1. **You can scroll down and view all the speaker bios and presentations except the presentation on "Electrical Resistivity Method for Marine Exploration," only abstract.**

2. **Or you can click on the individual presenter to view his bio and presentation.**

   The Role of Non-uniqueness in the Application of near surface geophysics to Environmental and Engineering Applications by Thomas Brackman.

   Reflection and Refraction Seismology: Concepts Review with Case Histories by Edward W. Woolery, PhD.

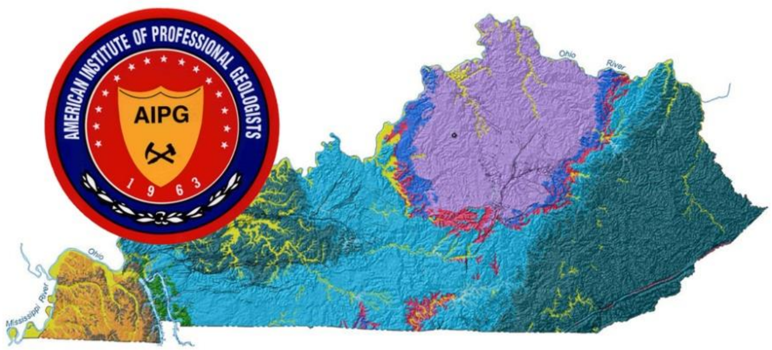
   Application of Downhole Geophysical Methods to Geotechnical and Hydrogeological Investigations by Mark S. Smith, P.G.

   Electrical resistivity Method for Karst Feature Investigation by Junfeng Zhu, PhD.

   Electrical Resistivity Method for Marine Exploration, abstract only.

Geophysical Techniques and Applications –Non-Invasive Methods for Subsurface Characterization and Interpretation

A Professional Development Conference
Hosted by
Kentucky Section - American Institute of Professional Geologists (KY-AIPG)
http://ky.aipg.org



Kentucky Geological Survey – Well Sample and Core Library
2500 Research Park Drive
Lexington, Kentucky 40511
Friday, October 16, 2015

Geophysical Techniques and Applications –Non-Invasive Methods for Subsurface Characterization and Interpretation

Friday, October 16, 2015

8:45 a.m. **Registration** *(Coffee and Donuts provided)*

9:00 a.m. **Welcome and Introductions –** (*Bill Brab, KY-AIPG Past President)*

9:10 a.m. **Session 1 –** The Role of Non-Uniqueness in the Application of Near Surface Geophysics to Environmental and Engineering Applications *(Tom Brackman, Western Kentucky University/Cardno)*

9:55 a.m. **Break**

10:10 a.m. **Session 2 –** Reflection and Refraction Seismology: Concepts Review with Case Histories *(Edward W. Woolery, University of Kentucky/Kentucky Geological Survey)*

10:55 a.m. **Break**

11:10 a.m. **Session 3 –** Application of Downhole Geophysical Methods to Geotechnical and Hydrogeological Investigations *(Mark Smith, Cardno GLS)*

12:00 p.m. **Lunch Break** *(Barbeque buffet provided)*

1:15 p.m. **Session 4 –** Electrical Resistivity Method for Karst Feature Investigation (*Junfeng Zhu, PhD, In-Situ)*

2:00 p.m. **Break**

2:15 p.m. **Session 5 –** Electrical Resistivity Method for Marine Exploration *(Thomas Brackman on behalf of Markus Lagmanson, Advanced Geosciences, Inc.)*

3:00 p.m. **Closing Remarks –** *(Bill Brab, KY-AIPG Past President)*

3:05 p.m. **Field/Outside Demonstrations**

4:30 p.m. **Adjournment**

THE ROLE OF NON-UNIQUENESS IN THE APPLICATION OF NEAR SURFACE GEOPHYSICS TO ENVIRONMENTAL AND ENGINEERING APPLICATIONS

Thomas Brackman, Sr. Geophysicist; Research Faculty Western Kentucky University, Bowling Green KY, nearsurfacegeophysics@yahoo.com

Speaker Bio: Thomas Brackman M.S., P.G., is a Geophysicist and Registered Professional Geologist specializing in geophysics with applications to real world problems. Broad background in seismology and near surface geophysics including cave and karst, environmental and geotechnical arenas. Fifteen years of experience in owning and operating a personal business. Eleven years of teaching and research experience in geology/geophysics at the university level. Currently consulting for Cardno Inc., soon to be starting as Research Faculty at Western Kentucky University. Proficient in the use of electrical resistivity, seismic surface wave techniques, ground penetrating radar, magnetics, electromagnetics and gravimetric studies.

Presentation Abstract: Near surface geophysics has the ability to distinguish a diversity of targets. Geophysical properties can be correlated to Geological properties and Engineering parameters. Sometimes the geophysical properties correlate to multiple geological properties. Enter Non-Uniqueness. Multiple methods can often be used to aid in overcoming multiple solutions. We will look into the problem of non-uniqueness and multiple methods on how to solve this problem. Multiple case studies involving horizontal directional drilling for pipeline installations, detection of deep voids and seismic site classification will be covered.

REFLECTION AND REFRACTION SEISMOLOGY: CONCEPTS REVIEW WITH CASE HISTORIES

Edward W. Woolery, Professor of Geophysics and Director of Graduate Studies, University of Kentucky EES; Faculty Associate, Kentucky Geological Survey, woolery@uky.edu

Speaker Bio: Edward W. Woolery received undergraduate degrees in geology (BS, 1984) and civil engineering (BSCE, 1996) from Eastern Kentucky University and the University of Kentucky, respectively. His MS (1993) and PhD (1998) degrees were in Geological Sciences (Geophysics) from the University of Kentucky. Ed's career began as a geotechnical engineer and geologist for the Louisville District U.S. Army Corps of Engineers before returning to the University of Kentucky to begin the Geologic Hazards Section for the Kentucky Geological Survey. Currently, he is a Professor of Geophysics and the Director of Graduate Studies in the University of Kentucky's Department of Earth and Environmental Sciences. Ed's research bridges the interface between geophysics and the engineering disciplines, primarily as a field-oriented experimentalist focused on seismic hazards in general, and near-surface geophysical methods, ground-motion site response, and neotectonics (active-fault assessment) in particular. Most research has been concentrated in the central United States (i.e., New Madrid and Wabash Valley seismic zones), but more recently along the northern edge of the Tibetan Plateau in western China.

Presentation Abstract: Although a pure mathematical description of exploration seismology can appear somewhat daunting, the basic conceptual physics for explaining the subject is remarkably straightforward. Consider an area or point of earth material: if disturbed, the resultant displacement energy is propagated outward from the source as an attenuating elastic wave until it encounters a boundary separating material with contrasting elastic properties, wherein it predictably partitions into refraction and reflection components. We review the spatial and temporal consequences of this process for both P- and S-wave modes in the context of seismic data acquisition, processing and interpretation, as well as highlighting potential pitfalls and advantages using examples from geotechnical engineering, geological hazard assessment, and petroleum exploration.

APPLICATION OF DOWNHOLE GEOPHYSICAL METHODS TO GEOTECHNICAL AND HYDROGEOLOGICAL INVESTIGATIONS

Mark S. Smith, P.G, Sr. Geologist; Business Unit Manager - Mining, GLS, Engineering & Environmental Services Division, Cardno GLS, mark.s.smith@cardno.com

Speaker Bio: Mr. Smith is a Professional Geologist with over 34 years' professional experience in resource and mining geology, hydrogeology, borehole geophysics, and engineering applications. At Cardno, he directs the geophysical logging division Cardno GLS, and performs geologic and hydrogeological investigations, principally for the mining industry. Such studies include assessments of probable hydrologic consequences of mining; evaluation of hydrogeological, geochemical, and geotechnical conditions and their potential impact on mining activities; and investigations of water quality and/or quantity impacts resulting from past mining. His focus in downhole geophysics has been high resolution data collection and the application to geotechnical evaluations and hydrogeologic studies, as well as mineral resource evaluations.

Presentation Abstract: Modern high resolution geophysical logging tools have numerous applications for geotechnical and hydrogeologic studies. Measuring fracture orientations and understanding joint sets and rock strength parameters are critical components of slope stability analysis, underground mine design, slope-shaft-tunneling design, as well as other types of geotechnical investigations. Downhole geophysical logging tools such as acoustic televiewer, waveform sonic, electromagnetic flowmeter, density, temperature, fluid conductivity and other probes provide a cost effective method of obtaining the required data for geotechnical and hydrogeologic investigations. Through properly located boreholes and the use of geophysical logging it is possible to predict relative strength of strata, identify fracture patterns, locate weak strata and water inflow and outflow zones for controlling water during excavation.

ELECTRICAL RESISTIVITY METHOD FOR KARST FEATURE INVESTIGATION

Junfeng Zhu, PhD, Water Resources Section, Kentucky Geological Survey, Junfeng.zhu@uky.edu

Speaker Bio: Dr. Junfeng Zhu received his B.S. and M.S. degrees in Hydrogeology from Nanjing University, China and his PhD degree in Hydrology from University of Arizona. He is a senior hydrogeologist with Kentucky Geological Survey, University of Kentucky. He is also an adjunct faculty member in the Department of Earth and Environmental Sciences, University of Kentucky. His research focuses on groundwater dynamics, hydrogeophysics, karst hydrology, and remote sensing.

Presentation Abstract: The electrical resistivity method is a common geophysical technique widely used in investigating geological features in the shallow subsurface. This method detects variations of electrical resistivity of earth materials through applying electric currents to the subsurface and measuring electric potentials on or below the ground. In this lecture, I will first introduce the basic principles of the method with a focus on clarification of common misconceptions and briefly present the procedures of conducting surface electrical resistivity surveys in the field. Then, I will spend the majority of this lecture to give examples on applying the method in studying water-related environmental issues in Kentucky, including investigating groundwater sources for public water supplies, monitoring soil moisture changes in agriculture fields, and understanding movements of contaminants in karst environment.

ELECTRICAL RESISTIVITY METHOD FOR MARINE EXPLORATION

Thomas Brackman (on behalf of Markus Lagmanson, Advanced Geosciences, Inc.), Sr. Geophysicist; Research Faculty Western Kentucky University, Bowling Green KY, nearsurfacegeophysics@yahoo.com

Use of 2D Electrical Resistivity in marine applications will highlight case studies including optimizing placement of horizontal well screens for water well intakes for the Florida Oceanographic Societies Marine Park, mapping of geology adjacent to seawalls adjacent to a waterfront canal system, determine dep to bottom in lacustrine environments, and investigation of a planned utility tunnel stretch between the mainland and Fisher Island in Miami, FL.

Thank you again to our Presenters and Sponsors

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DEPARTMENT OF EARTH & ENVIRONMENTAL SCIENCES

About the American Institute of Professional Geologists (AIPG) and the Kentucky Section of American Institute of Professional Geologists (KY-AIPG)

The **American Institute of Professional Geologists (AIPG)** is a nonprofit organization that was founded in 1963. It is the largest association dedicated to promoting geology as a profession. It presently has more than 7,000 members in the U.S. and abroad, organized into 36 regional sections.

The purpose of AIPG is promote and certify the competence and ethical conduct of geological scientists in all branches of geosciences with members employed in industry, government, and academia.

AIPG emphasizes competence, integrity and ethics. AIPG is an advocate for the profession and communicates regularly to federal and state legislators and agencies on matters pertaining to the geosciences.

The **Kentucky Section of AIPG (KY-AIPG)** was founded on November 10, 1967 in accordance with the Bylaws of the Institute. It presently has more than 140 members including Certified Professional Geologists (C.P.G.'s), Professional Members, Young Professional Members, Students, and Associates.

KY-AIPG hosted the 24th Annual Meeting of AIPG in Lexington, KY in 1987. Approximately 225 members and guests attended the 1987 Annual Meeting.

Several members of KY-AIPG were instrumental in a successful effort to lobby and observe the passage of the Professional Geologist Registration Bill in the Kentucky General Assembly in 1992. As of 2013, there were more than 1,500 persons registered to practice geology in Kentucky, however, only 500 of these reside within the Commonwealth.

Several members of KY-AIPG were instrumental in a successful effort to lobby and observe the passage of the Geologist-in-Training Bill in 2005.

KY-AIPG hosted the 42nd Annual Meeting of AIPG in Lexington, KY in 2005. Approximately 250 members and guests attended the 2005 Annual Meeting.

KY-AIPG initiated an Outreach Program in 2008 to promote public awareness of the geological sciences. The Program was initially vested in free public lectures and oral debates by Kentucky Professional Geologists or invited guests on topics of Global Warming, Climate Change, and Geologic Hazards. The annual Darwin Lecture Series, promoting lectures on evolution and geologic history delivered by distinguished guests, was inaugurated in 2009, and continues to date. Professional Development Conferences began in 2010 to provide low-cost technical workshops and short courses to upgrade the knowledge base of geoscientists.

For more information about AIPG membership categories, requirements, and application forms, visit the AIPG website at: http://aipg.org

For more information about KY-AIPG events, meetings, and other links to field trip guidebooks, presentations, and short courses, visit the KY-AIPG website at: http://ky.aipg.org

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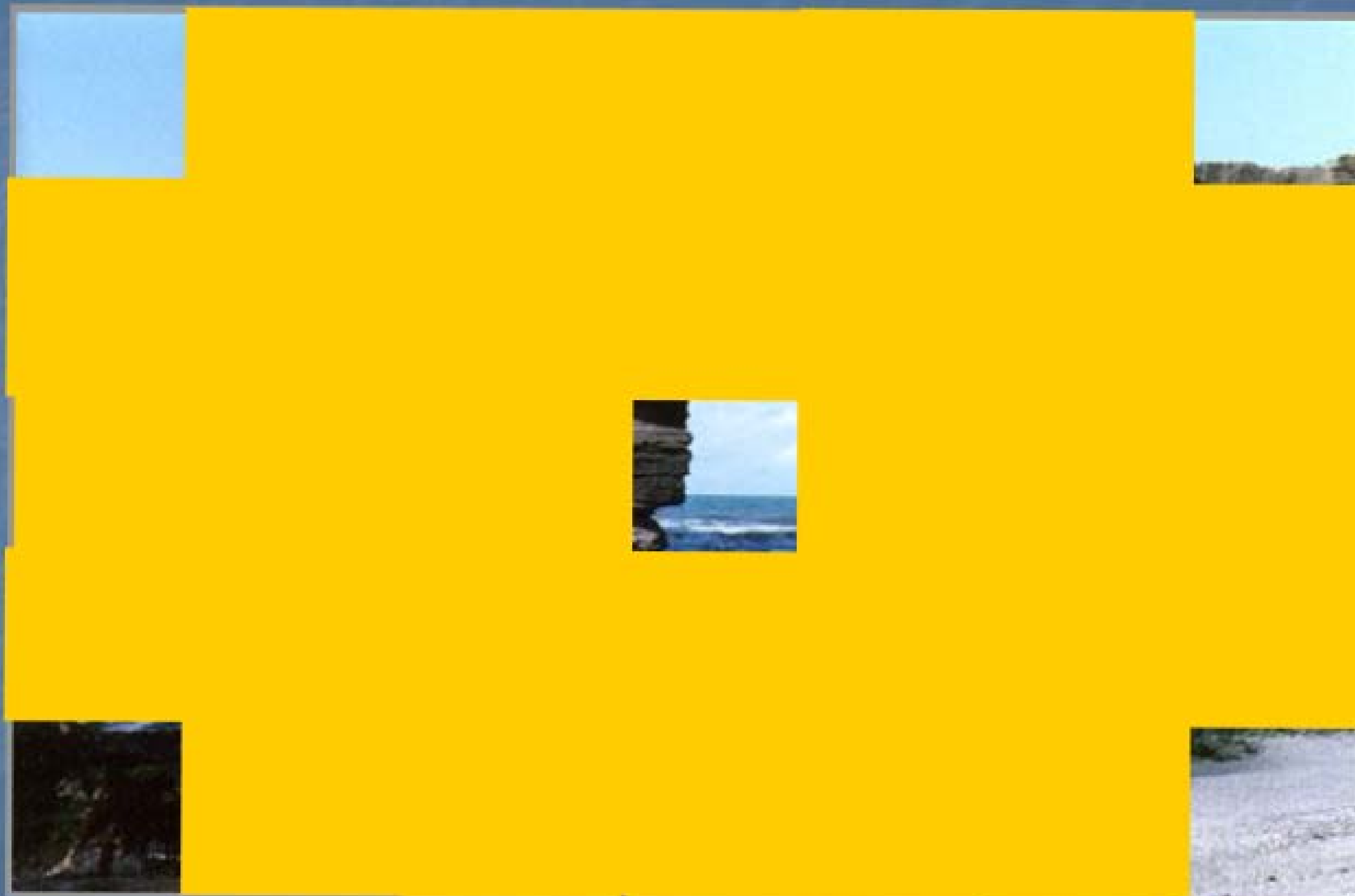
Non-Uniqueness GEOPHYSICAL METHODS Applications for Engineering

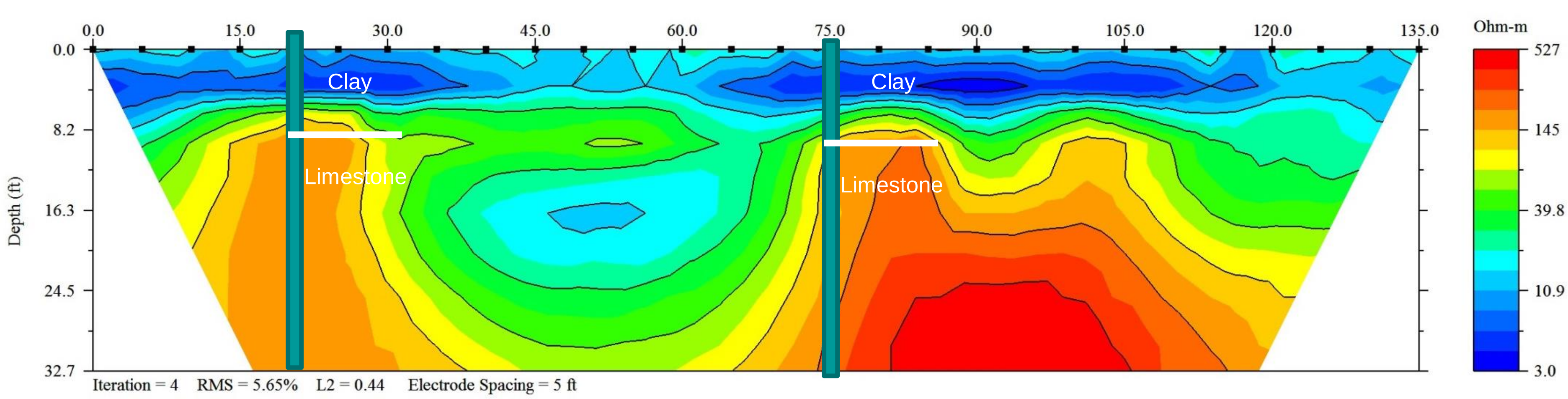
KY AIPG
October 16, 2015

Near Surface Geophysics is a set of tools.

Ground Penetrating Radar
Electromagnetics
Magnetics
Electrical Resistivity
Gravity
Seismic

It completes the picture.





0.0
15.0
30.0
45.0
60.0
75.0
90.0
105.0
120.0
135.0
0.0
8.2
16.3
24.5
32.7
Depth (ft)
Clay
Clay
Limestone
Limestone
Ohm-m
527
145
39.8
10.9
3.0
Iteration = 4 RMS = 5.65% L2 = 0.44 Electrode Spacing = 5 ft

Non-Uniqueness

- The rigorous mathematical label of non-uniqueness can lead to the erroneous impression that no single interpretation in a geological sense is better than any other interpretation (Saltus 2011).
- Nearly all results in the earth science are subject to uncertainty because of incomplete and imprecise data.
- You will perform better as an exploration geophysicist if you are a good geologist (Burger)

Non Uniqueness
Measuring Geophysical properties of the subsurface

Geophysical properties
To
Geological properties

Can more than one geological property be attributed to one geophysical property?

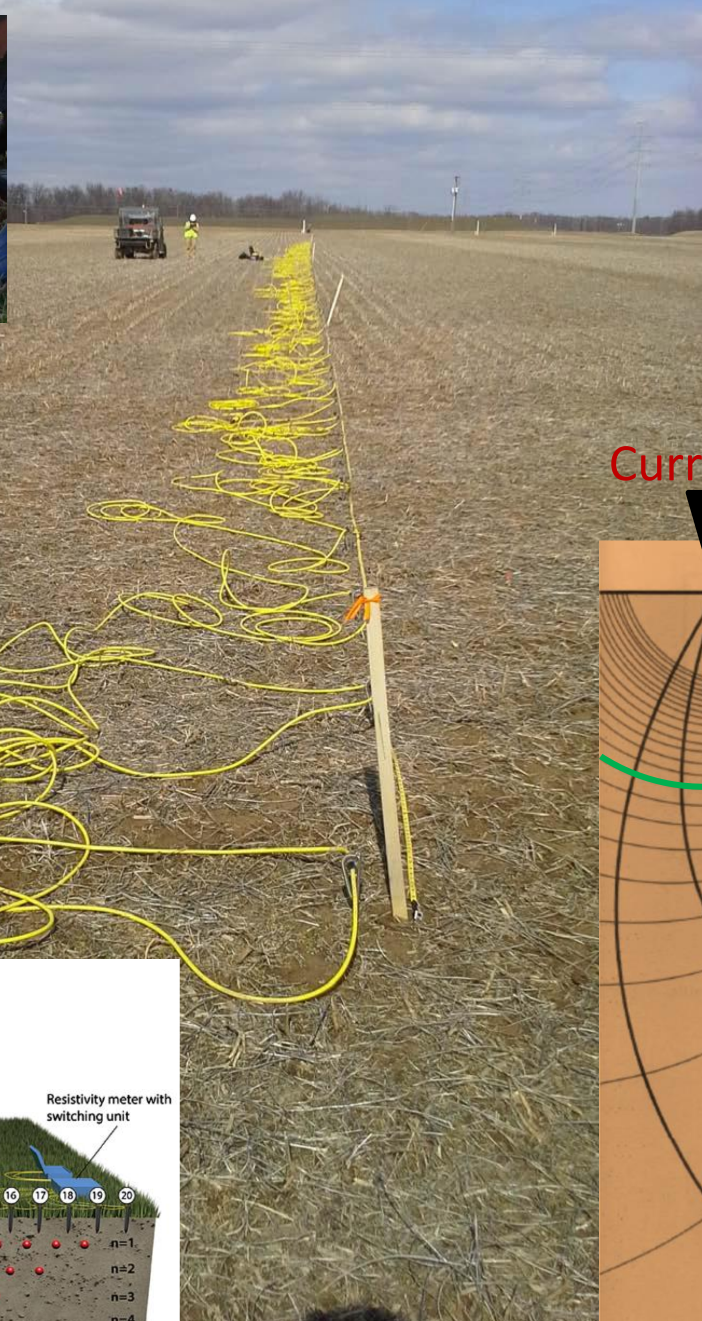
Physical Properties Measured

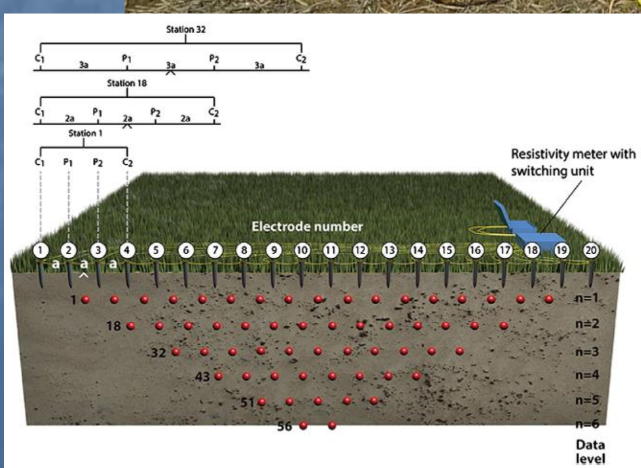
- Velocity of P and S waves, Surface waves
  - Seismic
  - Radar
- Electrical Impedance
  - Electromagnetics
  - Resistivity
- Magnetic
  - Magnetics
- Density
  - Gravity

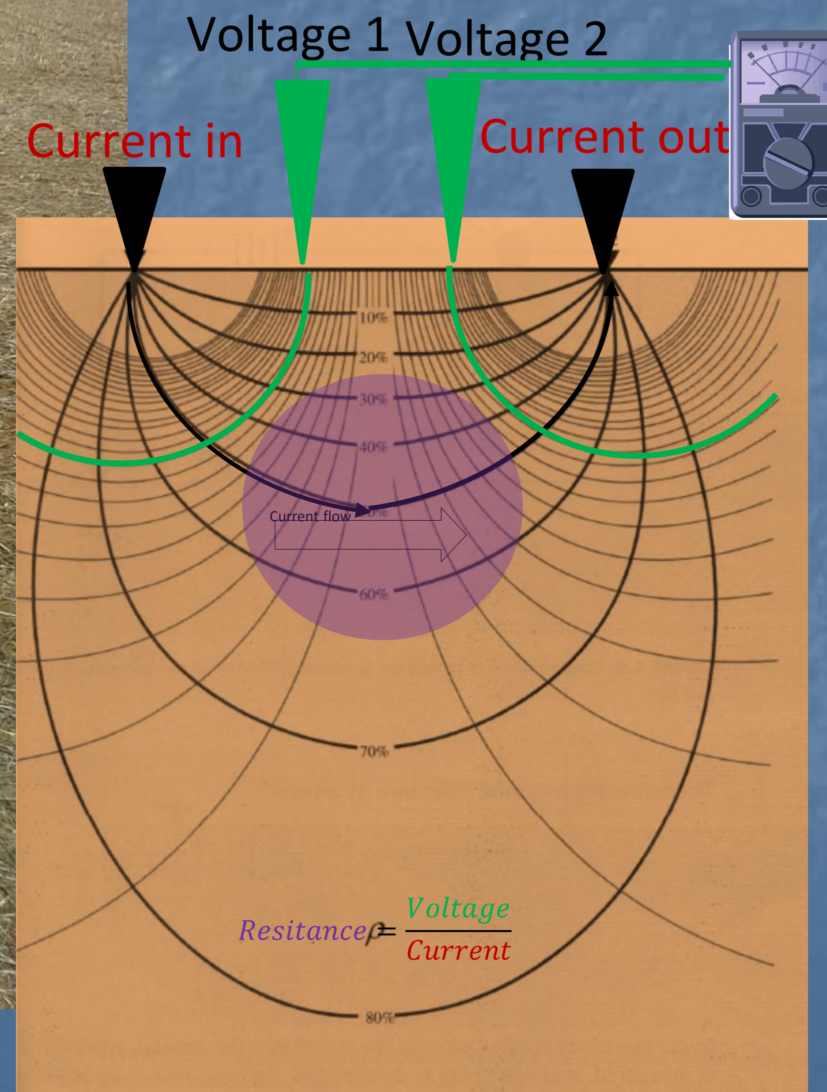
Electrical Resistivity

- Injects current into ground
- Measures resultant voltage
- Water and Ions
- Think what conducts electricity.
- Sand? Hardrock?
- Silt? Igneous?
- Clay? Karst?
- Limestone? Fluvial?
- Cave? Lacustrine?

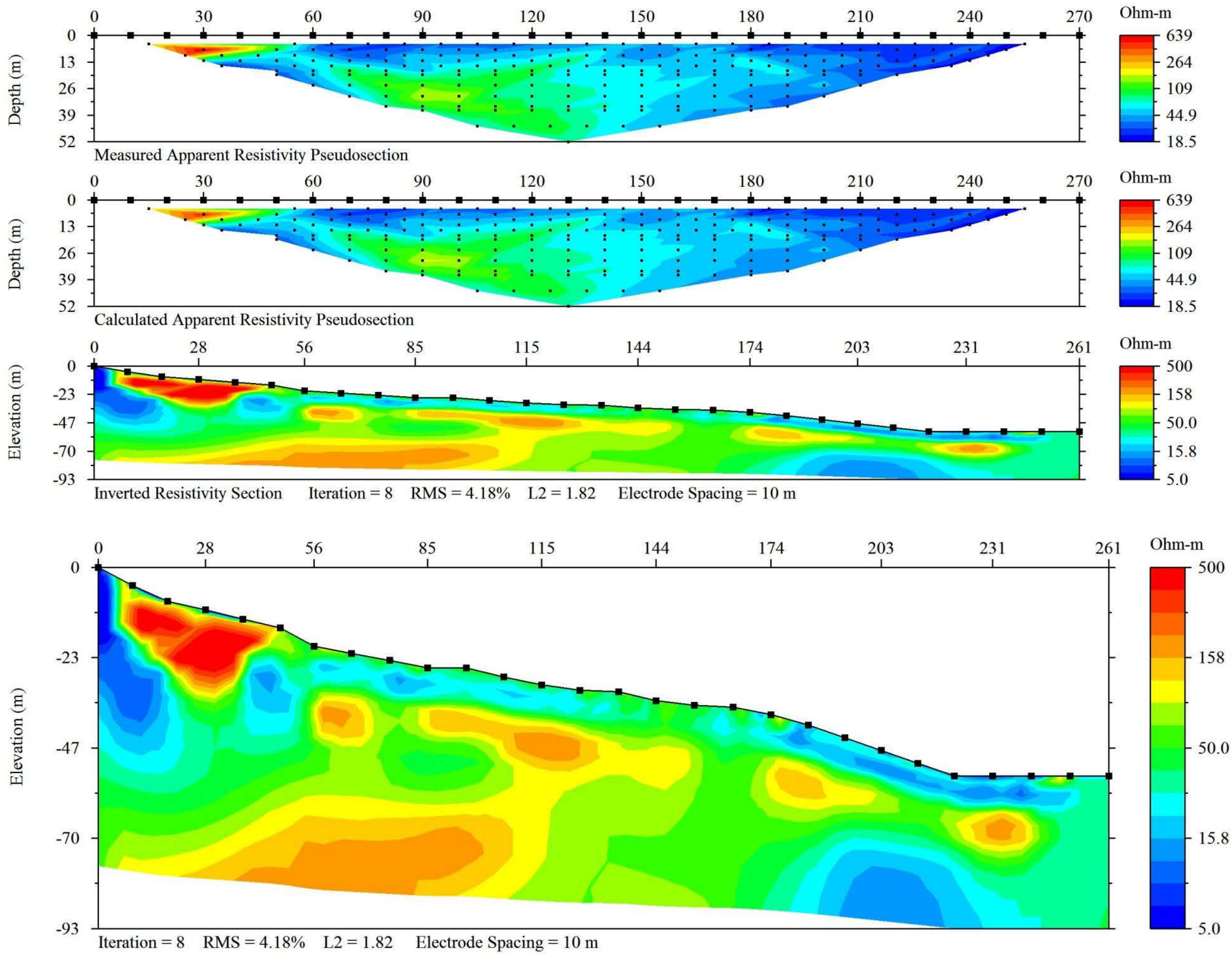
Sting Resistivity Unit

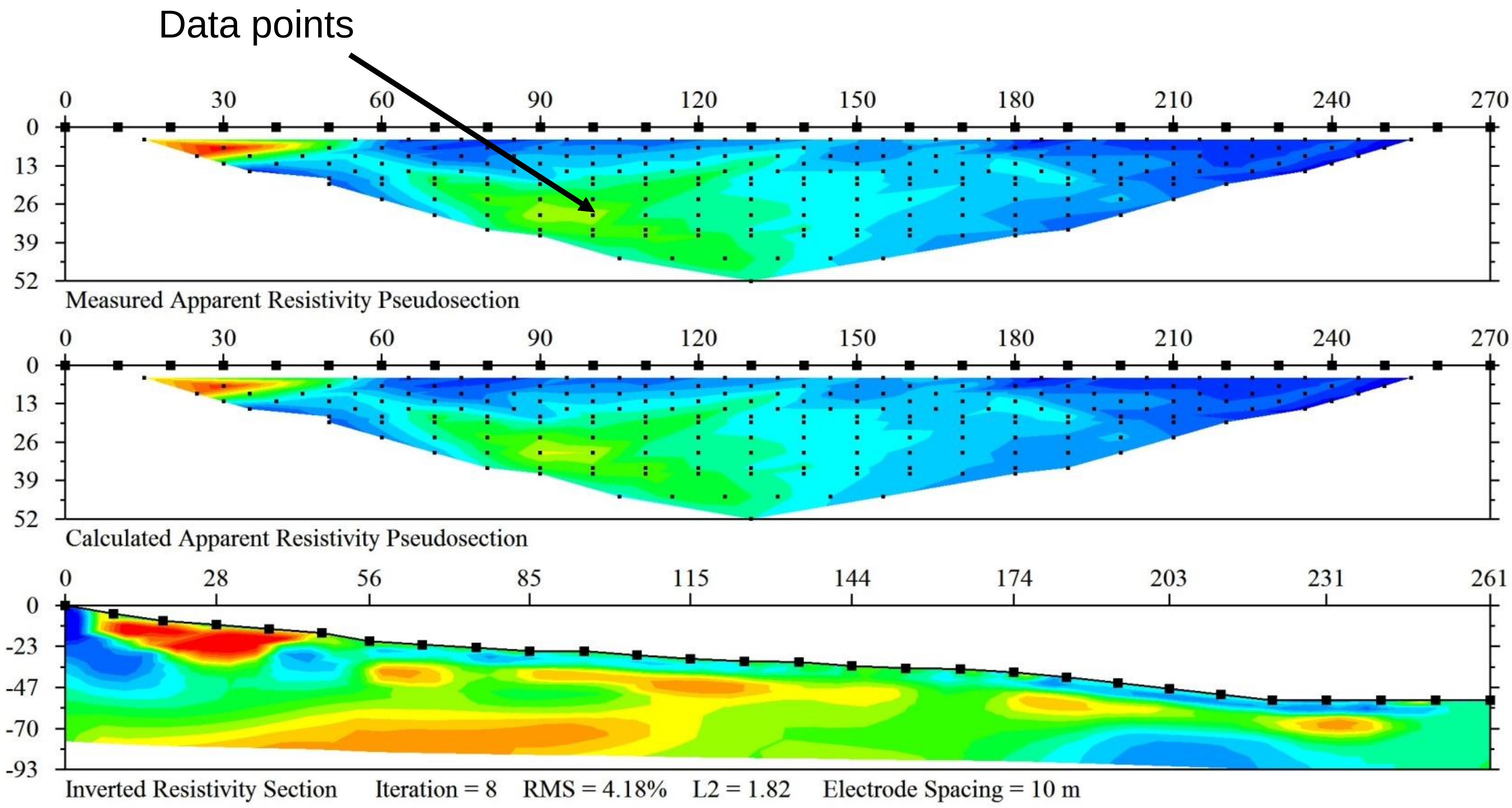




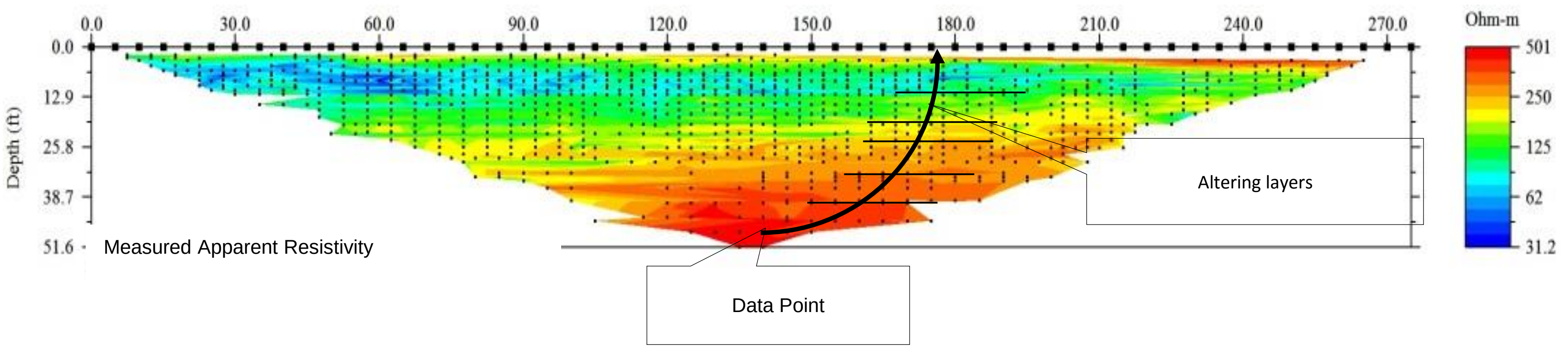


Dakota dpdp_trial2.stg

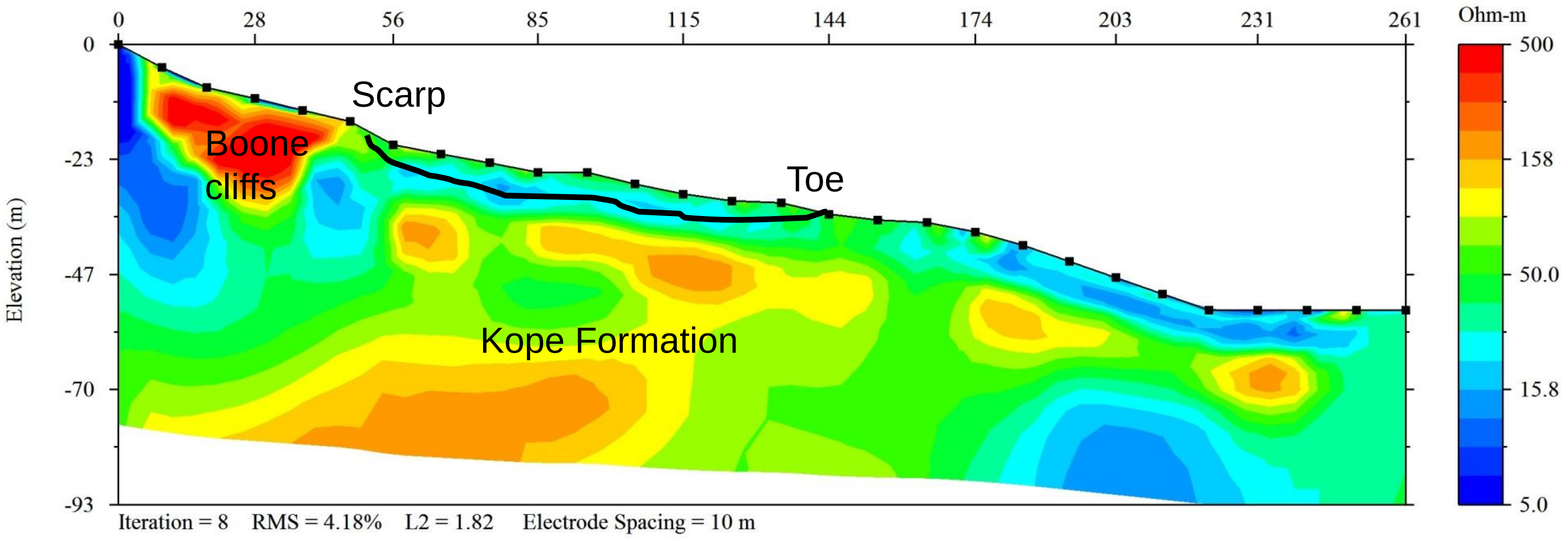




Data points
0 30 60 90 120 150 180 210 240 270
0 13 26 39 52
Measured Apparent Resistivity Pseudosection
0 30 60 90 120 150 180 210 240 270
0 13 26 39 52
Calculated Apparent Resistivity Pseudosection
0 28 56 85 115 144 174 203 231 261
0 -23 -47 -70 -93
Inverted Resistivity Section Iteration = 8 RMS = 4.18% L2 = 1.82 Electrode Spacing = 10 m



Inverted Resistivity Section

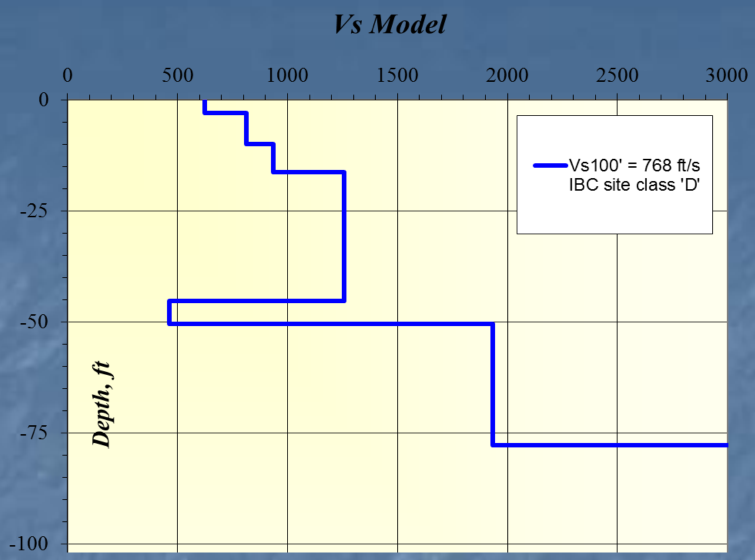


Be Aware

- May need to use multiple methods.
- Boreholes are the best check.
- Know your geology.
- Put together a team and interpret together
- Geologist
- Geophysicist
- Engineer

Seismic Methods

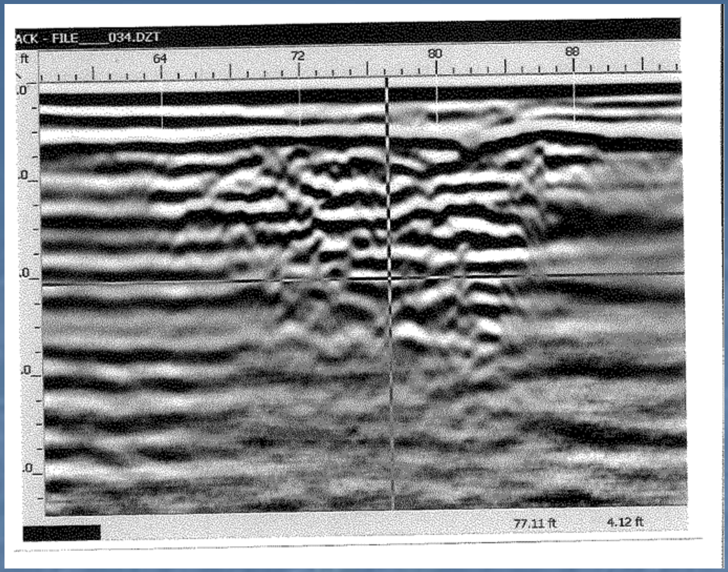
- Uses acoustic energy
- Refraction - Determines velocity and thickness of geologic beds
- Reflection - Maps geologic layers and bed topography
- Surface Waves MASW, ReMi



ReMi Seismograph

Ground Penetrating Radar

- Transmits and receives electromagnetic energy
- Maps geology
- Locates cultural targets
- Has very high resolution



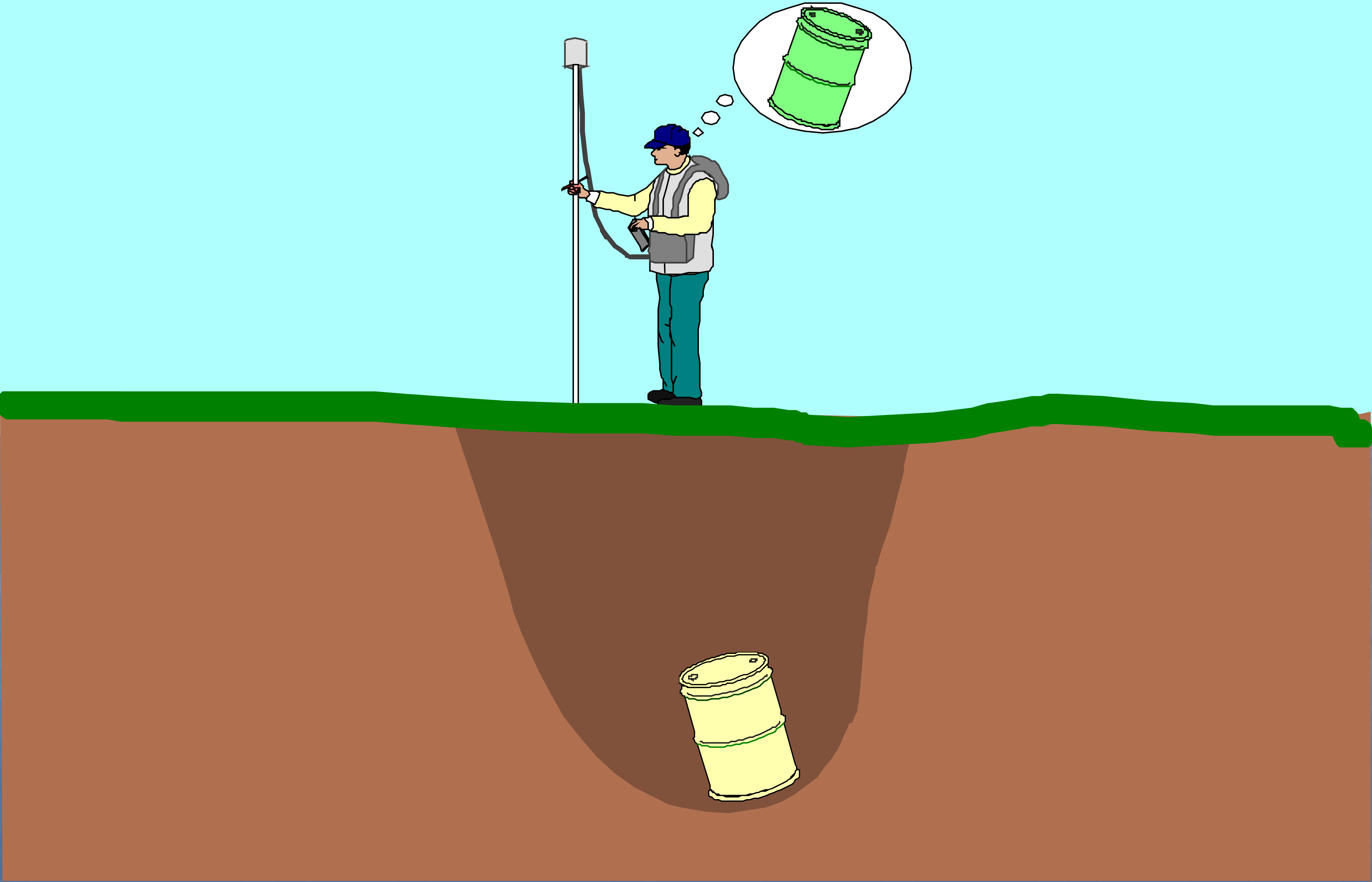
Noggin Ground Penetrating Radar Unit

Mala Geosciences Ground Penetrating Radar Unit

Geophysical Methods Advantages

- Non-intrusive
- Rapid data collection
- Detects a variety of targets
- Screens large areas
- Fills in data gaps

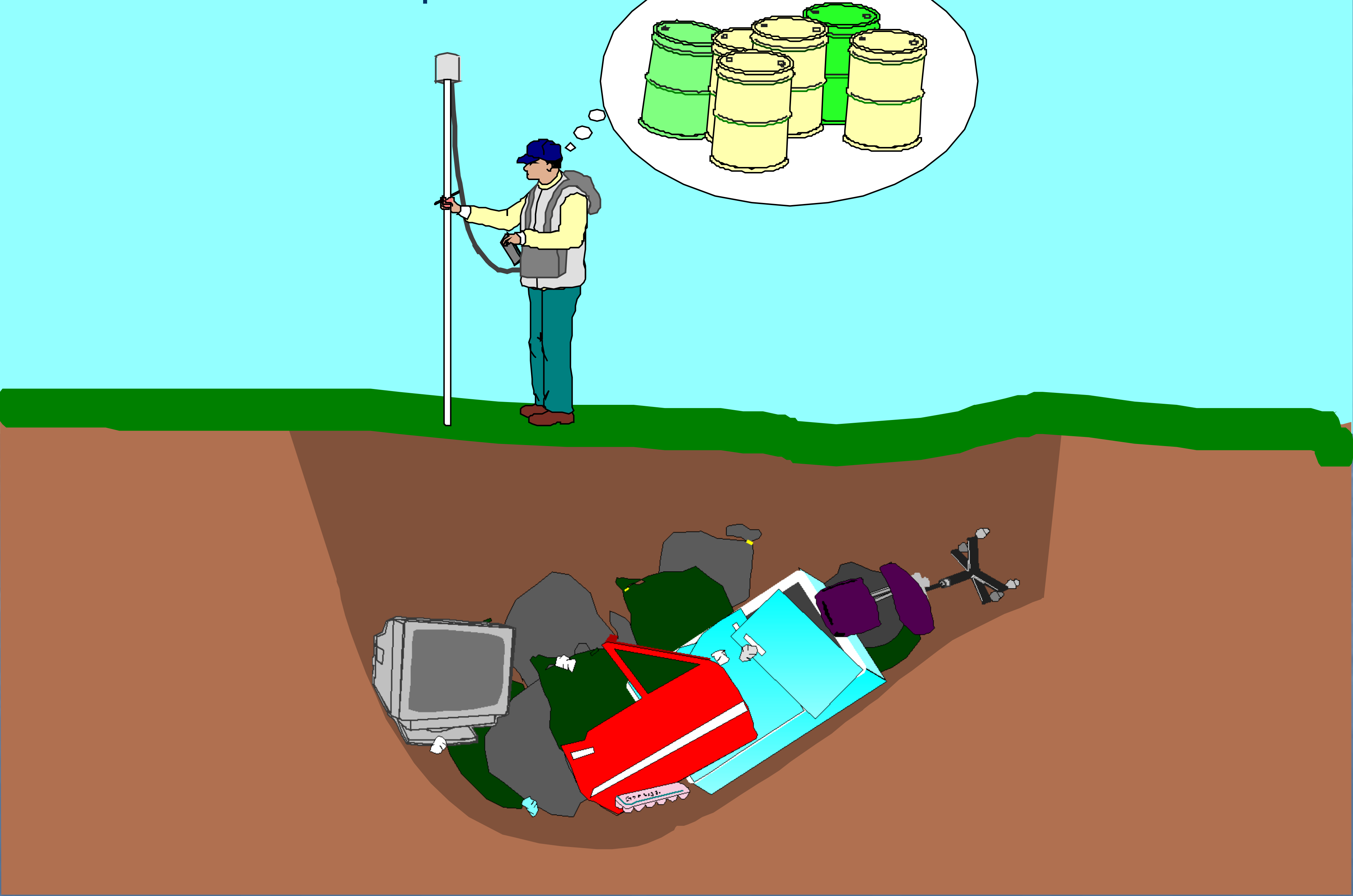
Correct Interpretation



Geophysical Methods Limitations

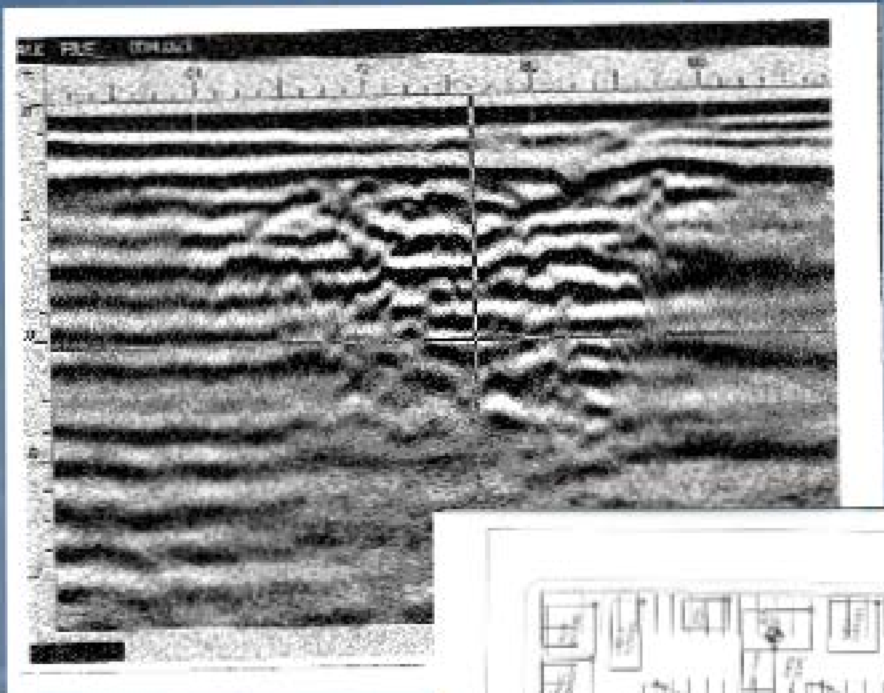
- Methods require a specialist
- Interpretations are non-unique
  - Forward Modeling
  - Inverse Modeling
- May be expensive
- Physical contrasts must exist
- Resolution varies by method and depth of target
- Noise

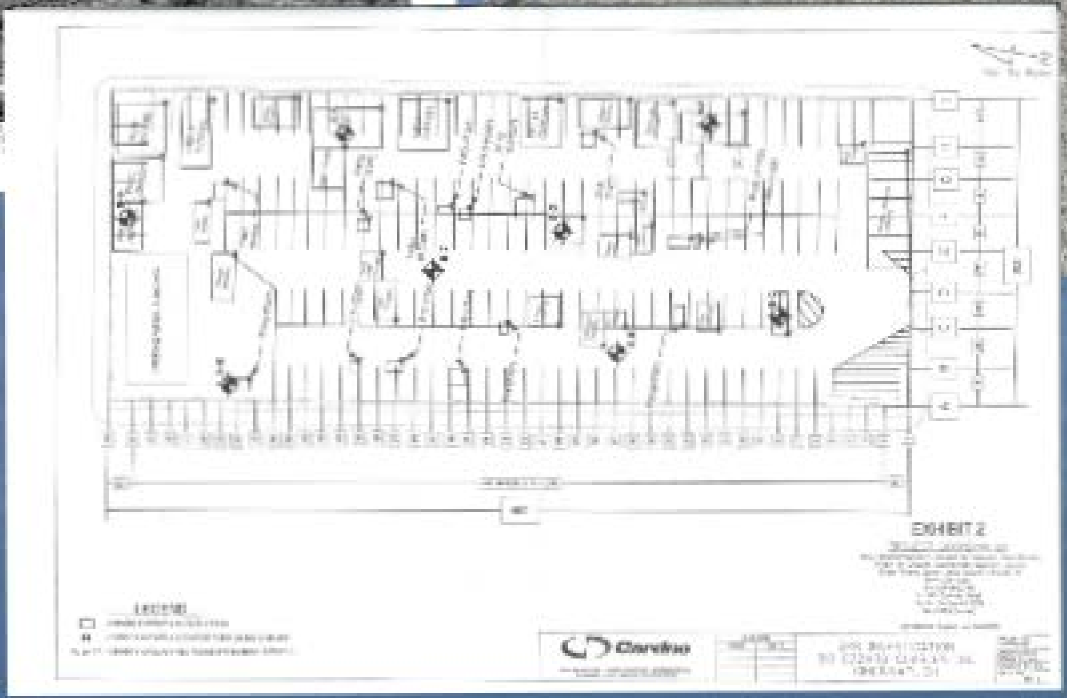
Problematic Interpretation



Case Studies

GPR Survey – Cinti Police Dist. 1





Delineating Ground Water Flow Paths in a Potential Karst Region.

Objective: Determine if site is suitable for a rubber membrane-lined decorative pond. The area has a high degree of karst development with a cave within 200ft of the site. Currently the pond does not retain water. Investigations show a lateral movement of groundwater. Seismic studies indicate bedrock just below the max depth of the ER surveys.

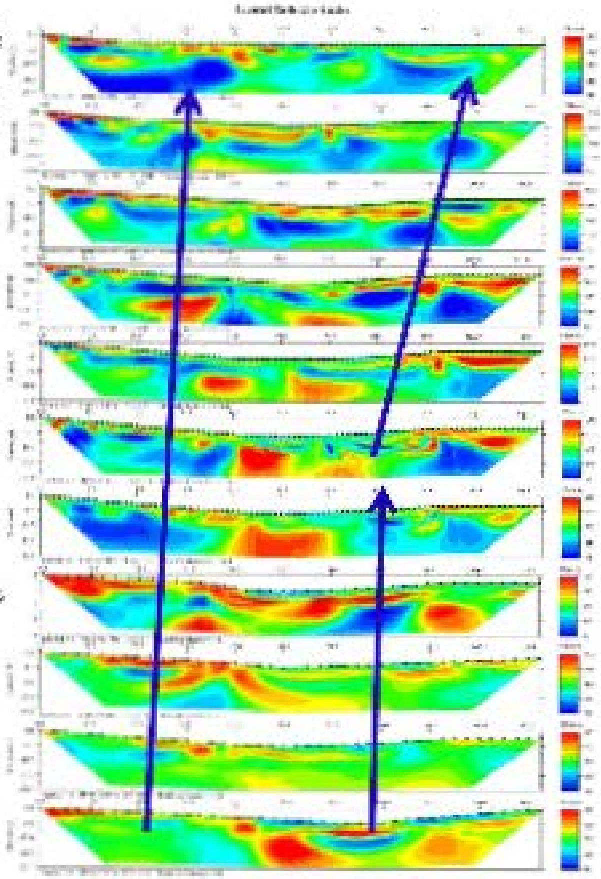
Survey Site: Clarksville, TN USA

Method: Dipole-dipole resistivity
SuperSting/Swift 84 electrodes
1.5/3.0 ft spacing

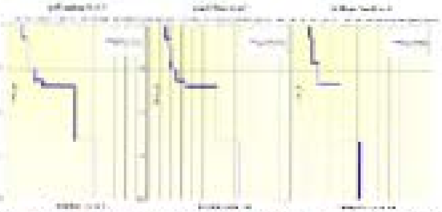
Processing: EarthImager 2D Software
Units Feet and Ohmmeters

Electrical resistivity line 84 electrodes 1.5 ft spacing across existing pond.

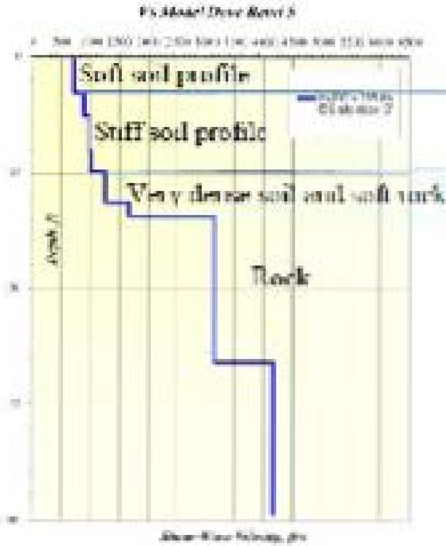
Old dam structure lies to the northeast. Top ER profile corresponds to far NW line. Bottom ER profile to far SE line. Blue lines are Seismic lines.

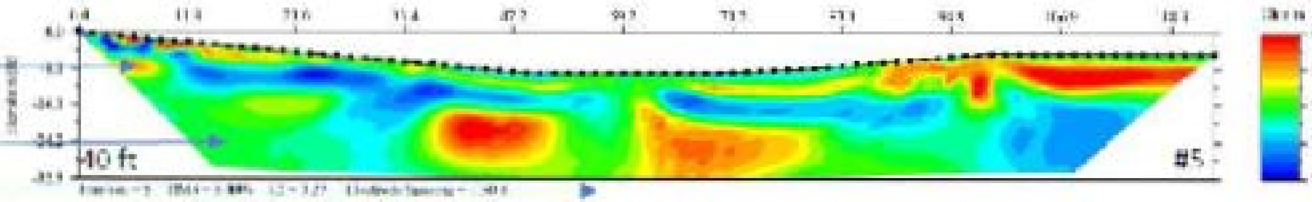


[illegible] 2D profiles of pond. Blue arrows indicate potential groundwater paths.

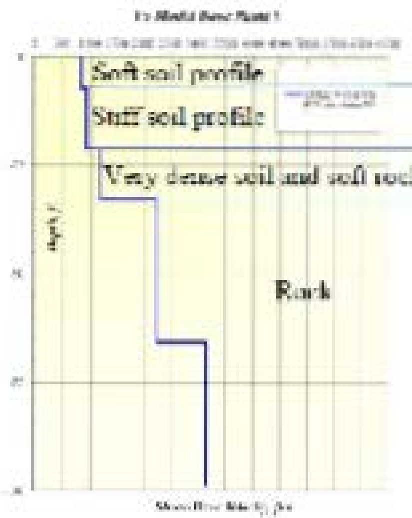


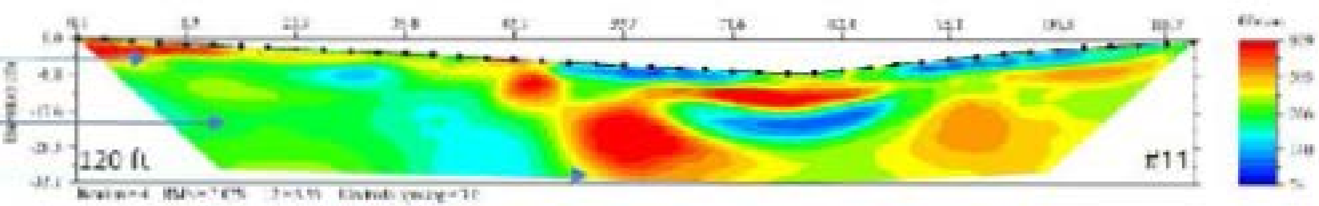
Refraction Microtremor seismic survey of area. Shearwave velocity profiles indicate bedrock at approximately [illegible] feet with stiff and soft soils above bedrock.



