Applications of Geophysical Methods To Engineering Problems

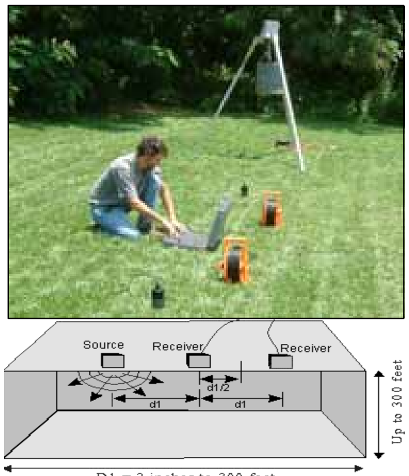
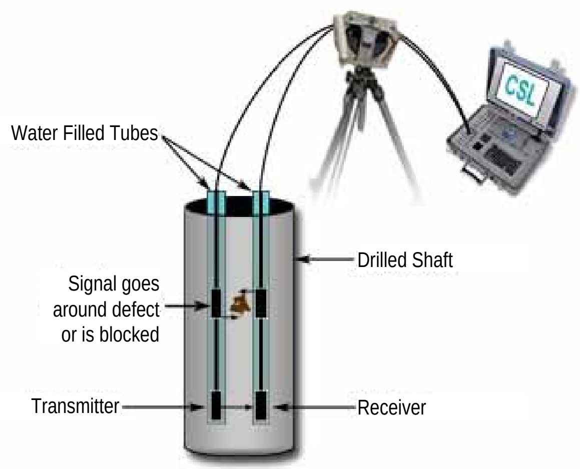


Image Courtesy of Olson Instruments

Spectral Analysis of Surface Waves



Crosshole Sonic Logging

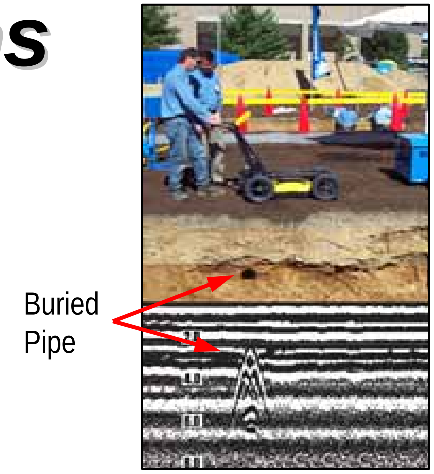
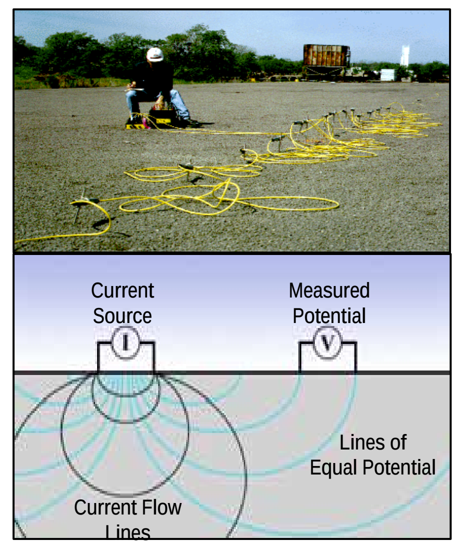


Image Courtesy of Sensors & Software Inc.

Ground Penetrating Radar



Electrical Resistivity Imaging

ATS International

Advanced Technical Services

Engineering Geology • Hydrogeology • Geophysics
Computer Modeling • Visualization • GIS

Geophysical Methods Offer Means of Non-Destructive Testing (NDT)

- **NDT methods can be utilized in a wide variety of settings with little or no impact on the structures being tested**
- **NDT can be applied to a variety of materials including:**
  - **Earth: Soil and Rock**
  - **Concrete**
  - **Steel**
  - **Wood**

Primary Methods

- **Electrical Resistivity Imaging**
  - **2-Dimensional**
  - **3-Dimensional**
- **Ground Penetrating Radar**
- **SASW (Spectral Analysis of Surface Waves)**
  - **Earth Materials**
  - **Concrete**
- **MASW (Multi-channel Analysis of Surface Waves)**
- **Crosshole Sonic Logging**

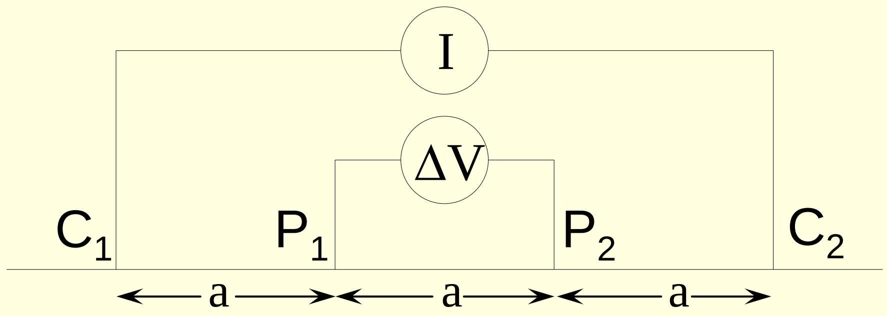
Secondary Methods

- **Electromagnetic Induction (EM, Terrain Conductivity)**
- **Seismic Refraction**
- **Microgravity**
- **Impact Echo**

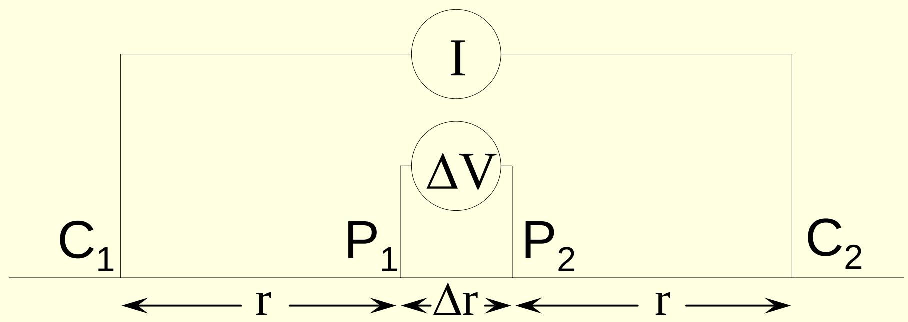
Electrical Resistivity

- **The property of a material to inhibit or resist the flow of electric current**

