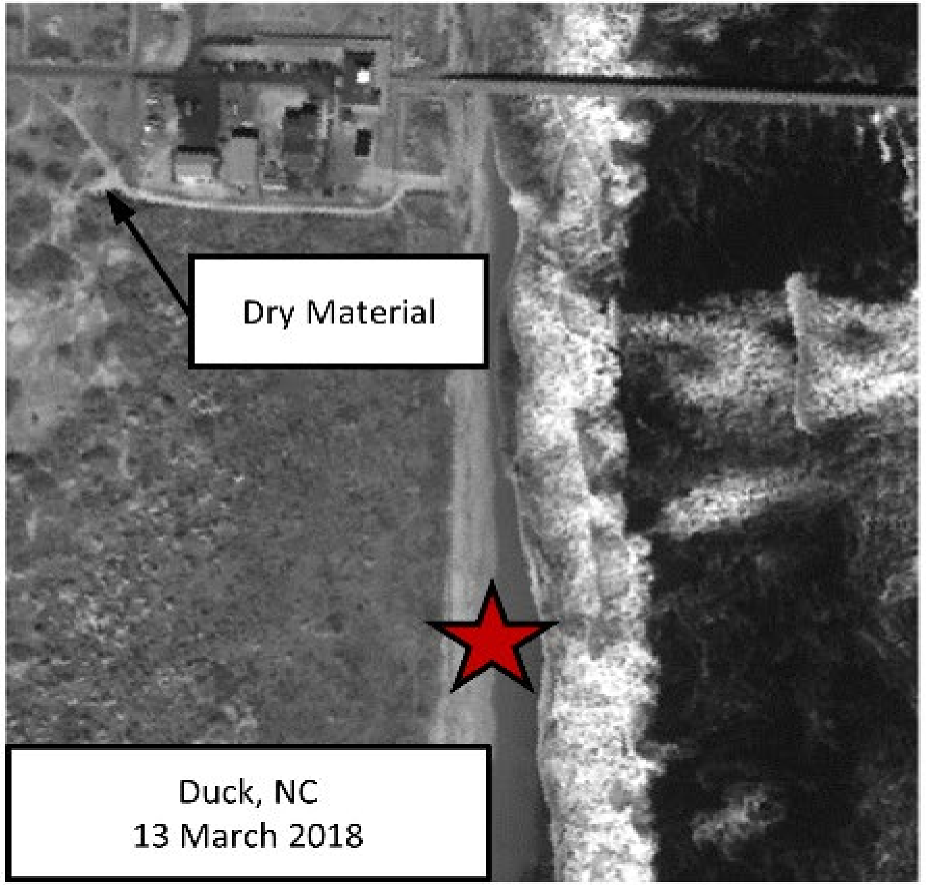


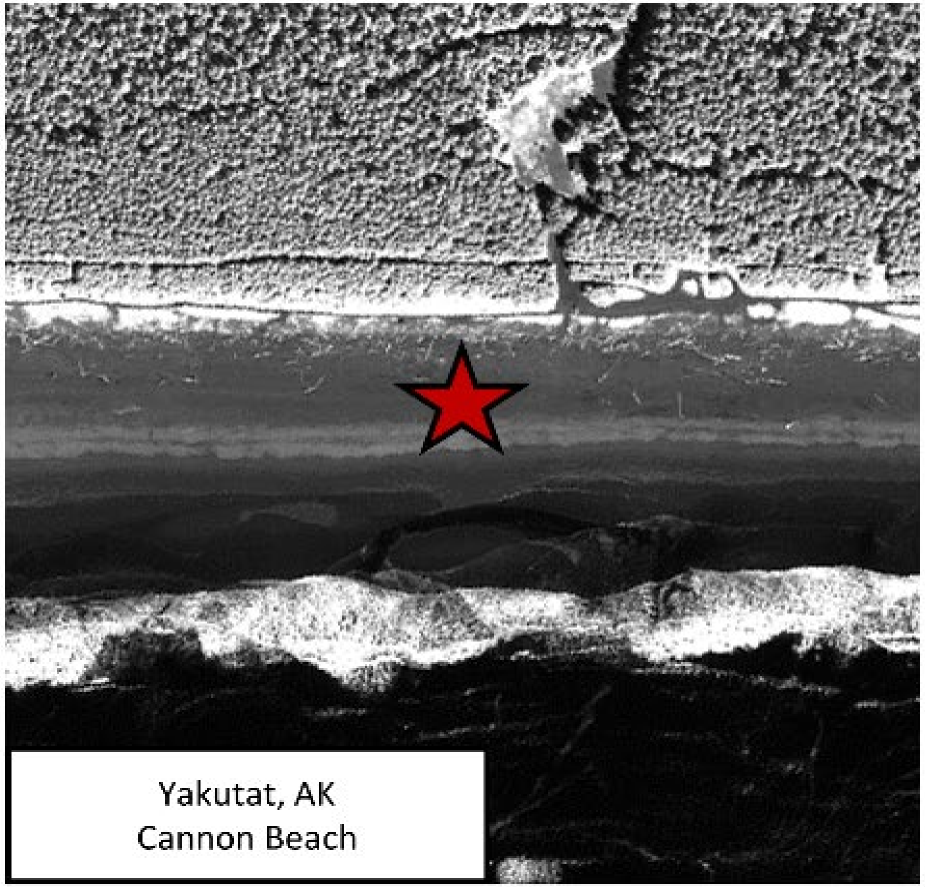
Stark et al. (2021a)

Remote sensing: *SAR*



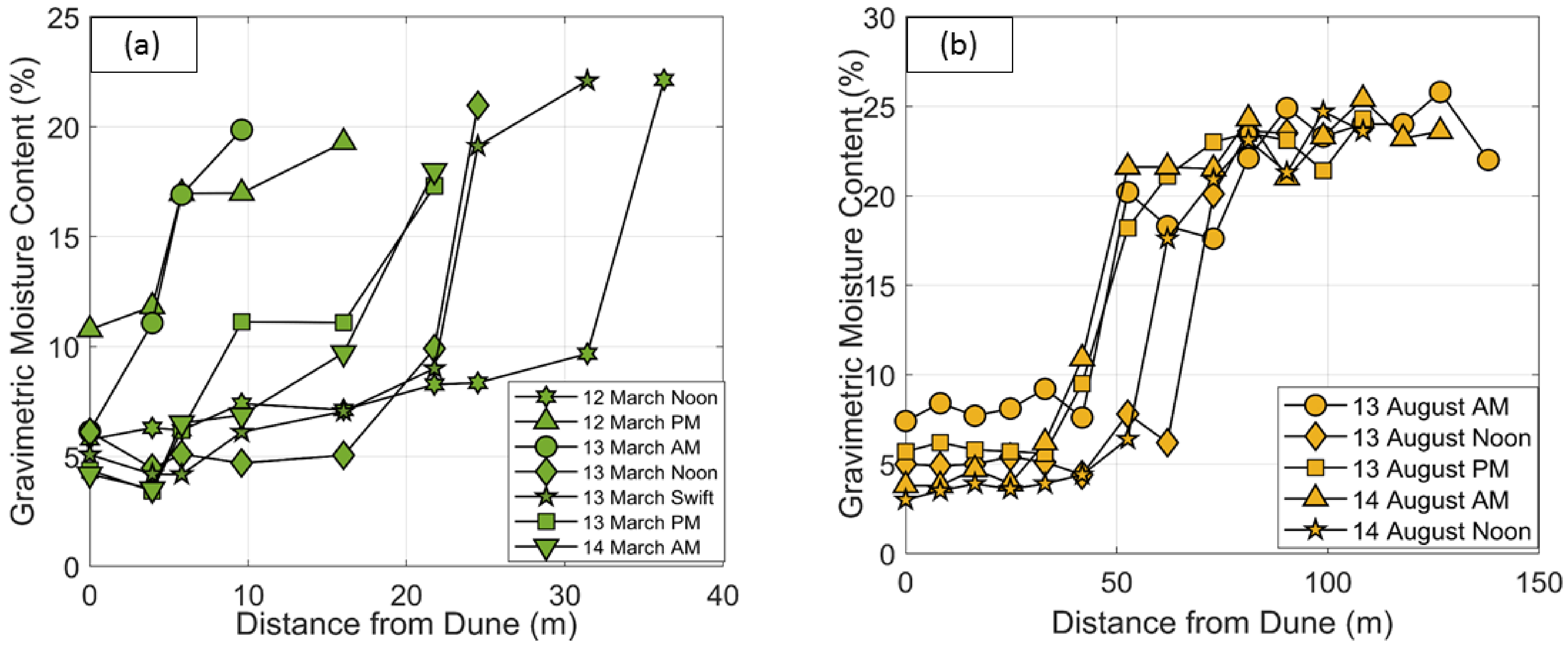
Remote sensing: *Multi-spectral imaging*





Paprocki et al. (2021)

Remote sensing: *Multi-spectral imaging*



Paprocki et al. (2021)

Concluding remarks

- Extreme event related data in subaquatic environments are highly perishable due to the direct relationships between hydrodynamics, geomorphology, and sediment properties
- Measurements are often challenged by risks to personnel and equipment, as well as access issues
- Pre-event deployments, post-event reconnaissance measurements, and remote sensing in a combined strategy can offer pathways to overcome these challenges
- Recent advances in geotechnical and geophysical sensor technologies and the integration of both offer potentially safer and more efficient options for extreme event related data collections

Electrical geotechnics for rapid testing

Stacey Kulesza, PhD, PE
Associate Professor
Kansas State University
May 24, 2021

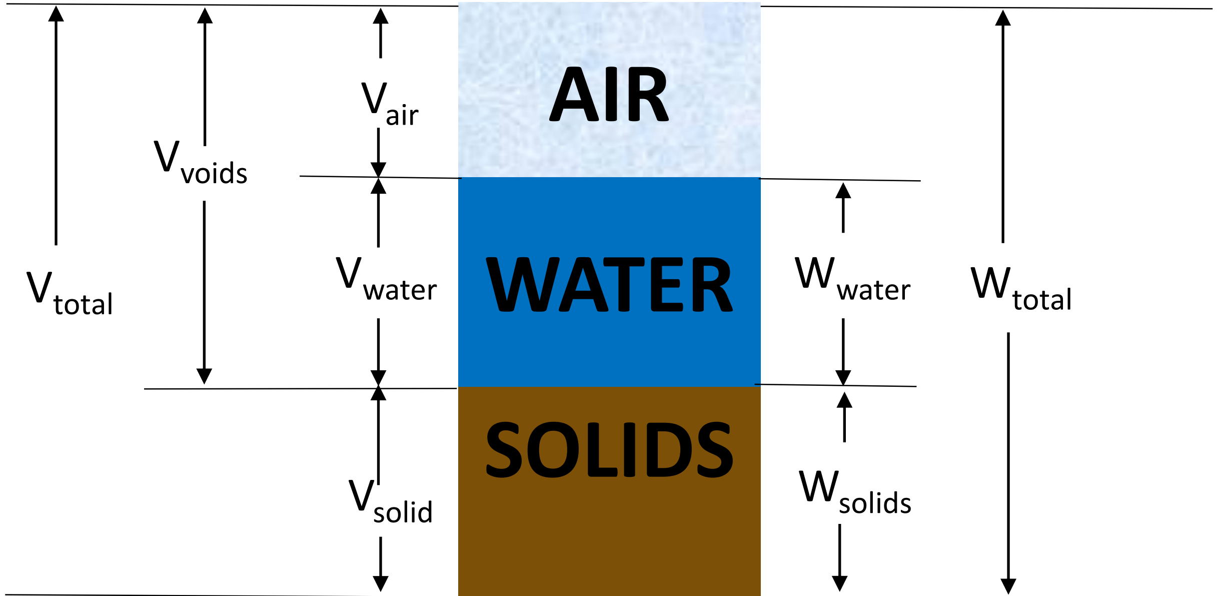
Electrical Resistivity Fundamentals

Electrical Properties of the Subsurface

Ohm's Law

- $\boldsymbol{J} = \sigma \boldsymbol{E} = \frac{1}{\rho} \boldsymbol{E}$

σ= conductivity (S/m)
ρ= resistivity (Ωm)



Influencing variables

- Temperature
- Water content
- **Degree of saturation**
- Porosity
- Permeability
- Mineralogy
- Mobilized ions

Extreme events

Influencing variables

- Temperature
- Water content
- **Degree of saturation**
- Porosity
- Permeability
- Mineralogy
- Mobilized ions

