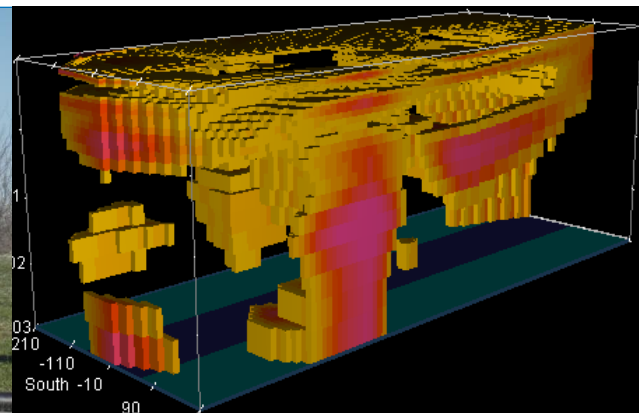
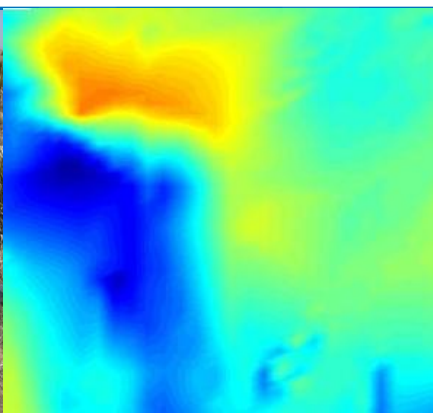
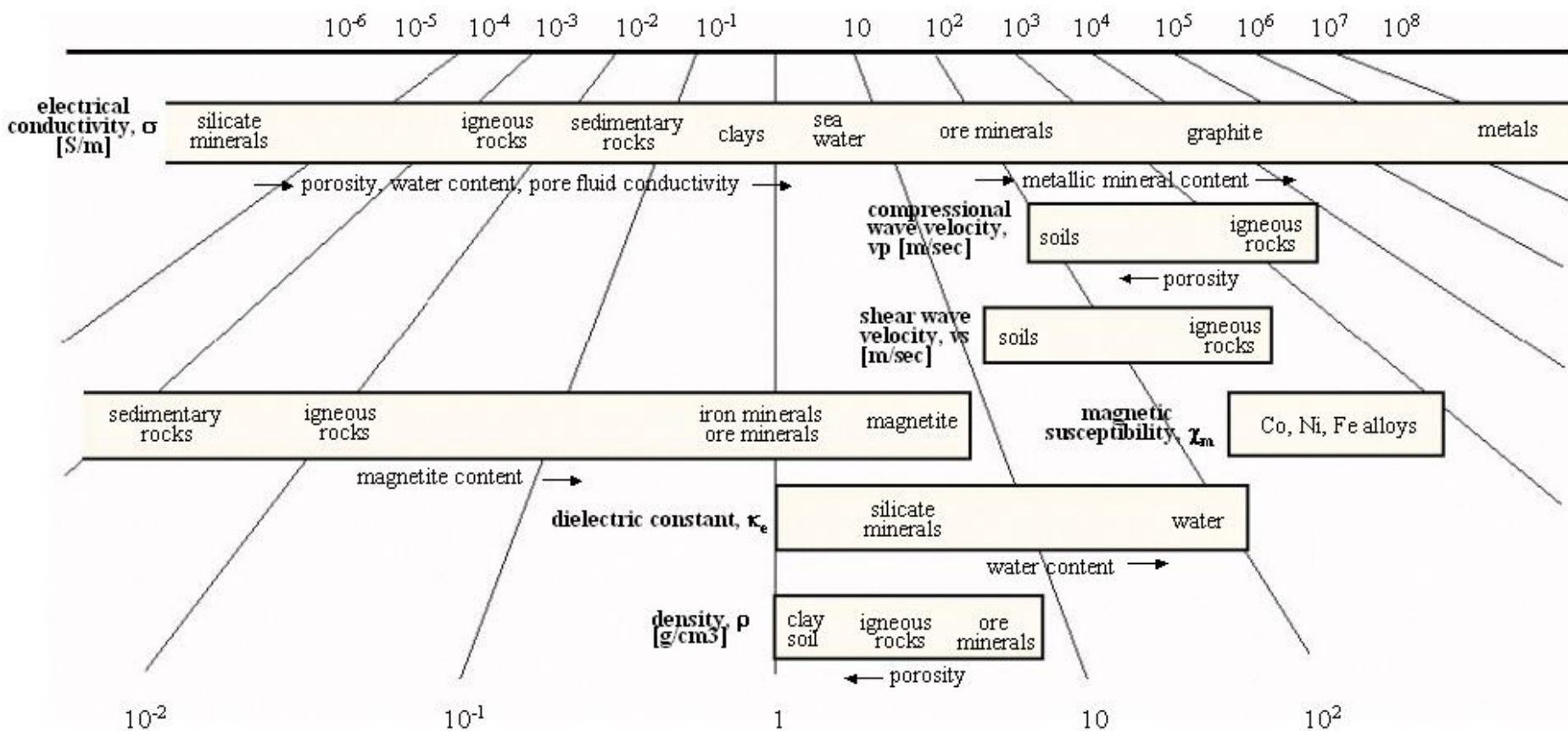


Overview of Geophysics for Environmental Site Characterization and Monitoring

Carlyle R. Miller, Ph.D.
U.S. Environmental Protection Agency
Office of Research and Development