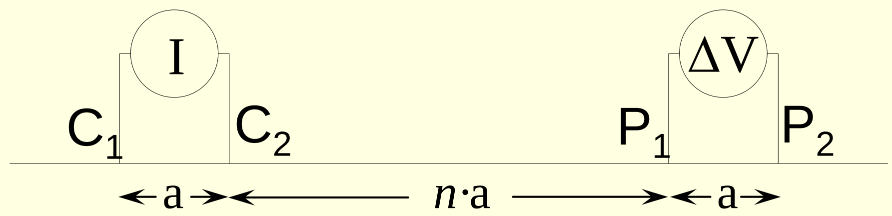
Popular Arrays



- **Wenner**

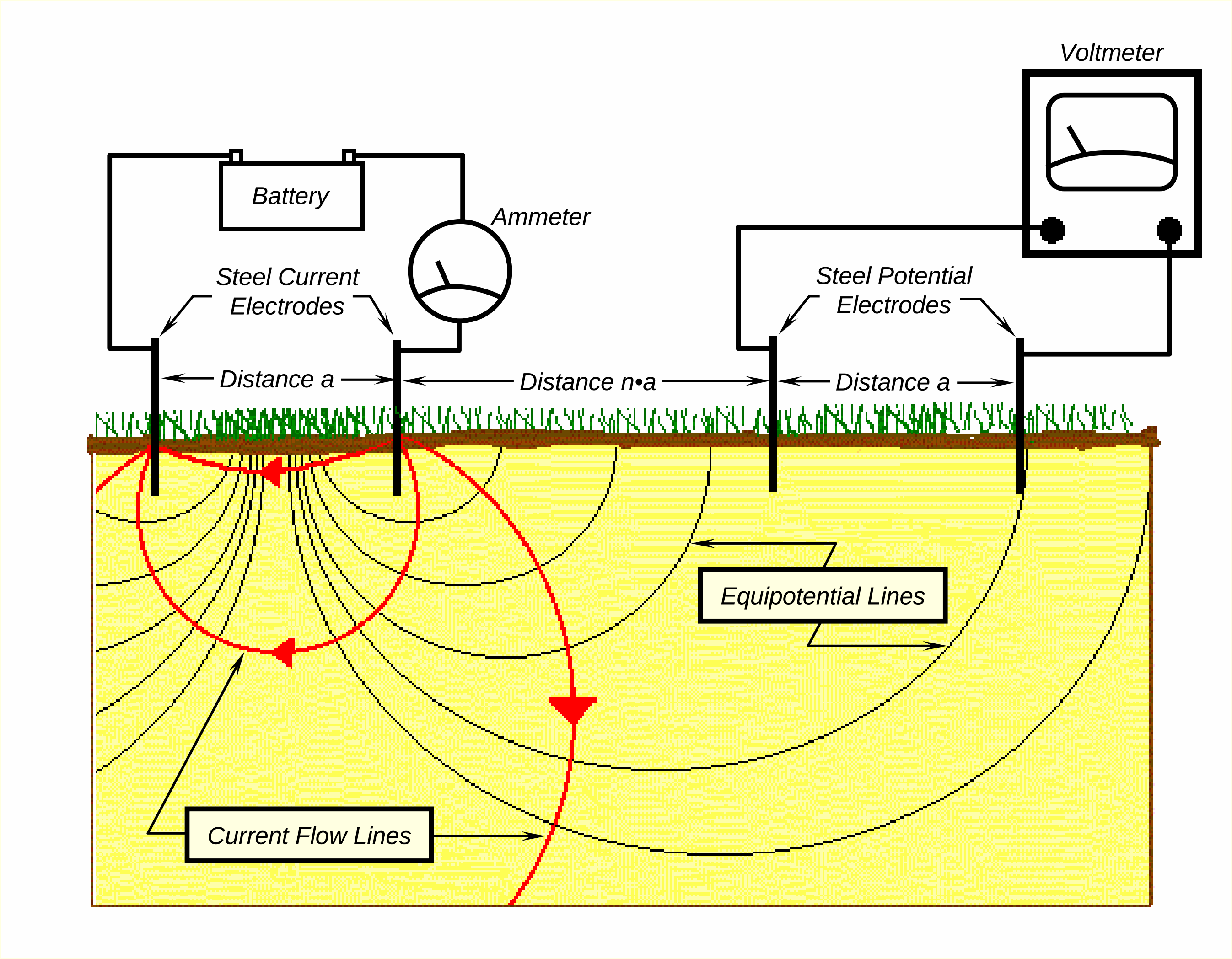


- **Schlumberger**

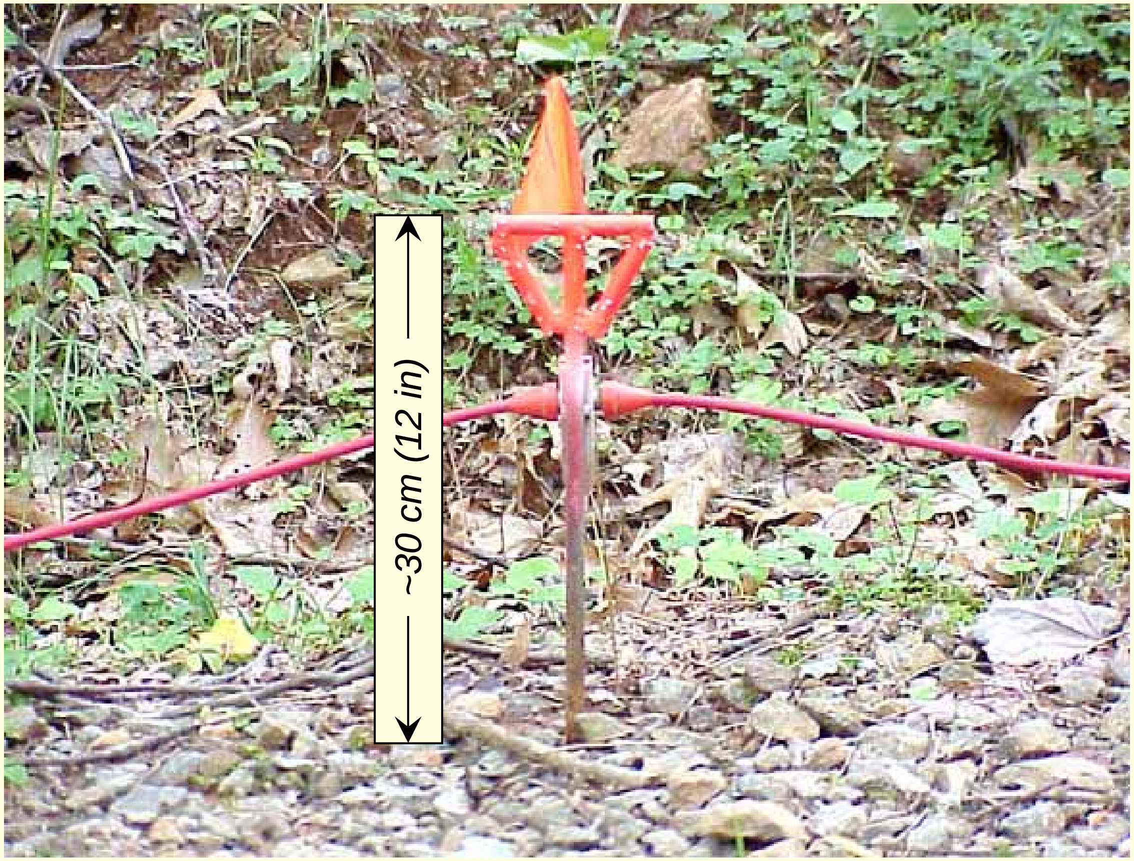


- **Dipole-Dipole**

Schematic Diagram of Dipole-Dipole Array



Electrode attached to multiconductor cable

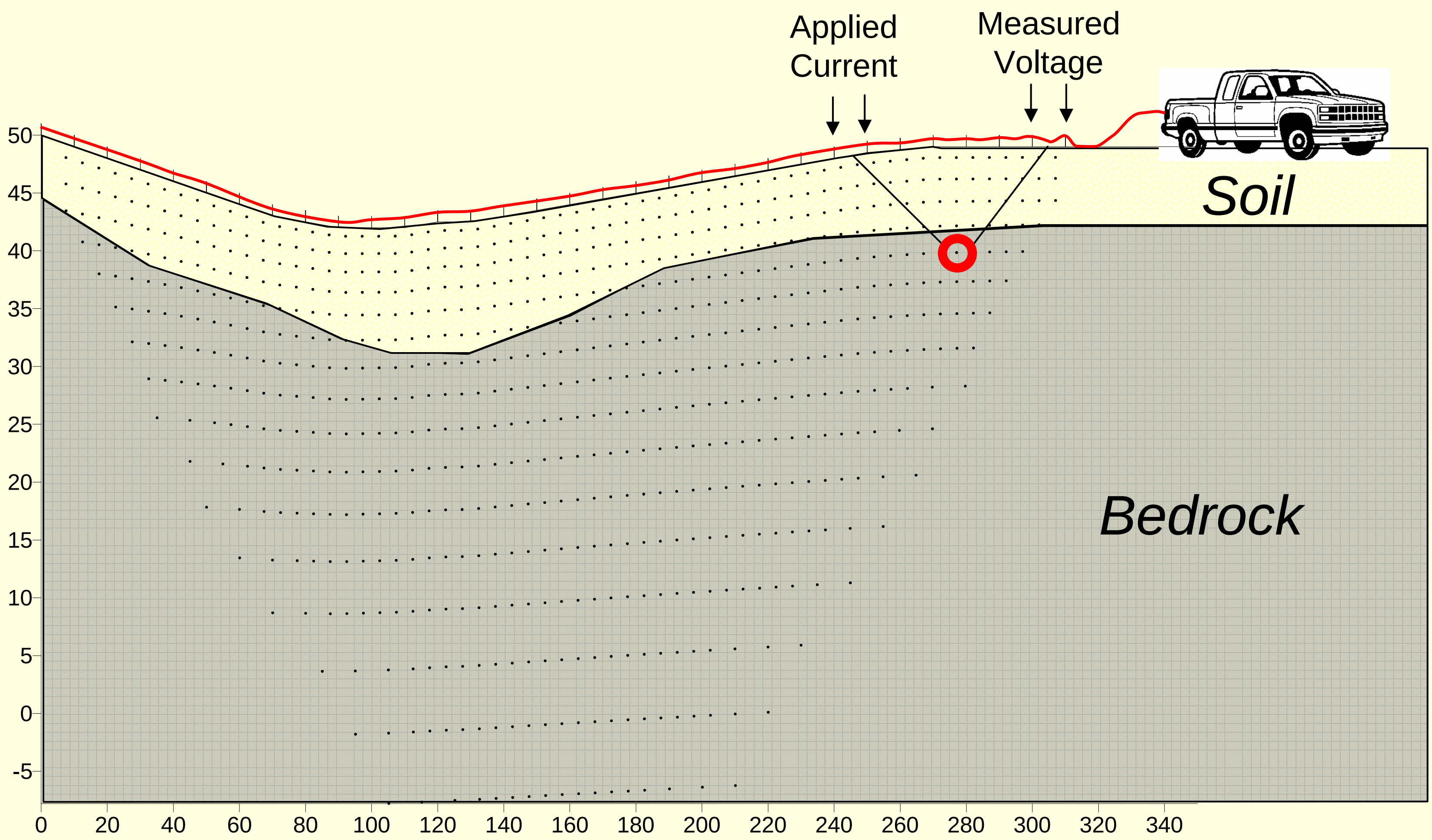


Resistivity Meter with Laptop Computer

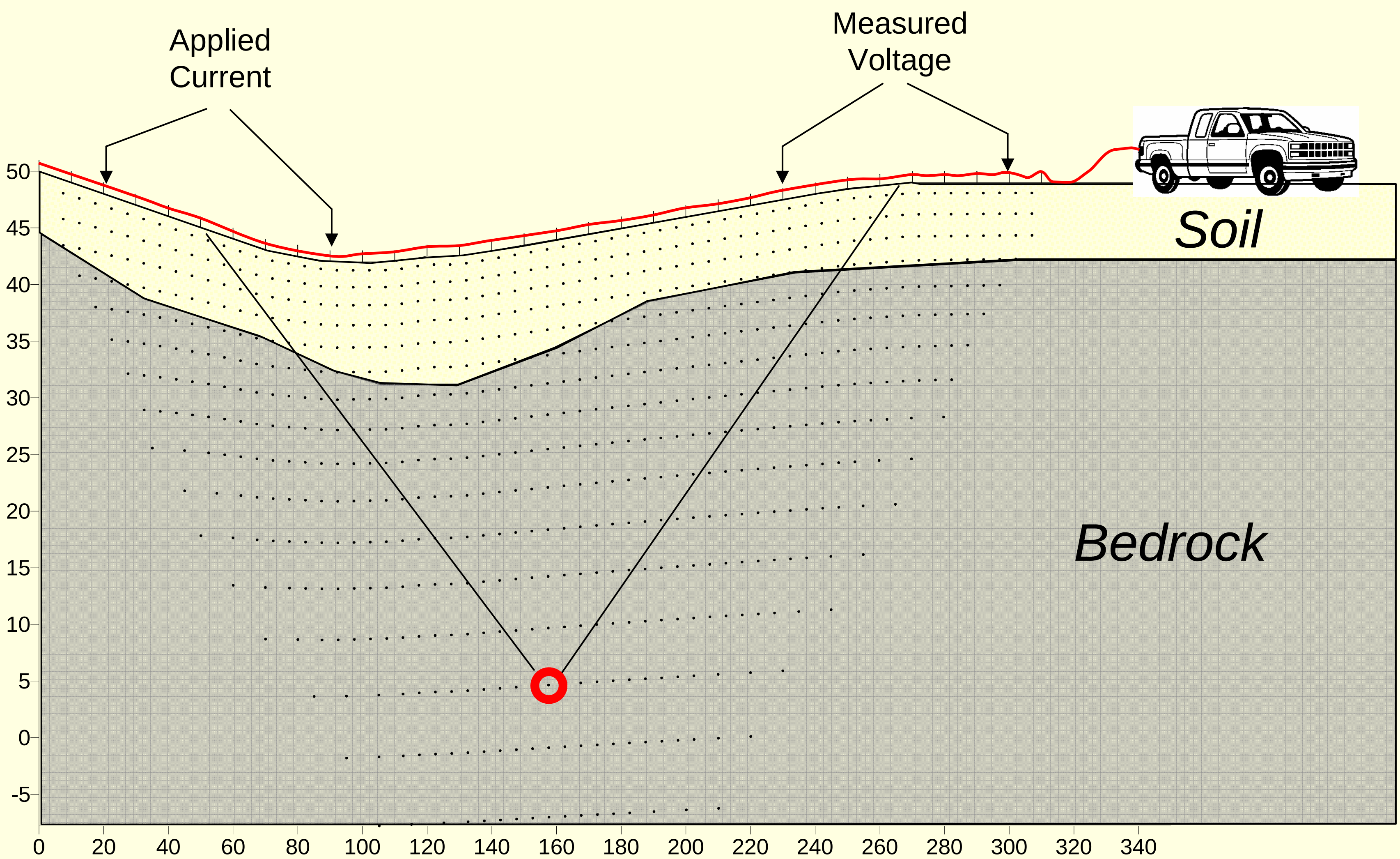
2-Dimensional Array

Urban Environments

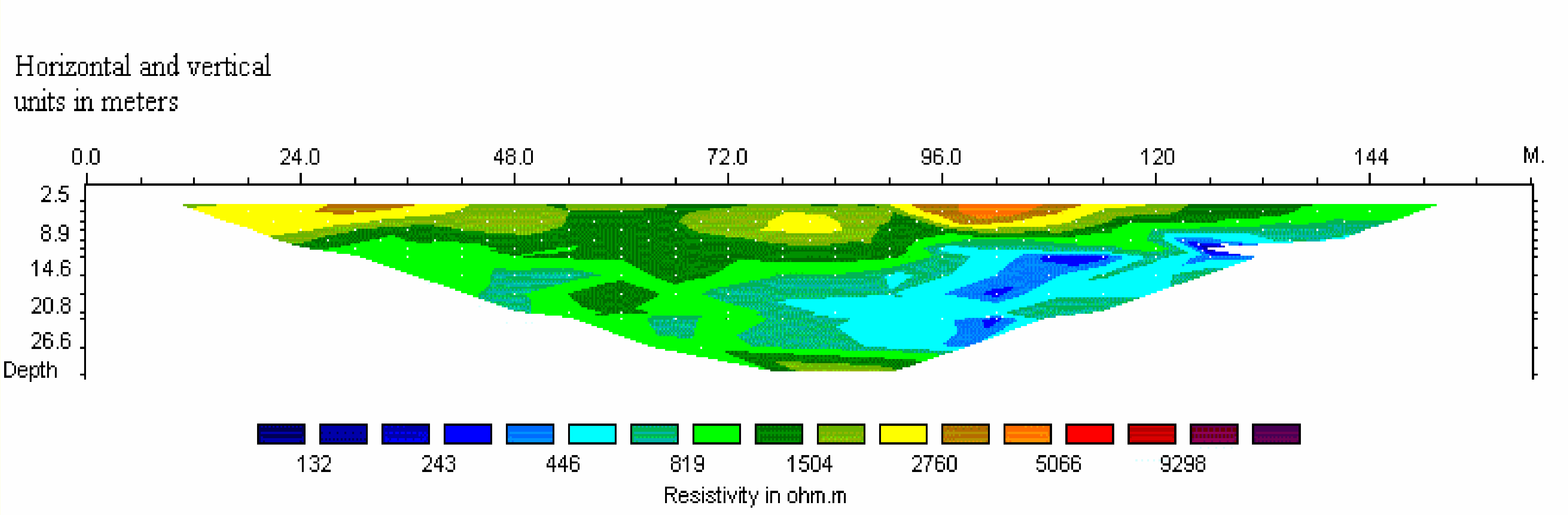
Shallow Data Acquisition



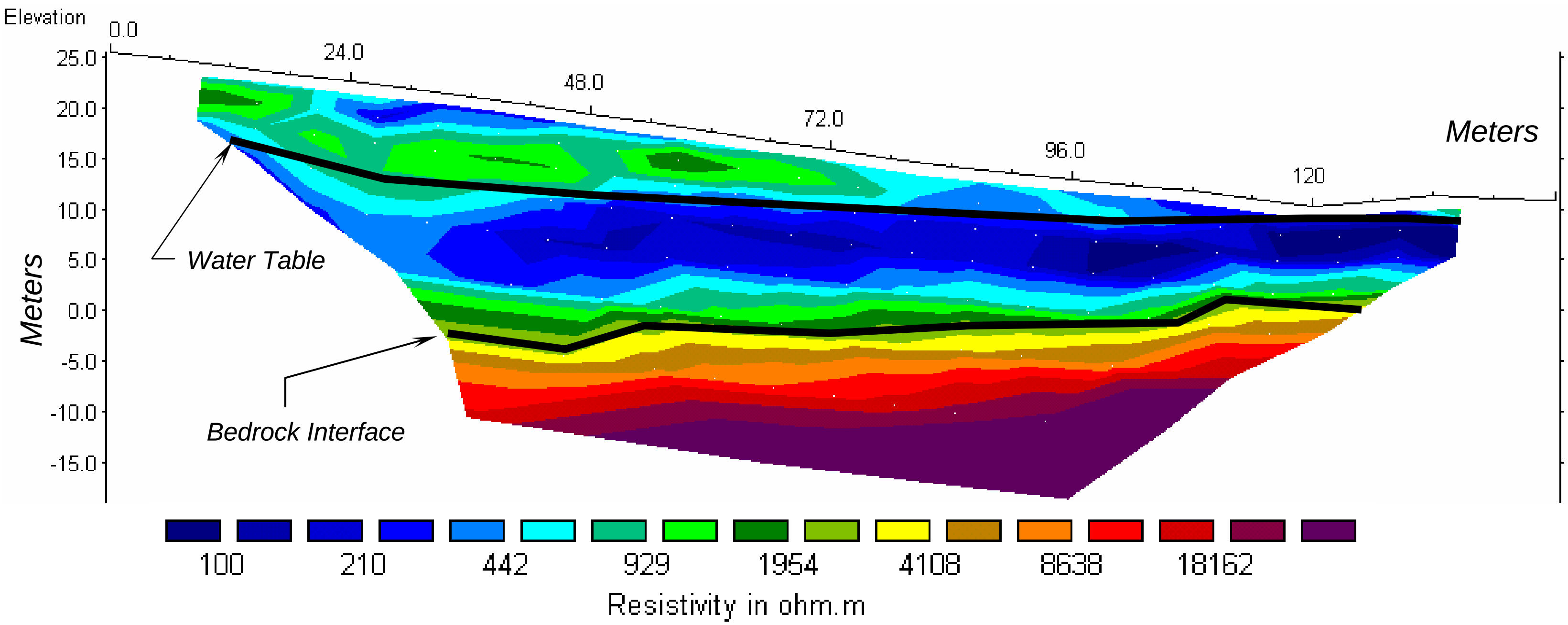
Deep Data Acquisition



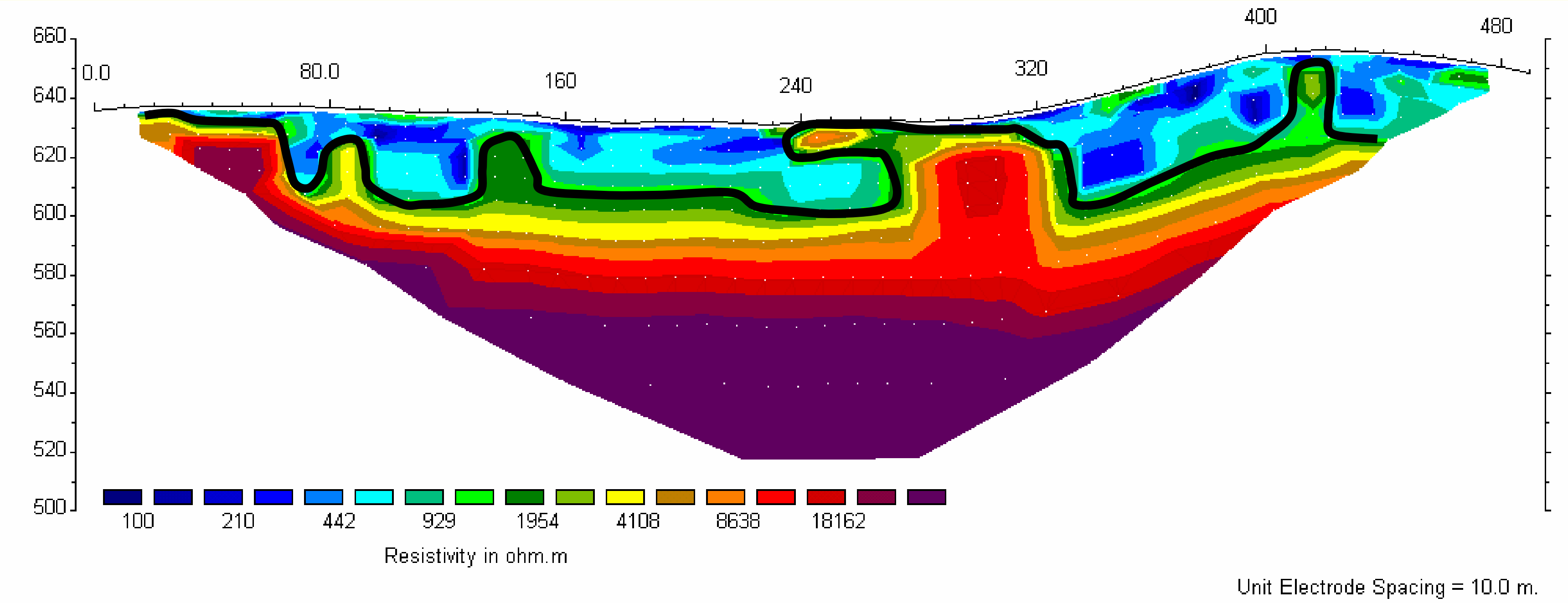
Apparent Resistivity



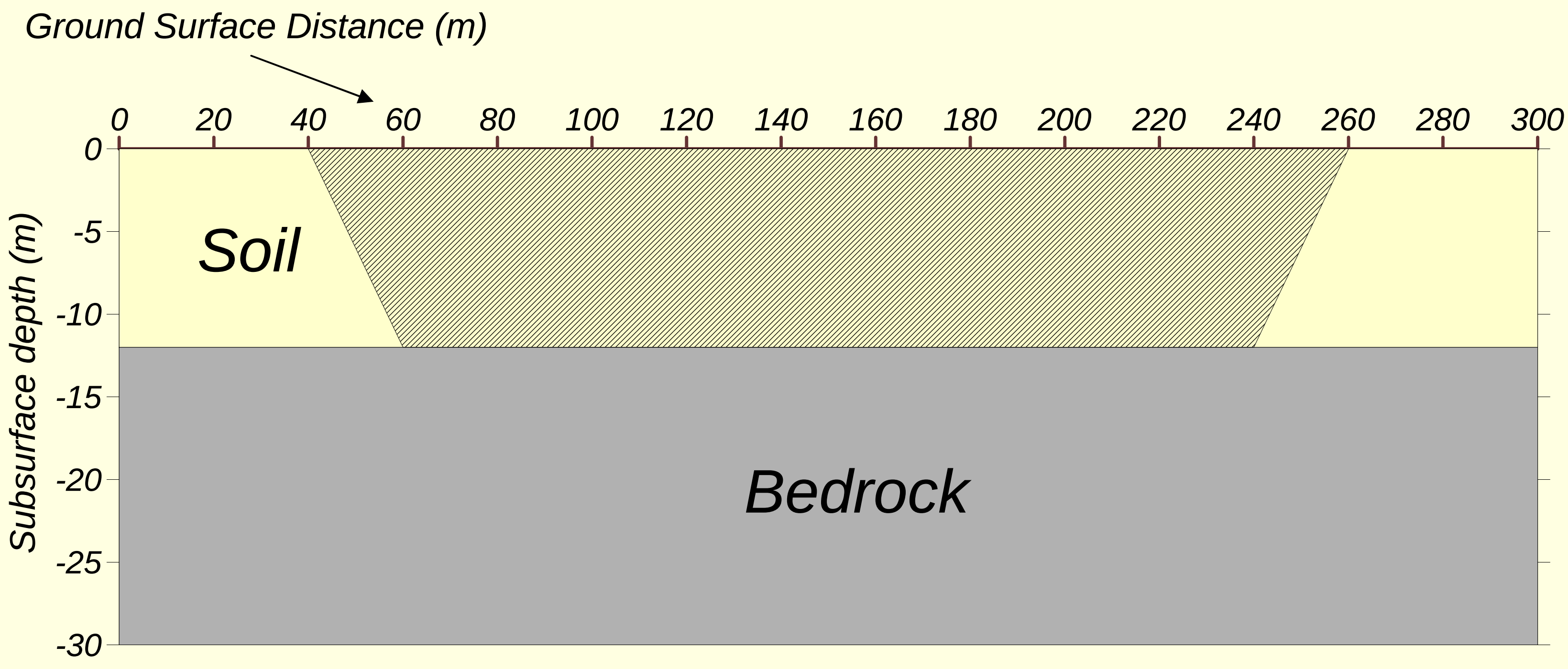
Earth Model after Inversion



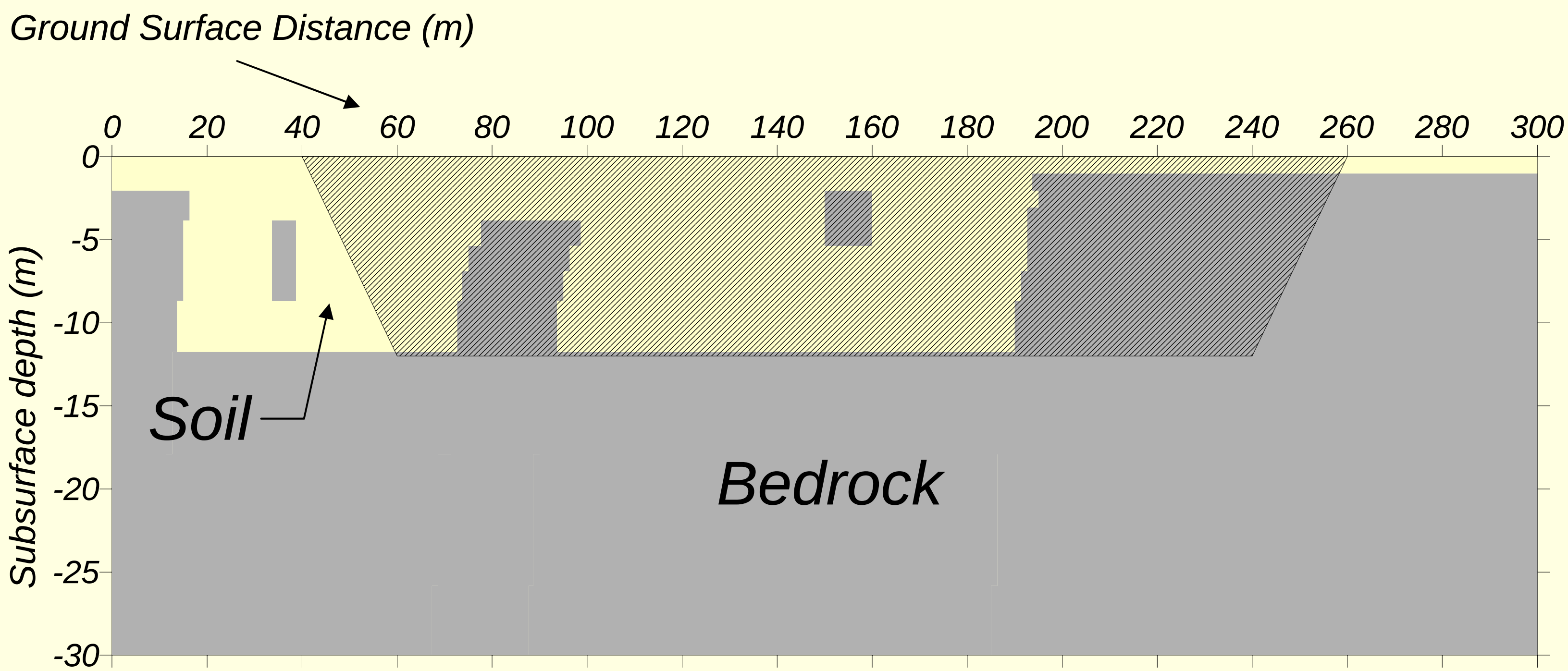
Irregular Bedrock Surface



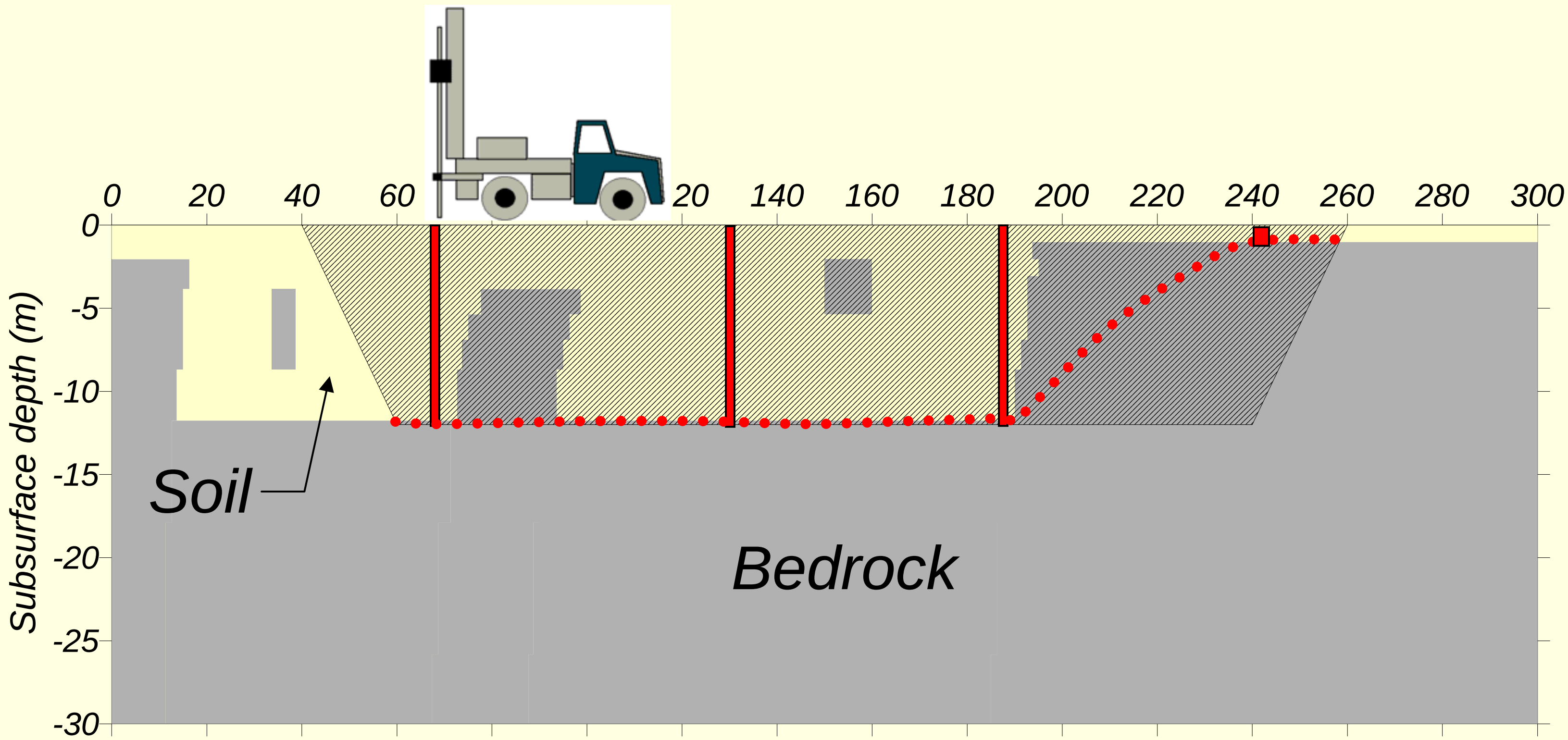
Example: Excavation Profile



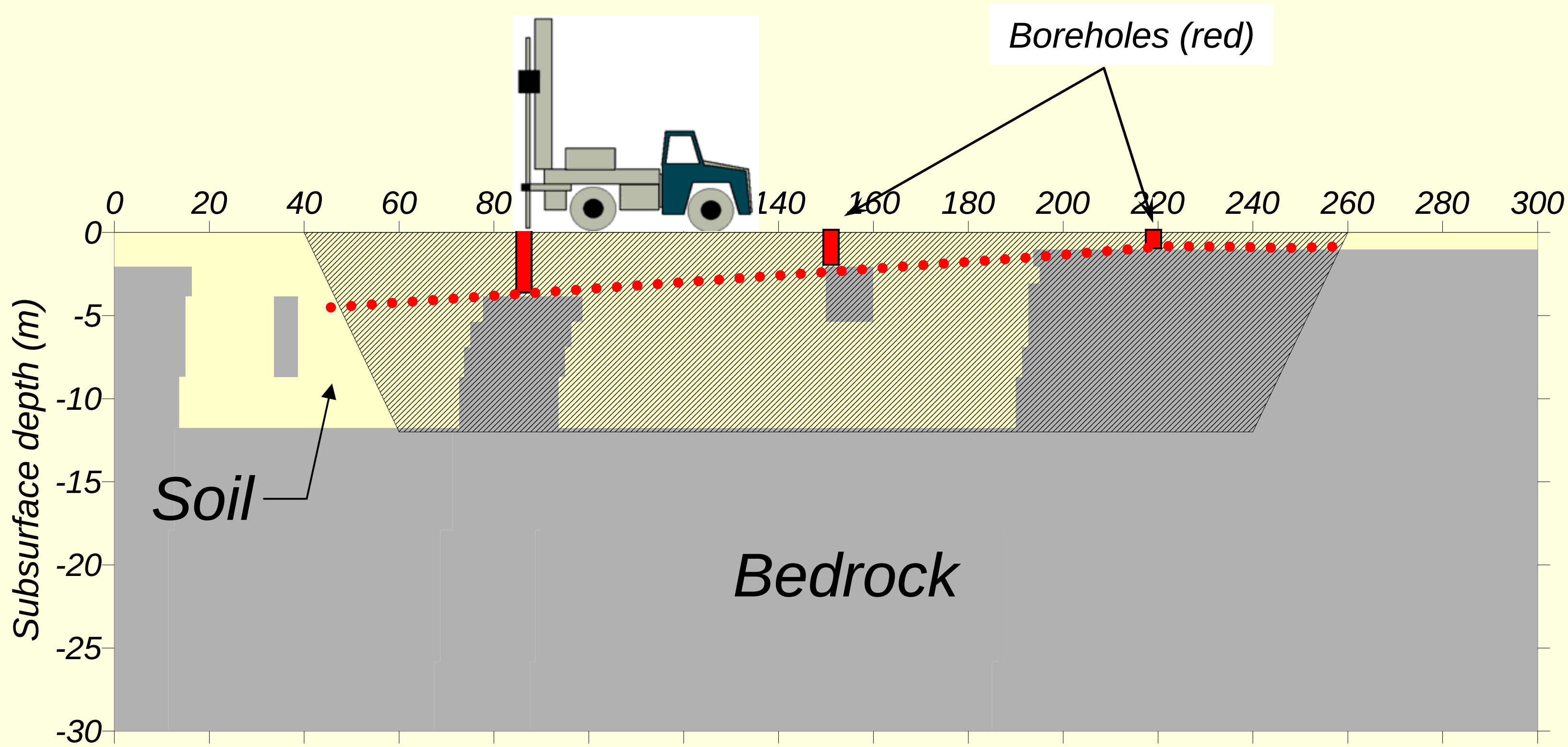