Applications

Post flood/debris flow anomalies

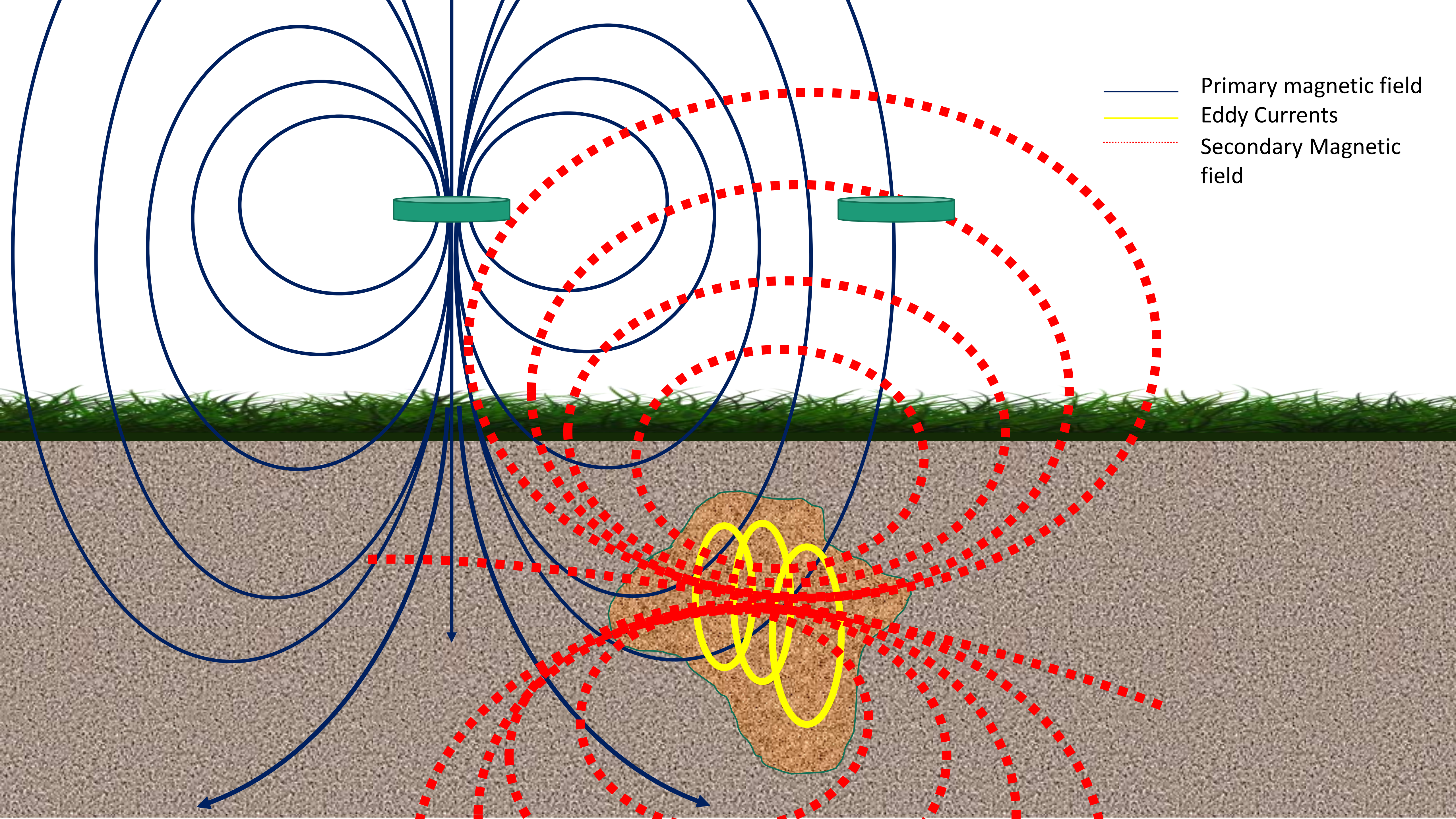
Identify layers post wildfire or landslide

Identify scour holes, seepage channels, buried infrastructure

Quickly measure of general stratigraphy

Near surface electrical conductivity

- Electromagnetic induction, non-contact
  - Remote, natural source
  - Controlled source
    - Frequency domain
    - Time domain


Primary magnetic field
Eddy Currents
Secondary Magnetic field

Electromagnetic Induction

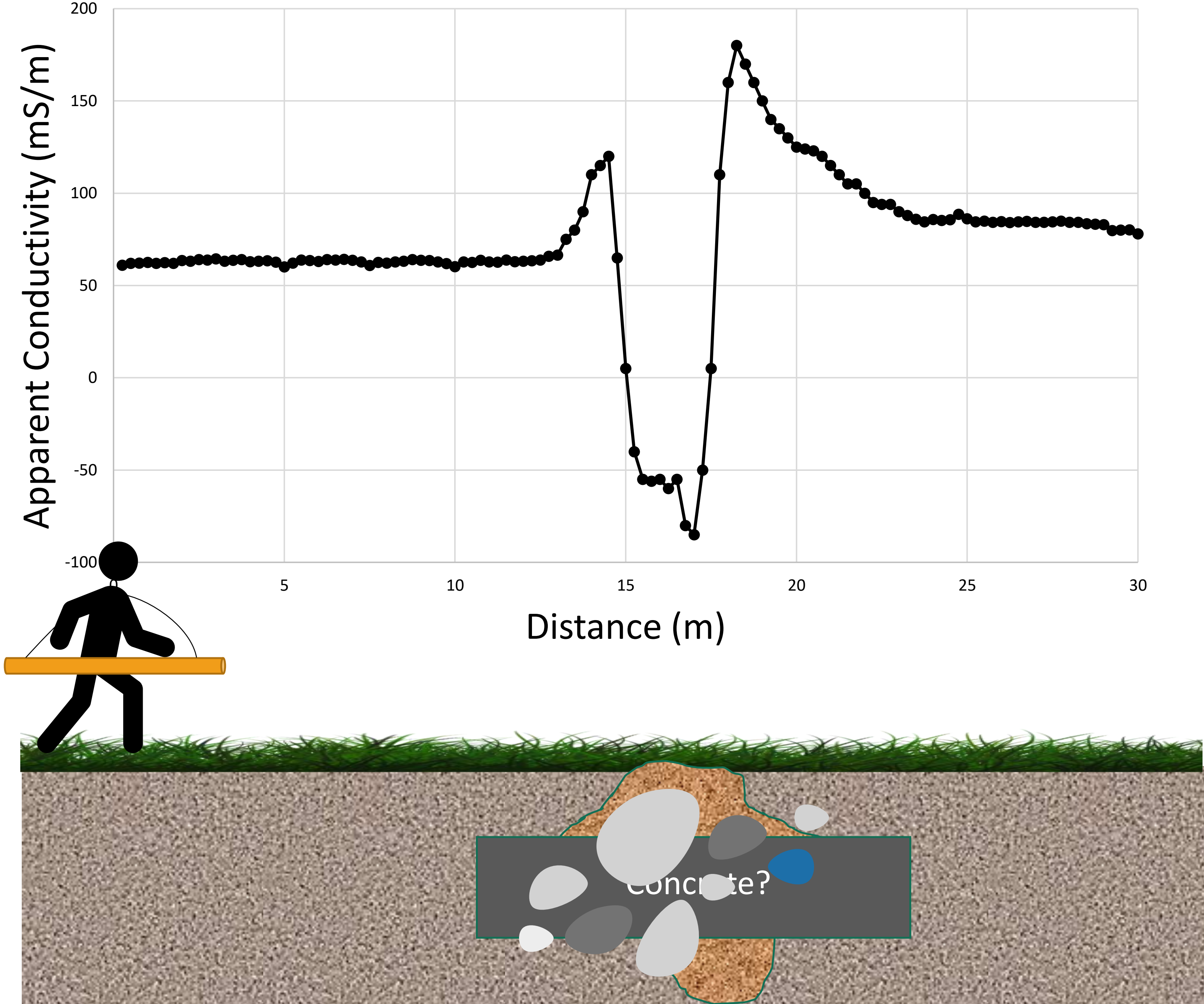
Advantages

- Non-destructive
- Fast
- Relatively inexpensive
- Inductive type are non-contact
- Obtain spatial mapping or monitoring of soil properties

Limitations

- Depth weighted average apparent conductivity
- Generally 1D very near surface (less than 10’) surveys
- True conductivity models non-trivial
- 2D or 3D profiles non-trivial

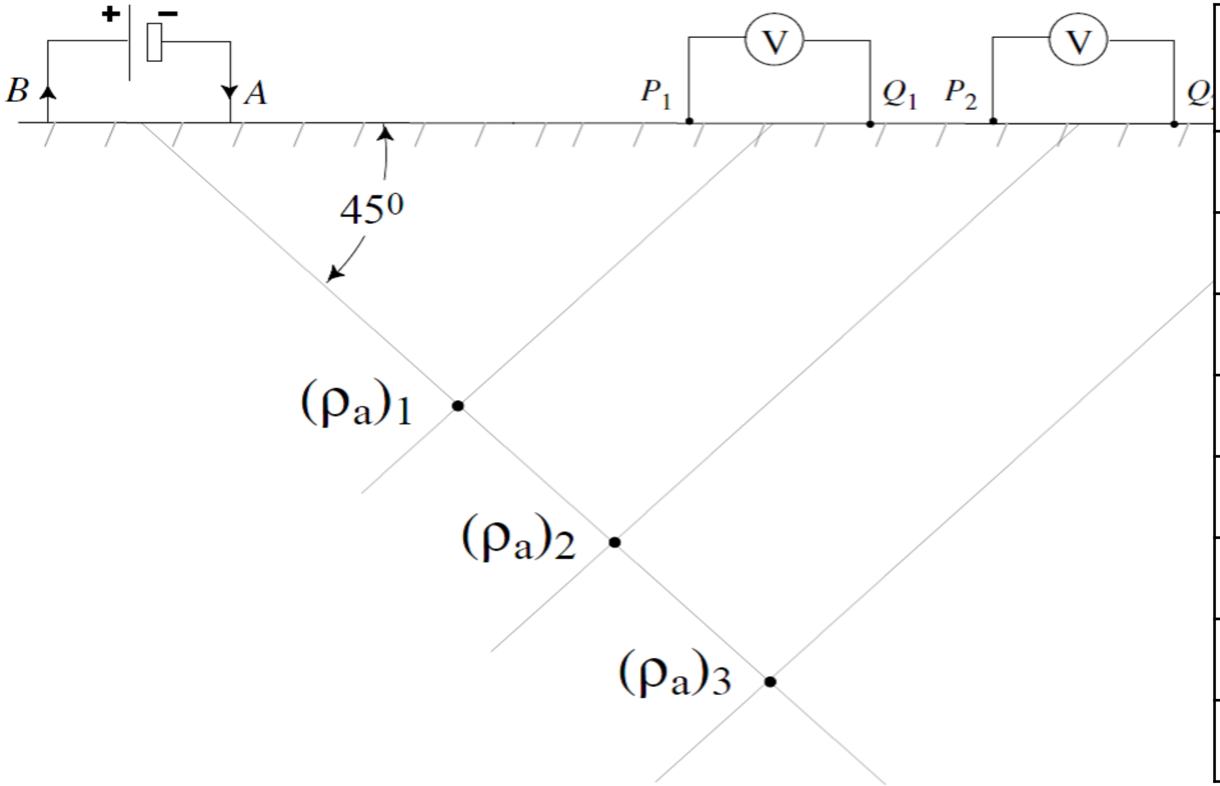
Electromagnetic Induction Example



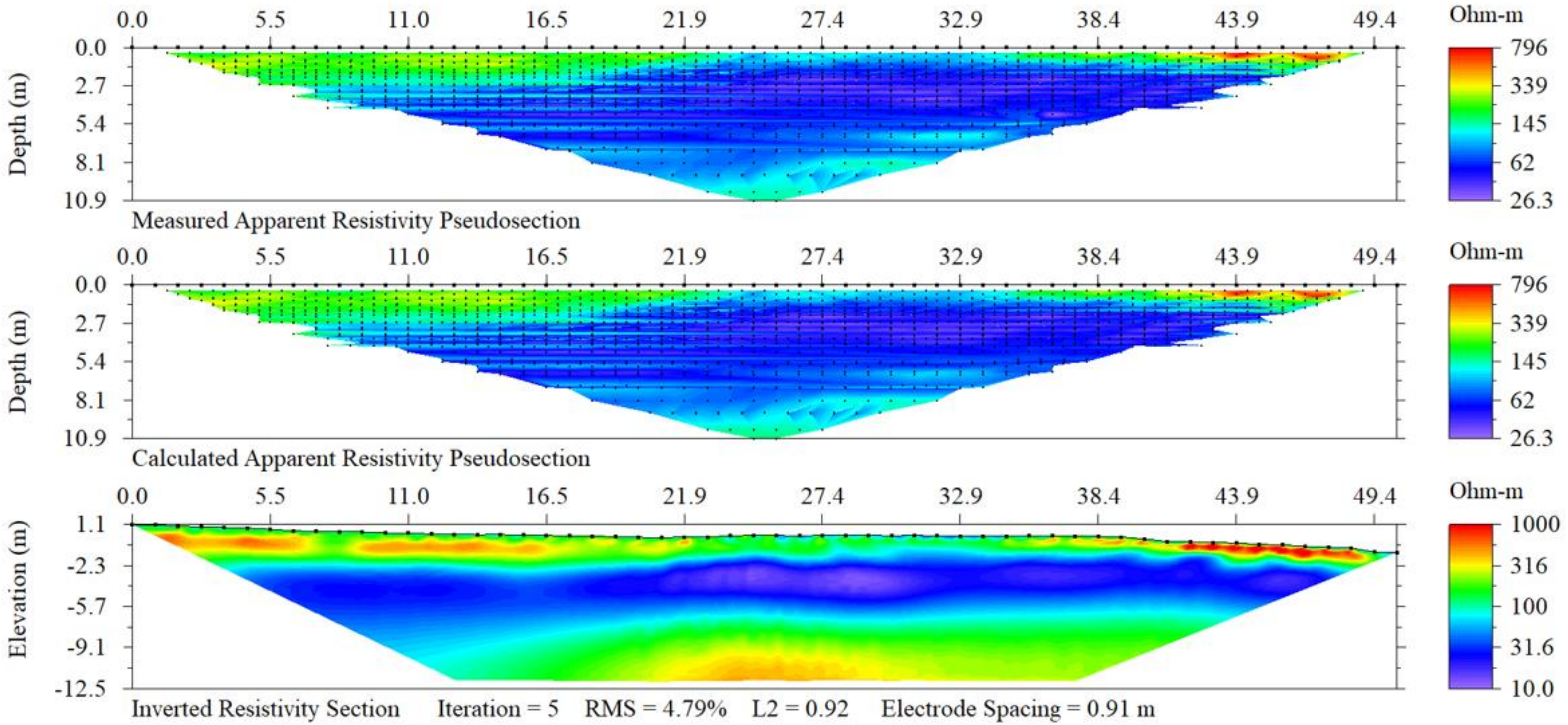
Near surface electrical resistivity

- Galvanic (direct current) contact with earth
  - High resolution characterization
  - Monitoring easy to implement
  - Charge storage (induced polarization properties) can be collected with galvanic methods
    - Frequency domain (lab)
    - Time domain (field)