Geophysical Properties



From http://appliedgeophysics.berkeley.edu:7057/intro/figures/fig_prop.jpg

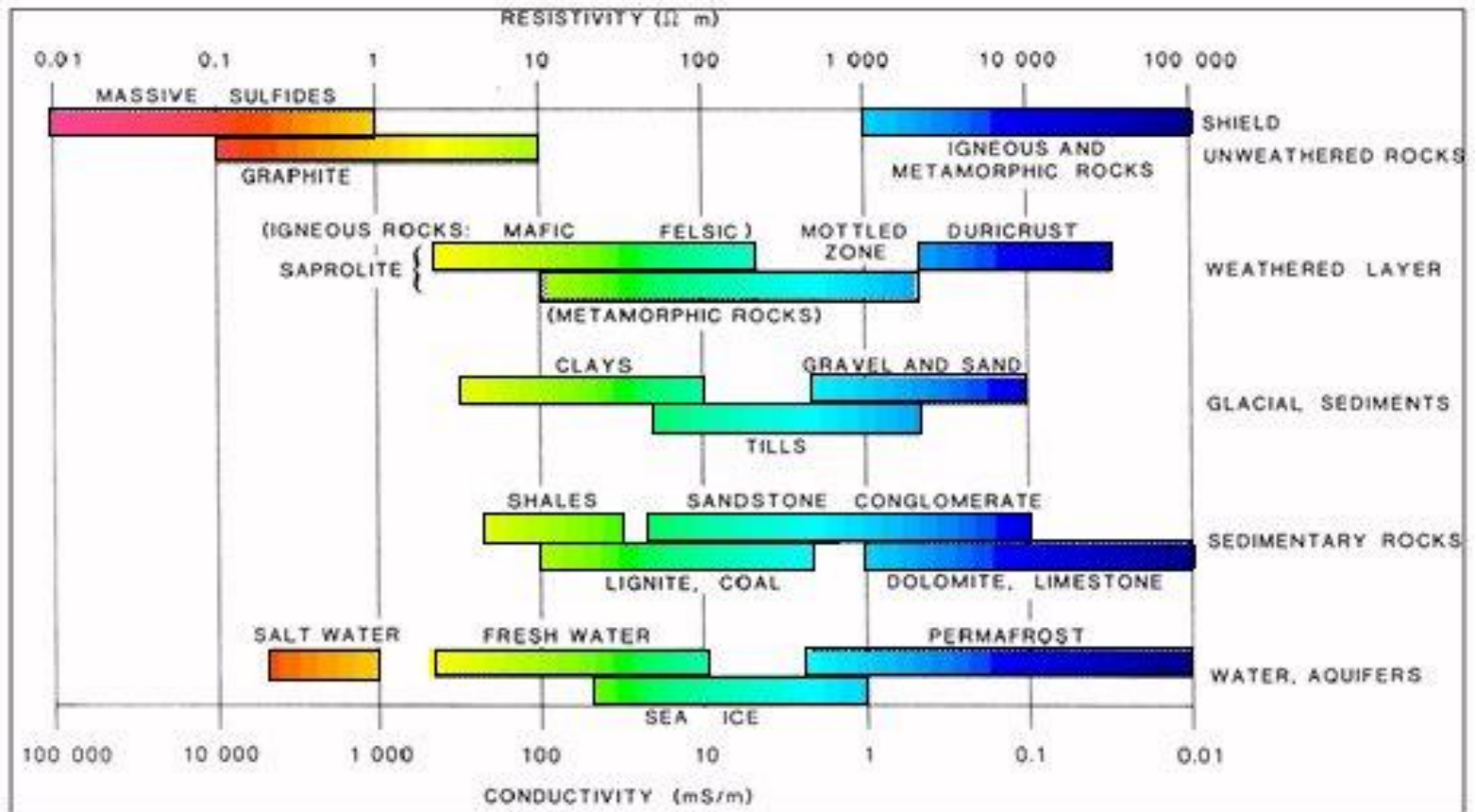
Electrical Conductivity

Units:

S/m

mS/cm

Ωm



From <http://www.eos.ubc.ca/ubcgif/> (adapted from Palacky, 1987)

Conductivity is a function of porosity, permeability, saturation, fluid conductivity, clay content, temperature

Seismic Wave Velocity

Material	v_p (m/s)
Soil	250-600
Weathered Layer	300-900
Alluvium	500-2000
Clay	1100-2500
Air	331.5
Water	1400-1600
Sandstone and Shale	2000-4500
Coal	1800-3400
Limestone	2000-6000
Igneous	5000-6400

Variability caused
by differences in:

Saturation
Consolidation
Weathering
Fracturing

Values summarized from various texts and online sources

v_p is the P-Wave (compressional) velocity, this is always greater than the S-Wave (shear) velocity, v_s . The ratio of v_p/v_s is diagnostic of rock type.

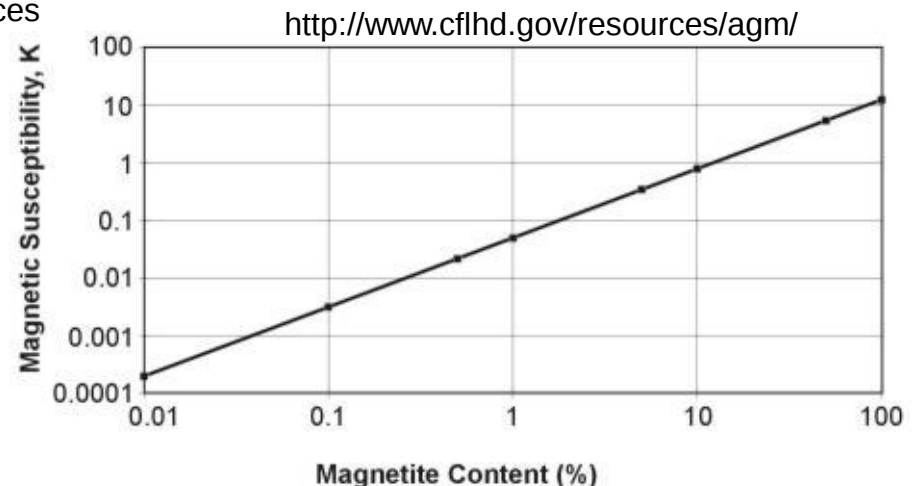
Magnetic Susceptibility

Rock or Mineral Type	Susceptibility X 1000 (SI units)
Sedimentary rocks	0.1-0.9
Metamorphic rocks	0.7-6
Igneous rocks	2.5-160
Magnetite	1200-19200
Ilmenite	300-3500
Pyrrhotite	1-6000

Dimensionless
quantity describing
the ability of a
material to be
magnetized

Values summarized from various texts and online sources

Depends primarily on
magnetite content



Dielectric Constant

Measure of polarization (electronic, ionic, or molecular) resulting from an applied electric field.

Diagnostic of
the amount of
water present

Material	Dielectric Constant
Water	80.36
Ice	3-4.3
Sandstone (dry to moist)	4.7-12
Packed sand (dry to moist)	2.9-105
Soil (dry to moist)	3.9-29.4
Clay (dry to moist)	7-43

Values summarized from various texts and online sources

Varies inversely with frequency

Density

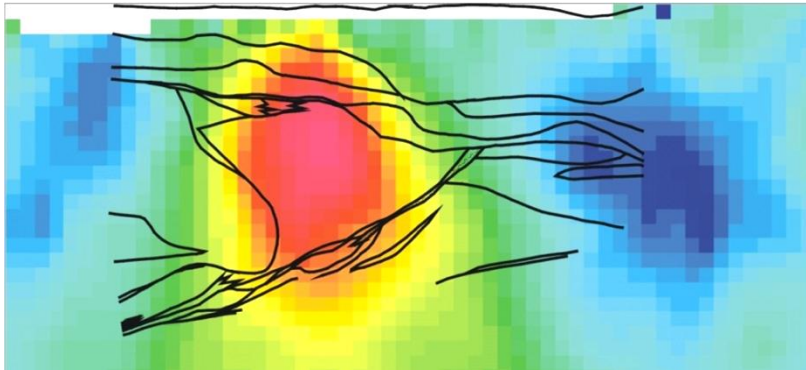
- Density generally increases with depth and time of burial
- Igneous and metamorphic rocks are generally more dense than sedimentary rocks
- Wider variability in sedimentary rocks due to variations in porosity

Material	Density (g/cm ³)
Water (fresh)	1.0
Soil / Overburden	1.2-2.4
Sandstone	1.6-2.7
Shale	1.7-3.2
Limestone	1.9-2.9
Granite	2.67-2.79
Basalt	2.7-3.3
Metamorphic	2.4-3.1