Example: Excavation Profile



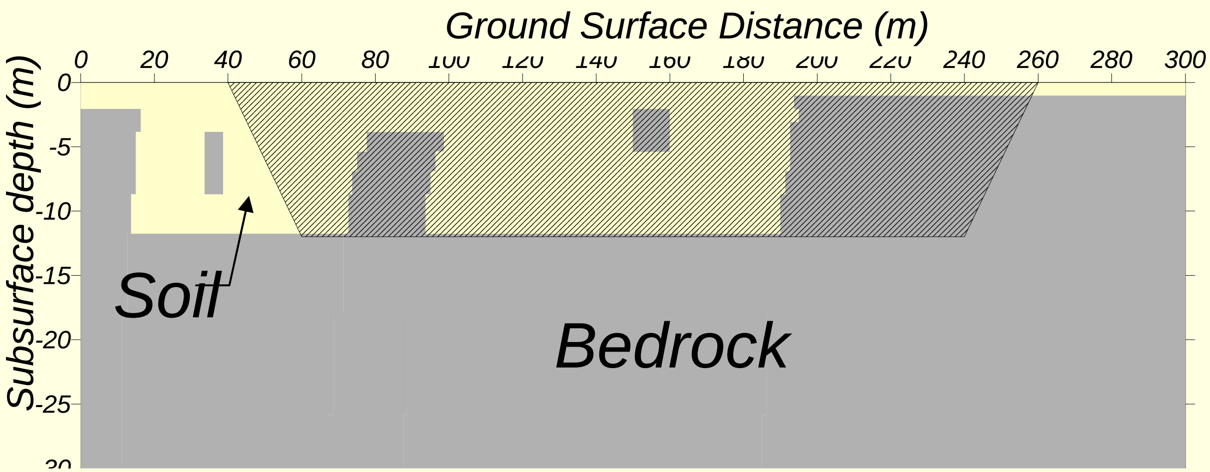
Underestimation of Rock

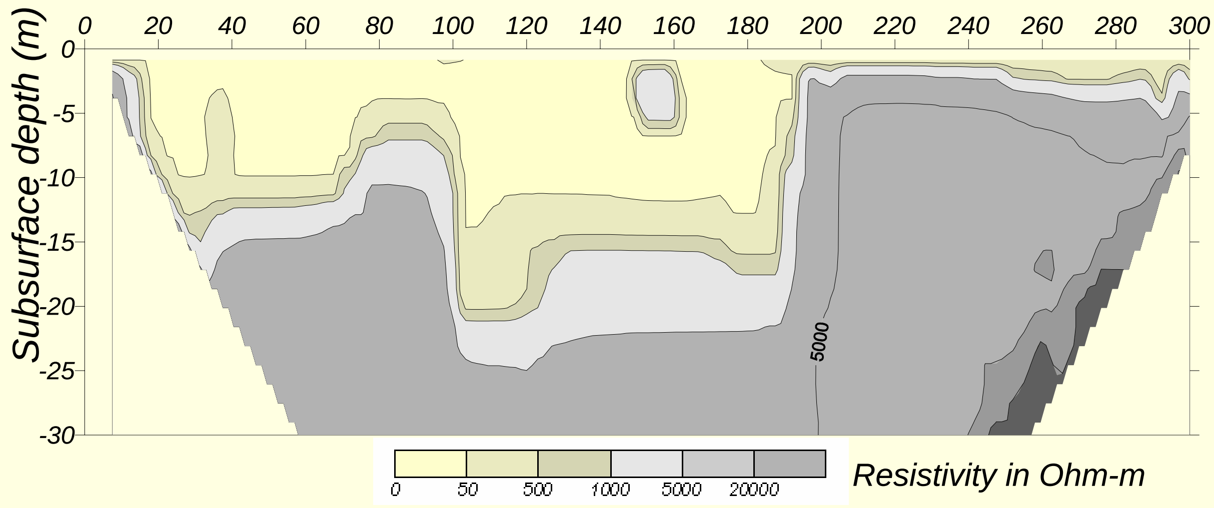


Overestimation of Rock

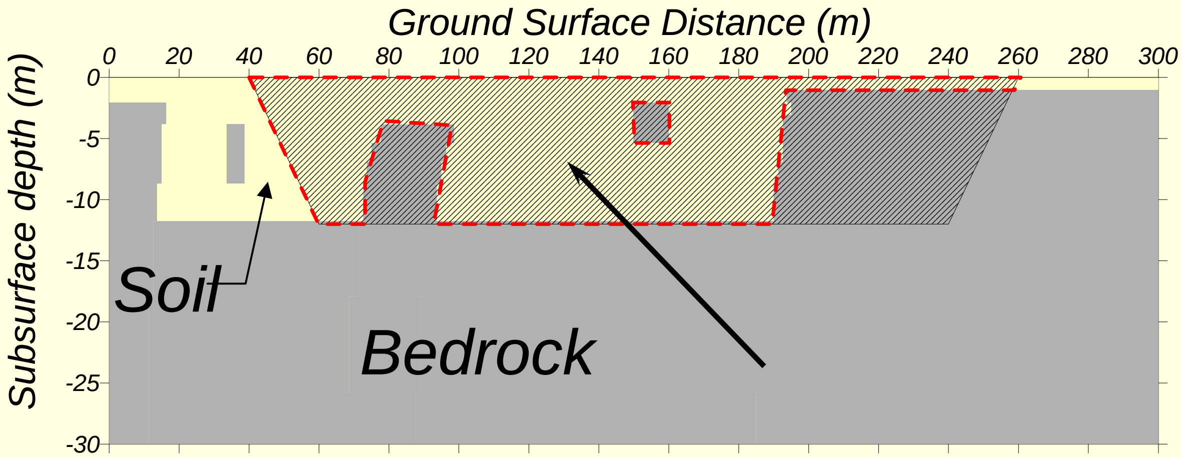


Synthetic Resistivity Section Based on our Example

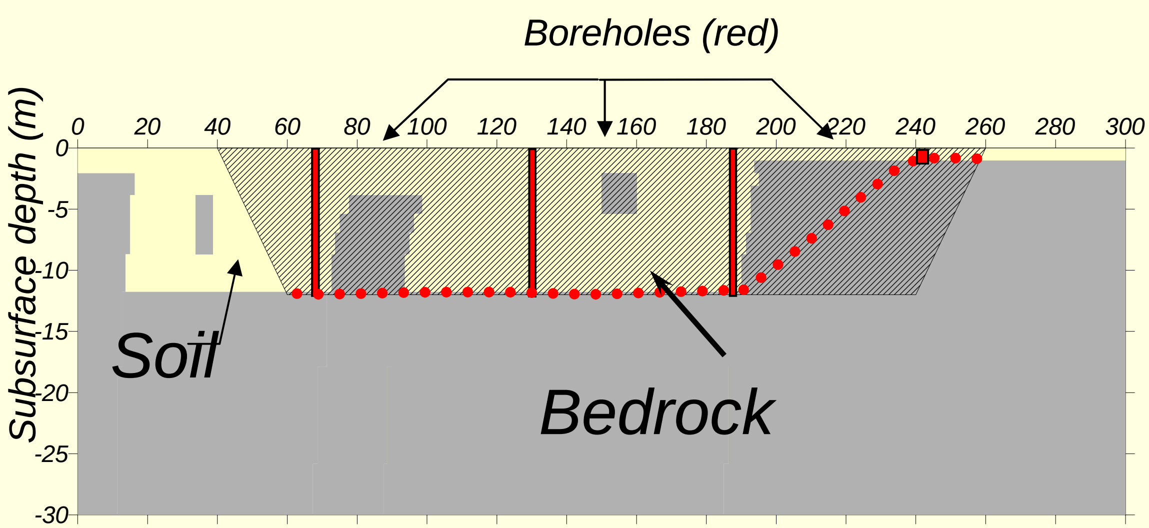




Underestimation of Rock with Limited Borings

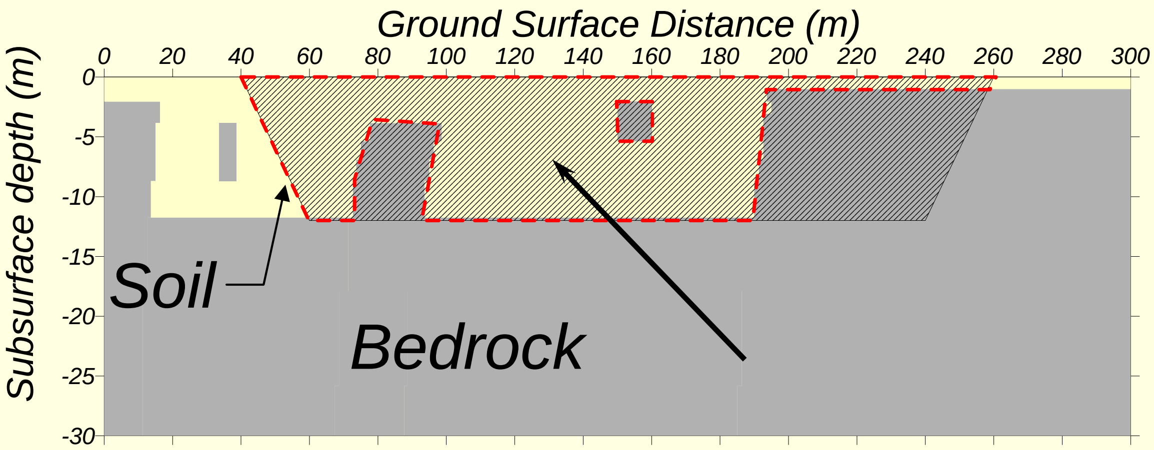


True Rock Area
810 m²

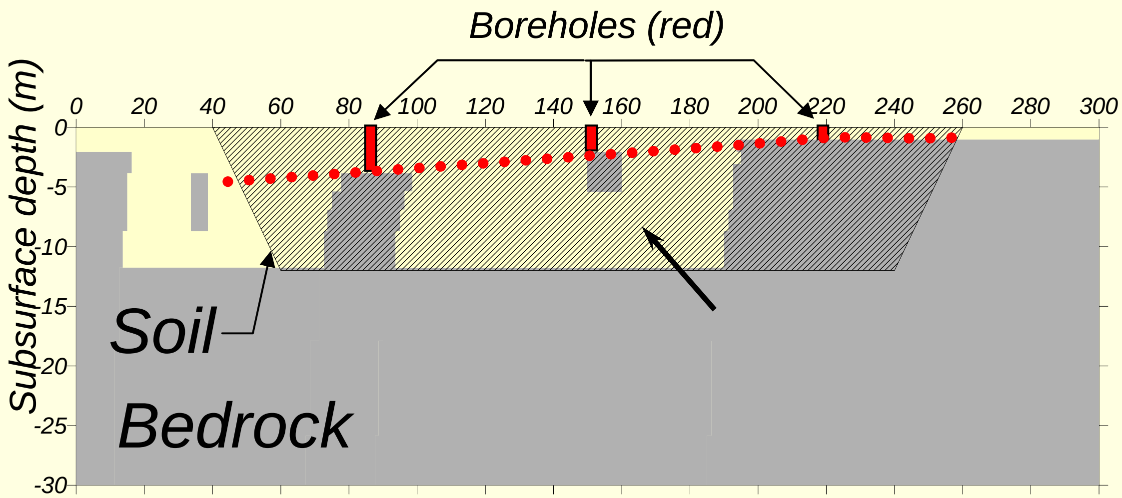


Rock Area from Borings
420 m² (-48% error)

Overestimation of Rock with Limited Borings

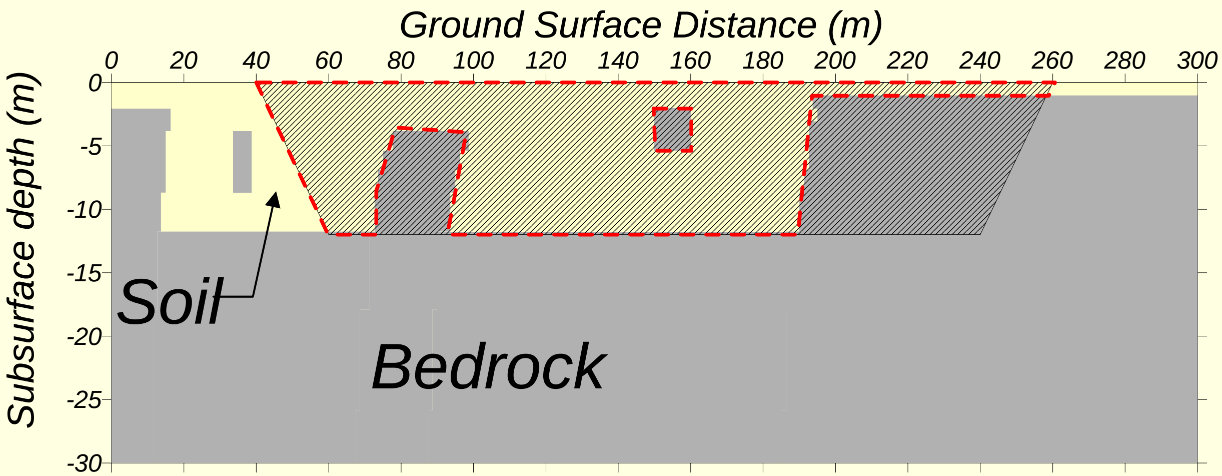


True Rock Area
810 m²

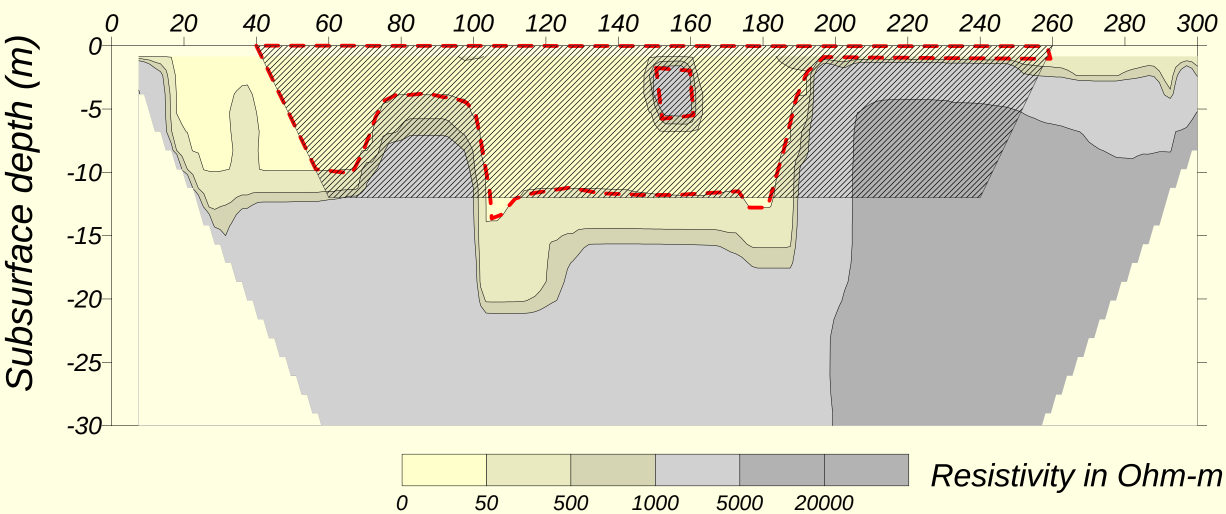


Rock Area from Borings
1861 m² (130% error)

Comparison of True Soil Area vs. Area Interpreted from Resistivity

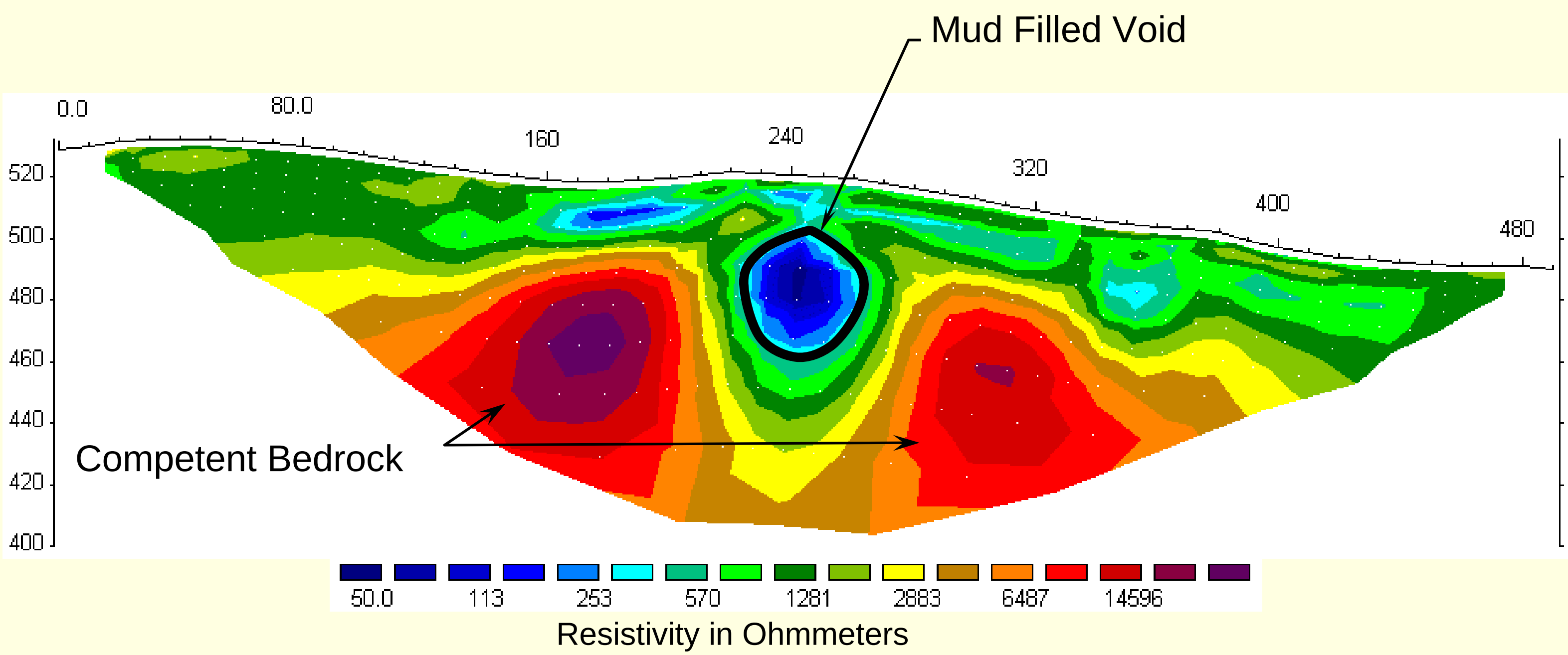


True Rock Area
810 m²



Rock Area from Resistivity
880 m² (9% error)