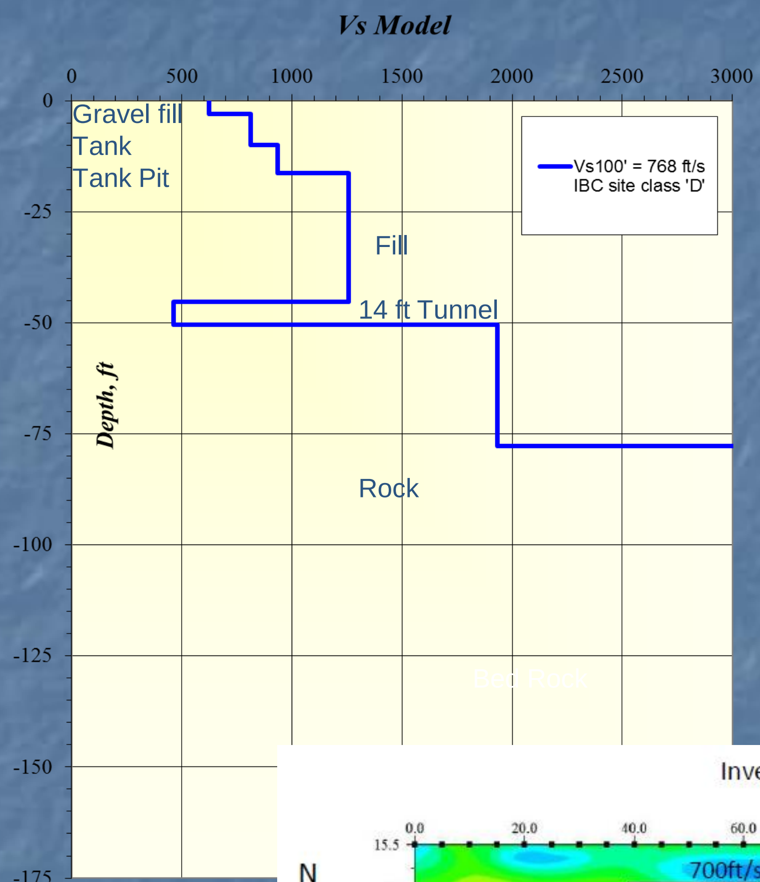


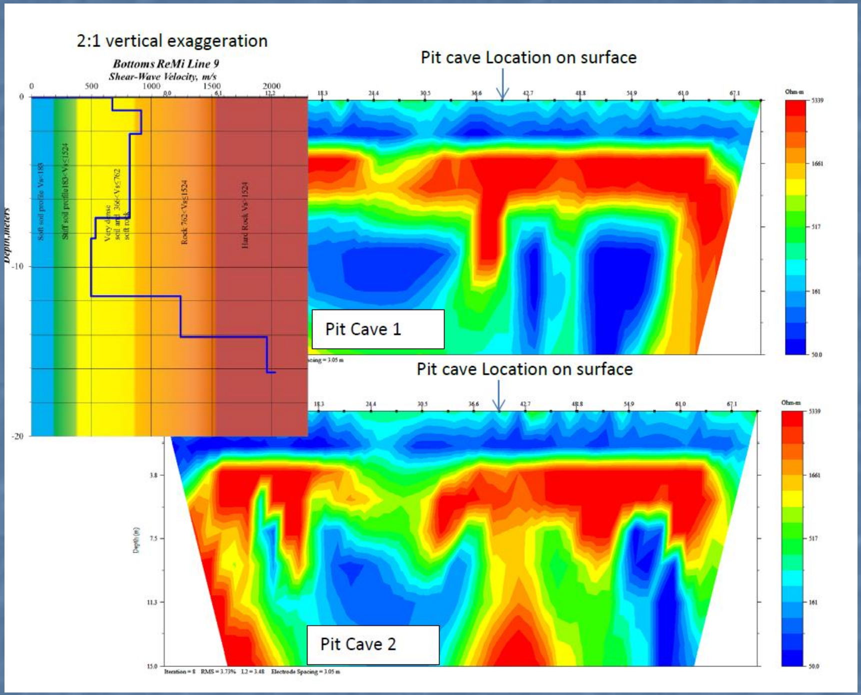
	Feet/second
Hard Rock	$V_s > 5000$
Rock	$2500 < V_s < 5000$
Very dense soil and soft rock	$1200 < V_s \leq 2500$
Stiff soil profile	$600 < V_s \leq 1200$
Soft soil profile	$V_s < 600$

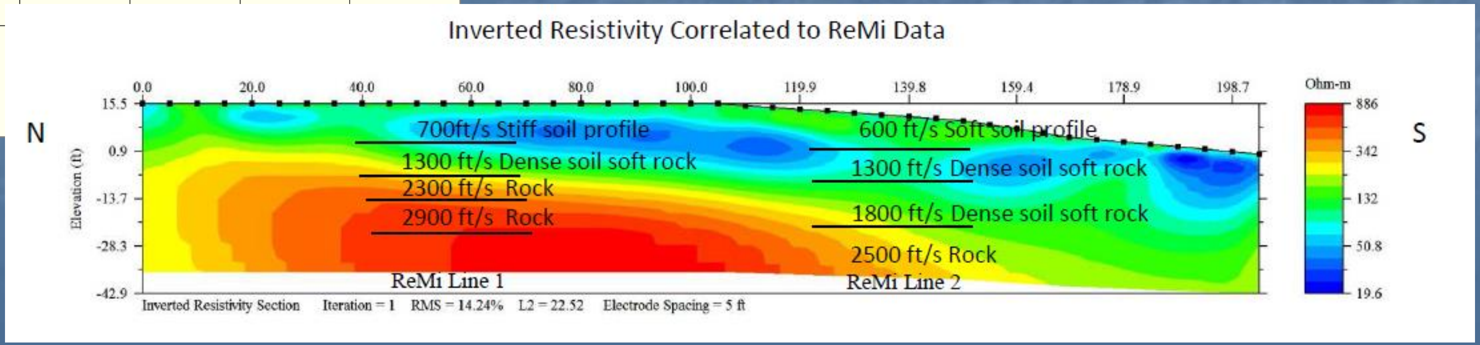




Subsurface Exploration Tools







Rippability

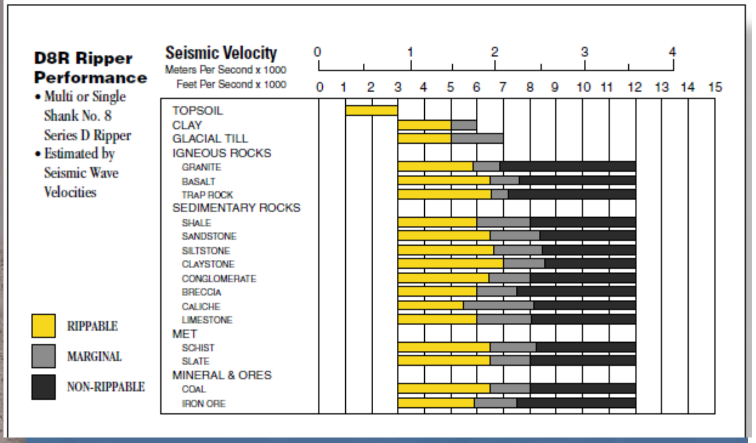
Seismic Refraction used to determine Rock velocity

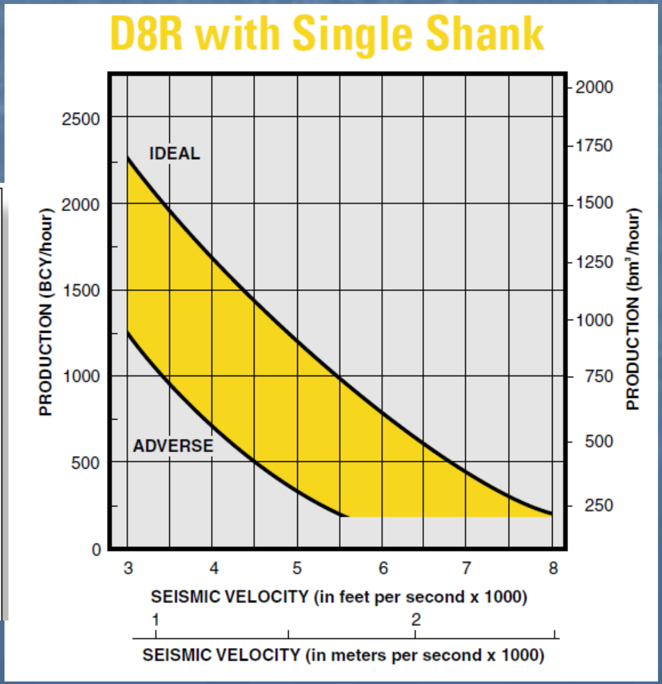
Refraction blind to low velocity zones

ReMi sees reversals

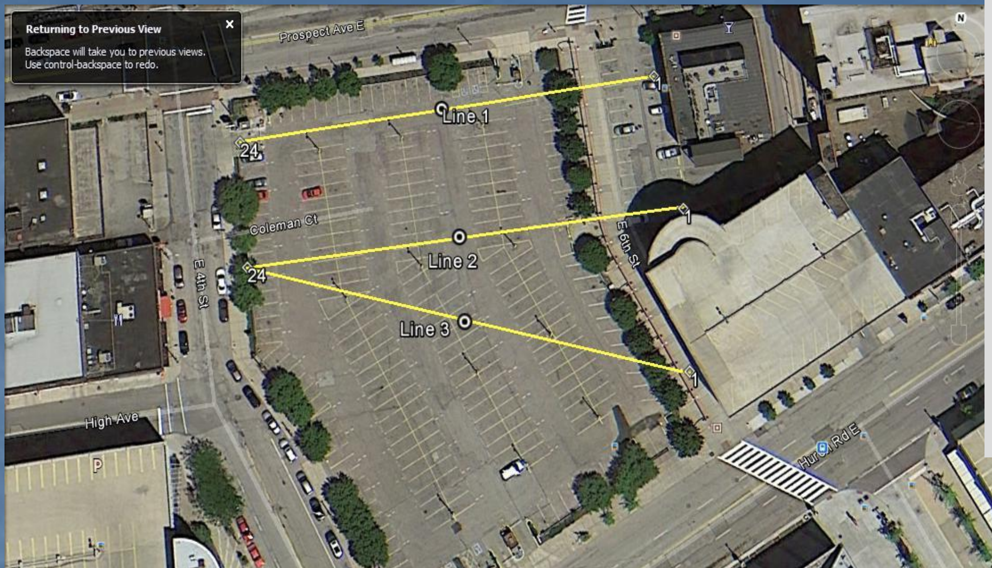
Shear Wave Velocity and Poisson's ratio Vp

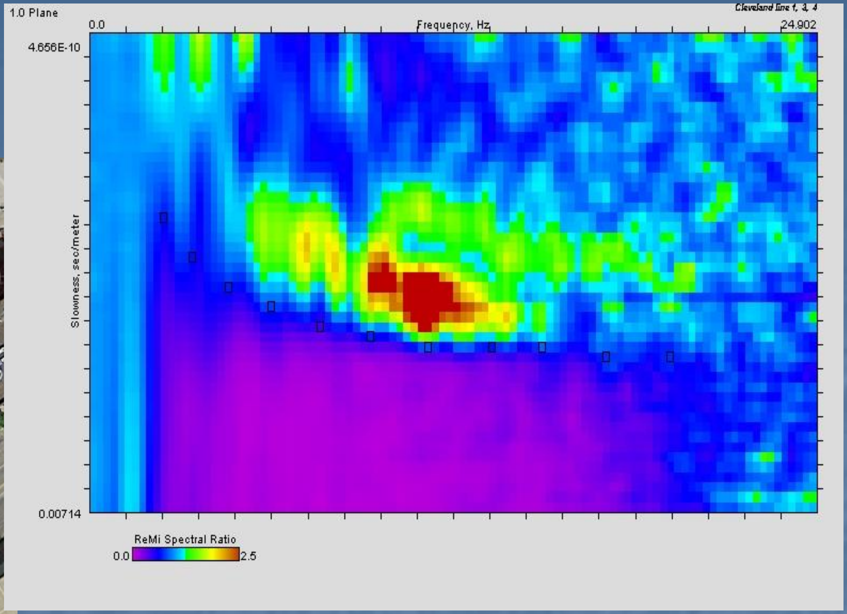
Caterpillar rippability index

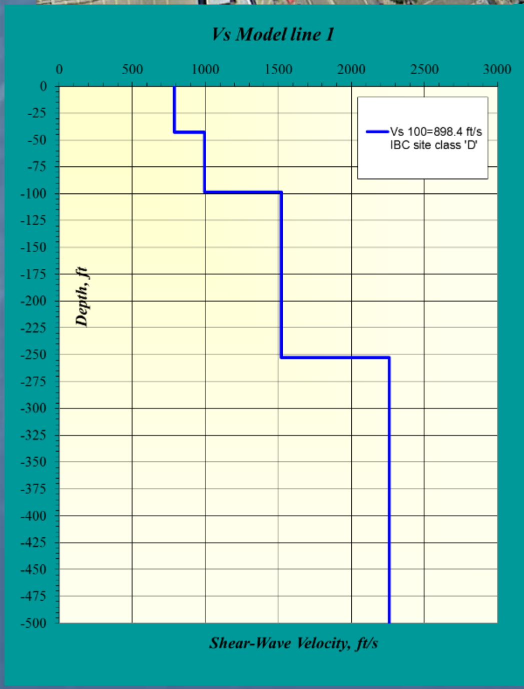


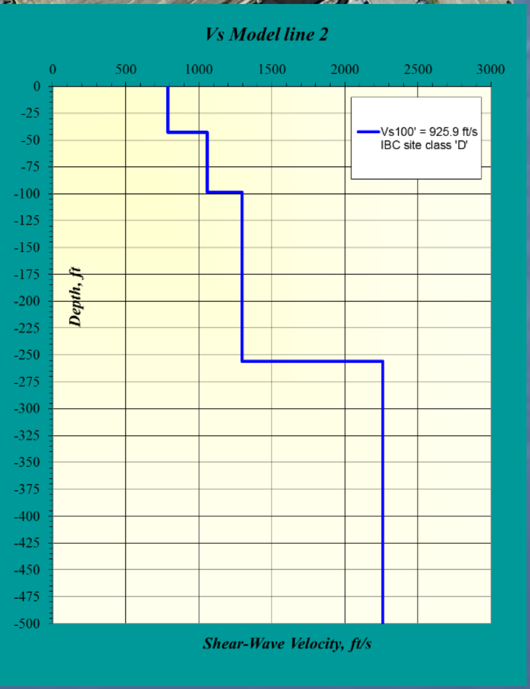


Seismic Site Classification









Shear modulus can be determined once *VS* is known.

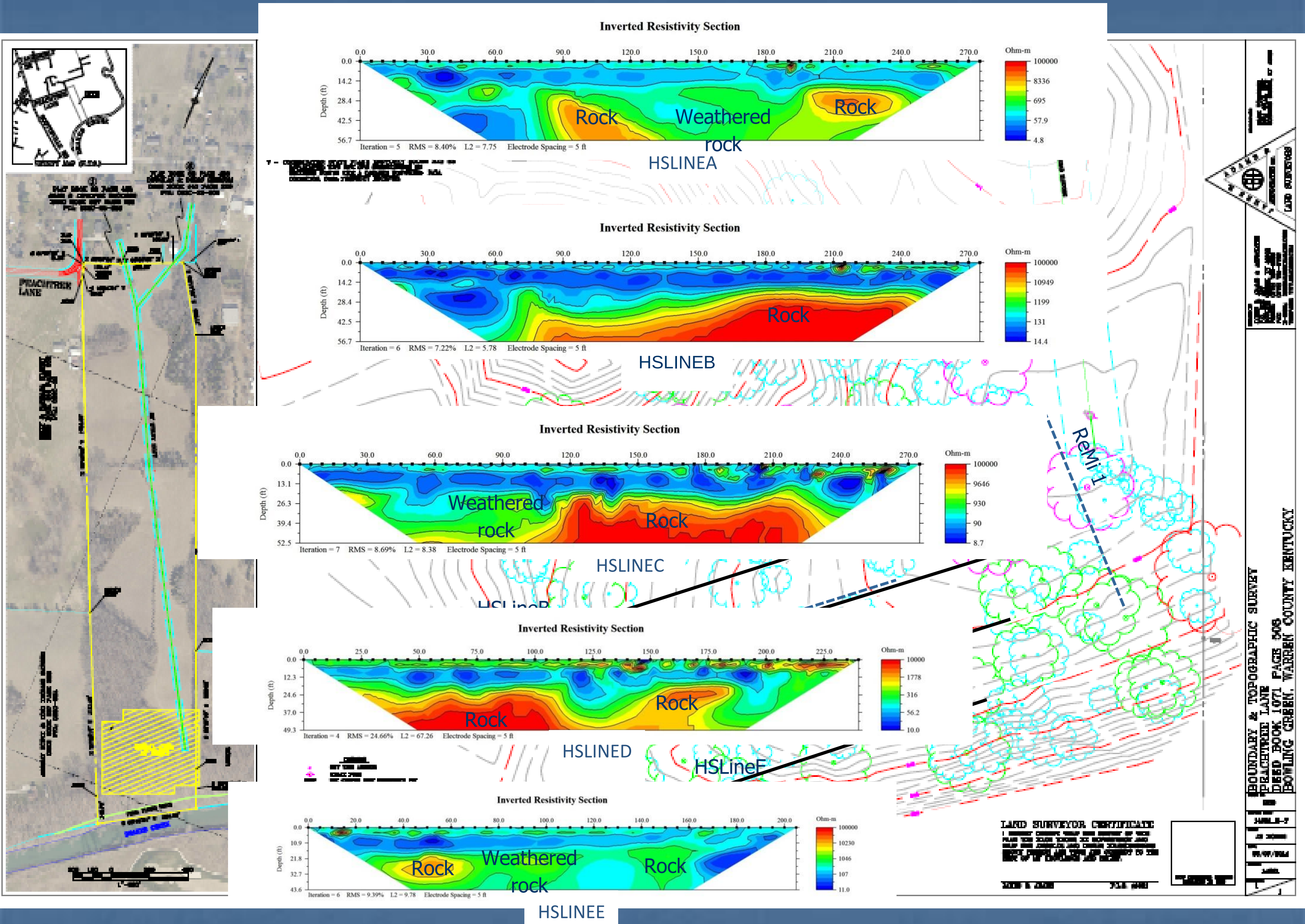
Assessment of load-bearing capacity,

Ground behavior under continuous and prolonged vibration,

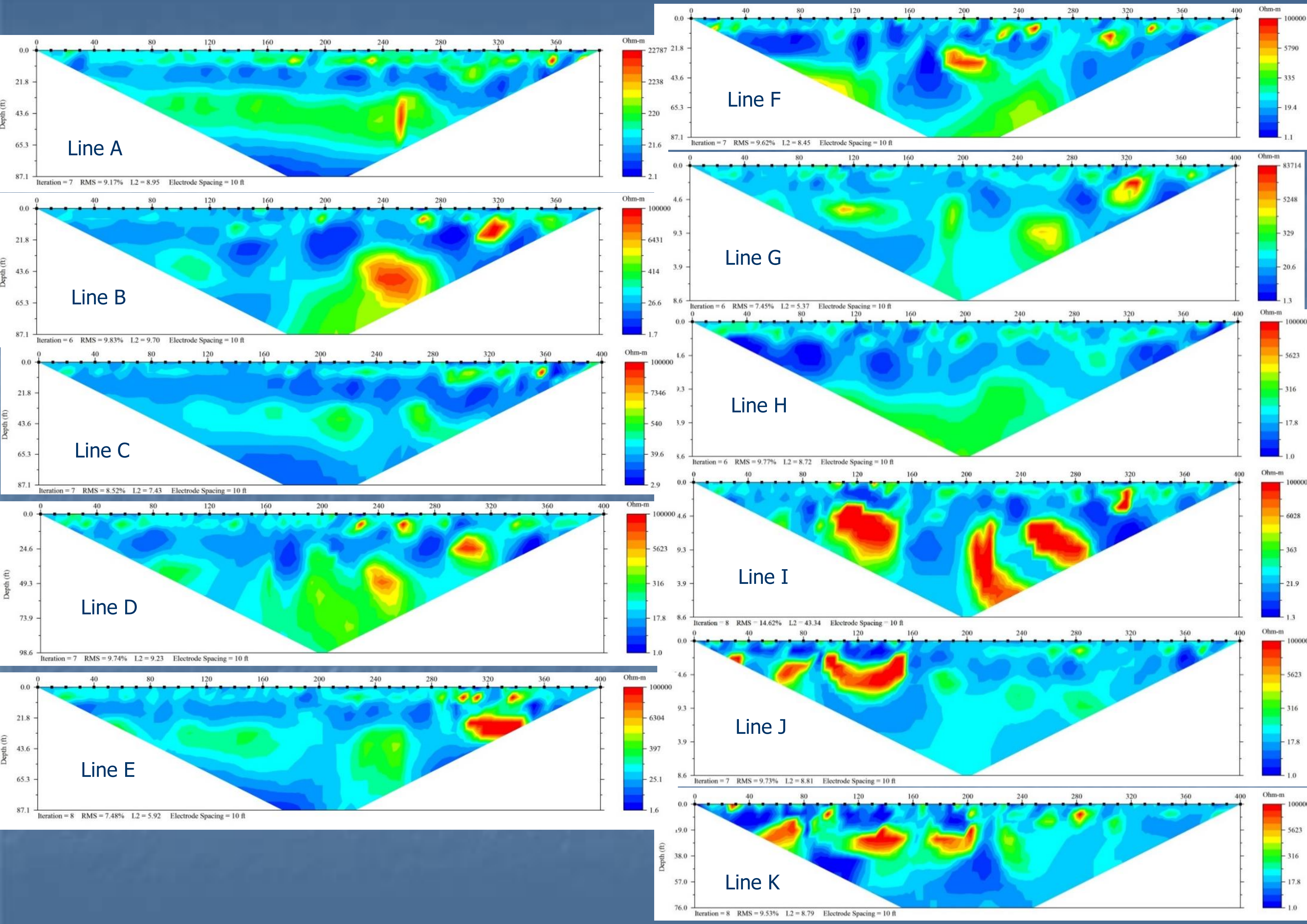
Ground amplification and liquefaction potential

Shear-wave velocity (VS) is the best indicator of stiffness

Used as an important criterion in the design of building structures.

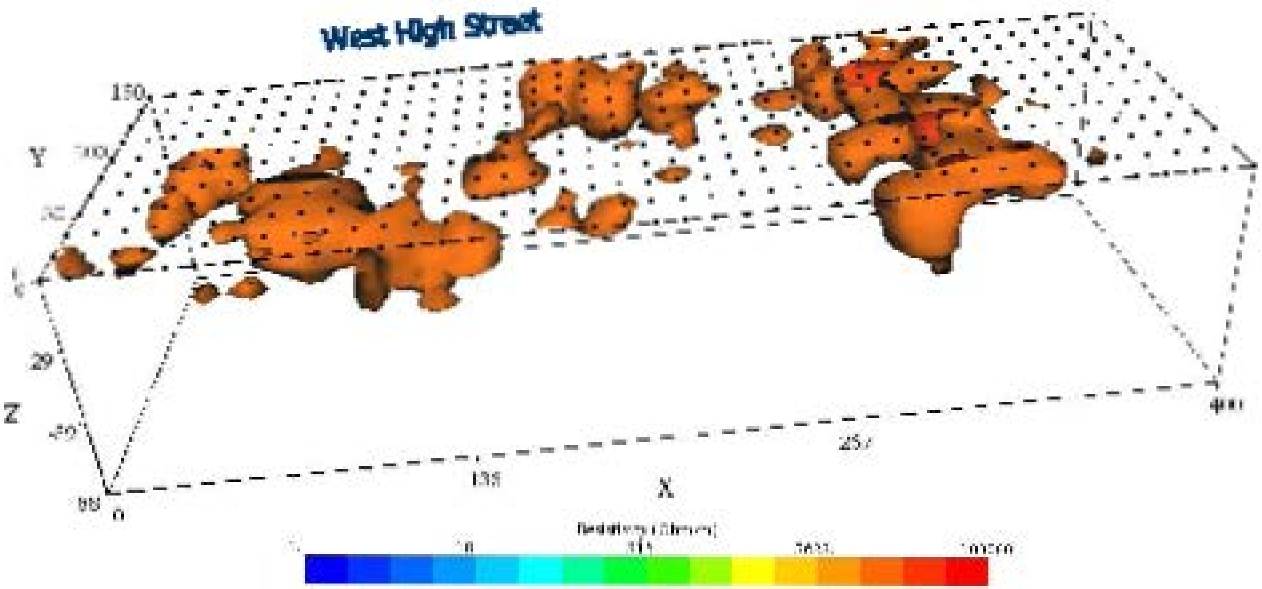

Inverted Resistivity Section
Depth (ft)
Ohm-m
Iteration = 5 RMS = 8.40% L2 = 7.75 Electrode Spacing = 5 ft
Rock
Weathered rock
Rock
HSLINEA
Inverted Resistivity Section
Iteration = 6 RMS = 7.22% L2 = 5.78 Electrode Spacing = 5 ft
Rock
HSLINEB
Inverted Resistivity Section
Iteration = 7 RMS = 8.69% L2 = 8.38 Electrode Spacing = 5 ft
Weathered rock
Rock
HSLINEC
ReMi 1
Inverted Resistivity Section
Iteration = 4 RMS = 24.66% L2 = 67.26 Electrode Spacing = 5 ft
Rock
Rock
HSLINED
HSLineE
Inverted Resistivity Section
Iteration = 6 RMS = 9.39% L2 = 9.78 Electrode Spacing = 5 ft
Rock
Weathered rock
Rock
HSLINEE
PEACHTREE LANE
LAND SURVEYOR CERTIFICATE
BOUNDARY & TOPOGRAPHIC SURVEY
PEACHTREE LANE
DEED BOOK 1071 PAGE 508
BOWLING GREEN, WARREN COUNTY KENTUCKY

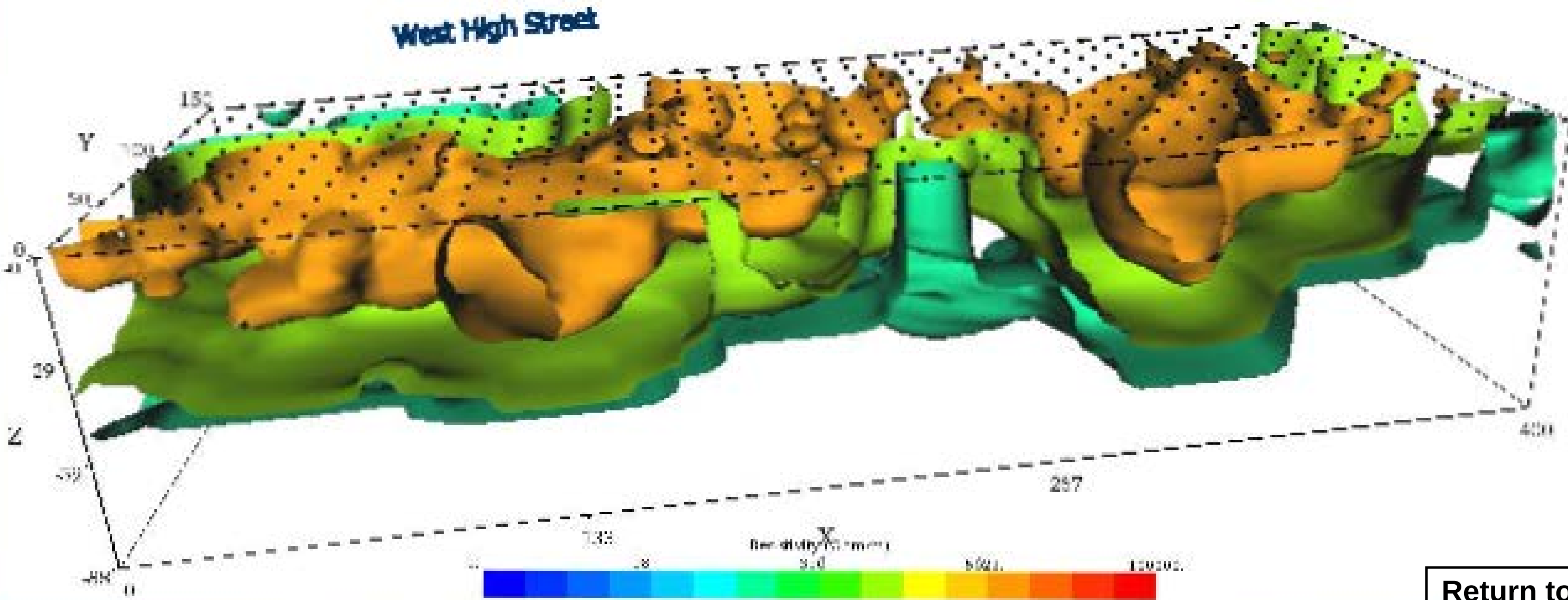

25 ft from line A to edge of
High Street
W High St
Maple St
W High St
Dearborn
County Museum
Line A
Line B
Line C
Line D
Line E
Line F
Line G
Line H
Line J
Line K



Line A
Iteration = 7 RMS = 9.17% L2 = 8.95 Electrode Spacing = 10 ft
Line B
Iteration = 6 RMS = 9.83% L2 = 9.70 Electrode Spacing = 10 ft
Line C
Iteration = 7 RMS = 8.52% L2 = 7.43 Electrode Spacing = 10 ft
Line D
Iteration = 7 RMS = 9.74% L2 = 9.23 Electrode Spacing = 10 ft
Line E
Iteration = 8 RMS = 7.48% L2 = 5.92 Electrode Spacing = 10 ft
Line F
Iteration = 7 RMS = 9.62% L2 = 8.45 Electrode Spacing = 10 ft
Line G
Iteration = 6 RMS = 7.45% L2 = 5.37 Electrode Spacing = 10 ft
Line H
Iteration = 6 RMS = 9.77% L2 = 8.72 Electrode Spacing = 10 ft
Line I
Iteration = 8 RMS = 14.62% L2 = 43.34 Electrode Spacing = 10 ft
Line J
Iteration = 7 RMS = 9.73% L2 = 8.81 Electrode Spacing = 10 ft
Line K
Iteration = 8 RMS = 9.53% L2 = 8.79 Electrode Spacing = 10 ft
Depth (ft)
Ohm-m

3D Resistivity Contour Plot





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REFLECTION AND REFRACTION SEISMOLOGY: CONCEPTS REVIEW WITH CASE HISTORIES

Edward W. Woolery, Professor of Geophysics and Director of Graduate Studies, University of Kentucky EES; Faculty Associate, Kentucky Geological Survey, woolery@uky.edu

Speaker Bio: Edward W. Woolery received undergraduate degrees in geology (BS, 1984) and civil engineering (BSCE, 1996) from Eastern Kentucky University and the University of Kentucky, respectively. His MS (1993) and PhD (1998) degrees were in Geological Sciences (Geophysics) from the University of Kentucky. Ed's career began as a geotechnical engineer and geologist for the Louisville District U.S. Army Corps of Engineers before returning to the University of Kentucky to begin the Geologic Hazards Section for the Kentucky Geological Survey. Currently, he is a Professor of Geophysics and the Director of Graduate Studies in the University of Kentucky's Department of Earth and Environmental Sciences. Ed's research bridges the interface between geophysics and the engineering disciplines, primarily as a field-oriented experimentalist focused on seismic hazards in general, and near-surface geophysical methods, ground-motion site response, and neotectonics (active-fault assessment) in particular. Most research has been concentrated in the central United States (i.e., New Madrid and Wabash Valley seismic zones), but more recently along the northern edge of the Tibetan Plateau in western China.

Presentation Abstract: Although a pure mathematical description of exploration seismology can appear somewhat daunting, the basic conceptual physics for explaining the subject is remarkably straightforward. Consider an area or point of earth material: if disturbed, the resultant displacement energy is propagated outward from the source as an attenuating elastic wave until it encounters a boundary separating material with contrasting elastic properties, wherein it predictably partitions into refraction and reflection components. We review the spatial and temporal consequences of this process for both P- and S-wave modes in the context of seismic data acquisition, processing and interpretation, as well as highlighting potential pitfalls and advantages using examples from geotechnical engineering, geological hazard assessment, and petroleum exploration.

Reflection and Refraction Seismology
Concepts Review with Case Histories

KY–AIPG 2015 Professional Development Conference

Geophysical Techniques and Applications – Non-invasive Methods for Subsurface Characterization and Interpretation

October 16, 2015
Lexington, Kentucky

Edward W. Woolery, University of Kentucky

University of Kentucky
College of Arts & Sciences
Department of Earth & Environmental Sciences

Geophysics

"The physics of the Earth, Moon, and planetary bodies"

Quantitative spatial and/ or temporal analysis of… …physical processes and/or properties

Solid Earth Geophysics

"Physics of the Earth's interior (land surface to inner core)"

Atmosphere/ Hydrosphere

Astrophysics…

Pure/Global Geophysics

"Study of the whole or substantial parts of the Earth"

Applied Geophysics

"Investigation of the Earth's crust and near-surface to achieve a practical (often economic) objective

- Application of geophysical methods to investigate subsurface materials & structures that are likely to have significant societal implications.
- Application of geophysical methods to investigate near-surface physio-chemical phenomena that are likely to have significant implications for the management of the local environment.

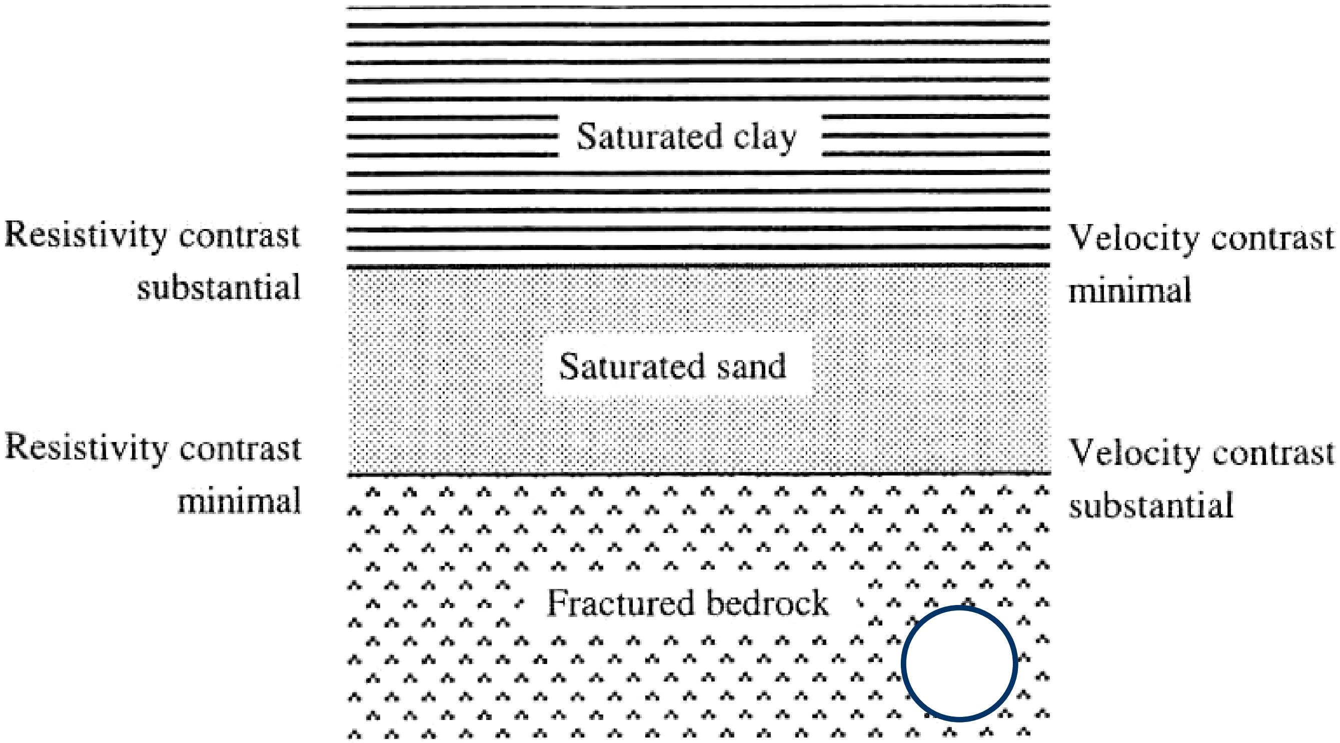
Geophysical Measurements

- ➢ *Passive methods*: detect variations within the natural fields associated with the Earth (i.e., gravitational, magnetic, & electrical fields).

- ➢ *Active methods*: those using artificially generated "signals" that are modified by the materials through which they travel; the altered signals are measured by appropriate detectors whose output is displayed and ultimately interpreted.

Geophysical Technique			Property Measured at Earth's Surface	Property Investigated within Earth
SEISMIC	Natural Source: Earthquake		*Ground Motion (Displacement, Velocity or Acceleration)*	Seismic Velocity (V) and Attenuation (Q)
	Controlled Source	Refraction		Seismic Velocity (V)
		Reflection		Acoustic Impedance (Seismic Velocity, V, and Density, ρ)
POTENTIAL FIELD	Gravity		*Gravitational Acceleration ($\vec{g}$)*	Density (ρ)
	Magnetics		*Strength and Direction of Magnetic Field ($\vec{F}$)*	Magnetic Susceptibility (χ) and Remanent Magnetization ($\vec{J}_{rem}$)
HEAT FLOW			*Geothermal Gradient ($\partial T/\partial z$)*	Thermal Conductivity (k) and Heat Flow (q)

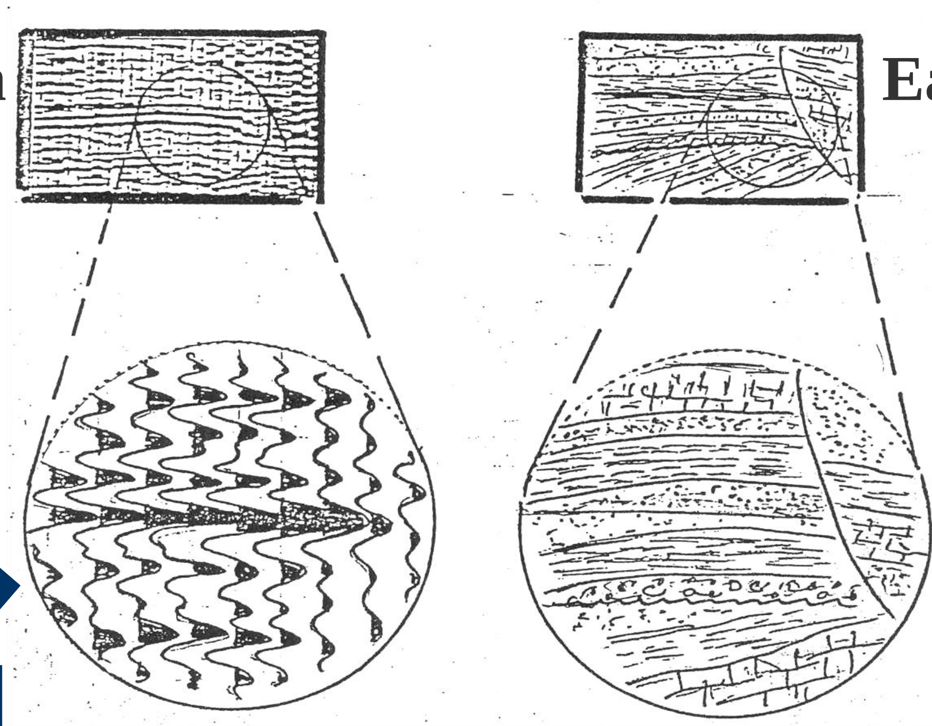
Geophysical Measurements



- Match methods to application.
  - *Physical properties*
  - *Resolution*

Seismic Exploration: General

Seismic Section



Earth Section

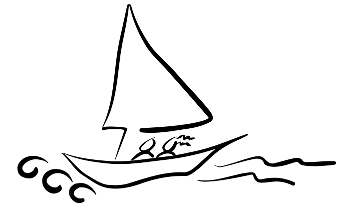
- Amplitude
- Frequency
- Time
- Phase
- Coherency/ Pattern

It is the elastic properties of the rock/soil and their contrasts that influences the correlation success

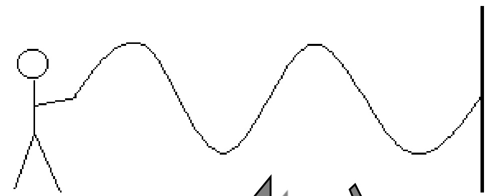
- Lithology
- Depth
- Structure
- Depositional environment

Seismic Exploration: General

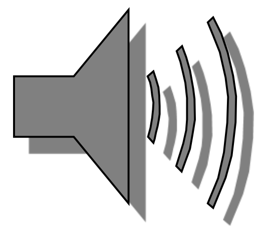
IN WATER



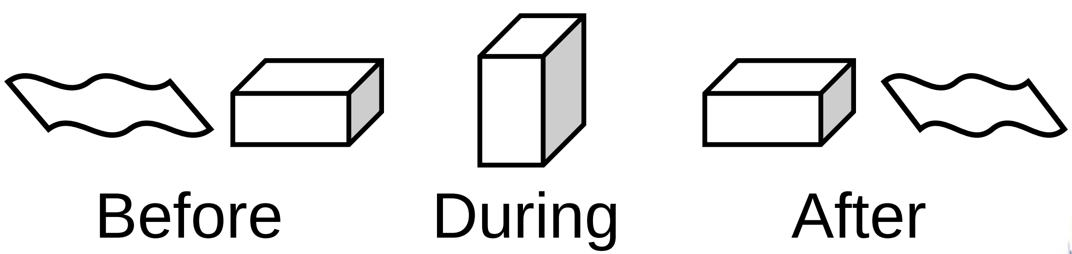
ON A ROPE



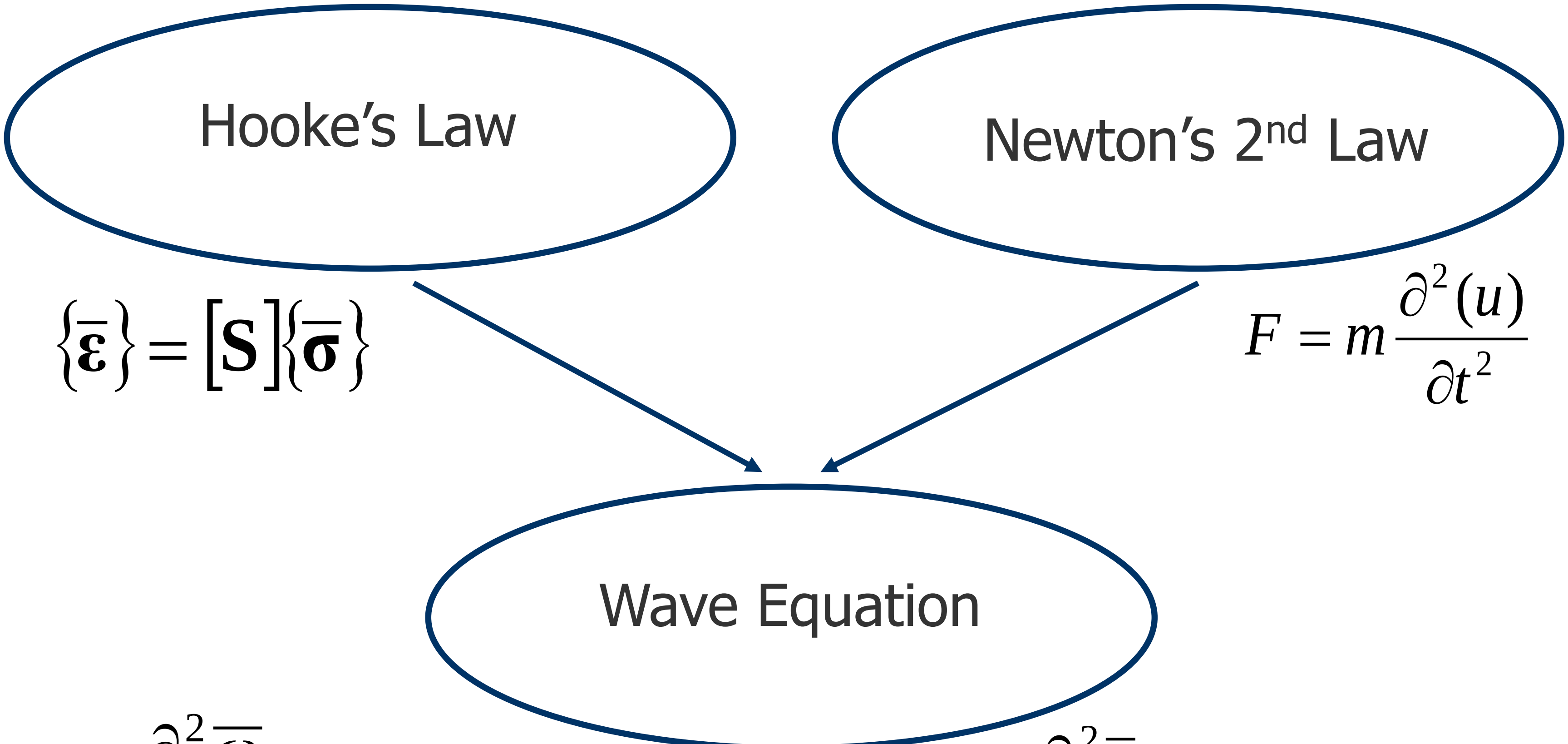
SOUND



- Waves are moving disturbances of media particles in which wave is traveling
- Our interest is in disturbances that are small and temporary…the rock/ soil "bounce back" after wave passes (i.e., elastic!)



Waves in Solids
Mechanical Wave Genesis



$$\{\overline{\boldsymbol{\varepsilon}}\} = [\mathbf{S}]\{\overline{\boldsymbol{\sigma}}\}$$

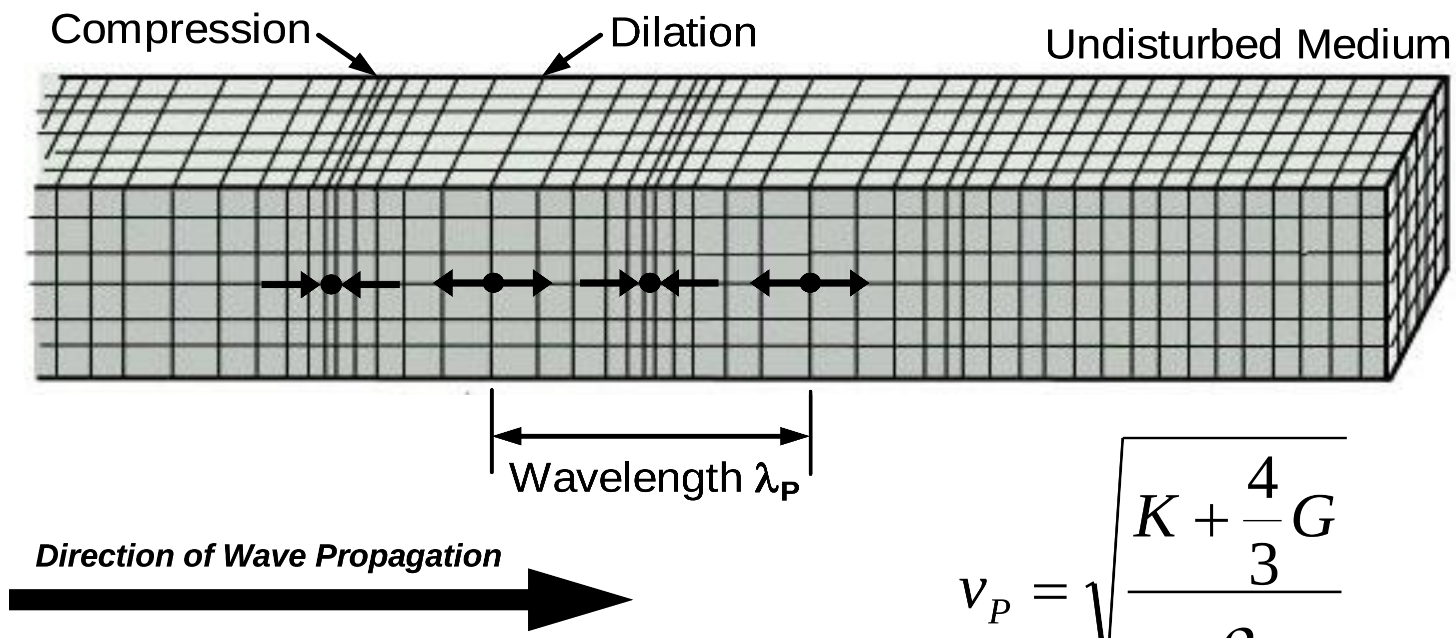
$$F = m\frac{\partial^2(u)}{\partial t^2}$$

$$\frac{\partial^2 \overline{\omega}_x}{\partial t^2} = v_S \nabla^2 \overline{\omega}_x$$

$$\frac{\partial^2 \overline{\varepsilon}}{\partial t^2} = v_P \nabla^2 \overline{\varepsilon}$$

Seismic Exploration: Body Waves

Primary Wave (P-wave)

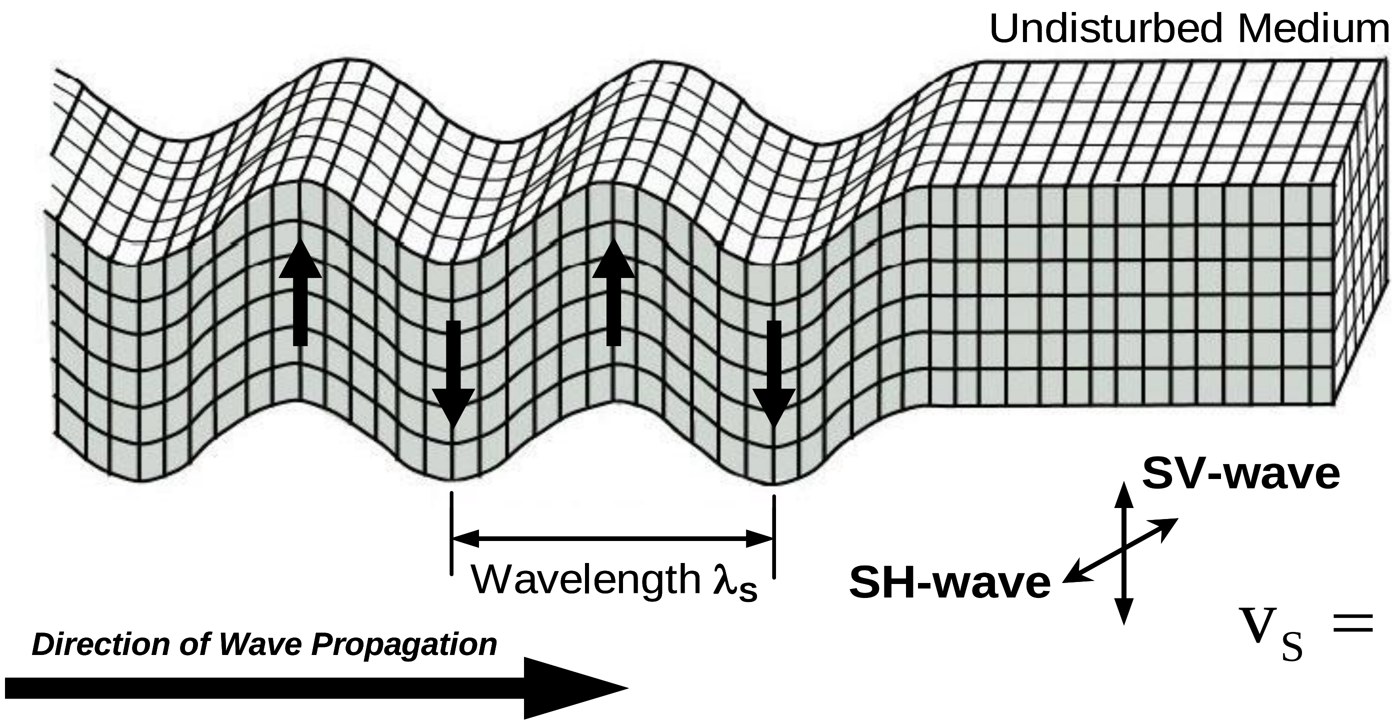


$$v_P = \sqrt{\frac{K + \frac{4}{3}G}{\rho}}$$

- analogous to sound waves, i.e., individual particle motion is parallel to direction of travel.
- travel as volumetric change thru solids and fluids.

Seismic Exploration: Body Waves

Secondary wave (S-wave)

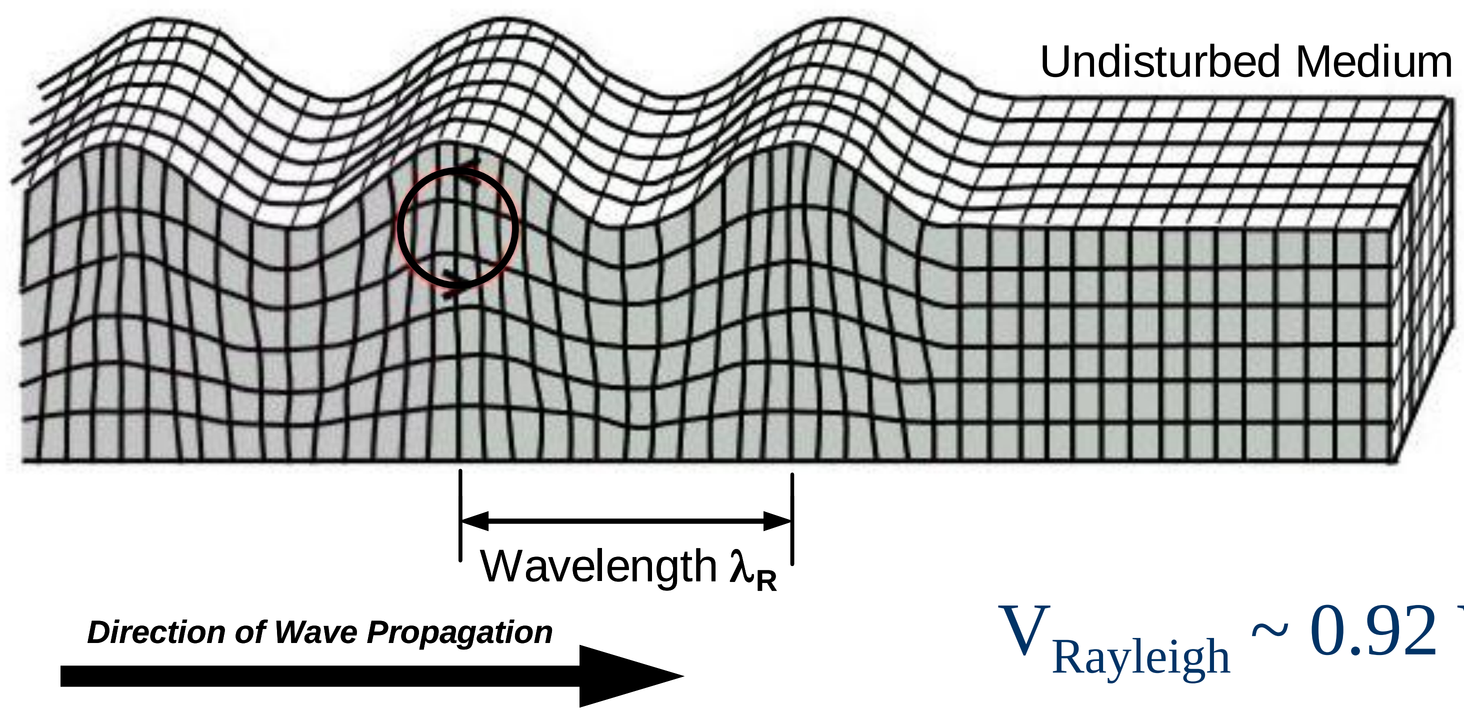


$$v_S = \sqrt{\frac{G}{\rho}}$$

- cause elastic shearing/shape deformation as they travel thru material.
- particle motion is perpendicular to the direction of wave propagation.
- divide direction of particle movement into 2 components: SV and SH

Seismic Exploration: Surface Waves

Rayleigh Wave

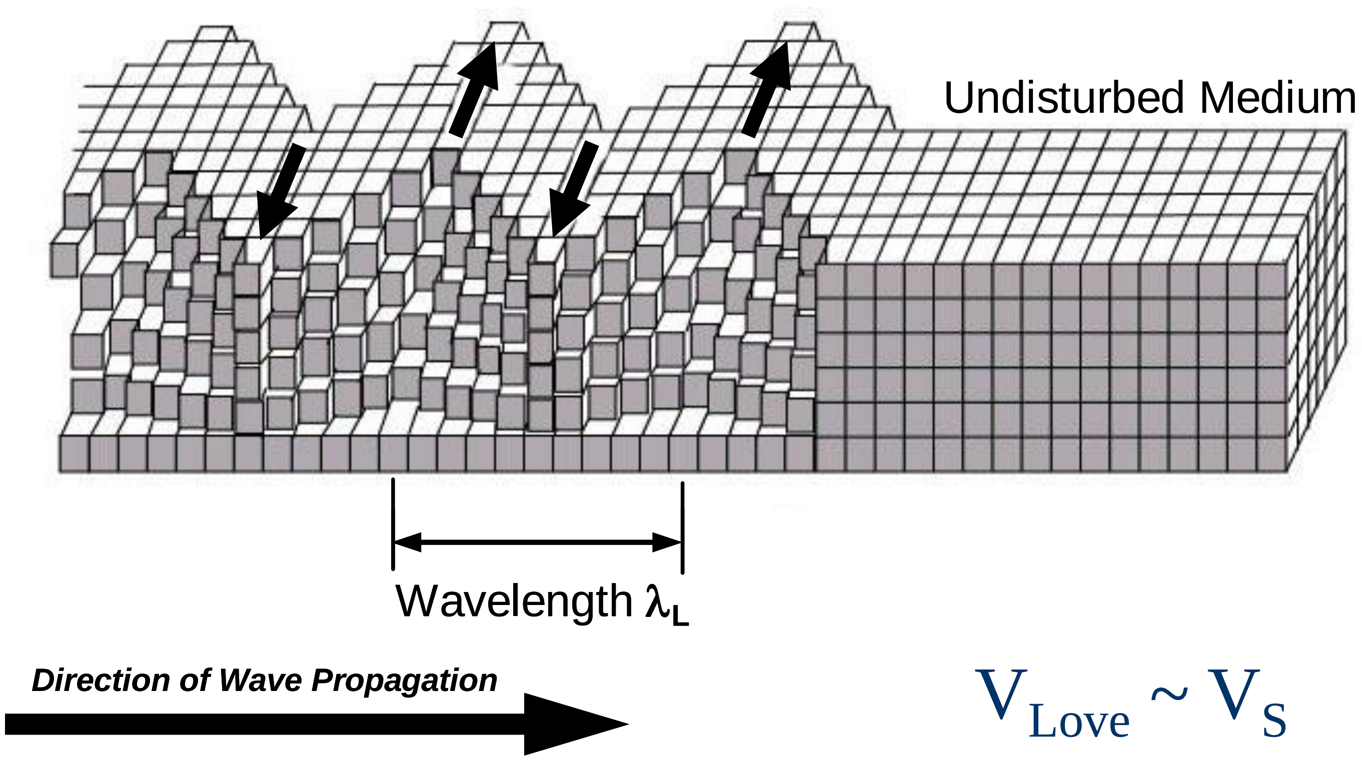


$V_{Rayleigh} \sim 0.92\ V_S$

- Produced from P- and SV- interaction
- Both vertical and horizontal motion

Seismic Exploration: Surface Waves

Love Wave



$$V_{Love} \sim V_S$$

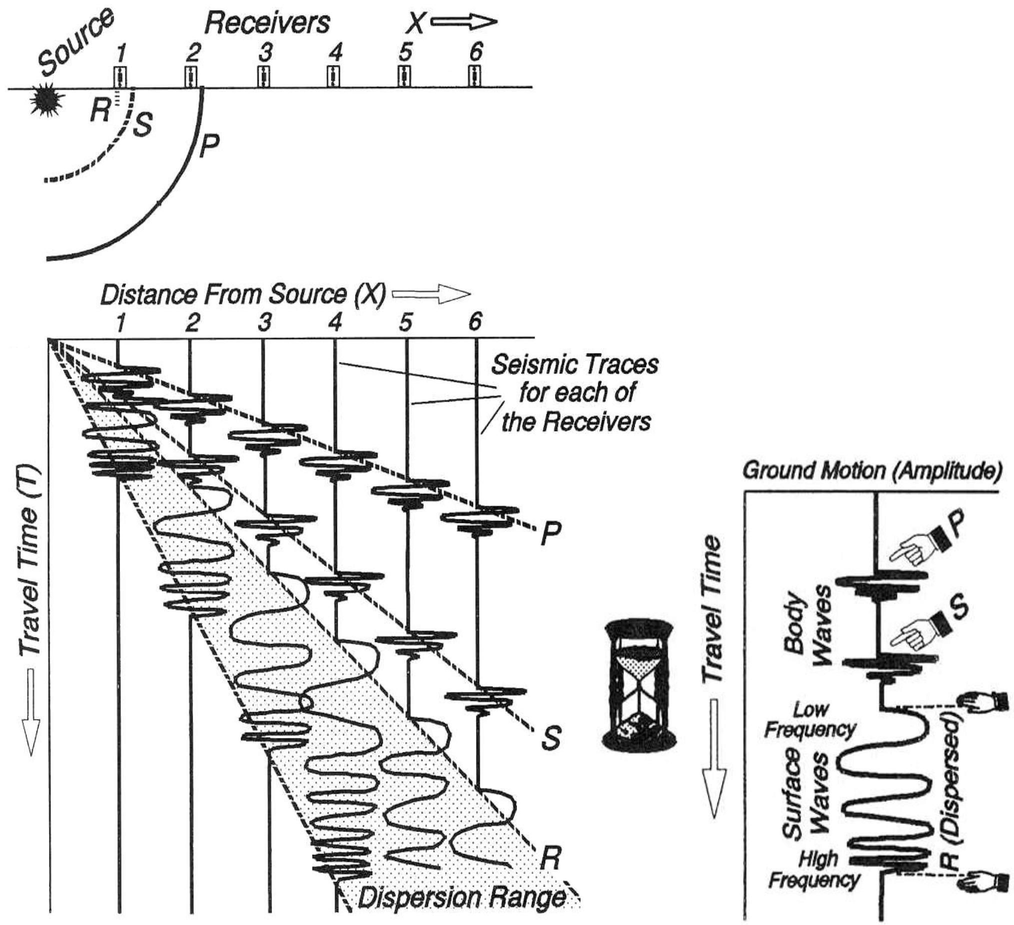
- Horizontal motion only
- Surface wave acting like a SH-wave

Seismic Exploration: Seismic Waves Summary

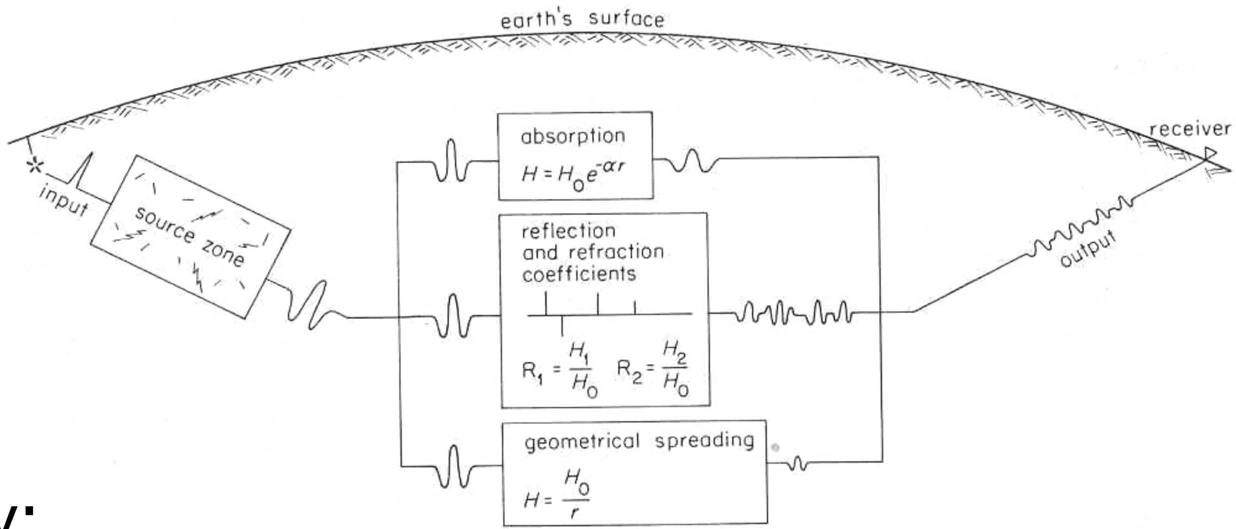
- Wavefronts for P,S, & R propagating across R-array which is set @ ↑ distance from source

- Travel time seismogram; traces are plotted as fnc of S→R distance

- NOTE:
  - No impedance boundary encountered
  - No attenuation considered



Seismic Waves: Summary



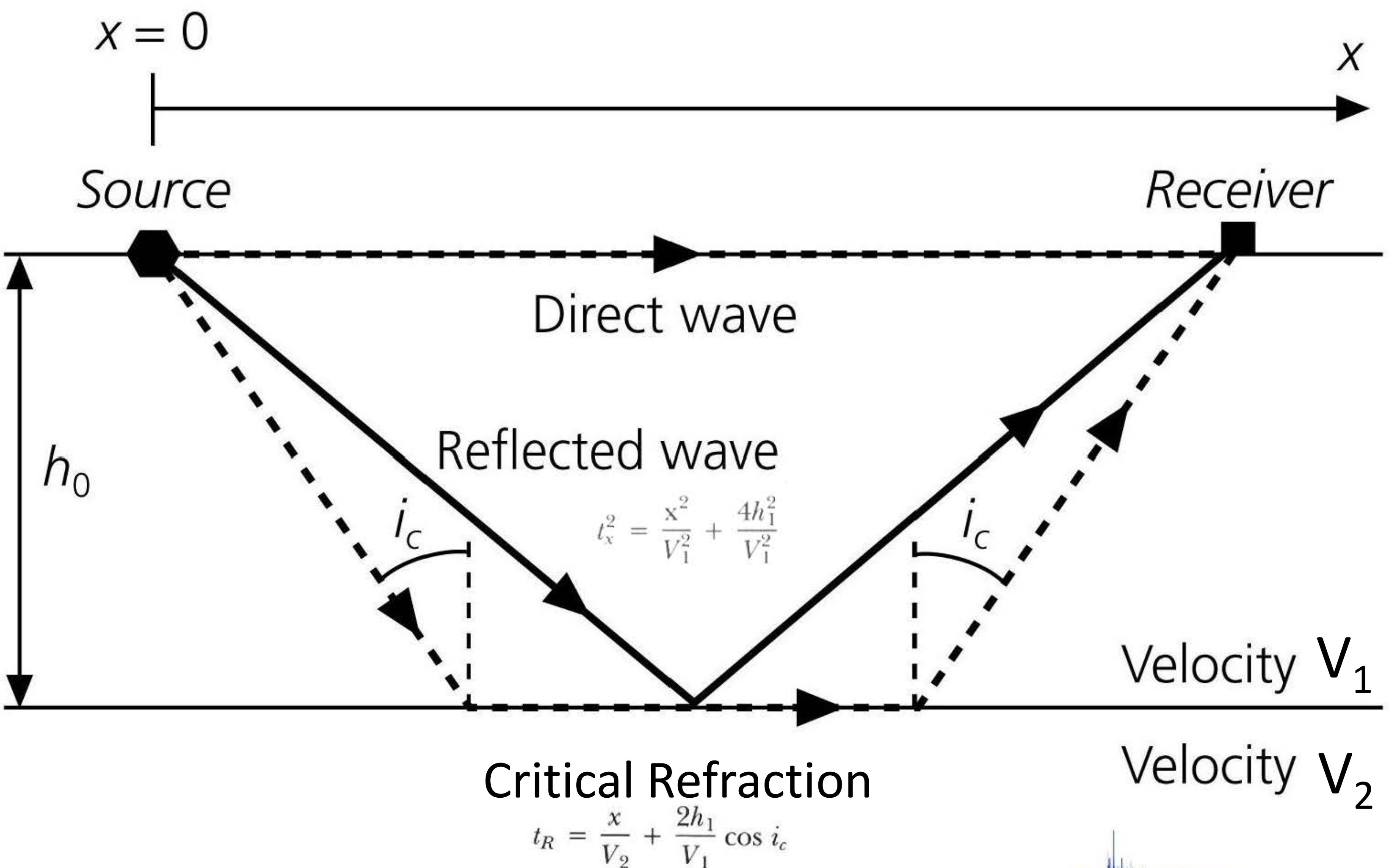
Summary:

- Earth is filter (i.e., it turns impulse signal into series of vibrations on seismogram)

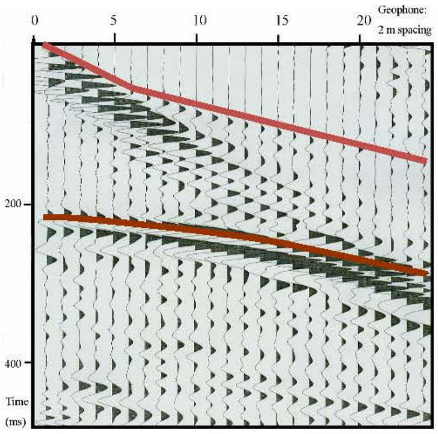
- Consists of 4 processes
  - Conversion of impulse wavelet w/in source zone
  - Partitioning of wavelet into succession of wavelets by reflection/refraction @ boundaries (e.g., R.C.'s and T.C's); Zoeprittz and Knott equations govern waveform properties (amplitude, phase, etc.)
  - Wave direction governed by Snell's Law
  - Wave energy loss governed by geometrical spreading and absorption

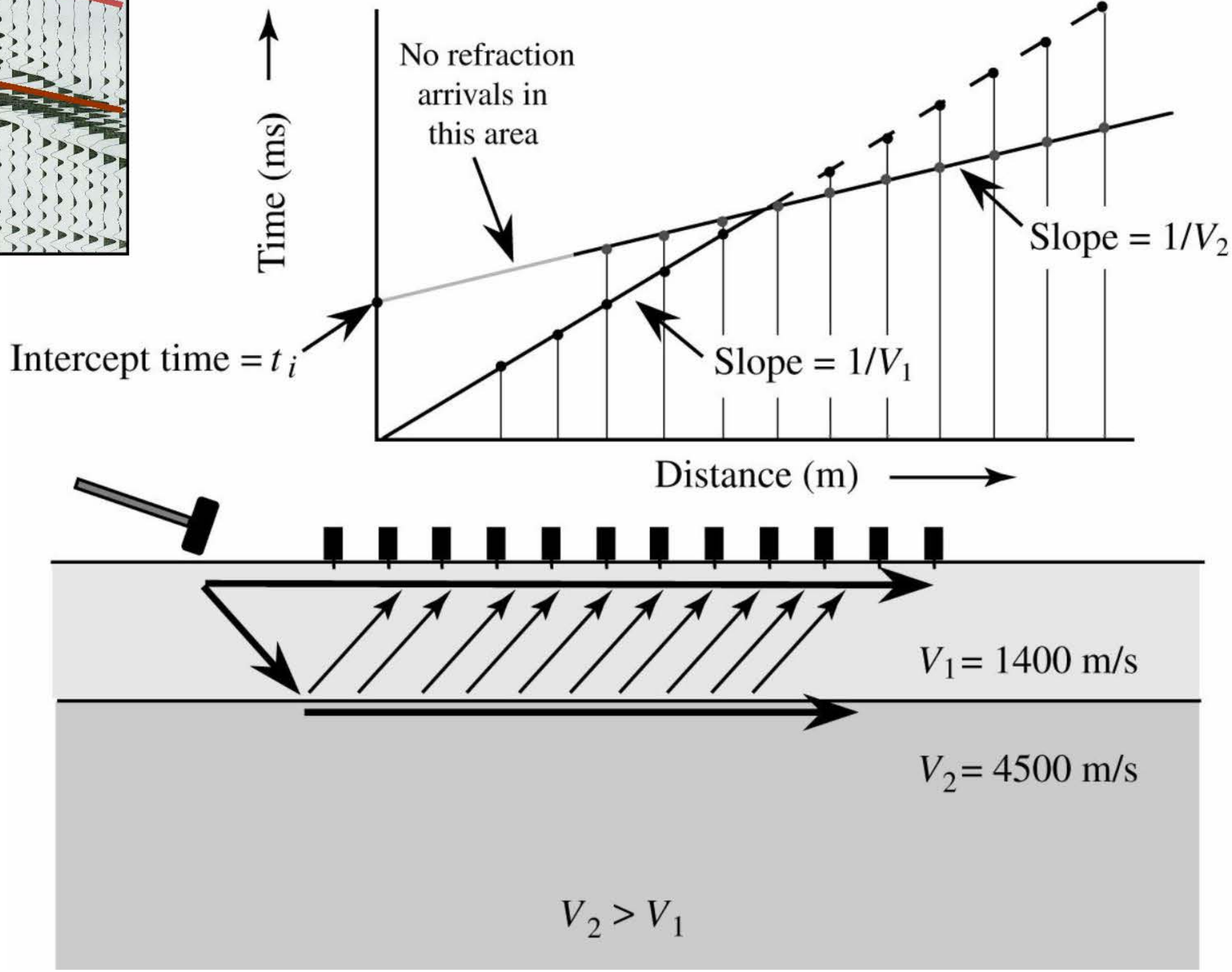
Waves in Solids

Preview:

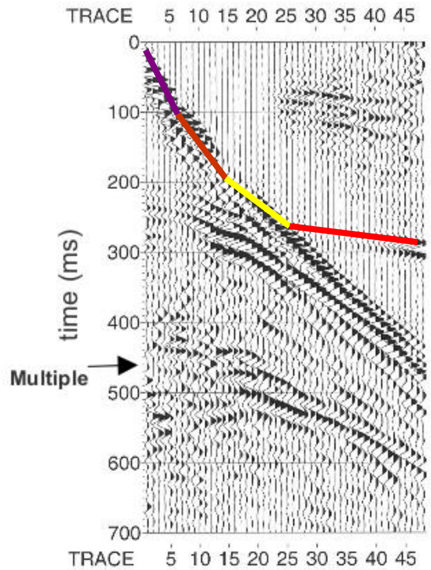


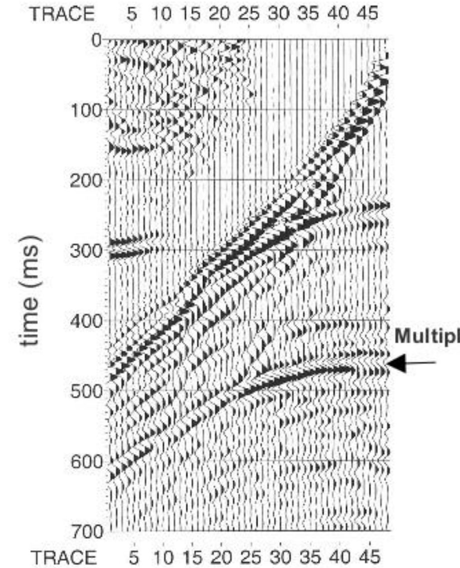
Seismic Refraction

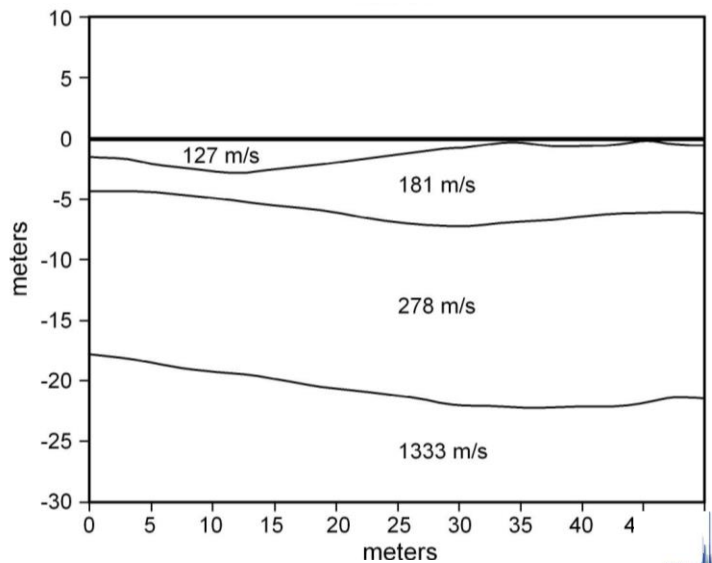




Seismic Refraction







Output motion

1-D Transfer Function SHAKE91

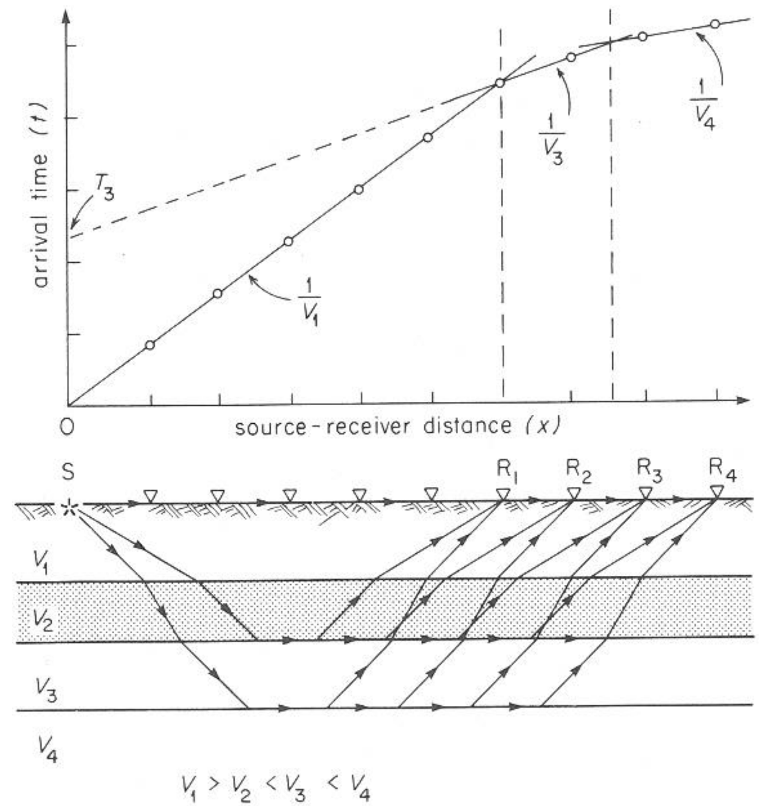
Input bedrock motion

Seismic Refraction

Refraction:

Limitations I

- By Snell's Law, no critical refraction @ "2"
- Obtain smaller refraction angle
- No evidence of "2" on x–t, but rays to/from deeper boundaries must pass thru
- Result is distortion in T_i; ∴ incorrect depth calcs.
- CANNOT be corrected for!
- The low-velocity zone called "***blind zone***"



Seismic Refraction

Refraction:

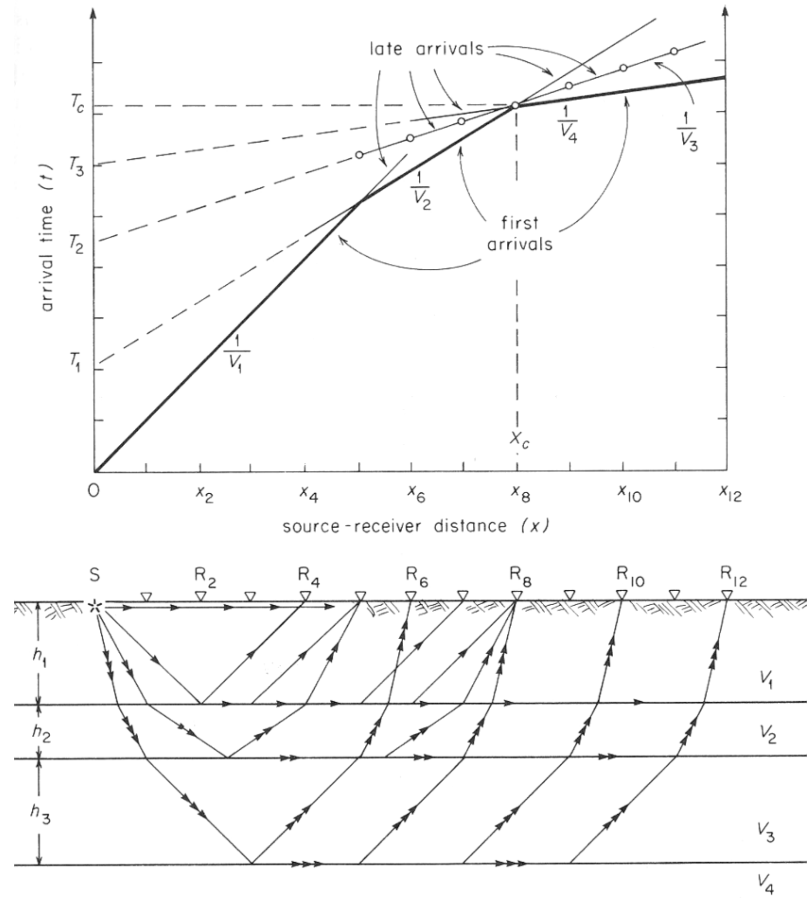
Limitations II (con't)

- If only 1st arrivals are recognized, then layer "3" is called a "***hidden layer***"

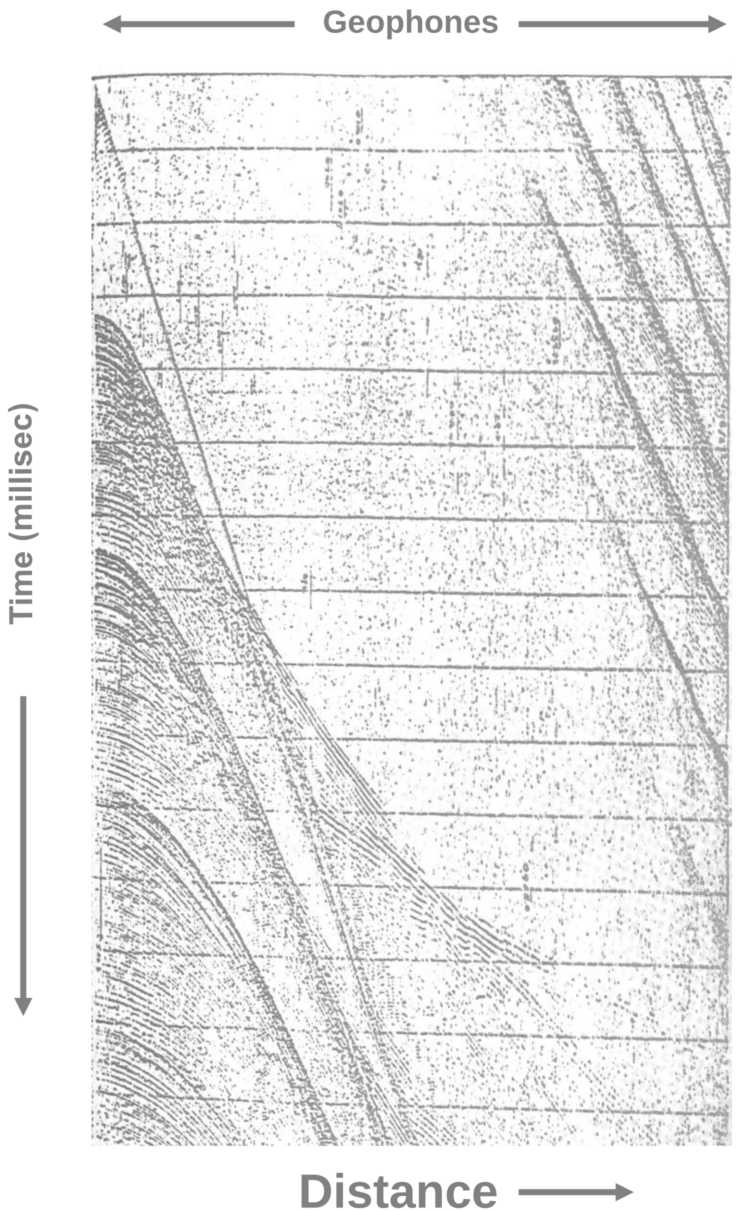
- So, depth calculation is INCORRECT.

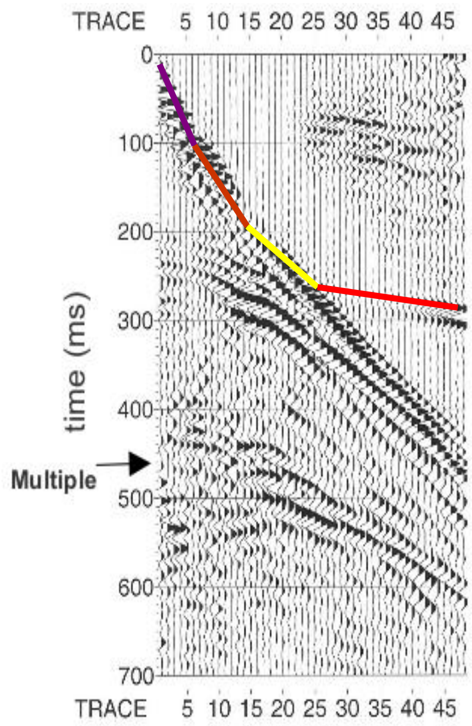
- Phenomenon can also result from v. large velocity contrasts (i.e., small critical angles @ deeper refractors create steep ray paths, and therefore small X_C.

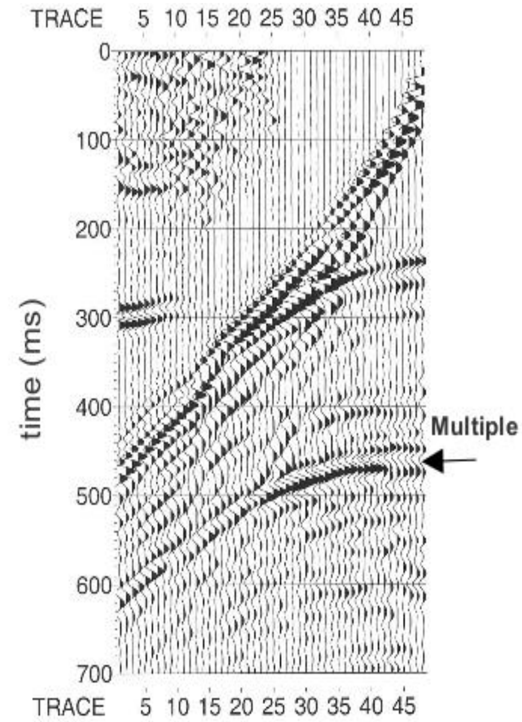
- Check for "***blind zones***" or "***hidden layers***" by using reflected waves, where only physical limitation is resolution (function of λ).



Seismic Reflection







Seismic Reflection

CMP

- Principal difficulty w/ reflections is often recognizing weak signal.

- Common practice to enhance weak pulse called multifold reflection surveying (i.e., combining many reflections from same pt. on reflector – called "common-mid-point", CMP or "common-depth-point", CDP).

- Reflections come from different source-to-receiver spacings; therefore, must apply NMO correction before seismogram traces appear equal.

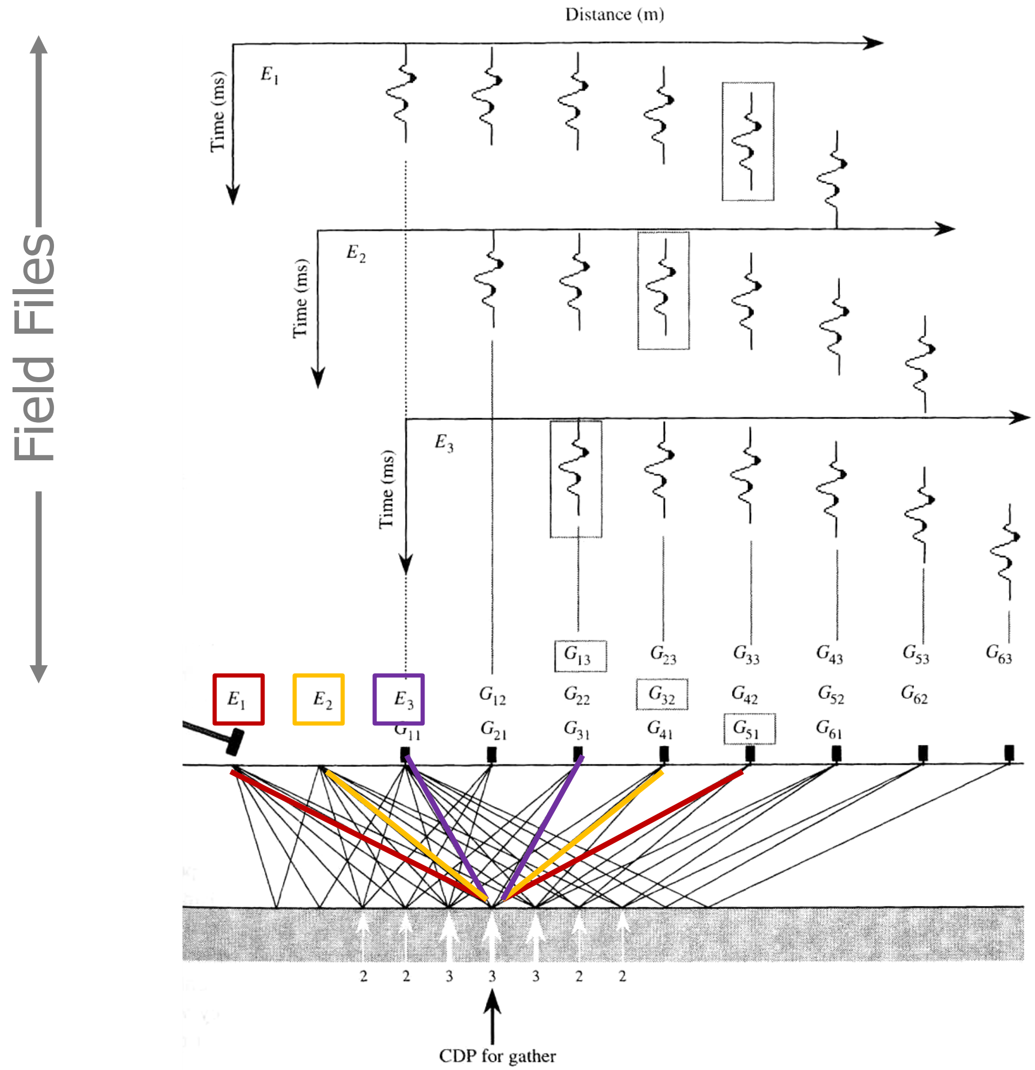
- Other, "obscuring" waves are NOT adjusted to equal times.

- Therefore, summing traces are ENHANCED, and others destructively interfered.

- This process of adding NMO adjusted traces is called : Stacking

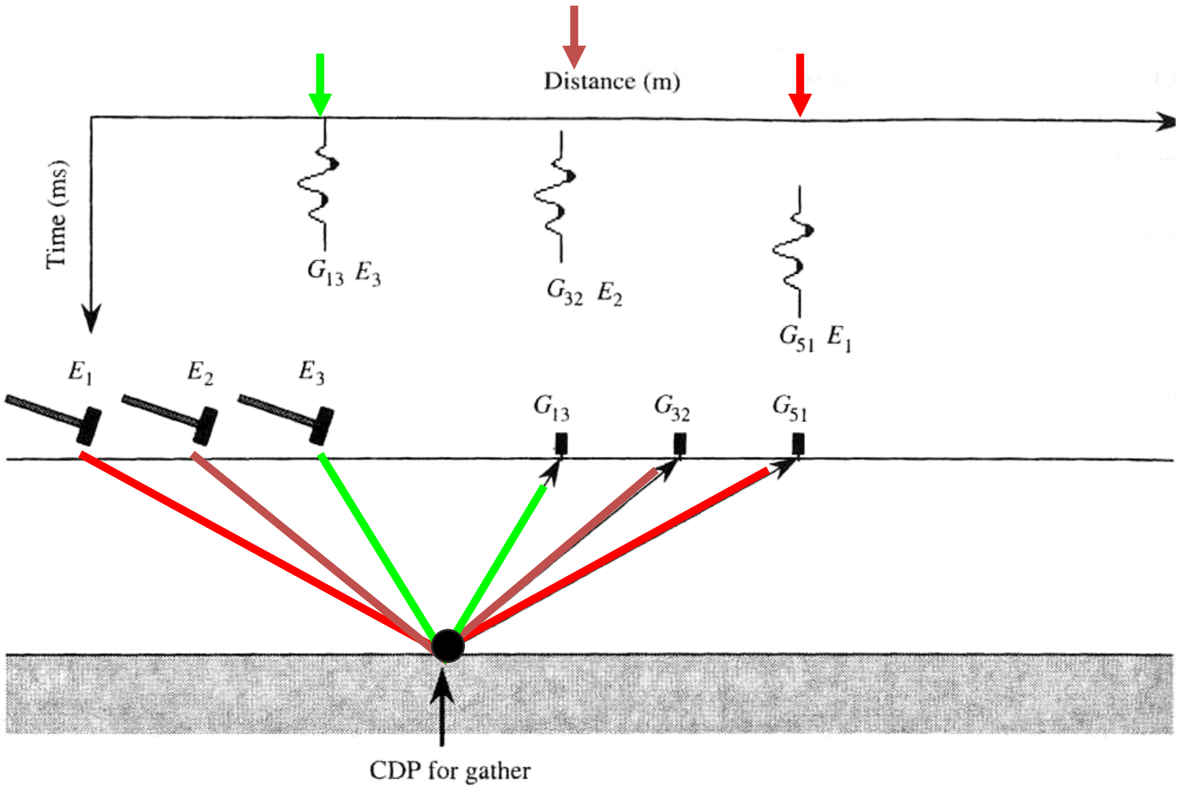
Seismic Reflection

X. CMP



Seismic Reflection

X. CMP



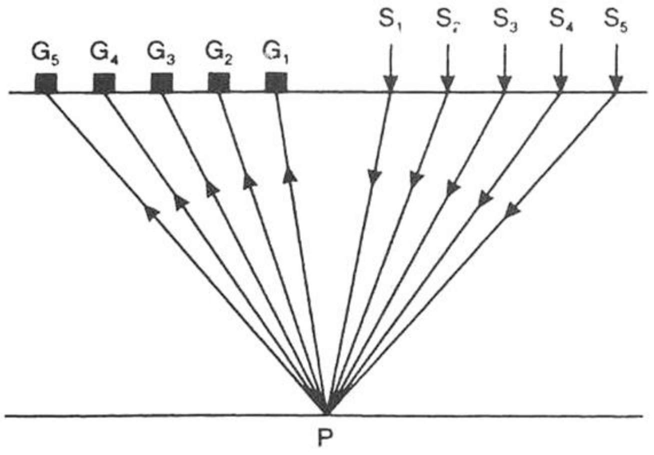
- Extract traces from "field files"
- Place in a new file called a "gather"

Seismic Reflection

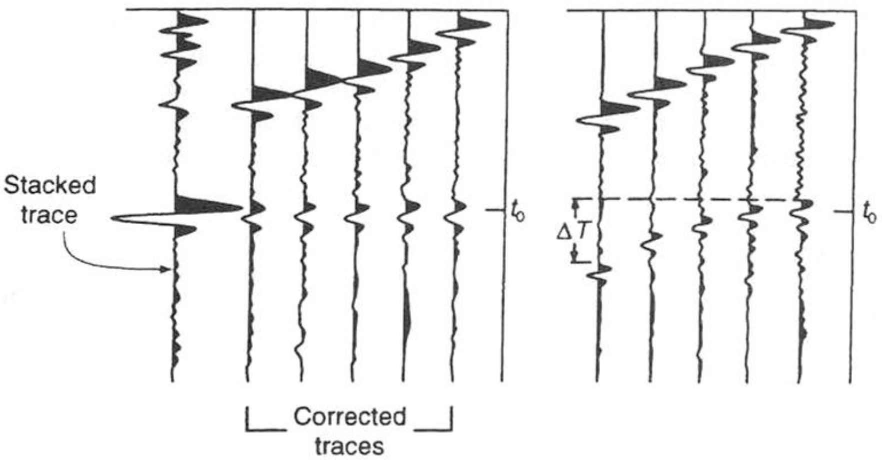
X. CMP

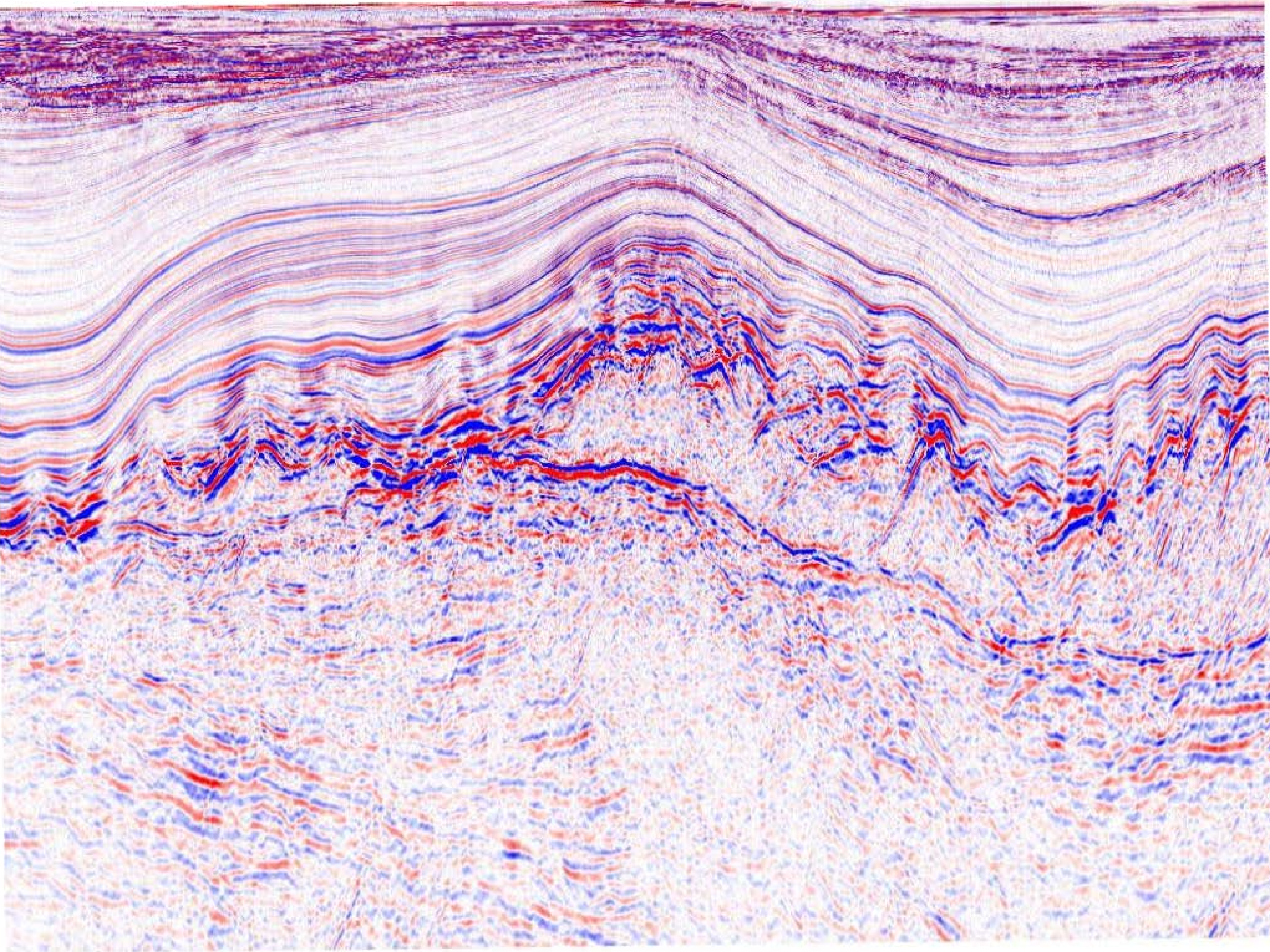
- Perform NMO correction:

$$\Delta t = \sqrt{t_0^{\ 2} + \frac{x^2}{V_{RMS}^{\ \ 2}}} - t_0$$



- Sum traces; signal enhanced, and “noise” (not necessarily the “coherent noise,” however.





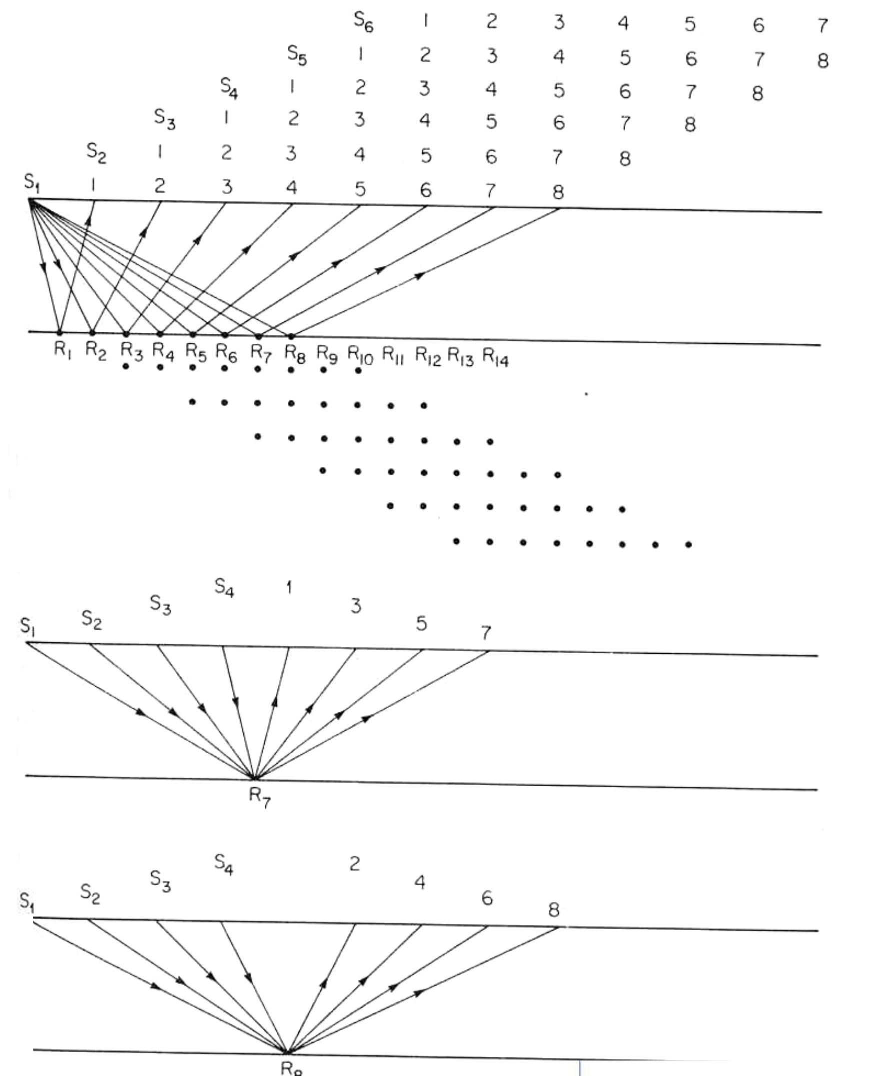
Seismic Reflection

X. CMP

- Multi-channel schematics of subsurface sample points from various shots and geophone locations are called "stacking charts."

$$\text{Fold} = \frac{N \bullet \Delta G}{2 \bullet \Delta S}$$

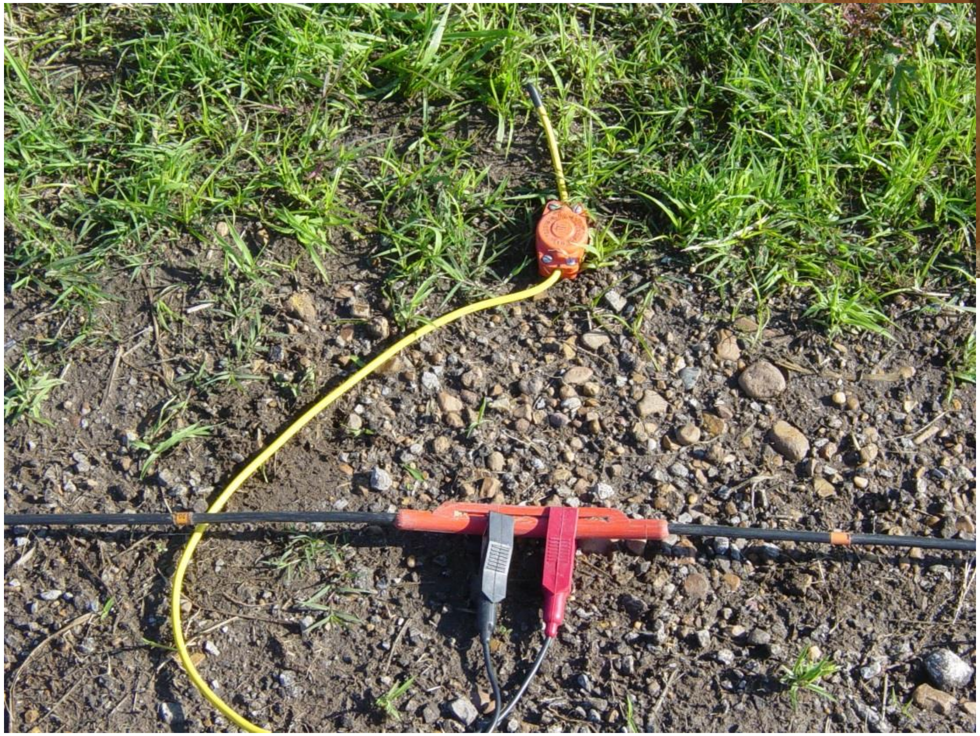
where, N = no. geophones
ΔG = group interval
ΔS = shot interval



Instrumentation

Instrumentation:

Seismograph/Geophone/ Takeout Cable



Instrumentation:
Seismic Energy Sources

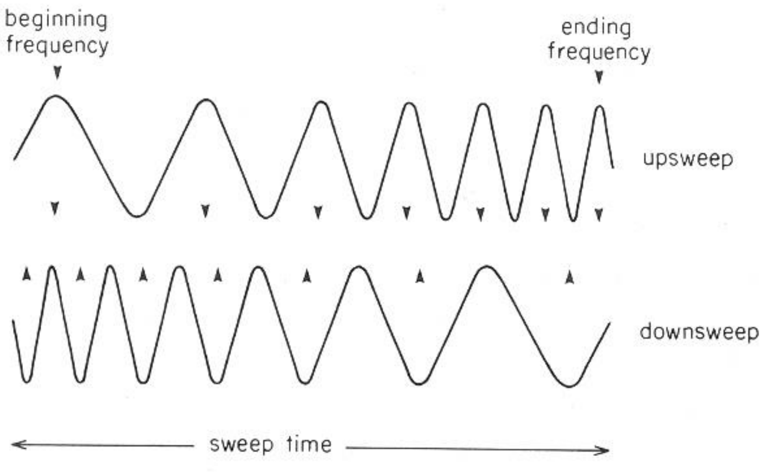
1. Impulsive

UK

Instrumentation: Seismic Energy Sources

Instrumentation: Seismic Energy Sources

2. Non-impulsive (or controlled source)
   - a. Vibroseis = known vibration series imparted and returned; during the vibration, which can range between a few seconds to >30 sec., frequency can (will) vary.
     - i. One sequence of vibration = “sweep”
     - ii. Use process called “correlation” to produce equivalent pulses of short duration



Instrumentation: Seismic Energy Sources

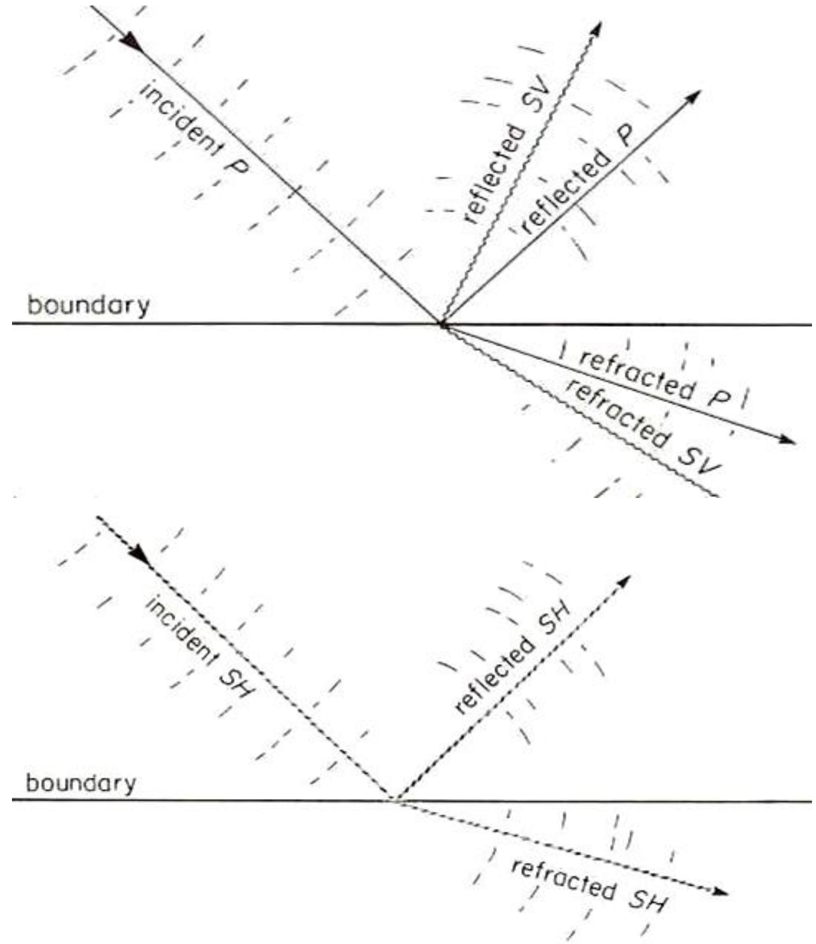
b. Psuedo-Random Vibration

- Human controlled, pseudo-random "sweep"
- No repeated frequencies – impact rate must be varied.
- Base plate decoupled from ground
- Portable and Inexpensive

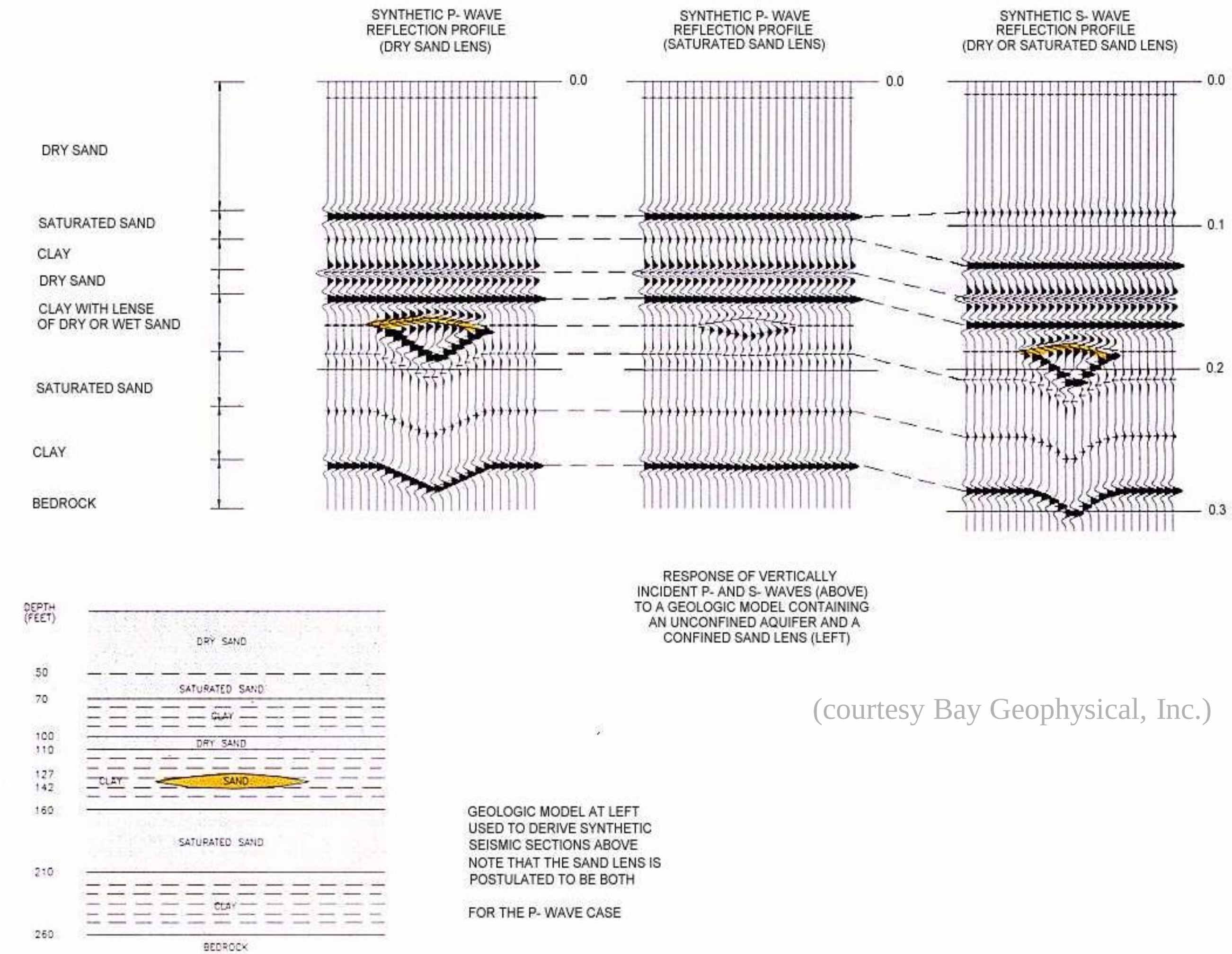
Instrumentation: Seismic Energy Sources

a. BENEFITS

i. No mode conversions at refracting and reflecting boundaries (unlike P or SV)



Instrumentation: Seismic Energy Sources

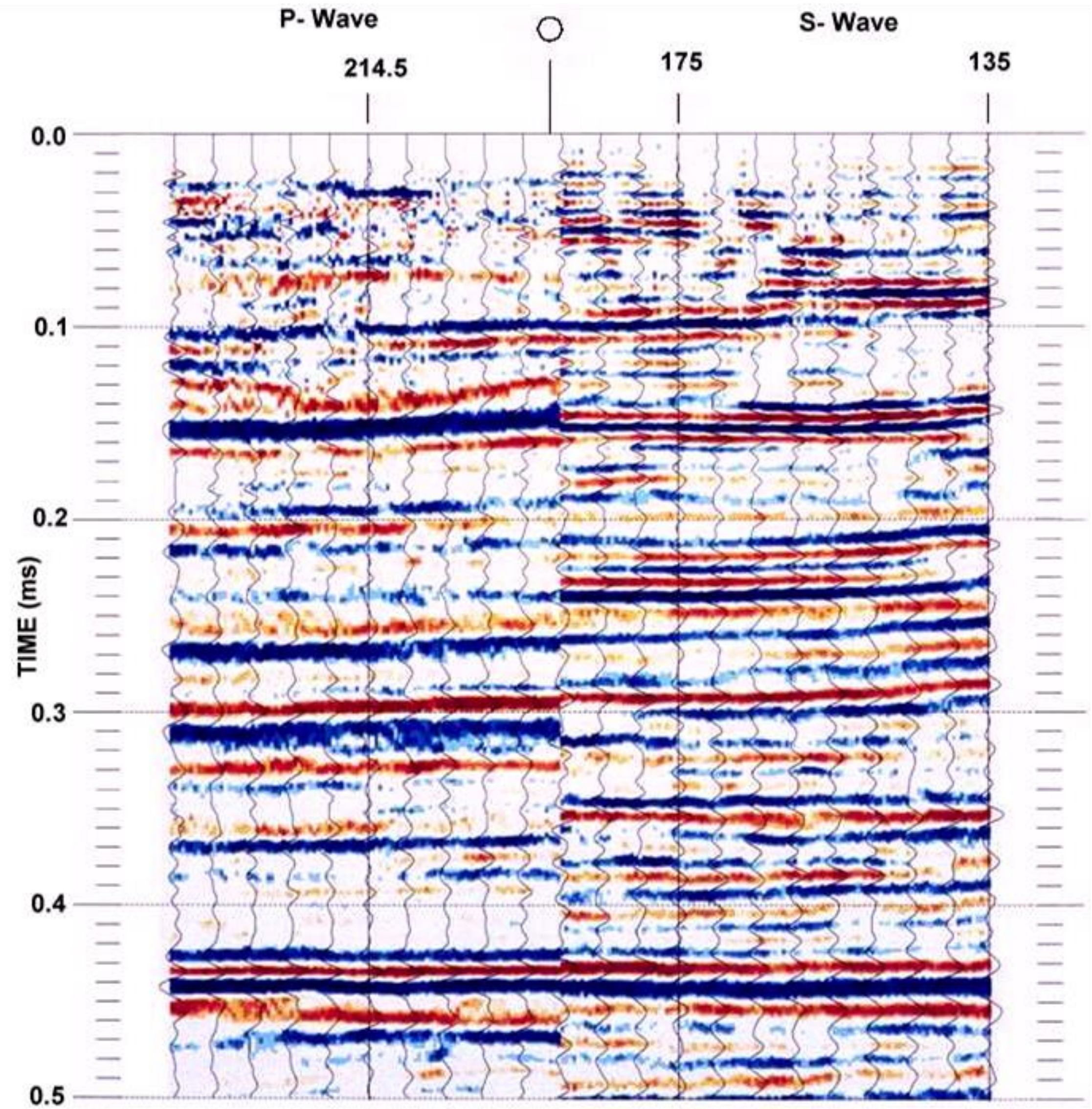


(courtesy Bay Geophysical, Inc.)

ii. Framework waves (i.e., not affected by water saturation); therefore sample the low-velocity geologic/particulate medium

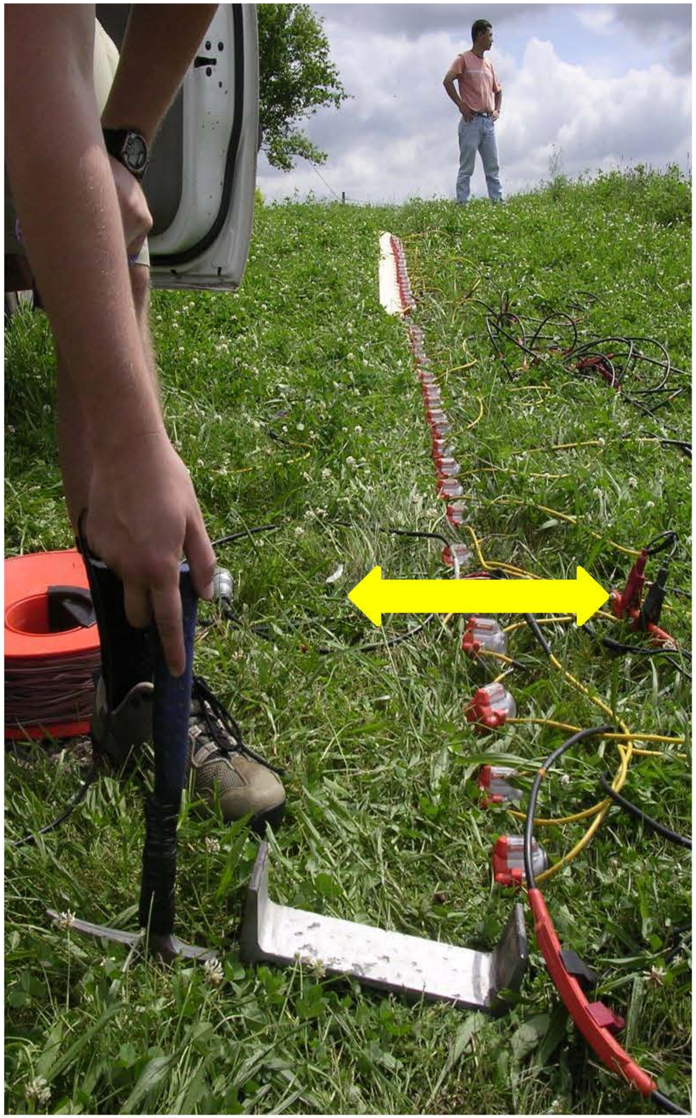
Instrumentation: Seismic Energy Sources

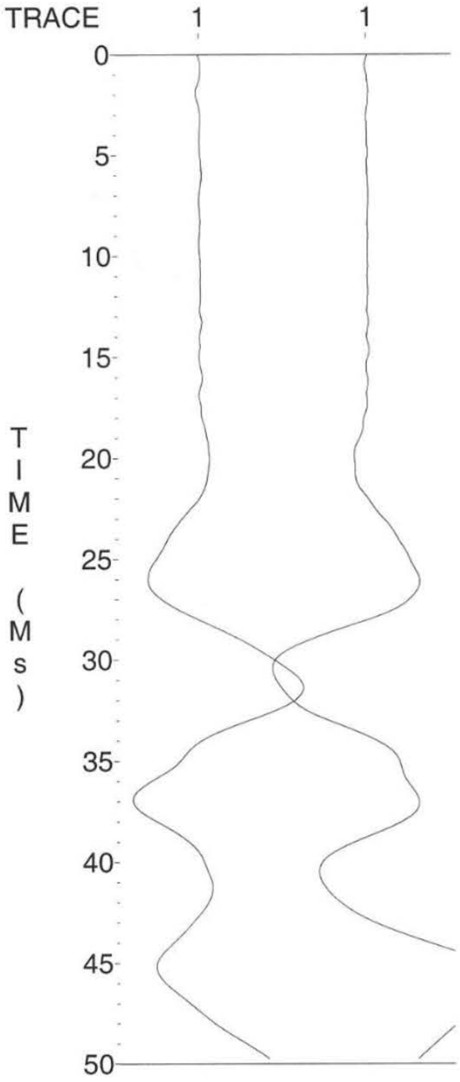
iii. Although one-half to 1/3 the frequency of P-wave, have velocities 5 to 10 times less; therefore resolution improved by a factor of 2 to 3



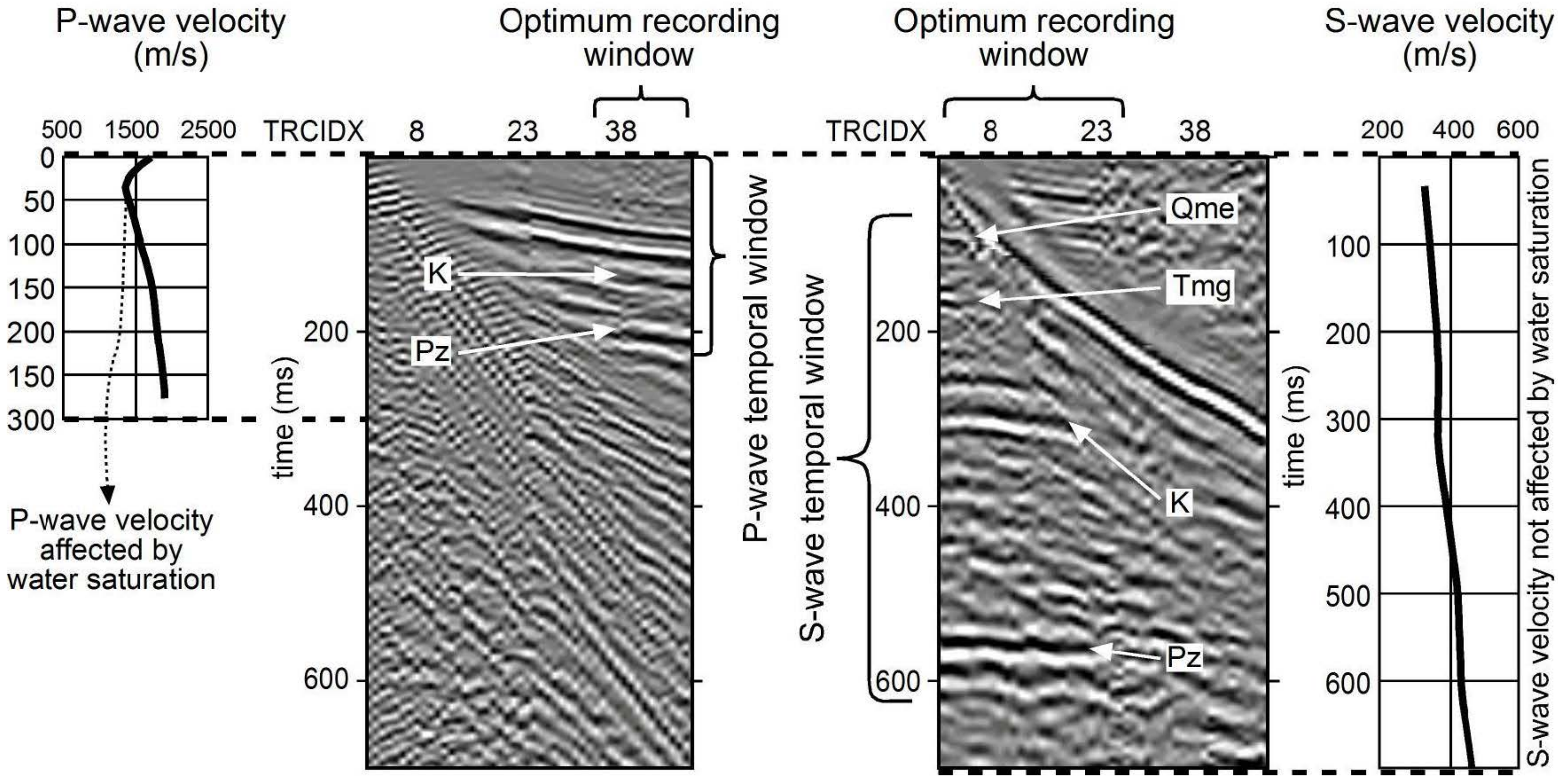
(courtesy Bay Geophysical, Inc.)

Instrumentation: Seismic Energy Sources





Instrumentation: Seismic Energy Sources



(Woolery and Almayahi, *2013*)

~~High-Resolution~~ Geophysical Characterization of a Complex Near-Surface Geological Environment – PGDP

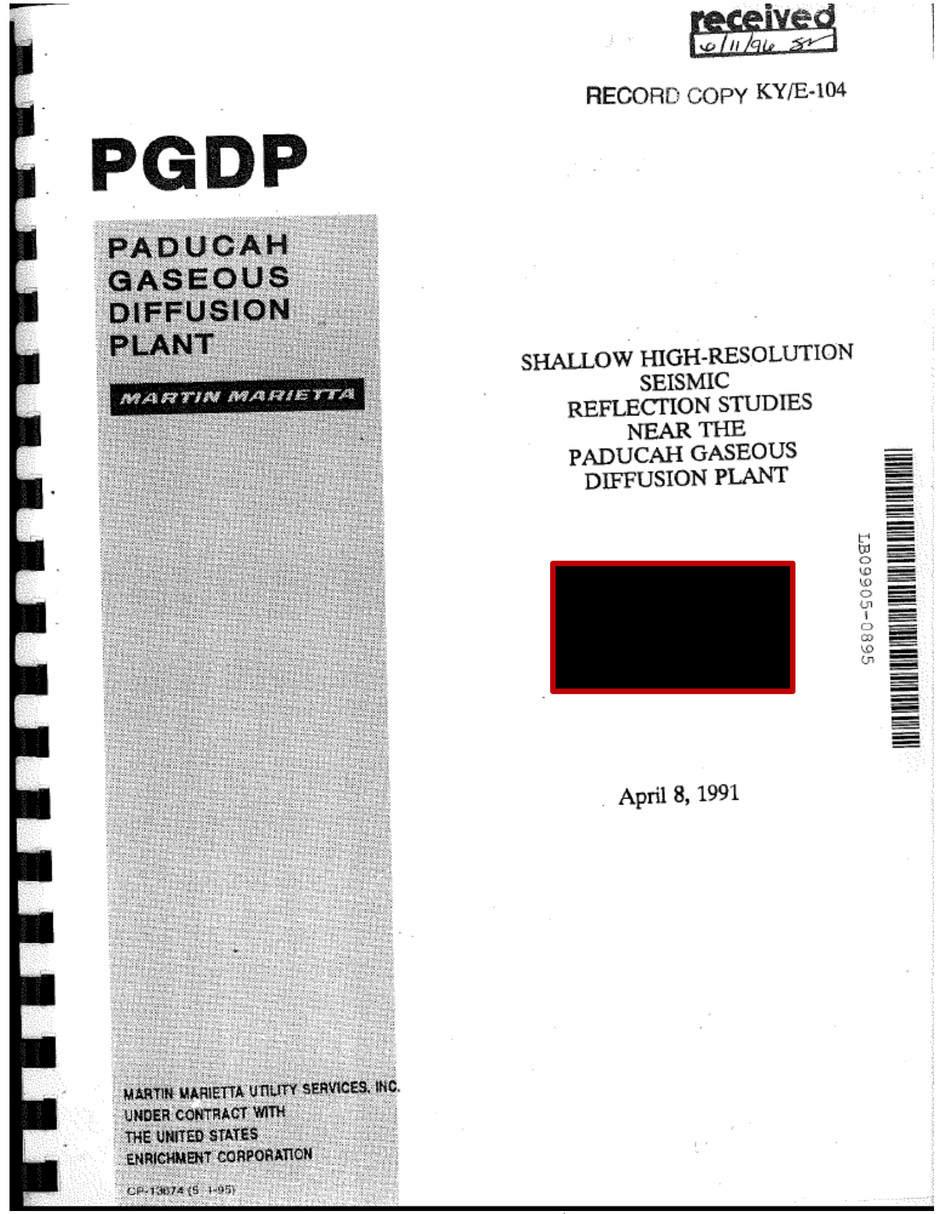
KRCEE Quarterly Meeting

May 24, 2012

Lexington, Kentucky

E.W. Woolery
University of Kentucky
Department of Earth and Environmental Sciences

Seismic Methods Historically @ PGDP



received 6/11/96

RECORD COPY KY/E-104

PGDP

PADUCAH GASEOUS DIFFUSION PLANT

MARTIN MARIETTA

SHALLOW HIGH-RESOLUTION SEISMIC REFLECTION STUDIES NEAR THE PADUCAH GASEOUS DIFFUSION PLANT

[redacted]

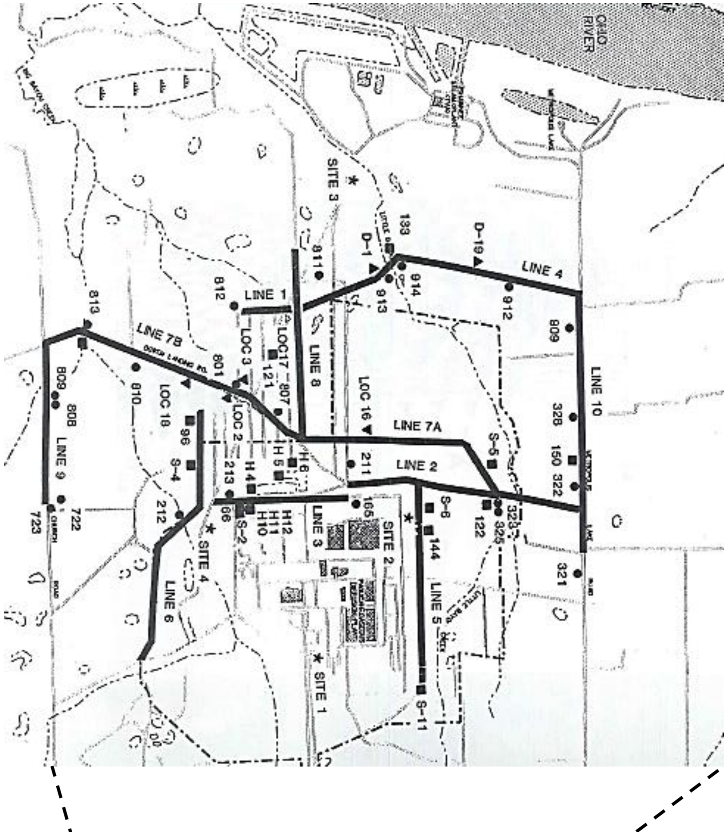
LB09905-0895

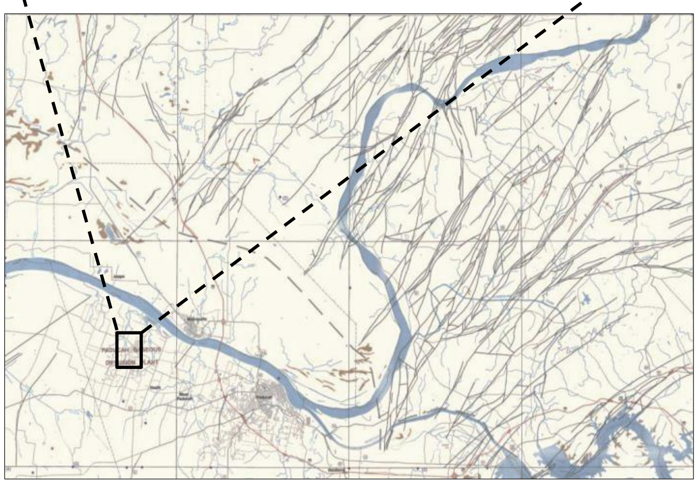
April 8, 1991

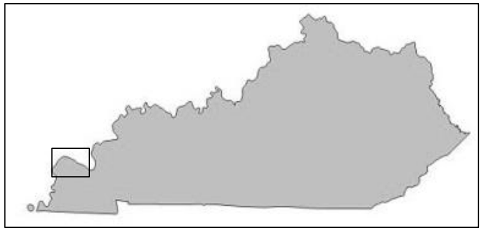
MARTIN MARIETTA UTILITY SERVICES, INC.
UNDER CONTRACT WITH
THE UNITED STATES
ENRICHMENT CORPORATION

CP-13874 (5 1-95)

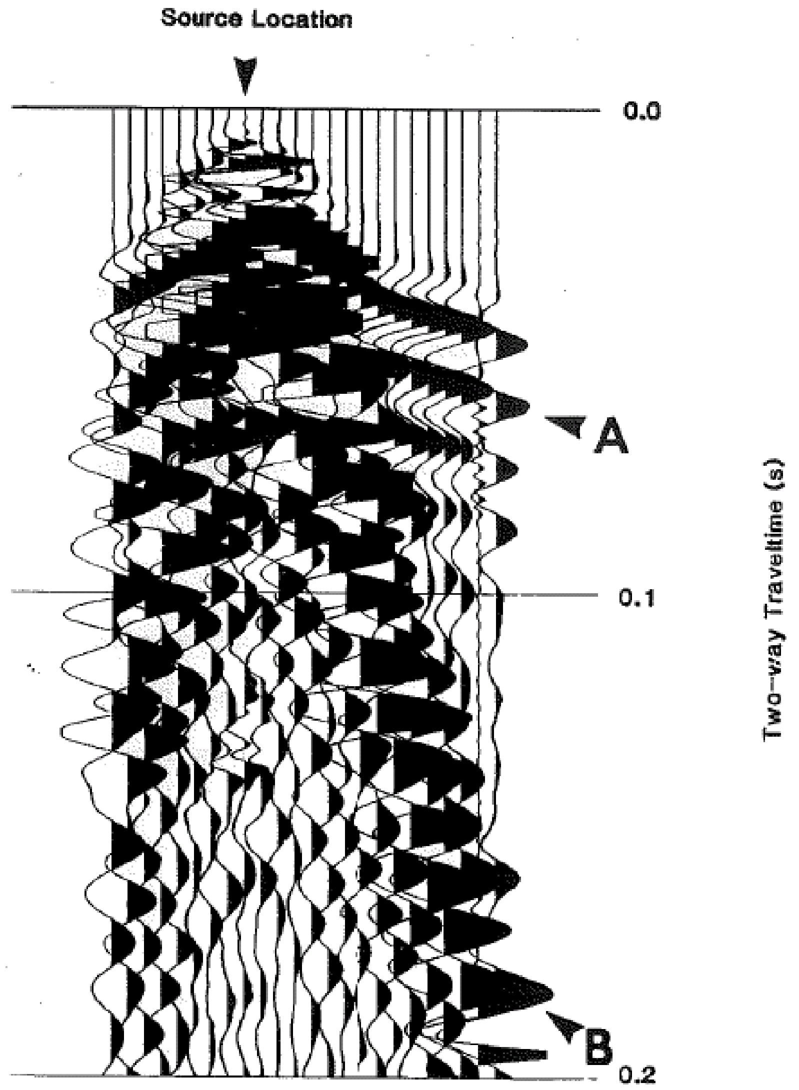
Seismic Methods Historically @ PGDP





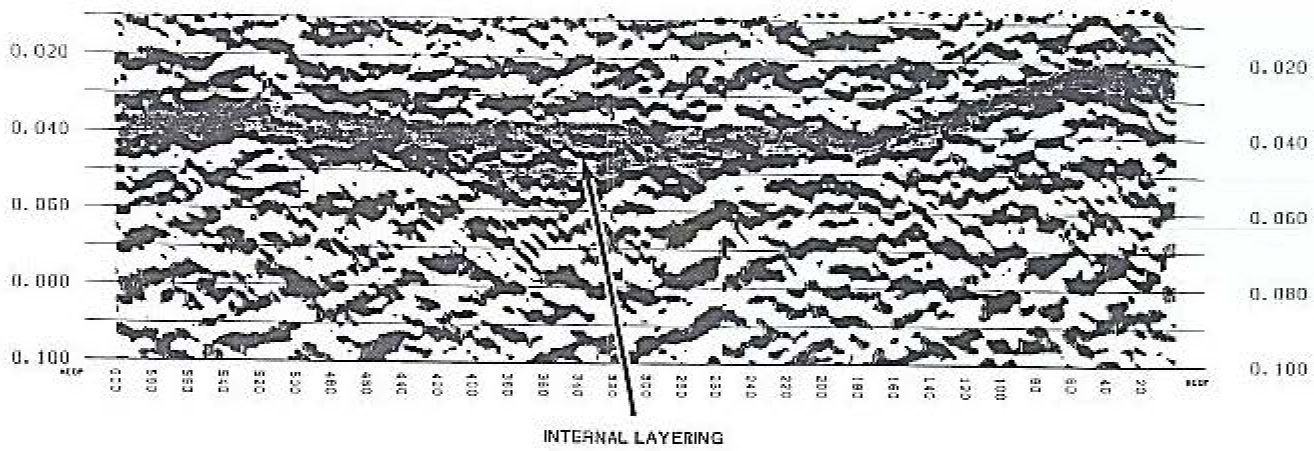


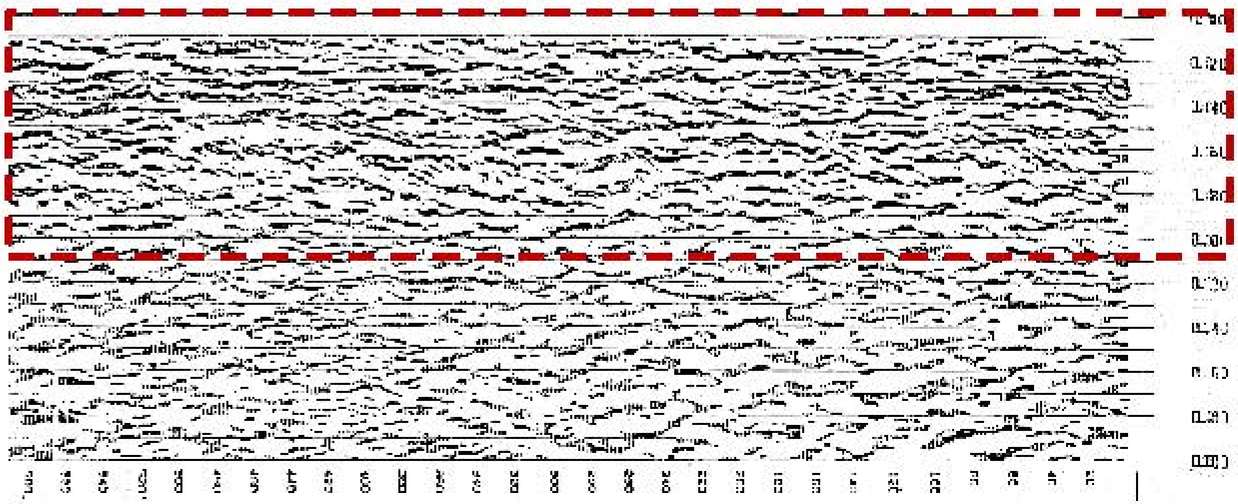
Seismic Methods Historically @ PGDP



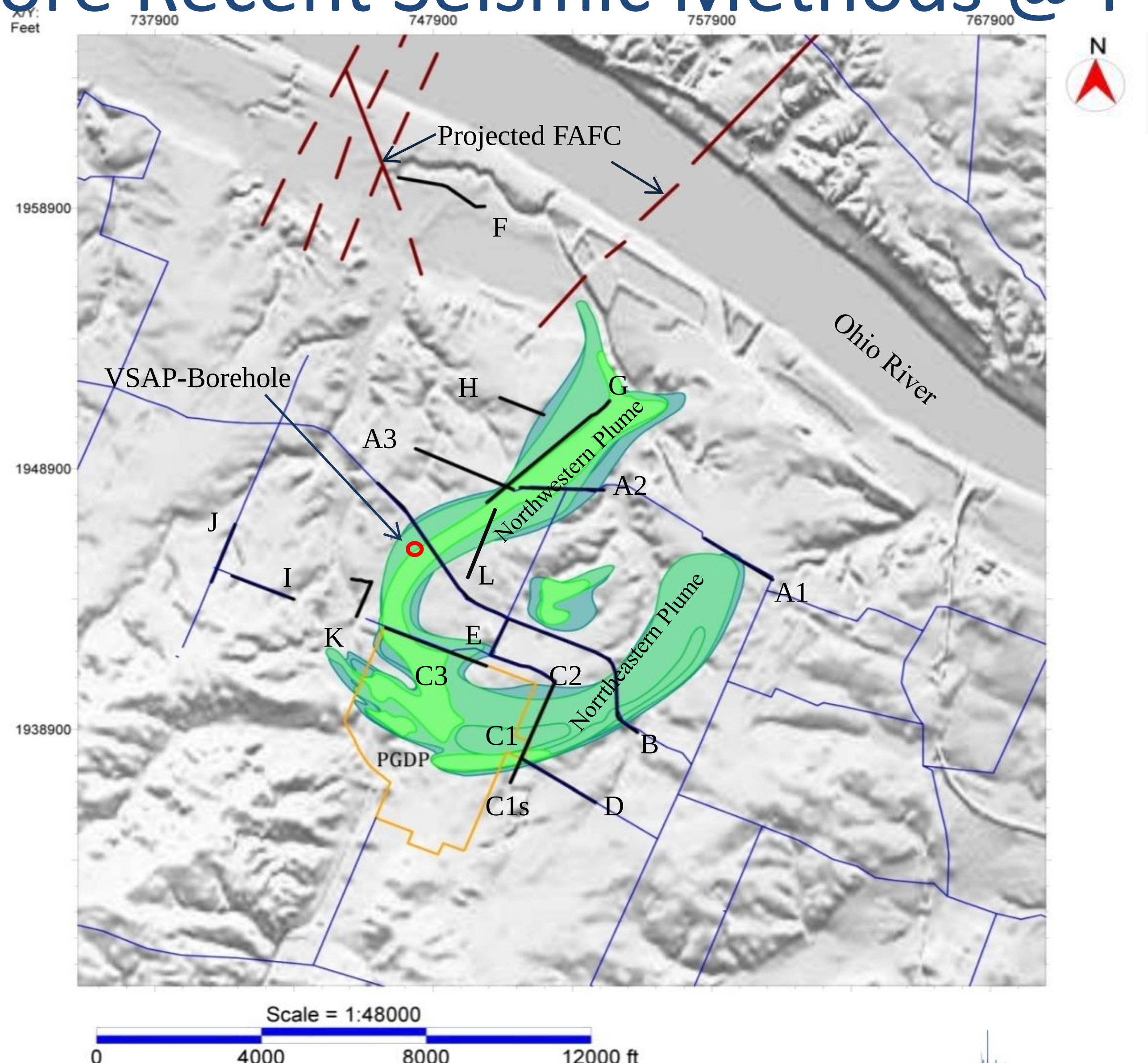
Typical Field Record from Line 4. [A is large amplitude ground-roll. B is a reverberating refraction arrival from the water table.]