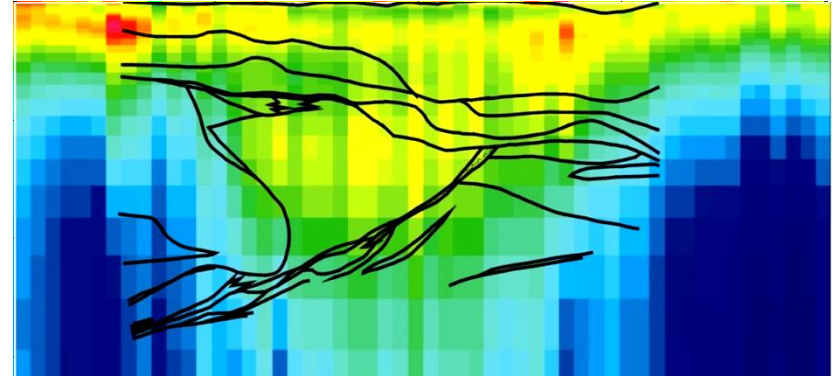
Values summarized from various texts and online sources

Global average for crustal rocks is 2.67 g/cm³ (2670 kg/m³)

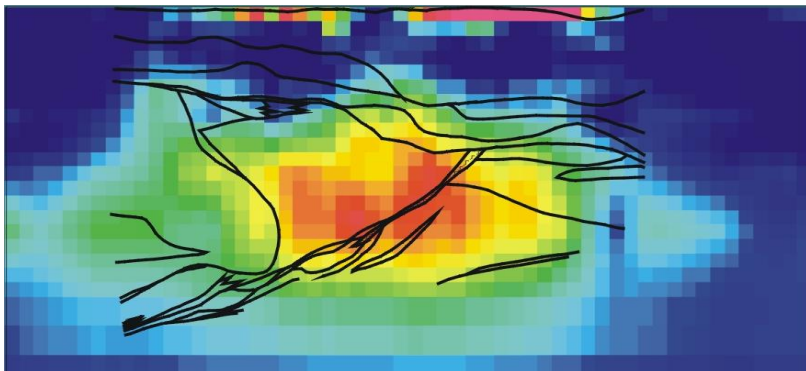
Which is Best to Use?



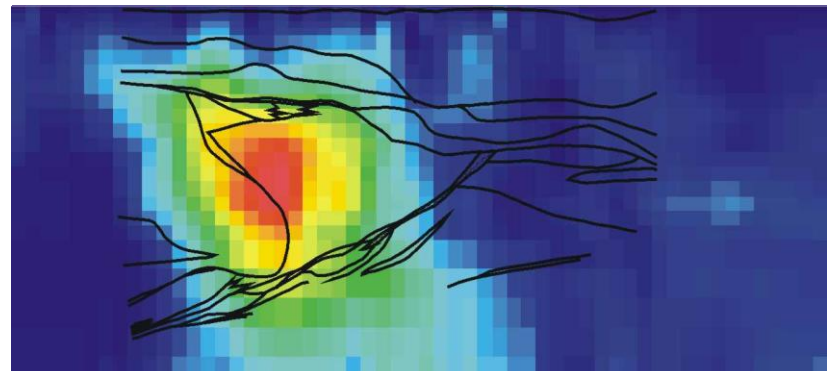
density-contrast



conductivity



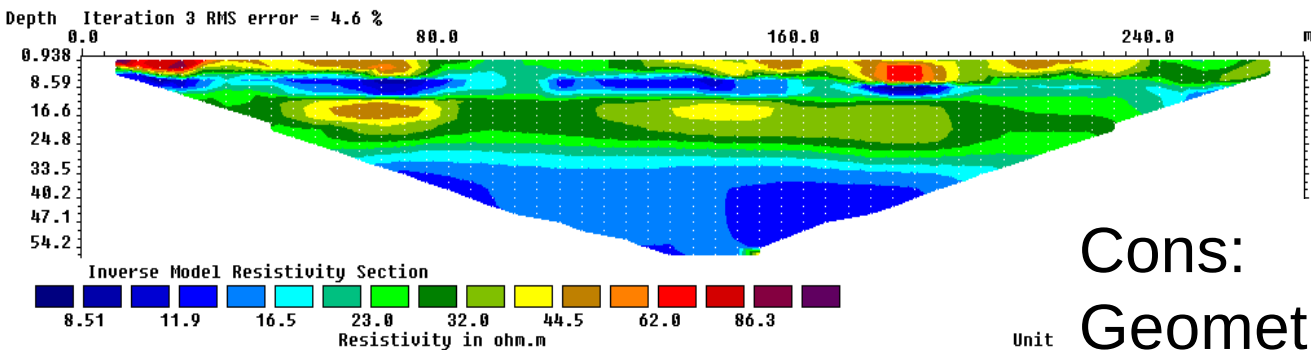
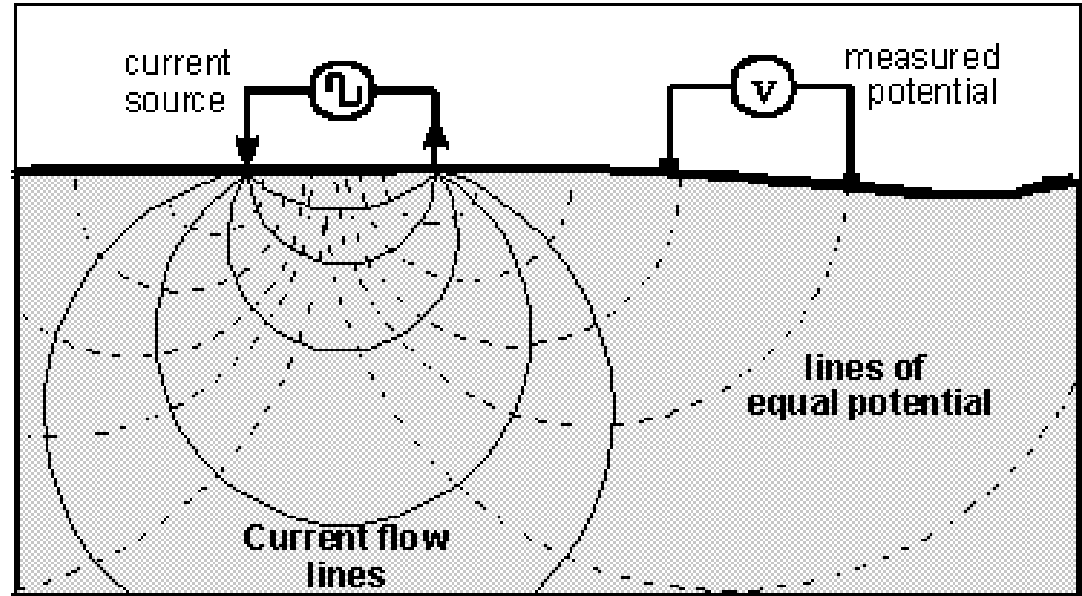
chargeability