Electrical Resistivity Imaging



Material	Resistivity (Ωm)
Fresh water	1 - 100
Clay	1-20
Partially saturated sand	20-200
Dry sand and gravel	500 - 10^4
Shale	1-500
Sandstone	100 - 10^3
Limestone	10^3 – 10^5
Igneous rocks	10^2 - 10^5

0.0 5.5 11.0 16.5 21.9 27.4 32.9 38.4 43.9 49.4
Depth (m)
0.0 2.7 5.4 8.1 10.9
Ohm-m
796 339 145 62 26.3
Measured Apparent Resistivity Pseudosection
0.0 5.5 11.0 16.5 21.9 27.4 32.9 38.4 43.9 49.4
Depth (m)
0.0 2.7 5.4 8.1 10.9
Ohm-m
796 339 145 62 26.3
Calculated Apparent Resistivity Pseudosection
0.0 5.5 11.0 16.5 21.9 27.4 32.9 38.4 43.9 49.4
Elevation (m)
1.1 -2.3 -5.7 -9.1 -12.5
Ohm-m
1000 316 100 31.6 10.0
Inverted Resistivity Section
Iteration = 5
RMS = 4.79%
L2 = 0.92
Electrode Spacing = 0.91 m

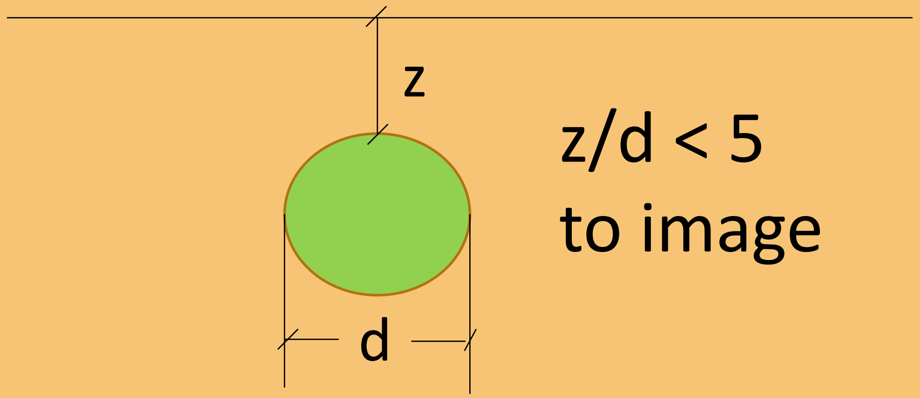
Electrical Resistivity Imaging

Advantages

- Non-destructive
- Capable of imaging large areas
- Intrinsic material property
- Increasingly common
- Obtain spatial mapping or monitoring of soil properties
- Obtain 2D or 3D profile of the subsurface
- Can tow through water or test underwater

Limitations

- Strong contrast between medium required
- High water content/salt content can distort images
- Need strong conceptual model and/or groundtruth



$z/d < 5$

to image

Electrical Resistivity Imaging

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- Obtain 2D or 3D profile of the subsurface
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Limitations

- Strong contrast between medium required
- High water content/salt content can distort images
- Need strong conceptual model and/or groundtruth
- Equipment is expensive
- Data processing requires experience
- Not a mobile measurement

Induced Polarization

- Temporary, reversible storage of charge by porous medium
  - Diffusion controlled EDL mechanism
  - Maxwell-Wagner mechanism

Measurement

Time domain — Primarily field

Frequency domain — Primarily lab

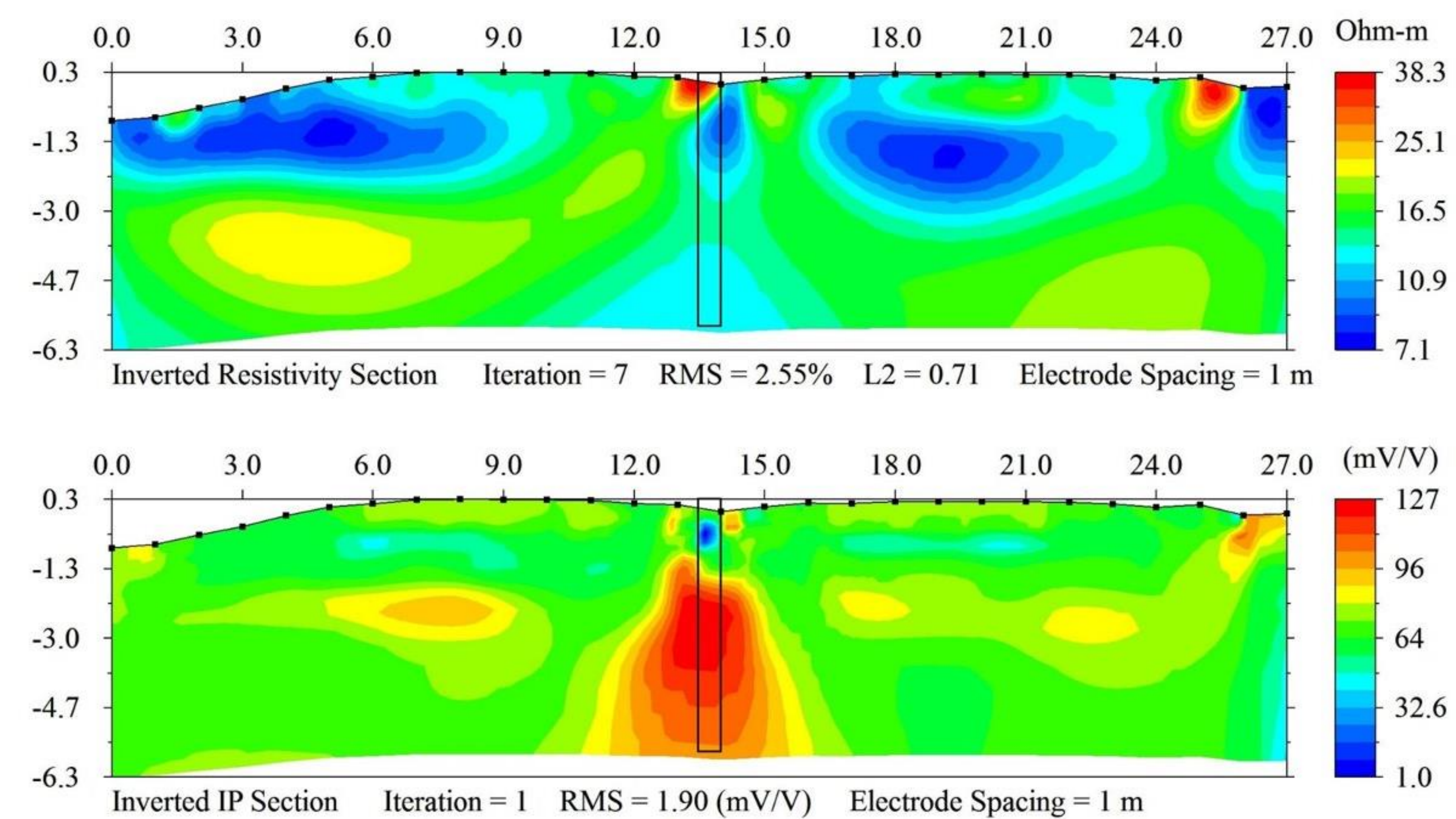
Induced Polarization Imaging

Advantages

- Non-destructive
- Capable of imaging large areas
- Provides additional data to supplement resistivity
- Polarization of reinforcement highly detectable

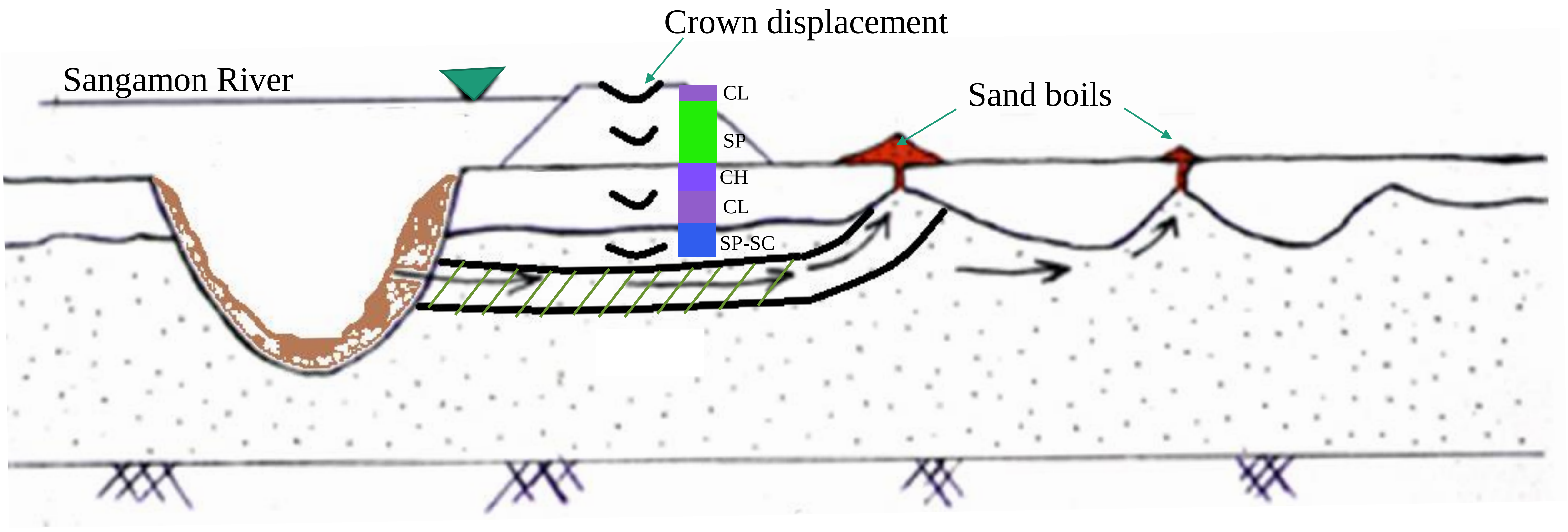
Limitations

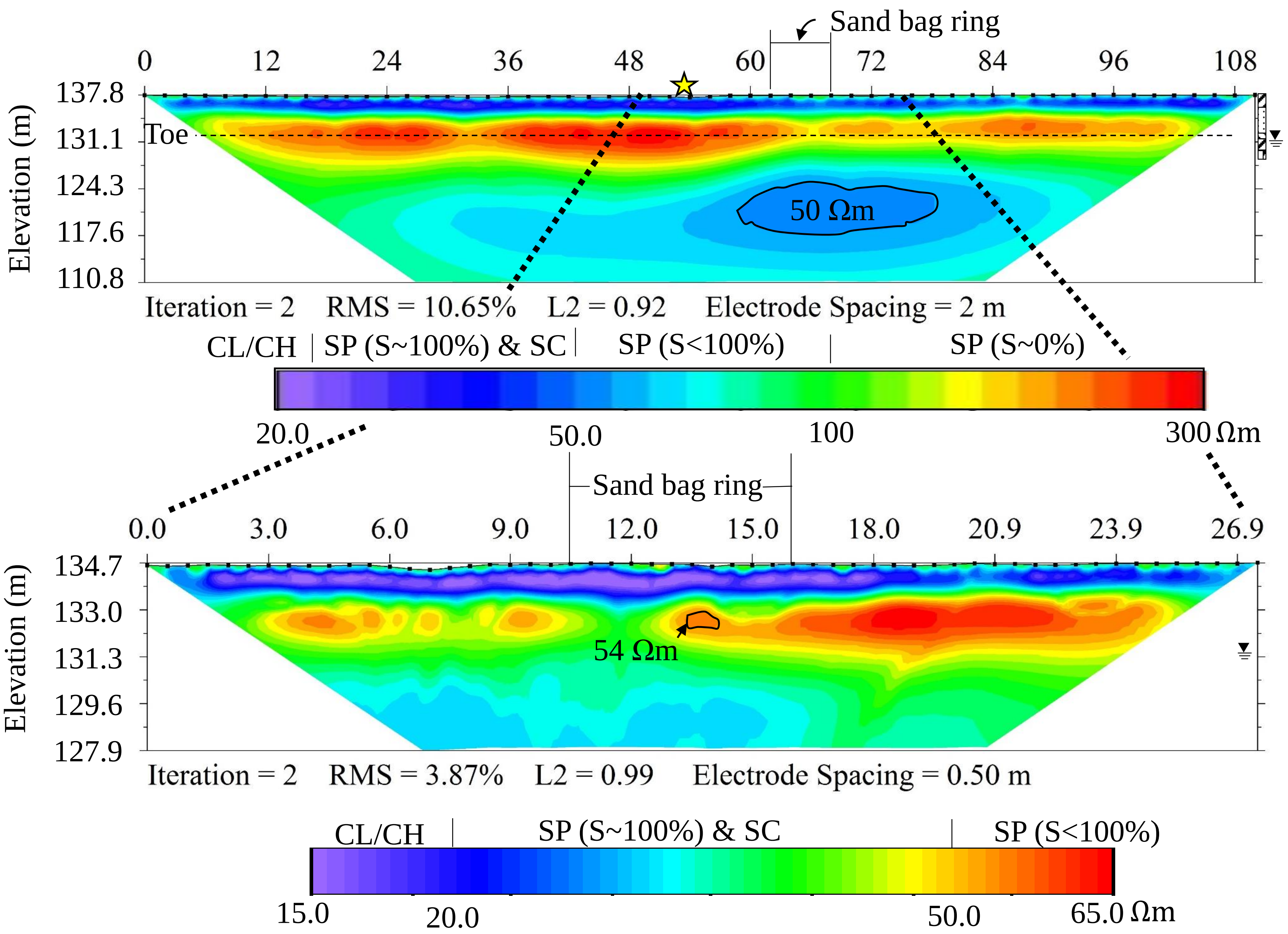
- Phenomena
- Can increase field measurement time x 3
- Non-polarizing electrodes increase installation time