Seismic Methods Historically @ PGDP

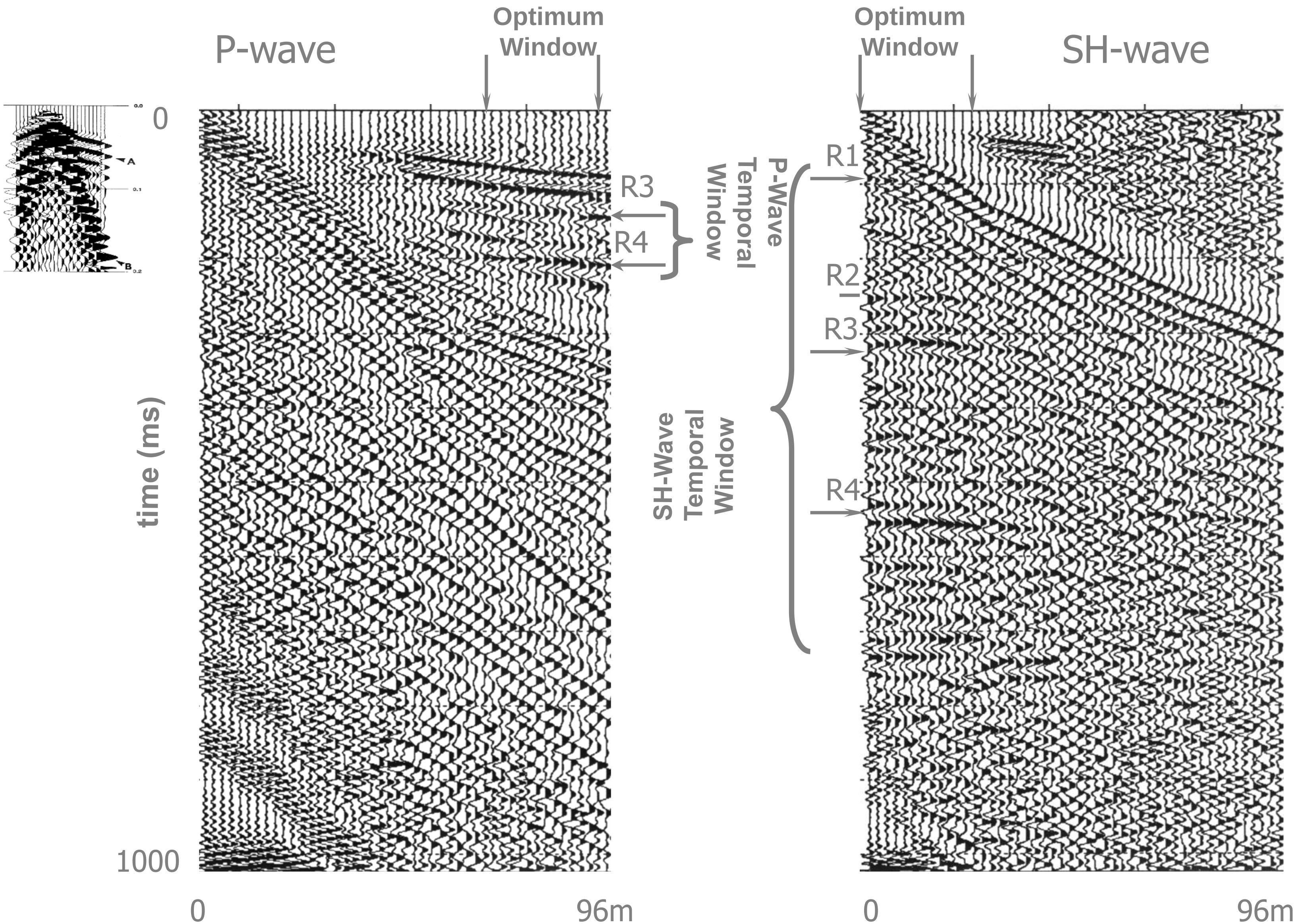




More Recent Seismic Methods @ PGDP

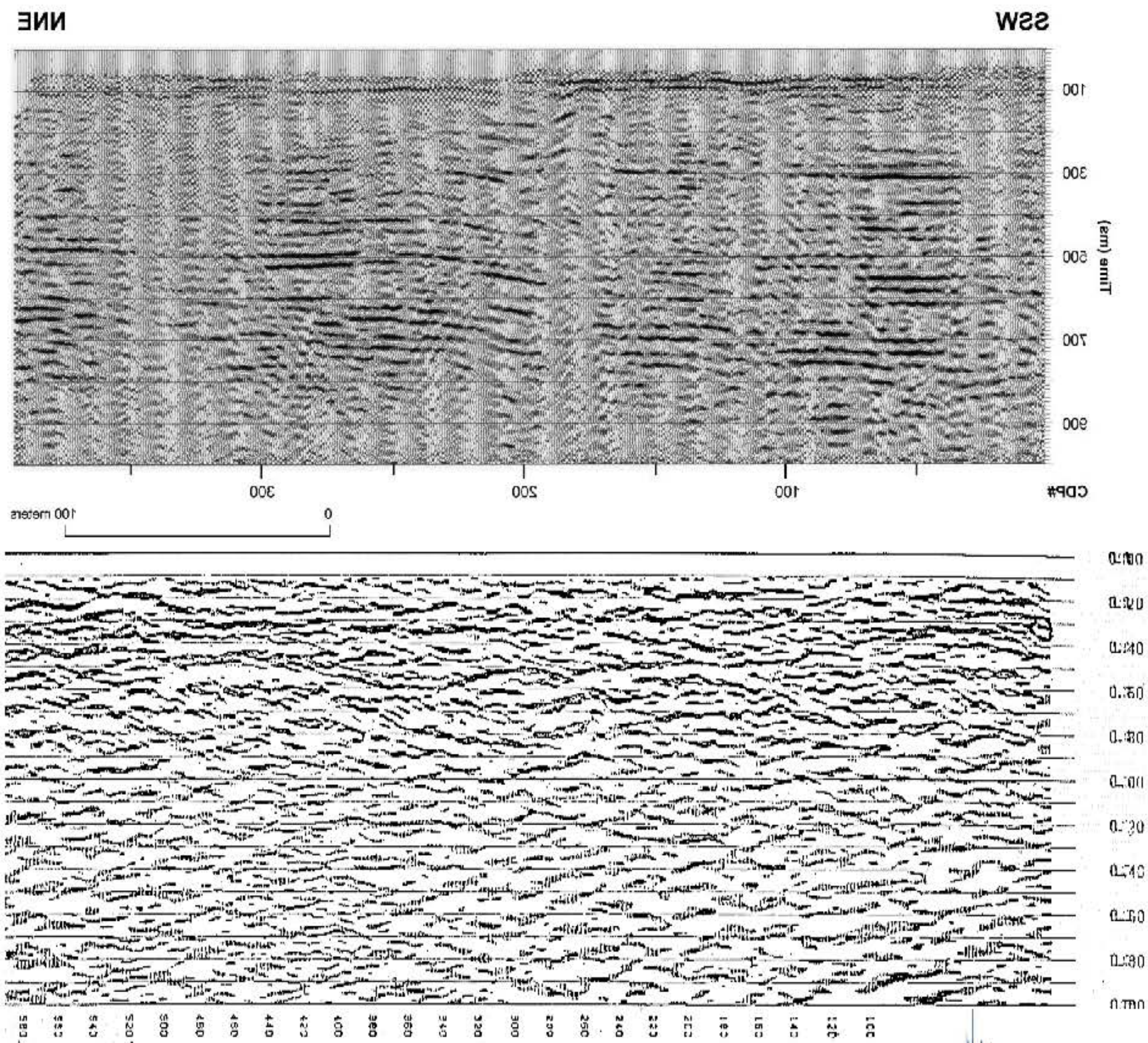


More Recent Seismic Methods @ PGDP

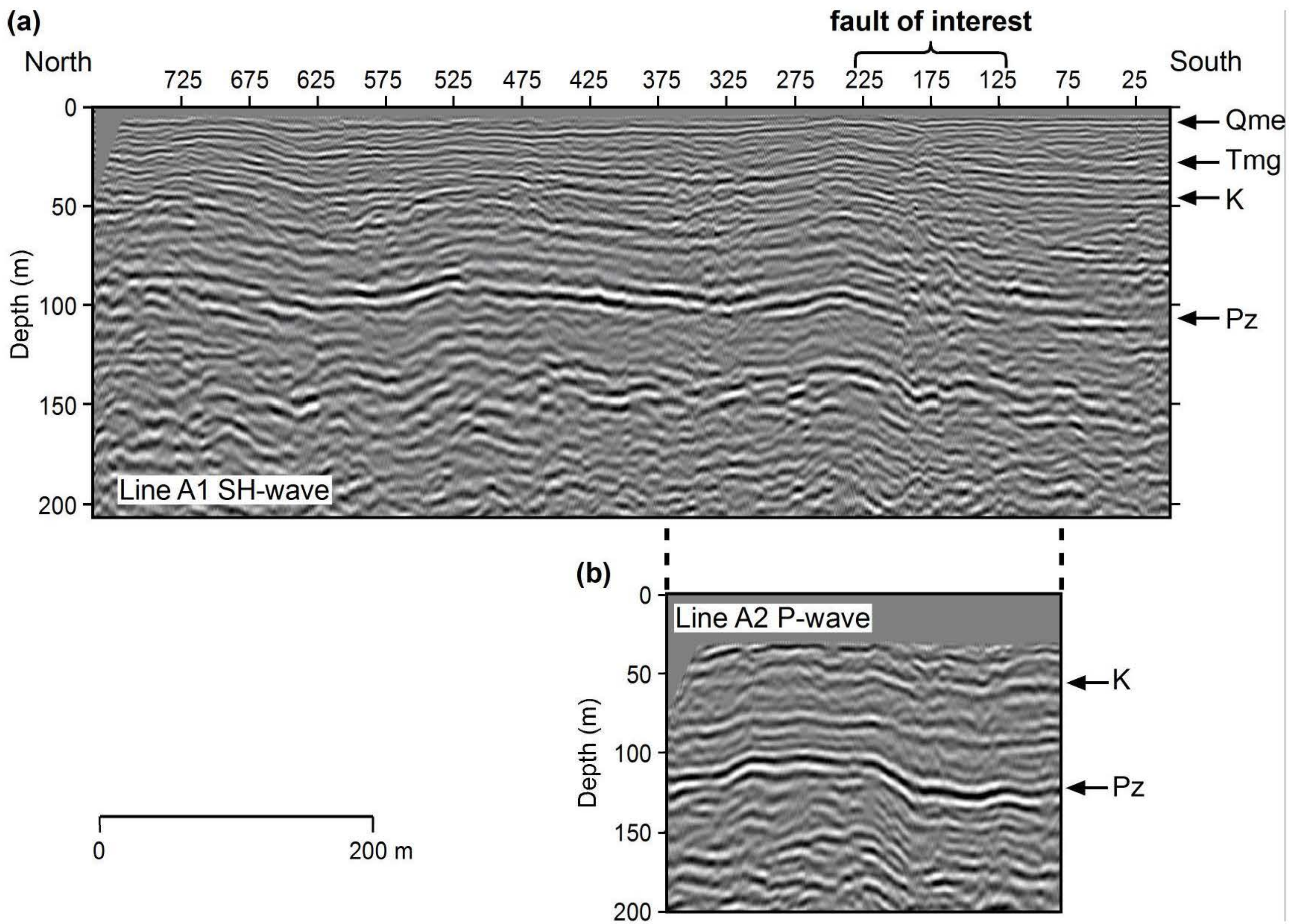


(Woolery and Street, 2002)

More Recent Seismic Methods @ PGDP

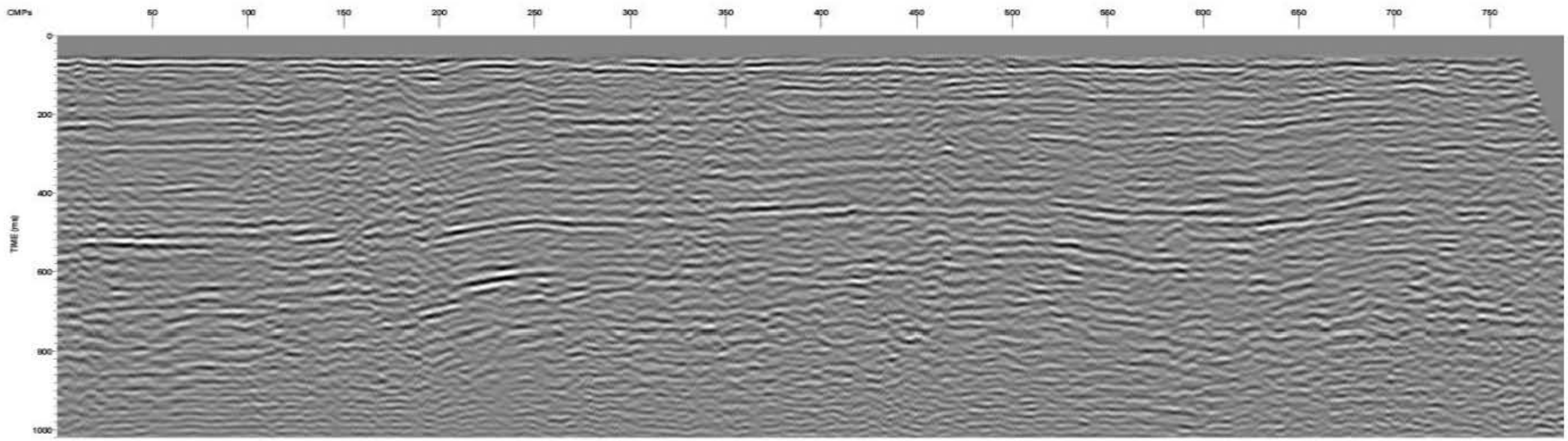


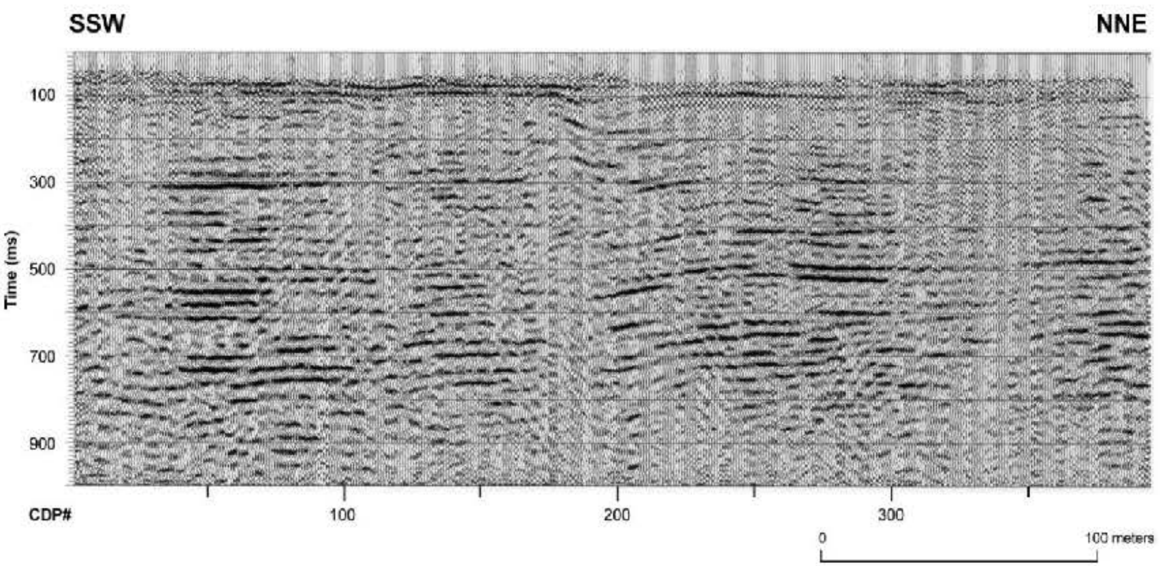
More Recent Seismic Methods @ PGDP



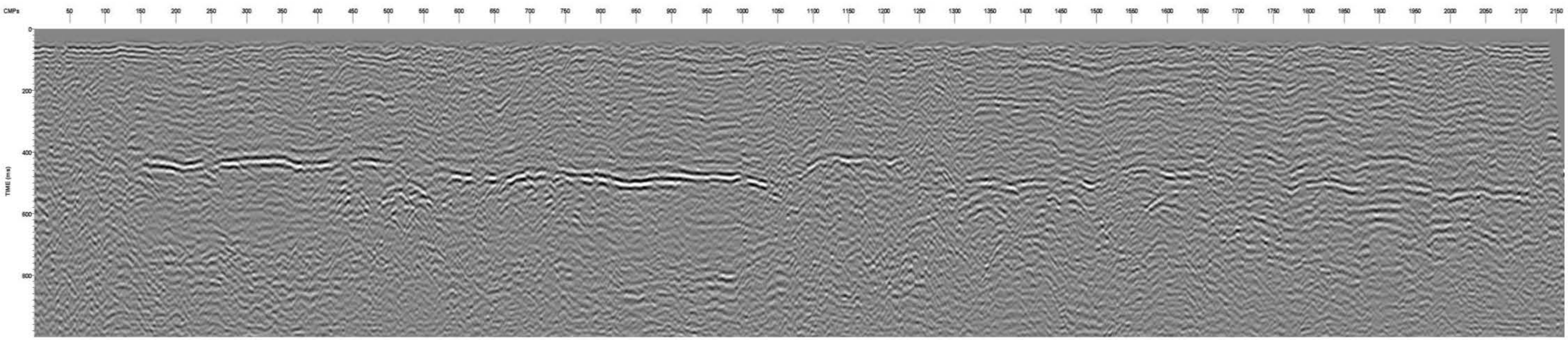
(Woolery and Almayahi, *2013*)

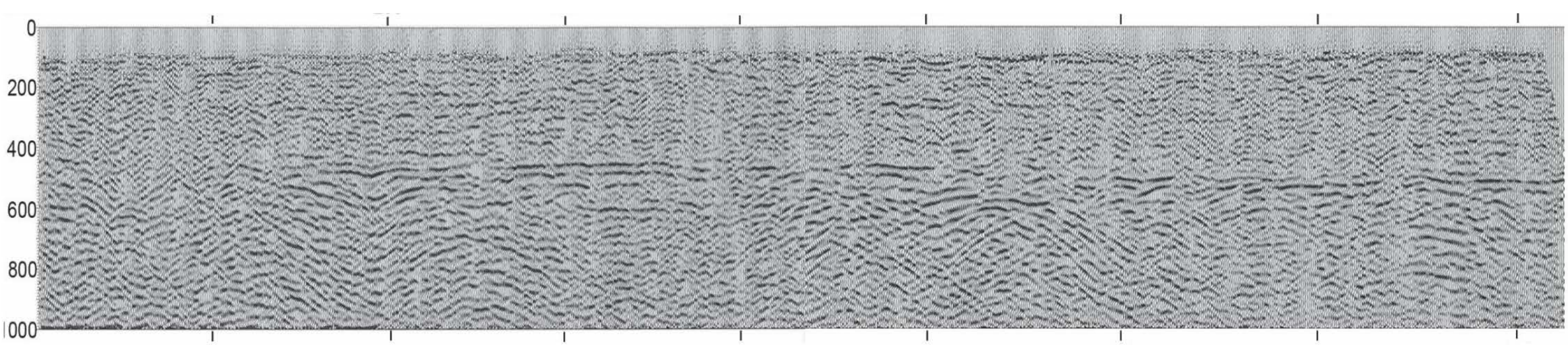
Most Recent Seismic Methods @ PGDP



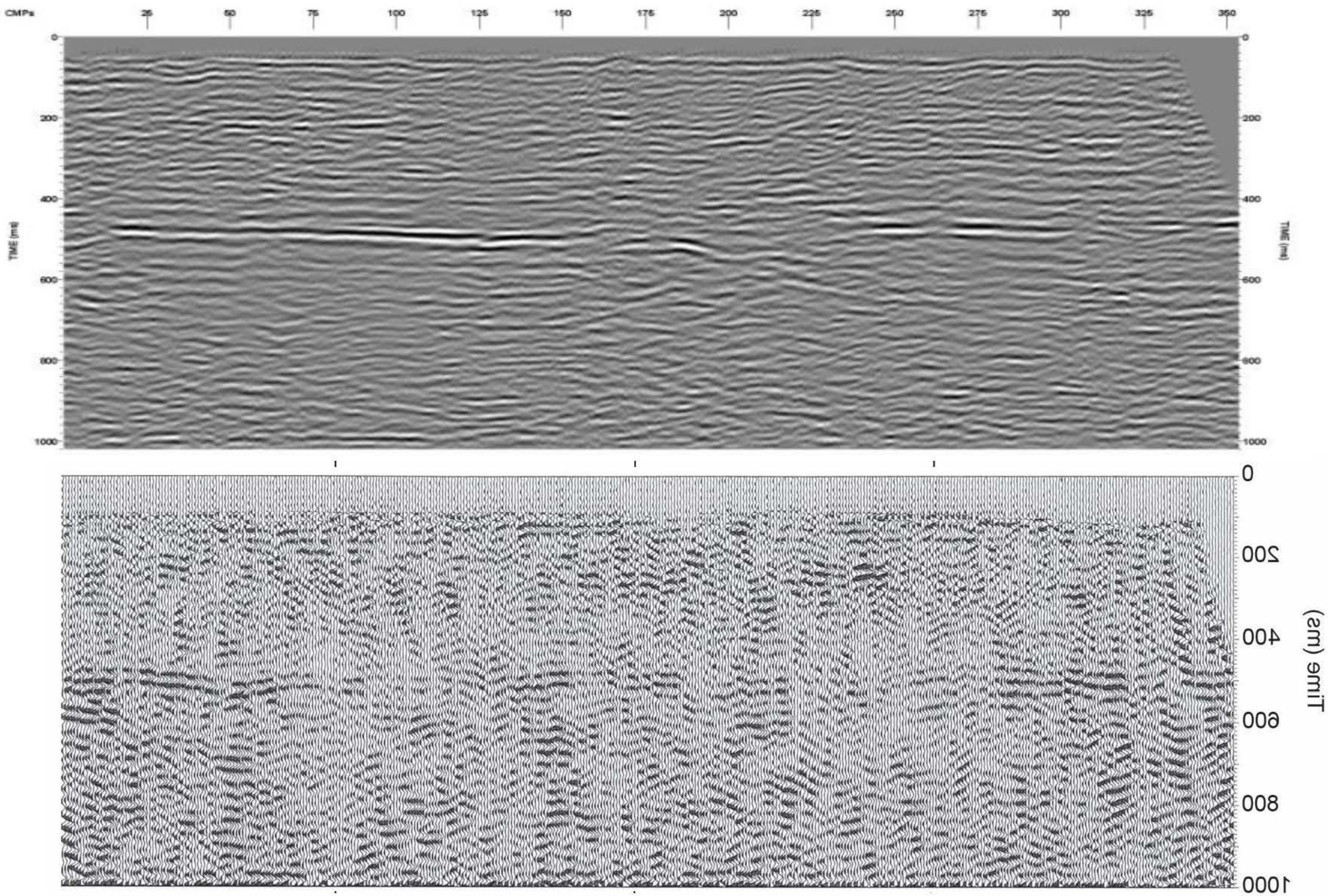


Most Recent Seismic Methods @ PGDP

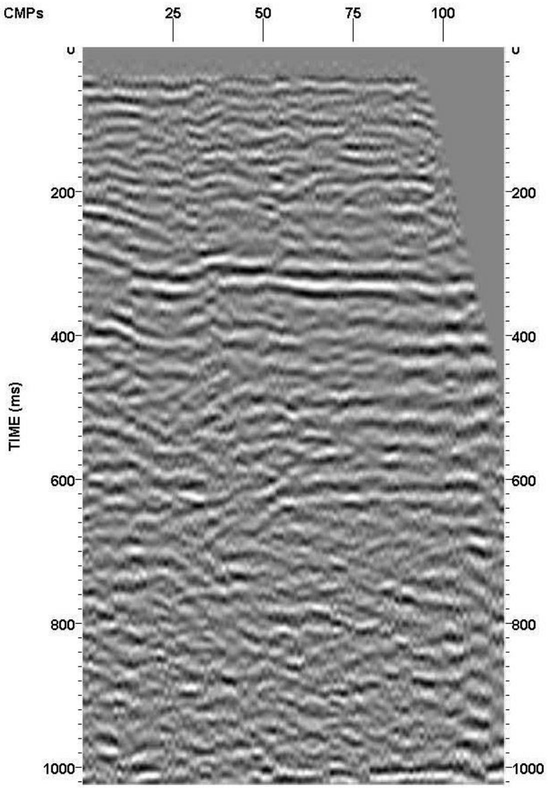




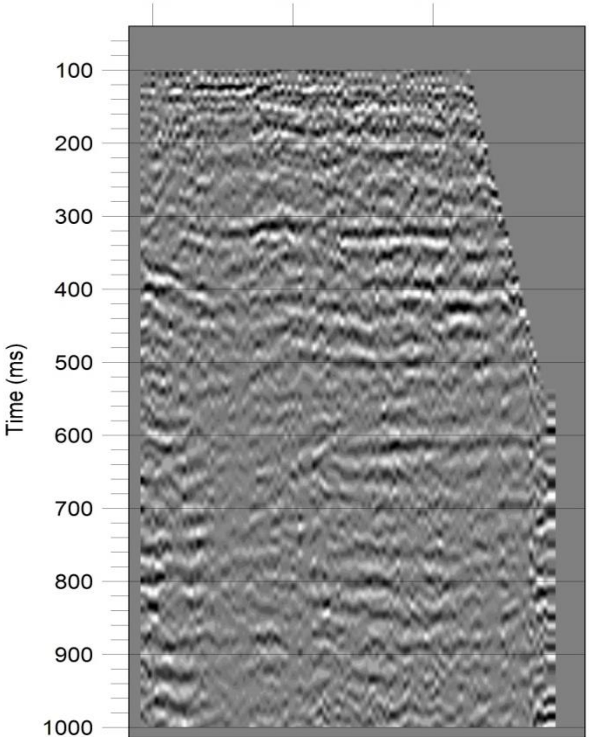
Most Recent Seismic Methods @ PGDP



Continued Seismic Processing Progress

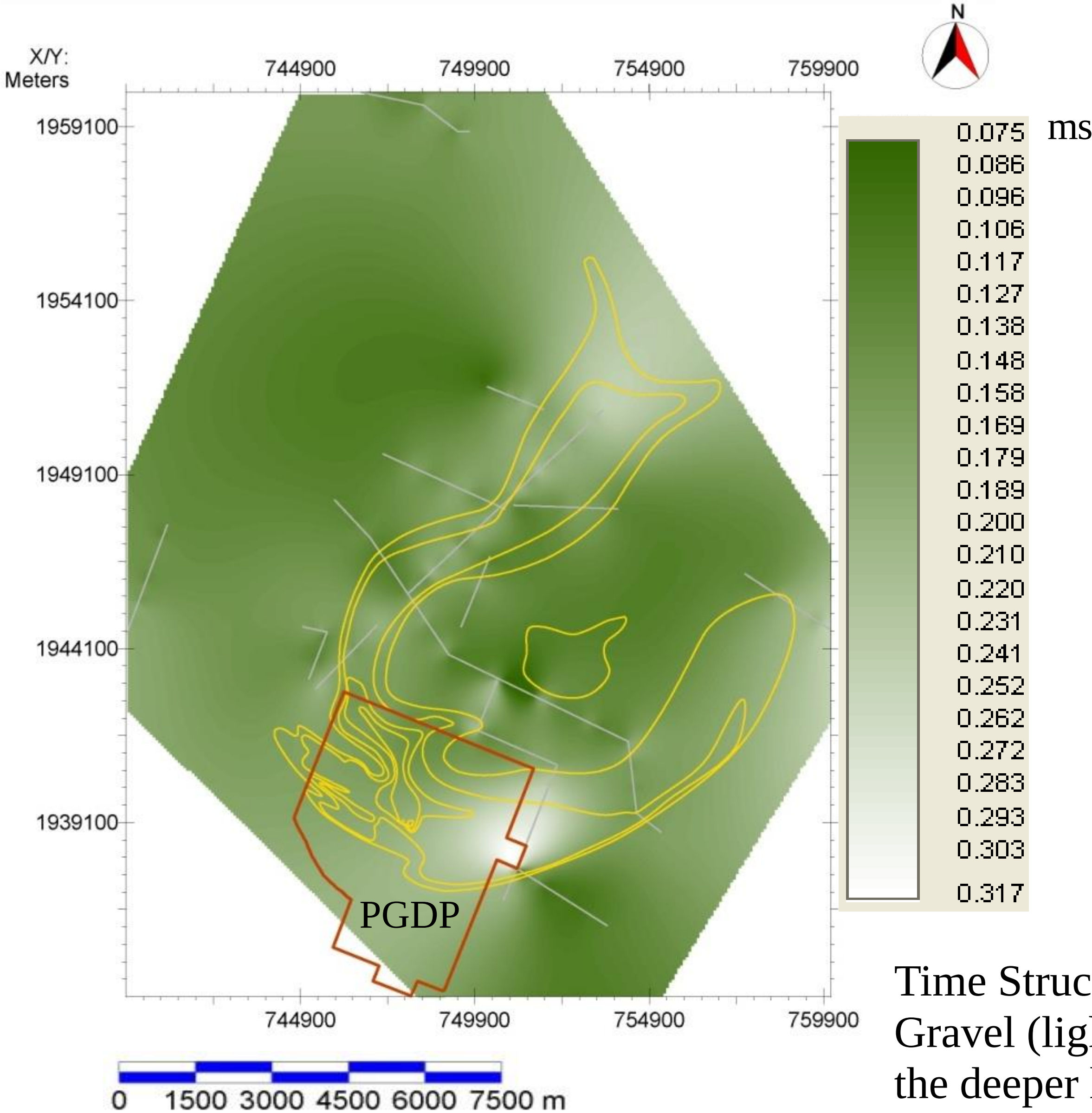


A



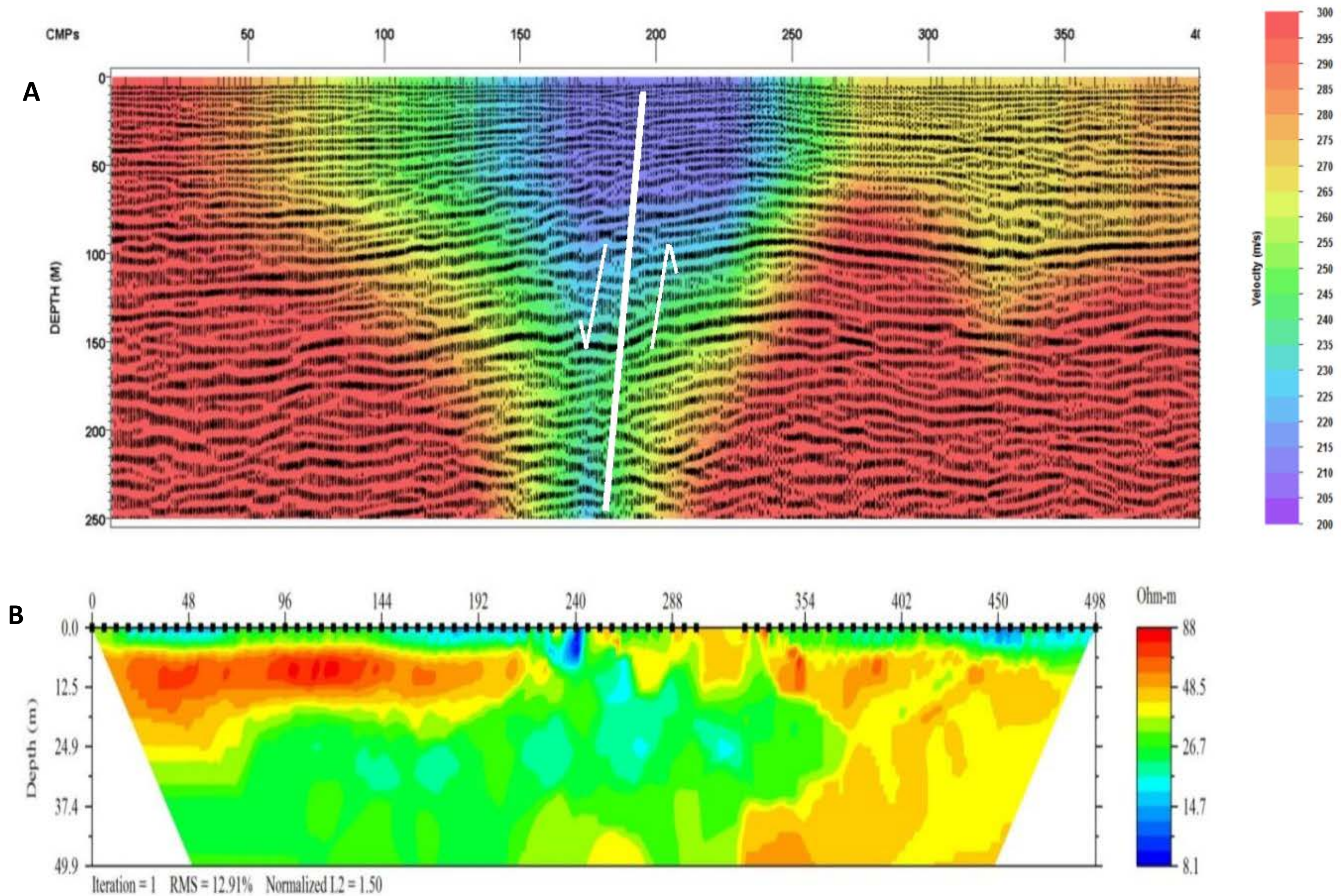
B

Seismic data processing. A) Profile C1_S processed with VISTA 11
B) Profile C1_S processed with SPW

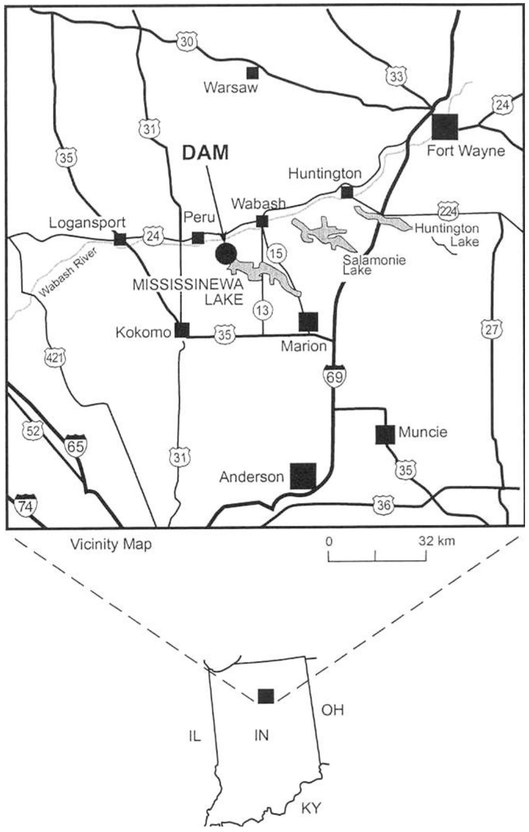


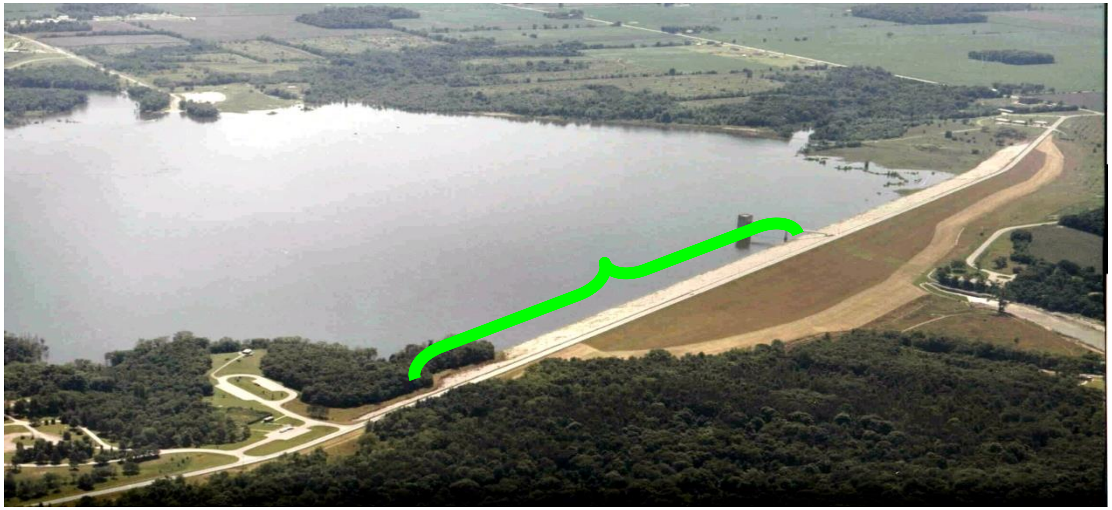
Time Structure map for the Mounds Gravel (lighter areas correspond to the deeper locations.

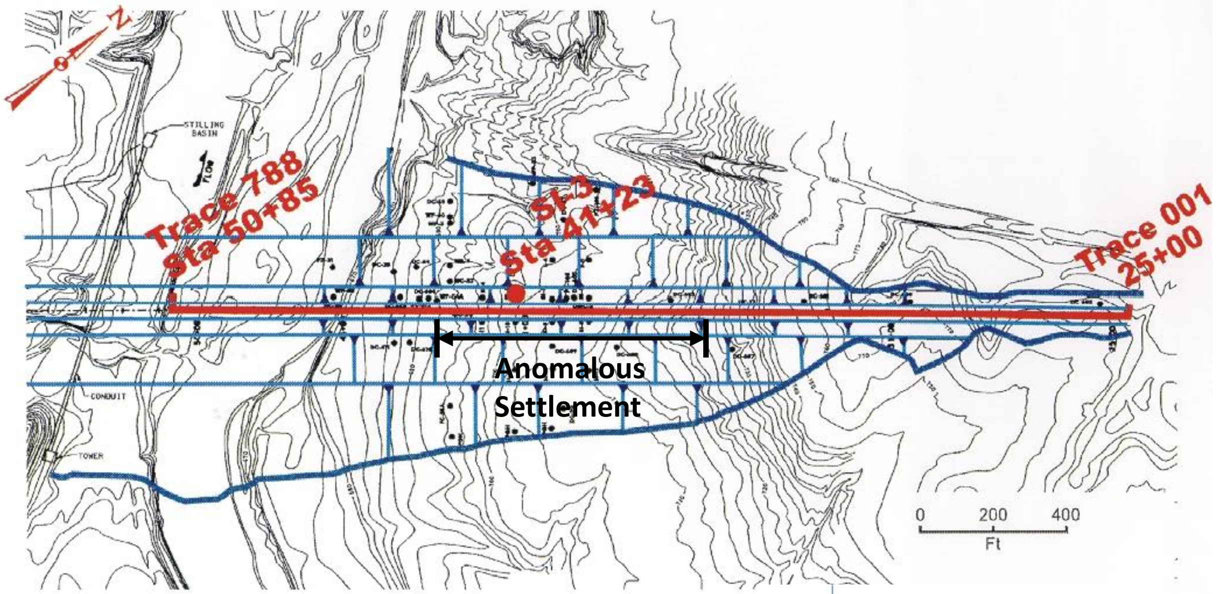
SH-wave Velocity and Electrical Resistivity



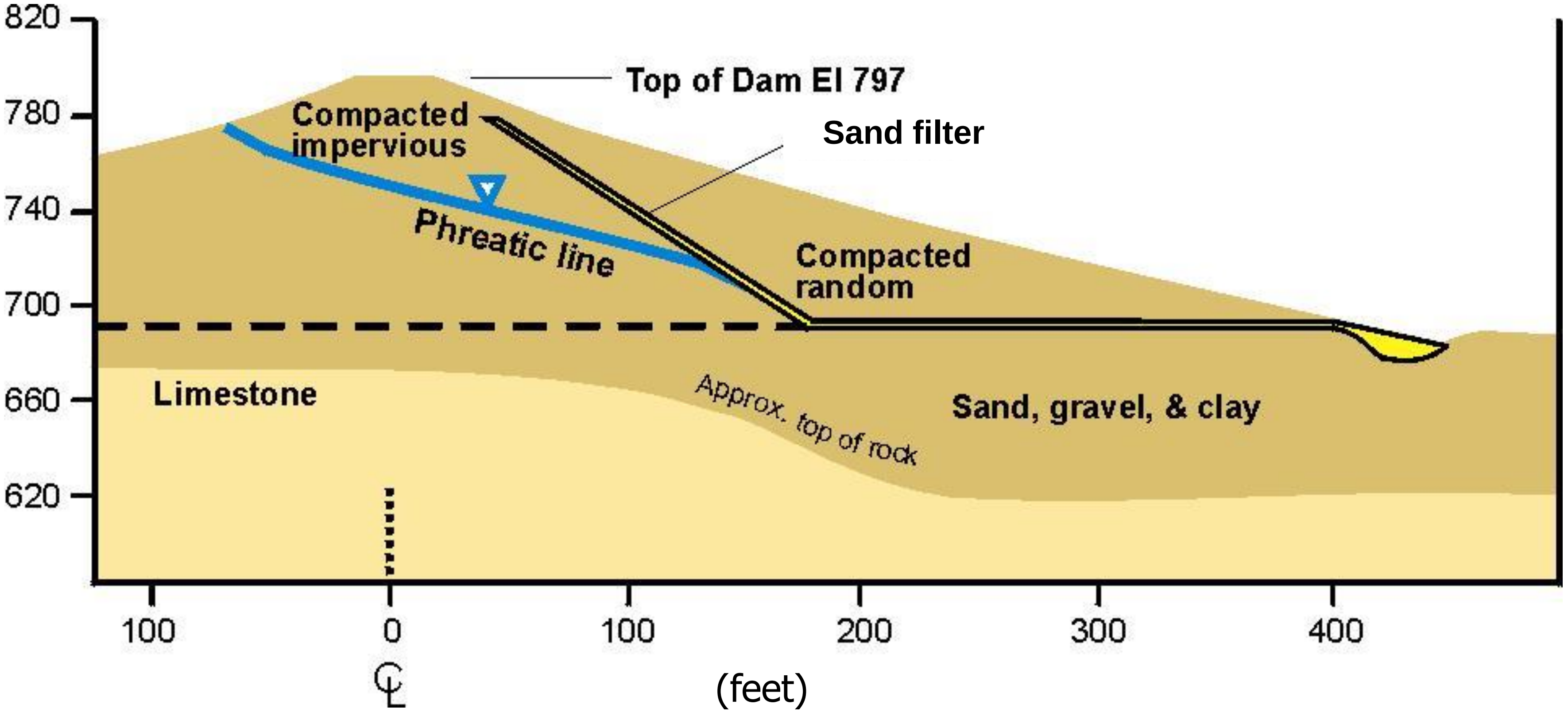
Mississinewa Dam



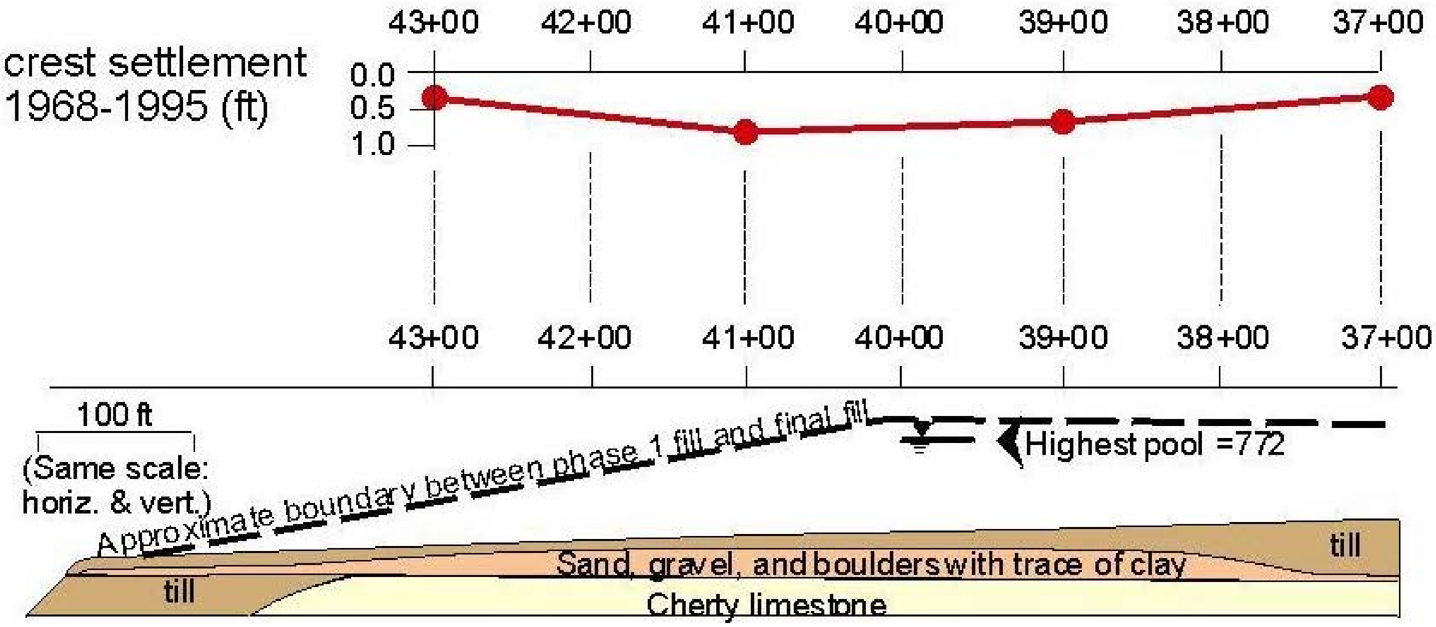




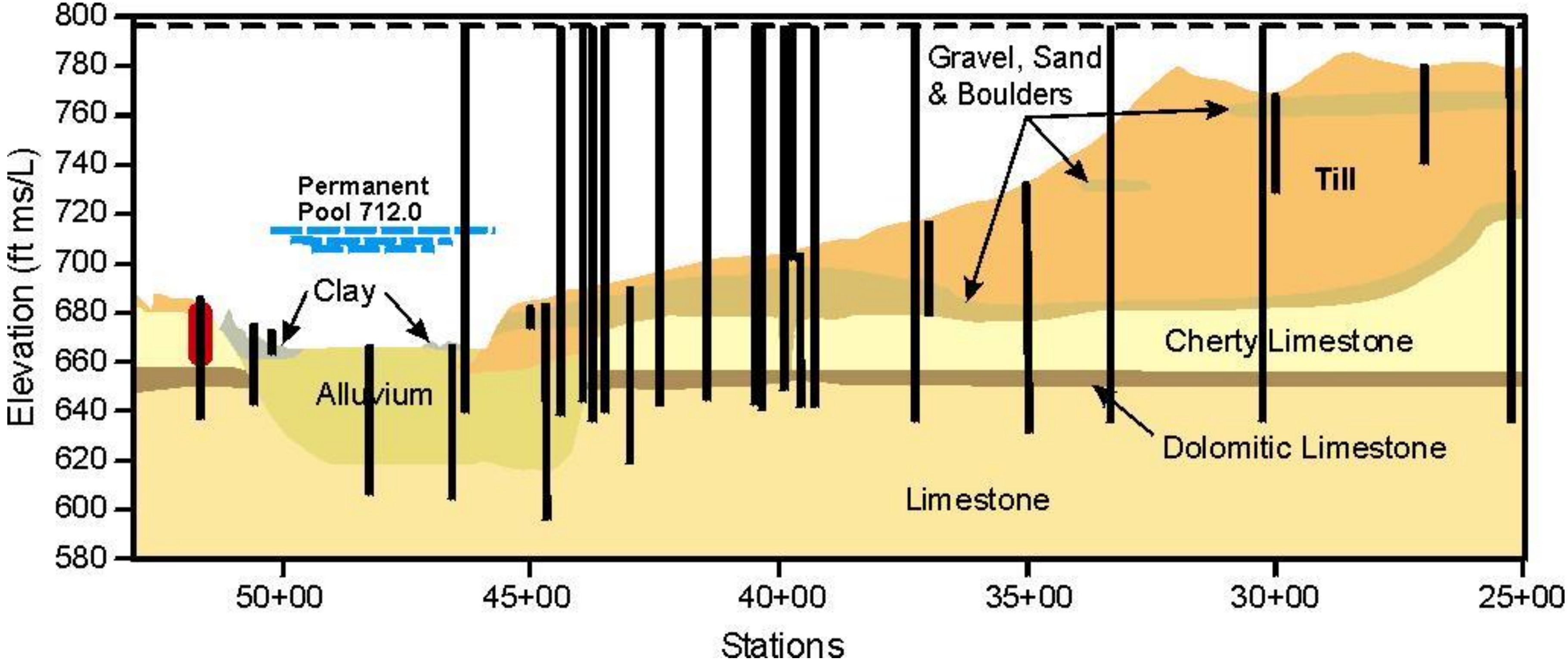
Transverse Section @ STA 41+00



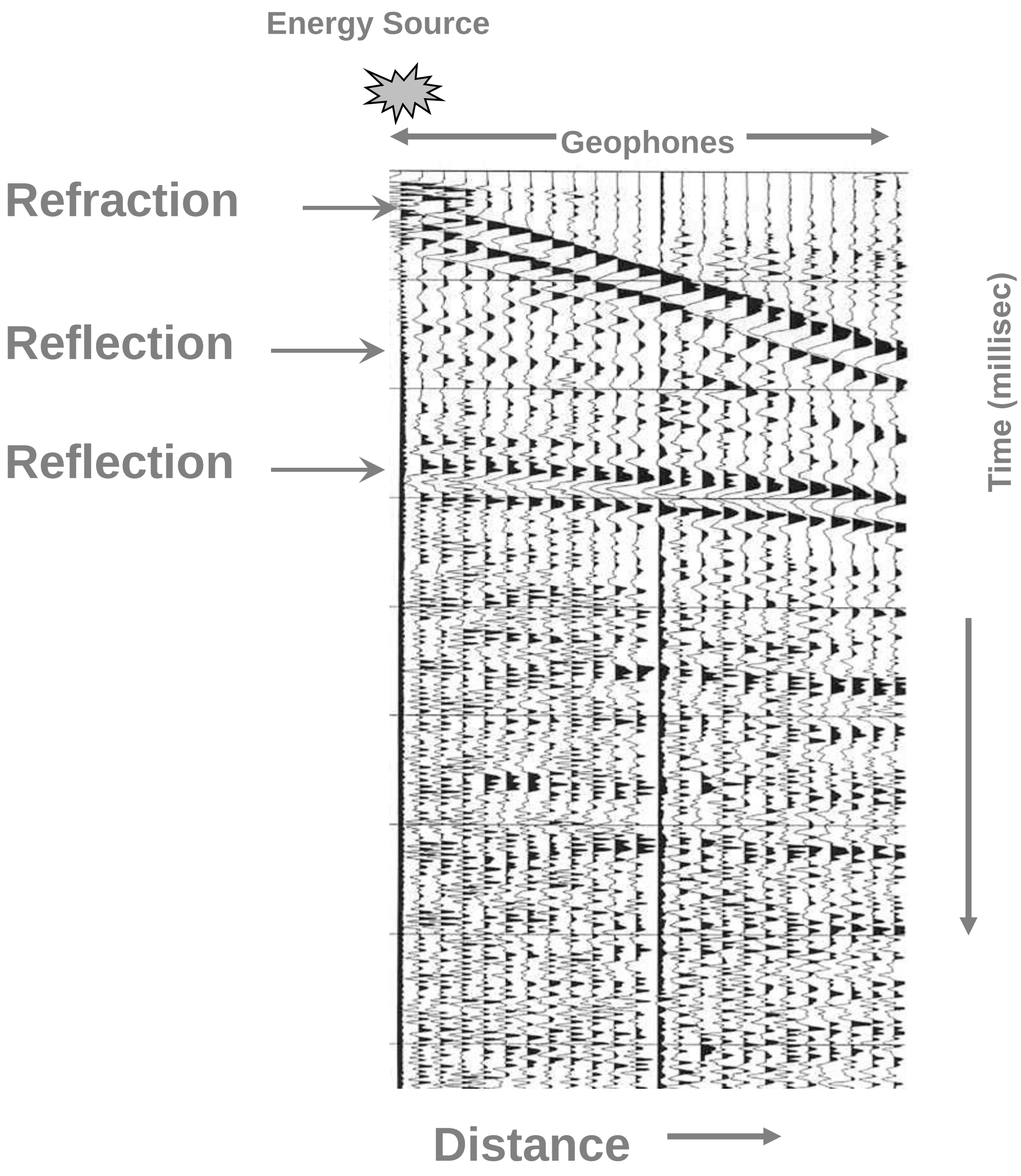
Total Crest Deflection



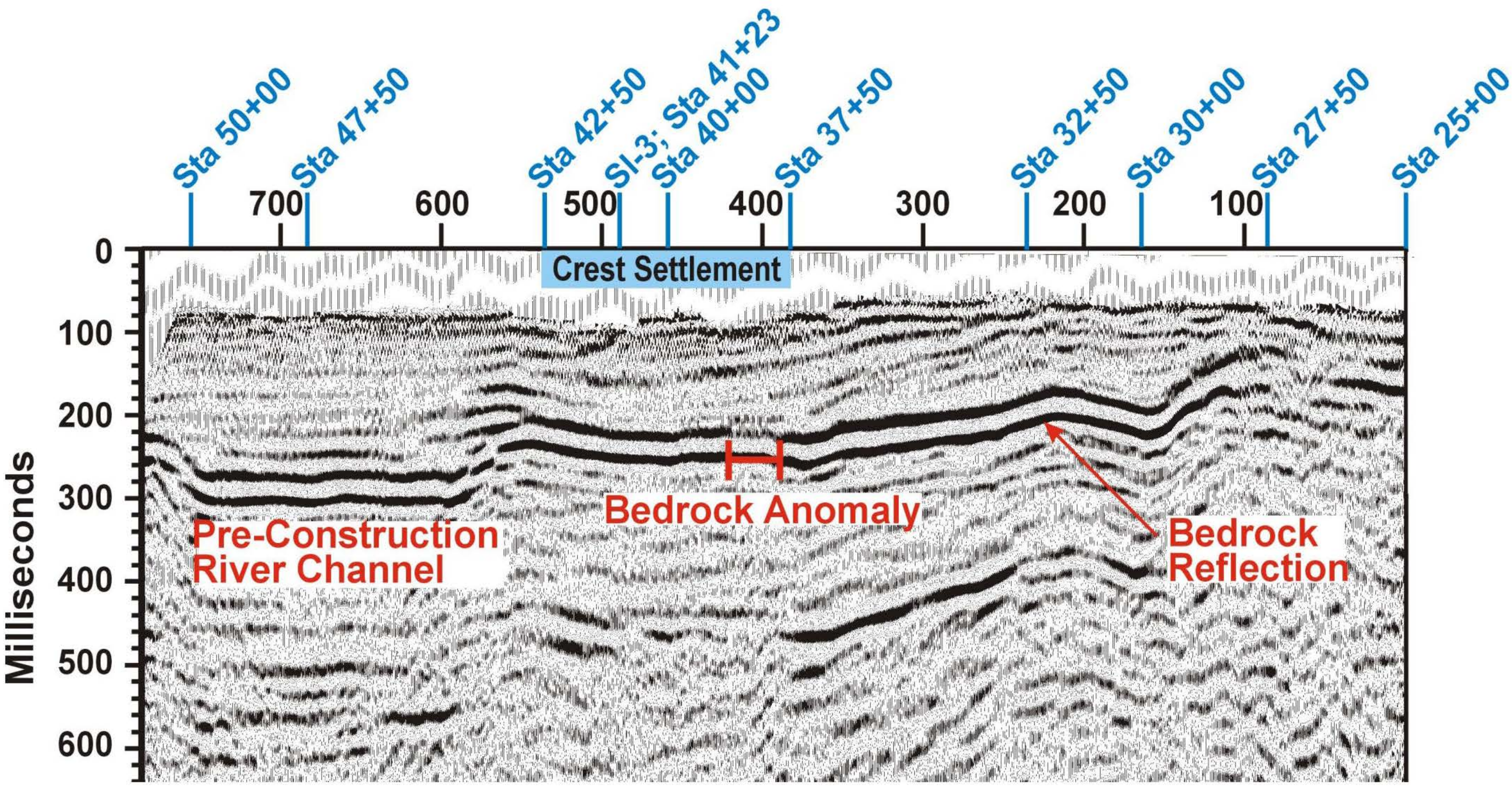
Axial Profile



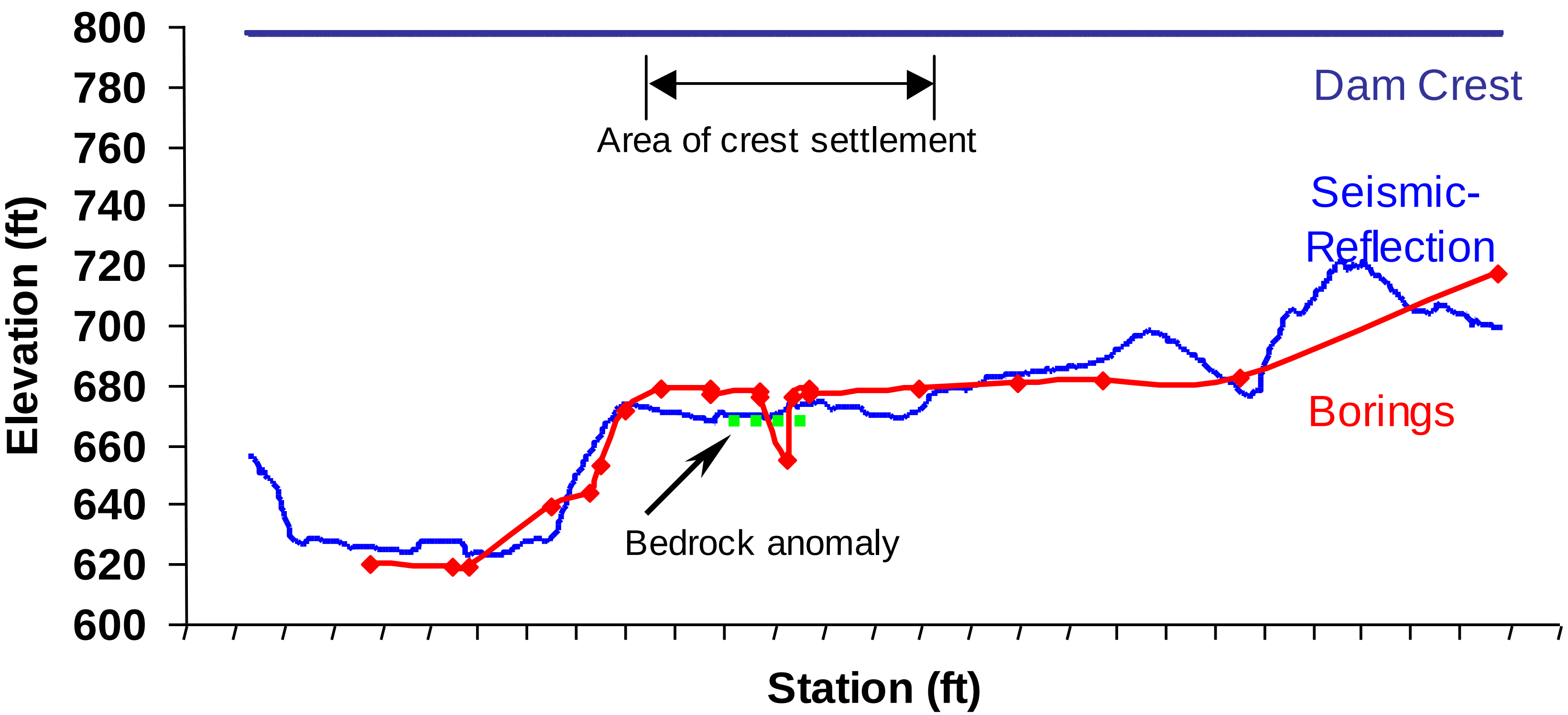
Pre-stack Field File



Stacked CMP Profile

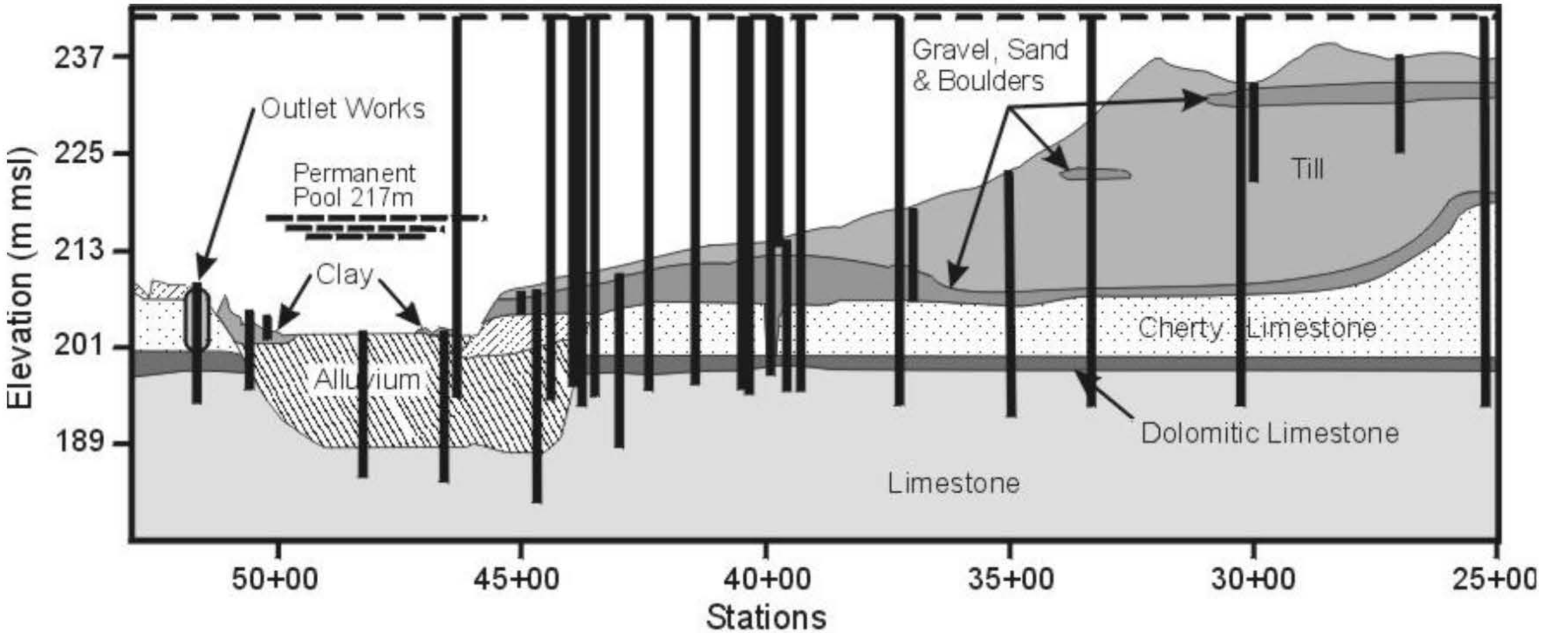


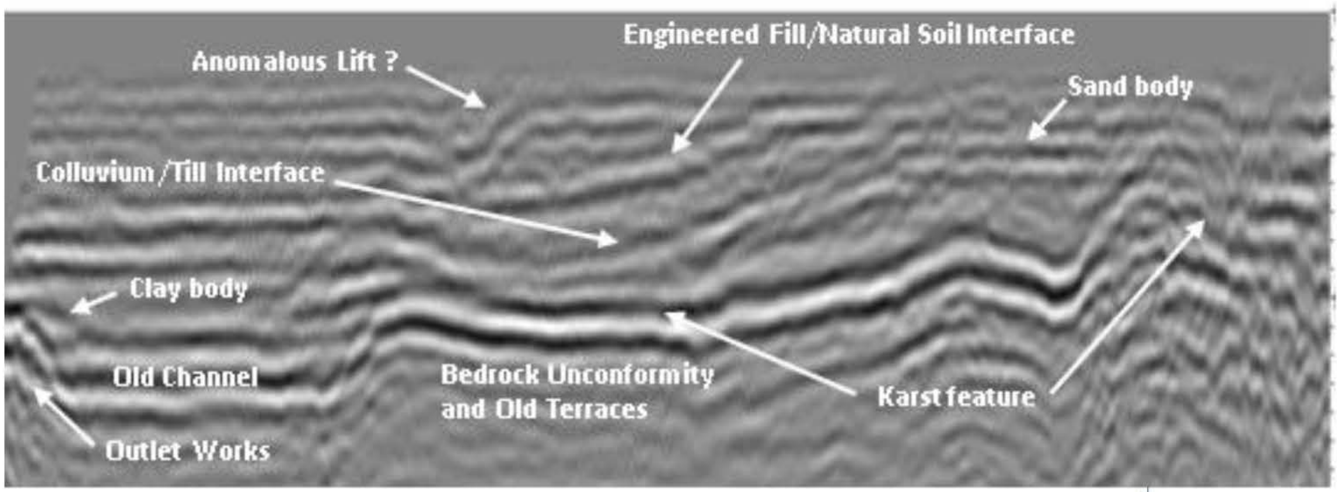
Subsurface Comparison



Vertical Exaggeration 6.4X

Subsurface Comparison





Return to top

APPLICATION OF DOWNHOLE GEOPHYSICAL METHODS TO GEOTECHNICAL AND HYDROGEOLOGICAL INVESTIGATIONS

Mark S. Smith, P.G, Sr. Geologist; Business Unit Manager - Mining, GLS, Engineering & Environmental Services Division, Cardno GLS, mark.s.smith@cardno.com

Speaker Bio: Mr. Smith is a Professional Geologist with over 34 years' professional experience in resource and mining geology, hydrogeology, borehole geophysics, and engineering applications. At Cardno, he directs the geophysical logging division Cardno GLS, and performs geologic and hydrogeological investigations, principally for the mining industry. Such studies include assessments of probable hydrologic consequences of mining; evaluation of hydrogeological, geochemical, and geotechnical conditions and their potential impact on mining activities; and investigations of water quality and/or quantity impacts resulting from past mining. His focus in downhole geophysics has been high resolution data collection and the application to geotechnical evaluations and hydrogeologic studies, as well as mineral resource evaluations.