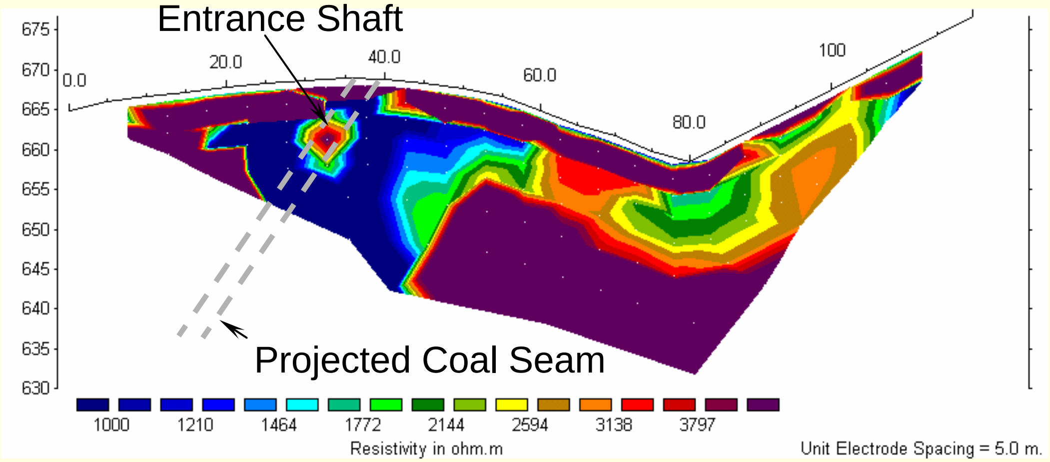
Karst Features/Voids



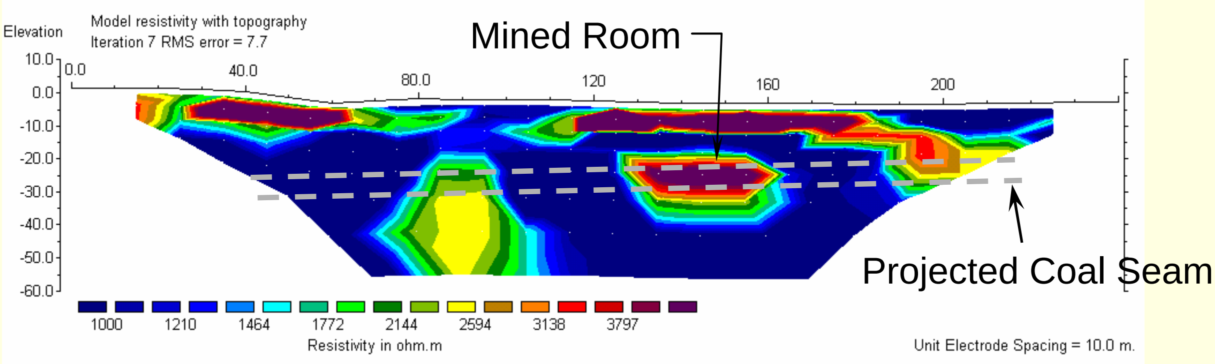
Air-Filled Voids: Abandoned Coal Mine

Resistivity and Ground Truth

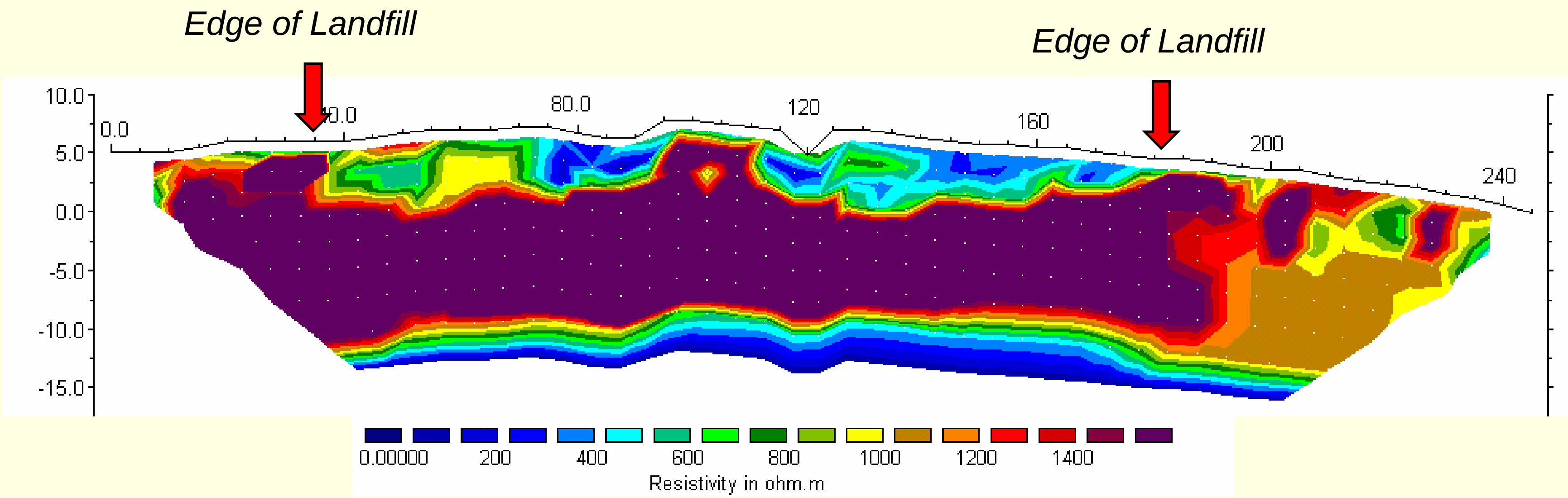
Resistivity Along Dip



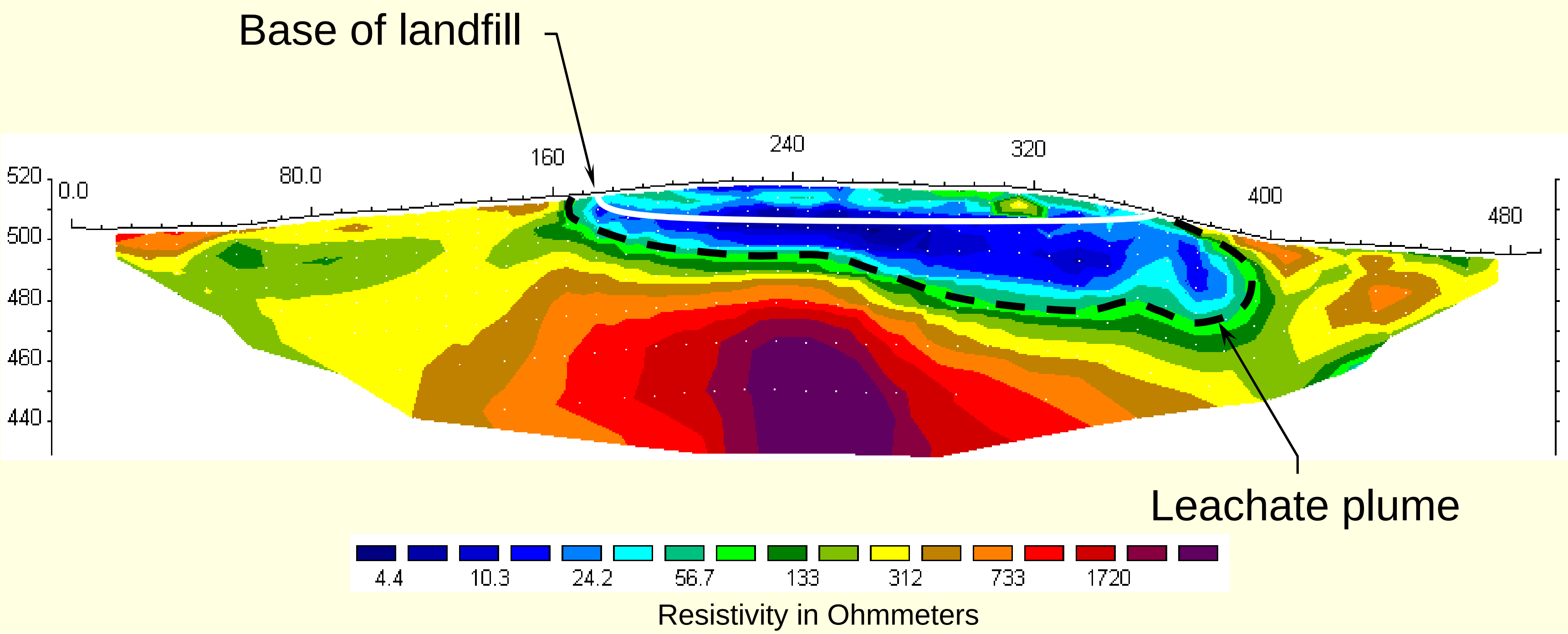
Resistivity Along Strike



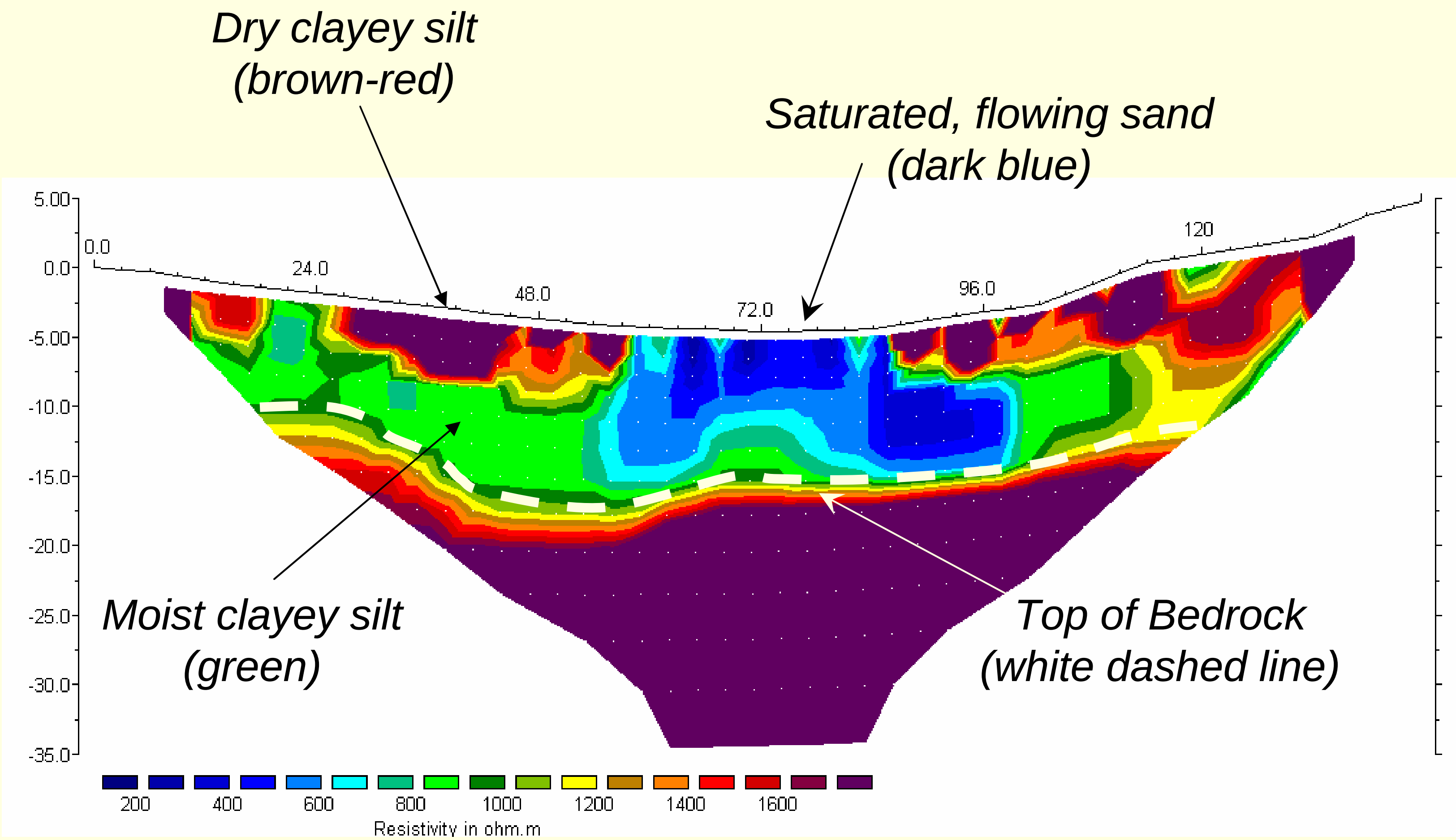
Landfill or Other Fill Materials



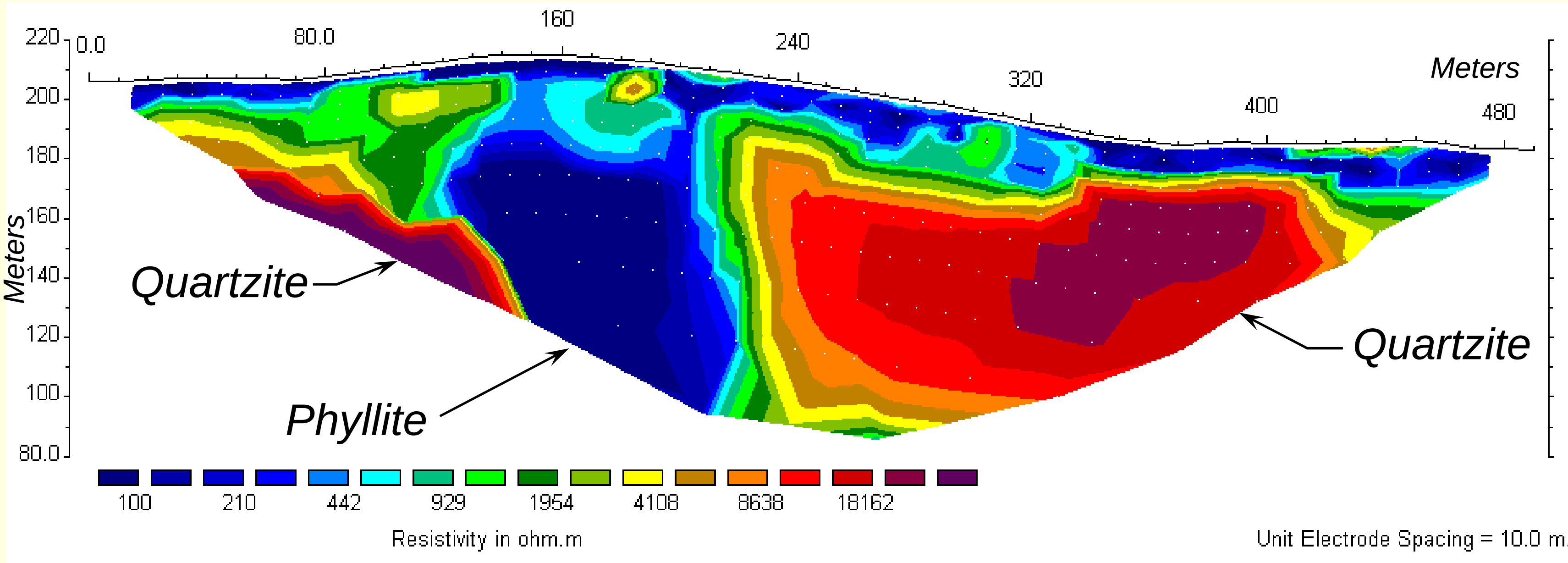
Contaminant Plumes



Relative Soil Moisture

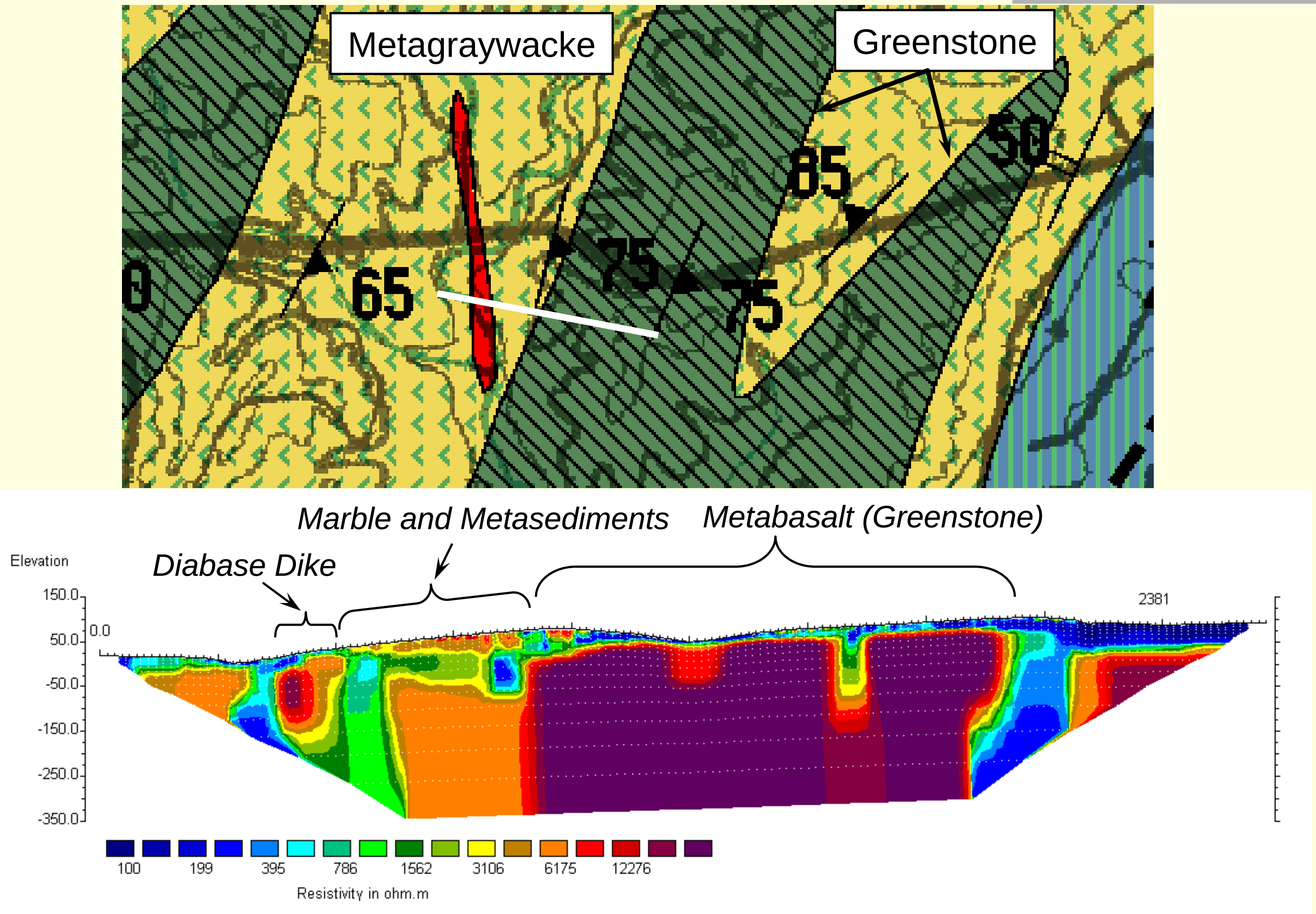


Fault Zones

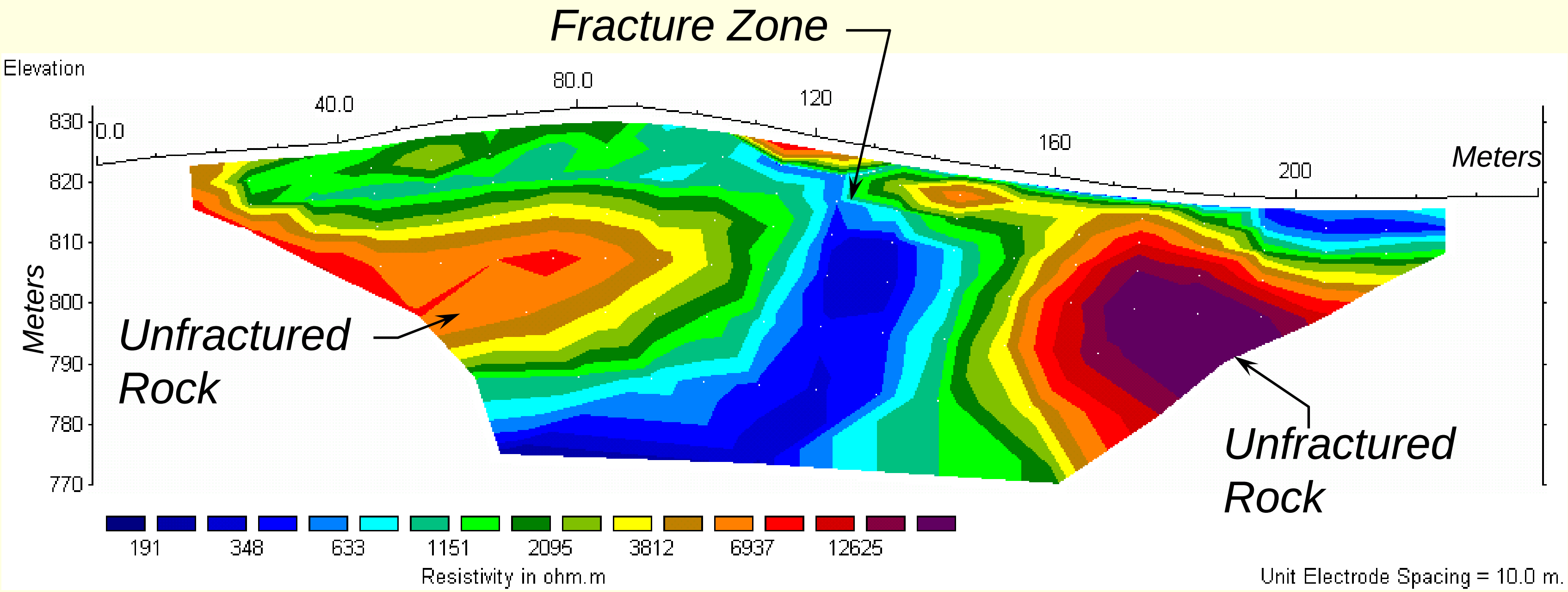


Meters
Quartzite
Quartzite
Phyllite
220
200
180
160
140
120
100
80.0
0.0
80.0
160
240
320
400
480
Meters
100
210
442
929
1954
4108
8638
18162
Resistivity in ohm.m
Unit Electrode Spacing = 10.0 m.

Lithologic Changes

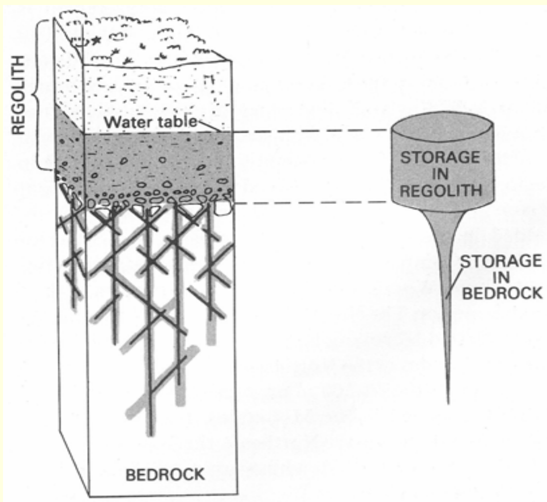


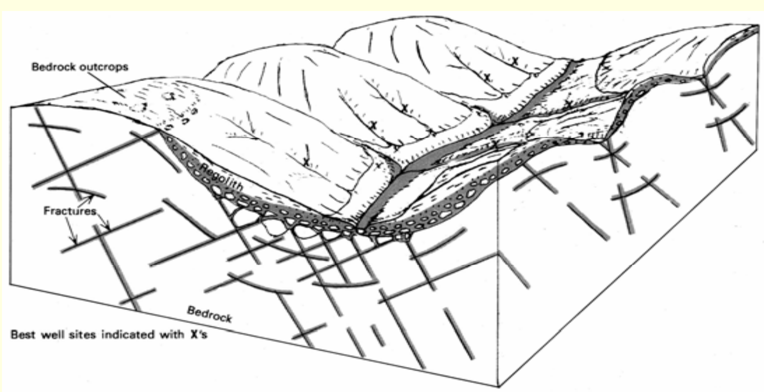
Fracture Zones



Previous Conceptual Model of Piedmont and Blue Ridge Aquifers

(Heath 1984, LeGrand, 1967)

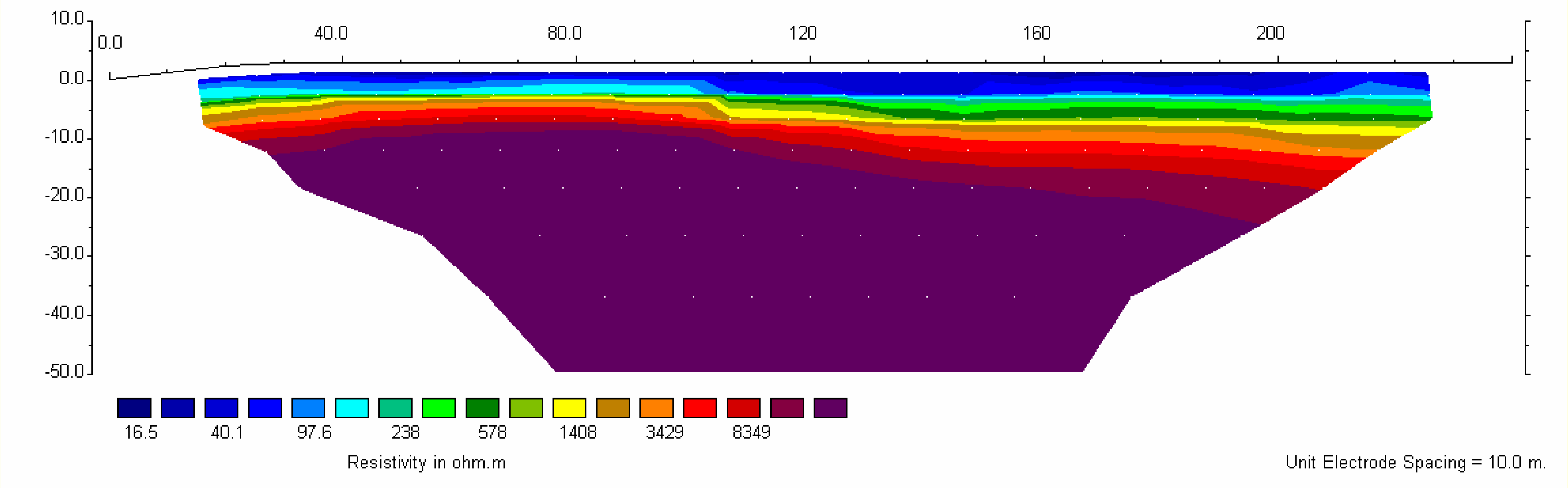




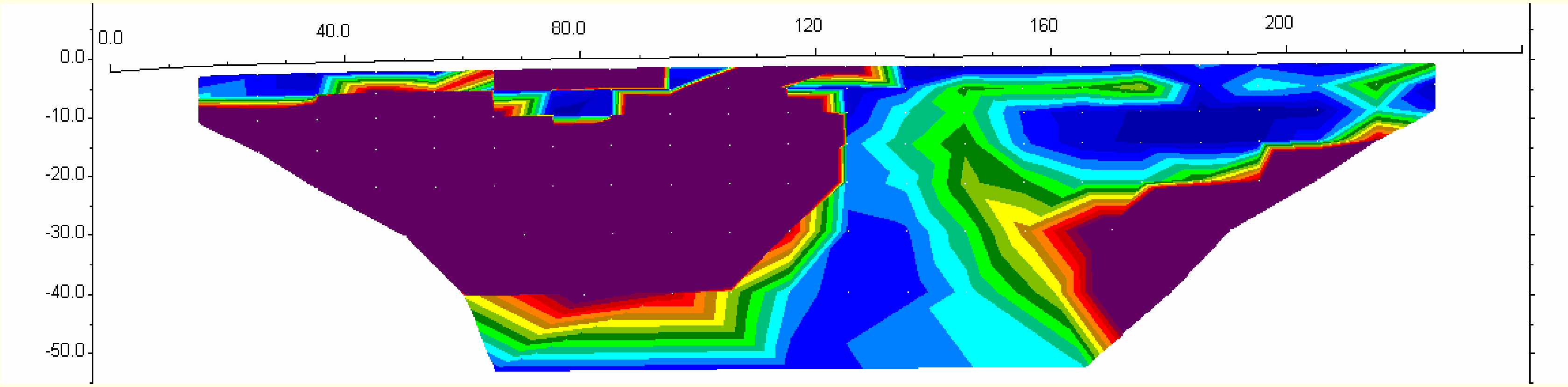
- **Shallow water table aquifer in saprolite**
- **Downward vertical flow from shallow aquifer to fractures in deep bedrock**
- **Water storage primarily in saprolite**
- **Similar hydraulic conductivities in saprolite and bedrock fractures**
- **Recharge occurs over majority of land surface**

Expected Results from Resistivity Profiles in a Crystalline Rock Terrane

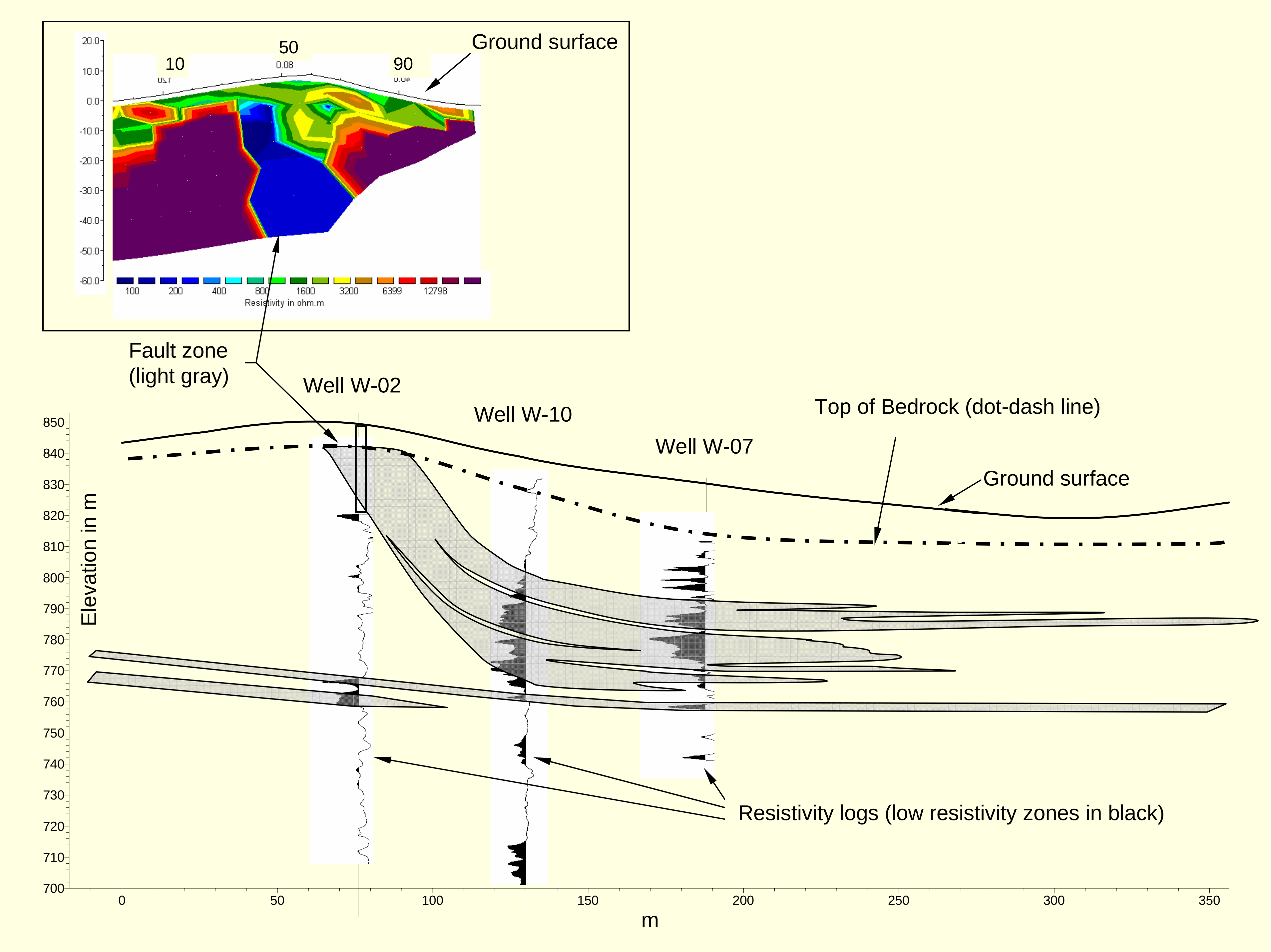
- thin shallow low resistivity zone (blue-yellow) in regolith
- massive high resistivity zone (red-dark red) in bedrock



Unexpected Results from Resistivity Profiles in a Crystalline Rock Terrane

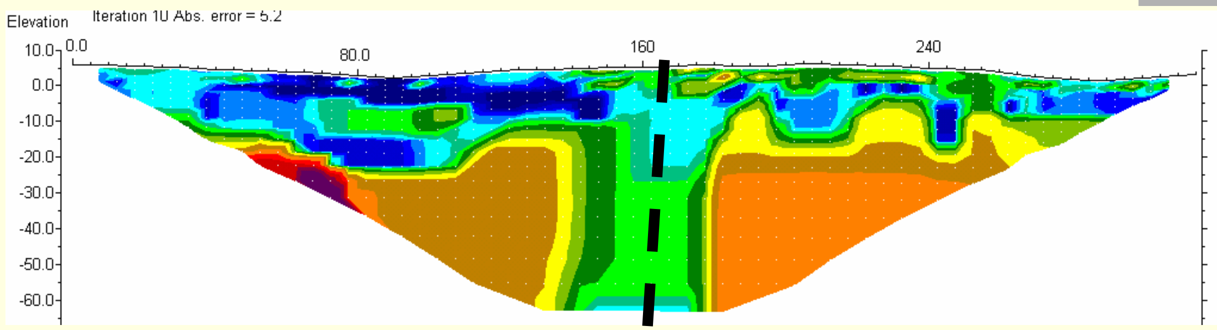


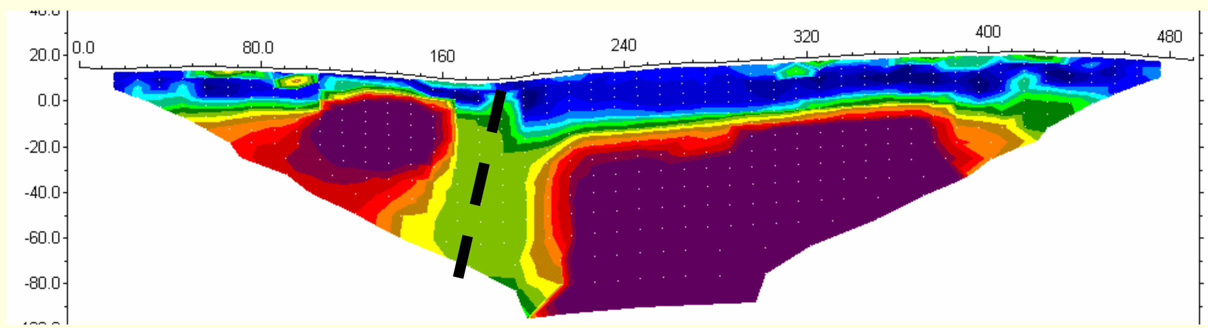
On the edge of the Blue Ridge Fault near Salem,Va.