magnetic susceptibility

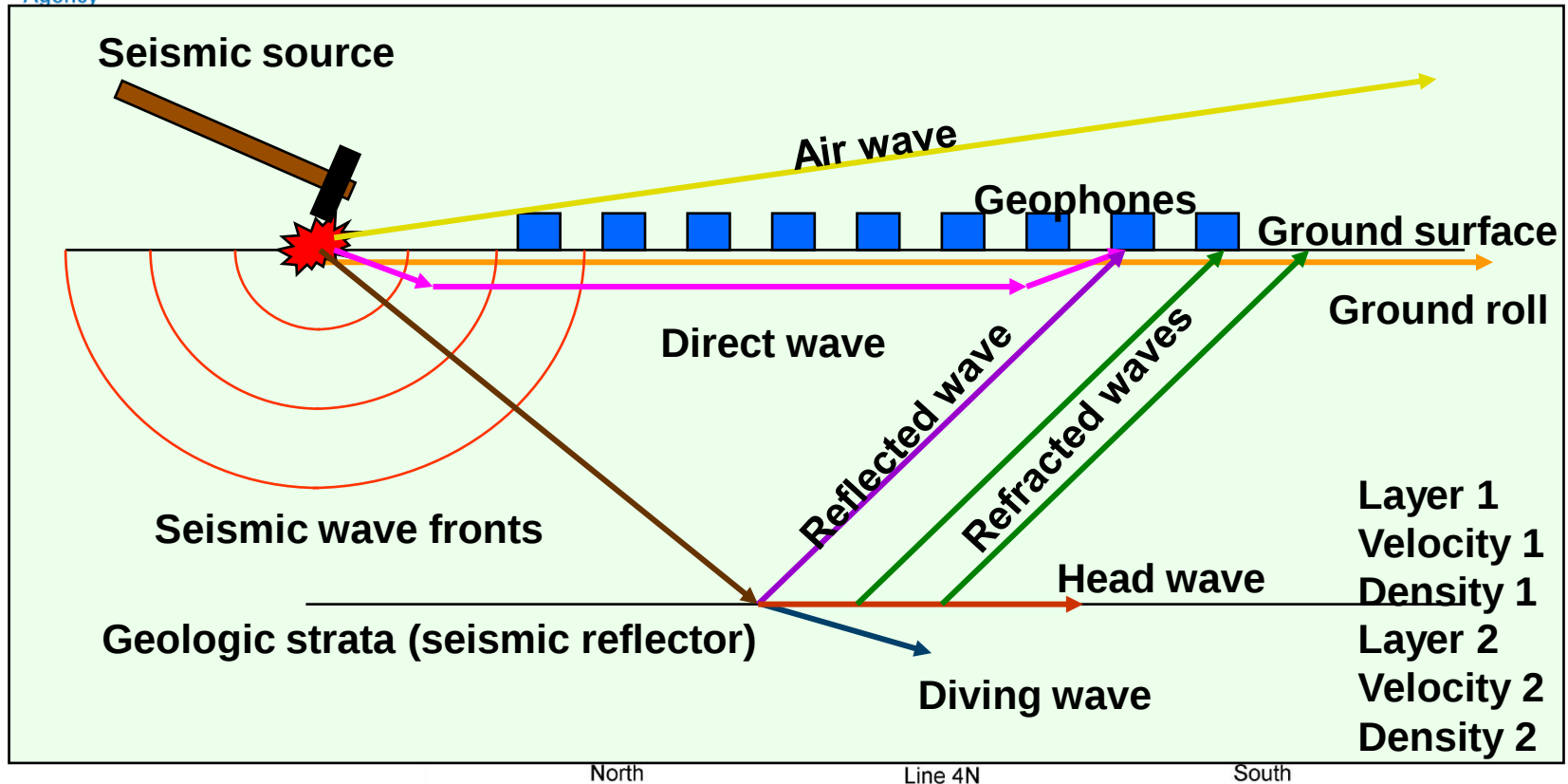
DC Resistivity

Pros:
Sensitive to water
Less interference vs. EM

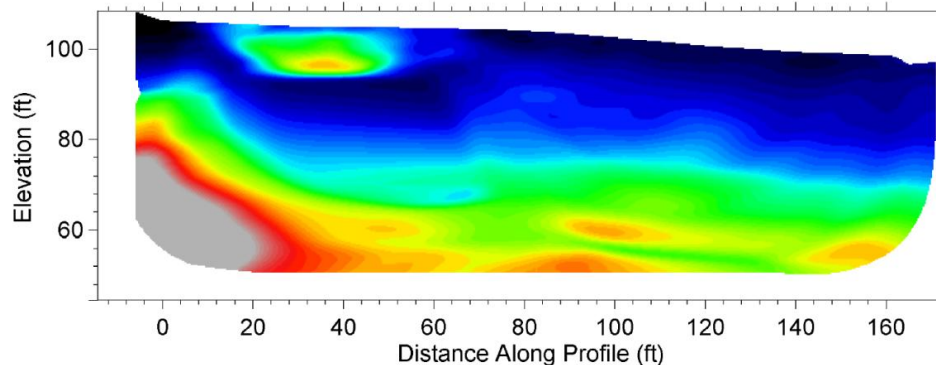


Cons:
Geometry dependent
Challenging in arid regions

Seismic Refraction

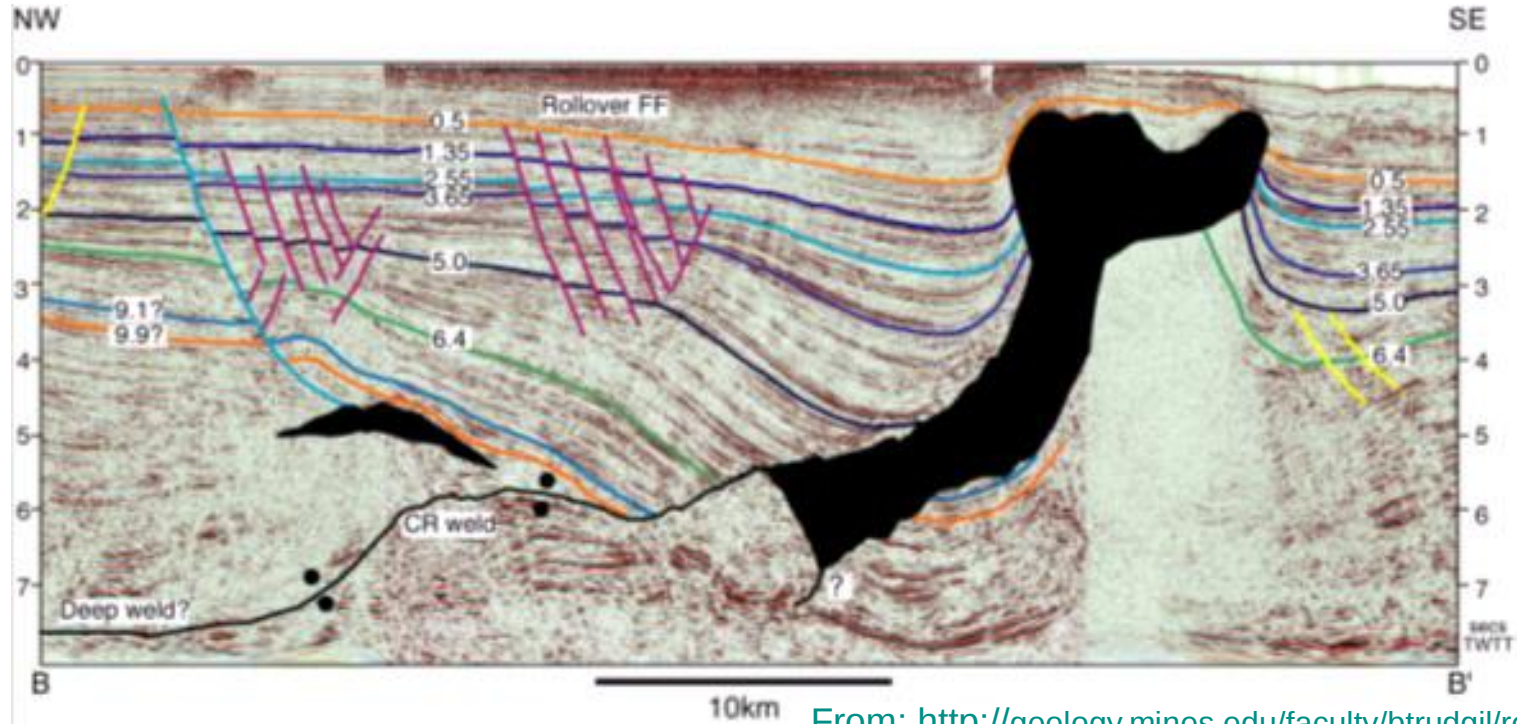


Pros:
Good resolution
Few interferences