Presentation Abstract: Modern high resolution geophysical logging tools have numerous applications for geotechnical and hydrogeologic studies. Measuring fracture orientations and understanding joint sets and rock strength parameters are critical components of slope stability analysis, underground mine design, slope-shaft-tunneling design, as well as other types of geotechnical investigations. Downhole geophysical logging tools such as acoustic televiewer, waveform sonic, electromagnetic flowmeter, density, temperature, fluid conductivity and other probes provide a cost effective method of obtaining the required data for geotechnical and hydrogeologic investigations. Through properly located boreholes and the use of geophysical logging it is possible to predict relative strength of strata, identify fracture patterns, locate weak strata and water inflow and outflow zones for controlling water during excavation.

Application of Downhole Geophysical Methods to Geotechnical and Hydrogeological Investigations

Presenter: Mark S. Smith, P.G.
Phone: 304 809 0574

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Geophysical Logging

Common Applications of Geophysical Logging

Mineral Exploration – Coal, Limestone, Aggregates, Uranium, Metal Ores, Other Minerals, and Oil and Gas. (Two types of logging probes, standard oil and gas and "Mineral Logging" probes)

Groundwater - Environmental Site Investigations- Hydrogeology: Water Supply, Contaminant Site Investigations, Mining Industry, Municipal Wells, Residential

Geotechnical – Surface Mining Highwall Design, Underground Mining or Tunneling - Rock Mass Evaluation, Foundation Studies, DOT- Road cuts, Undermining, Deep Soil Moisture-Density Studies,.

Miscellaneous Applications - If a boring or well is drilled in rock for any reason, we can provide geophysical logging to enhance understanding of the geology, mineralogy, hydrogeology, geotechnical or other aspects of the site.

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Geophysical Logging

Cardno Geophysical Logging Units | **4WD Pickup Truck or Van**

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High Resolution Geophysical Logging Probes

Acoustic Televiewer – Optical Televiewer

- Image Borehole side wall, sound or light
- Identifies fracture and bedding location and orientations –Dip angle and direction

Natural Gamma Ray

- Identifies changes in lithology – recorded with most all other logs

Gamma-Gamma Density

- Density of formations, for lithology, mineral exploration, mining, coal reserves, etc.

Neutron

- Porosity, hydrocarbons, water saturation

High Resolution Geophysical Logging Probes

Sonic - Waveforms, P wave and S wave travel times

> **Estimation of rock strength for mining, geotechnical.**
> **Elastic modulus properties of rock mass, fracture effects, porosity, etc.**

Caliper

> **Measures hole or casing diameter, fractures, washouts, soft strata, holes in casings, mine voids, etc.**

Temperature/Fluid Conductivity/SP

> **Fluid movement, water bearing fracture indicator.**
> **Hydrogeology and groundwater movement - applications for mining, geotechnical studies, environmental site assessments, contaminant migration, etc.**

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High Resolution Geophysical Logging Probes

Electromagnetic Flowmeter

- **Measures vertical fluid movement within a boring or well**
- **Under ambient conditions to measure natural flow – determine upward or downward vertical gradients**
- **Under pumping conditions to measure relative flow rates from different formations or fracture locations in a well**

Drill hole deviation (magnetic or gyroscope oriented)

- **Maps drill hole direction/hole location X-Y-Z**

Induction/Resistivity Logs

- **Measures conductivity/resistivity of formation- open hole or inside PVC cased wells**

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High Resolution Geophysical Logging Probes

Downhole Video Cameras

- **Several cameras for use in 2-inch holes up to 30+ feet diameter vertical shafts**
- **Water inflows, casing inspections, lithology, geotechnical, gas inflow, lost probes or drill steel, offset in wells due to mining subsidence, anything you can imagine**
- **Up to 5000 feet depth, downhole and side views, high resolution, low light settings for mine works, voids**

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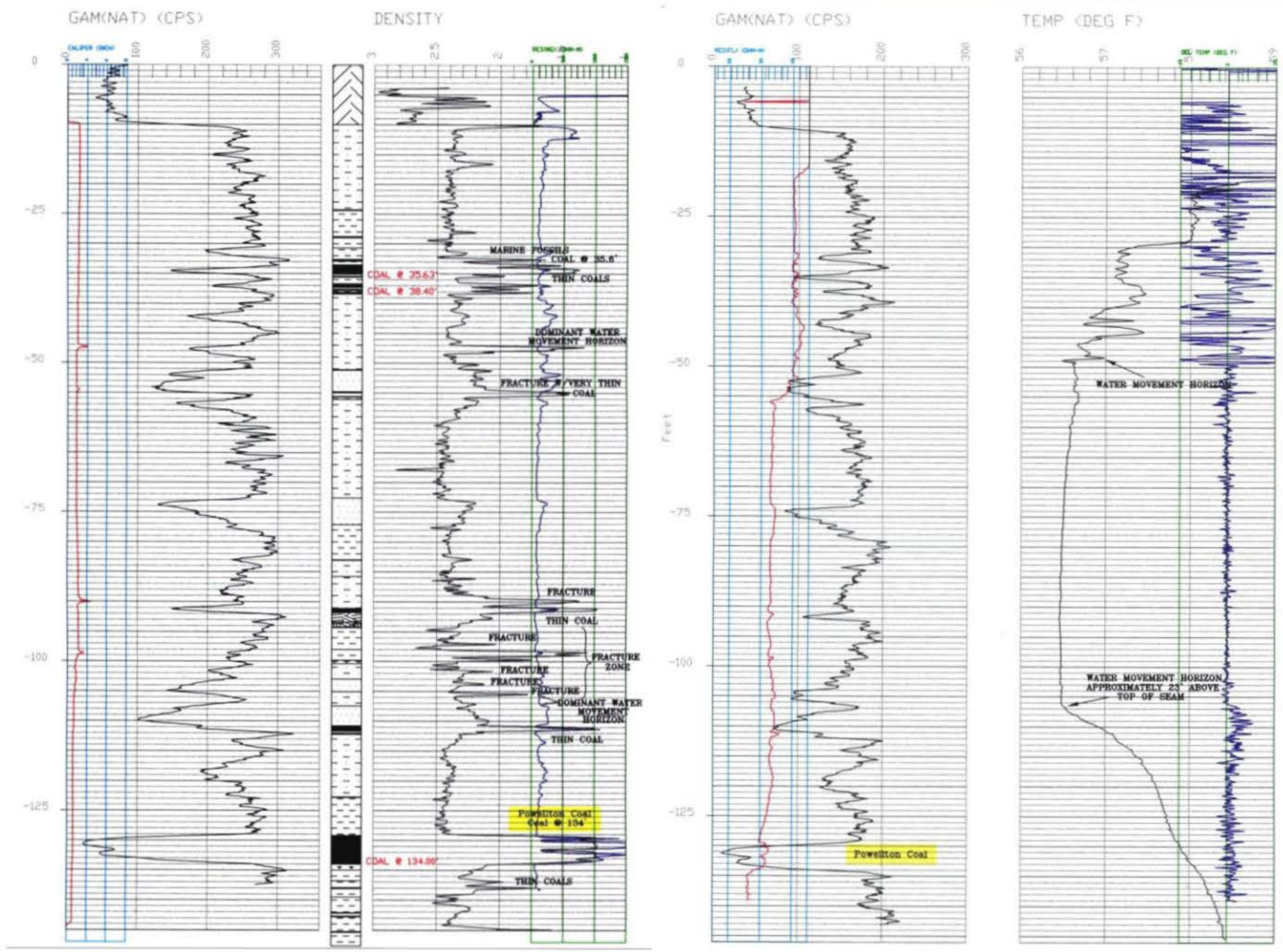
Coal and Mineral Exploration - Hydrogeology



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Geophysical Logging Application Examples

Acoustic Televiewer Logging for Slope Stability Assessment of Open Pit Copper and Limestone Mines

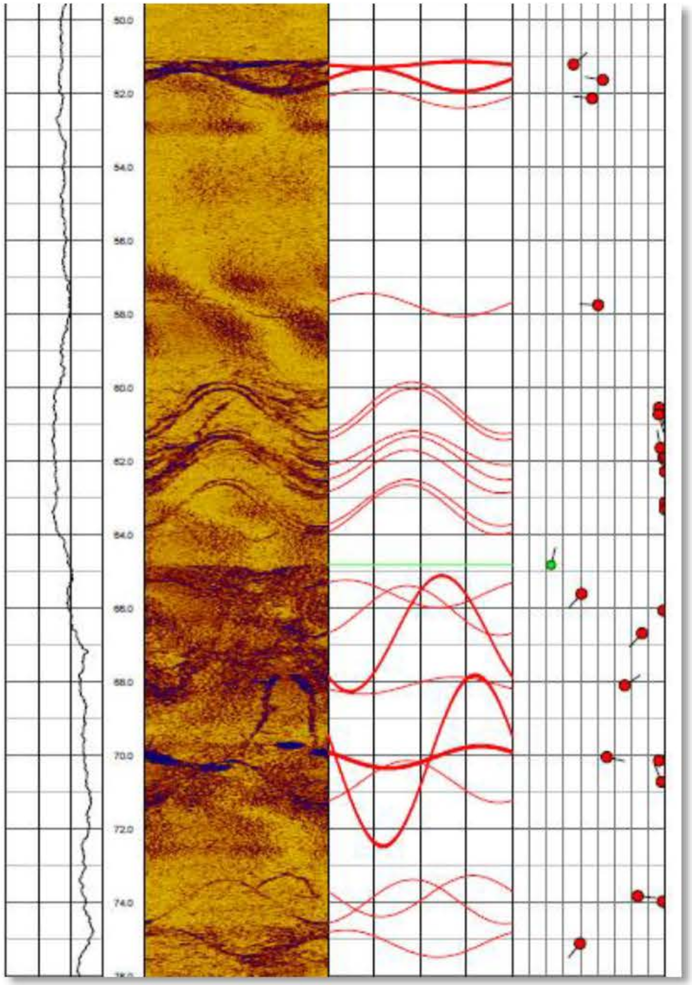
Sonic and Density Logging for Rock Strength Parameters – Deep Mine Roof Rock Assessment

Comprehensive Logging Suite for Deep Rock Tunnel Geotechnical and Hydrogeologic Assessment

Neutron and Density Logging for Bridge Settlement Investigation–Moisture/Density of Soils and Fill

Foundation Study for Urban High Rise Building near Subway Tunnel

Geophysical Logging Methods for Rock Slope Stability Assessment



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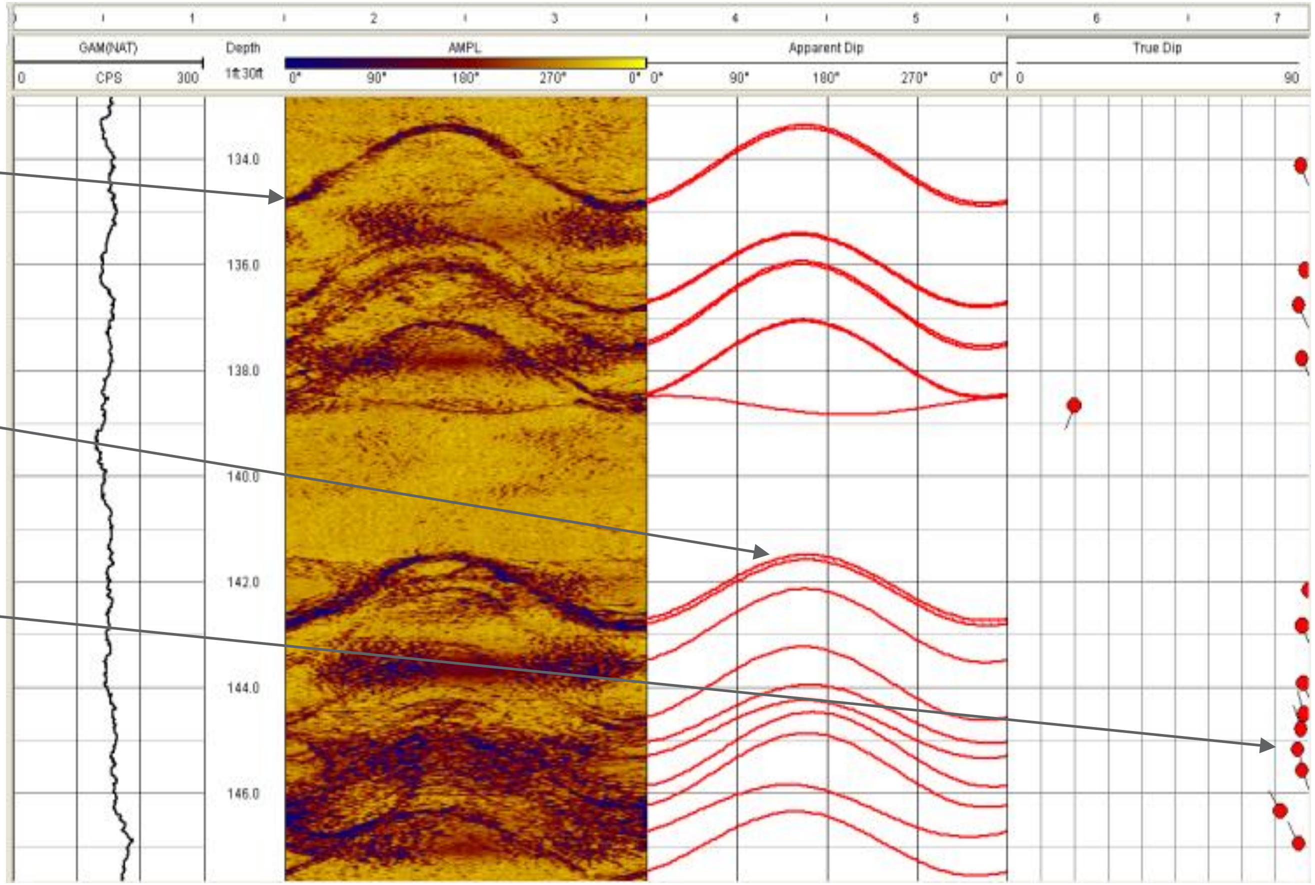
Acoustic Televiewer Log

Acoustic Televiewer Log Image

Interpreted Fractures- Projection in angled hole

Tadpole Plot –True Dip corrected for hole angle and direction.



Geotechnical:
Open Pit Mine Slope Stability Assessment

Gather data from aerial views and from the ground within the pit – where safe!!

Then select drill hole locations, angles and orientations for optimal joint set intersections

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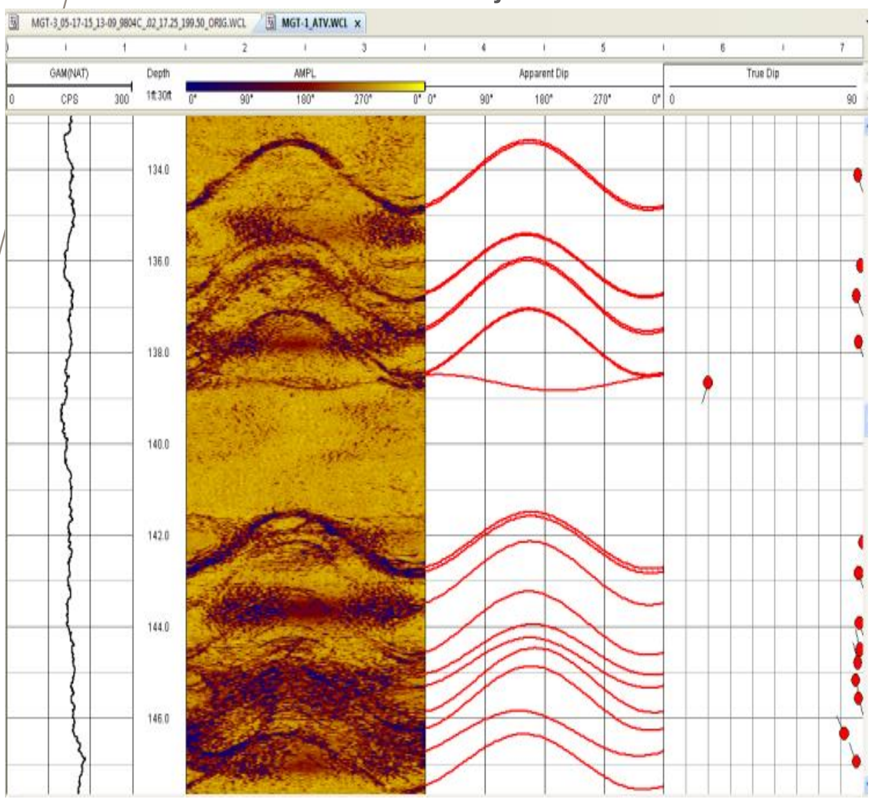
Cardno Borehole Geophysical Logging - Acoustic Televiewer Log and Data

Acoustic Televiewer Log Image

Interpreted Fractures Projection

Tadpole Plot



Hole Number 1	XYZ Company						
DEPTH Feet	Dip Direction Degrees	DIP Angle Degrees	APERTURE inch/10	Feature Category	Feature Category Legend		
39.5	23.29	74.09	0	1	Color	Label	Description
40.6	17.49	79.26	0	1	Black	0	Broken Zone / Undifferentiated
41.94	10.12	75.51	0	1	Red	1	Major Open Joint/Fracture
43.04	5.53	60.64	0	1	Magenta	2	Minor Open Joint/Fracture
43.66	347	54.58	0	1	Orange	3	Partially Open Joint/Fracture
44.19	354.21	62.7	0	1	Gray	4	Filled Fracture/ Joint
44.79	283.01	87.1	0	1	Green	5	Bedding/Banding/Foliation
44.83	345.34	60.51	0	1			
45.72	323.65	59.49	0	1			
45.97	328.93	63.79	0	1			
46.23	354.95	78.33	0	1			
46.76	23.76	76.94	6.43	1			
47.76	347.95	78.38	0	1			
47.97	338.81	70.38	0	1			
49.09	291.55	51.87	0	1			
49.72	270.81	65.25	0	1			
50.11	312.48	56.48	0	1			
50.57	233.19	44.67	0	1			
51.15	303.58	80.54	0	1			
51.96	224.47	64.4	0	1			
52.32	249.15	82.3	0	1			
52.33	24.35	82.64	0	1			
52.67	17.02	83.79	0	1			
53.75	290.34	74.34	0	1			
54.28	295.89	62.19	0	1			
54.97	322.12	84.76	0	1			
55.27	253.83	53.95	0	1			

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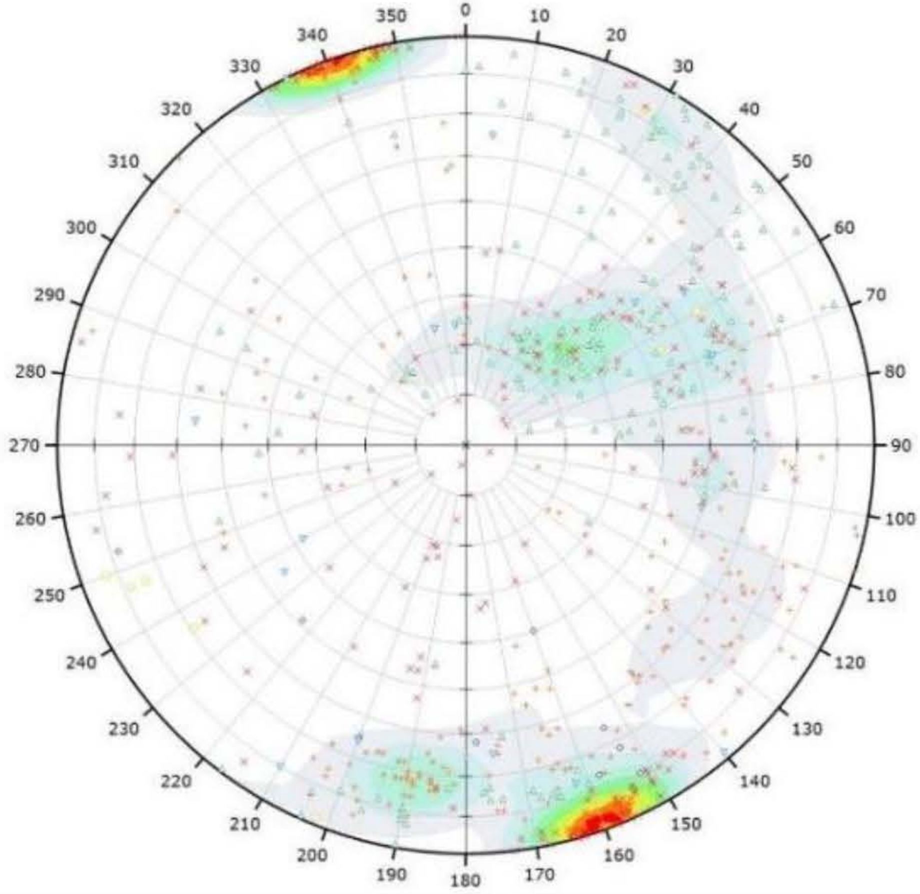
Discontinuity Data/Stereonet Assessment



Symbol	DATA SOURCE	Quantity
o	4-21-2015 Site Visit	10
×	ATV Data from MGT-1	228
△	ATV Data from MGT-2	164
+	ATV Data from MGT-3	181
▽	June 2015 Field Mapping	16
□	MGT-1 site cut exposure	8

Color	Density Concentrations
	0.00 - 1.20
	1.20 - 2.40
	2.40 - 3.60
	3.60 - 4.80
	4.80 - 6.00
	6.00 - 7.20
	7.20 - 8.40
	8.40 - 9.60
	9.60 - 10.80
	10.80 - 12.00
Maximum Density	11.96%
Contour Data	Pole Vectors
Contour Distribution	Fisher
Counting Circle Size	1.0%

Plot Mode	Pole Vectors
Vector Count	607 (607 Entries)
Hemisphere	Lower
Projection	Equal Area

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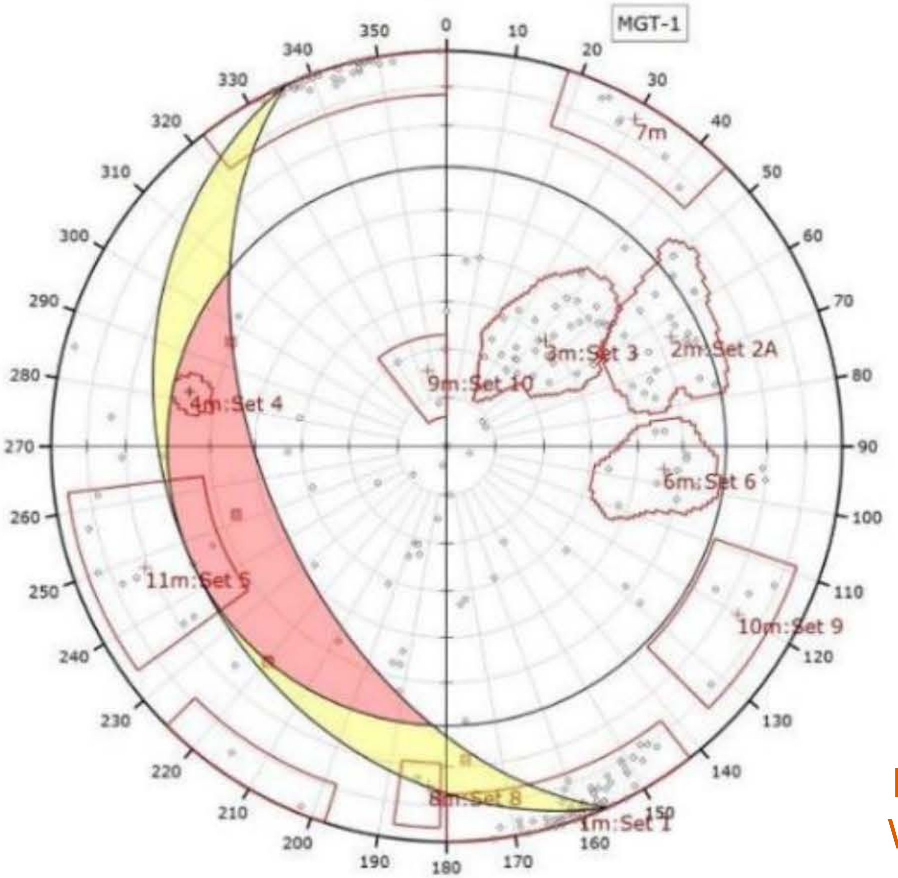
Discontinuity Data/Stereonet Assessment



Symbol	Feature
◦	Pole Vectors
▫	Critical Intersection

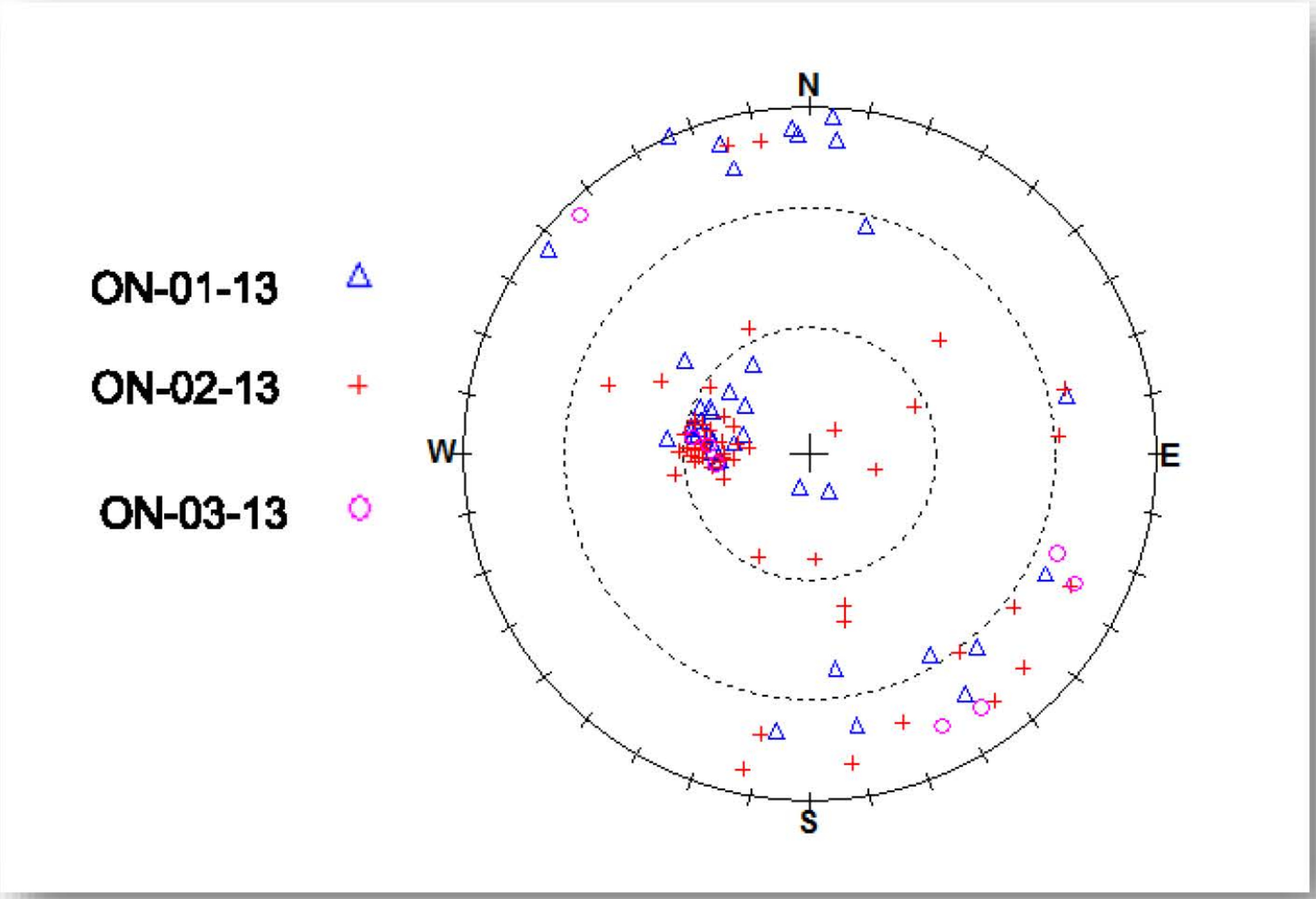
Kinematic Analysis	Wedge Sliding
Slope Dip	52
Slope Dip Direction	246
Friction Angle	30°

	Critical	Total	%
Wedge Sliding	6	45	13.33%

Plot Mode	Pole Vectors
Vector Count	236 (236 Entries)
Intersection Mode	Mean Set Planes
Intersections Count	45
Hemisphere	Lower
Projection	Equal Area

Example of Analysis for
Wedge Sliding Potential

Stereonet Plots of ATV data for Geotech Analysis



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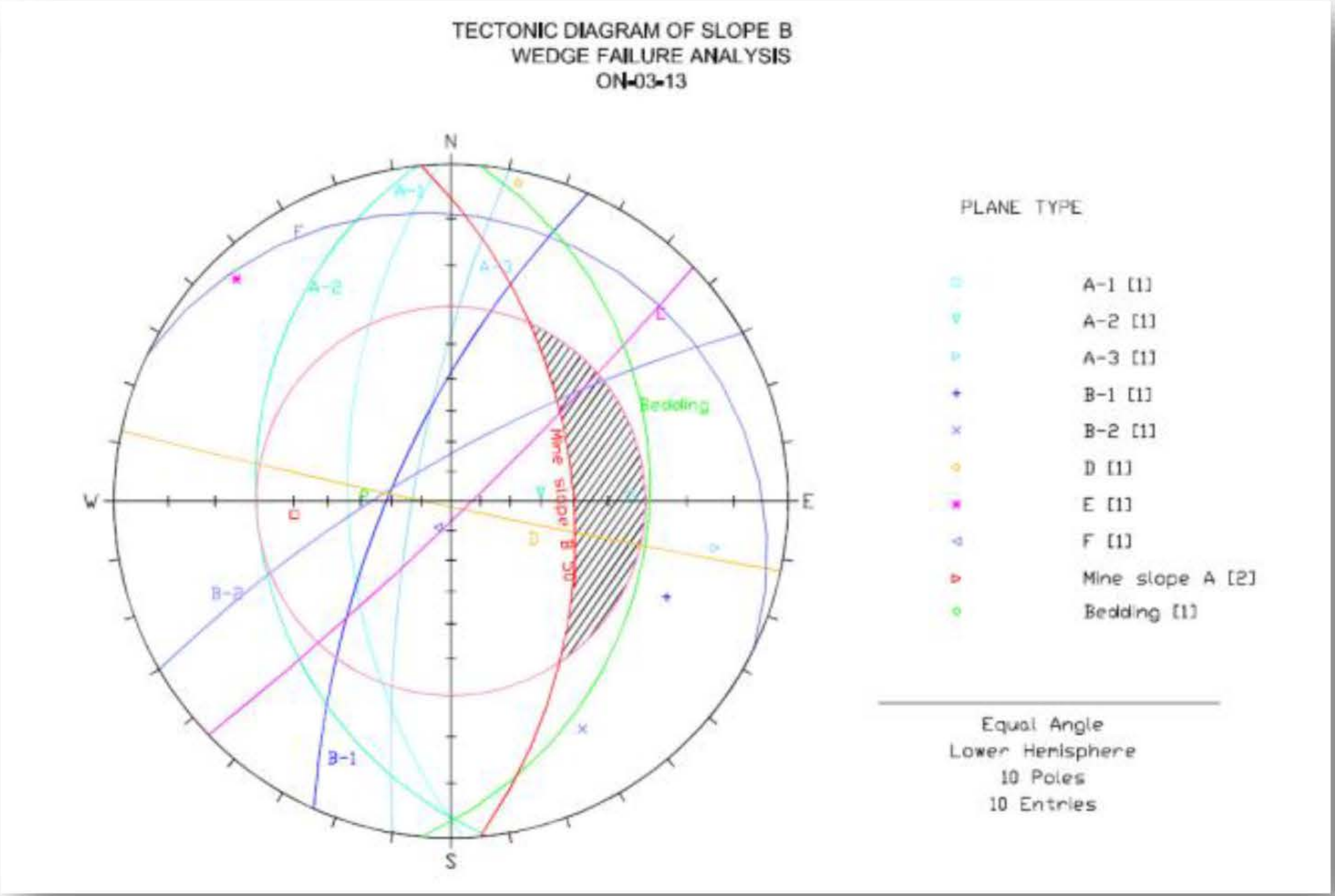
Stereonet Plot of ATV data for Geotech Analysis



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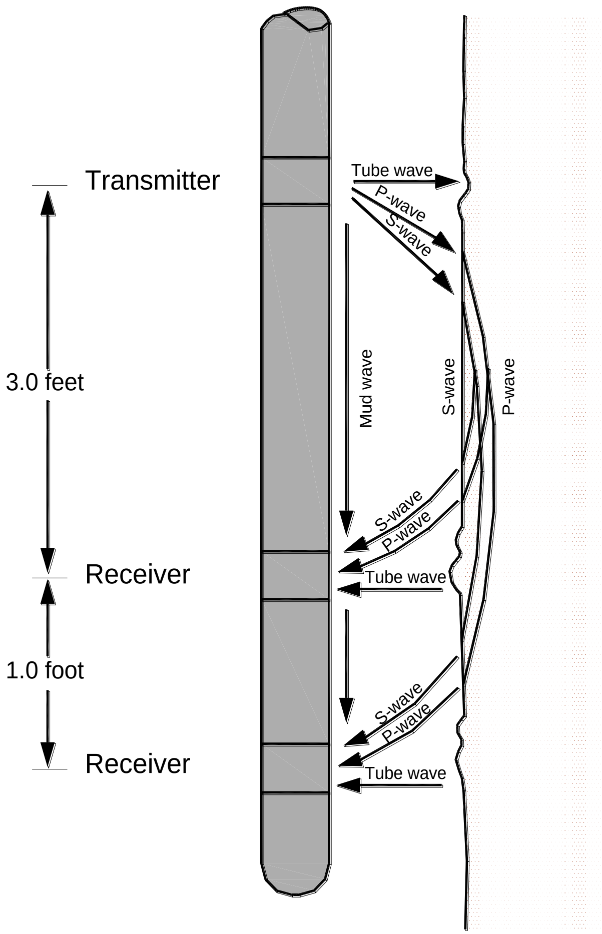
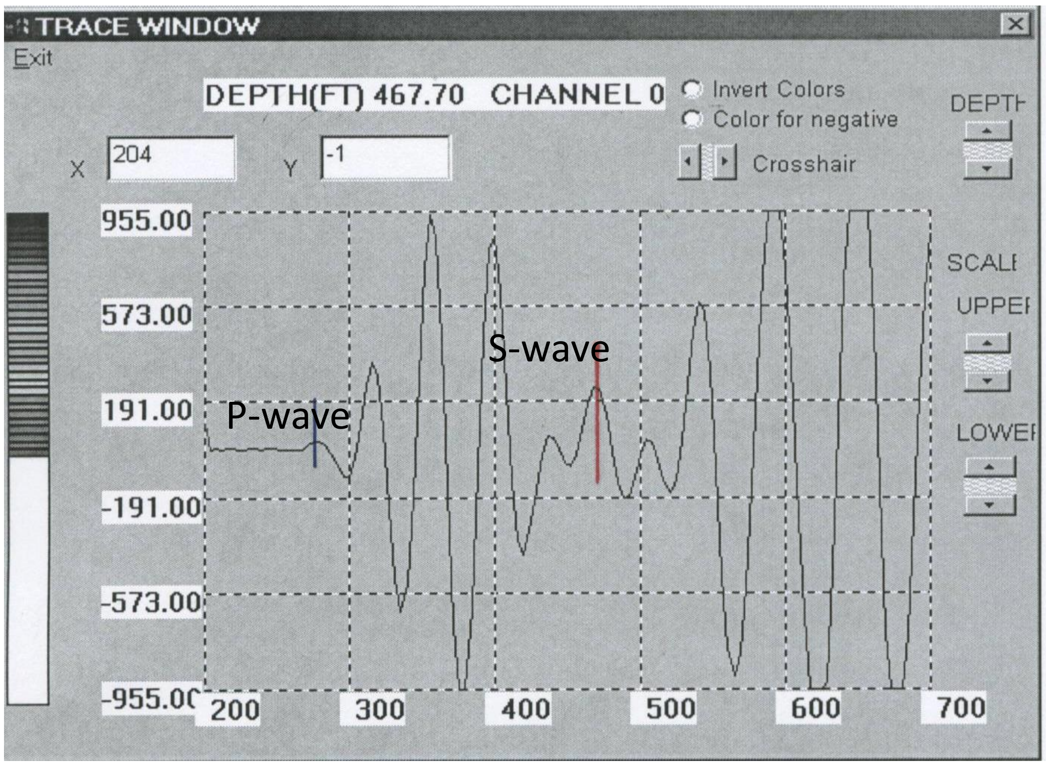
Sonic Log / Waveform

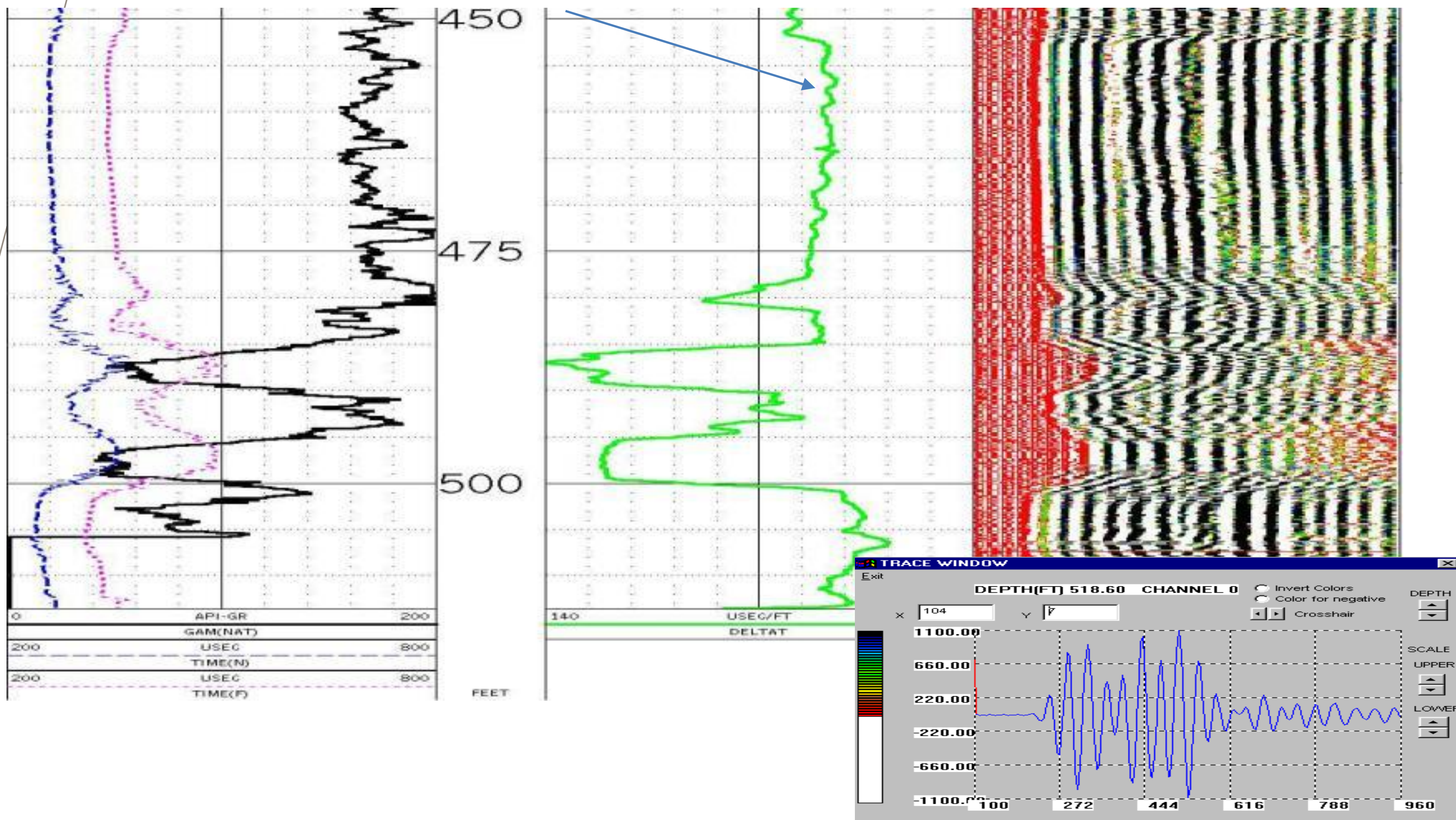
Sonic Log

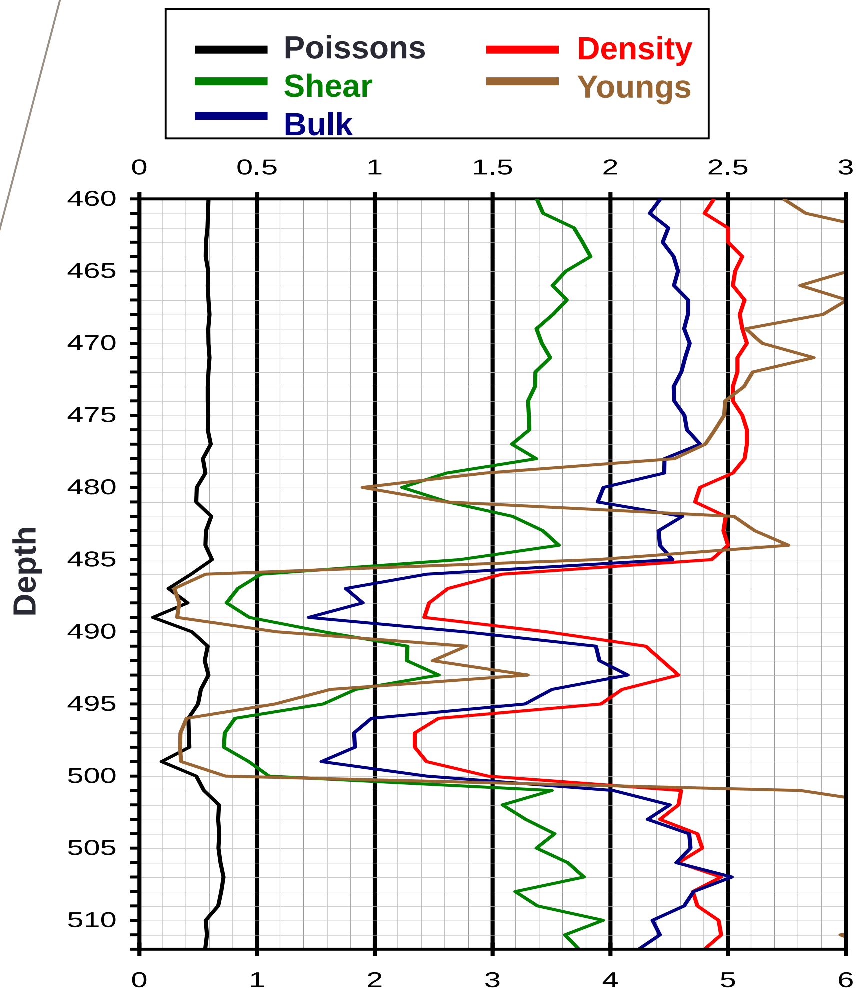


Sonic Waveform



A Sonic Log presentation: Green is P wave travel time VDL of waveform





Depth	Density	Sonic	delta-t s	TTc	TTs	Poissons	Youngs	Shear	Bulk	Vc	Vs	Vc/Vs
460	[illegible]	75.2	139	270	462	0.294	[illegible]	[illegible]	2.21	13298	7184	1.85
461	2.4	74.3	137	270	458	0.292	[illegible]	[illegible]	2.17	13459	7301	1.84
462	2.5	73.4	135	270	454	0.289	[illegible]	[illegible]	2.25	13624	7422	1.84
463	[illegible]	73.4	133	270	450	0.283	[illegible]	[illegible]	[illegible]	13624	7495	1.82
464	[illegible]	73.8	134	270	450	0.281	[illegible]	[illegible]	[illegible]	13550	7474	1.81
465	[illegible]	74.1	137	270	458	0.292	[illegible]	[illegible]	[illegible]	13495	7312	1.85
466	[illegible]	75.4	139	271	464	0.290	[illegible]	[illegible]	2.27	13263	7205	1.84
467	2.57	74.4	138	270	460	0.294	[illegible]	[illegible]	2.33	13441	7280	1.85
468	[illegible]	74.9	139	272	466	0.298	[illegible]	[illegible]	2.33	13369	7170	1.86
469	[illegible]	77.3	143	274	470	0.292	[illegible]	[illegible]	2.31	12937	7011	1.85
470	[illegible]	76.9	142	270	466	0.293	[illegible]	[illegible]	2.34	13004	7031	1.85
471	[illegible]	75	140	274	468	0.297	[illegible]	[illegible]	[illegible]	13353	7160	1.86
472	[illegible]	76.9	142	278	474	0.295	[illegible]	[illegible]	[illegible]	13004	7031	1.85
473	[illegible]	77.1	142	278	472	0.290	[illegible]	[illegible]	2.27	12970	7054	1.84
474	[illegible]	77.7	143	278	474	0.291	[illegible]	[illegible]	2.27	12870	6891	1.84
475	[illegible]	78	144	280	479	0.292	[illegible]	[illegible]	2.31	12821	6944	1.85
476	[illegible]	78.5	145	290	478	0.291	[illegible]	[illegible]	[illegible]	12739	6920	1.84
477	[illegible]	78.5	148	290	488	0.304	[illegible]	[illegible]	[illegible]	12739	6764	1.88
478	[illegible]	80.3	143	274	462	0.270	[illegible]	[illegible]	[illegible]	12453	6995	1.78
479	[illegible]	88.9	161	294	510	0.280	[illegible]	[illegible]	[illegible]	11249	6215	1.81
480	[illegible]	98.4	169	314	526	0.244	[illegible]	[illegible]	[illegible]	10163	5615	1.72
481	[illegible]	90.7	155	274	465	0.242	[illegible]	[illegible]	[illegible]	11025	6436	1.71
482	[illegible]	76.8	145	305	510	0.306	[illegible]	[illegible]	2.31	13021	6890	1.89
483	[illegible]	76.6	139	274	462	0.283	[illegible]	[illegible]	2.21	13055	7180	1.82
484	2.5	75.9	137	274	458	0.280	[illegible]	[illegible]	2.21	13103	7292	1.81
485	[illegible]	81.4	155	290	510	0.309	[illegible]	[illegible]	[illegible]	12285	6463	1.90
486	[illegible]	119.8	200	342	582	0.219	[illegible]	[illegible]	[illegible]	8347	5005	1.67
487	[illegible]	134.3	205	314	526	0.124	[illegible]	[illegible]	[illegible]	7446	4879	1.53
488	[illegible]	128.6	211	375	622	0.204	[illegible]	[illegible]	[illegible]	7776	4741	1.64
489	[illegible]	127.7	186	362	535	0.057	[illegible]	[illegible]	[illegible]	7831	5365	1.46
490	[illegible]	102.8	172	330	535	0.223	[illegible]	[illegible]	[illegible]	9726	5809	1.67
491	[illegible]	86.4	159	296	514	0.291	[illegible]	[illegible]	[illegible]	11574	6287	1.84
492	[illegible]	89.9	162	298	514	0.277	[illegible]	[illegible]	[illegible]	11136	6100	1.80
493	[illegible]	84	155	298	512	0.293	[illegible]	[illegible]	[illegible]	11905	6438	1.85
494	[illegible]	98.3	173	306	520	0.261	[illegible]	[illegible]	[illegible]	10173	5781	1.76
495	[illegible]	106.1	183	330	562	0.249	[illegible]	[illegible]	[illegible]	9425	5452	1.73
496	[illegible]	124.3	205	365	606	0.208	[illegible]	[illegible]	[illegible]	8045	4887	1.65
497	[illegible]	126	208	362	605	0.210	[illegible]	[illegible]	[illegible]	7937	4805	1.65
498	[illegible]	126.4	209	360	606	0.212	[illegible]	[illegible]	[illegible]	7911	4793	1.65
499	[illegible]	125.6	188	360	546	0.094	[illegible]	[illegible]	[illegible]	7962	5330	1.49
500	[illegible]	110.9	190	325	562	0.241	[illegible]	[illegible]	[illegible]	9017	5265	1.71
501	[illegible]	74	133	274	450	0.274	[illegible]	[illegible]	[illegible]	13514	7538	1.79
502	[illegible]	69.7	141	260	474	0.338	[illegible]	[illegible]	[illegible]	14347	7091	2.02
503	[illegible]	67	134	252	454	0.334	[illegible]	[illegible]	[illegible]	14925	7444	2.00
512	2.4	72.6	131	266	442	0.280	[illegible]	[illegible]	2.12	13774	7615	1.81

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Geophysical Logging

- **City of Atlanta Water Tunnels for Transporting Freshwater from Chatahoochee River to Hemphill Water Treatment Plant and then to Abandoned Quarry for Water Storage**
- **Two Legs, approximately 4 Miles from the river to the treatment plant and 2 Miles from the plant to the quarry/reservoir. Four vertical shafts, one on each end.**
- **250 to 600 feet in depth from surface.**
- **Purpose of investigation was a combination of geotechnical and hydrological data collection to identify problematic areas, any issues to be resolved and to be used for final design and selection of construction methods.**

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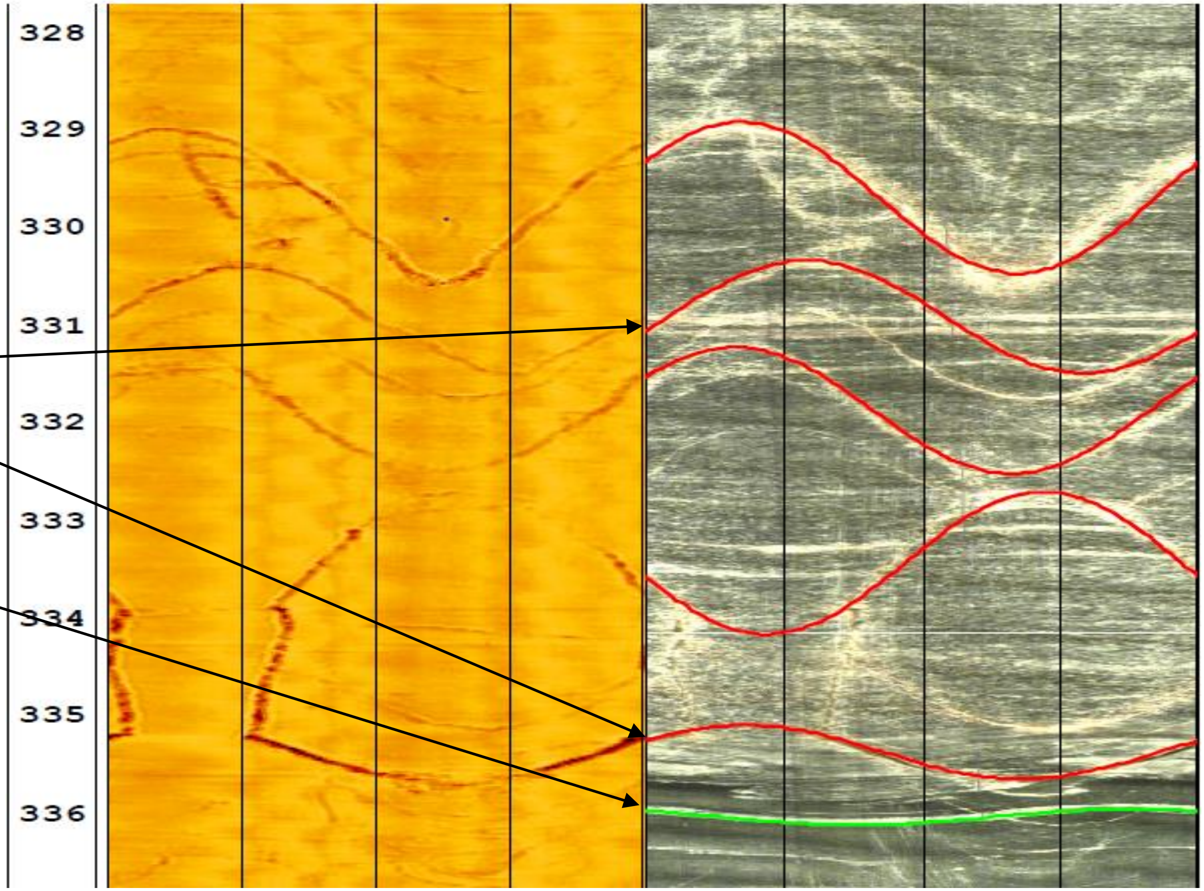
Acoustic and Optical Televiewer Logs

Acoustic and Optical Televiewer Logs with Interpreted Fractures and Bedding

Dip angle and Dip Direction



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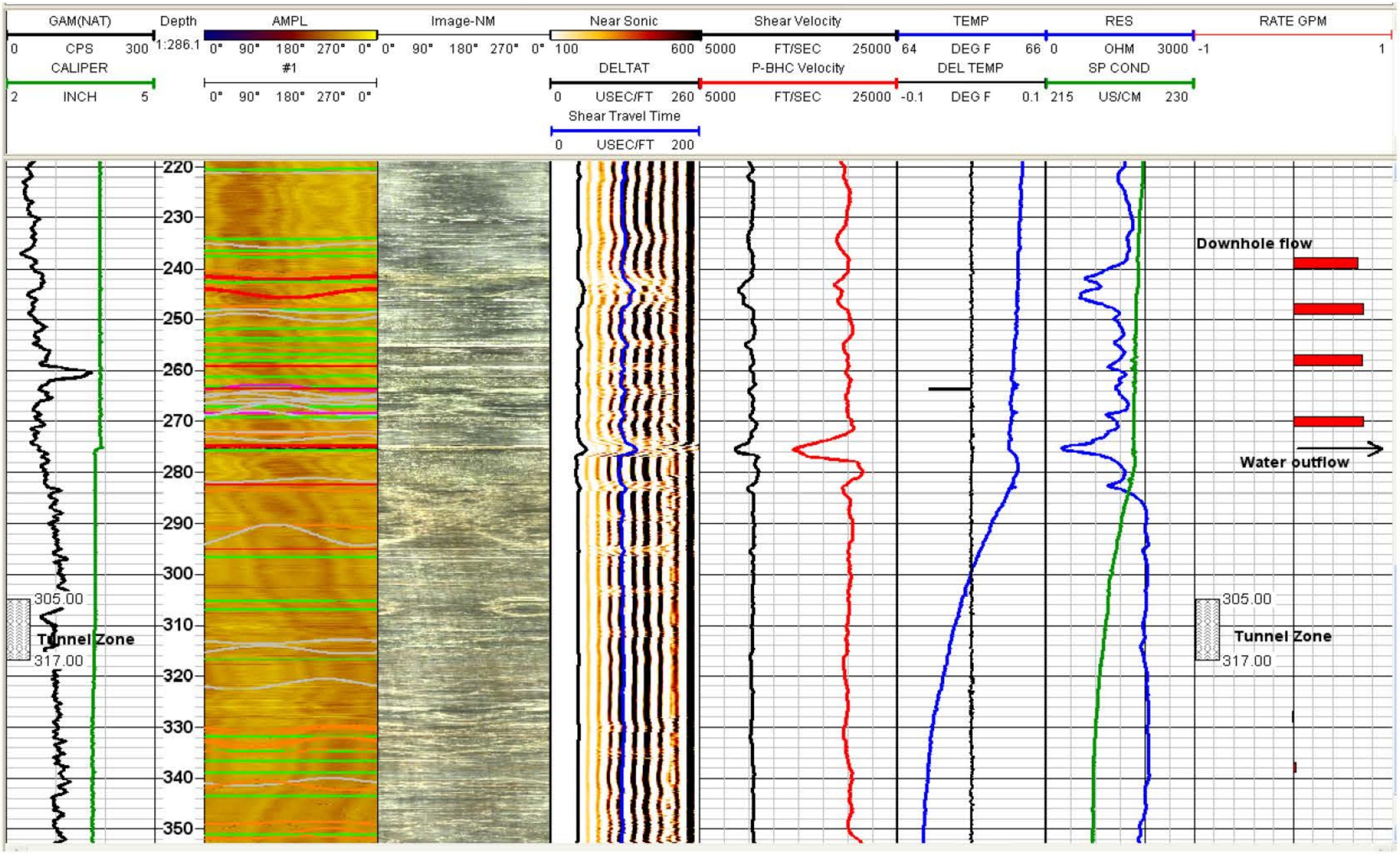
Cardno Borehole Geophysical Logging - Composite Log for Deep Rock Tunnel Project in Atlanta, GA



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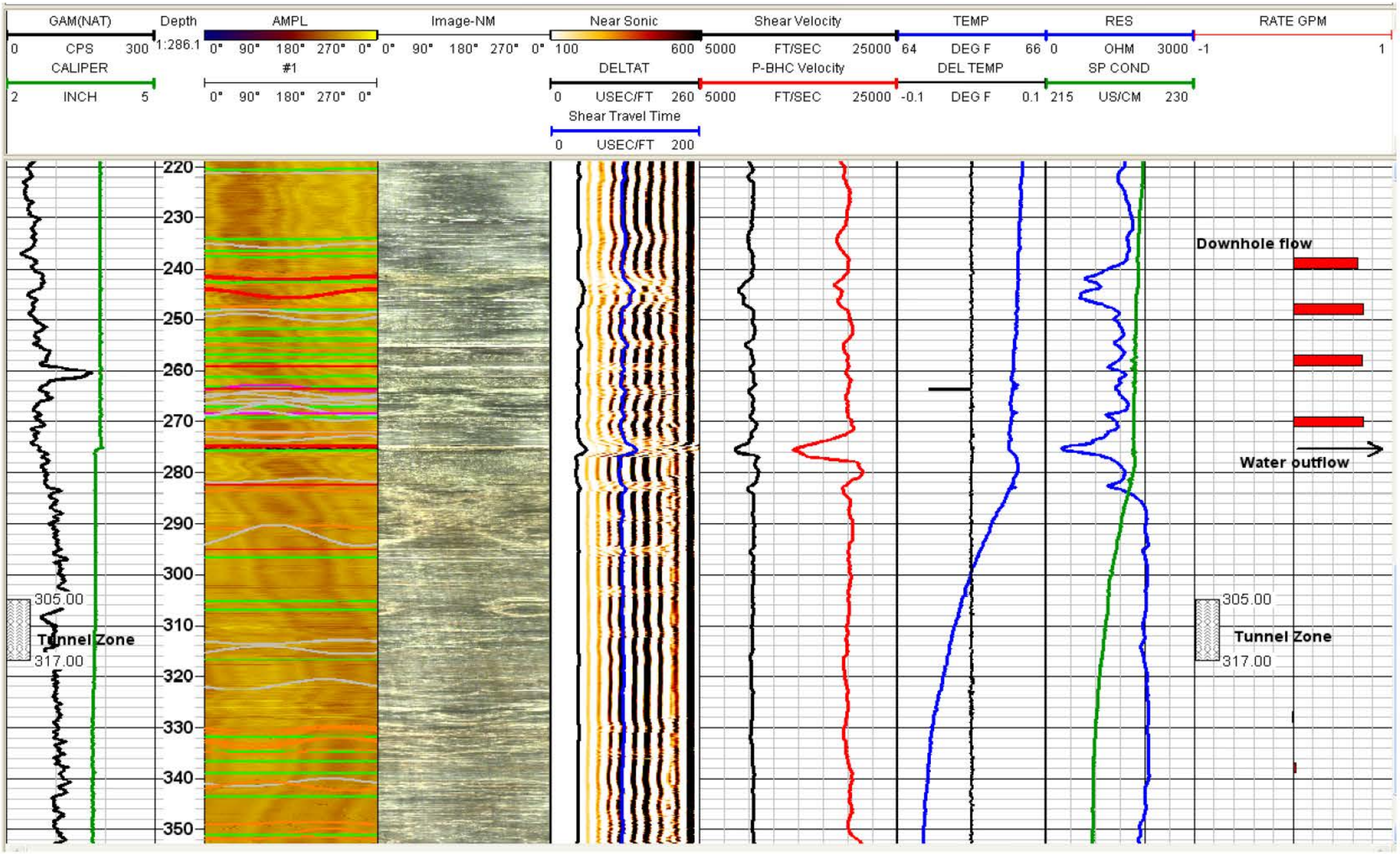
Cardno Borehole Geophysical Logging - Composite Log for Deep Rock Tunnel Project in Atlanta, GA



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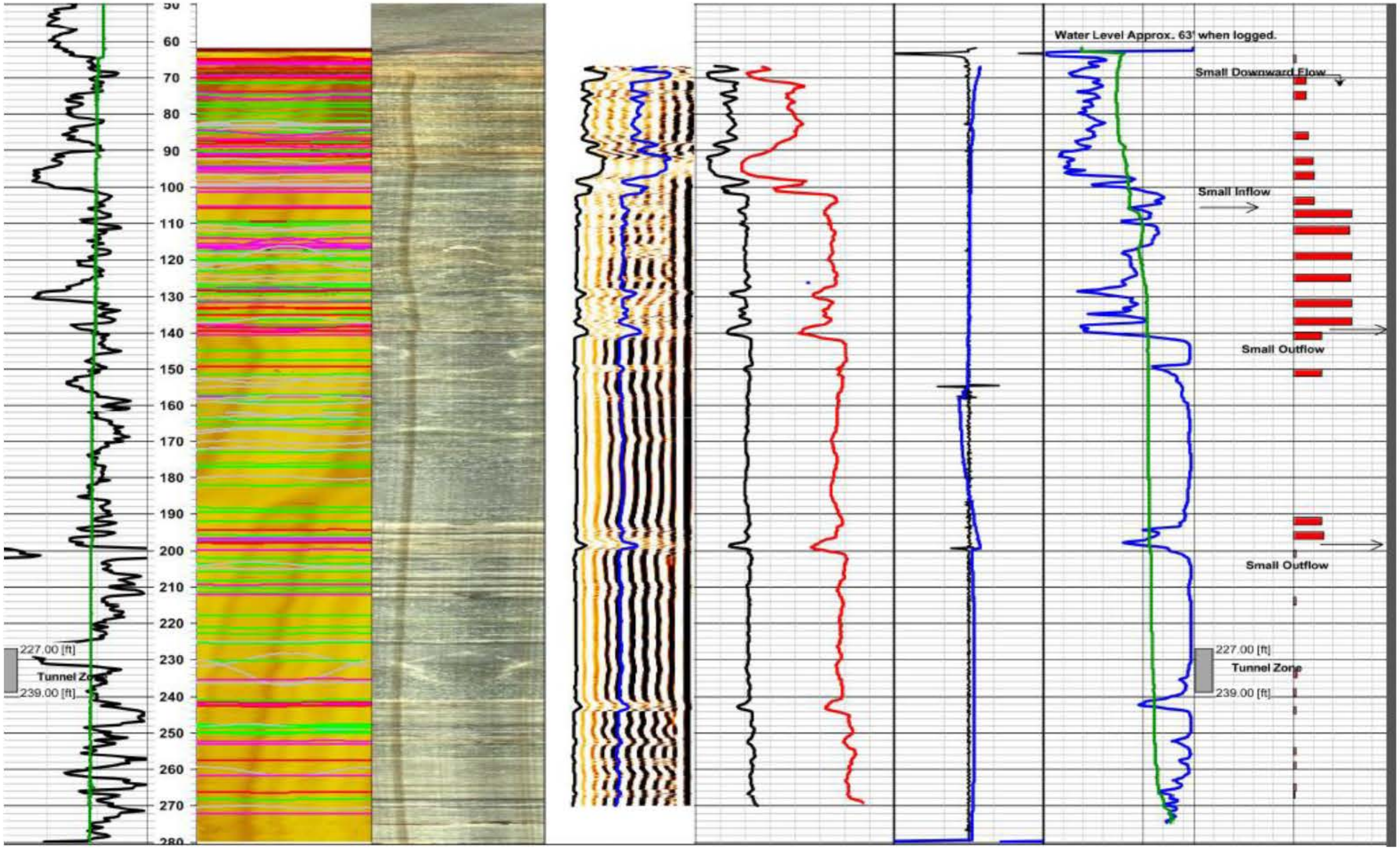
Cardno Borehole Geophysical Logging - Composite Log for Deep Rock Tunnel Project in Atlanta, GA



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Neutron and Density Log for Bridge Settlement Investigation–Moisture/Density of Soils and Fill

The Pennsylvania Department of Transportation (PennDOT) along with Cardno designed a drilling and logging program to investigate subsurface conditions at several locations where bridge abutment settlement was taking place.