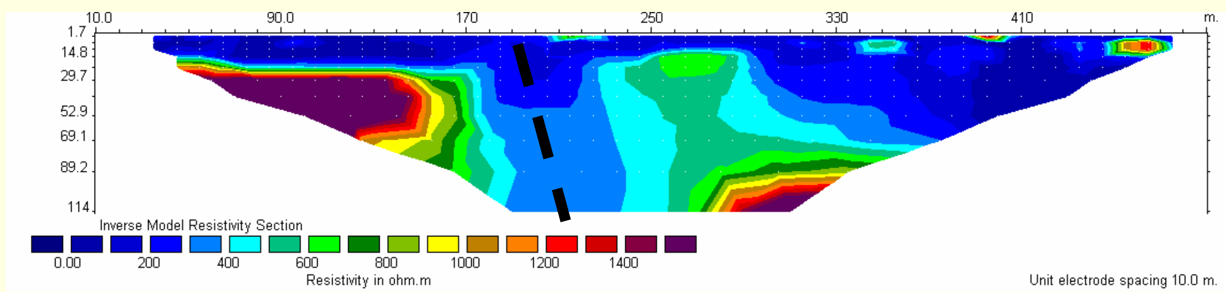


Ground surface
10
50
90
Resistivity in ohm.m
100
200
400
800
1600
3200
6399
12798
Fault zone
(light gray)
Well W-02
Well W-10
Well W-07
Top of Bedrock (dot-dash line)
Ground surface
Elevation in m
Resistivity logs (low resistivity zones in black)
m

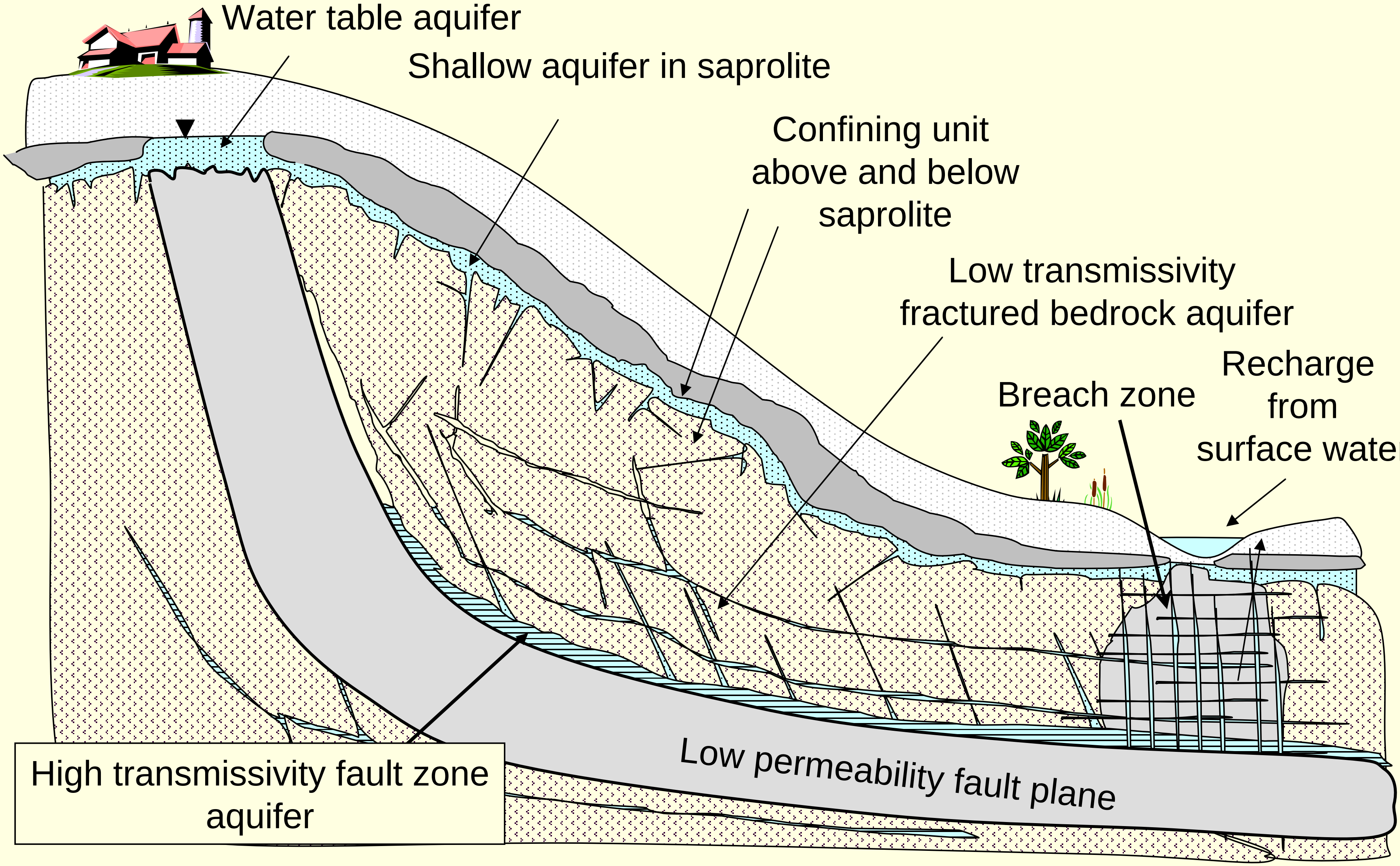
Steeply Dipping Fault/Fracture Zones



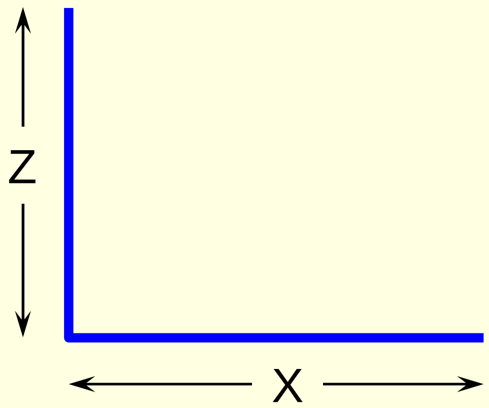




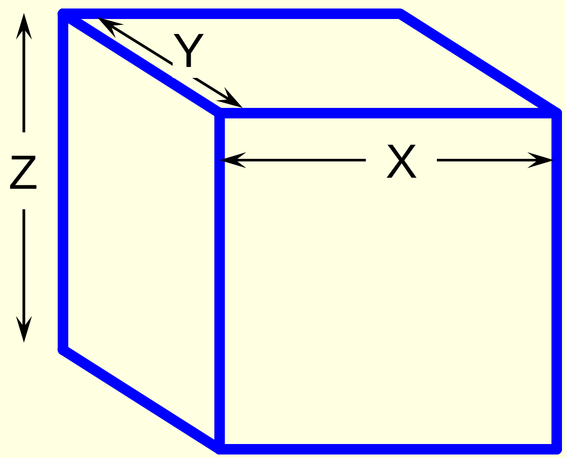
Conceptual Model for Groundwater Flow in the Blue Ridge Province



3-Dimensional Resistivity



2-D Resistivity measures in the X-Z plane



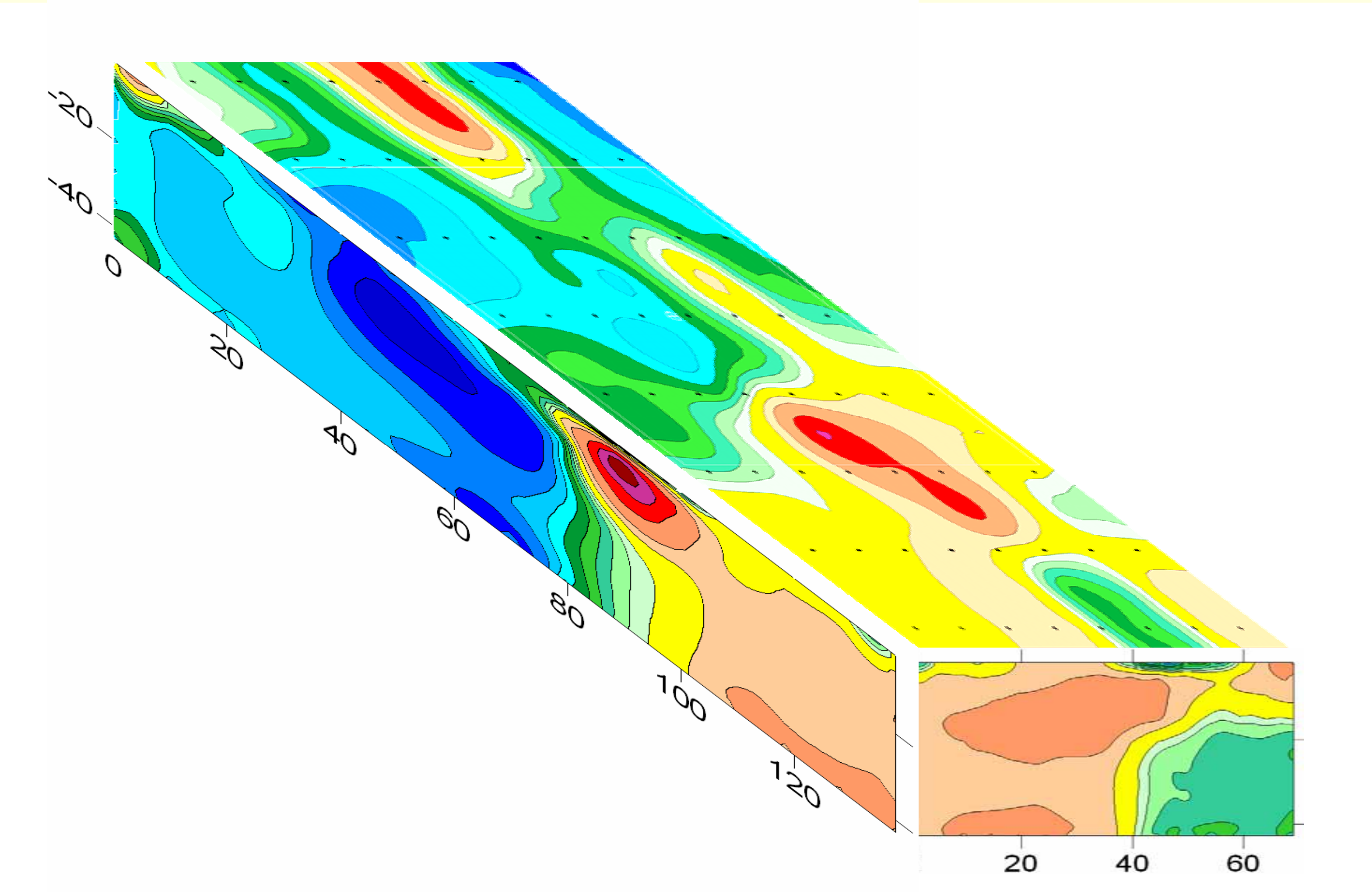
3-D Resistivity measures in:

- **X-Z Plane**
- **X-Y Plane**
- **Y-Z Plane**

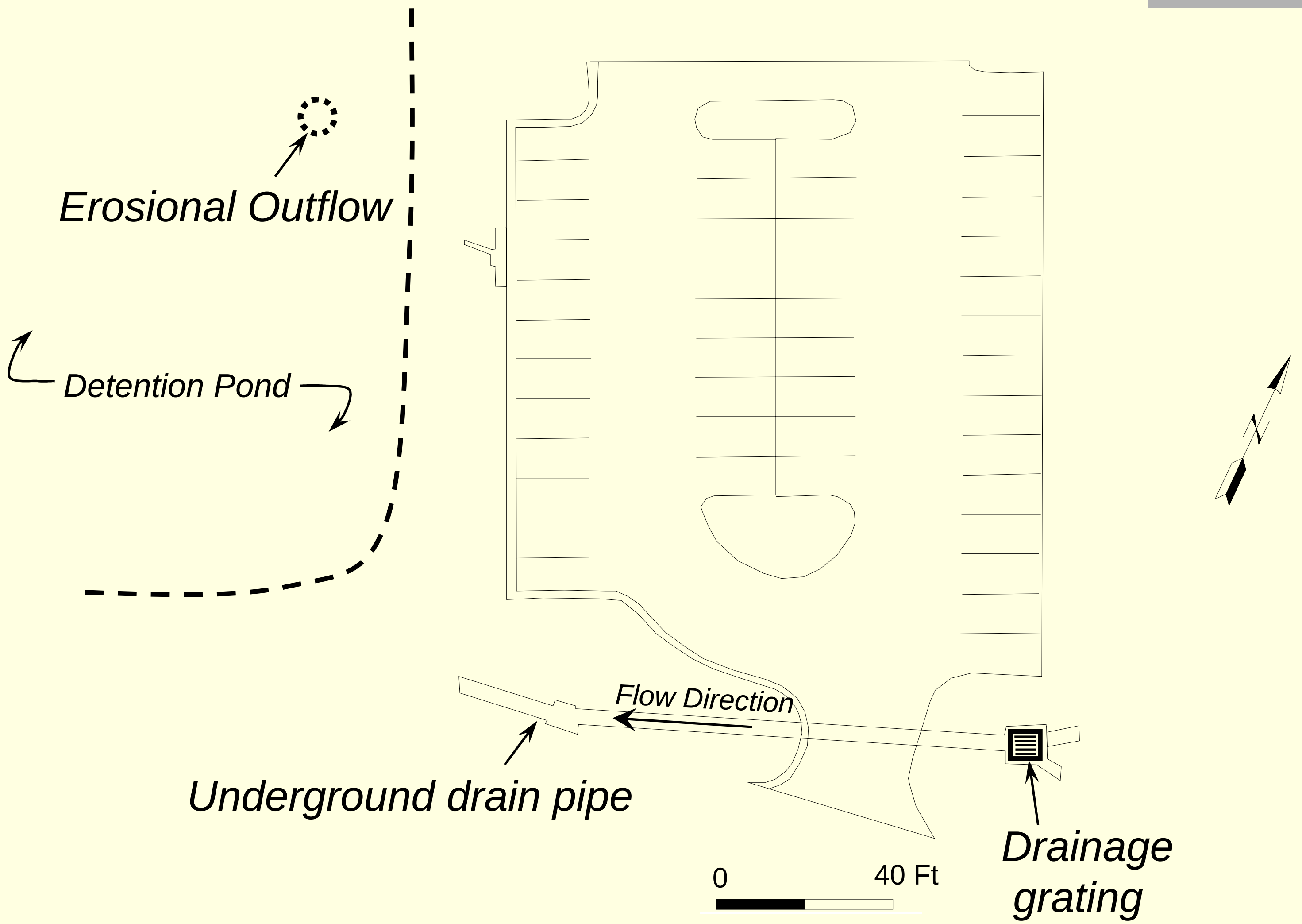
Two Possible Approaches

- Quasi 3-D: A series of 2-D resistivity sections collected in parallel lines; modeled using 3-D methods
- Explicit 3-D: Electrodes placed in a grid pattern

3-D Results



Example



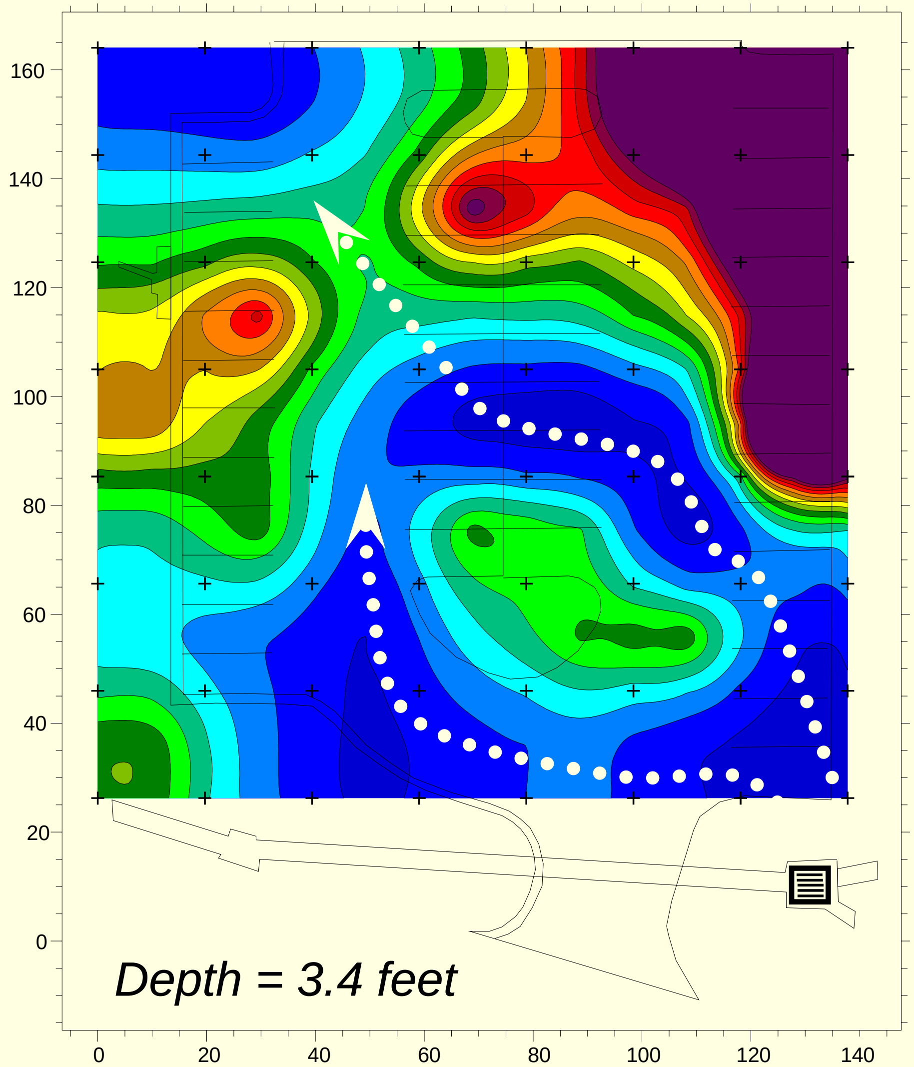
Erosional Outflow
Detention Pond
Flow Direction
Underground drain pipe
Drainage grating
0
40 Ft

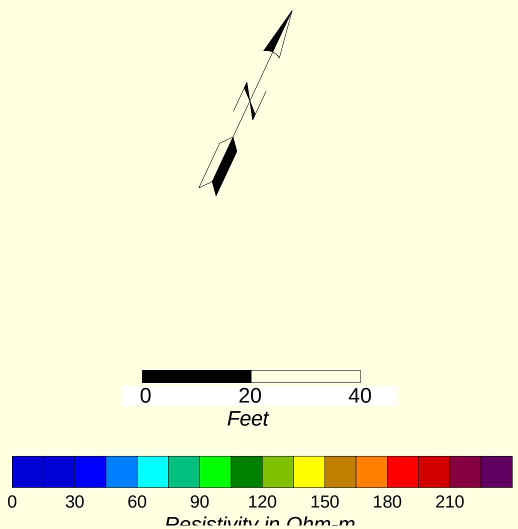
Looking Northwest

Looking North

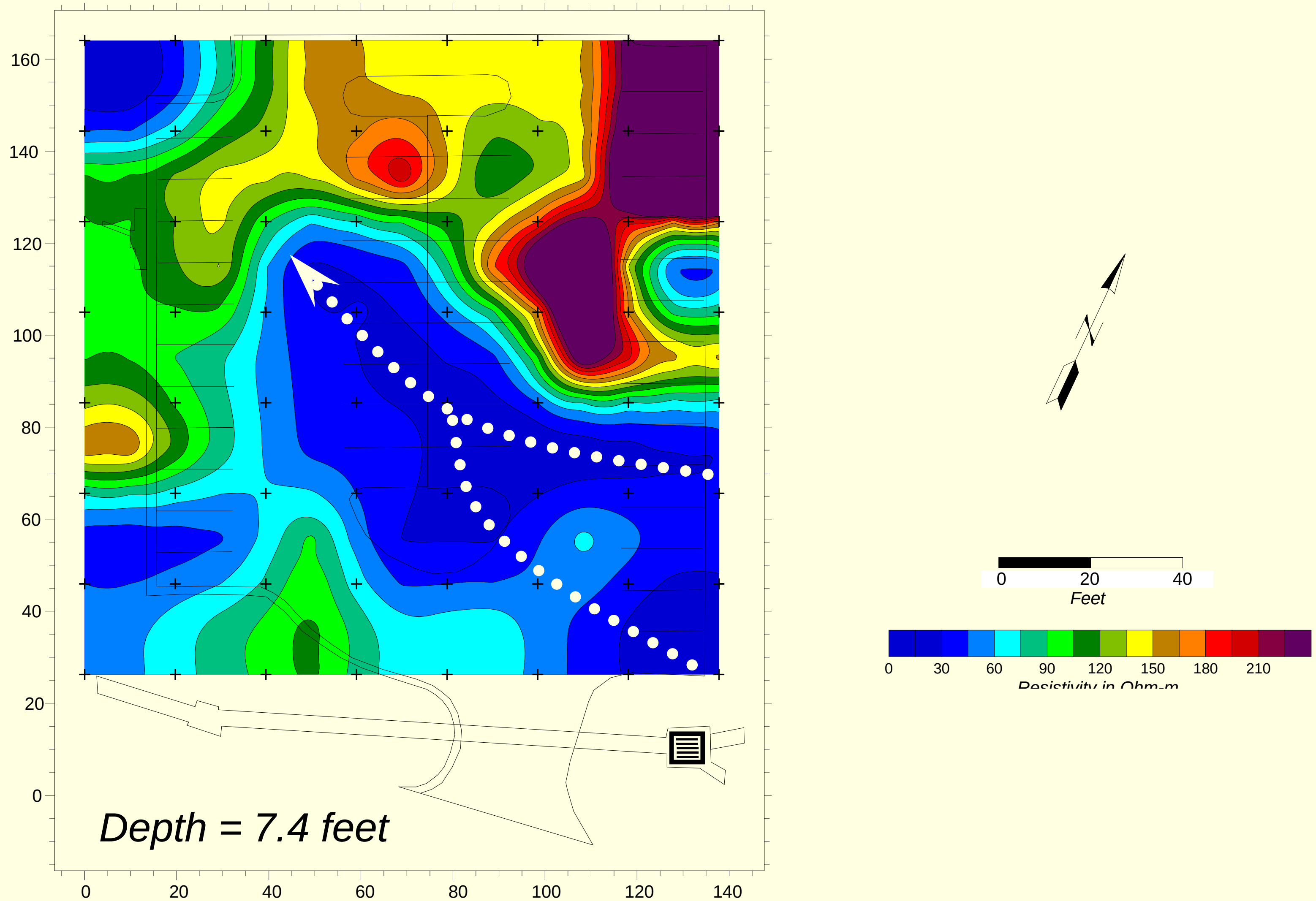
Looking West

Horizontal Depth Slice at 3.4 Feet

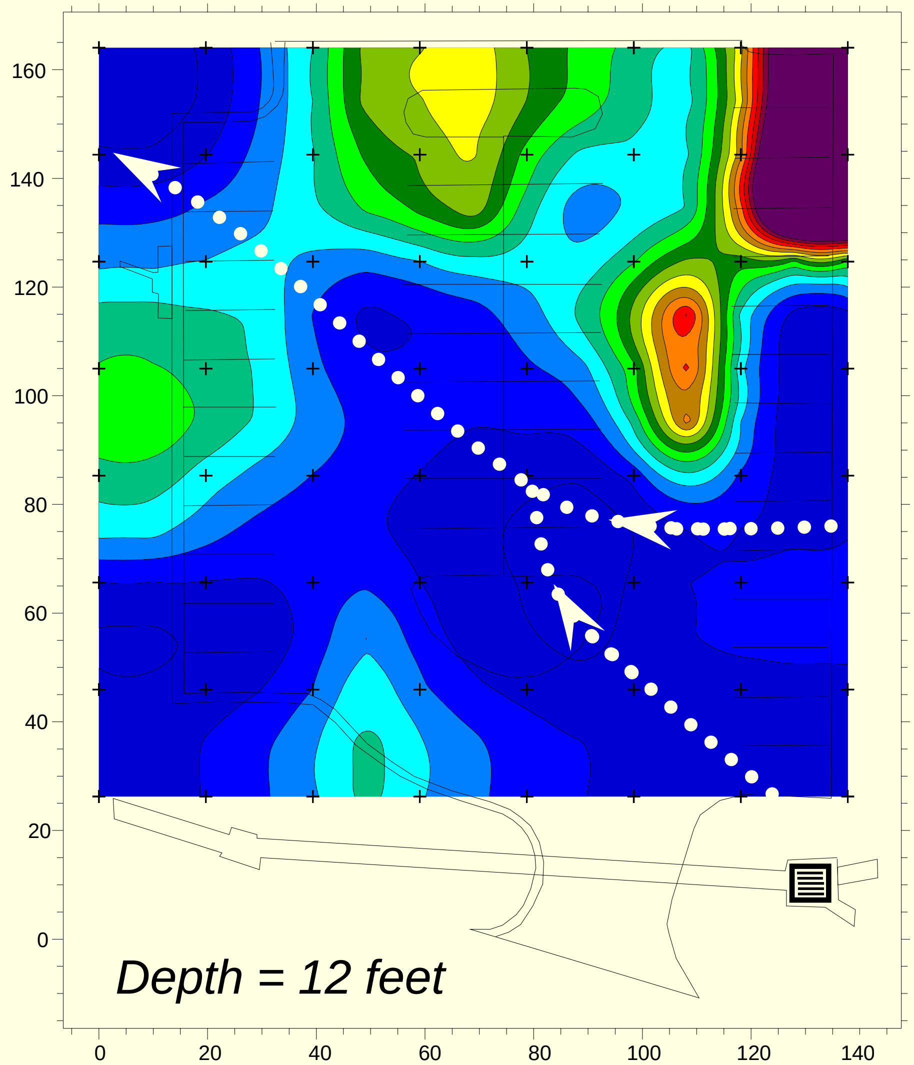


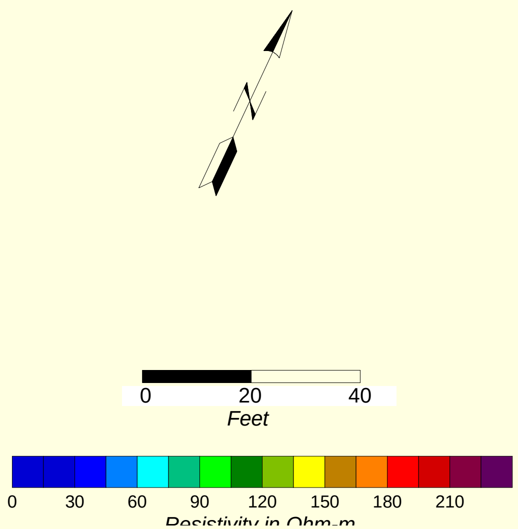


Horizontal Depth Slice at 7.4 Feet



Horizontal Depth Slice at 12 Feet



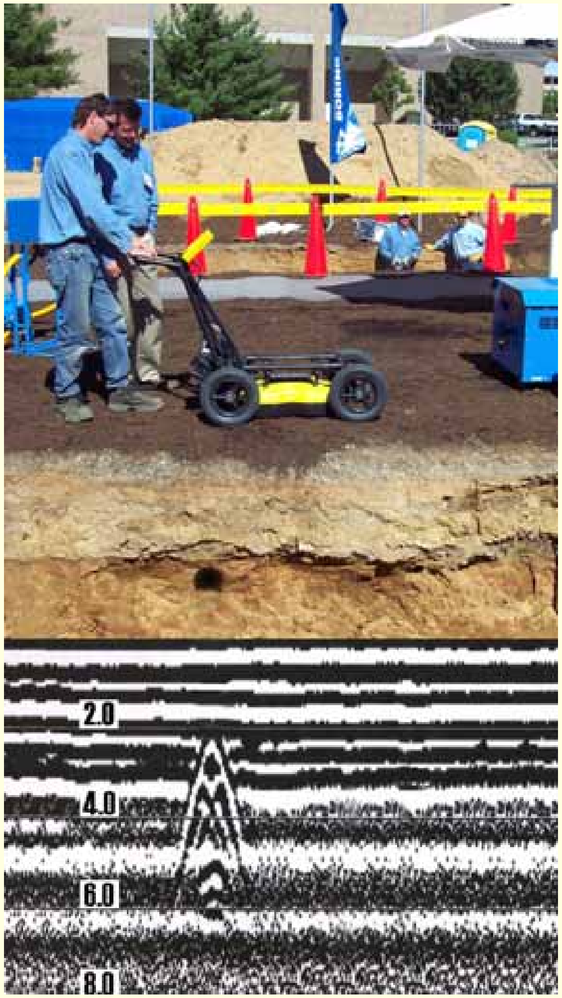


Summary of Resistivity Applications

- **Bedrock mapping-more comprehensive than borings alone.**
- **Water Table Mapping**
- **Lithology Changes**
- **Subsurface Voids**
- **Fracture Zones in Rock**
- **Contaminant Plumes**
- **Fill Materials**