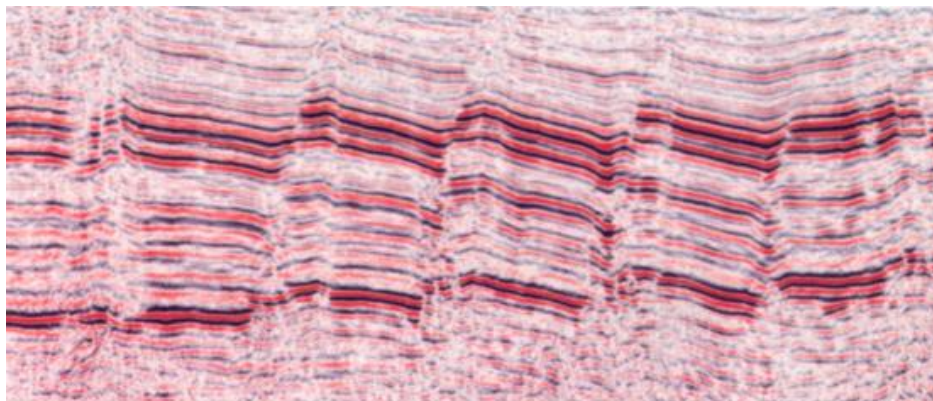
Cons:
Logistics
Assumptions

Seismic Reflection



From: <http://geology.mines.edu/faculty/btrudgil/research.html>

Pros:
High resolution
Scale & depth



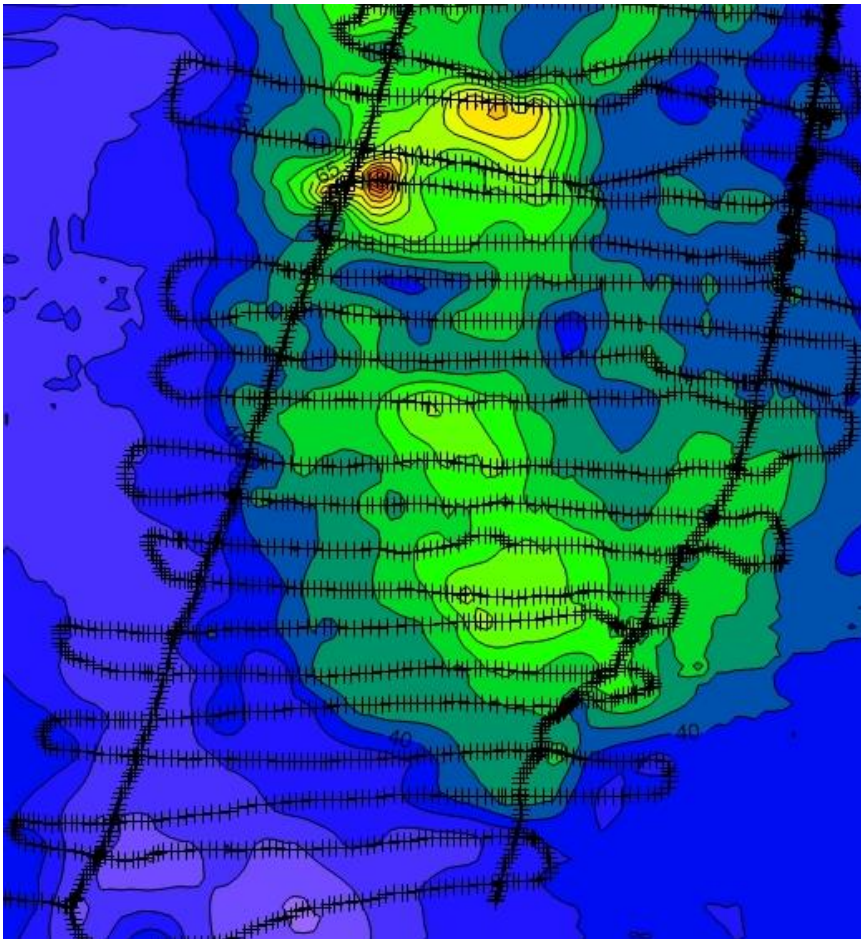
Con:
Cost
Permits/Access

Frequency Domain EM

Pros:

Fast

Good recon tool

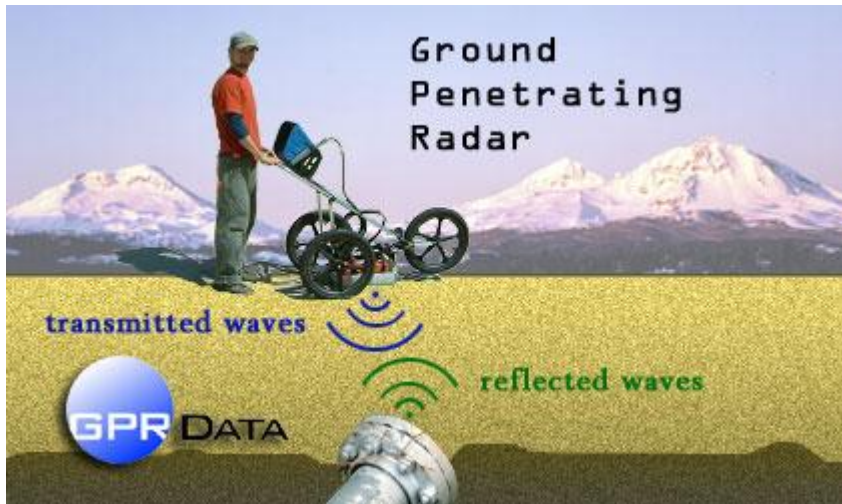


Cons:

Limited depth

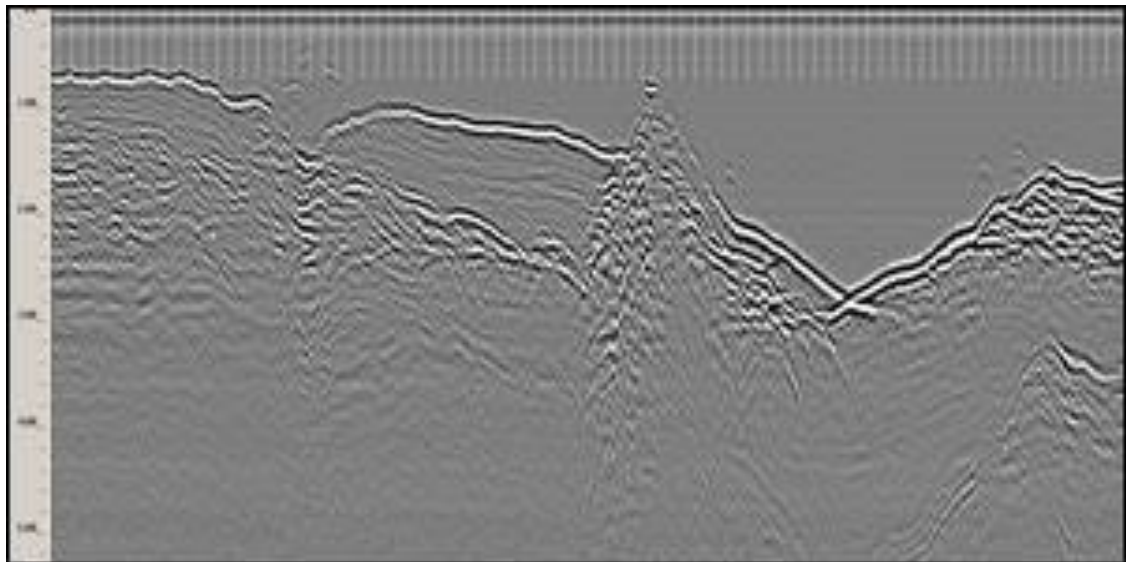
Interferences

Ground Penetrating Radar



Pros:
High resolution
Fast

Con:
Limited depth

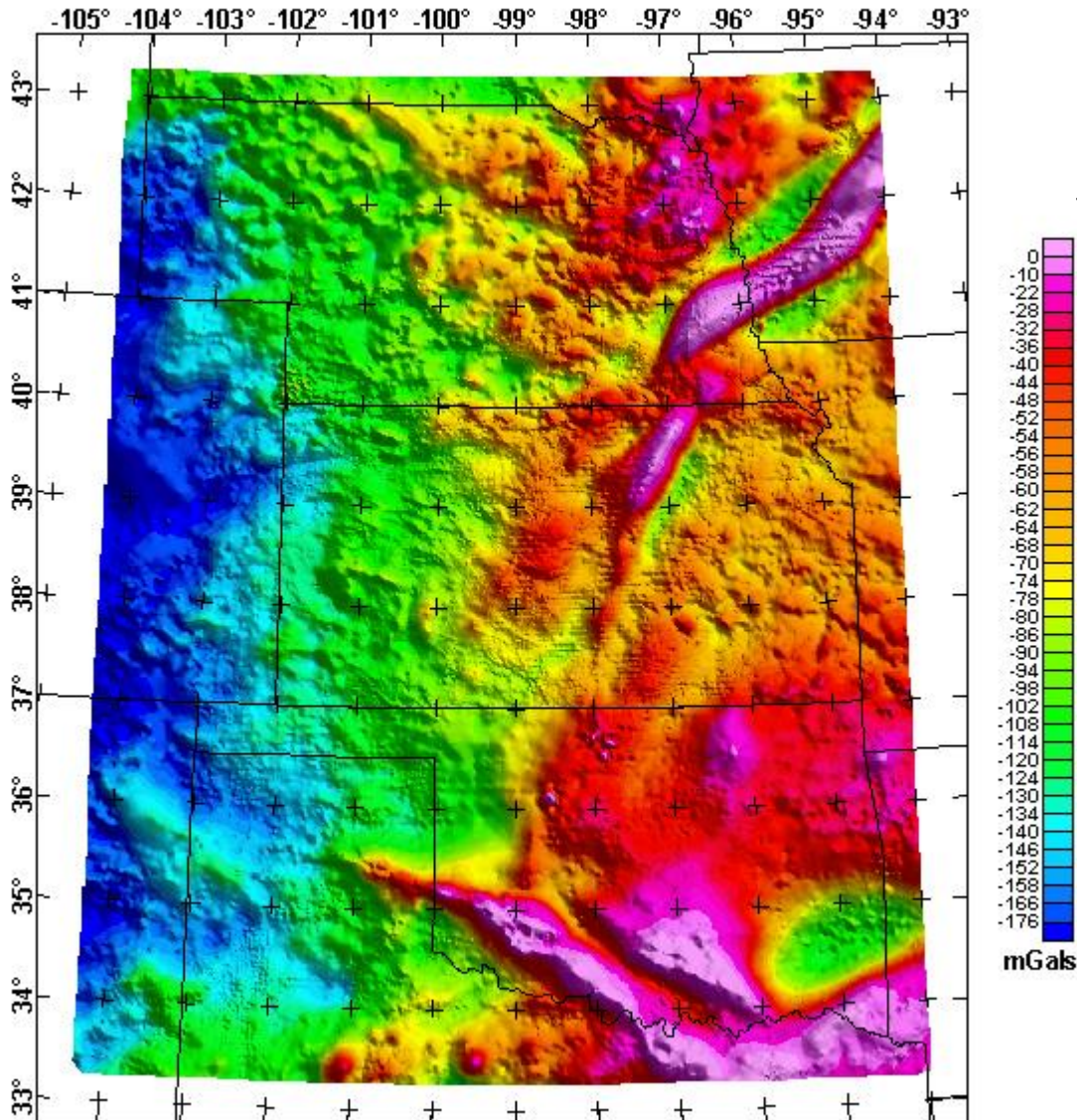


Gravity

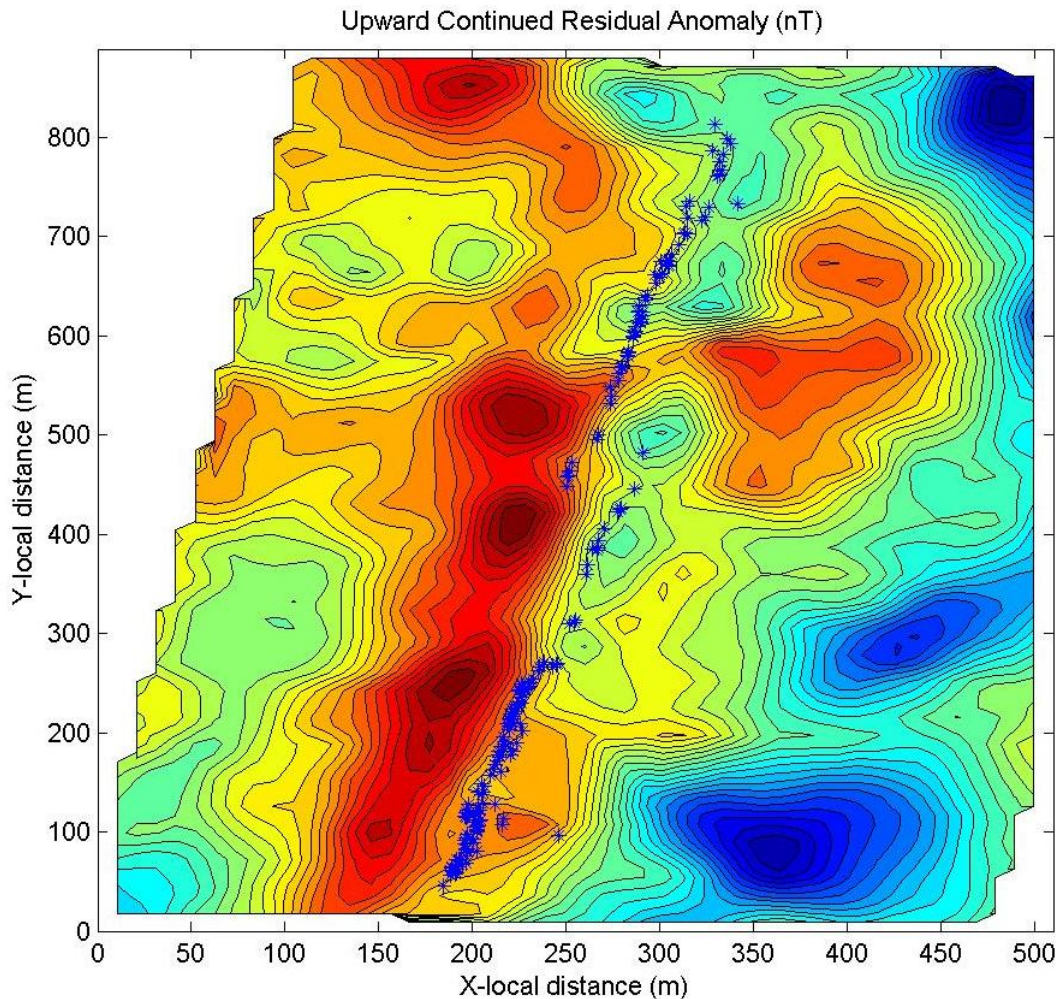
Pros:
Depth of investigation
Scale



Cons:
Slow data acquisition
Interpretation



Magnetics



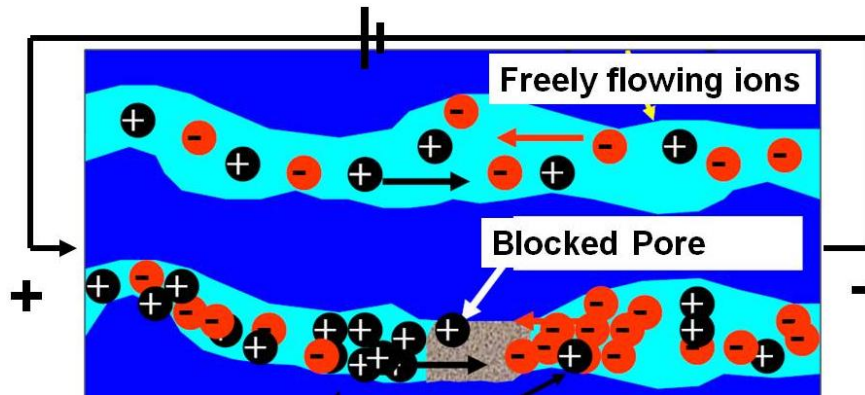
Pros: Relatively fast
Direct interpretation