0.0
3.0
6.0
9.0
12.0
15.0
18.0
21.0
24.0
27.0
Ohm-m
0.3
-1.3
-3.0
-4.7
-6.3
38.3
25.1
16.5
10.9
7.1
Inverted Resistivity Section
Iteration = 7
RMS = 2.55%
L2 = 0.71
Electrode Spacing = 1 m
0.0
3.0
6.0
9.0
12.0
15.0
18.0
21.0
24.0
27.0
(mV/V)
0.3
-1.3
-3.0
-4.7
-6.3
127
96
64
32.6
1.0
Inverted IP Section
Iteration = 1
RMS = 1.90 (mV/V)
Electrode Spacing = 1 m

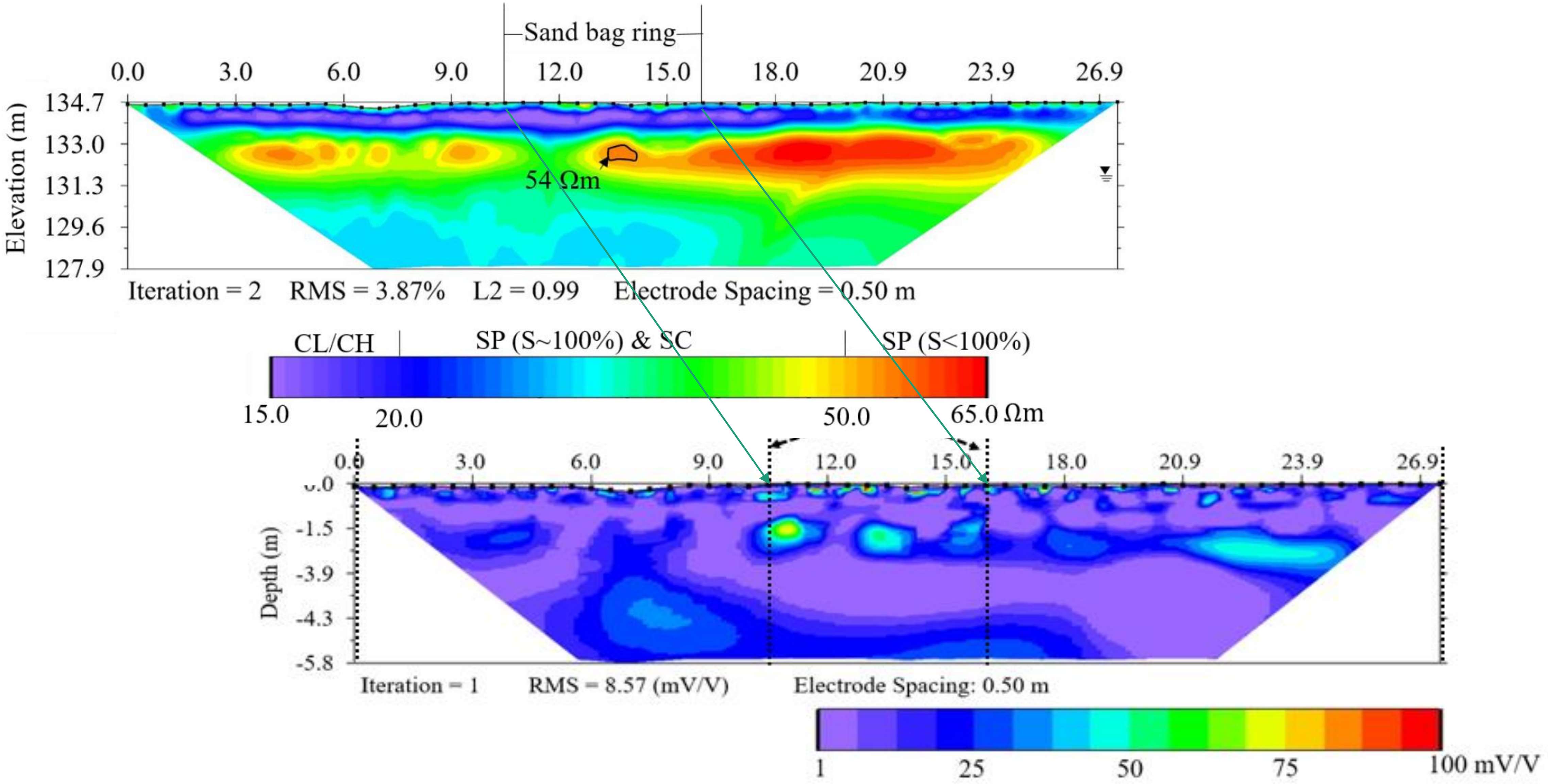
Electrical resistivity and induced polarization example

Conceptual Model




Sand bag ring
0
12
24
36
48
60
72
84
96
108
Elevation (m)
137.8
131.1
124.3
117.6
110.8
Toe
50 Ωm
Iteration = 2 RMS = 10.65% L2 = 0.92 Electrode Spacing = 2 m
CL/CH
SP (S~100%) & SC
SP (S<100%)
SP (S~0%)
20.0
50.0
100
300 Ωm
Sand bag ring
0.0
3.0
6.0
9.0
12.0
15.0
18.0
20.9
23.9
26.9
134.7
133.0
131.3
129.6
127.9
54 Ωm
Iteration = 2 RMS = 3.87% L2 = 0.99 Electrode Spacing = 0.50 m
CL/CH
SP (S~100%) & SC
SP (S<100%)
15.0
20.0
50.0
65.0 Ωm

IP Results



Sand bag ring
0.0
3.0
6.0
9.0
12.0
15.0
18.0
20.9
23.9
26.9
Elevation (m)
134.7
133.0
131.3
129.6
127.9
54 Ωm
Iteration = 2 RMS = 3.87% L2 = 0.99 Electrode Spacing = 0.50 m
CL/CH
SP (S~100%) & SC
SP (S<100%)
15.0
20.0
50.0
65.0 Ωm
Depth (m)
-1.5
-3.9
-4.3
-5.8
Iteration = 1 RMS = 8.57 (mV/V) Electrode Spacing: 0.50 m
1
25
50
75
100 mV/V

Conclusions

- Electrical methods can give valuable data very quickly following an extreme event
- Electrical resistivity / conductivity anomalies can guide where to sample, where to avoid, give general stratigraphy
- Many geophysical methods can test through water
- All methods have advantages and limitations
- Return on investment is high
  - Some data are better than no data following extreme event
  - Valuable tools when planning “normal” site investigation
  - Increasing research on other novel applications for transportation geotech

Electrical geotechnics for rapid testing

Stacey Kulesza, PhD, PE
Associate Professor
Kansas State University
May 24, 2021

Surface & Borehole Geophysical Methods for Rapid Geotechnical Response to Extreme Events

Robert Garfield, P.G.
Owner/Principal Borehole Geophysicist

Hager-Richter Geoscience, Inc.
www.hager-richter.com

Why geophysics for rapid geotechnical response to extreme events?

Geophysical Methods

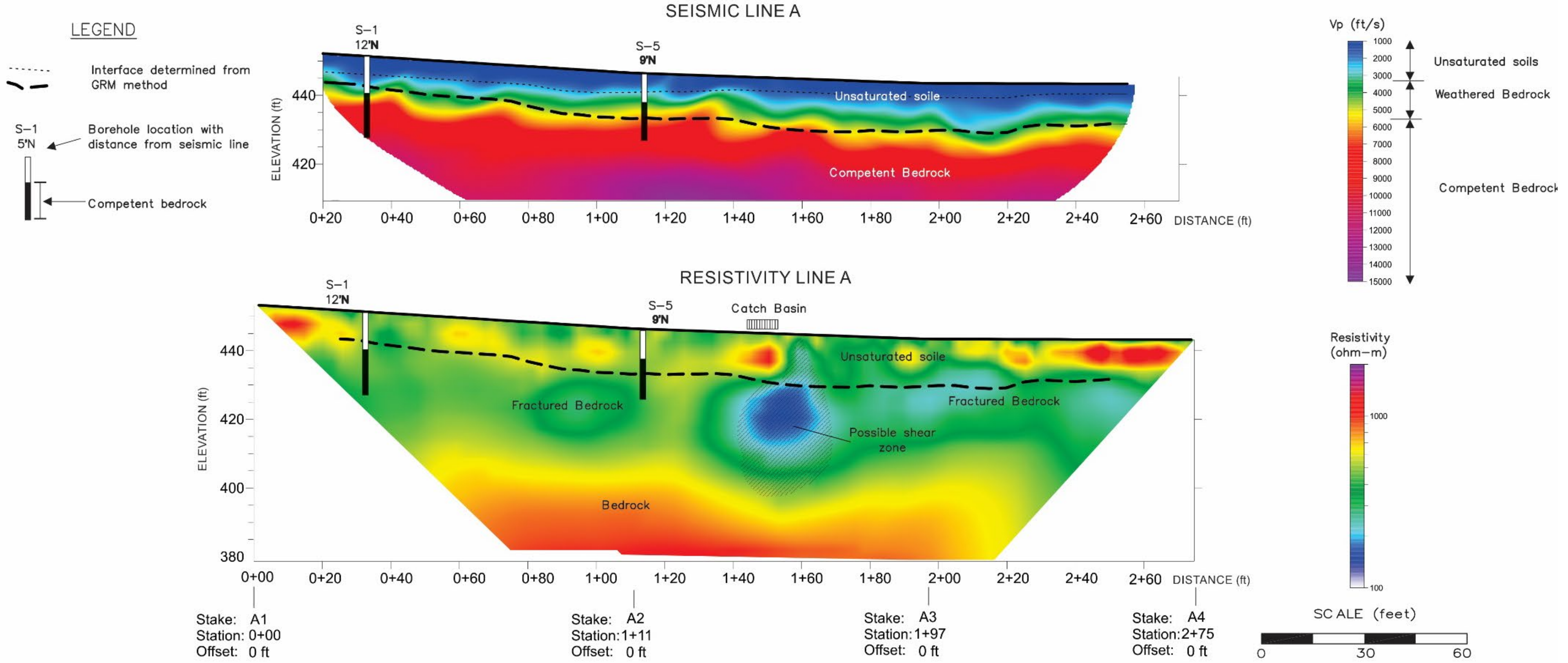
- Seismic
- Electrical
- Ground Penetrating Radar
- Electromagnetic
- Magnetic
- Gravity
- Televiewer Imaging

Geotechnical Applications

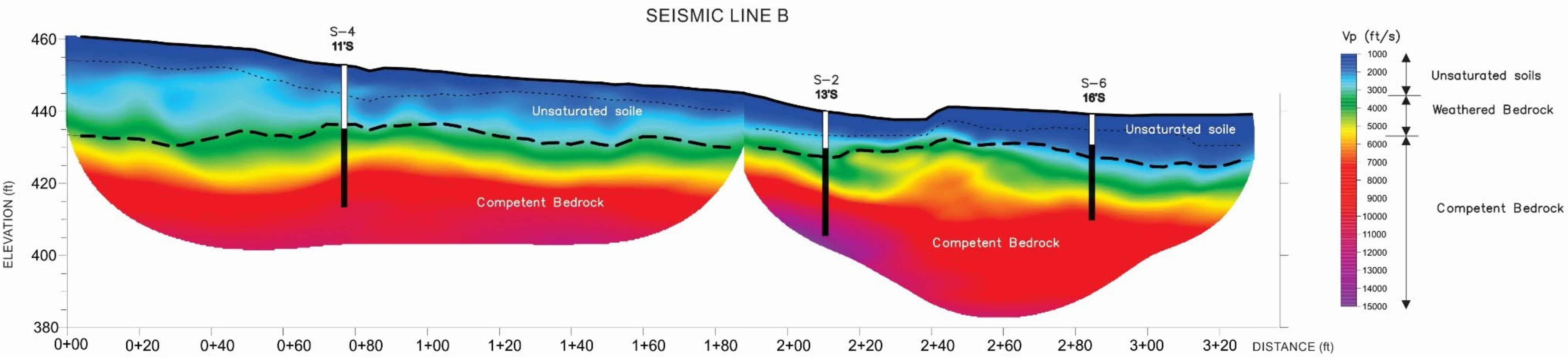
- Location of natural and man-made subsurface objects and voids
- Nature of geology
- Condition and depths of foundations
- Depth and rippability of bedrock
- Rock slope stability
- Temporal subsurface changes