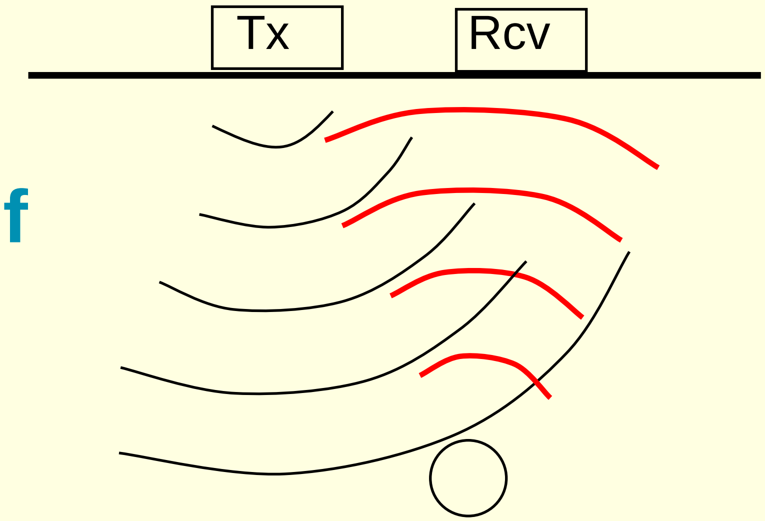
Ground Penetrating Radar (GPR)

- **Location of Buried drums or tanks**
- **Location of Buried Utilities**
- **Archeological-forensic studies**
- **Delineation of Landfills and trenches**



Principles

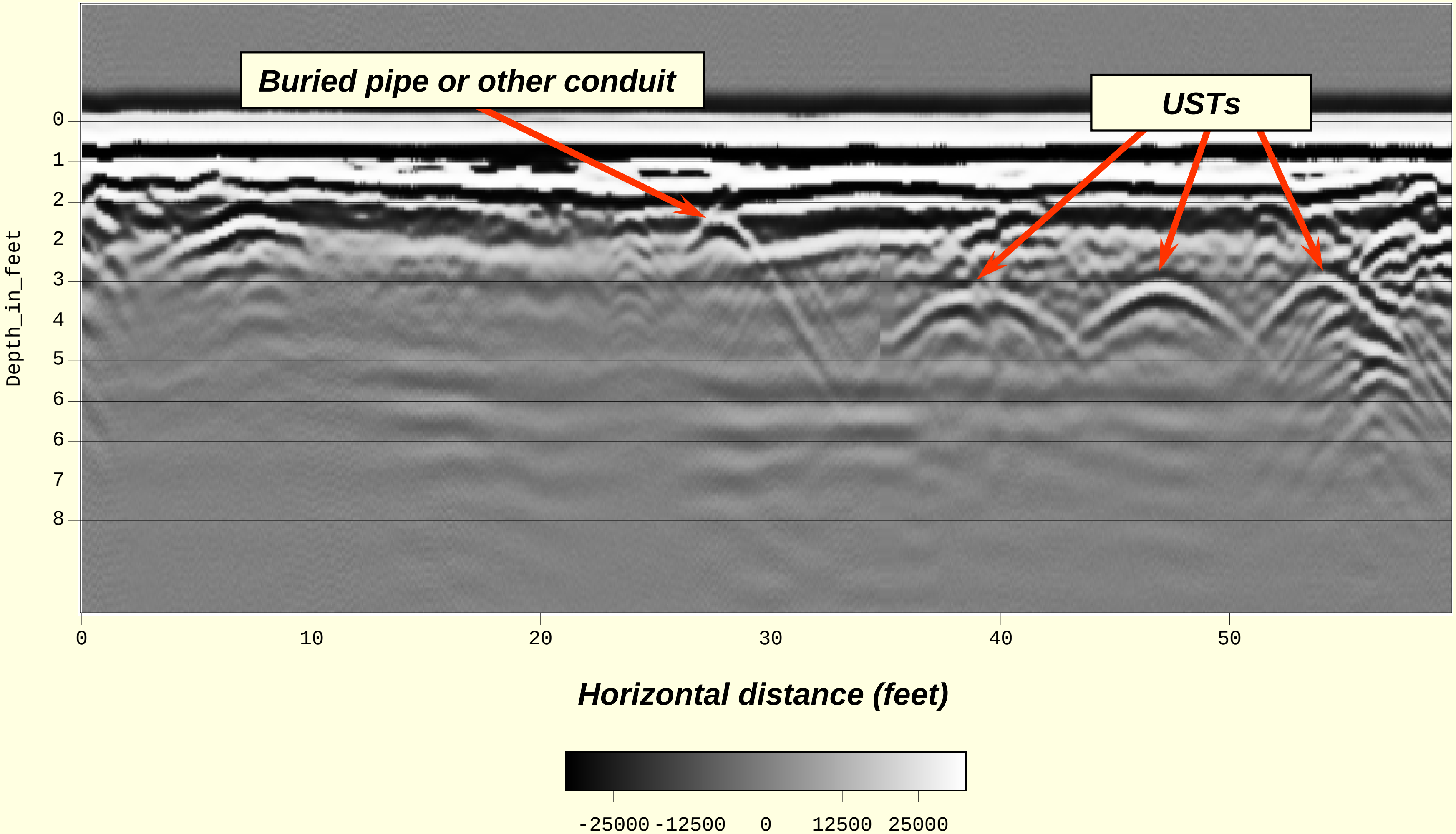
- Transmitter emits pulses of high-frequency radio waves.
- Waves are reflected off of subsurface objects and travel back to a receiver.
- The greater the contrast in electrical properties between materials the stronger the reflection.



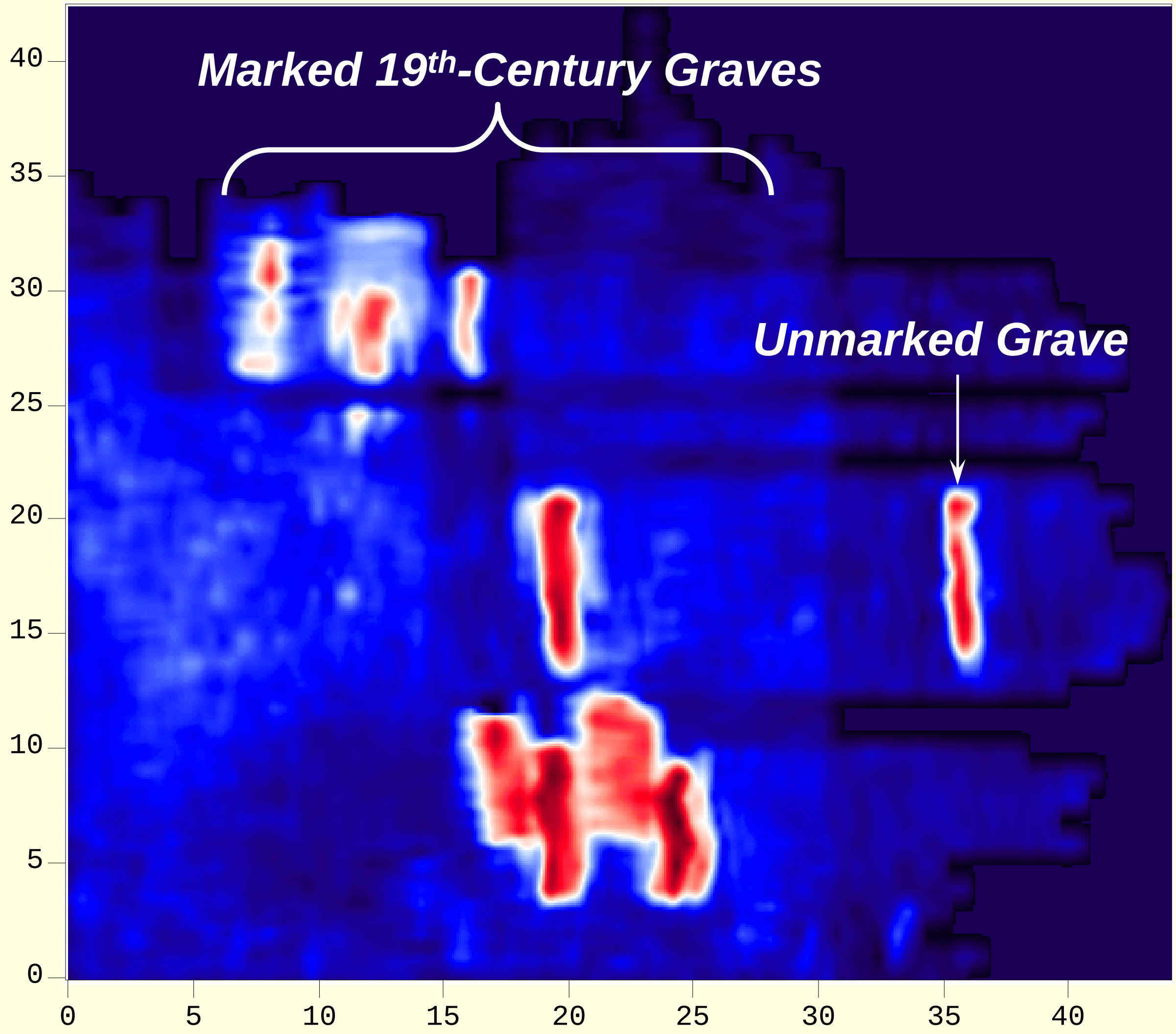
Penetration vs. Resolution

- **Frequency: Lower frequencies penetrate deeper but have lower resolution.**
  - **200 MHz to 300 MHz will generally penetrate 6 to 12 feet- Buried utilities and Archaeological Studies**
  - **1000 MHz will penetrate 1 to 2 feet- Concrete testing**
- **Electrical Conductivity of Material: Penetration is inversely proportional to the conductivity of the material.**

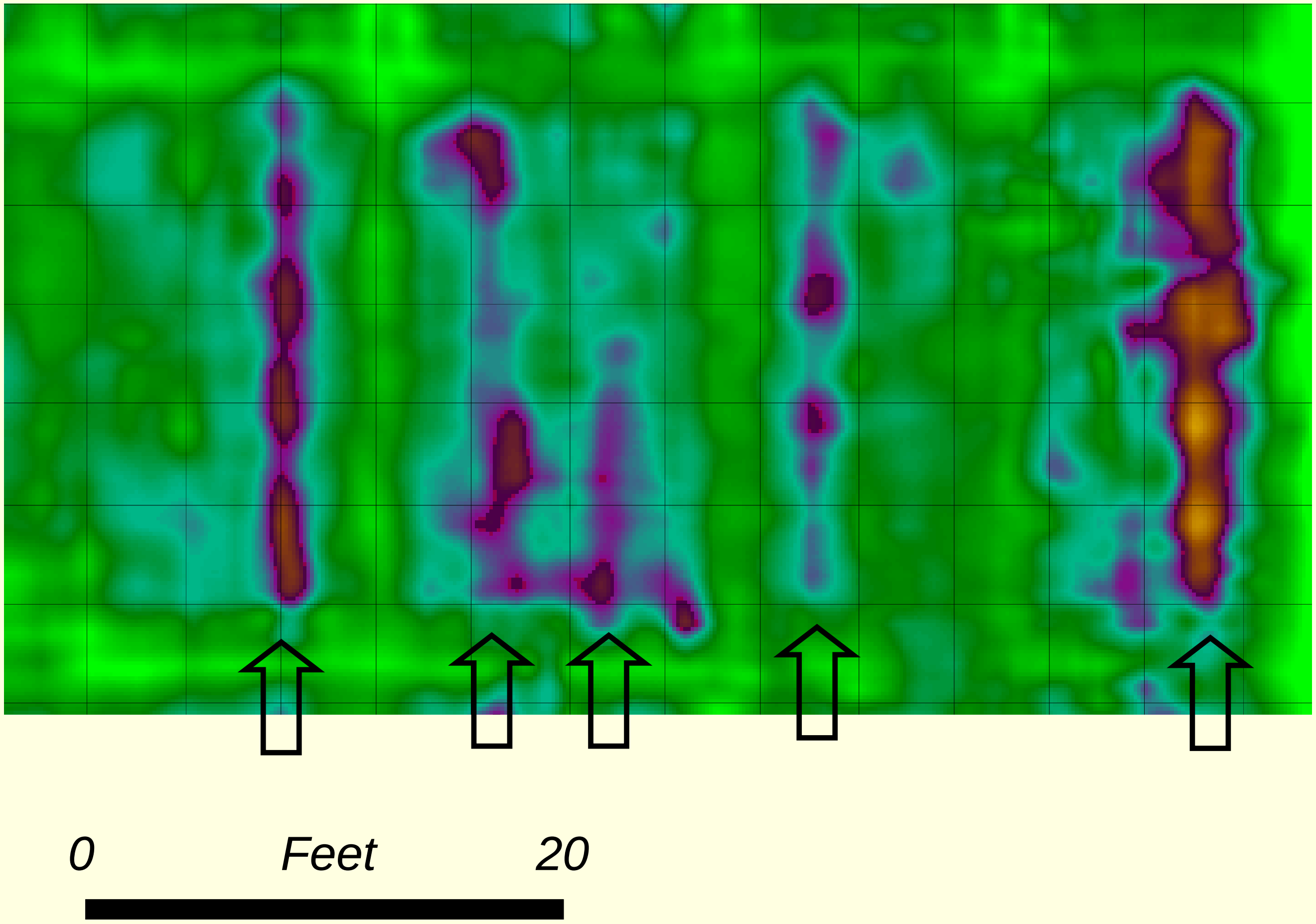
GPR in Cross-Section



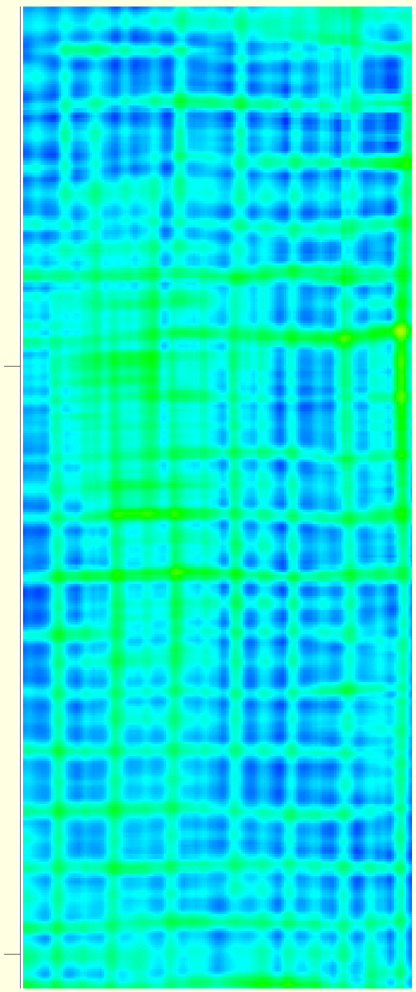
Archaeological Studies



USTs



Concrete Reinforcement and Utilities



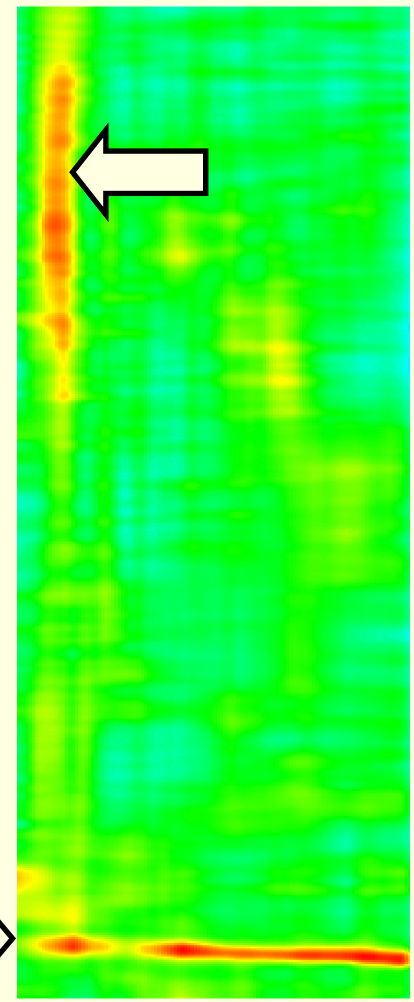
Rebar/wire mesh

Depth 2.5 -7.5 inches

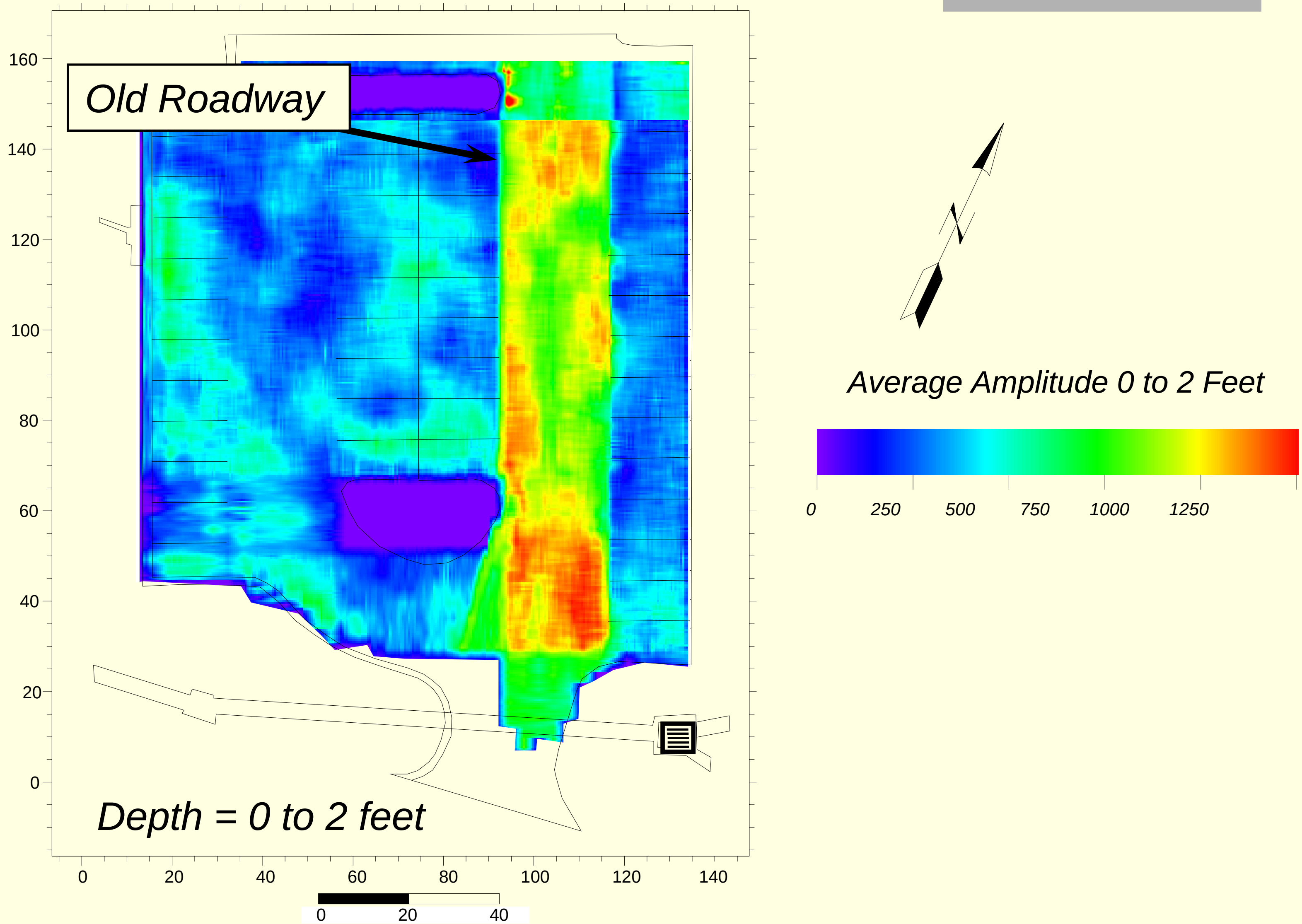
Utilities below concrete slab

Depth 10-14 inches

0 Feet 5



Other



Old Roadway
Depth = 0 to 2 feet
Average Amplitude 0 to 2 Feet
0
250
500
750
1000
1250
N