Cons:
Modeling often complex
Interferences

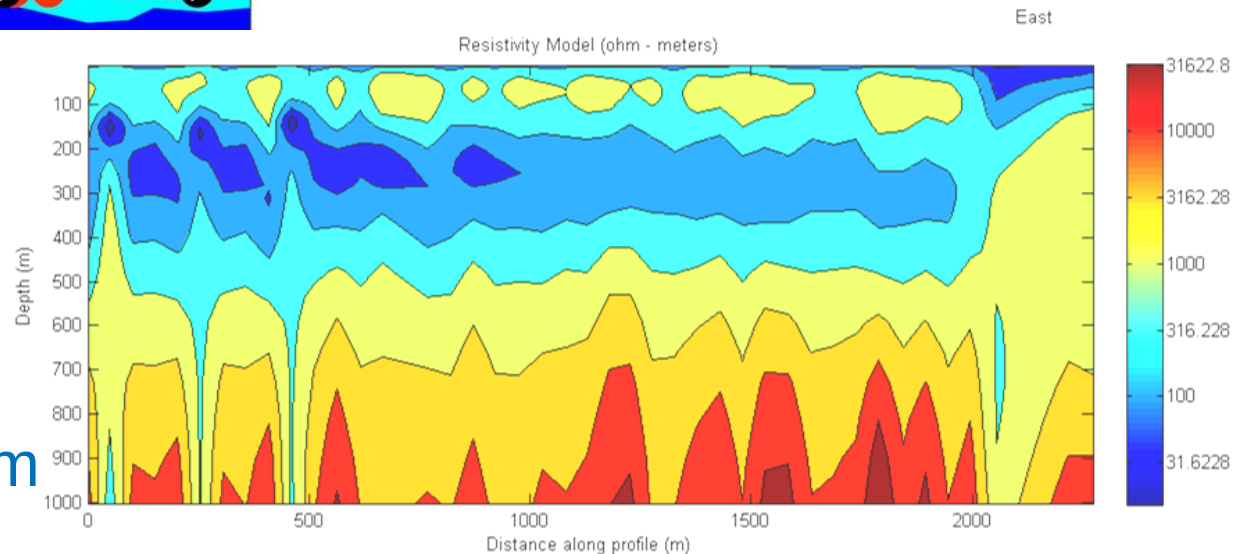
Other Methods

Electrical self potential – provides information about groundwater flow, chemical and temperature gradients



Induced polarization – Measures chargeability, related to porosity structure, mineral grain size

Controlled source electromagnetics – Surface techniques used to measure electrical conductivity to depths of several km