Case Study – Slope Failure
PA SR87, Barbours, PA
for PennDOT District 3 and its Representatives

- **Objectives**
  - Determine the depth and configuration of the bedrock surface.
  - Detect a possible bedrock shear zone that bisects the failed slope.
- **Methods**
  - Seismic Refraction Tomography
  - Electrical Resistivity Imaging (ERI)

SEISMIC LINE A
LEGEND
Interface determined from GRM method
S–1 5'N
Borehole location with distance from seismic line
Competent bedrock
S–1 12'N
S–5 9'N
ELEVATION (ft)
440
420
Unsaturated soile
Competent Bedrock
0+20 0+40 0+60 0+80 1+00 1+20 1+40 1+60 1+80 2+00 2+20 2+40 2+60 DISTANCE (ft)
Vp (ft/s)
1000 2000 3000 4000 5000 6000 7000 8000 9000 10000 11000 12000 13000 14000 15000
Unsaturated soils
Weathered Bedrock
Competent Bedrock
RESISTIVITY LINE A
S–1 12'N
S–5 9'N
Catch Basin
Unsaturated soile
Fractured Bedrock
Fractured Bedrock
Possible shear zone
Bedrock
ELEVATION (ft)
440
420
400
380
0+00 0+20 0+40 0+60 0+80 1+00 1+20 1+40 1+60 1+80 2+00 2+20 2+40 2+60 DISTANCE (ft)
Resistivity (ohm–m)
1000
100
Stake: A1
Station: 0+00
Offset: 0 ft
Stake: A2
Station: 1+11
Offset: 0 ft
Stake: A3
Station: 1+97
Offset: 0 ft
Stake: A4
Station: 2+75
Offset: 0 ft
SCALE (feet)
0 30 60



Stake: B1
Station: 0+00
Offset: 0 ft

Stake: B2
Station: 1+88
Offset: 0 ft

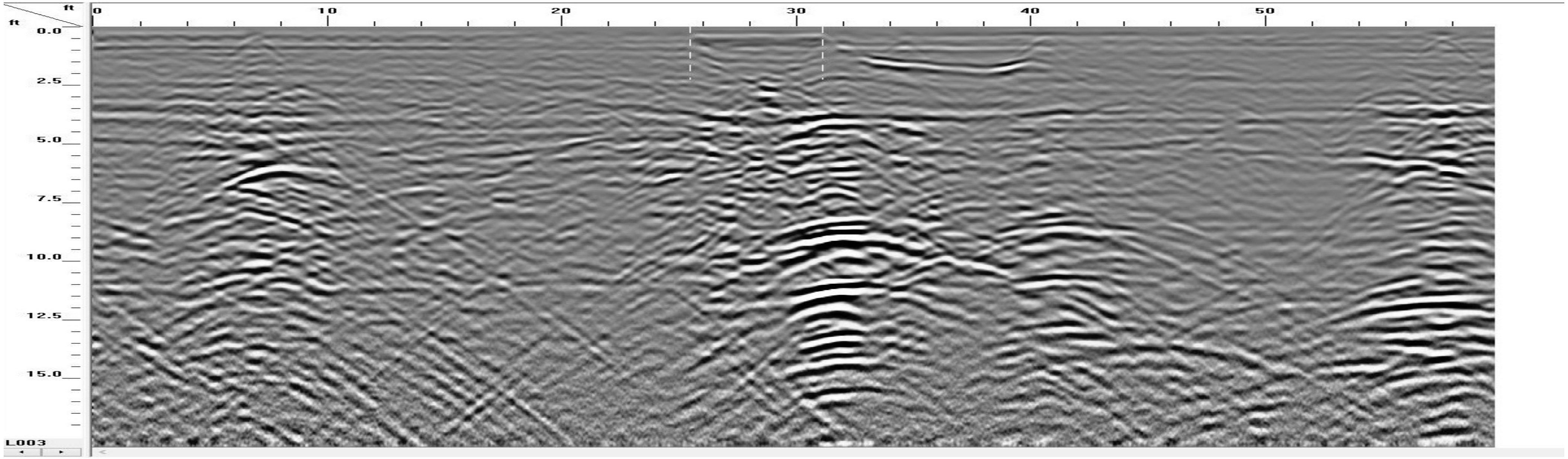
Stake: B4
Station: 3+29
Offset: 0 ft

Case Study – Void Survey
Spaulding Turnpike over Blackwater Brook
Dover, NH

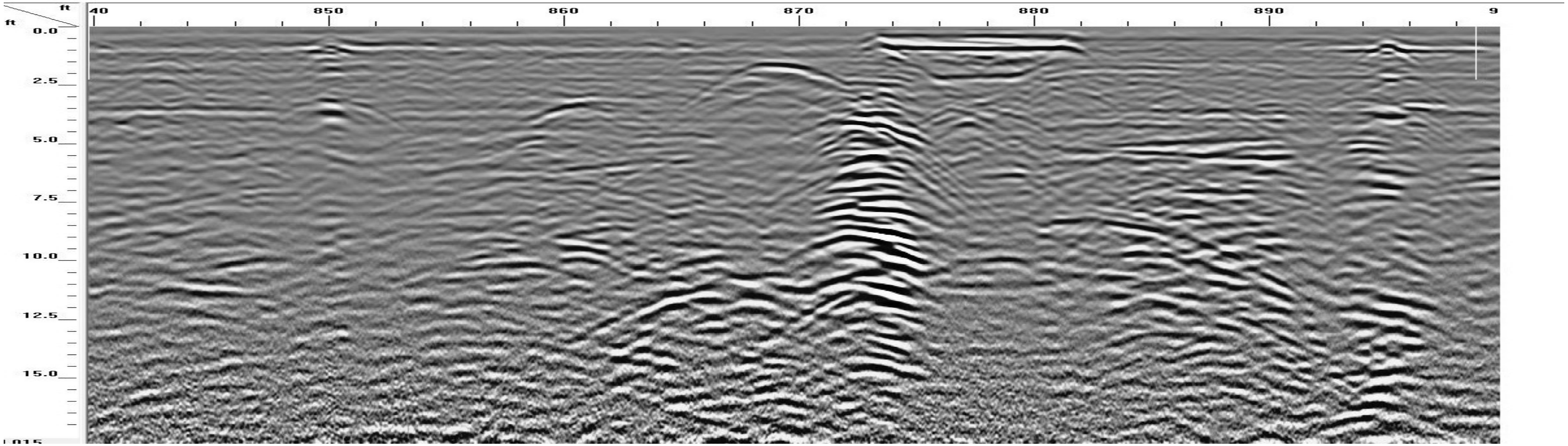
for NHDOT and its Representatives

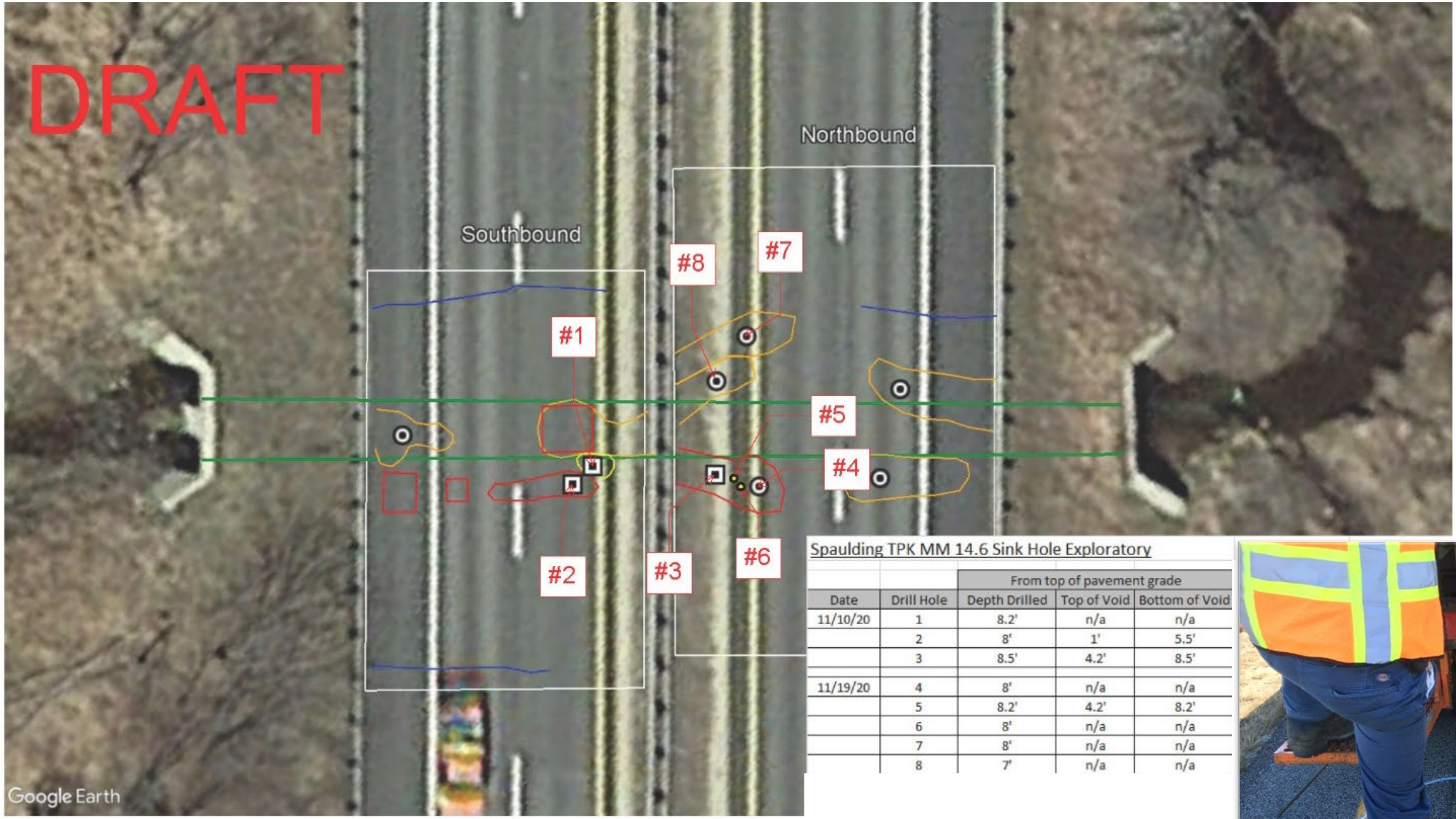
- Objectives
  - Detect and locate subsurface voids and disturbed soils causing surface depressions in the active roadway.
- Method
  - Ground Penetrating Radar

SE Southbound - GPR Profile 1 NW



SE Southbound - GPR Profile 2 NW





Spaulding TPK MM 14.6 Sink Hole Exploratory

		From top of pavement grade		
Date	Drill Hole	Depth Drilled	Top of Void	Bottom of Void
11/10/20	1	8.2'	n/a	n/a
	2	8'	1'	5.5'
	3	8.5'	4.2'	8.5'
11/19/20	4	8'	n/a	n/a
	5	8.2'	4.2'	8.2'
	6	8'	n/a	n/a
	7	8'	n/a	n/a
	8	7'	n/a	n/a

Void - Confirmed by drilling

Repaired Void - Pavement Patch

Possible Void - marked on ground

Marked Feature - Not a Void

Pavement Crack

Positions of Culverts

Proposed Boring

Existing Boring

SCALE (feet)

0 15 30

NOTES

1. Modified from Google Earth photo

Ground Penetrating Radar (GPR)