Cardno was contracted to perform geophysical logging of steel cased borings with both density and neutron logging probes in the fill material and natural soils in the vicinity of several bridges.

The goal was to derive the moisture - density relationship for the fill and soil materials at each location from near surface down to the bedrock horizon.

Steel casings were installed using a casing advancer by the drilling contractor, and split spoon samples were collected for moisture content analysis at various intervals within each boring.

Each cased boring was logged by Cardno for natural gamma, neutron and density inside the steel casing as it was completed.

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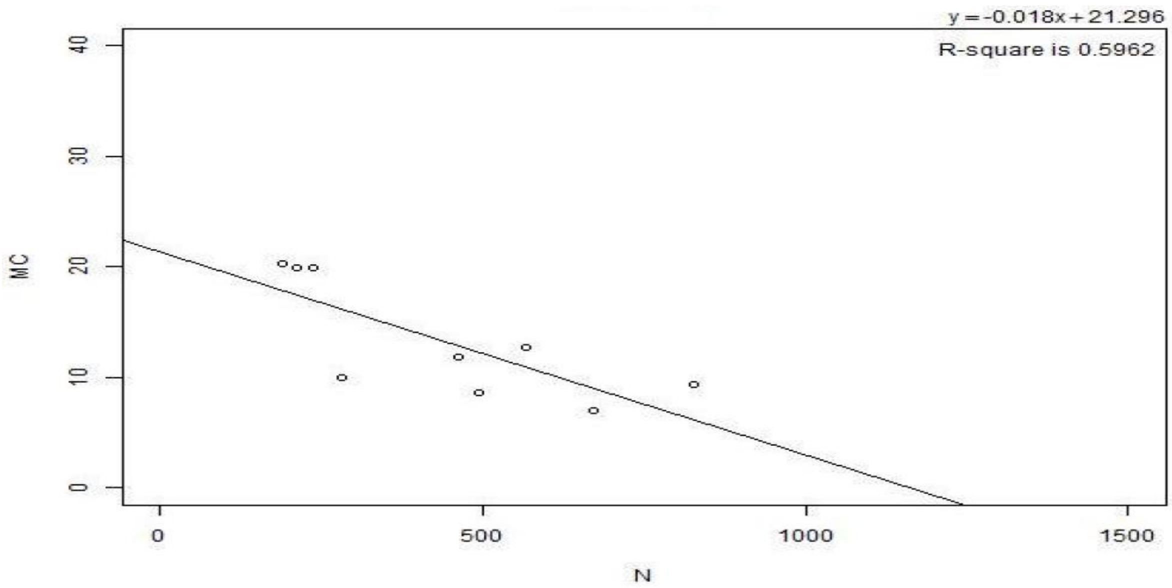
Neutron and Density Log for Bridge Settlement Investigation–Moisture/Density of Soils and Fill

The density curve was calibrated using two calibration jigs constructed with known density material outside pieces of the actual steel casing used.

Calibration curves to convert the raw neutron data to moisture content were developed by linear regression analysis of the raw neutron counts and the reported moisture contents of the laboratory analysis of samples.

The resulting formulas were used to create an Apparent Moisture Content curve by applying each calibration curve to the raw Neutron counts.



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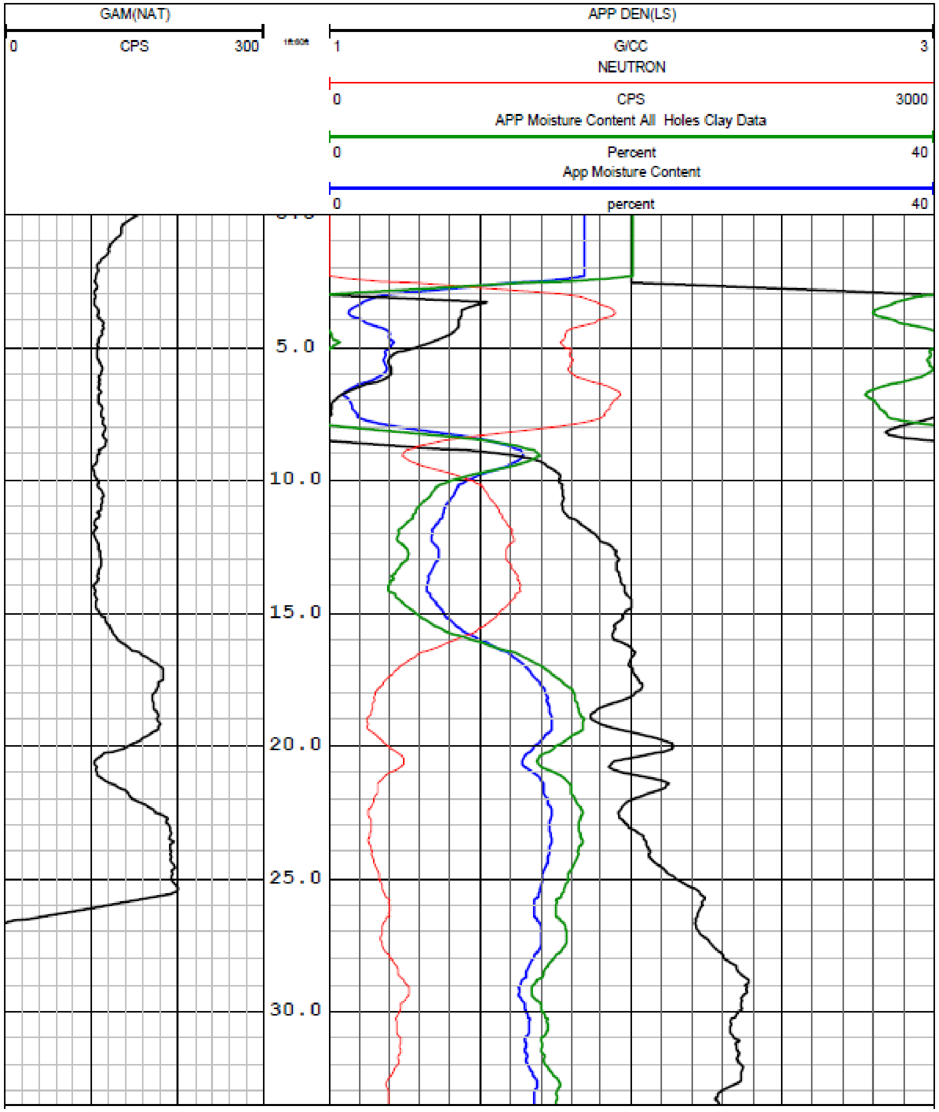
Neutron and Density Log for Bridge Settlement Investigation–Moisture/Density of Soils and Fill



Log plots were developed for each boring showing the natural gamma curve, apparent density curve, raw neutron counts, and apparent moisture content curves. Density and moisture content curves are labeled as apparent density or apparent moisture content, as these were logged through the steel casing and are not compensated for any conditions, such as washouts, that may occur outside the casing.

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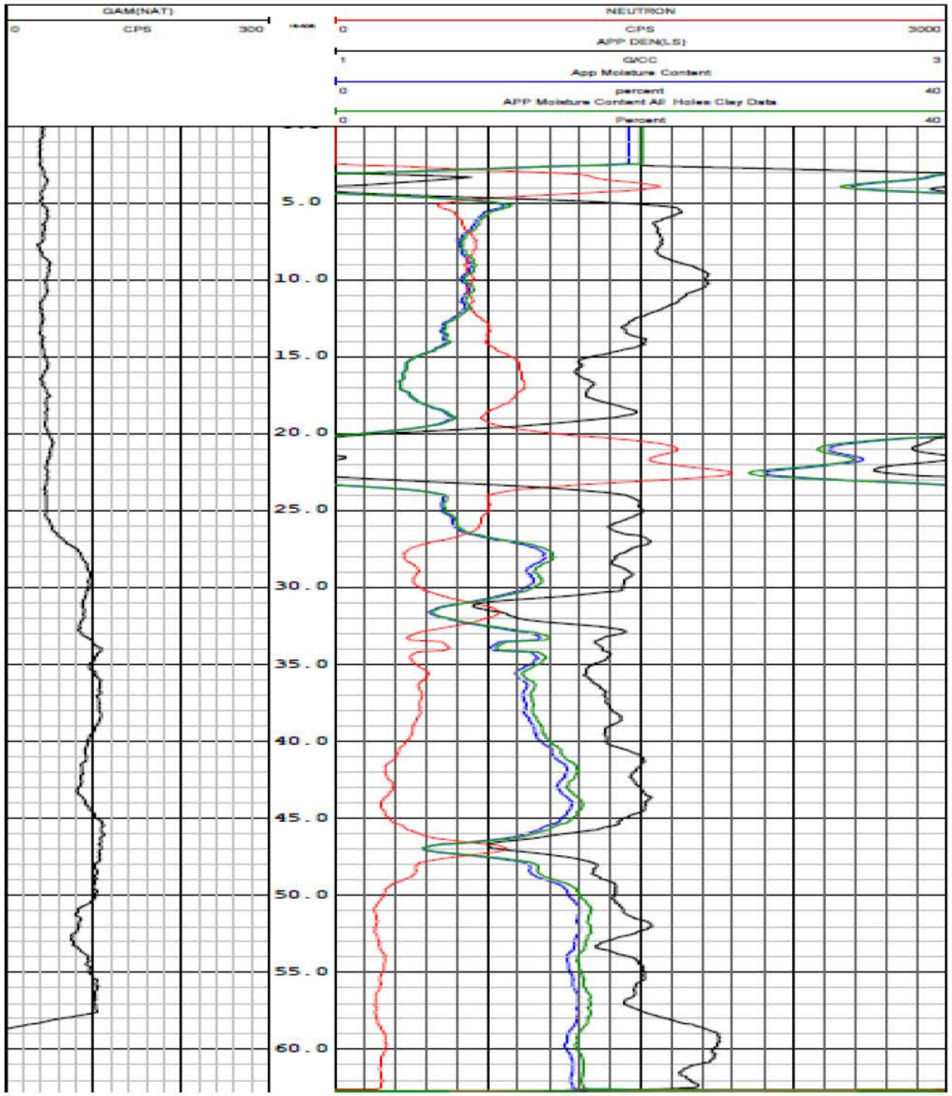
Neutron and Density Log for Bridge Settlement Investigation–Moisture/Density of Soils and Fill



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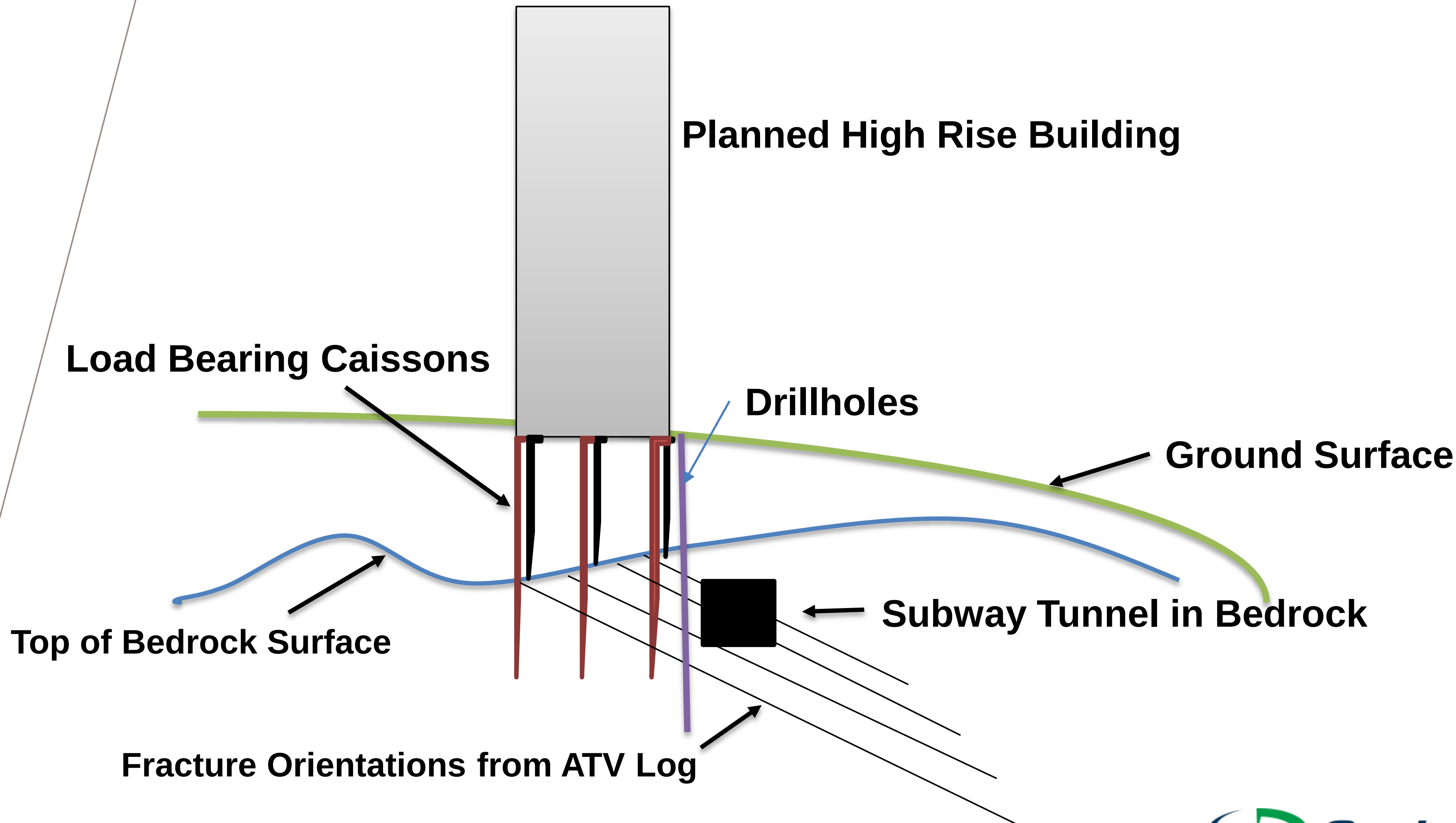
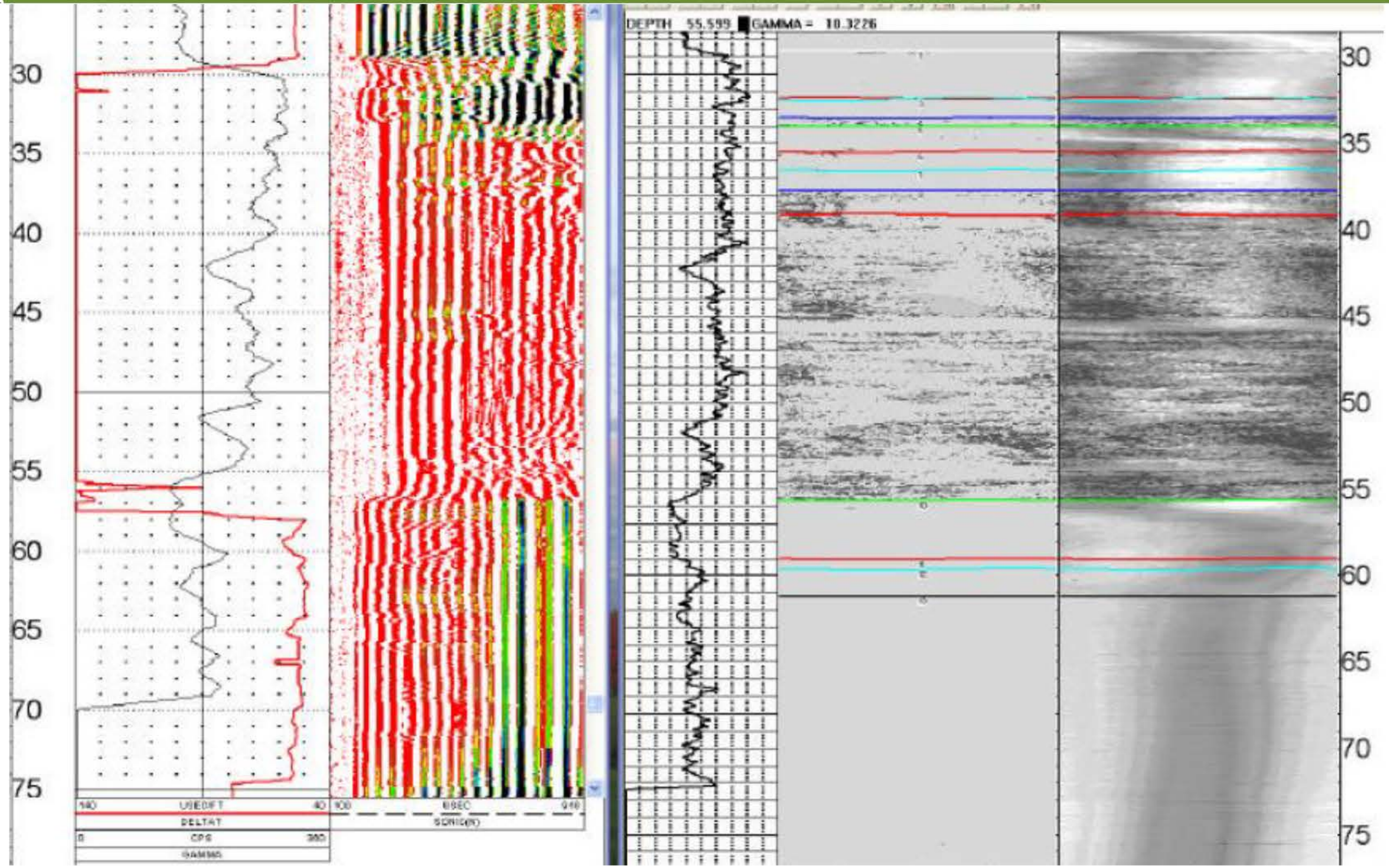
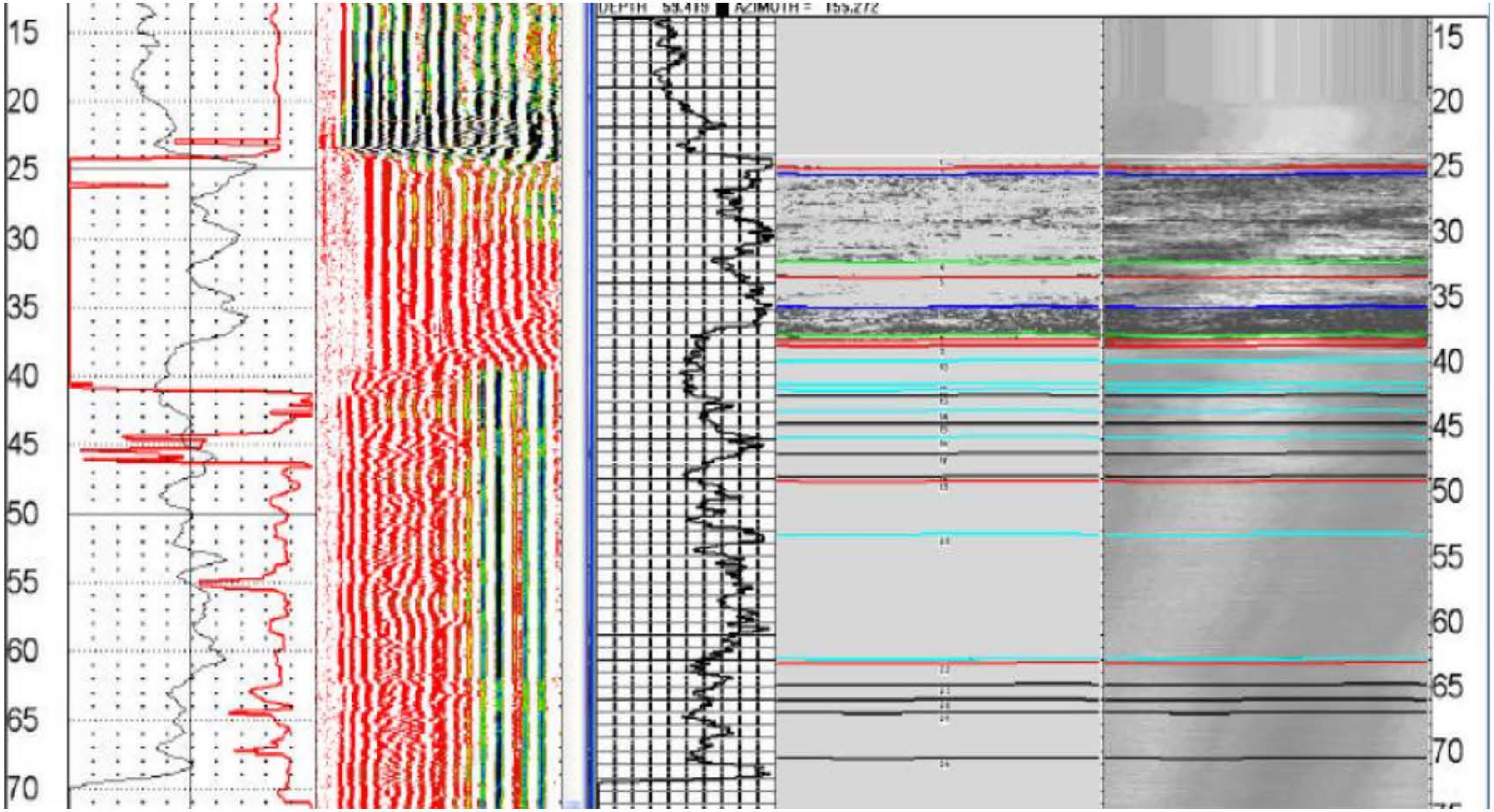
Sonic and Acoustic Televiewer Logs for High Rise Foundation Study Adjacent to Metro Subway Tunnel



Sonic and Acoustic Televiewer Logs for High Rise Foundation Study Adjacent to Metro Subway Tunnel



Sonic and Acoustic Televiewer Logs for High Rise Foundation Study Adjacent to Metro Subway Tunnel



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Cardno Borehole Geophysical Logging – Case Study Washington, DC - Northern Maryland

Multiple deep core borings were drilled and logged to characterize the geotechnical, hydrogeologic and other bedrock characteristics at several sites for deep tunneling.

Determine geotechnical conditions and physical properties of the rock mass
Cardno collected a suite of geophysical logs that included acoustic televiewer, density, neutron, caliper, full wave sonic, normal resistivity, temperature, fluid conductivity, and borehole deviation. These parameters allow identification of fractures and orientations (joint sets and preferred groundwater flow paths), rock strength indices, elastic modulus, zones of groundwater movement and other physical characteristics of the metamorphic rocks.

The work took place in congested urban and security sensitive areas with multiple Government agencies, other consultants, and contractors involved in the projects

Cardno staff have extensive training, and are proficient in cooperating with multiple contractors and agencies, and meeting the multiple challenges associated with working in this type environment.

Utilization of large amounts of data to characterize the sites

Cardno assisted site project managers with data interpretations: presentation of the geophysical data was done in various graphic formats to enhance the utilization of the data in understanding site geology and geotechnical and hydrogeologic characteristics.

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Cardno Borehole Geophysical Logging – Case Study Superfund Site - Ground Water Contaminants

The Chemtronics Superfund site is a 1,027-acre parcel located in Swannanoa, North Carolina. Ground water contaminants include volatile organic compounds, semi-volatile organic compounds and heavy metals. Cardno has logged more than 50 bedrock wells at this site from 200 to 500 feet deep over several years of drilling and site evaluation.

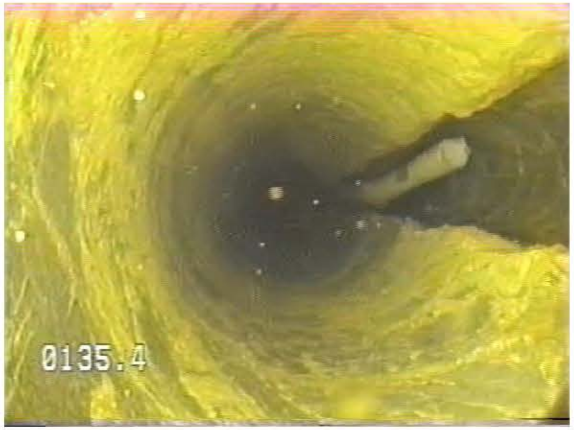
Determine hydrogeologic conditions and groundwater flow paths

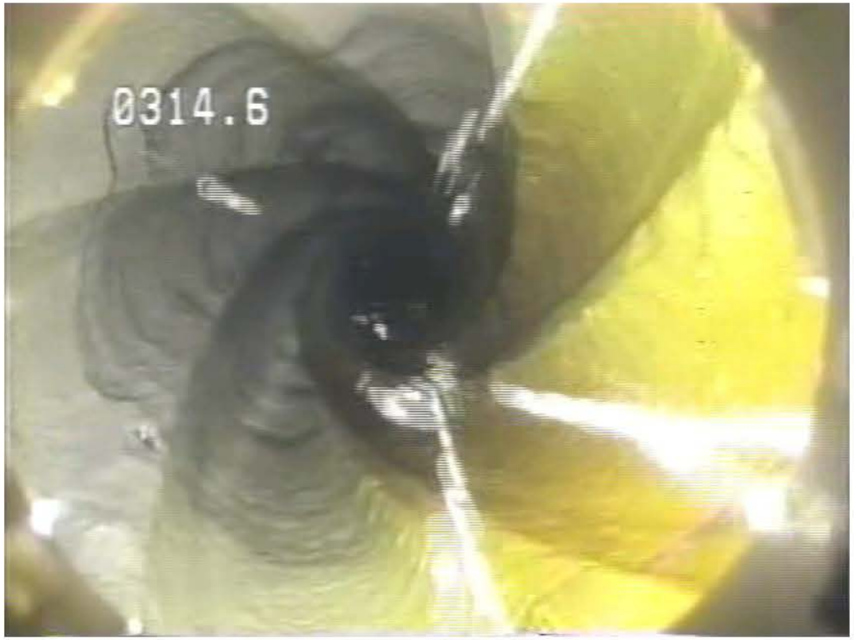
Cardno collected a suite of geophysical logs that included acoustic televiewer, flowmeter, caliper, sonic, resistivity, borehole video, temperature, fluid conductivity, and borehole deviation. These parameters allow identification of fractures orientations (preferred groundwater flow paths), zones of groundwater movement, vertical gradients and other characteristics of the complex metamorphic geology and fractured rock aquifer.

Utilization of large amounts of data to characterize the site

Cardno assisted the project managers with data interpretations: presentation of the geophysical data was done in various graphic formats to enhance the utilization of the data in understanding the complex setting.

Cardno Downhole Video Cameras





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ELECTRICAL RESISTIVITY METHOD FOR KARST FEATURE INVESTIGATION

Junfeng Zhu, PhD, Water Resources Section, Kentucky Geological Survey, Junfeng.zhu@uky.edu

Speaker Bio: Dr. Junfeng Zhu received his B.S. and M.S. degrees in Hydrogeology from Nanjing University, China and his PhD degree in Hydrology from University of Arizona. He is a senior hydrogeologist with Kentucky Geological Survey, University of Kentucky. He is also an adjunct faculty member in the Department of Earth and Environmental Sciences, University of Kentucky. His research focuses on groundwater dynamics, hydrogeophysics, karst hydrology, and remote sensing.

Presentation Abstract: The electrical resistivity method is a common geophysical technique widely used in investigating geological features in the shallow subsurface. This method detects variations of electrical resistivity of earth materials through applying electric currents to the subsurface and measuring electric potentials on or below the ground. In this lecture, I will first introduce the basic principles of the method with a focus on clarification of common misconceptions and briefly present the procedures of conducting surface electrical resistivity surveys in the field. Then, I will spend the majority of this lecture to give examples on applying the method in studying water-related environmental issues in Kentucky, including investigating groundwater sources for public water supplies, monitoring soil moisture changes in agriculture fields, and understanding movements of contaminants in karst environment.

Electrical Resistivity Method for Karst Feature Investigation

Dr. Junfeng Zhu
Kentucky Geological Survey
Email: junfeng.zhu@uky.edu
Phone: (859)323-0530

Ohm's Law:

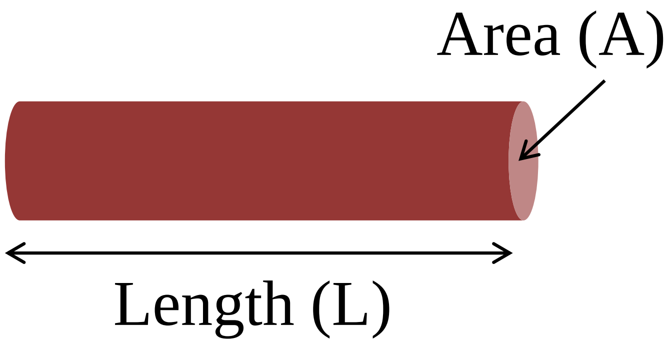
$$R = \frac{V}{I}$$

V: voltage (Volts)

I: current (Amperes)

R: resistance (Ohms)

Resistivity vs Resistance:



$$R = \rho \frac{L}{A}$$

ρ: resistivity (Ohm-m)

intrinsic property of materials

Resistivity Ranges of Common Materials

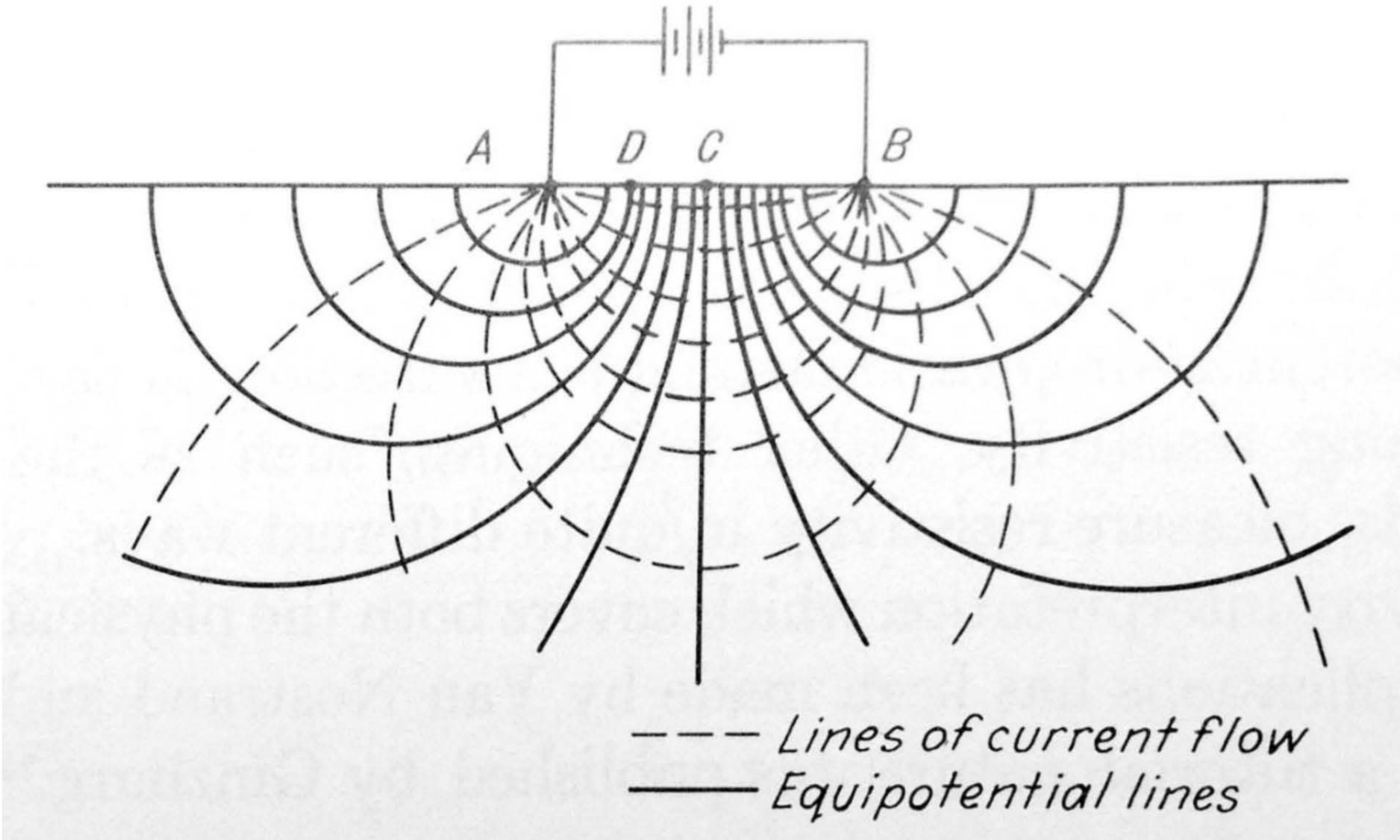
Rock/material type:	Resistivity range (Ωm):
Air	Infinite
Igneous	100 – 1,000,000
Limestone	100 – 10,000
Sandstone	100 – 10,000
Gravel	100 – 10,000
Sand	1 – 1,000
Clay	1 – 100
Soil	1 – 10,000
Ground water	0.5 – 300
Sea water	0.2
Copper (native)	0.0000002

(Modified from AGI and http://galitzin.mines.edu/)

Resistivity of soil and rock is affected by:

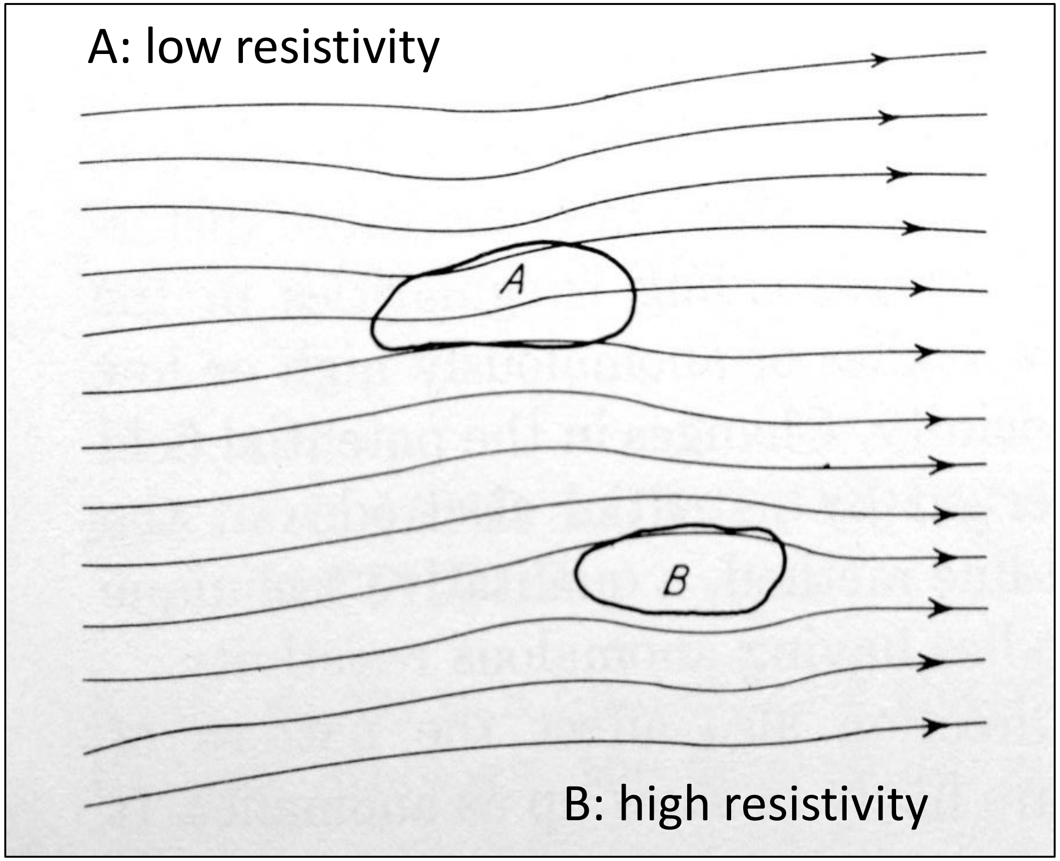
1) Water content, **a dominant factor** (resistivity decreases with increasing water content)
2) Dissolved electrolytes
3) Porosity
4) Temperature of pore water (resistivity decreases with increasing temperature)
5) Resistivity of minerals

Electrical Current in the Subsurface



(Dobrin, 1976)

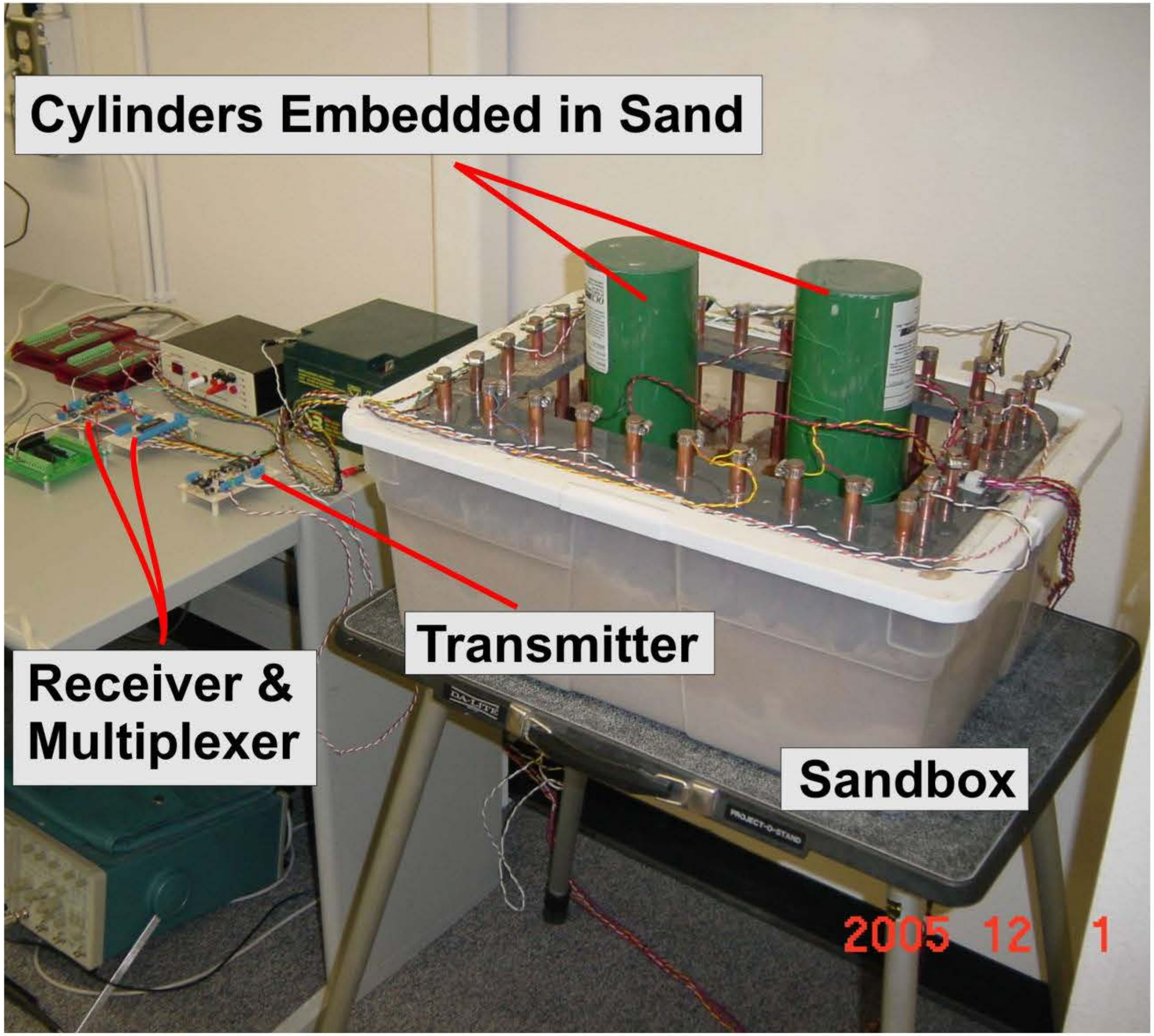
Electrical Current in the Subsurface



(Dobrin, 1976)

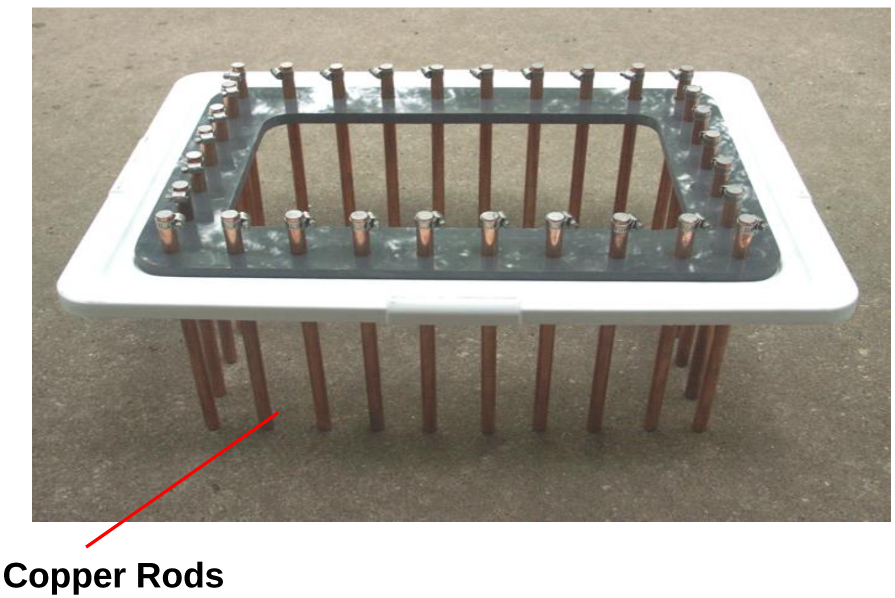
- Electrical resistivity describes how well a material resists the flow of electrical current.

A Sandbox Experiment

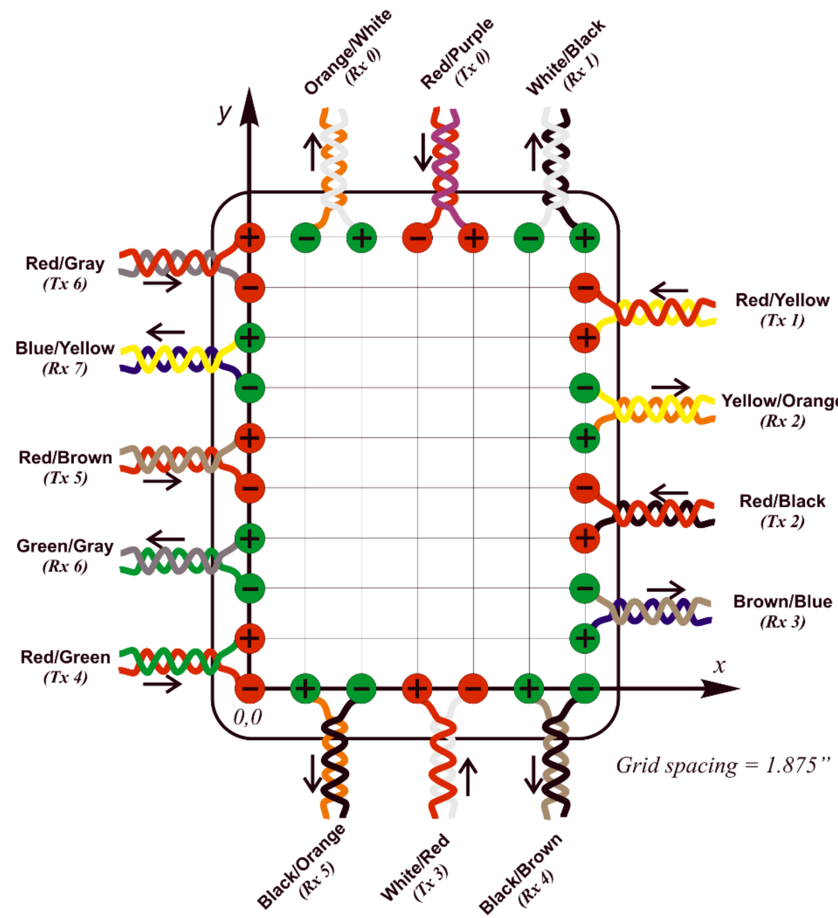


A. Kruger, W. Ilman, S. Yang (University of Iowa), T.-C. Jim Yeh and J. Zhu

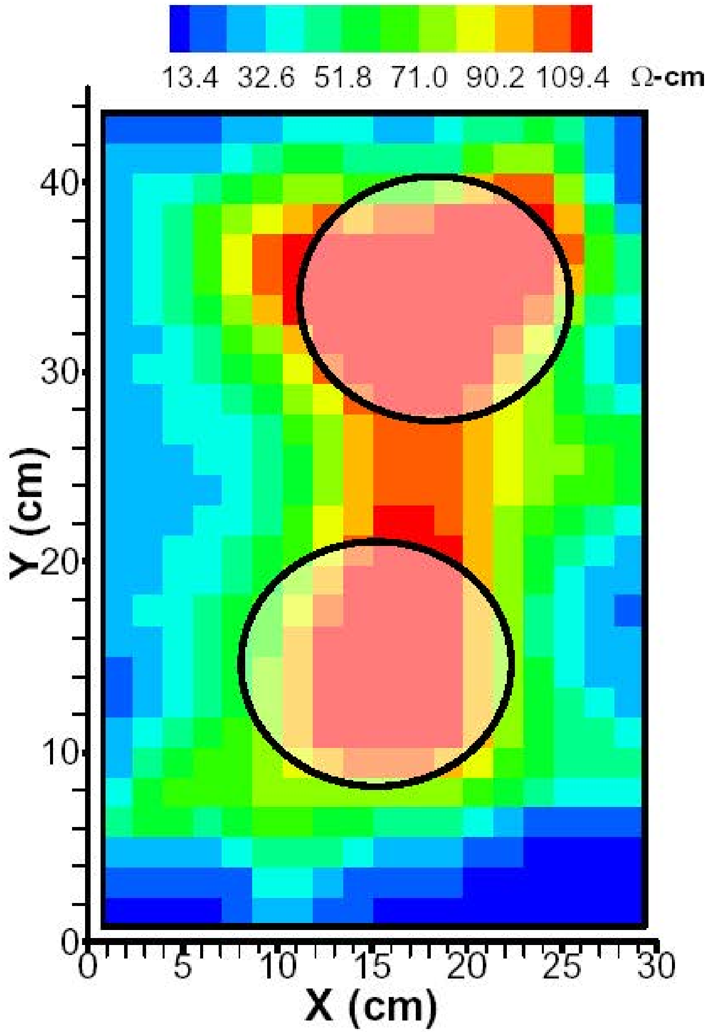
Electrodes

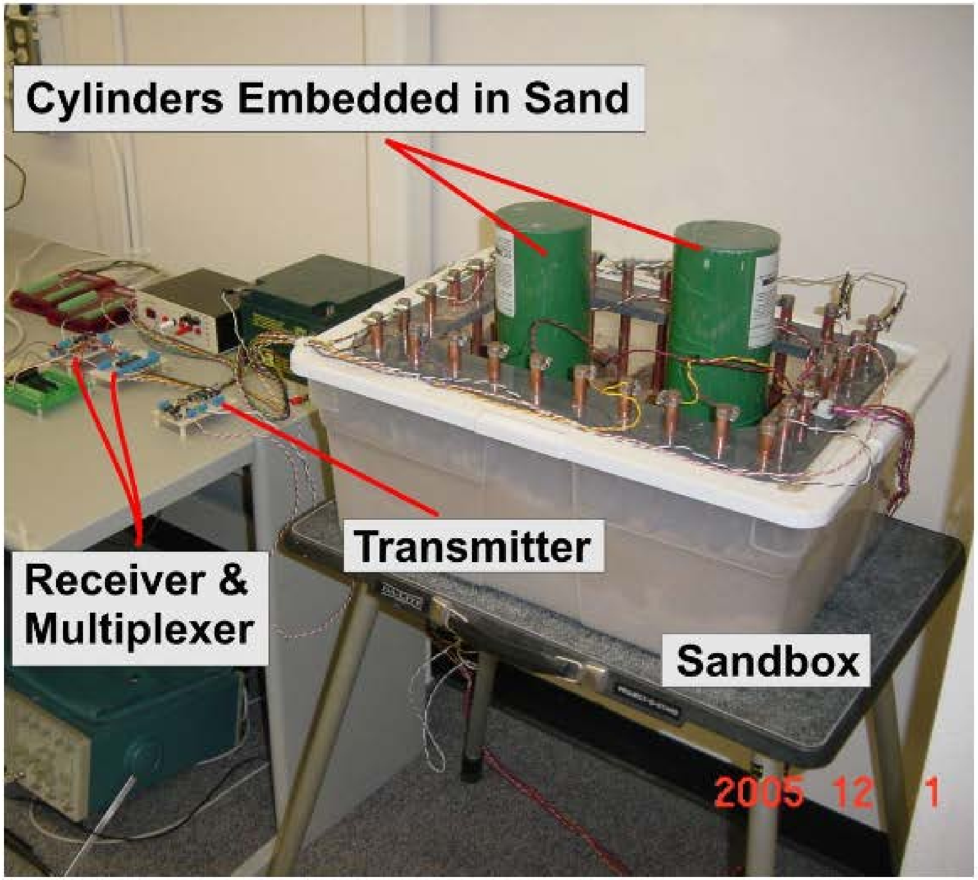


Diagram

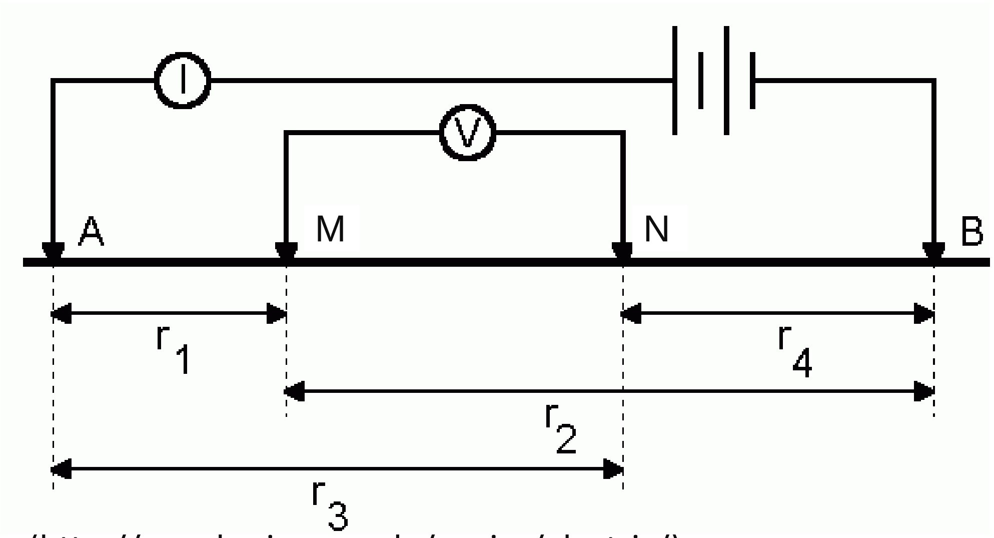


Estimated Resistivity: Mysterious Objects





Apparent Resistivity

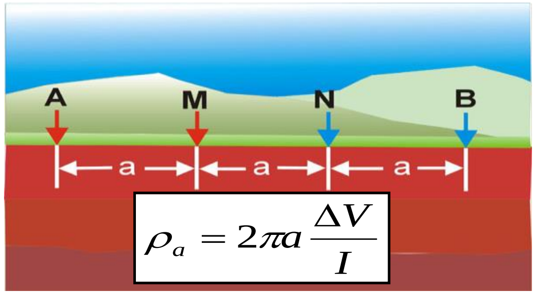


(http://geophysics.ou.edu/enviro/electric/)

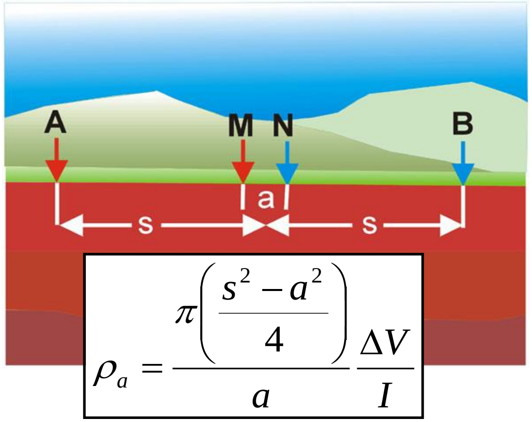
$$\rho_a = \frac{2\pi V}{I} \frac{1}{\left(\frac{1}{r_1} - \frac{1}{r_2} - \frac{1}{r_3} - \frac{1}{r_4}\right)}$$

Apparent resistivity can be seen as a weighted average of the different resistivities in the subsurface affecting the readings. If the subsurface is homogeneous the apparent resistivity equals the true resistivity. In reality, the subsurface is always inhomogeneous.

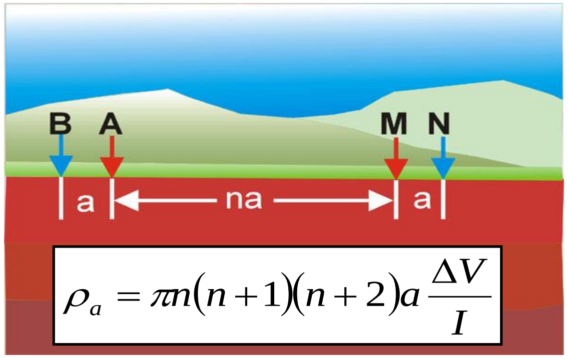
Resistivity & Induced Polarization



Wenner, highest signal to noise ratio, excellent vertical resolution but poor later resolution, unable to take advantage of multi-channels (only a single channel is used).



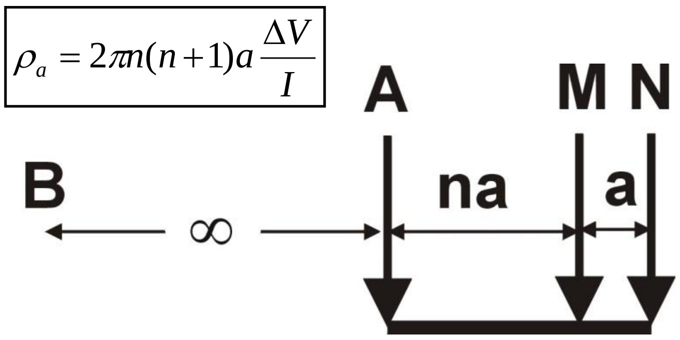
Schlumberger, AB/2 is 5 times more than MN. It is similar to Wenner array. Unable to take advantage of multi-channels (only a single channel is used). Inverse Schlumberger may use up to four channels.



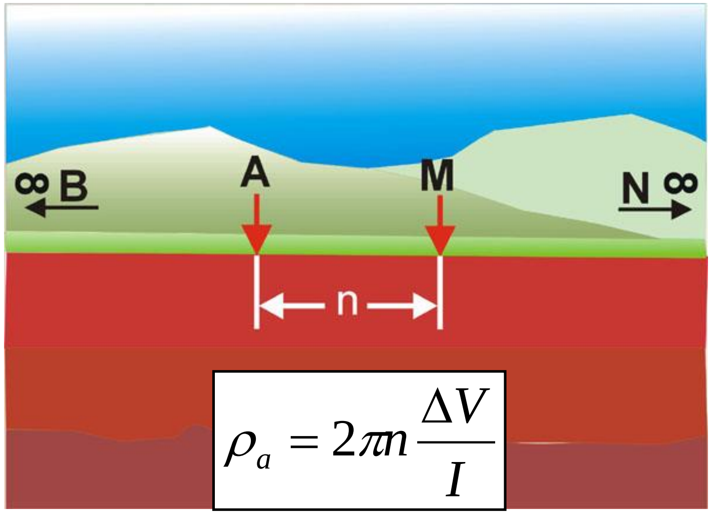
Dipole-dipole, best resolution but poor signal to noise ratio. The best way to ensure an acceptable signal to noise ratio is to maintain n <= 8. This array is excellent for multi-channel instruments.

Courtesy of Advanced Geosciences, Inc.

Resistivity & Induced Polarization



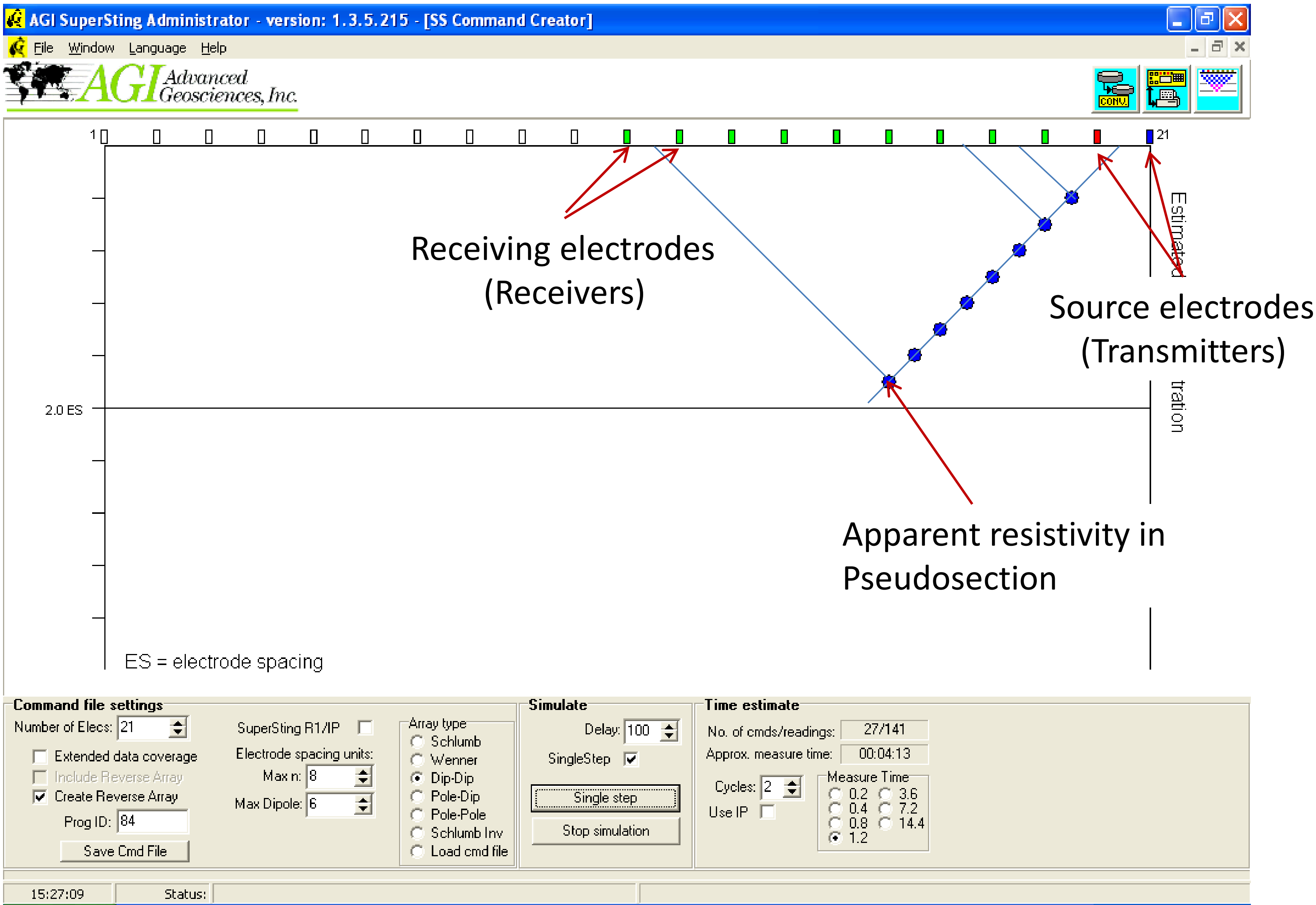
Pole-dipole, AB > (5*AM) for less than 5% error. Stronger signal than that of dipole-dipole, good resolution, but difficult handling of the infinity electrode in the field. The inverted resistivity image may be asymmetric.



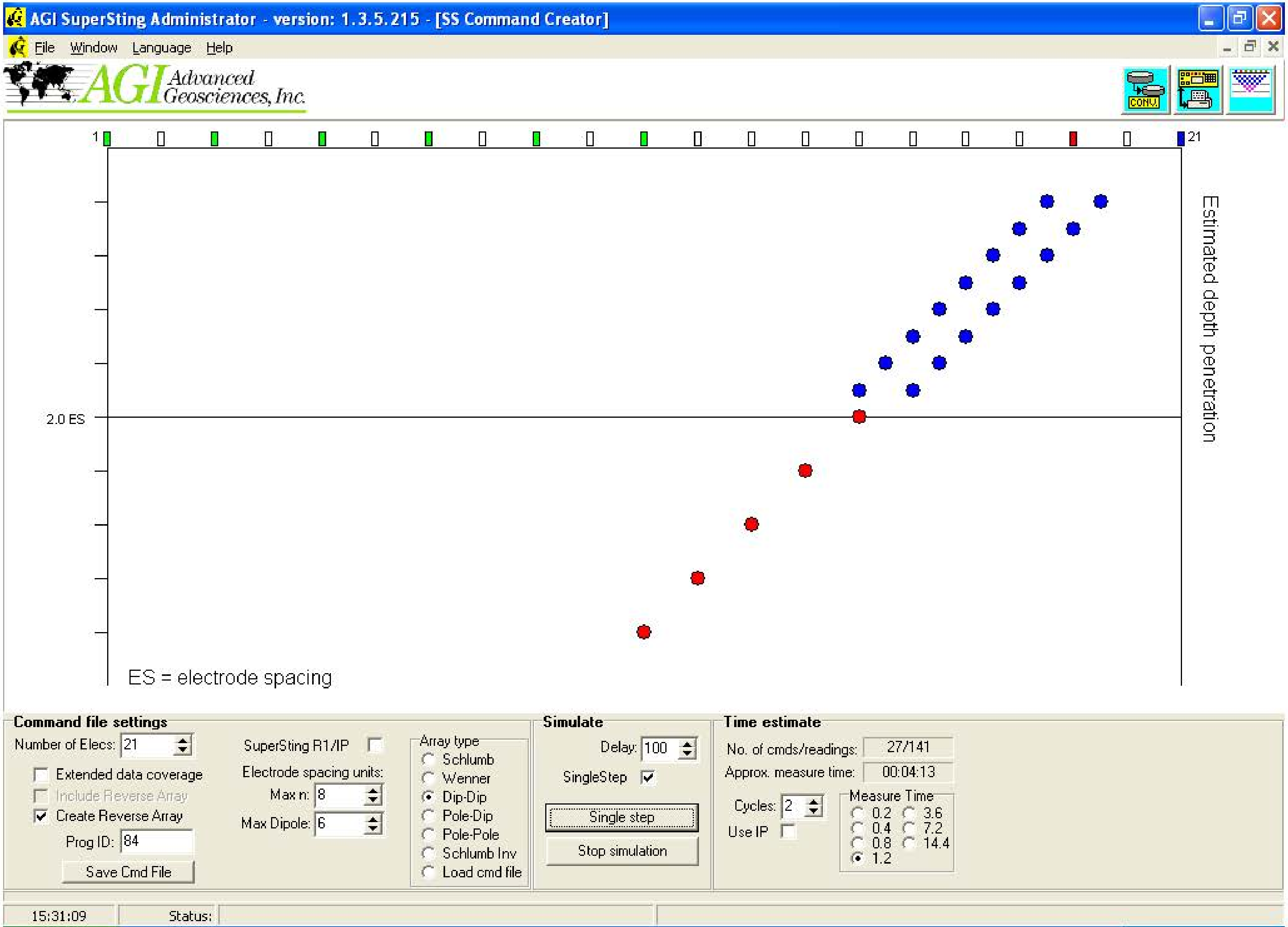
Pole-pole, AB > (20*AM) and MN > (20*AM) for less than 5% error. Very strong signal, good resolution, but difficult handling of two infinity electrodes. A large MN may pick up plenty of cultural, SP and telluric noise.

Courtesy of Advanced Geosciences, Inc.