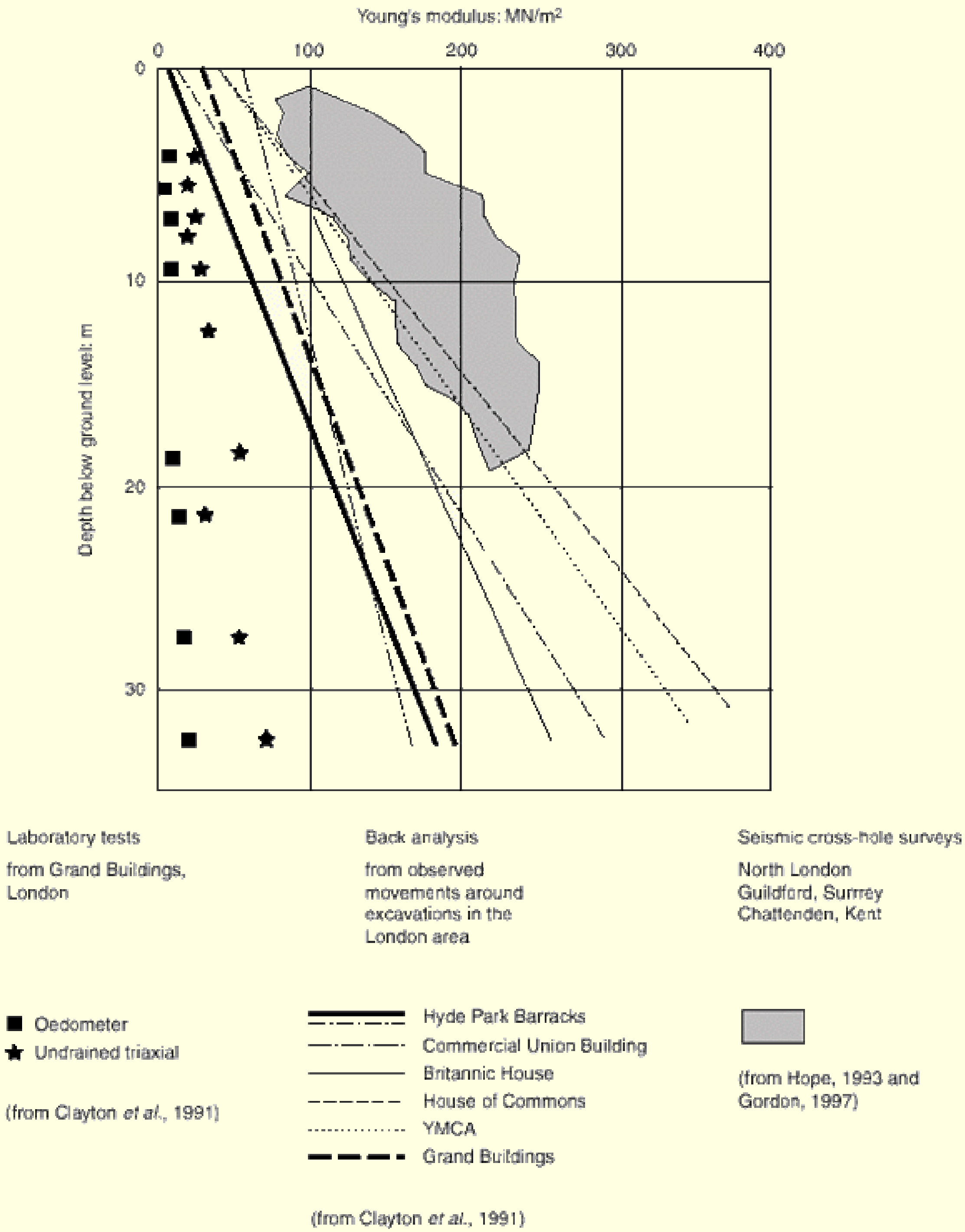
Summary of GPR Applications

- **Utility detection**
- **Underground storage tank detection**
- **Reinforcement in concrete**
- **Graves/Archaeological applications**

SASW Applied to Earth Materials

- **Stiffness/Velocity profiles: Meets IBC 2000 Section 1615.1.5.**

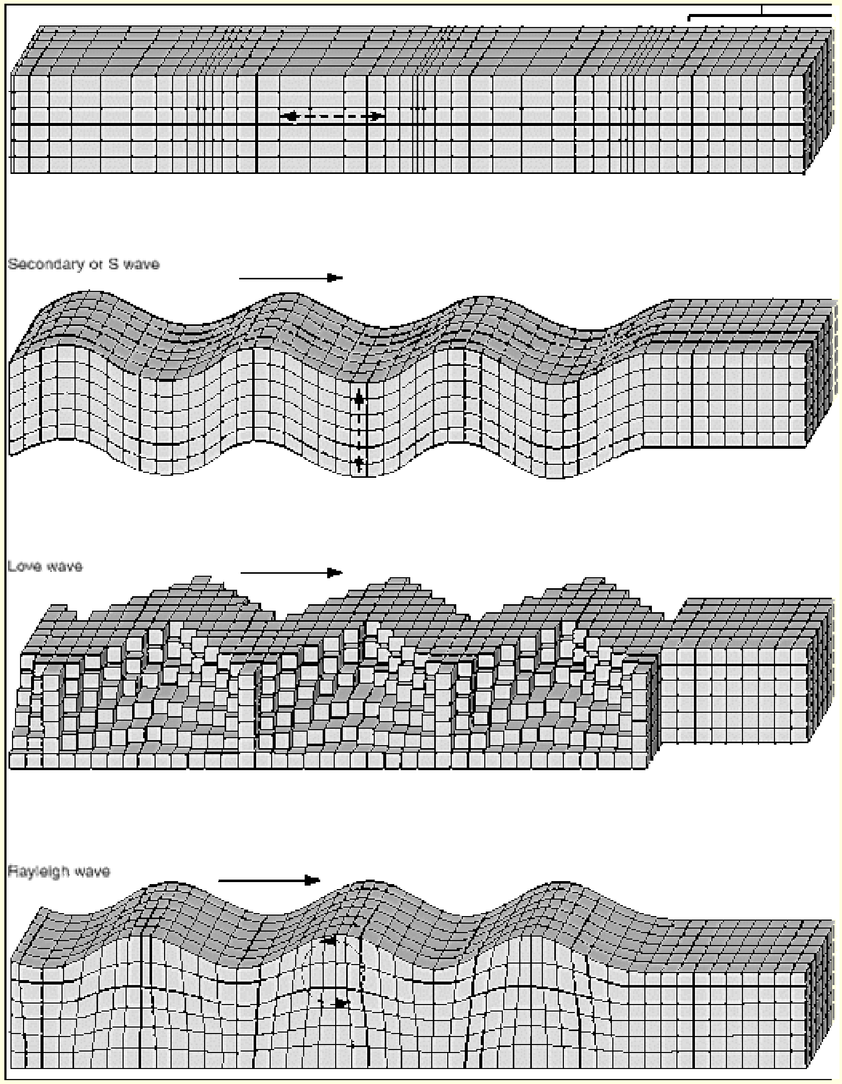
- **More accurate and less conservative than pressure methods (N-value, triaxial tests, etc.)**



Pressure Methods Under-Predict Stiffness

SASW Equipment

Wave Types



Primary (P) Wave

Secondary (S) Waves

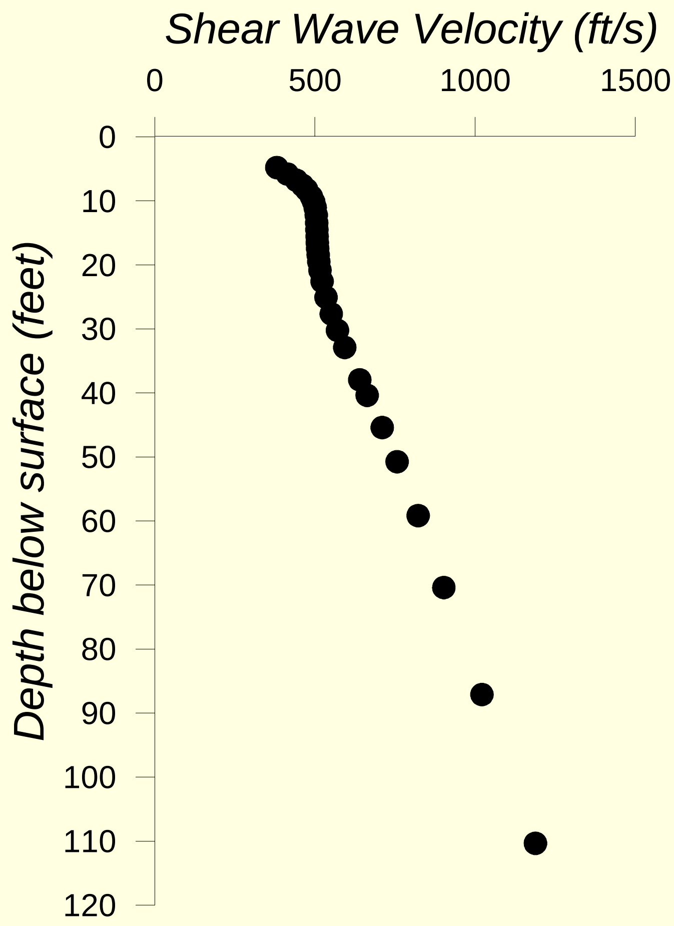
Love Wave

Rayleigh Wave

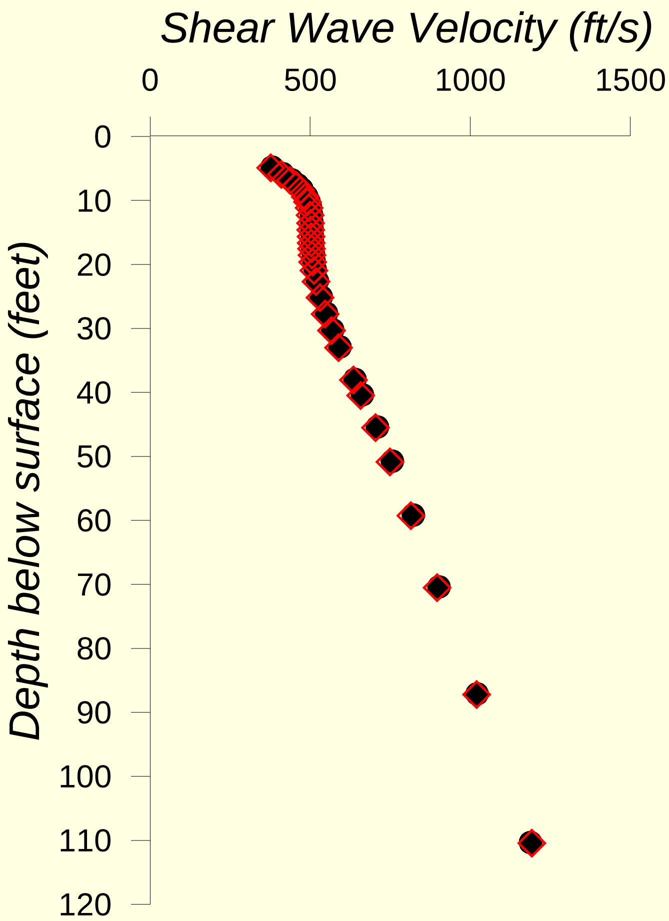
Rayleigh Wave Properties

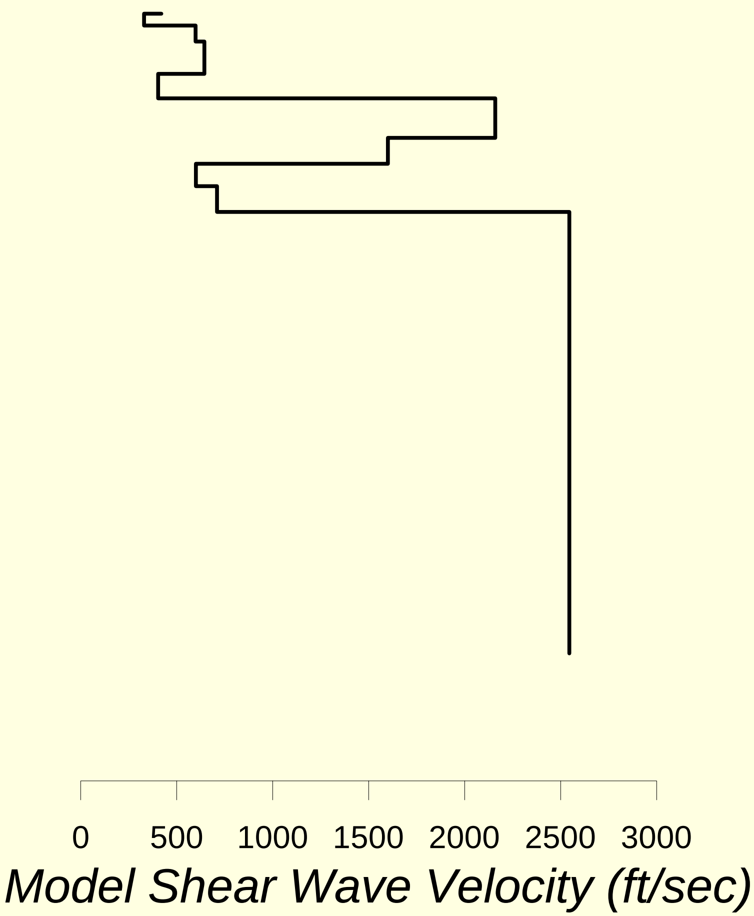
- In a homogeneous material, the speed of the Rayleigh wave is independent of its wavelength.
- In non-homogeneous materials, low-frequency (long wavelength) waves extend deeper than high-frequency (short wavelength) waves.
- This behavior is described as "dispersive" in seismological terms.
- A curve of velocity versus wavelength (or depth) is called a dispersion curve.

SASW Dispersion Curve

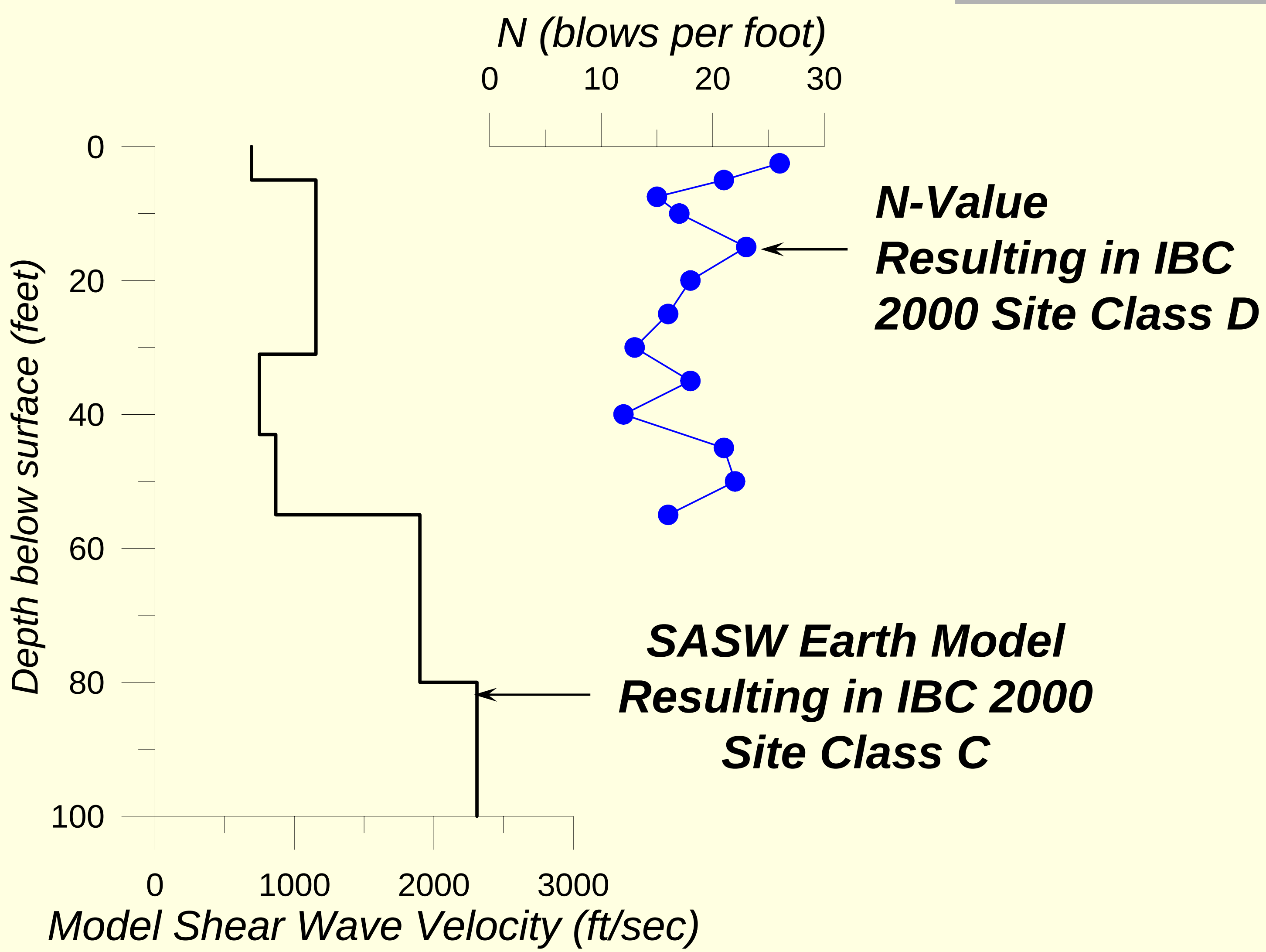


SASW Earth Model

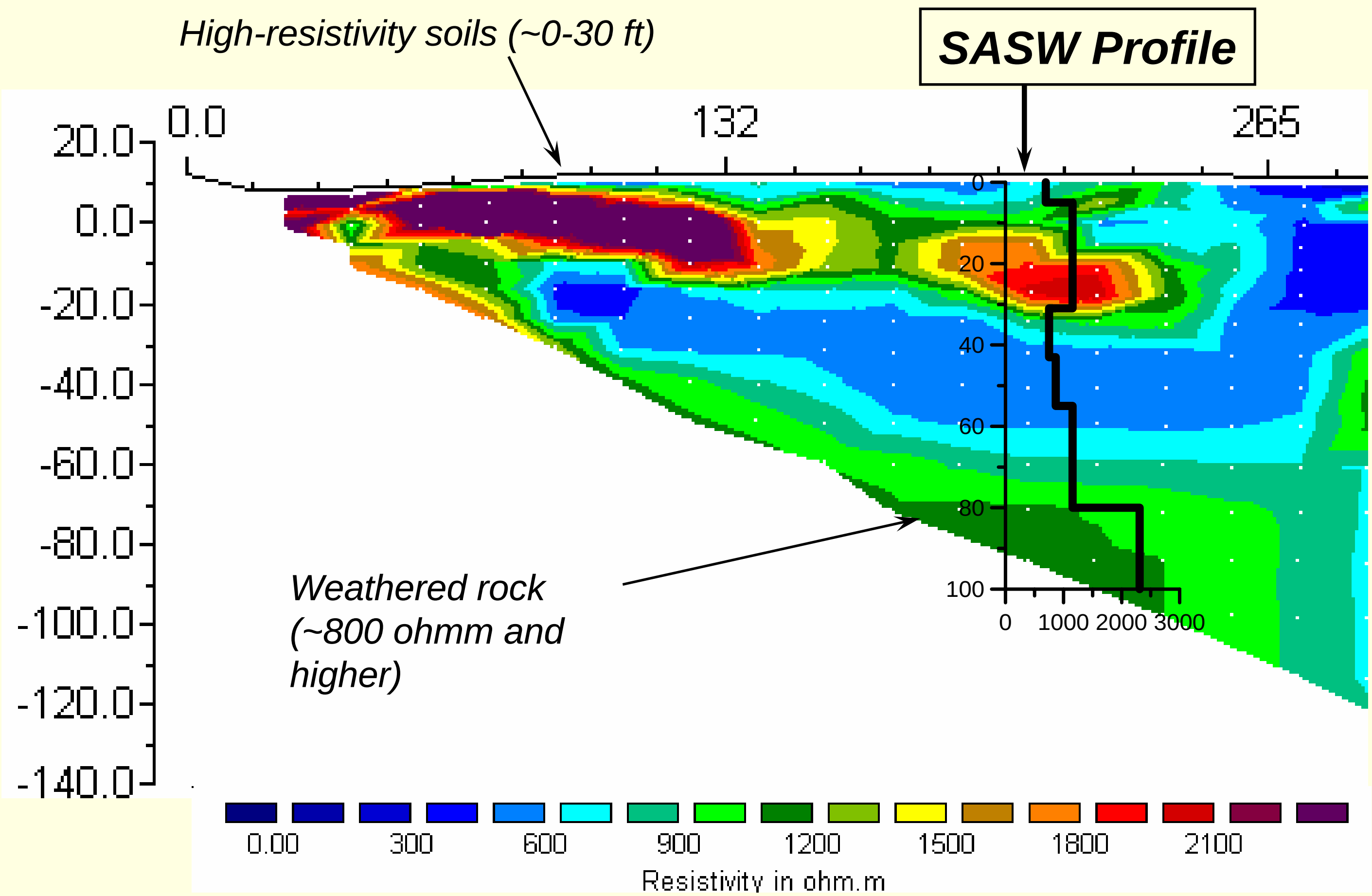




Comparison of SASW and SPT results



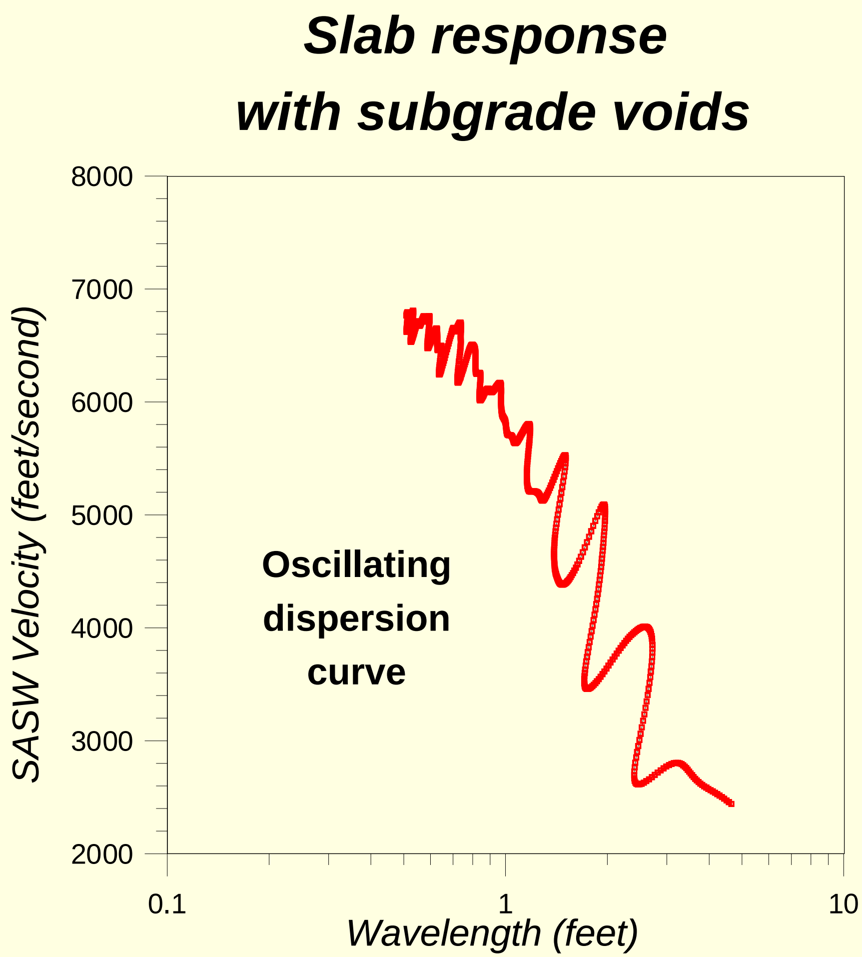
Resistivity with SASW

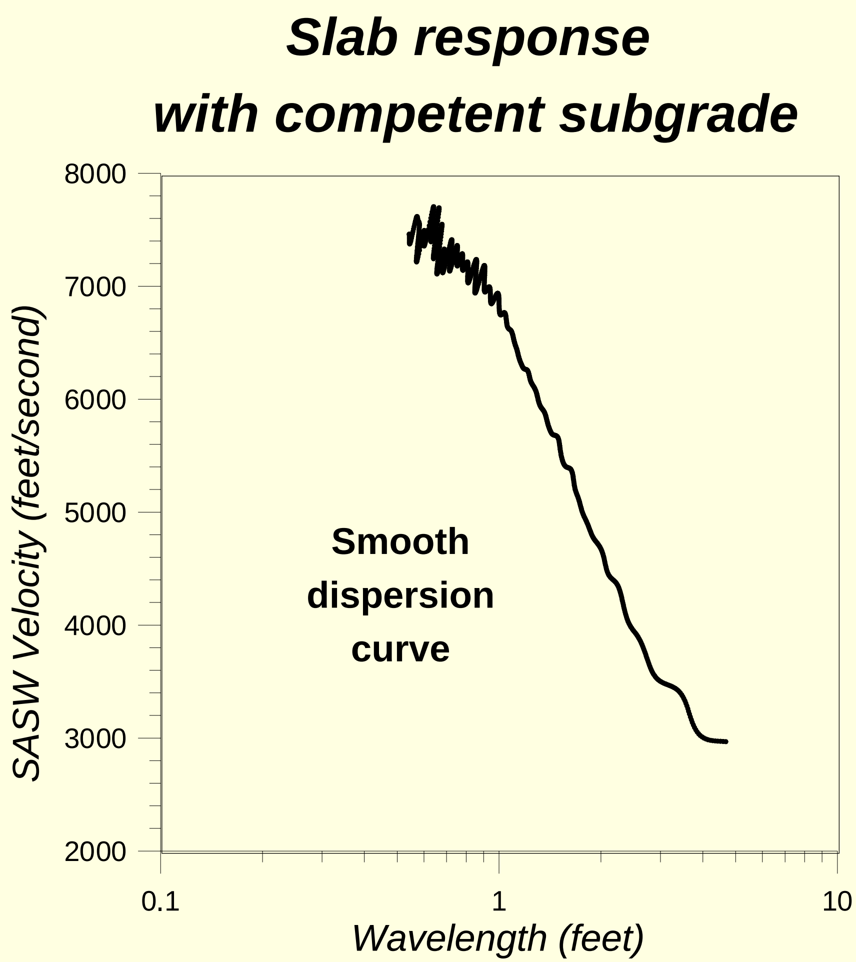


SASW Applied to Concrete

- Concrete integrity testing
- Location of voids or defects in concrete
- Concrete thickness measurement