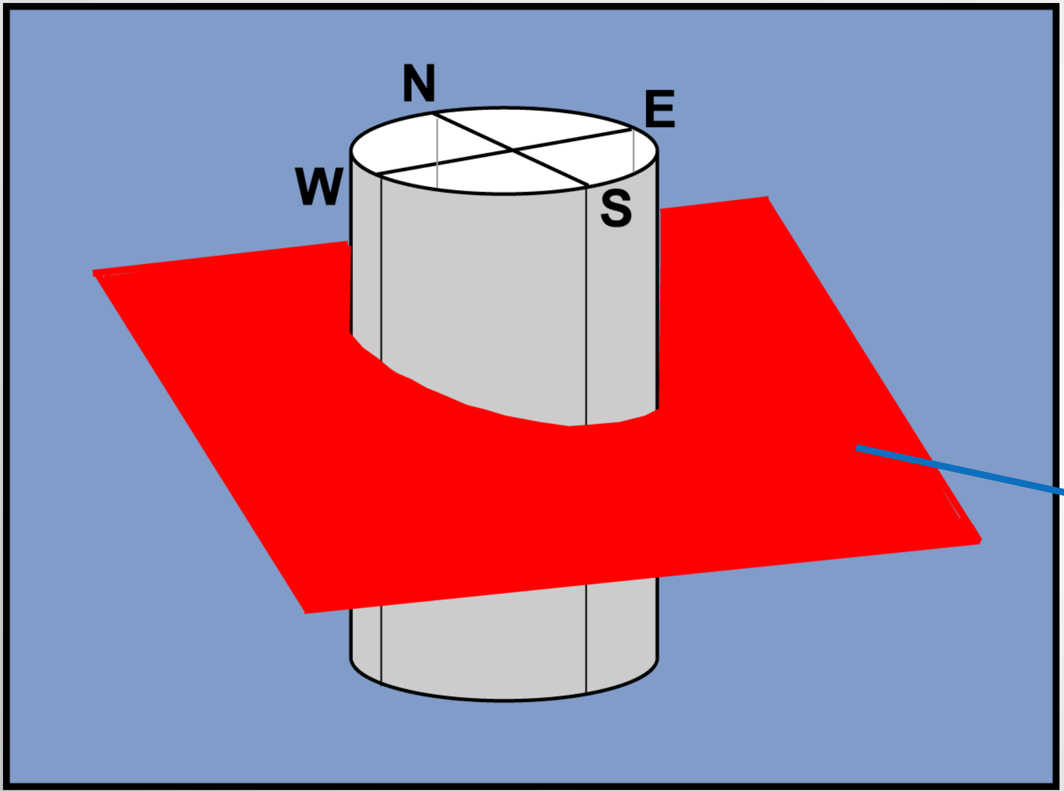
Borehole Geophysical Logging Methods

- Standard Logging
  - Caliper
  - Natural Gamma Ray
  - Electrical (Normal Res, SP, SPR)
  - EM Induction & Magnetic Field
- Flow Logging
  - Fluid Properties
    - (Temp, Cond/Res, + Others)
  - Flow Meters (HPFM & Spinner)
- Image Logging
  - Optical Televiewer (OTV)
  - Acoustic Televiewer (ATV)
  - Borehole Video
- Deviation Logging

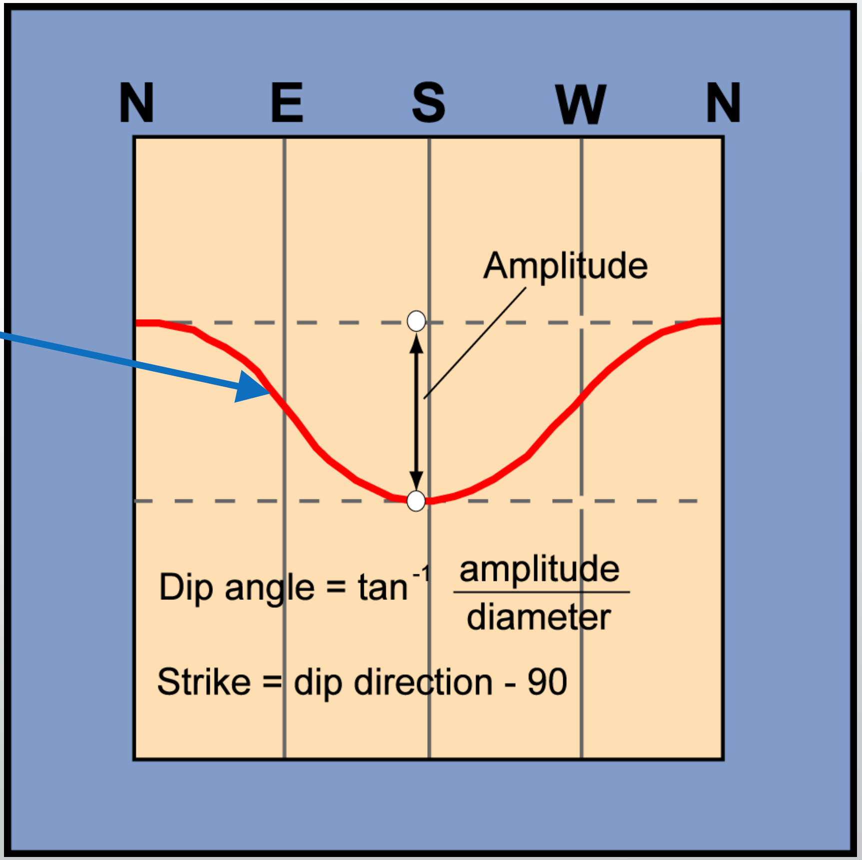
Borehole Geophysical Logging Setup on Roadways

Borehole Geophysical Logging Setup from Rock Slopes

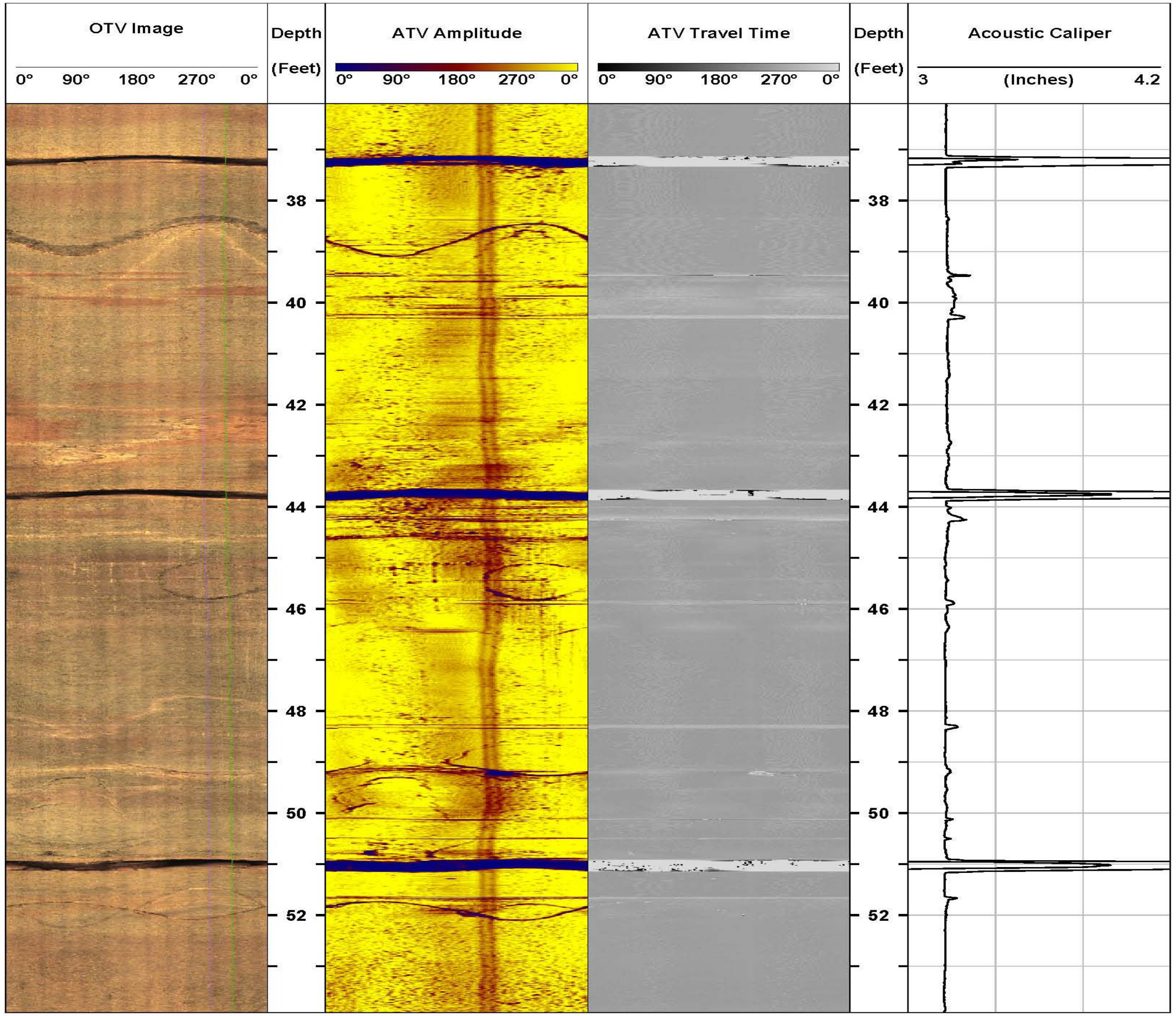
Borehole Televiewer Explanation



Projected "unwrapped"