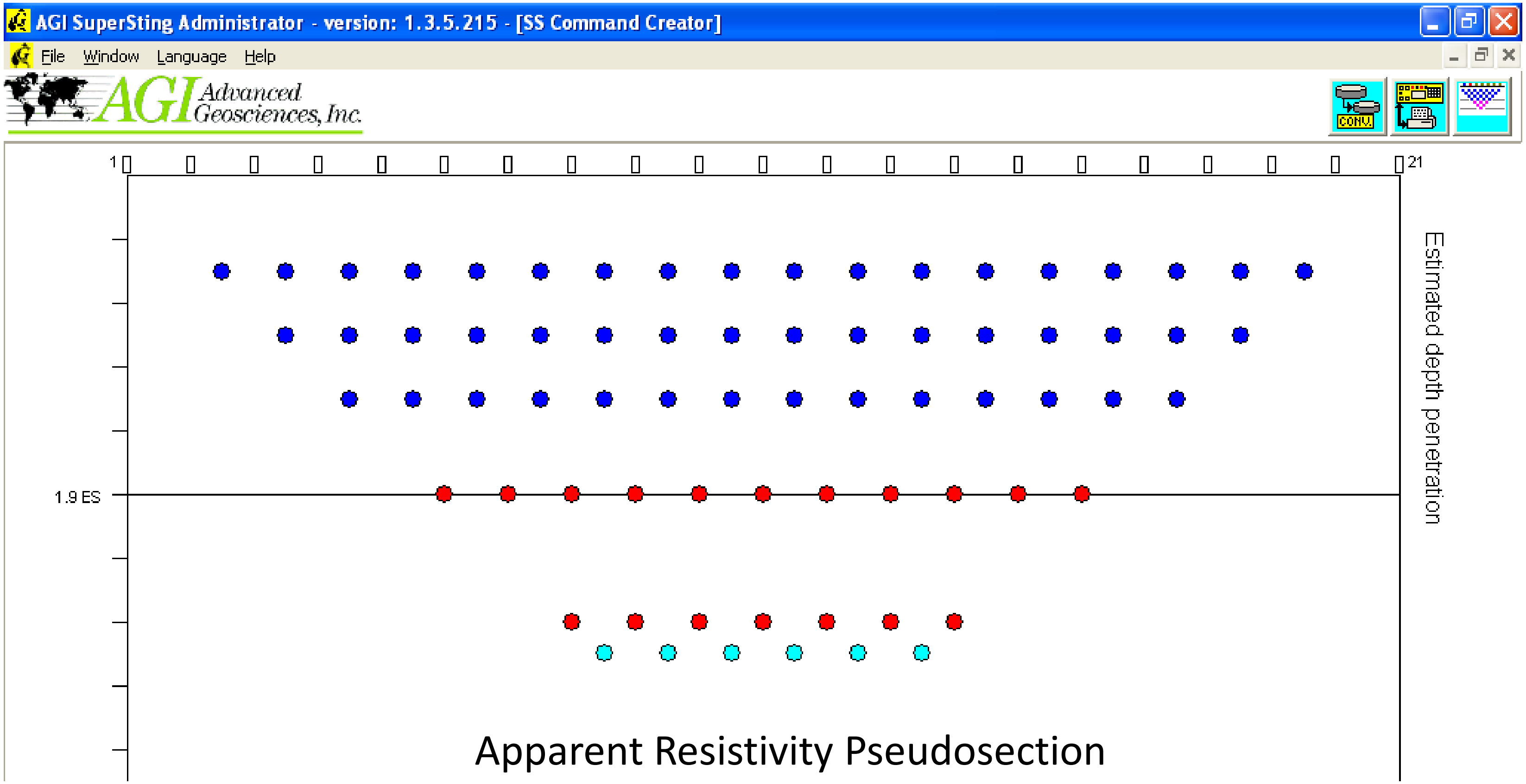
ER Data Collection Scheme &Display



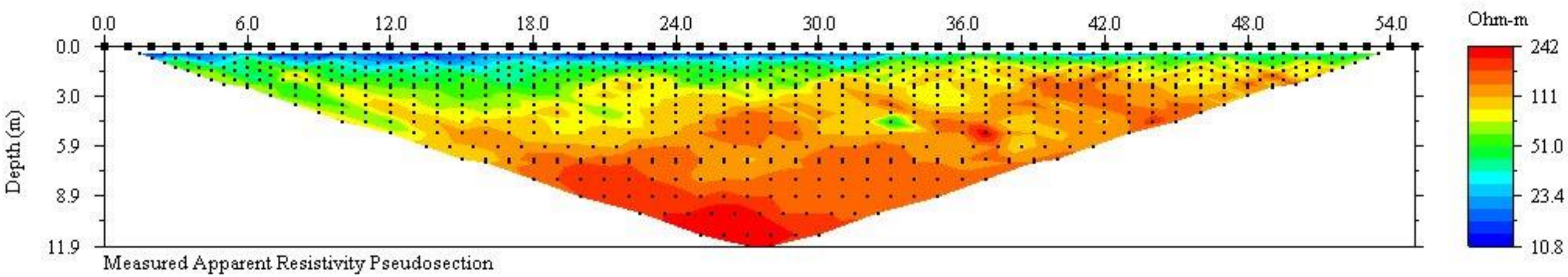
ER Data Collection Scheme &Display



ER Data Collection Scheme &Display

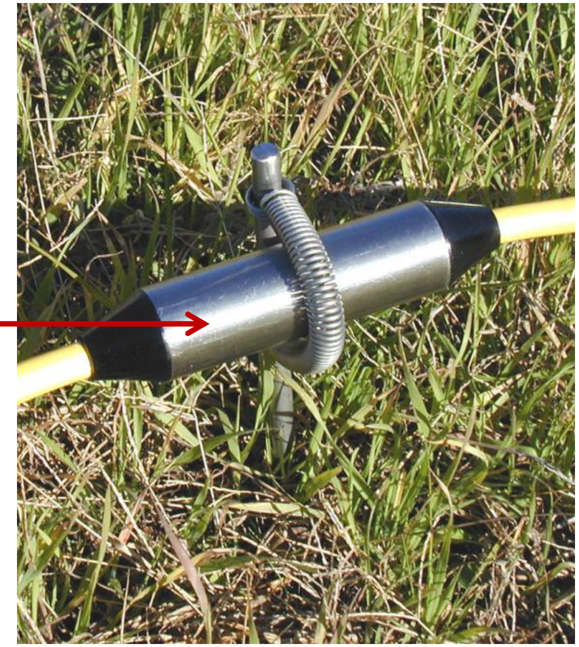


Apparent Resistivity Pseudosection



AGI SuperSting 8-channel Resistivity and IP Meter

Electrode



Switch B

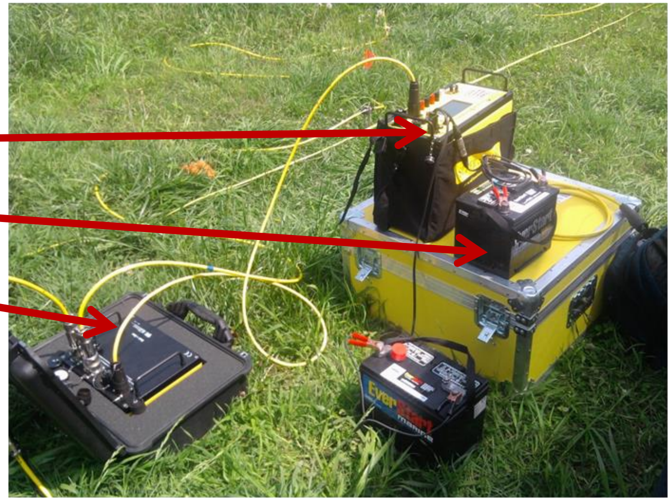
l Stake

Electrical Resistivity (ER) Field Survey

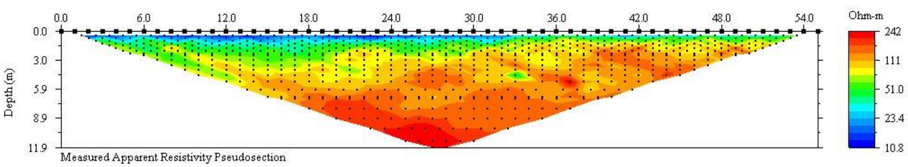
ER Meter

Battery

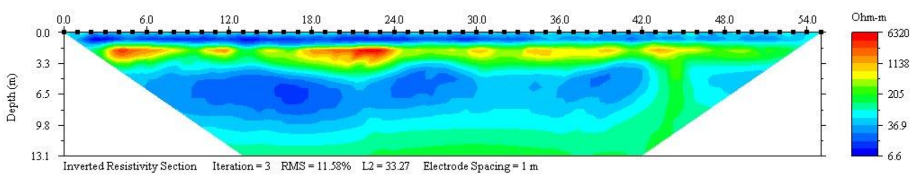
Switch Box



Cable layout



Measured Apparent Resistivity



Inverted Resistivity

Electrode & cable

Time for a survey:

	28 Electrodes			56 Electrodes			84 Electrodes		
Array	**# of points**	**Time SS R1**	**Time SS R8**	**# of points**	**Time SS R1**	**Time SS R8**	**# of points**	**Time SS R1**	**Time SS R8**
Wenner	117	18 min	18 min	495	1.3 hr	1.3 hr	1134	3.0 hr	3.0 hr
Schlumberger, inv.	171	27 min	9 min	842	2.2 hr	37 min	1068	2.8 hr	48 min
Dipole-dipole	237	37 min	7 min	762	2.0 hr	26 min	1453	3.8 hr	57 min
Pole-pole	378	59 min	9 min	1540	4.0 hr	34 min	3486	9.1 hr	1.2 hr

- Calculated using 1.2 sec. measurement time and two stacks at each station

Courtesy of Advanced Geosciences, Inc.

ER Data Interpretation

The flow of a DC current through the earth can be described by the following partial differential equation,

$$\frac{\partial}{\partial x}\left(\sigma\frac{\partial V}{\partial x}\right)+\frac{\partial}{\partial y}\left(\sigma\frac{\partial V}{\partial y}\right)+\frac{\partial}{\partial z}\left(\sigma\frac{\partial V}{\partial z}\right)=I(x,y,z),$$

where V is the scalar electrical potential, σ is electrical conductivity (1/ σ is electrical resistivity), and I(x,y,z) is the electric current source term.

ER Data Interpretation

Assuming resistivity is constant in y direction, the above equation can be Fourier-transformed into a 2D equation to reduce computing time,

$$\frac{\partial}{\partial x}\left(\sigma\frac{\partial V}{\partial x}\right)+\frac{\partial}{\partial z}\left(\sigma\frac{\partial V}{\partial z}\right)-k^2\sigma V=-I\cdot\delta(x)\cdot\delta(z),$$

Where *k* is the wave number in the transform domain

ER Data Interpretation

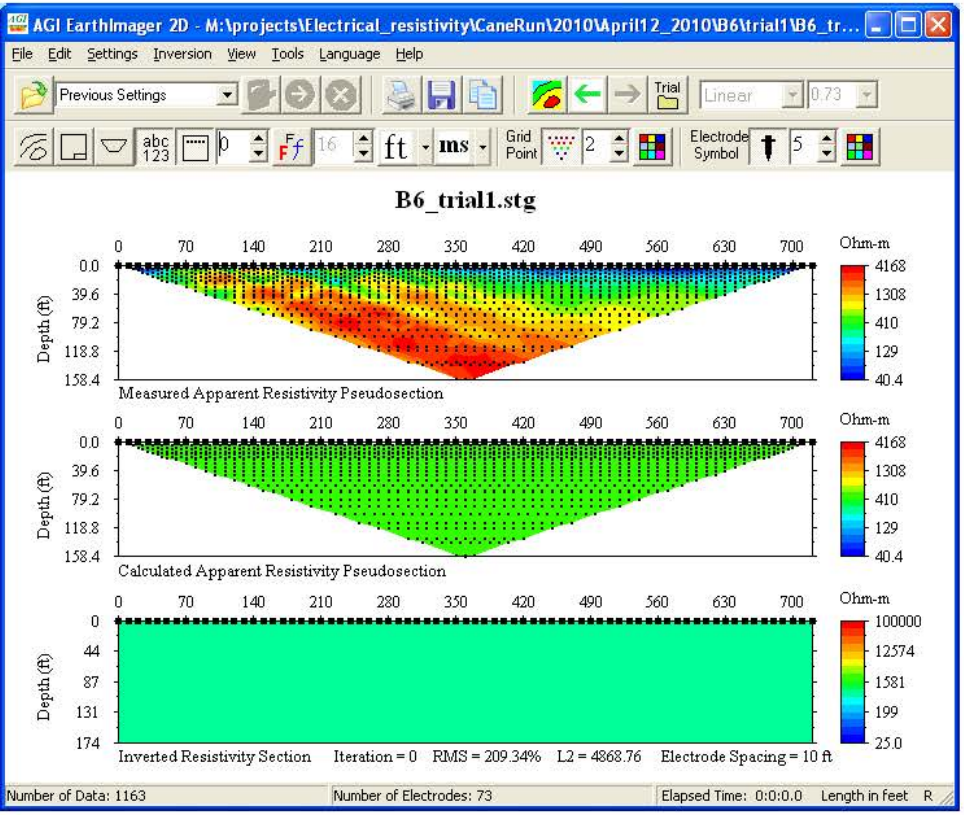
The process is called **data inversion**.

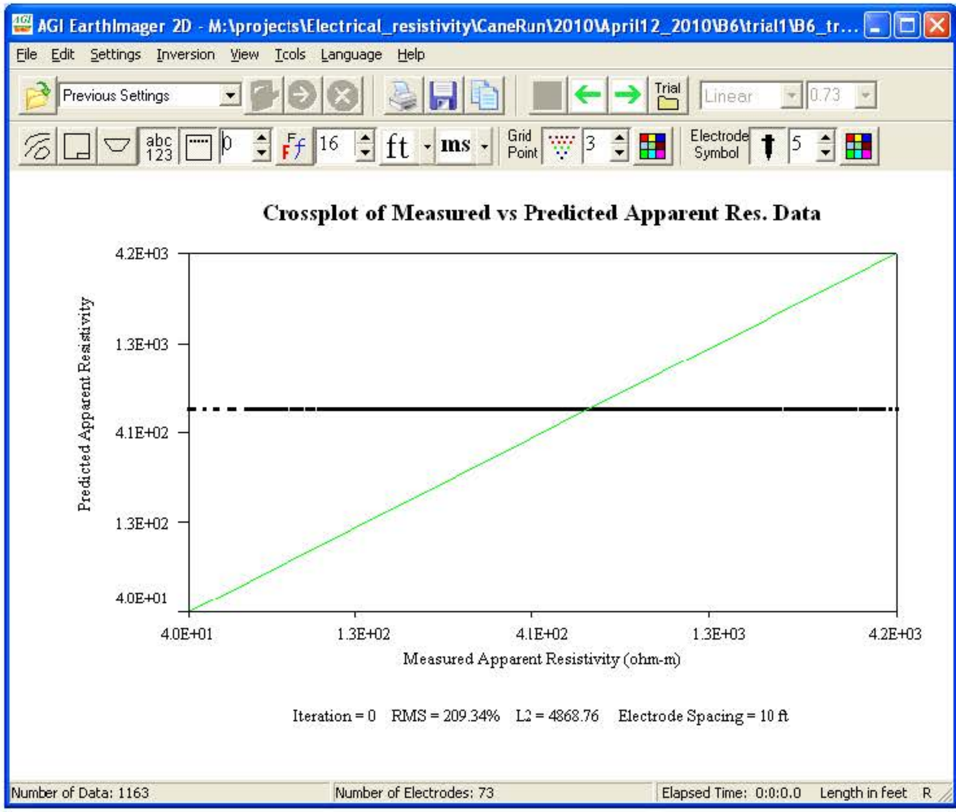
An inversion process minimizes the difference between observed data and calculated data. The process usually consists of :

1. Given an initial guess of the ER field, run forward model (i.e. the partial differential equation) to get the calculated data.
2. Compare calculated data to observed data. If the difference doesn't satisfy predefined stop criteria, the ER field will be changed. Then go back to step 1.

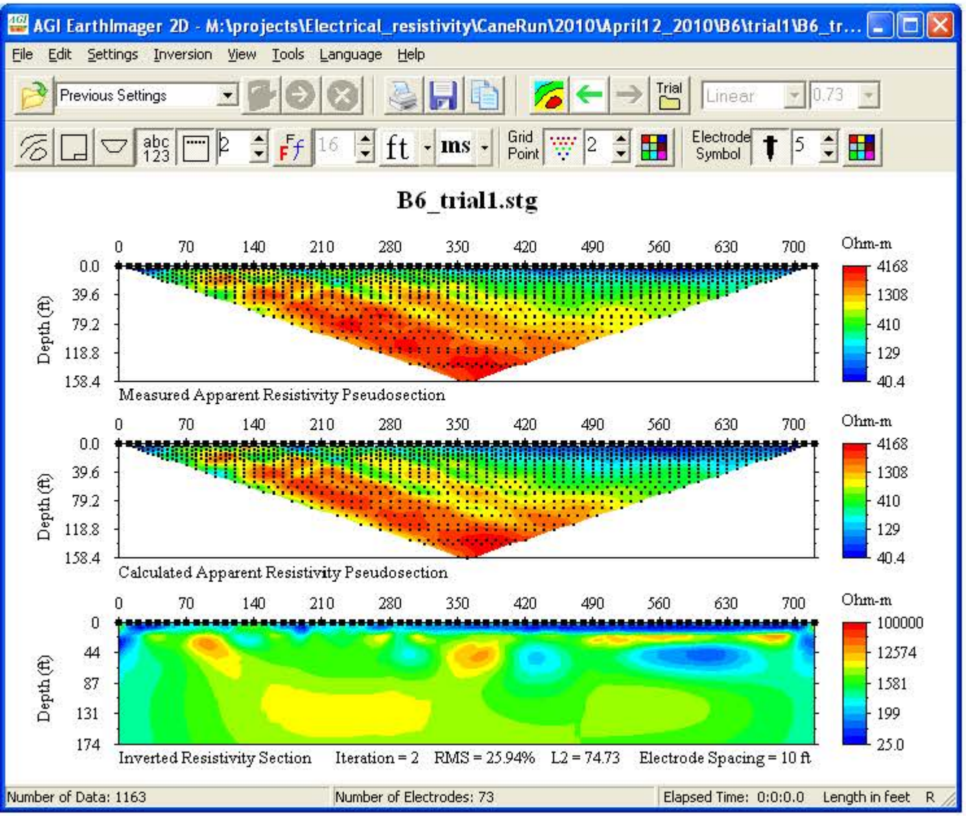
Steps 1 and 2 are an iterative process. The process will stop when the criteria are satisfied.

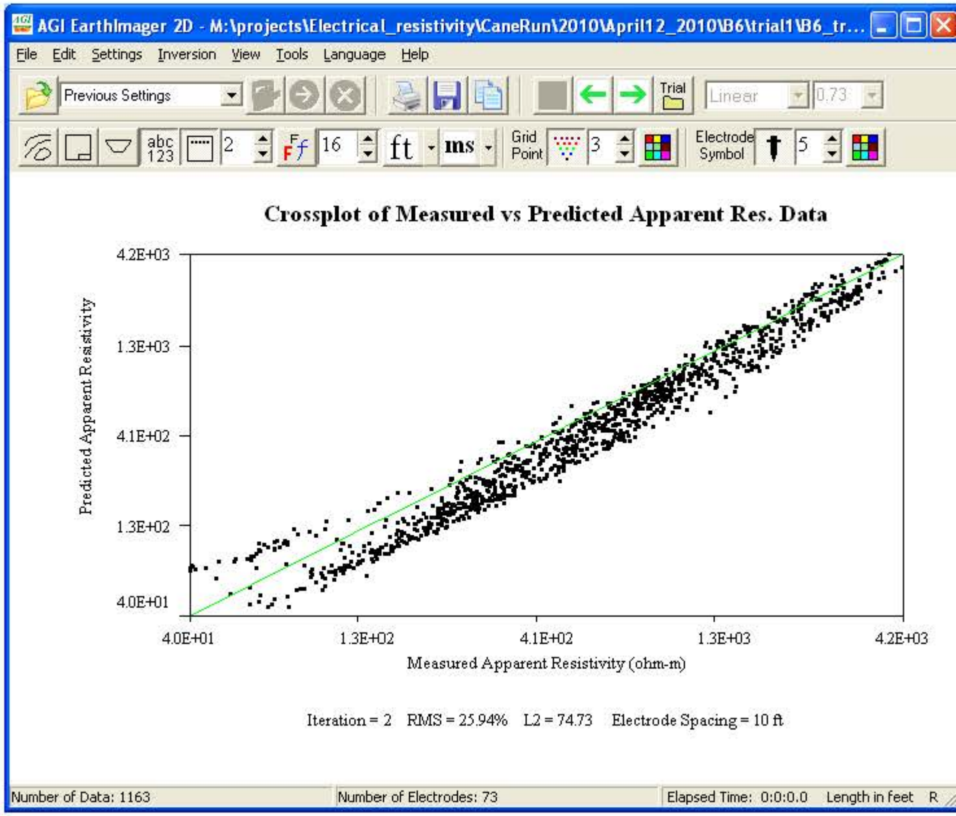
ER Data Interpretation



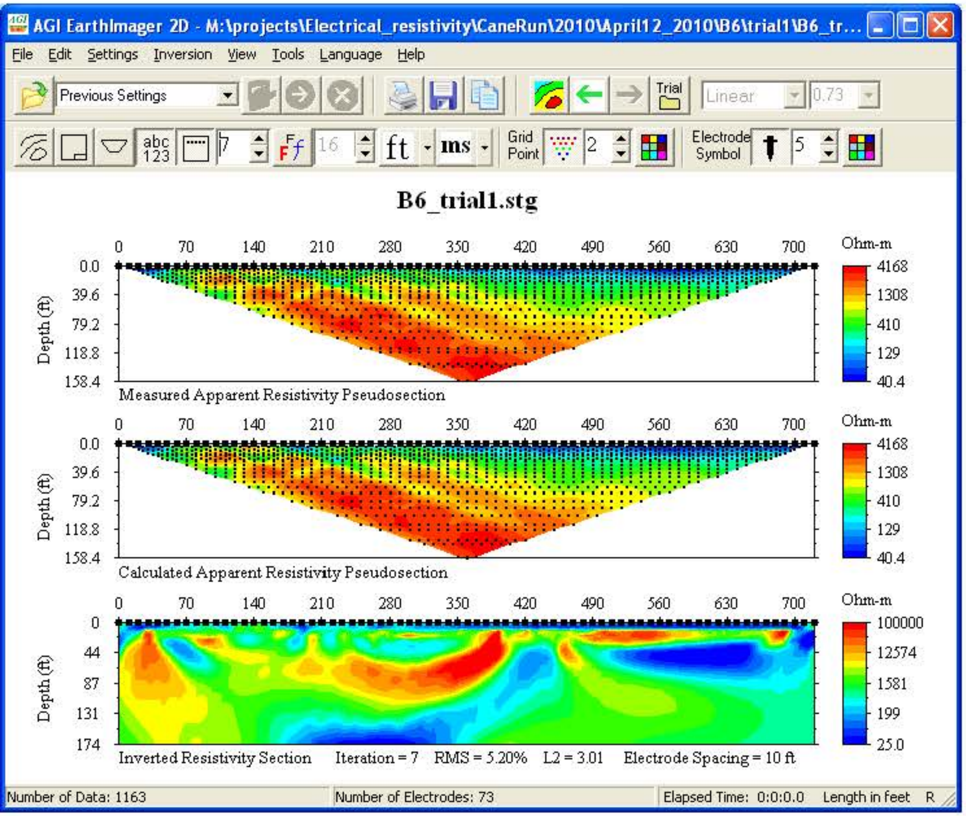


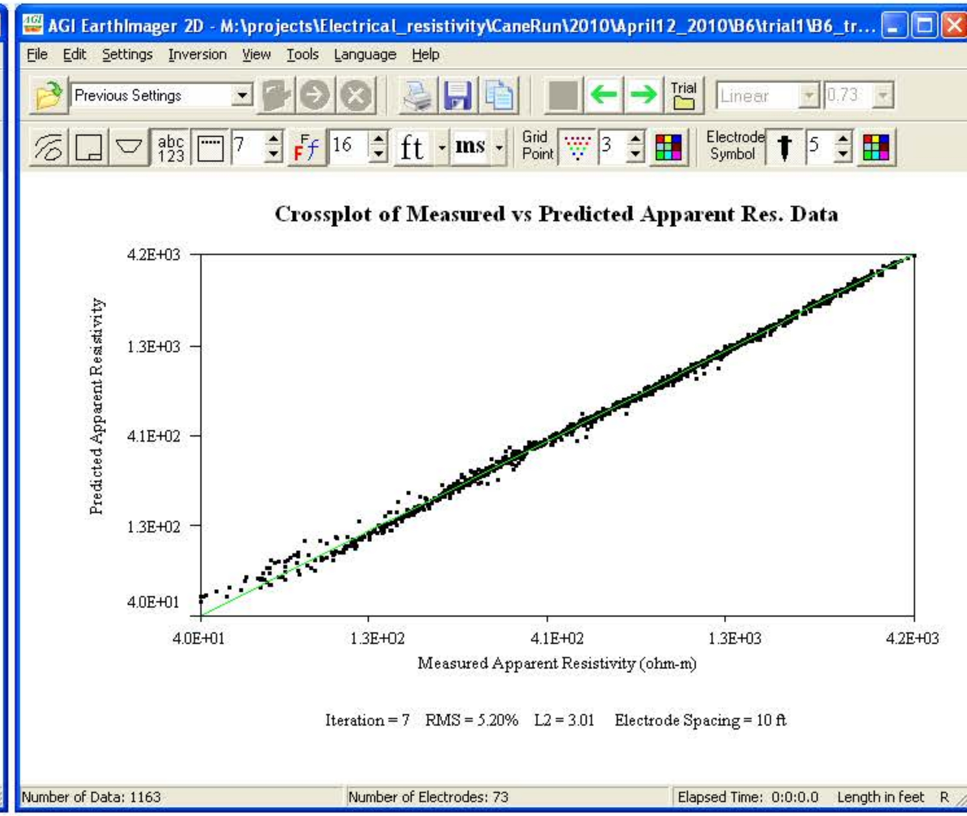
ER Data Interpretation

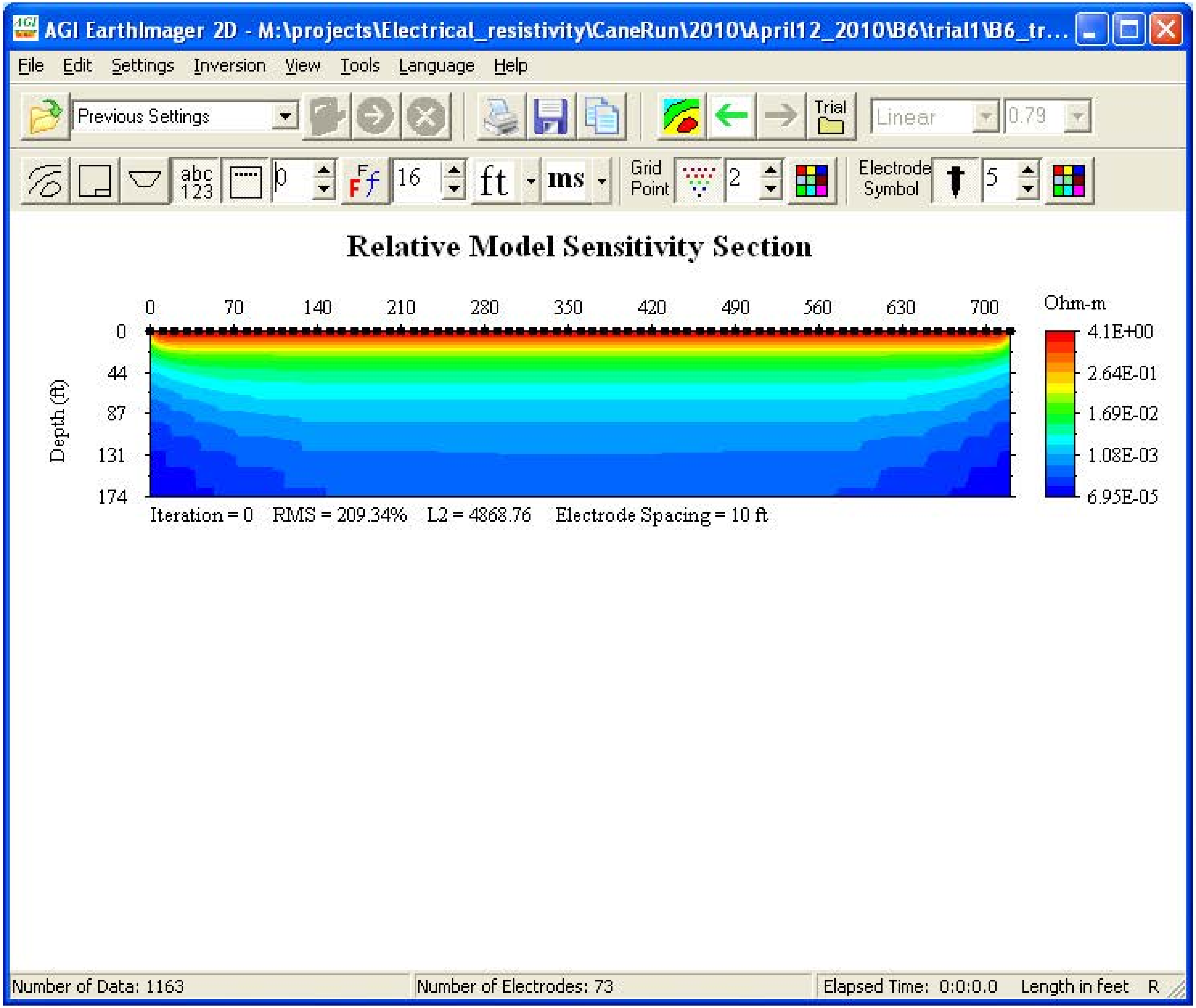




ER Data Interpretation



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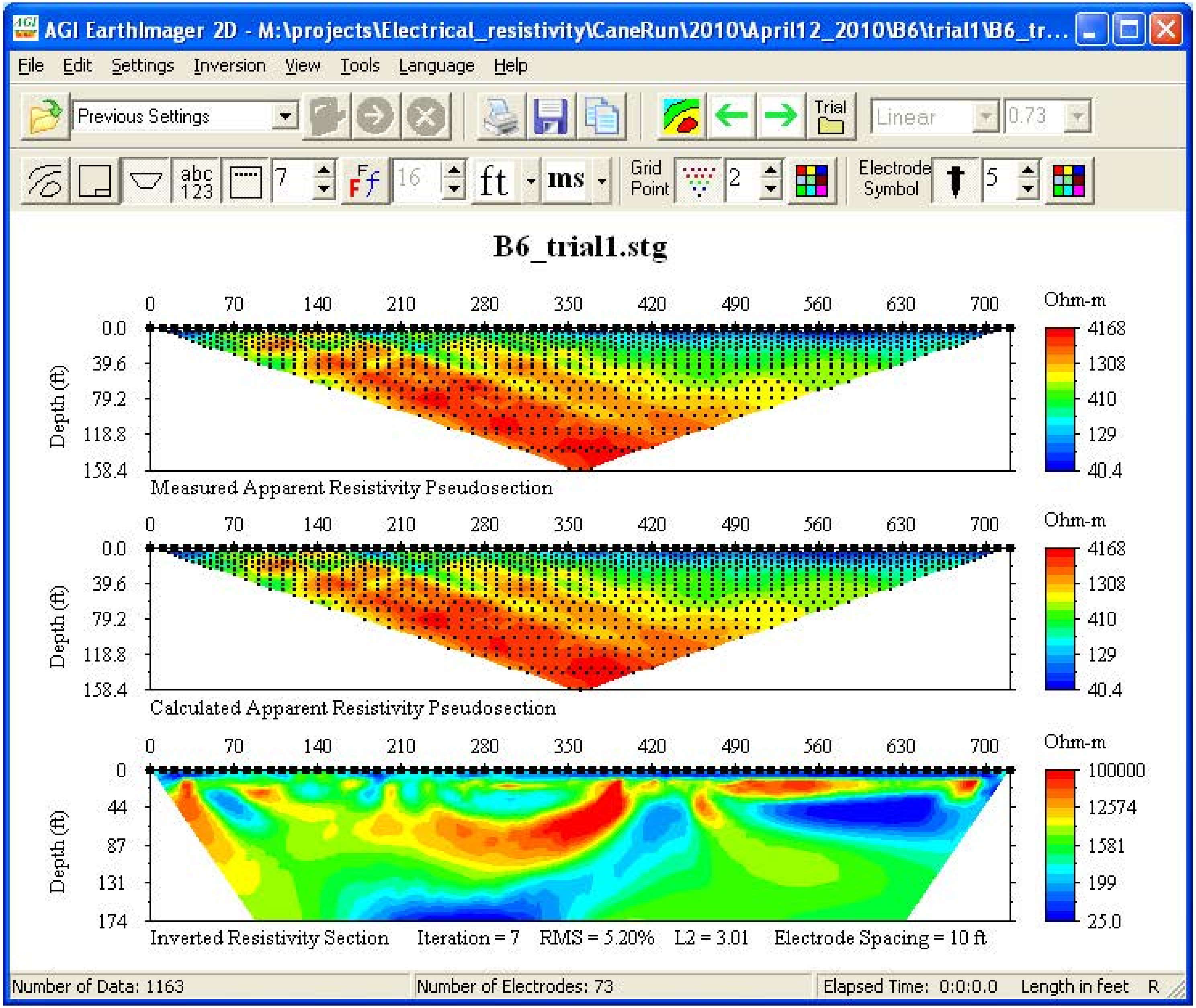
Previous Settings
Trial
Linear
0.79
16
ft
ms
Grid Point
2
Electrode Symbol
5
Relative Model Sensitivity Section
0 70 140 210 280 350 420 490 560 630 700
Depth (ft)
0 44 87 131 174
Ohm-m
4.1E+00
2.64E-01
1.69E-02
1.08E-03
6.95E-05
Iteration = 0 RMS = 209.34% L2 = 4868.76 Electrode Spacing = 10 ft
Number of Data: 1163
Number of Electrodes: 73
Elapsed Time: 0:0:0.0
Length in feet
R


AGI EarthImager 2D - M:\projects\Electrical_resistivity\CaneRun\2010\April12_2010\B6\trial1\B6_tr...
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Previous Settings
Trial
Linear
0.73
abc 123
7
16
ft
ms
Grid Point
2
Electrode Symbol
5
B6_trial1.stg
0 70 140 210 280 350 420 490 560 630 700
Ohm-m
0.0 39.6 79.2 118.8 158.4
Depth (ft)
4168 1308 410 129 40.4
Measured Apparent Resistivity Pseudosection
0 70 140 210 280 350 420 490 560 630 700
Ohm-m
0.0 39.6 79.2 118.8 158.4
Depth (ft)
4168 1308 410 129 40.4
Calculated Apparent Resistivity Pseudosection
0 70 140 210 280 350 420 490 560 630 700
Ohm-m
0 44 87 131 174
Depth (ft)
100000 12574 1581 199 25.0
Inverted Resistivity Section
Iteration = 7
RMS = 5.20%
L2 = 3.01
Electrode Spacing = 10 ft
Number of Data: 1163
Number of Electrodes: 73
Elapsed Time: 0:0:0.0
Length in feet
R

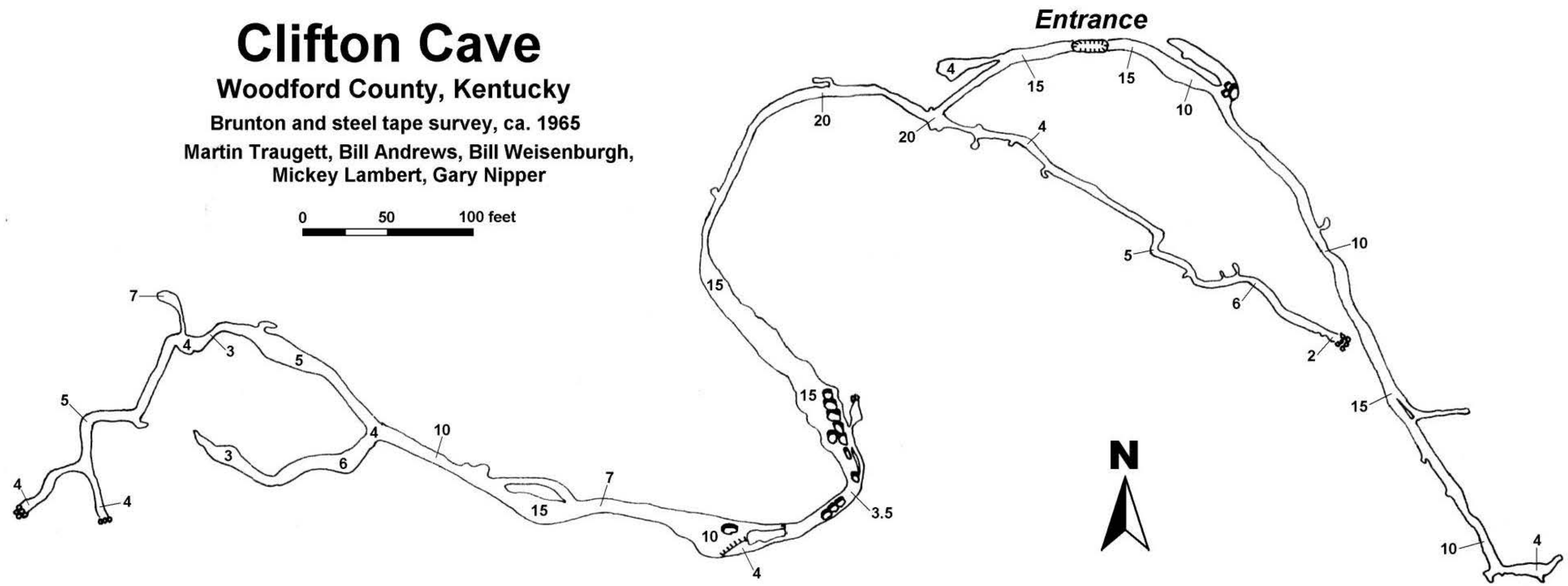
ER Application

- Groundwater exploration
- Cave and tunnel detection
- Bedrock mapping
- Sinkhole investigation
- Dam leakage
- Fracture detection
- Mineral exploration
- Road subsidence investigation
- Active fault delineation

Locate an existing cave

A survey of the cave was made in 1965 by members of the Blue Grass Grotto of Lexington (local chapter of National Speleological Society).

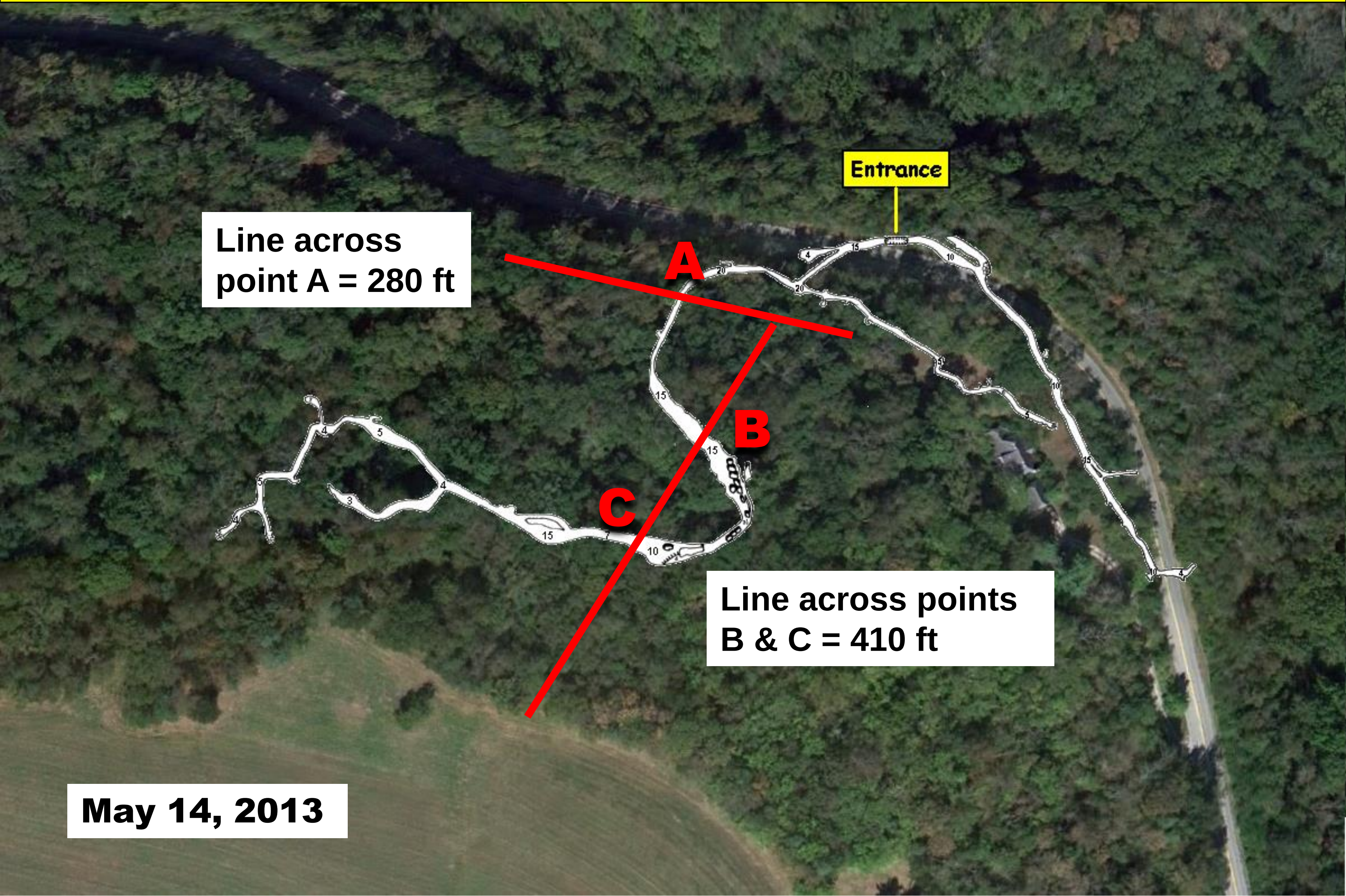
- **Mapped passages totaled about 1,800 feet (550 meters)**



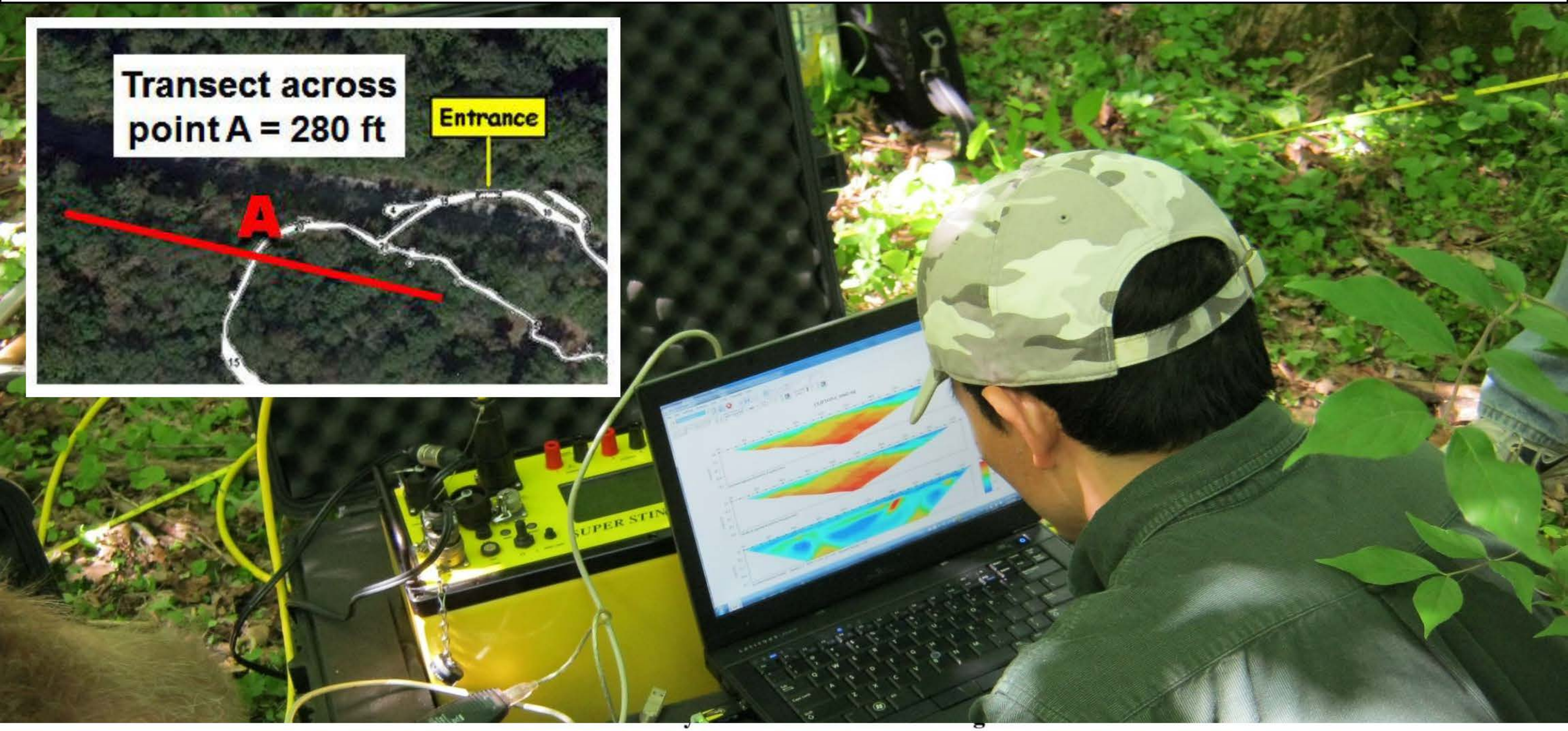
Presenter O'Dell made a single visit to the cave in 1968

Clifton Road today, area near former cave entrance

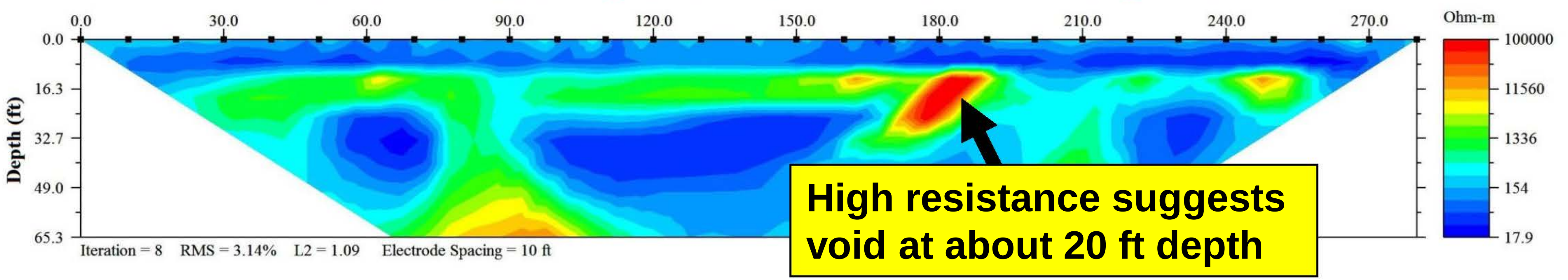
- Georeferenced cave map and GPS used to estimate passage positions
- Resistivity transects made perpendicular to passages



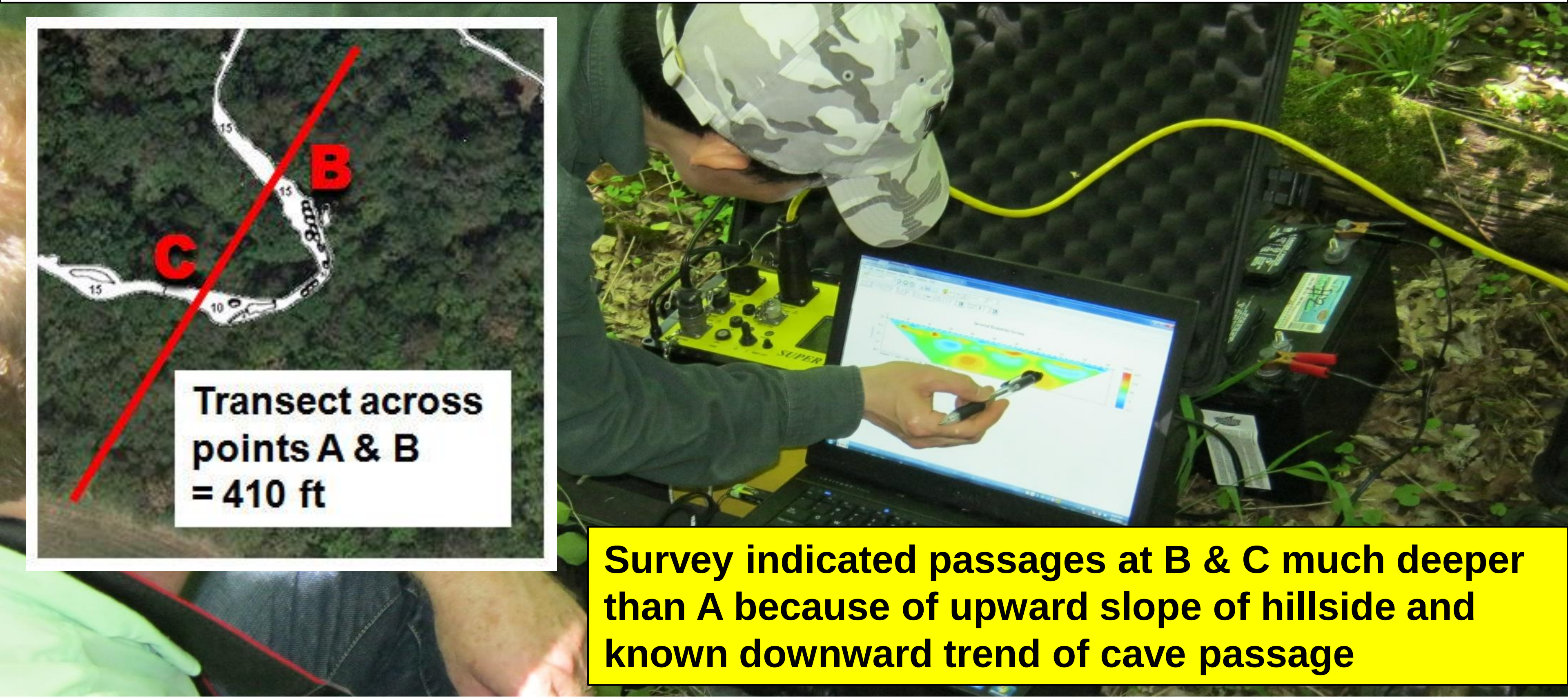
Results for Target A



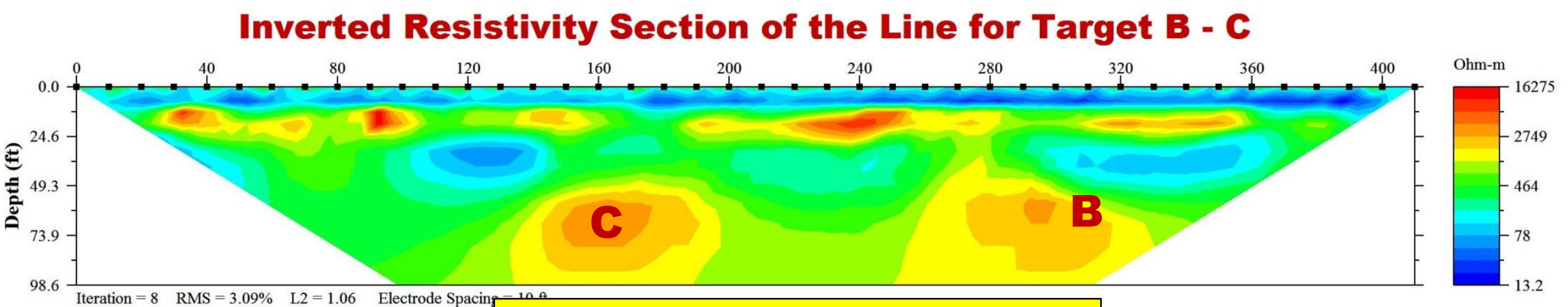
Inverted Resistivity Section of the Line for Target A



Results for Targets B & C



Survey indicated passages at B & C much deeper than A because of upward slope of hillside and known downward trend of cave passage

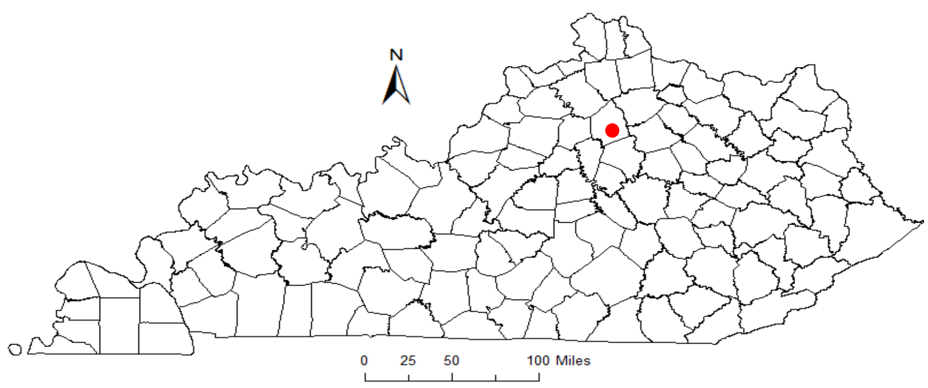


Possible voids at 70 and 60 ft

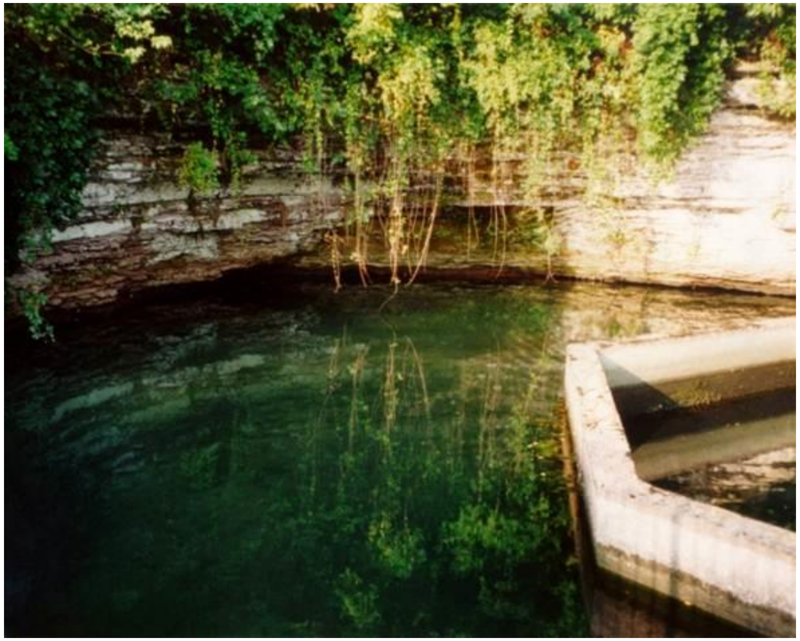
Locate a Karst Conduit

- Royal Spring services as the main drinking water for City of Georgetown, Ky.

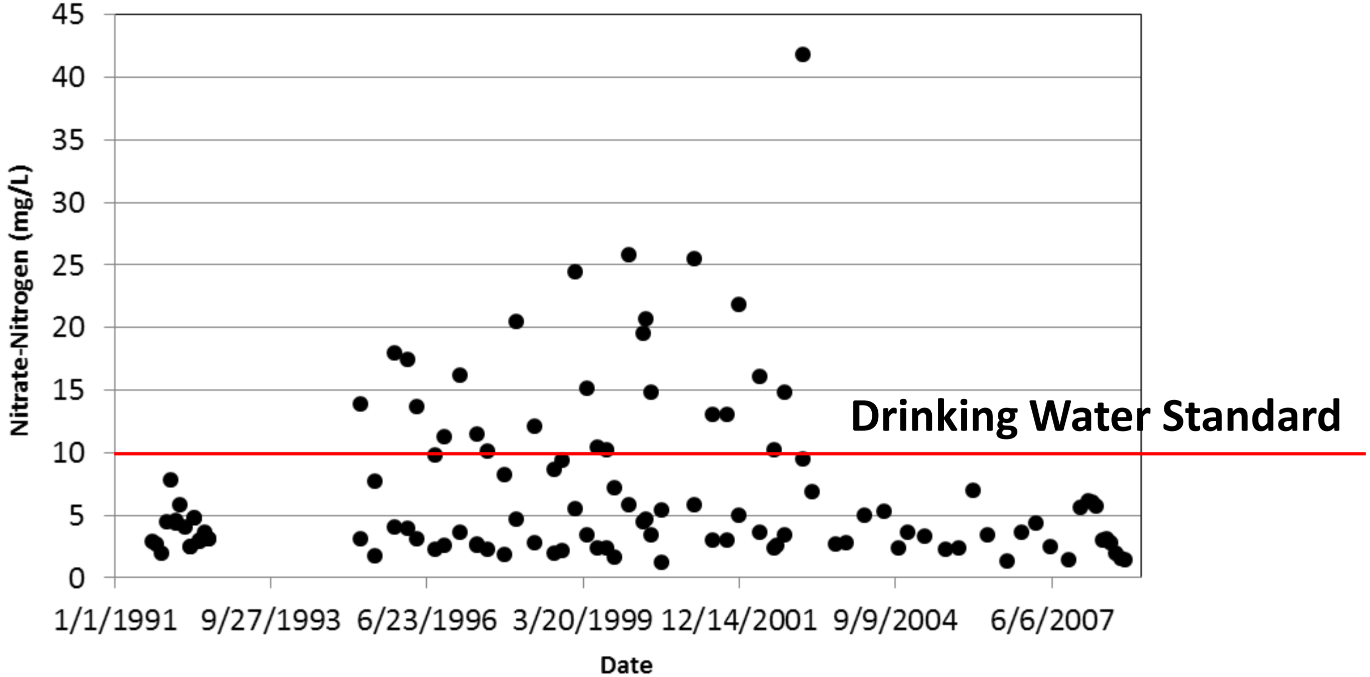
- Water is degraded by pathogens, nutrients, siltation, and organic enrichment.



Royal Spring



Nitrate Concentration in Royal Spring

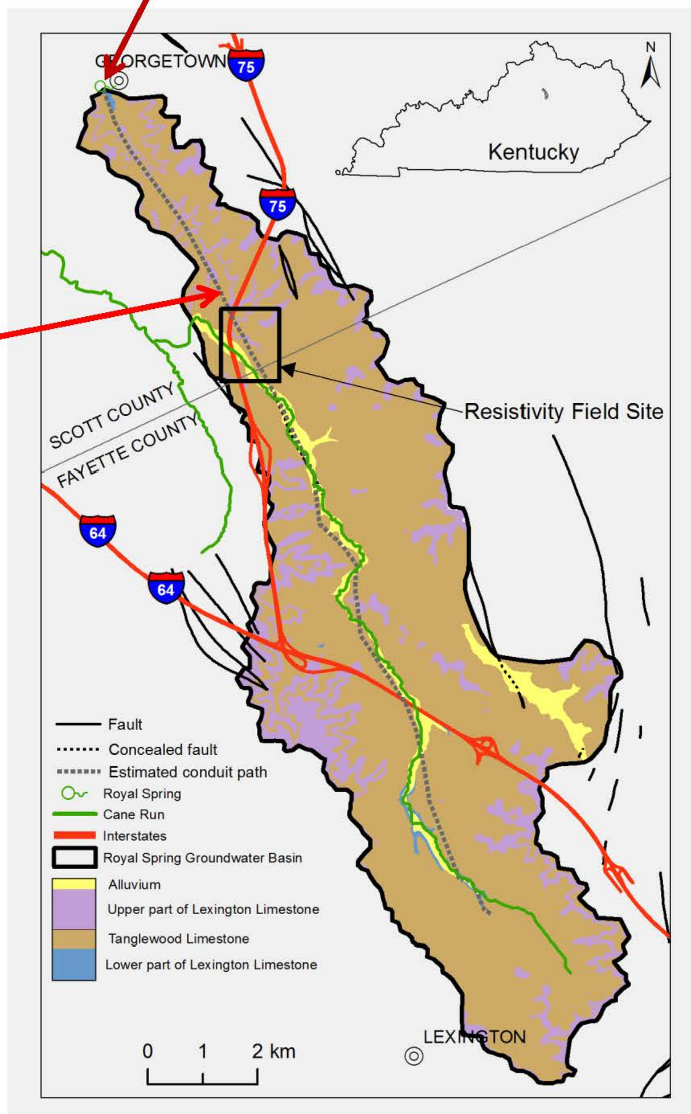


Data source: Kentucky Groundwater Data Repository

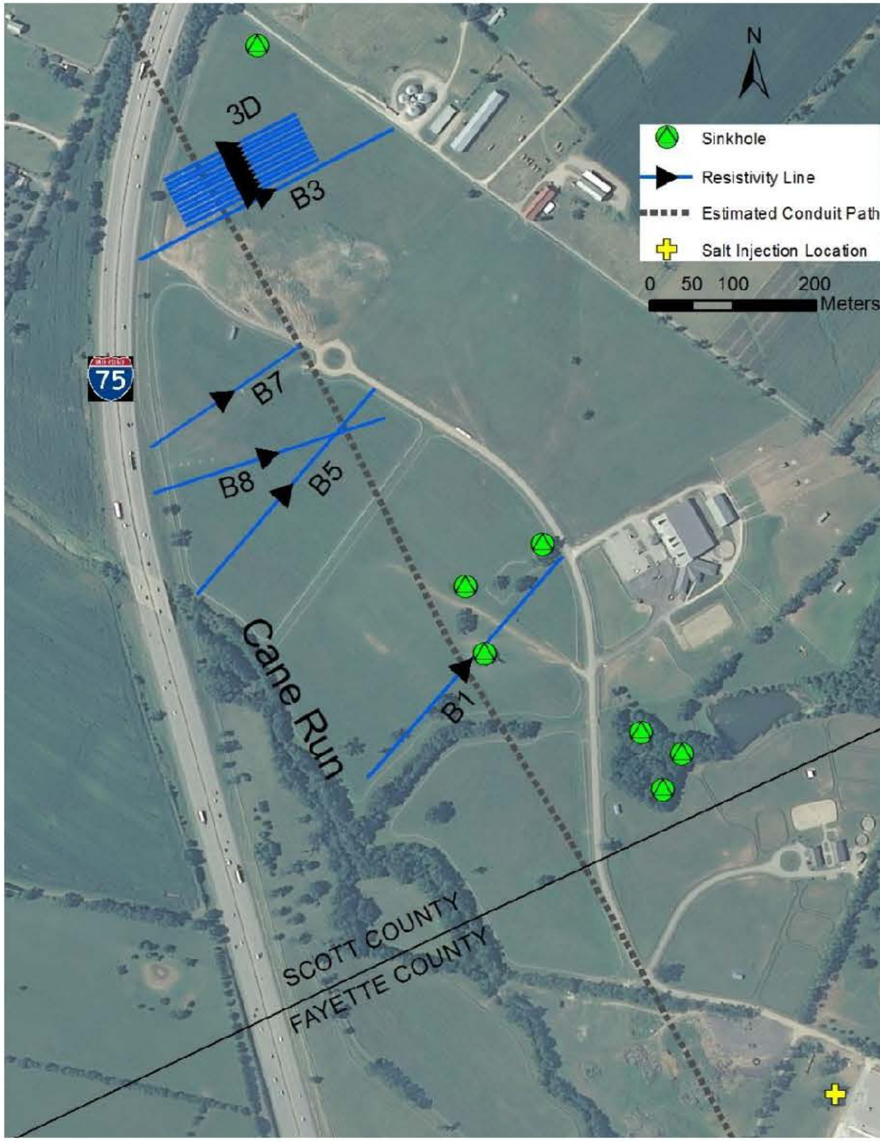
Royal Spring Groundwater Basin

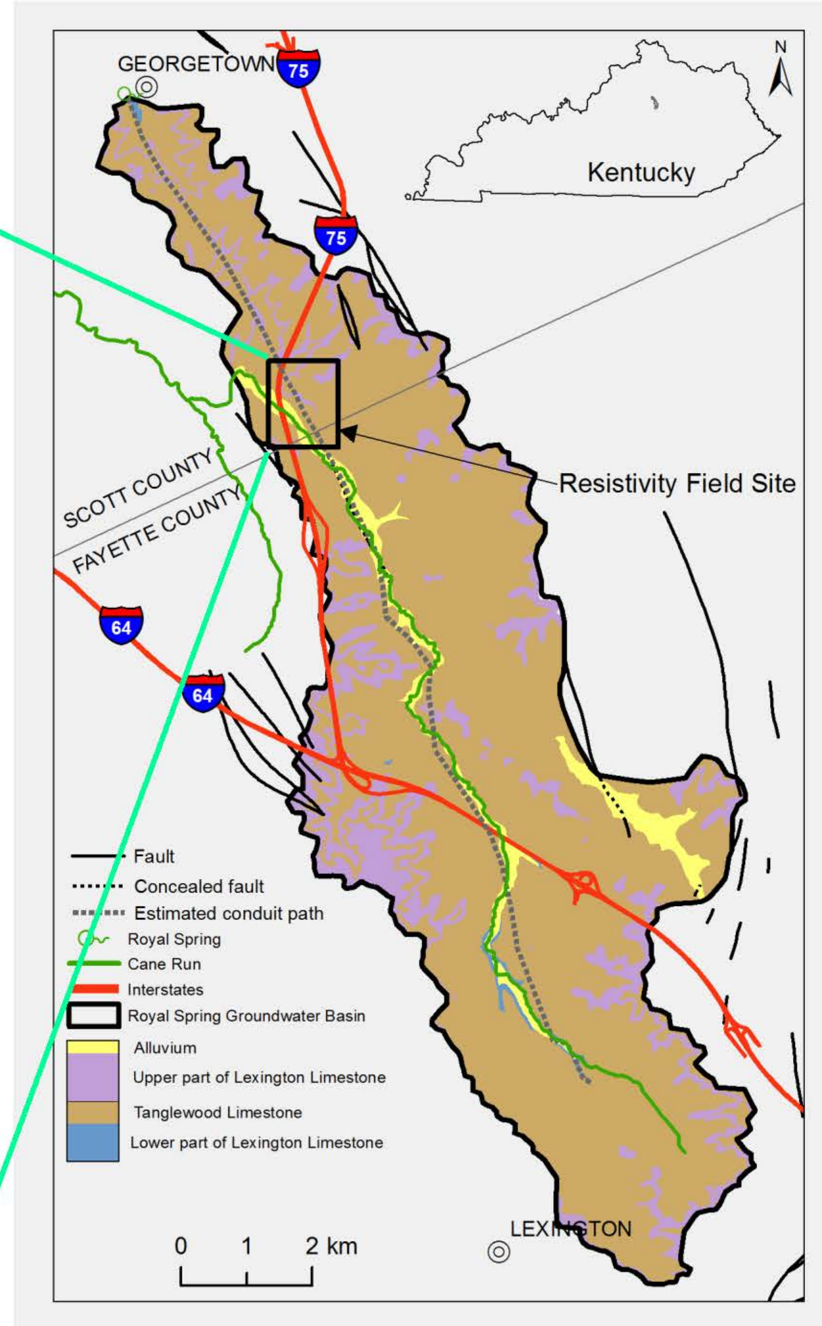
Royal Spring

Estimated Conduit Path



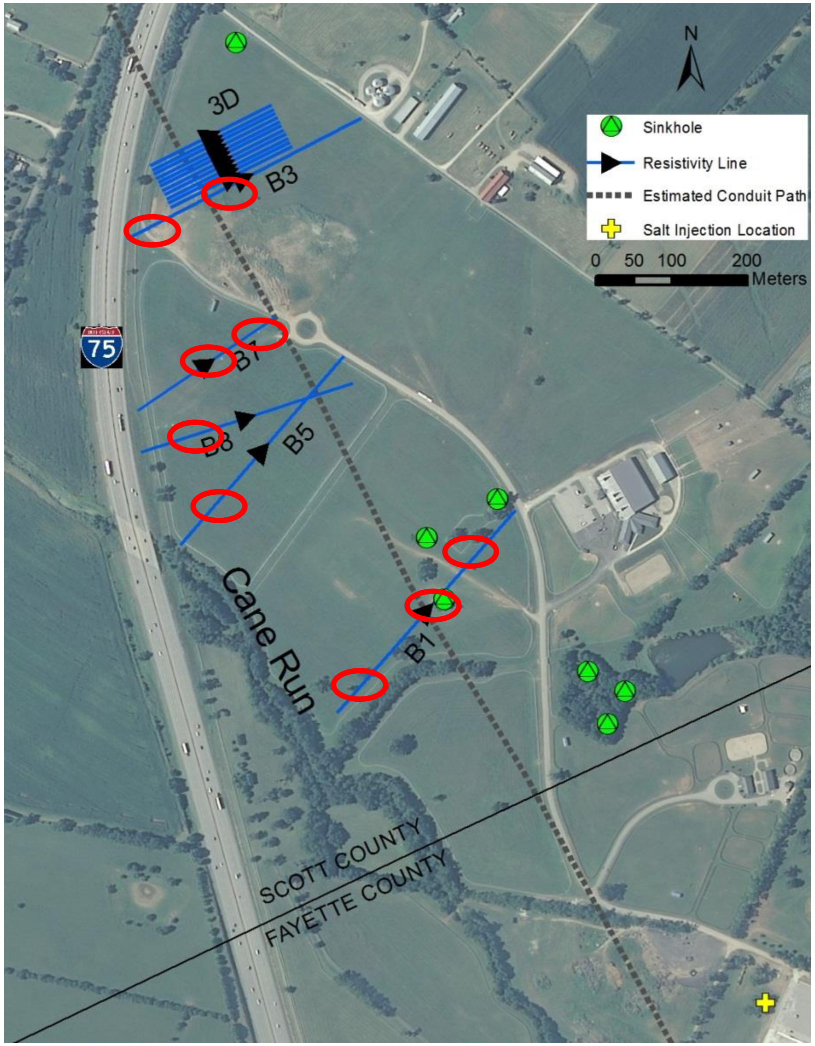
Field Site

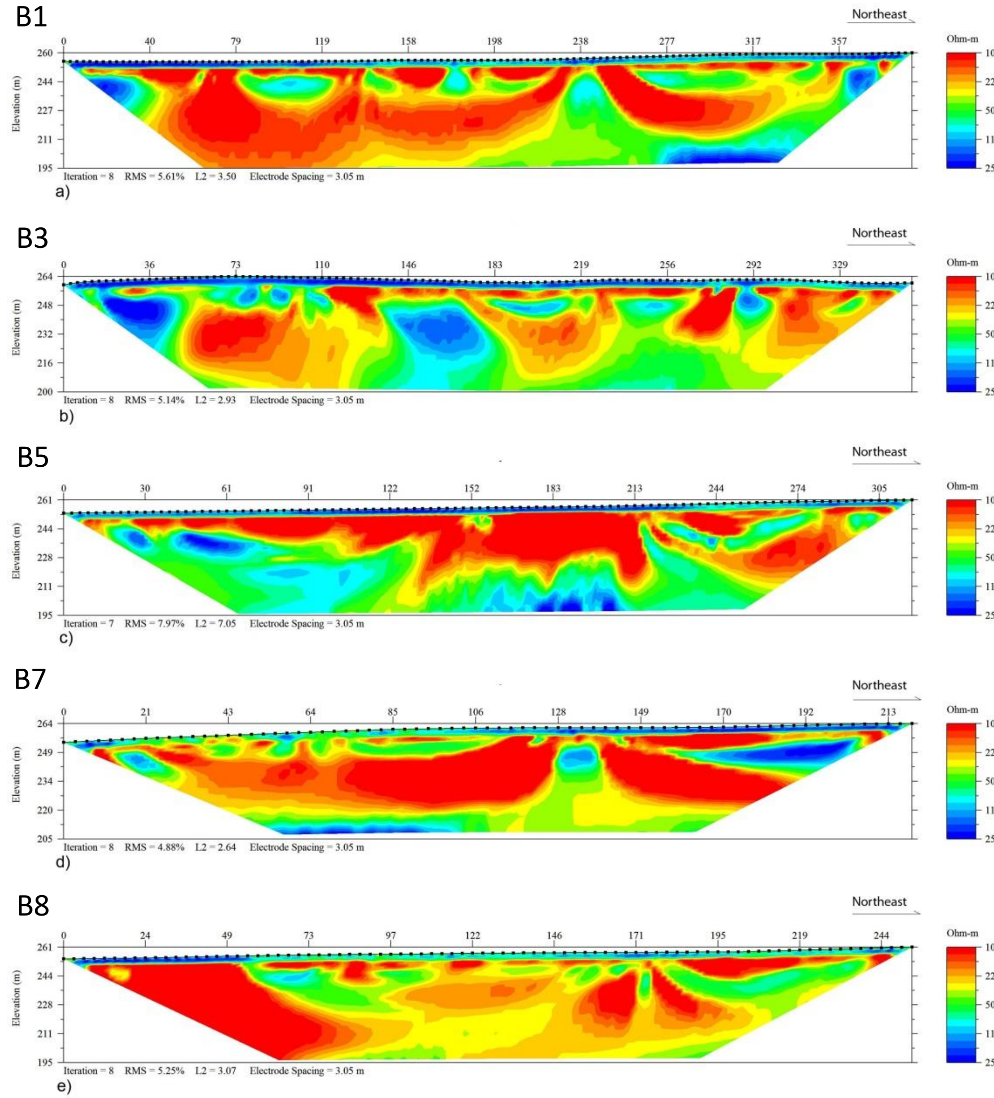




Zhu et al. (2011)