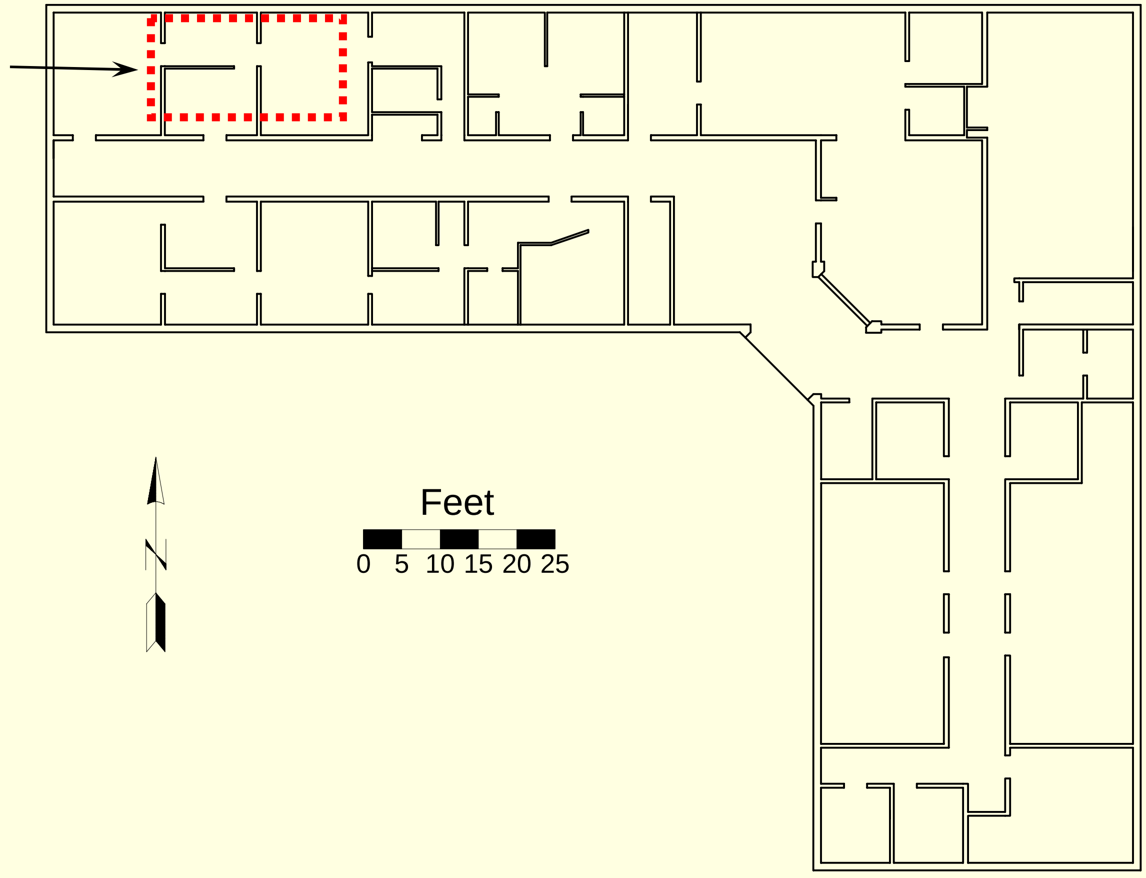
Detecting Voids Beneath Slabs



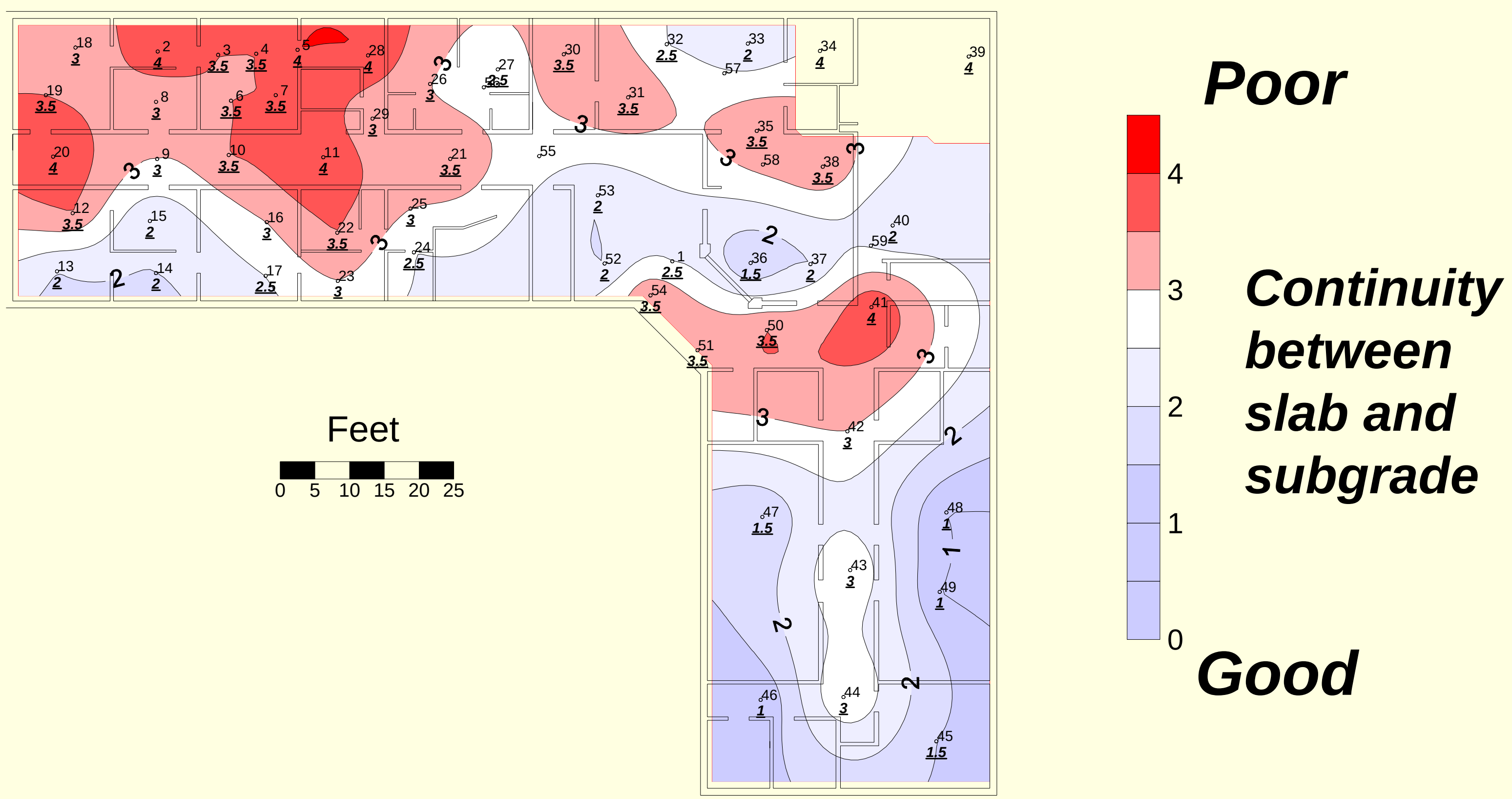


Ground Subsidence Resulting in Structural Damage

Area of greatest observed structural damage to walls and floor (dashed rectangle)



Mapping Subgrade Voids with SASW



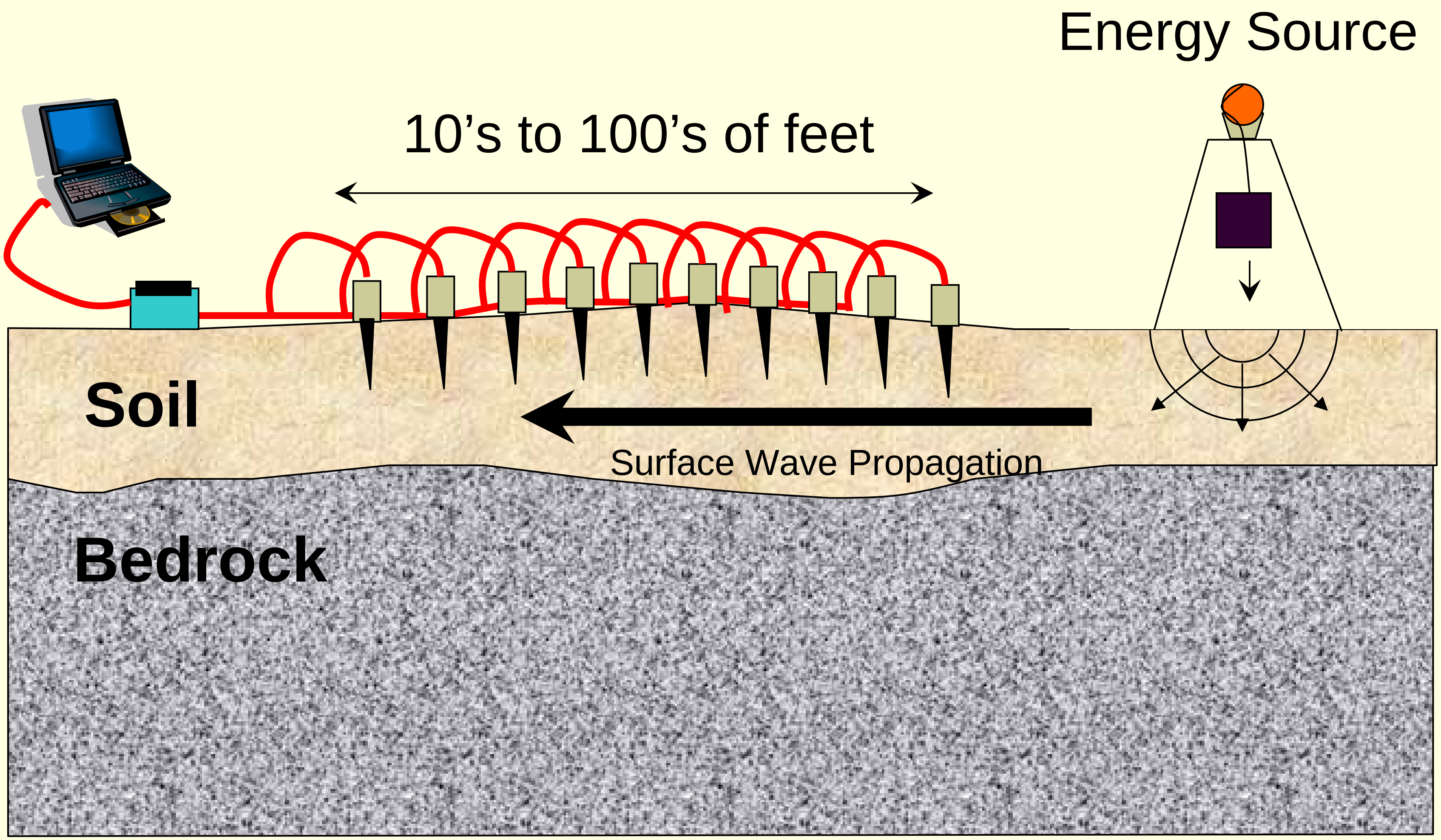
Summary of SASW Applications

- **More accurate IBC site classification**
- **Evaluation of concrete integrity**
- **Mapping subgrade voids**
- **Concrete thickness measurements**

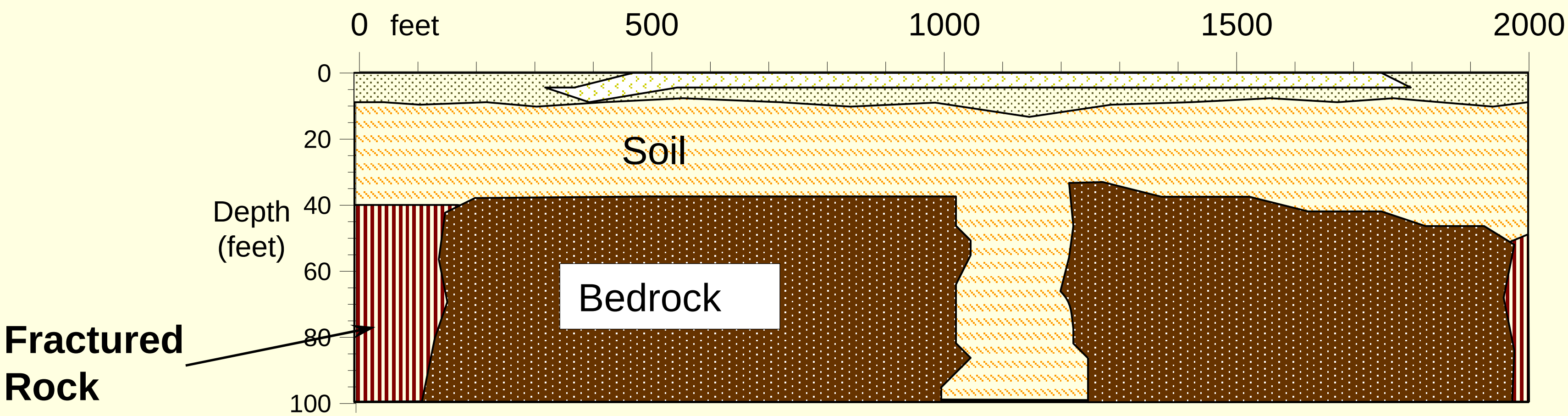
MASW
Multi-channel Analysis of Surface Waves

- **Uses surface waves like the SASW method**
- **SASW - a single channel method with acquisition of shear wave velocities beneath a single point on the surface**
- **MASW - a multi-channel method that can create a 2D cross-sectional view of subsurface shear wave velocities**

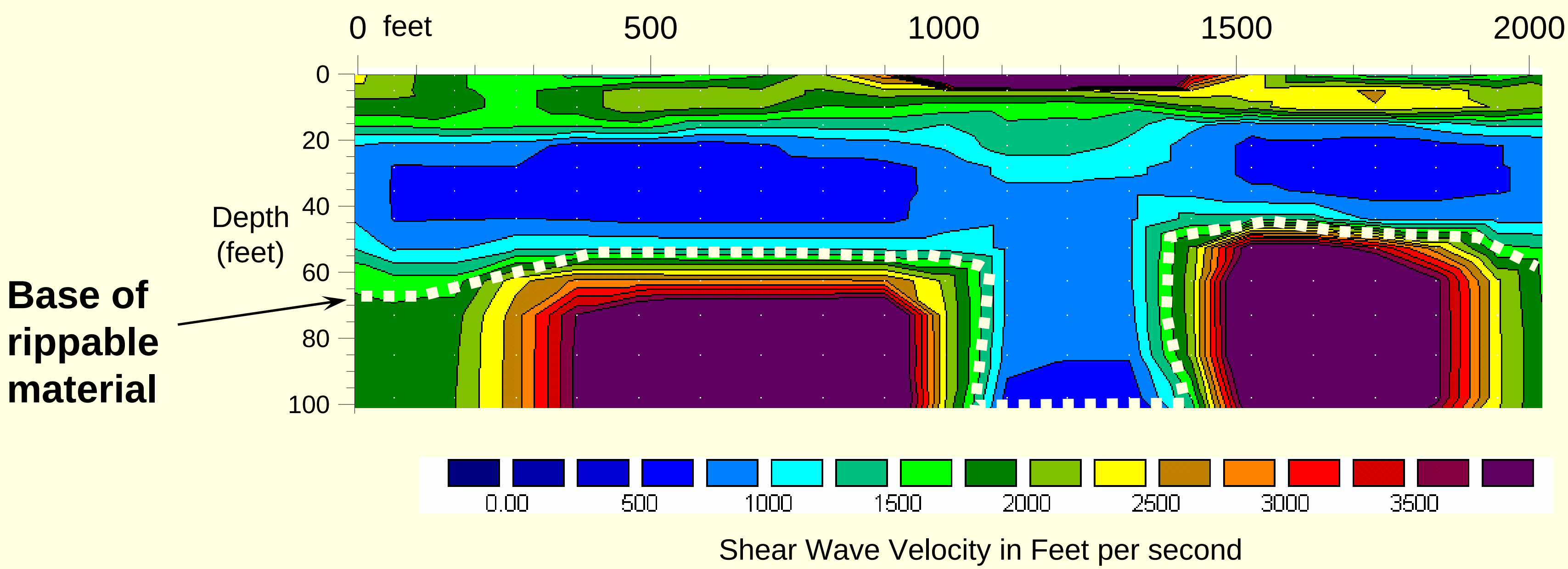
MASW Field Equipment



Geologic Cross-Section of True Subsurface Conditions



Inversion Model Illustrating Soil and Rock Zones



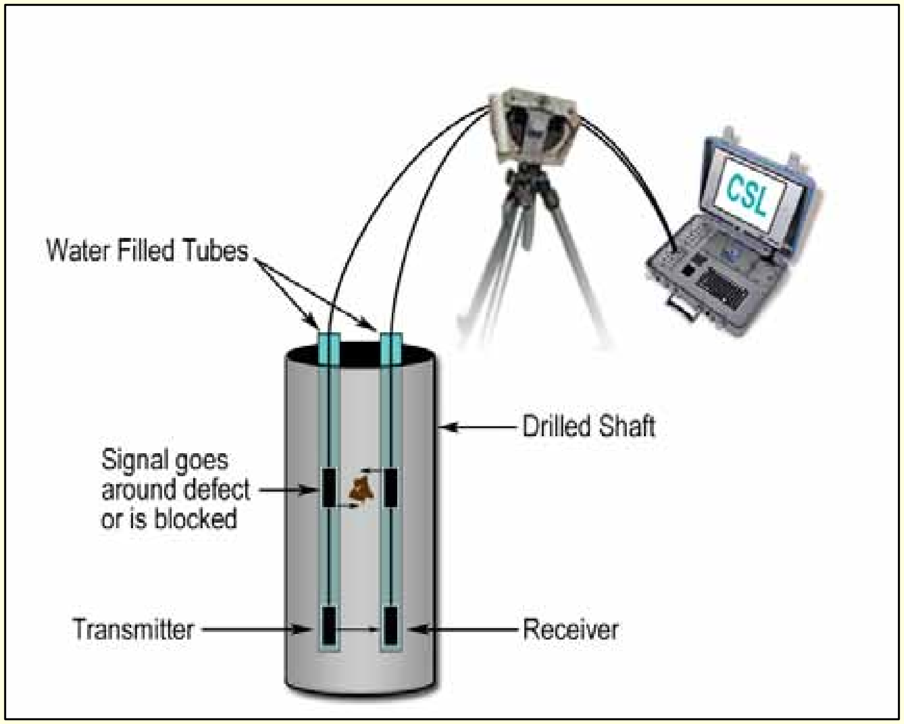
MASW Applications

- **IBC 2000 Site Specific Seismic Classification**
- **Rippability**
- **Depth to bedrock studies**
- **Detect presence of subsurface voids, caves, fractures,etc**

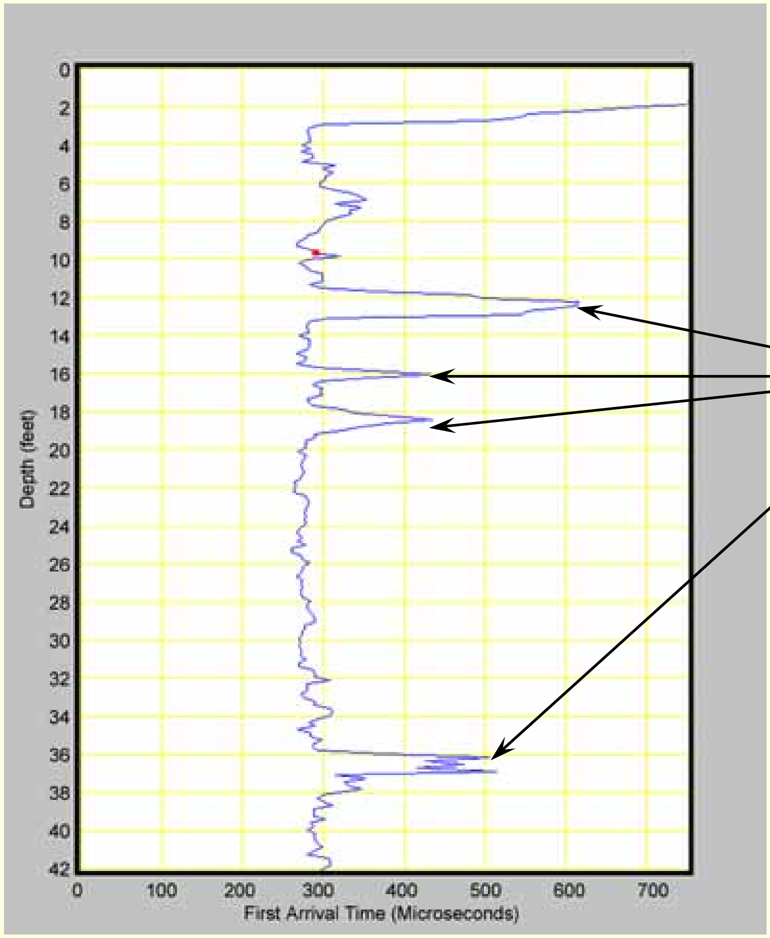
Cross-Hole Sonic Logging (CSL)

- **Tests the integrity of newly placed concrete**
  - **Drilled shafts**
  - **Seal footings**
  - **Slurry walls**

CSL Equipment



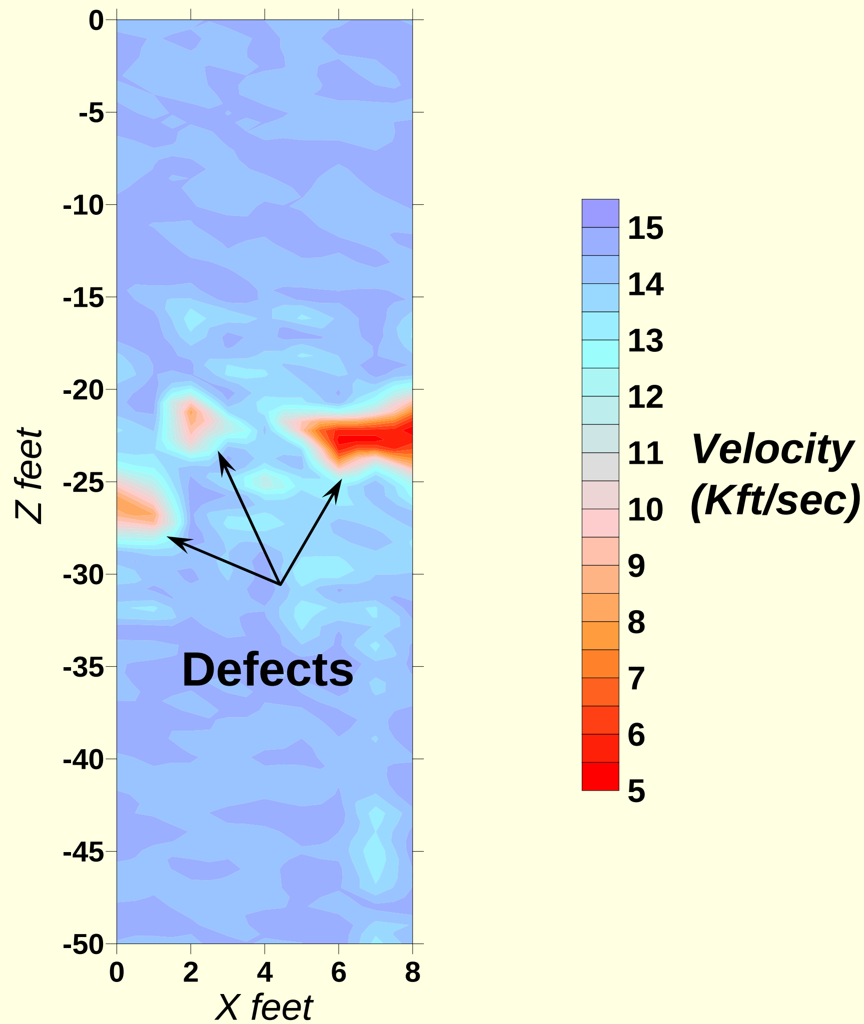
CSL Data



Weak Zones in Concrete

Depth Plot of First Arrival Times

Cross-Sectional CSL Tomography



In Conclusion

- **Geophysical Methods Offer Means of Non-Destructive Testing**
- **Wide Variety of Tools and Applications**
- **Technology is Constantly Advancing**

Thank You!

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