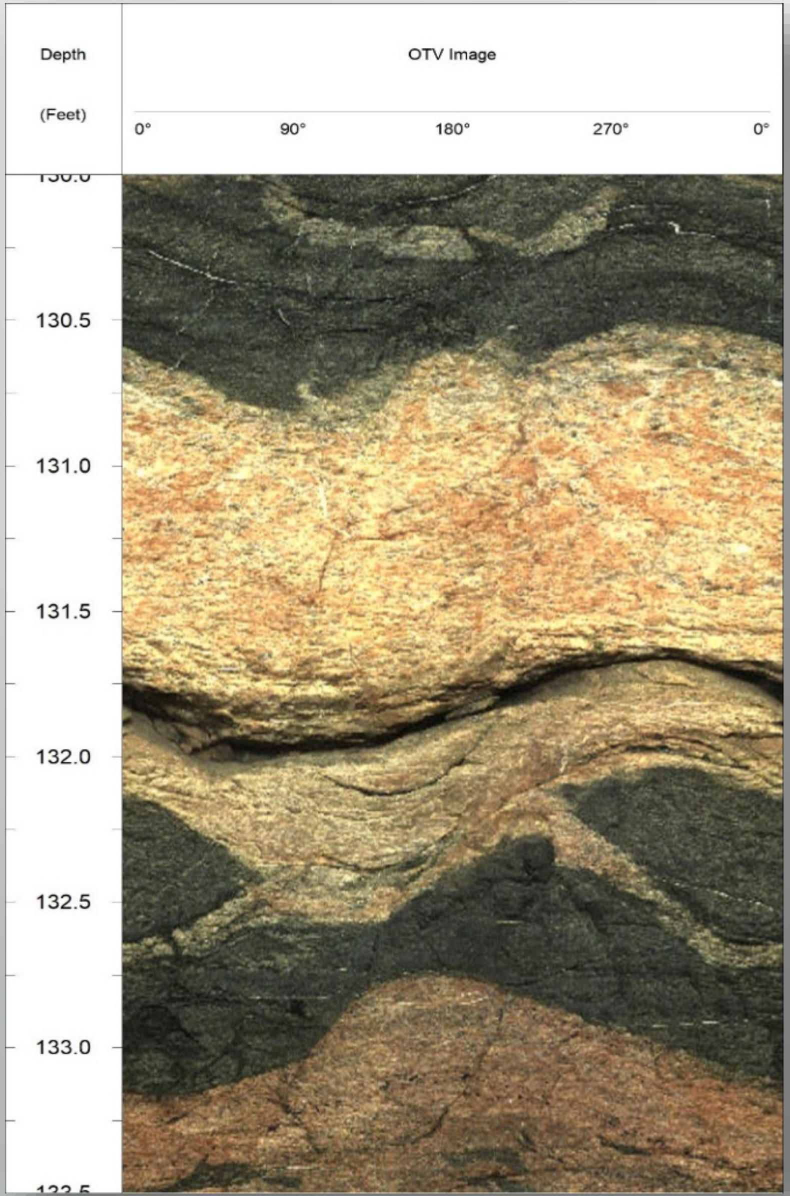


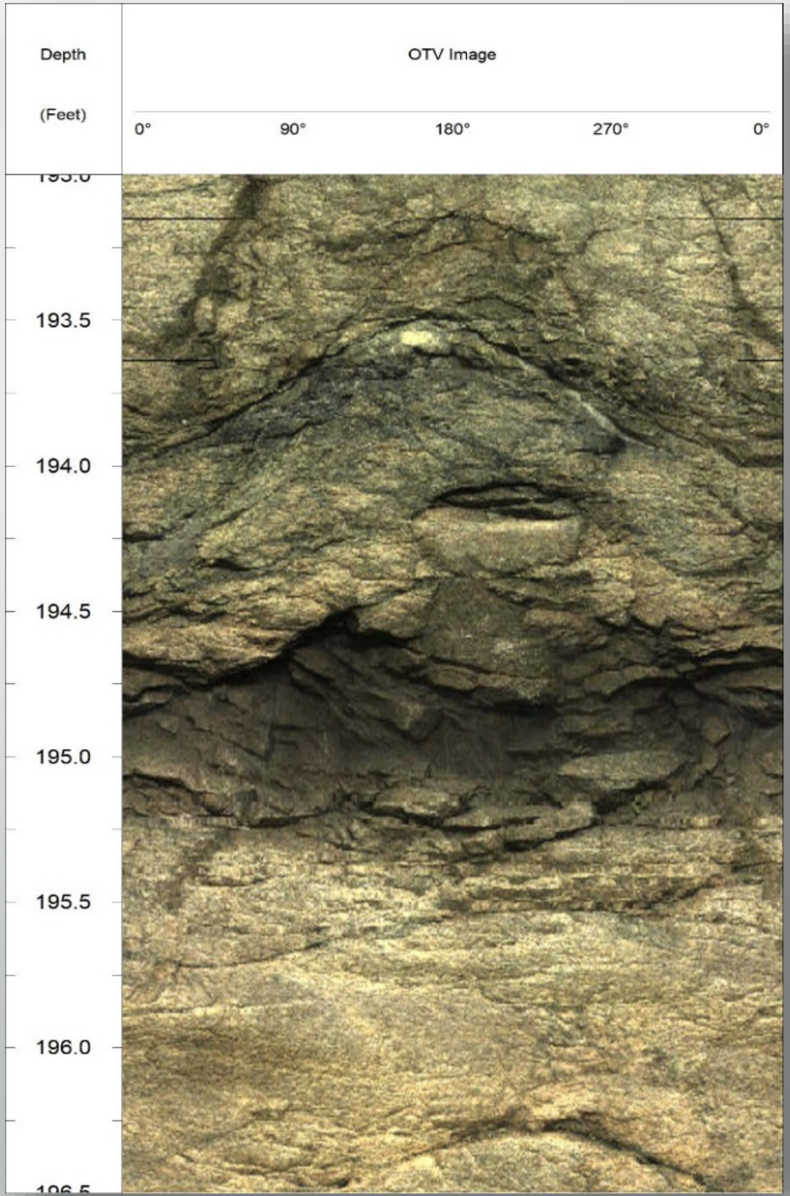
Borehole Televiewer Images



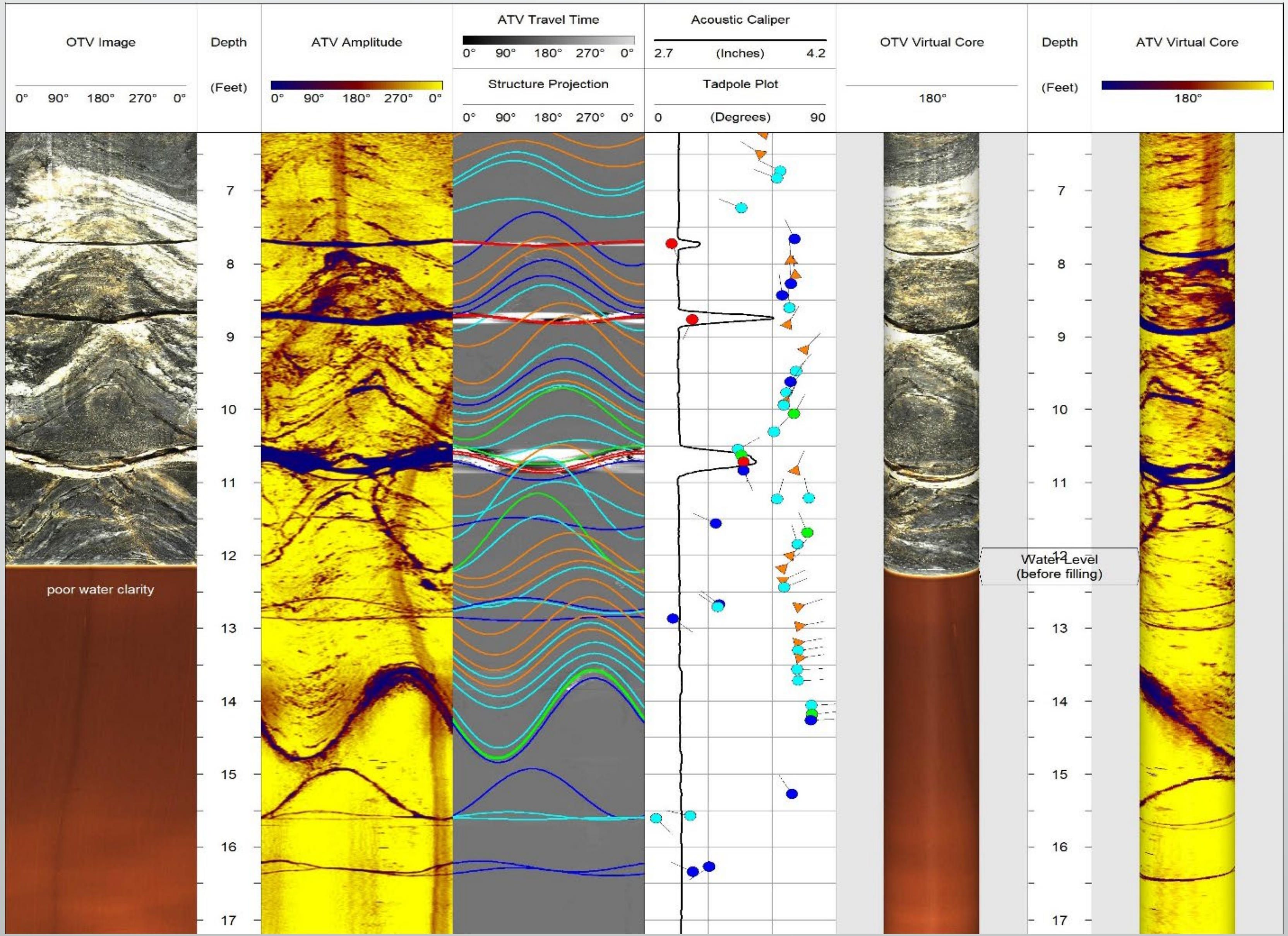


Optical Televiewer (OTV) Images





OTV & ATV Limitations & Borehole Conditions

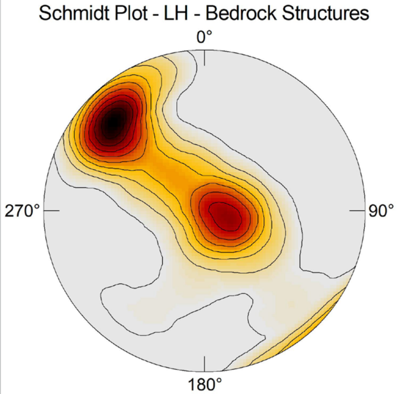


Bedrock Structure Statistics Plots

STRUCTURE LEGEND

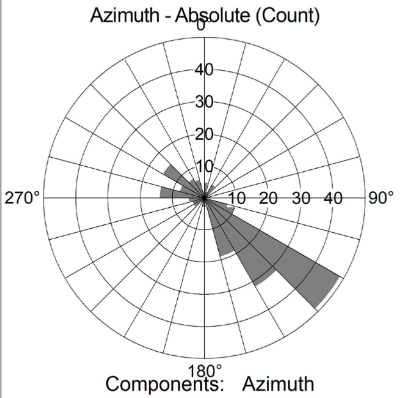
Fracture Rank 1 · Fracture Rank 2 · Fracture Rank 3 · Fracture Rank 4 · Foliation / Vein

Stereogram - Lower Hemisphere of Fractures



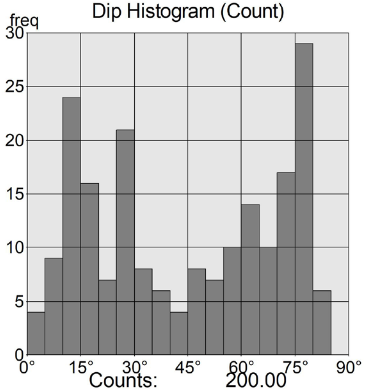
	Counts	Dip[deg]	Azi[deg]
Mean	200	44.65	147.57
Fracture Rank 1	66	52.94	141.05
Fracture Rank 2	73	44.32	147.62
Fracture Rank 3	44	39.87	149.20
Fracture Rank 4	17	27.66	298.53

Dip Azimuth Rose Diagram of Fractures



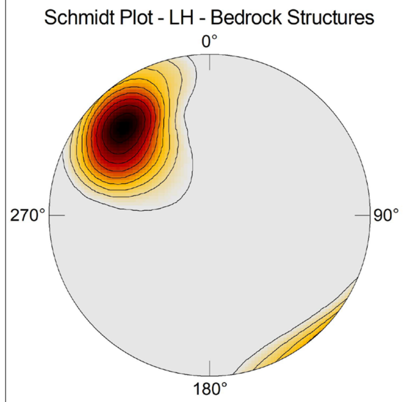
Components:	Azimuth
Counts:	200.00
Mean (2D):	147.57
Std.Dev.:	89.81
Min:	2.20
Max:	348.44

Dip Angle Histogram of Fractures



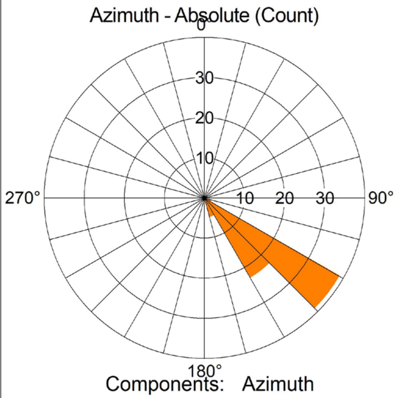
Counts:	200.00
Mean (2D):	44.65
Std.Dev.:	26.11
Min:	0.50
Max:	82.58

Stereogram - Lower Hemisphere of Foliation & Veins



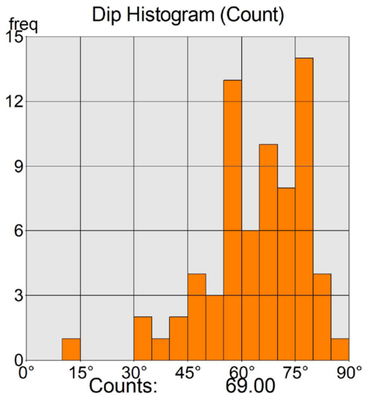
	Counts	Dip[deg]	Azi[deg]
Mean	69	64.29	134.73
Foliation / Vein	69	64.29	134.73

Dip Azimuth Rose Diagram of Foliation & Veins



Components:	Azimuth
Counts:	69.00
Mean (2D):	134.73
Std.Dev.:	9.57
Min:	118.24
Max:	155.85

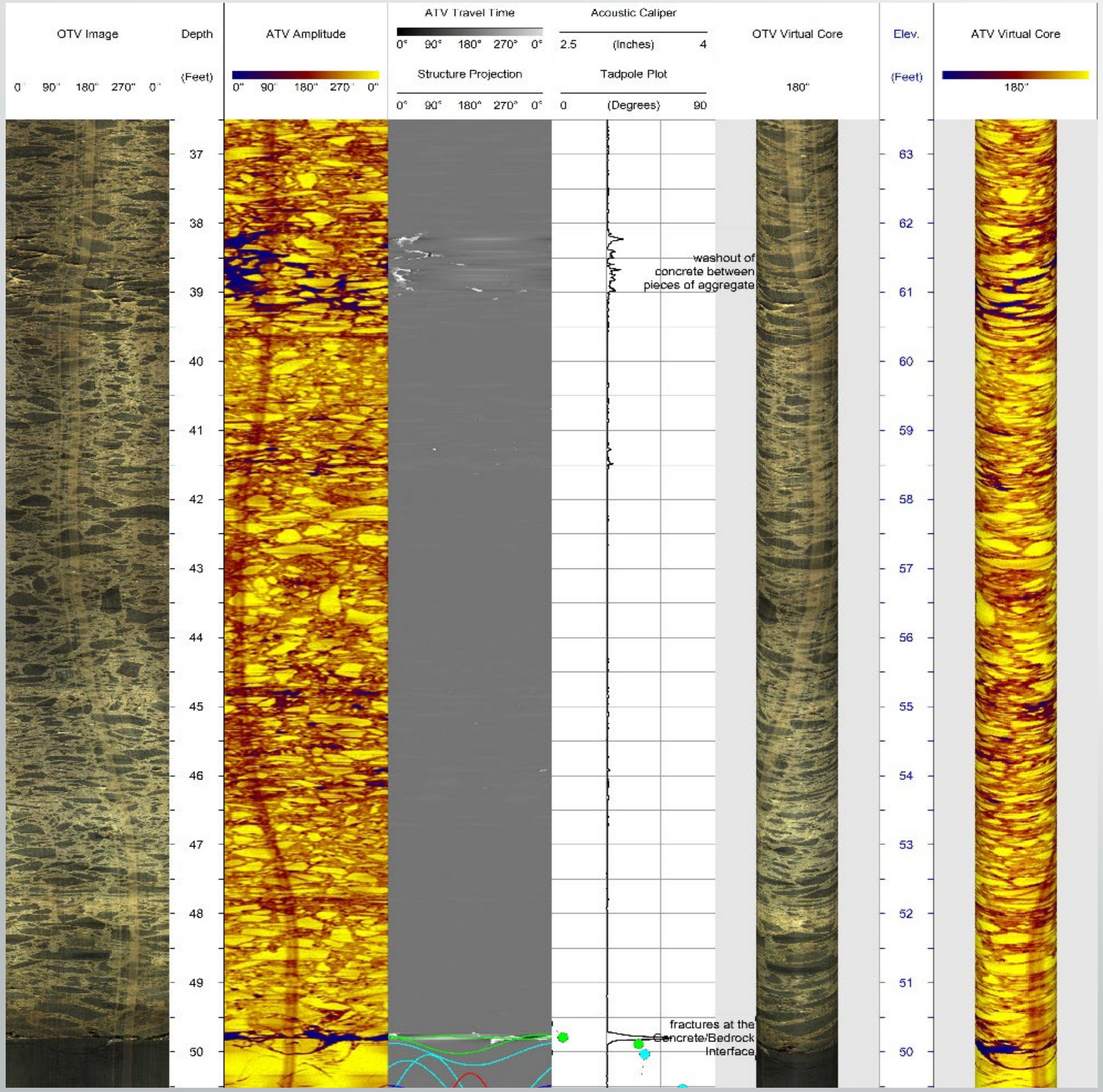
Dip Angle Histogram of Foliation & Veins