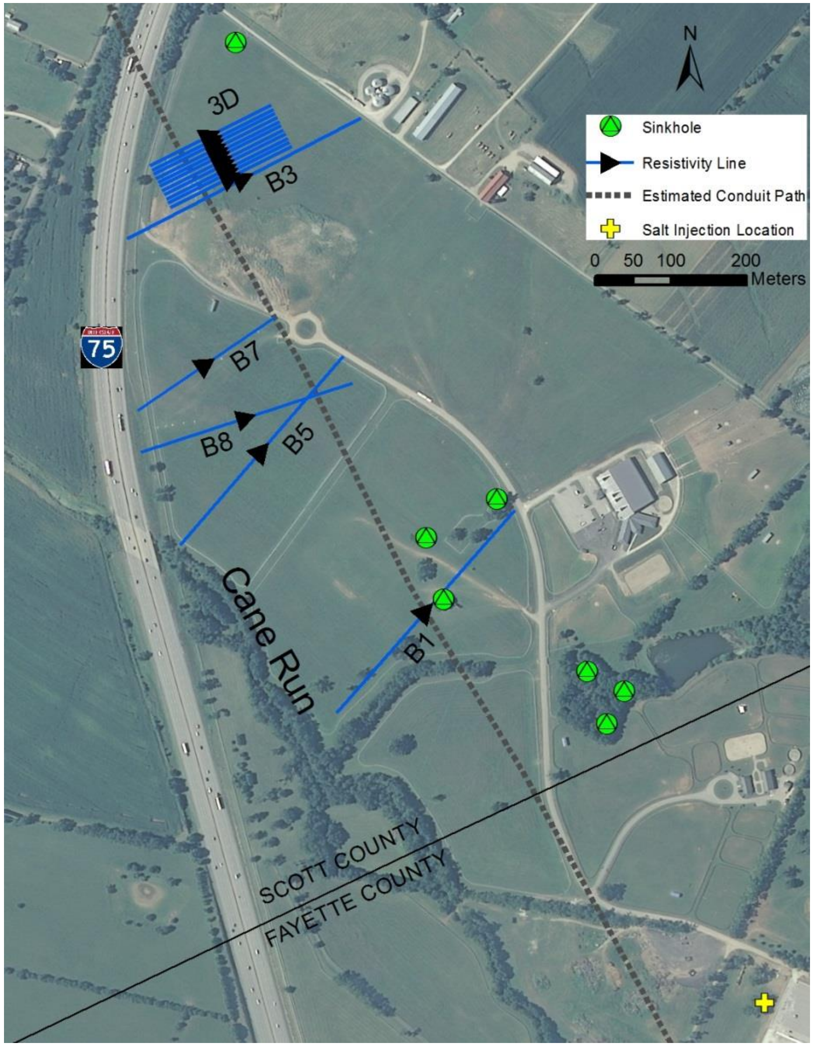
2D Electrical Resistivity Sections

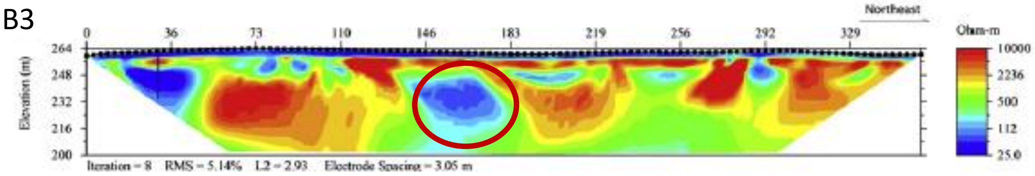


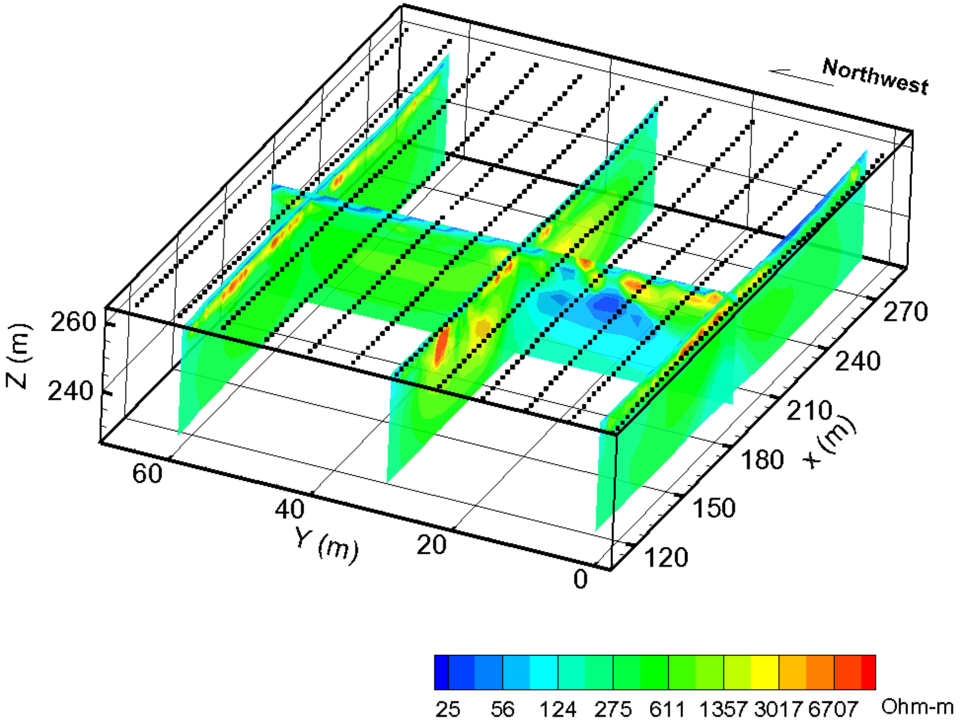


Zhu et al. (2011)

Quasi-3D Electrical Resistivity Sections

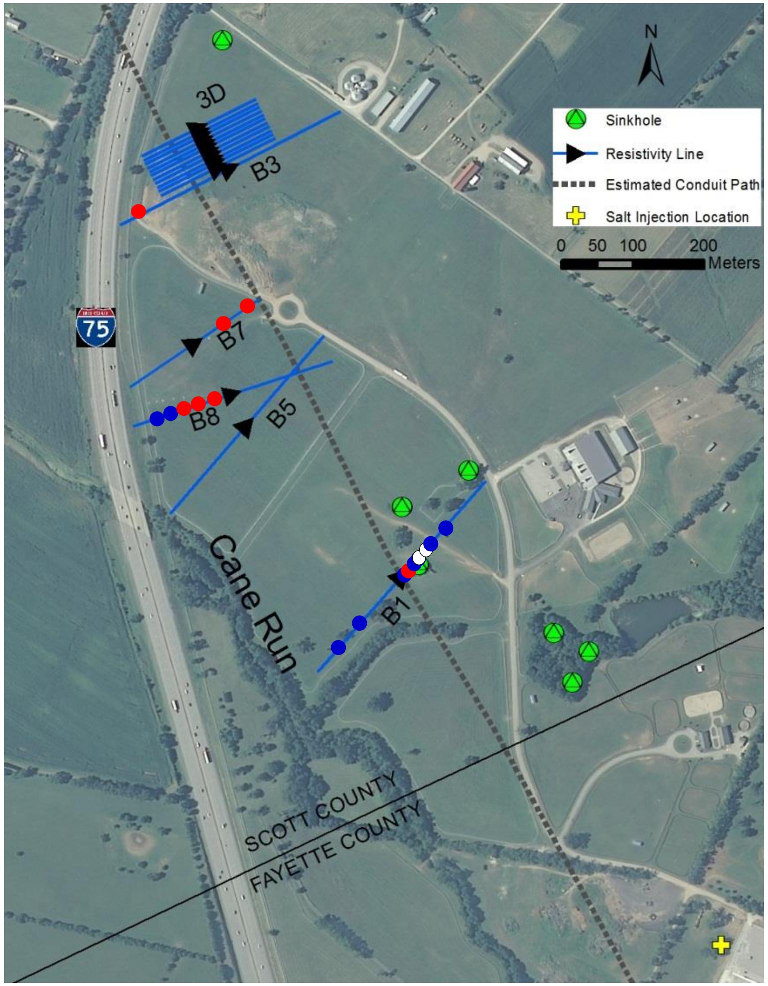






Zhu et al. (2011)

Drilling Result

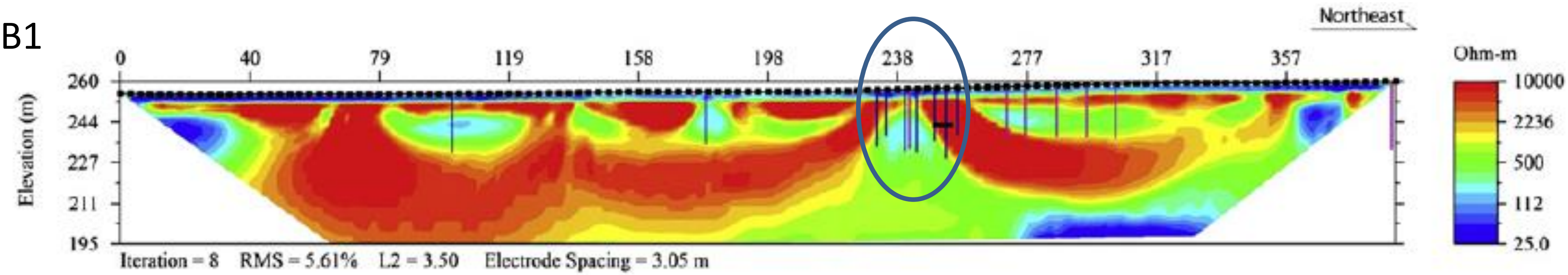


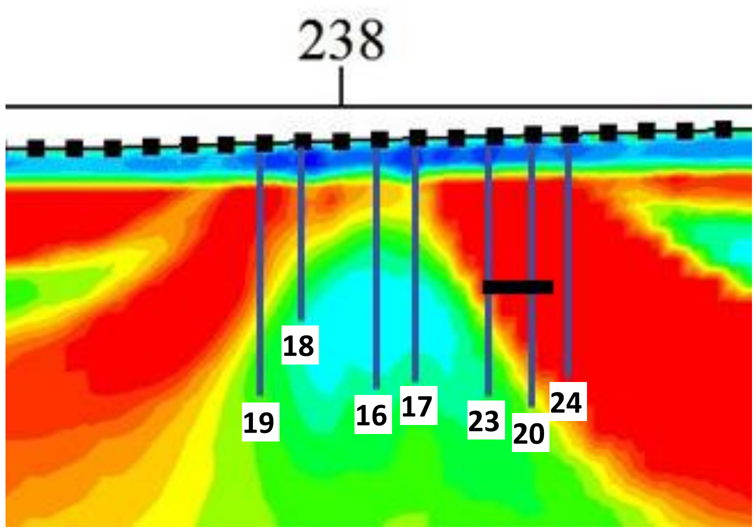
- Dry well
- Well with water, but no major conduit
- Well in the conduit

Field site B1 with wells (viewing from Northeast)

Drilling B1

B1





16: lots of water, broken rocks

17: lots of water, broken rocks

18: shallow conduit filled mud

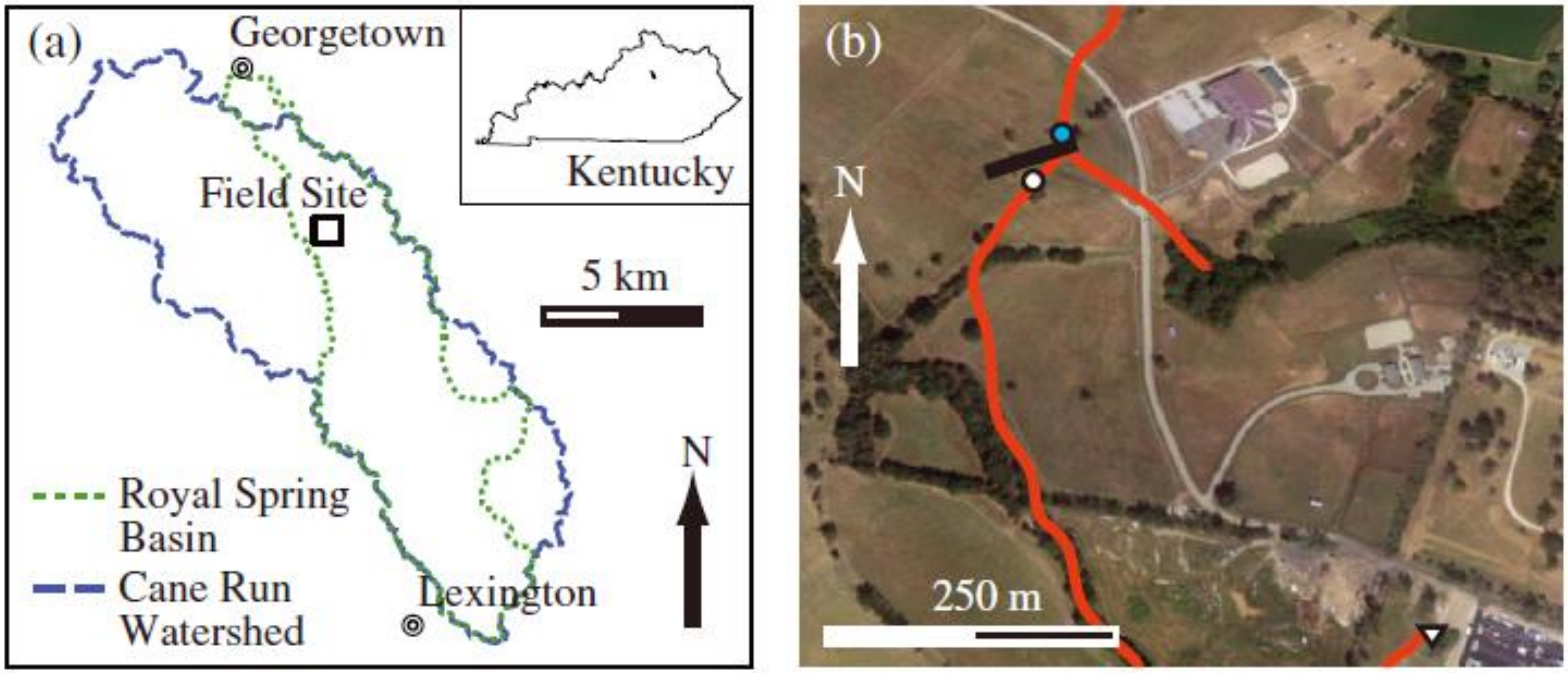
19: less water, more muddy

20: into the conduit, fast flow

23: into the conduit, slow flow

24: not in the conduit

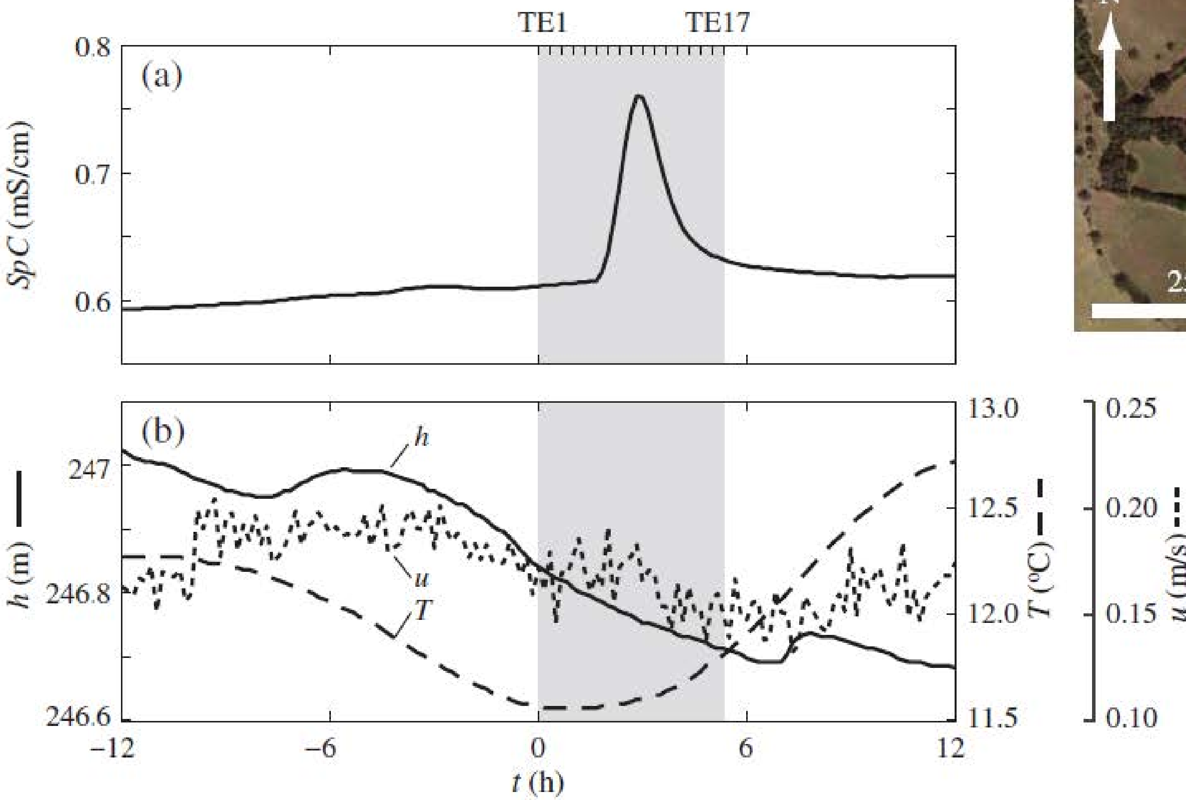
Monitoring solute transport in a conduit

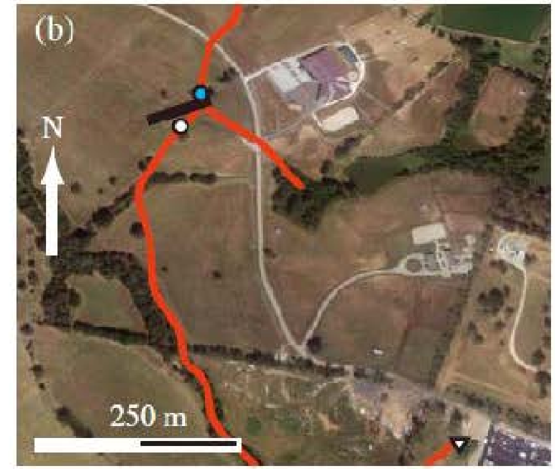


Sawyer et al. (2015)

Salt water injection: 900 kg mixed with 3400 liter of water

Injection interval: 45 mins

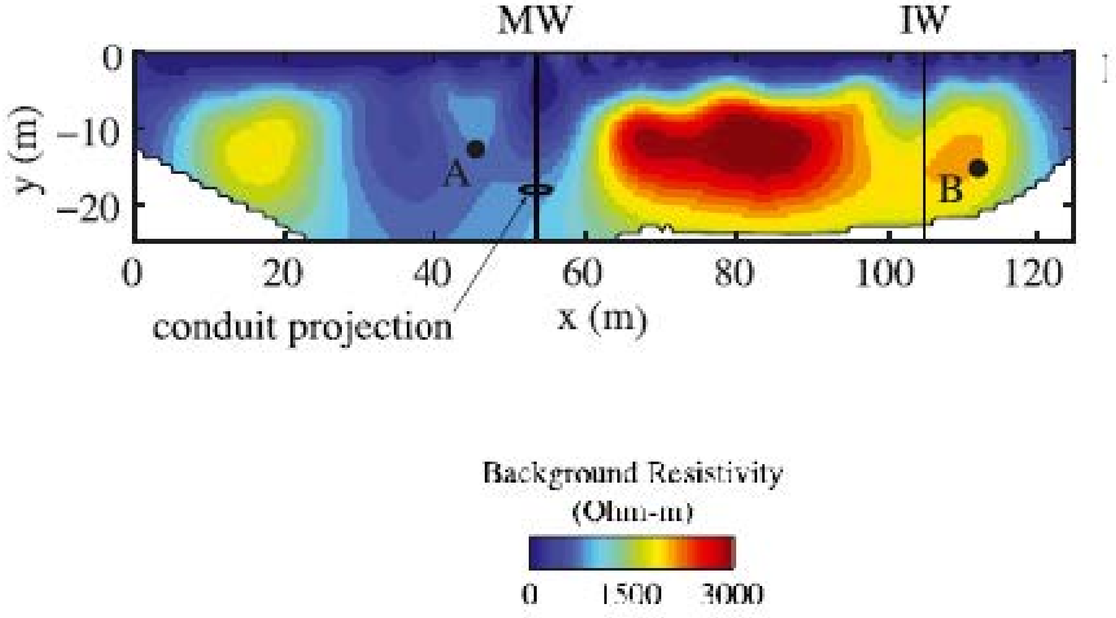




Real –time measurements in the monitoring well

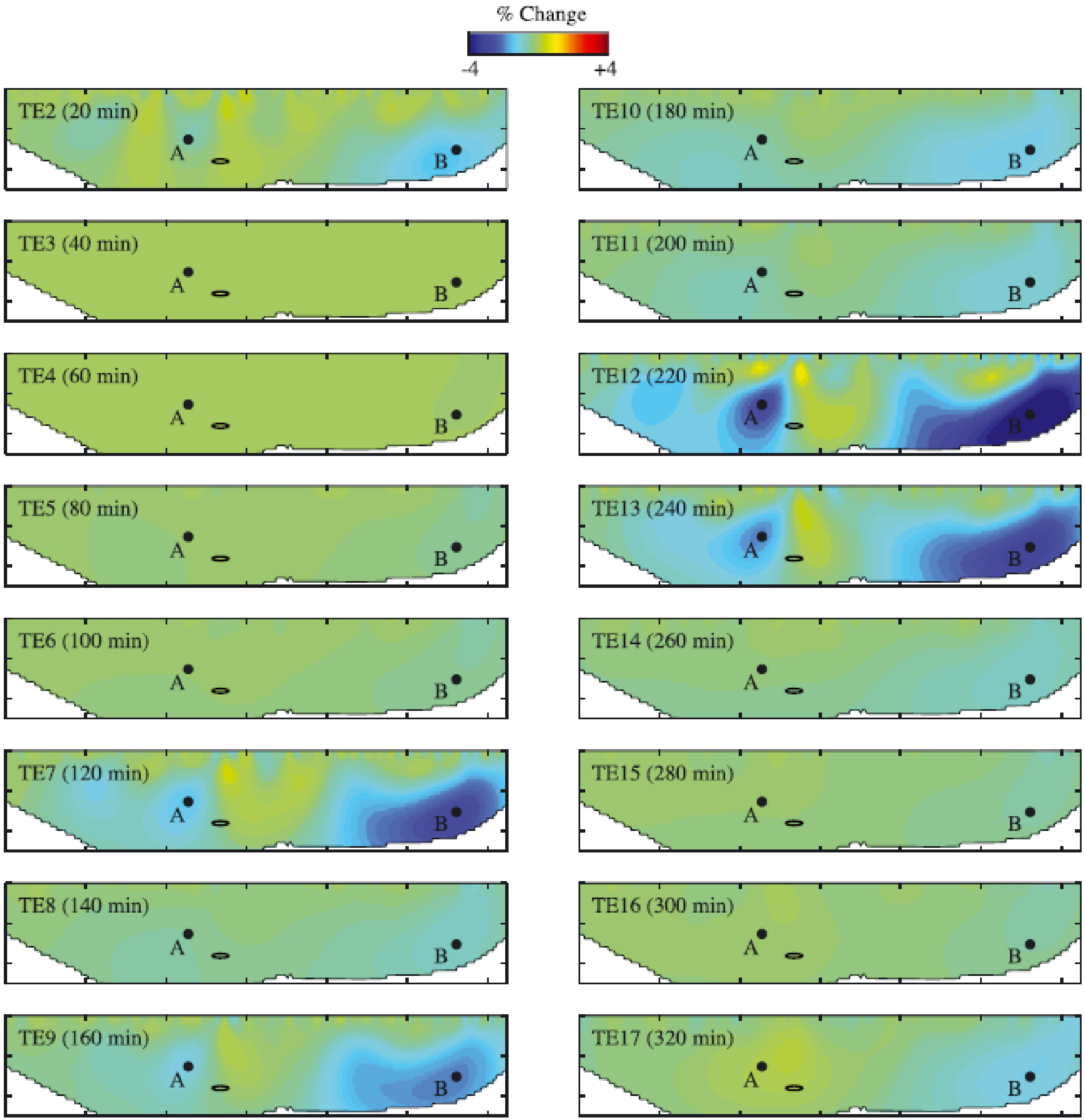
Sawyer et al. (2015)

Background Resistivity



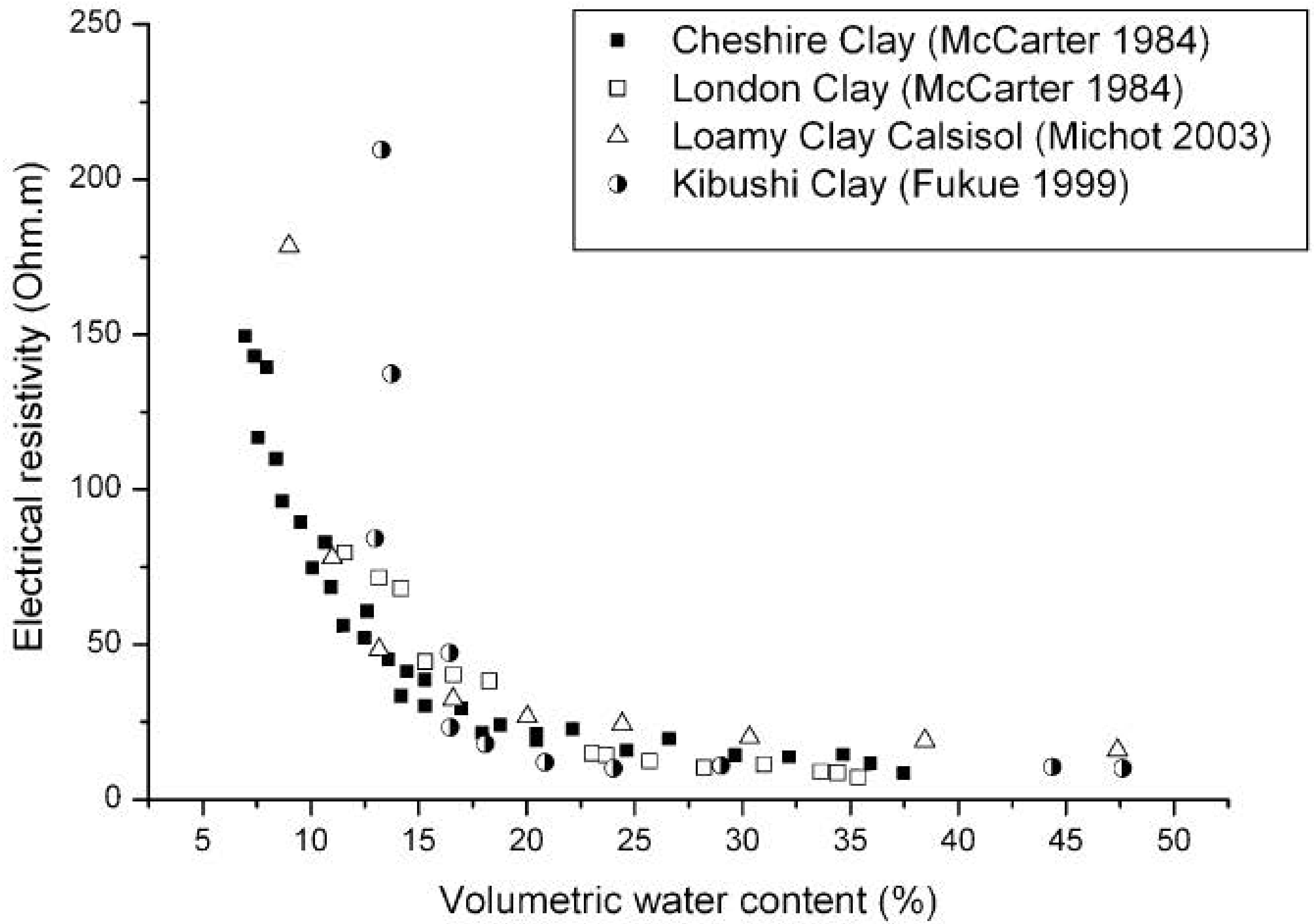
Sawyer et al. (2015)

Resistivity Time Differences



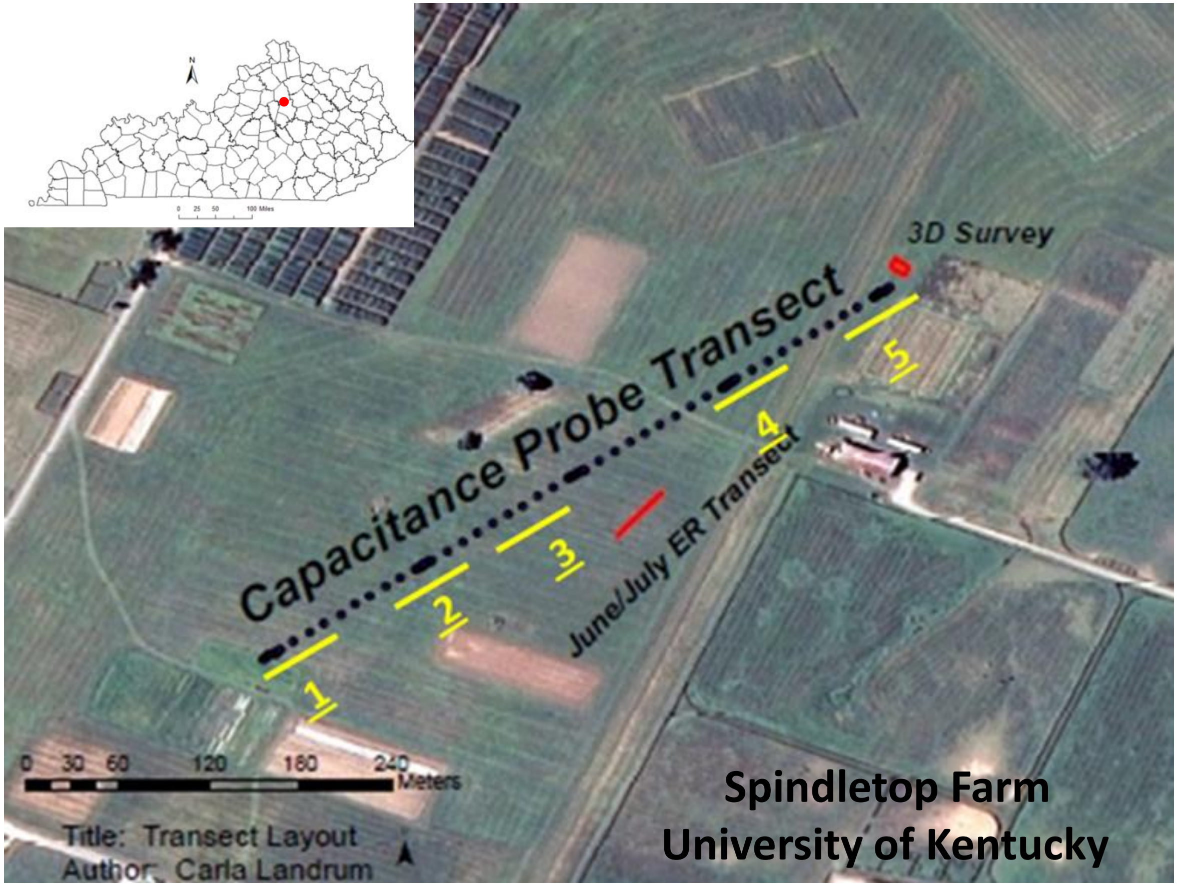
Sawyer et al. (2015)

Monitoring water content in soil



Samouelian et al. (2005)

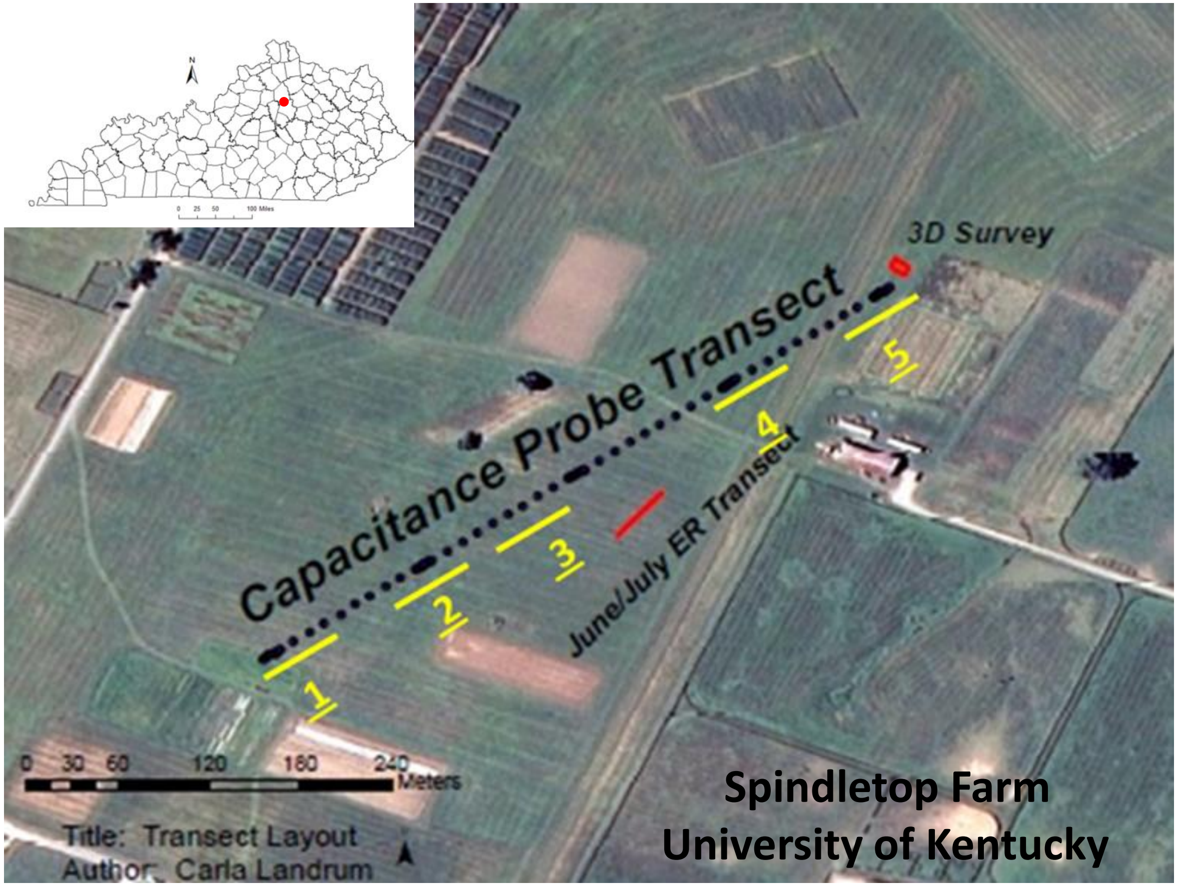
Spindletop Farm Site



1: higher elevation
6-12% slope
2: concave sideslope
6-12% slope
3: convex sideslope
2-6% slope
4: gently sloping
2-6% slope
5: flat footslope
0-2% slope

- Five ER lines(yellow), and each line was surveyed multiple times during Sept.- Nov. 2011.

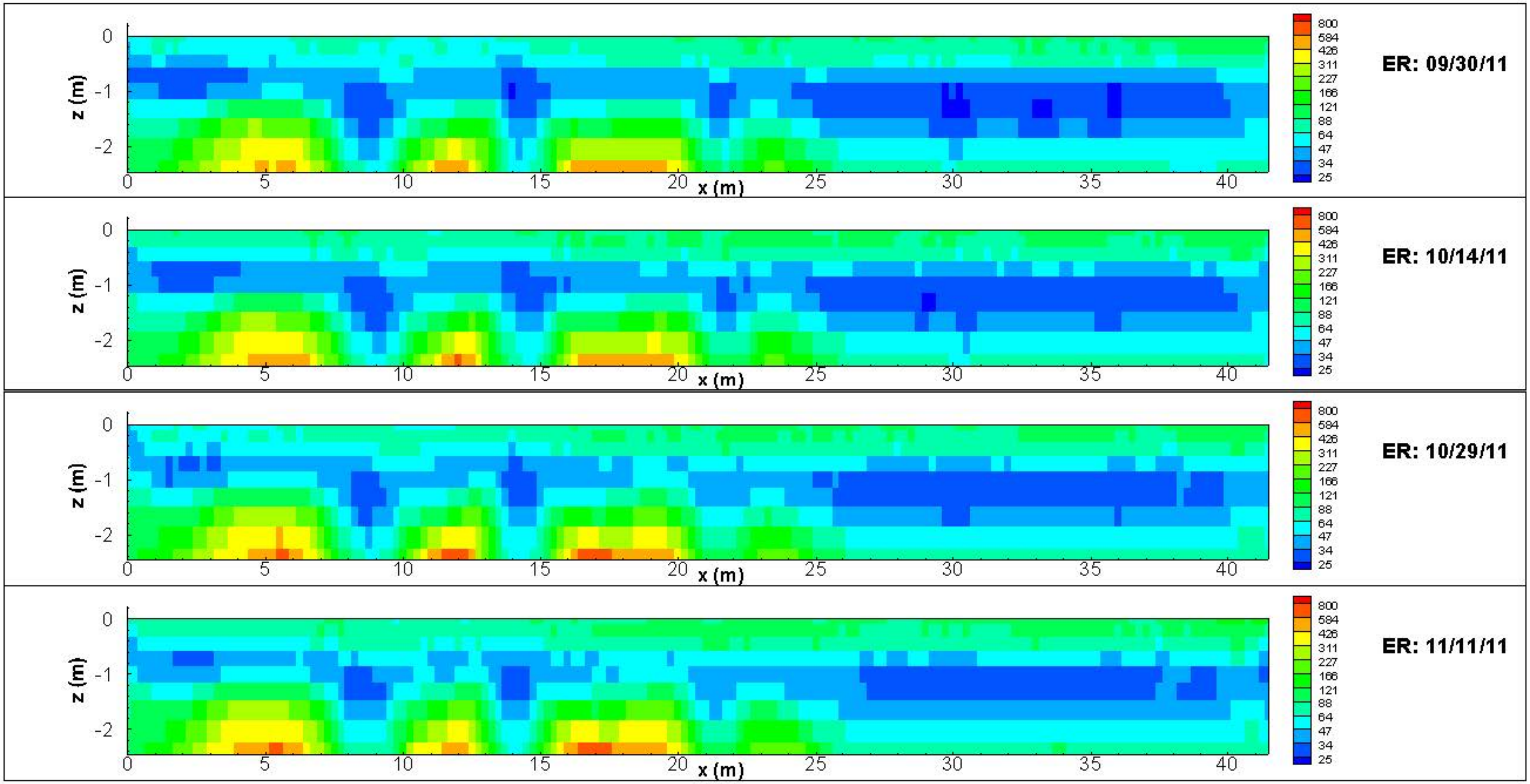
Spindletop Farm Site



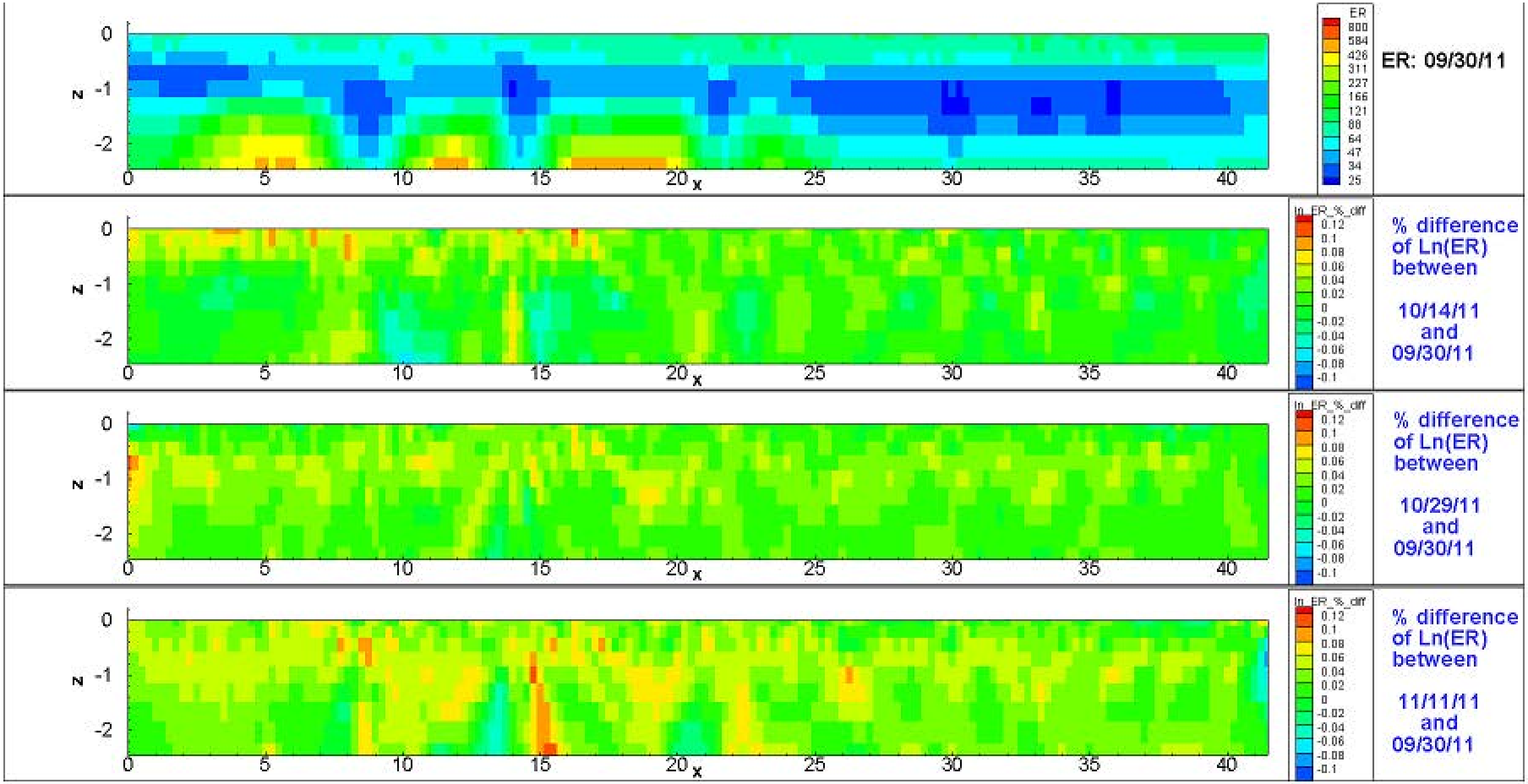
Soil is thin and typically consists of silt loam, silt clay loam, and clay in descending order.

Total 86 Capacitance probes (black dots) and data were collected weekly during Sept 9. – Oct. 28 2011. The probes measure water content in top 100 cm with 10-cm intervals.

Time Lapse Resistivity: Site 1



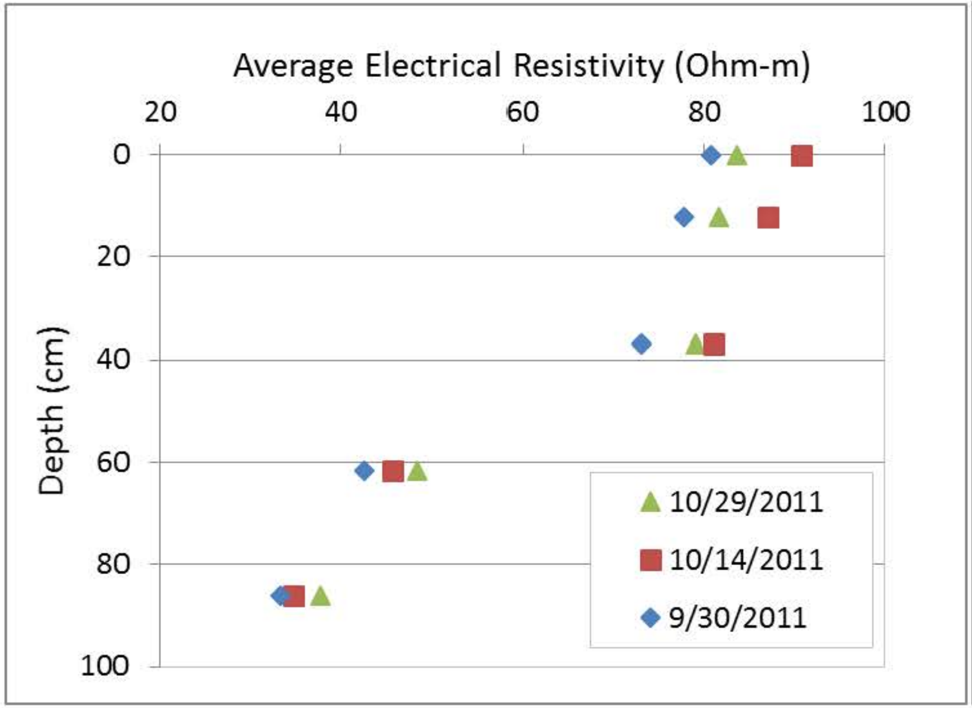
Differences: Site 1

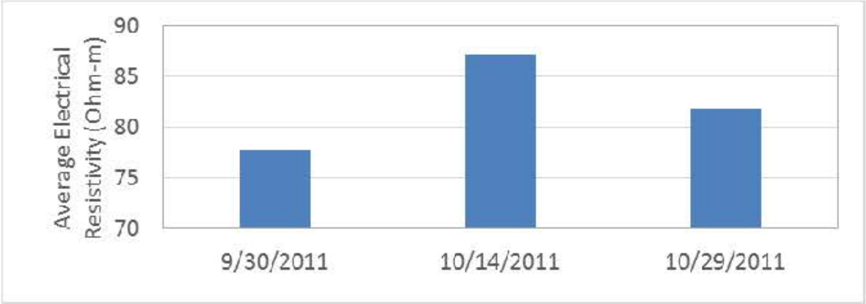


Top figure is inverted ER at time 1 and other figures show relative difference of log-transformed ER between other times and time 1.

Electrical Resistivity vs. Soil Moisture: Site 1

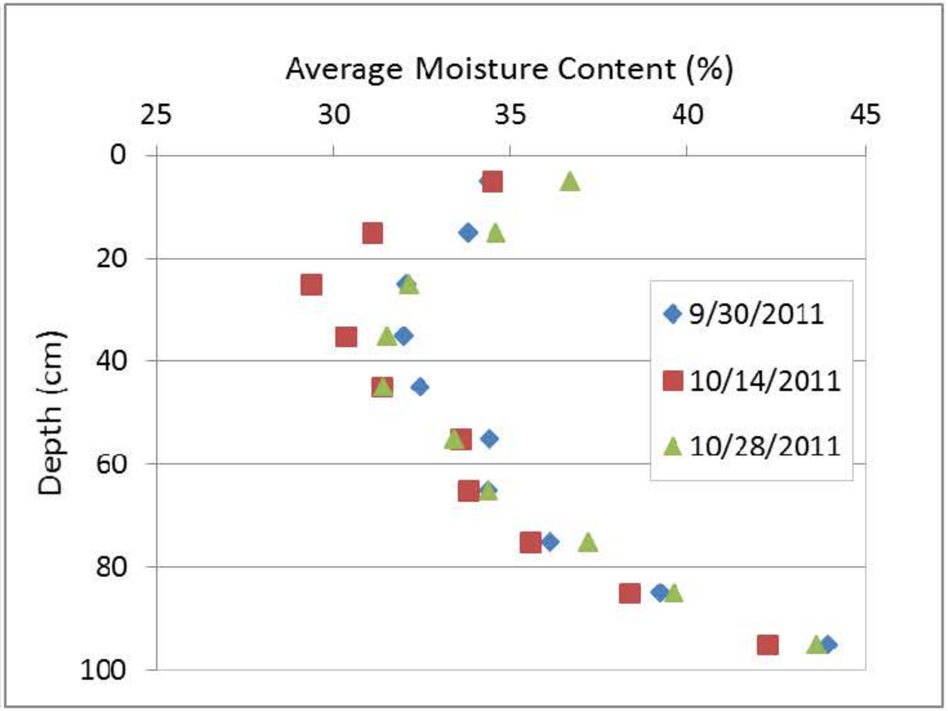
Average Electrical Resistivity

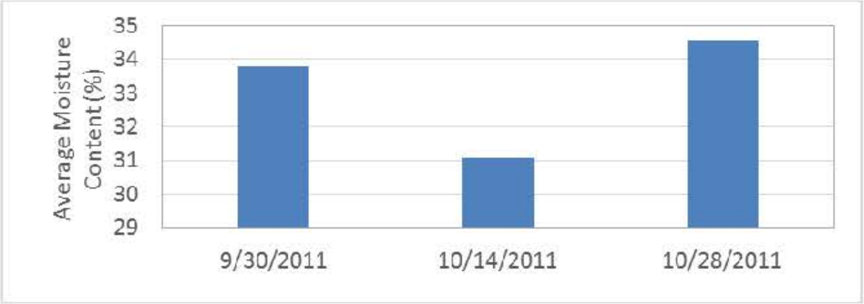




Avg. Resistivity at 12 cm

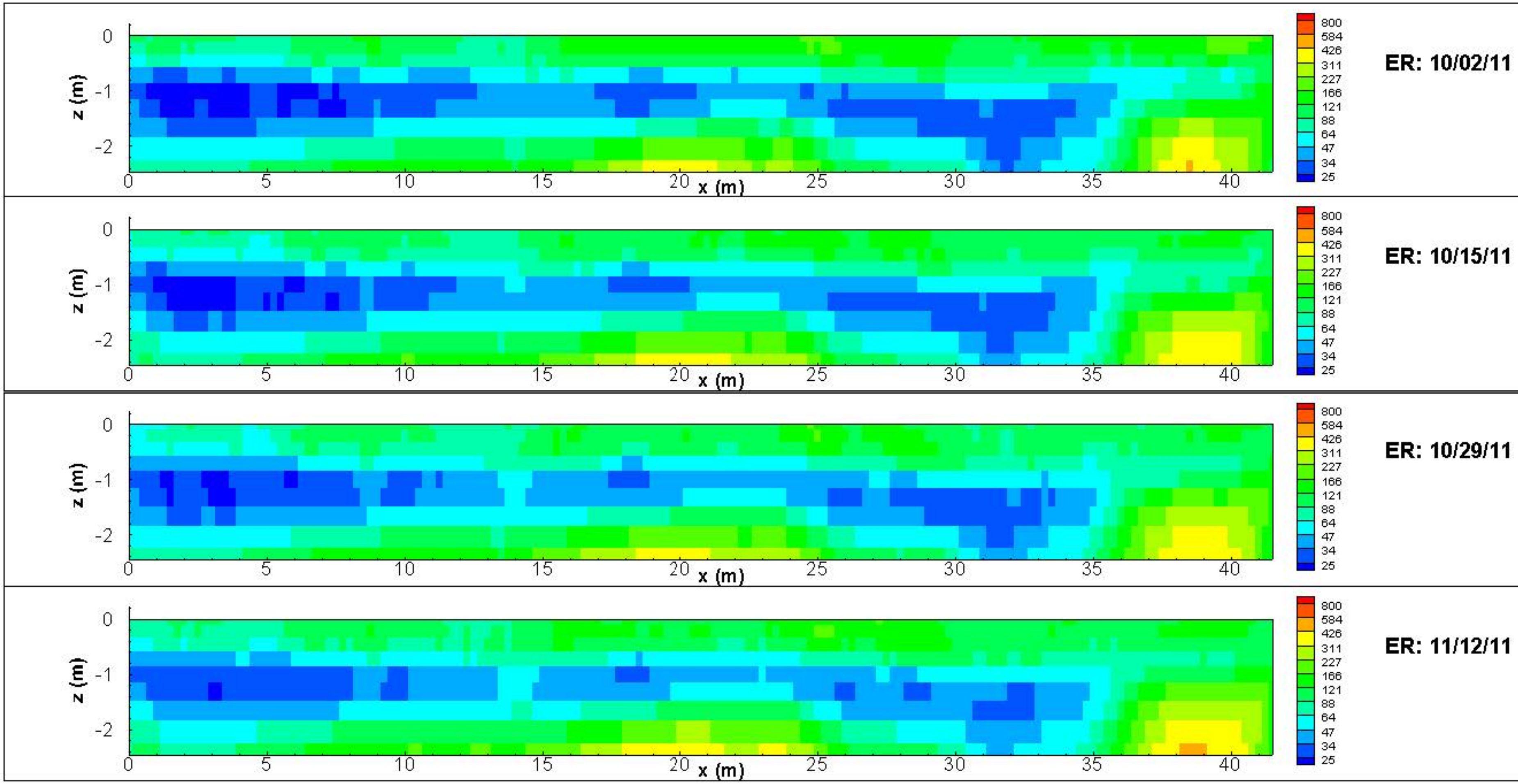
Average Moisture Content



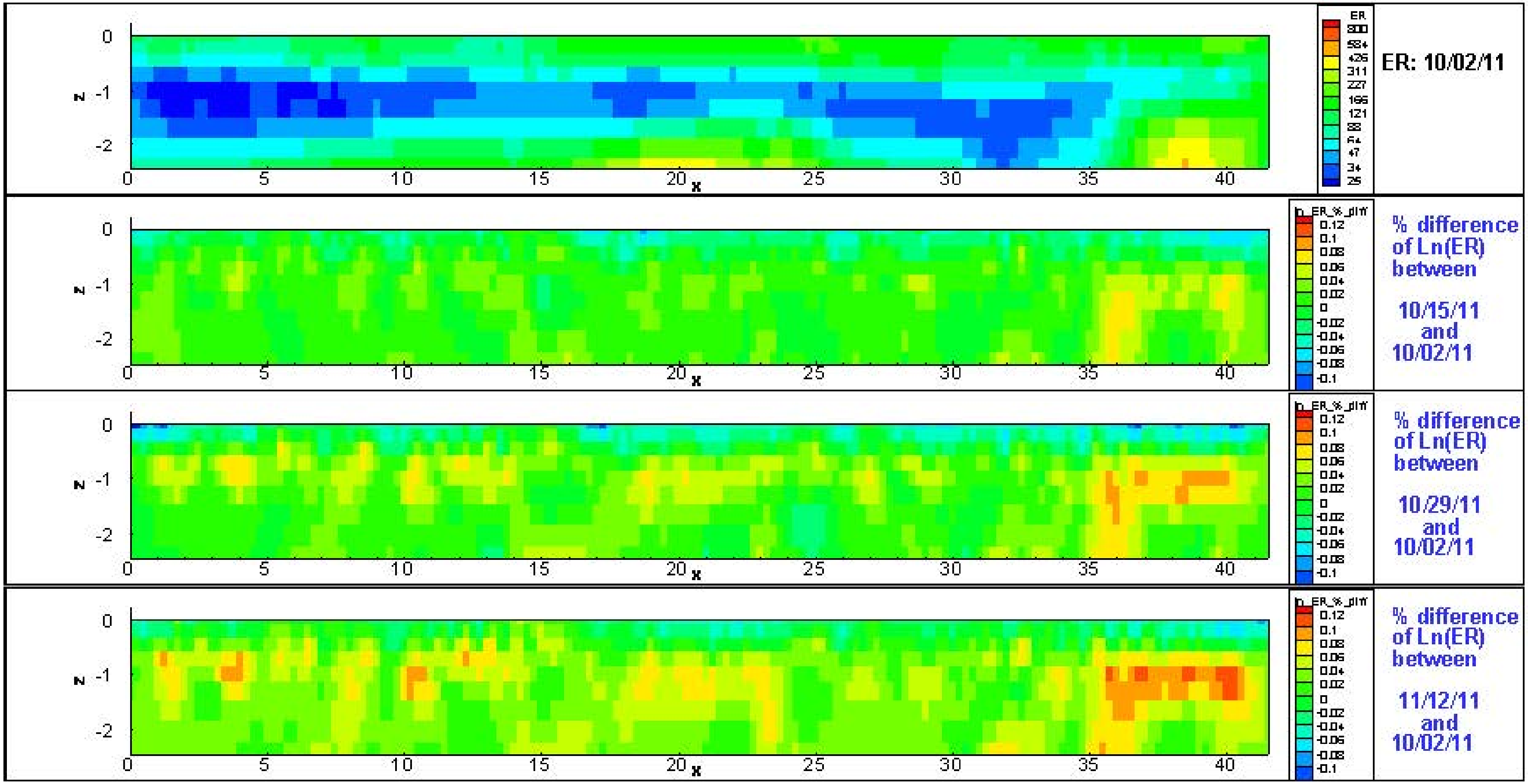


Avg. Water Content at 10-20 cm

Time Lapse Resistivity: Site 3



Differences: Site 3

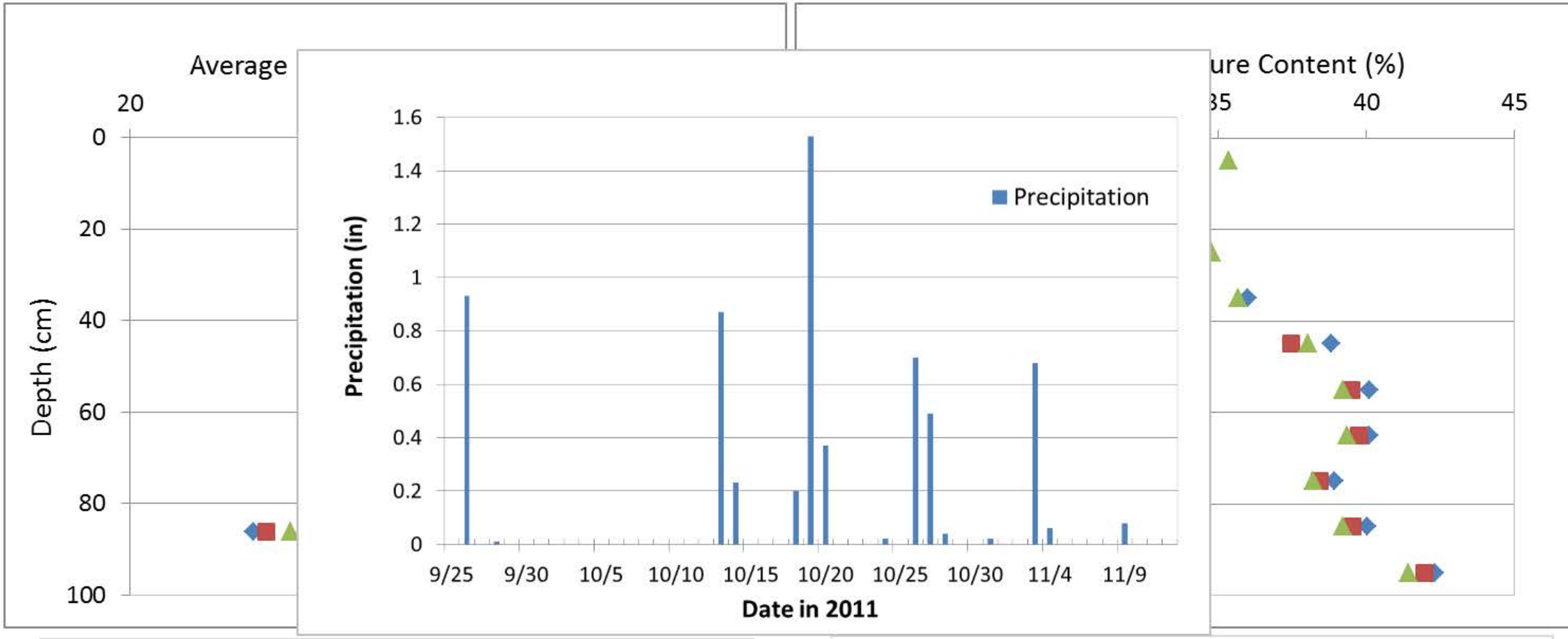


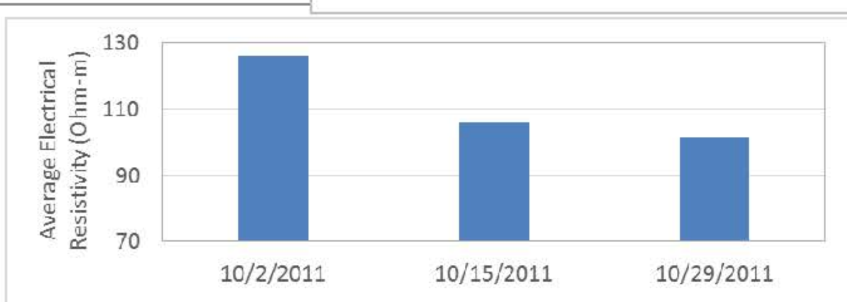
Top figure is inverted ER at time 1 and other figures show relative difference of log-transformed ER between other times and time 1.

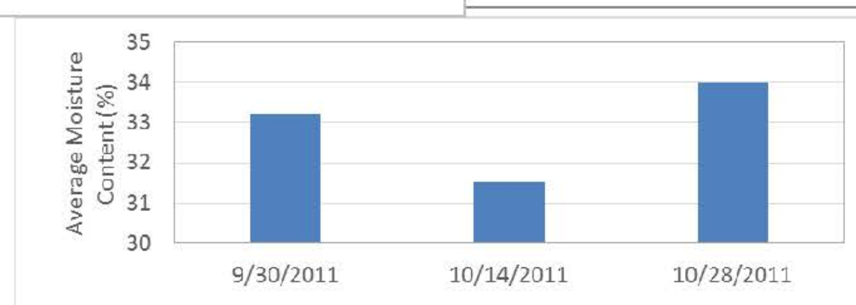
Electrical Resistivity vs. Soil Moisture: Site 3

Average Electrical Resistivity

Average Moisture Content







Avg. Resistivity at 12 cm

Avg. Water Content at 10-20 cm

Return to top

ELECTRICAL RESISTIVITY METHOD FOR MARINE EXPLORATION

Thomas Brackman (on behalf of Markus Lagmanson, Advanced Geosciences, Inc.), Sr. Geophysicist; Research Faculty Western Kentucky University, Bowling Green KY, nearsurfacegeophysics@yahoo.com

Use of 2D Electrical Resistivity in marine applications will highlight case studies including optimizing placement of horizontal well screens for water well intakes for the Florida Oceanographic Societies Marine Park, mapping of geology adjacent to seawalls adjacent to a waterfront canal system, determine dep to bottom in lacustrine environments, and investigation of a planned utility tunnel stretch between the mainland and Fisher Island in Miami, FL.

Return to top