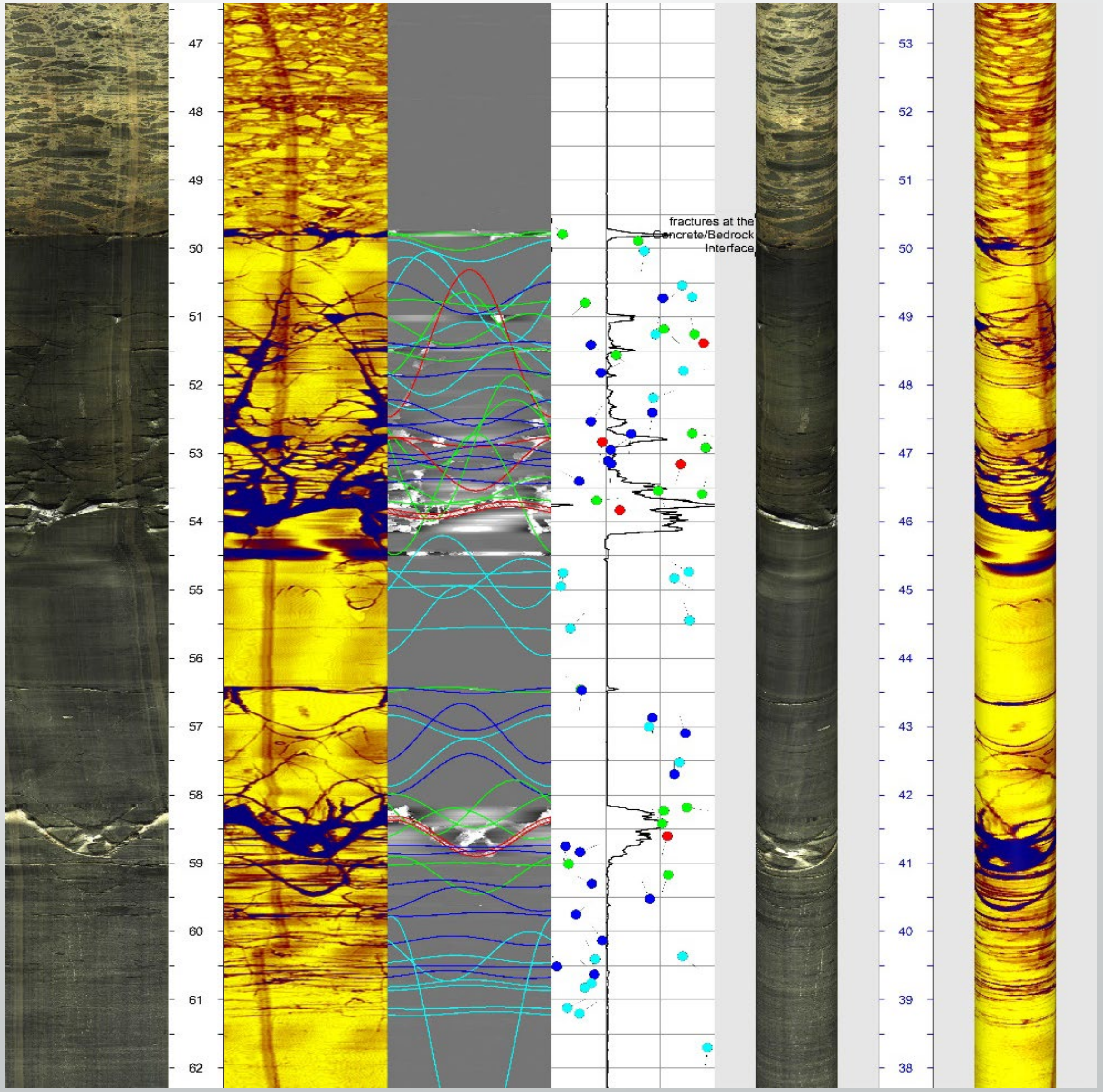


Counts:	69.00
Mean (2D):	64.29
Std.Dev.:	13.66
Min:	14.83
Max:	85.61

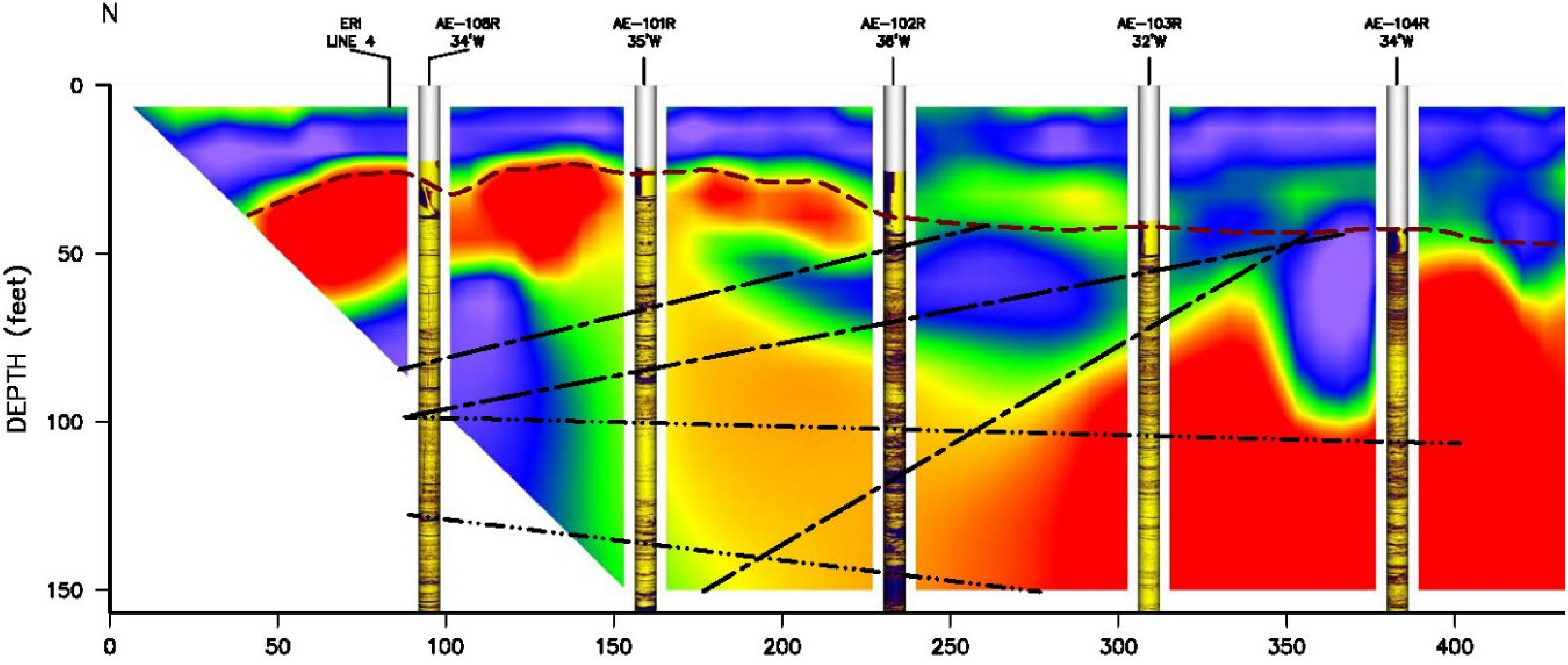
Borehole Geophysical Logging Setup Under a Bridge

OTV & ATV Logging Through a Bridge Foundation

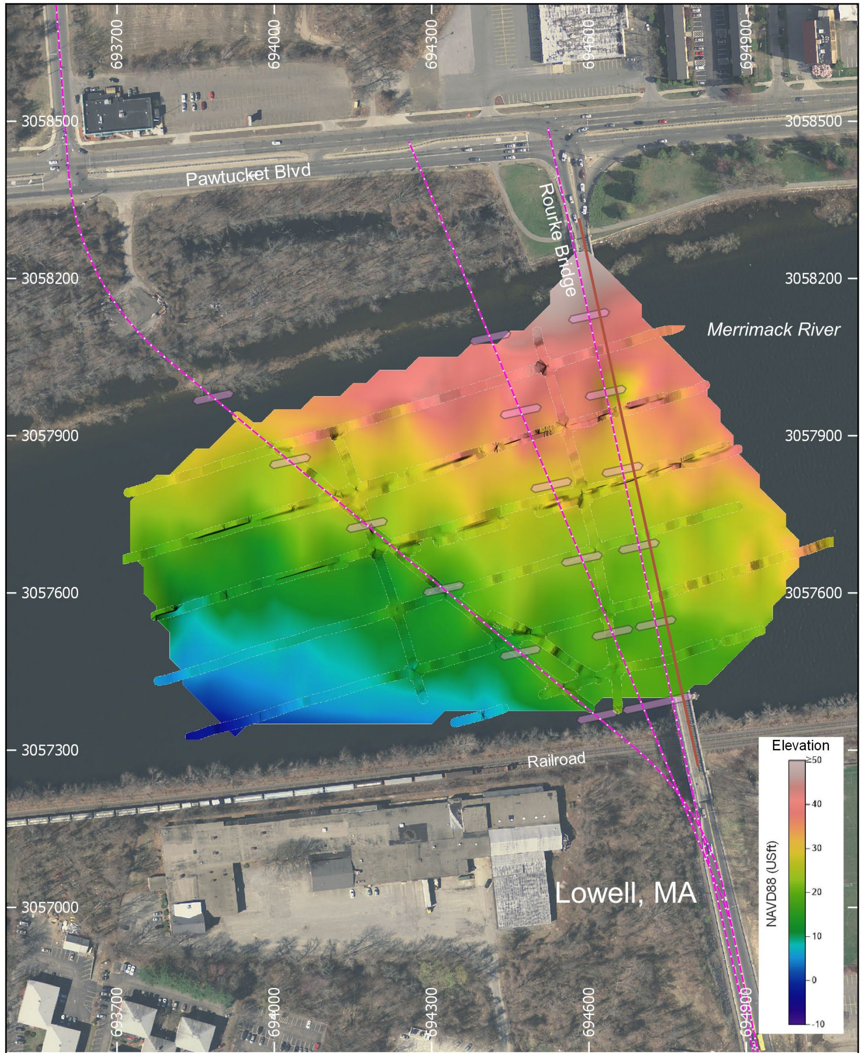




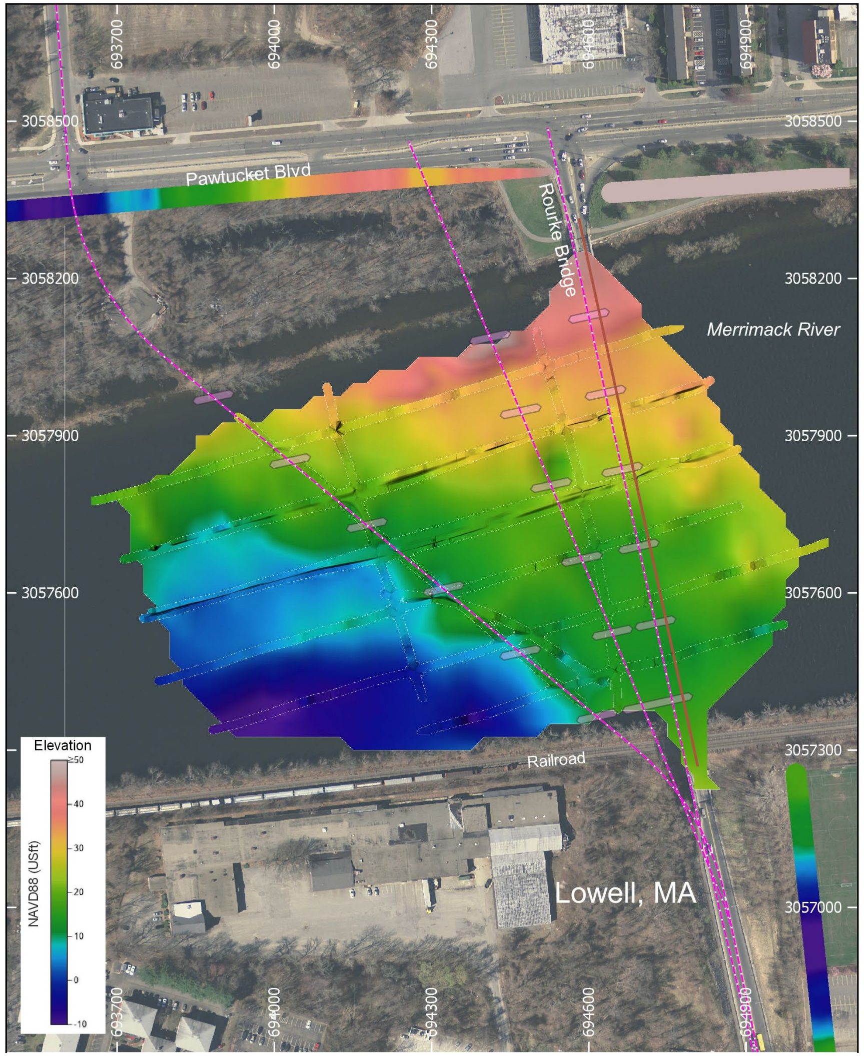
Integrated Land & Borehole Geophysical Results



Integrated Seismic Results from Marine & Land Geophysics



Top-of-Till Interpolated Surface Map



Top-of-Rock Interpolated Surface Map

Surface & Borehole Geophysical Methods for Rapid Geotechnical Response to Extreme Events

Robert Garfield, P.G.
Owner/Principal Borehole Geophysicist

Hager-Richter Geoscience, Inc.
www.hager-richter.com

Today's Panelists

#TRBWebinar

Moderator: Derrick Dasenbrock, *FHWA*

Stacey Kulesza, *Kansas State University*

Nina Stark

VIRGINIA TECH

Robert Garfield, *Hager-Richter*

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