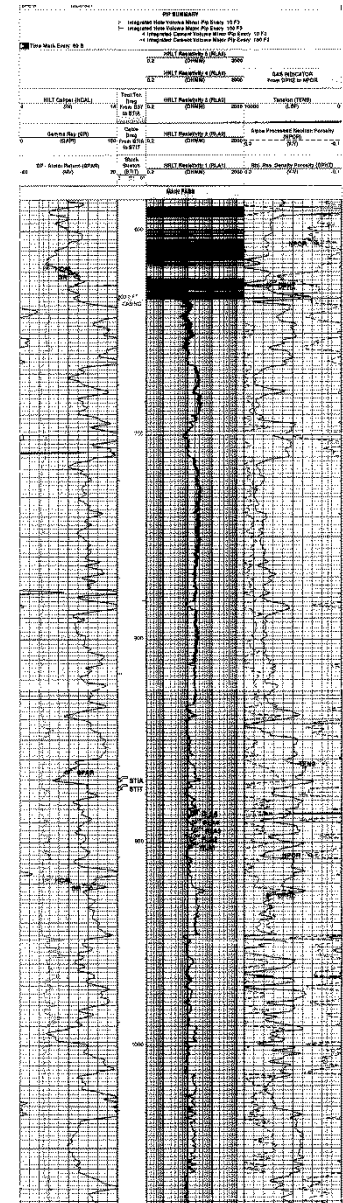


Borehole Logging

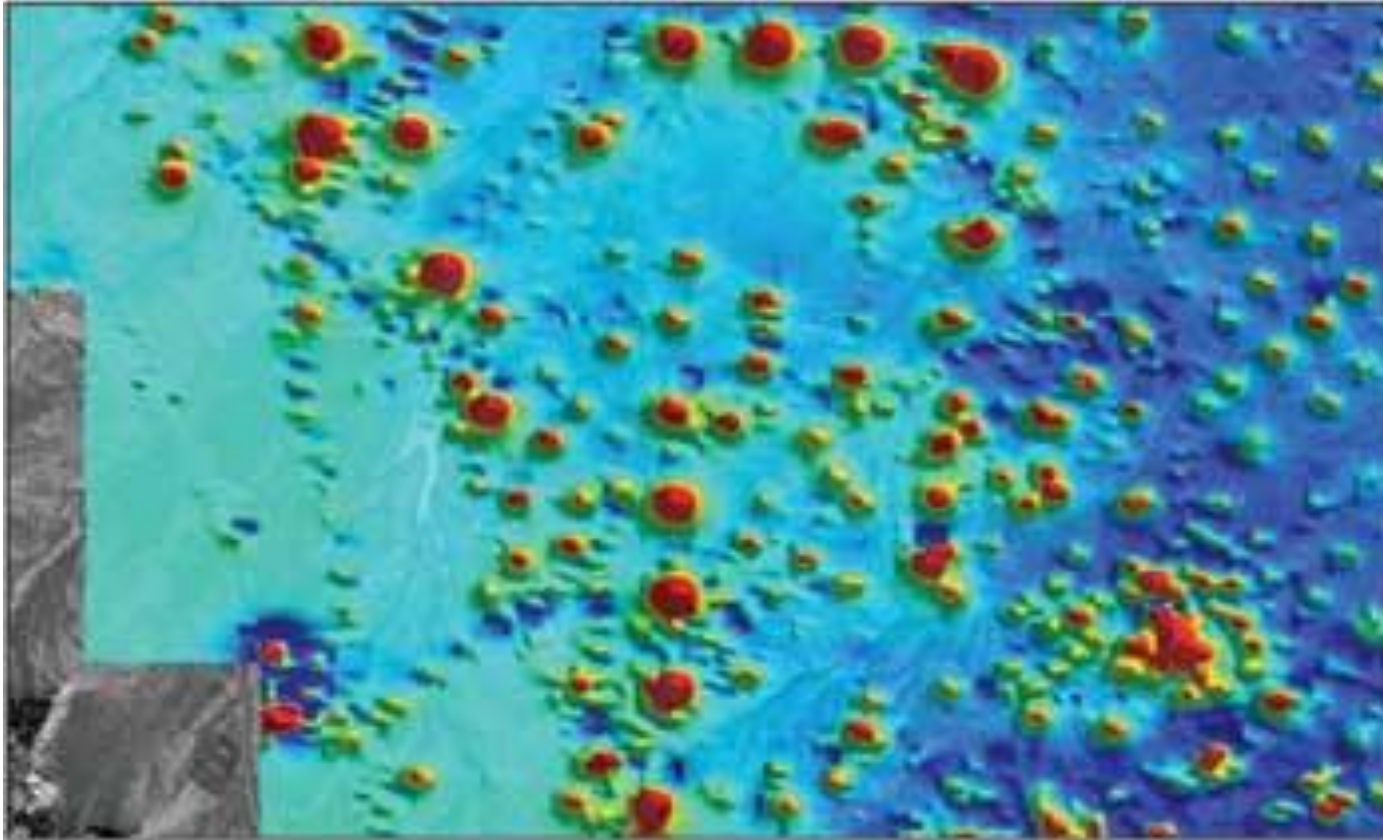
Spontaneous Potential
Magnetic Susceptibility
Natural Gamma
Caliper
Resistivity
Induction
Sonic
Density
Video
Temperature
Mud log
Cement Bond Log
Others...

Useful for determining:
Geological units
Water bearing zones
Screen settings
Pump depth
Packer locations

Also, can use some of
the previously
discussed methods in
boreholes.



Airborne Geophysics



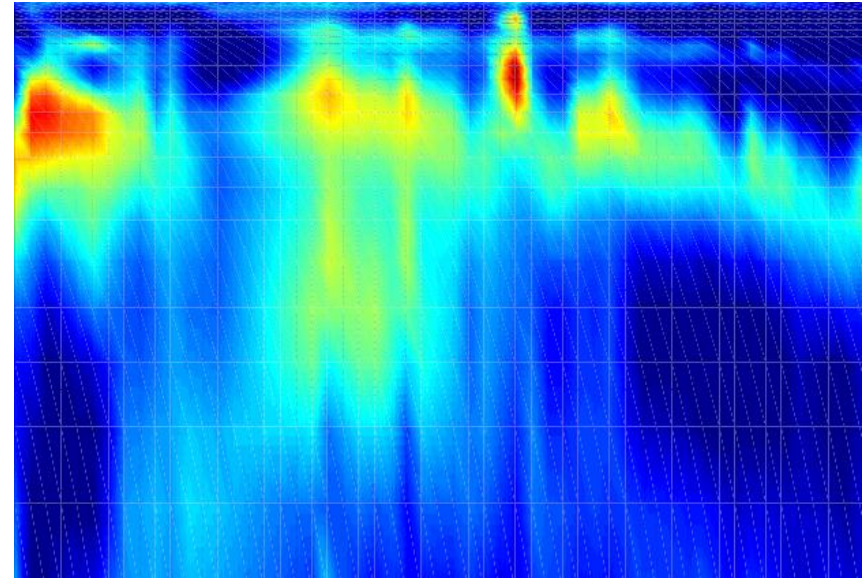
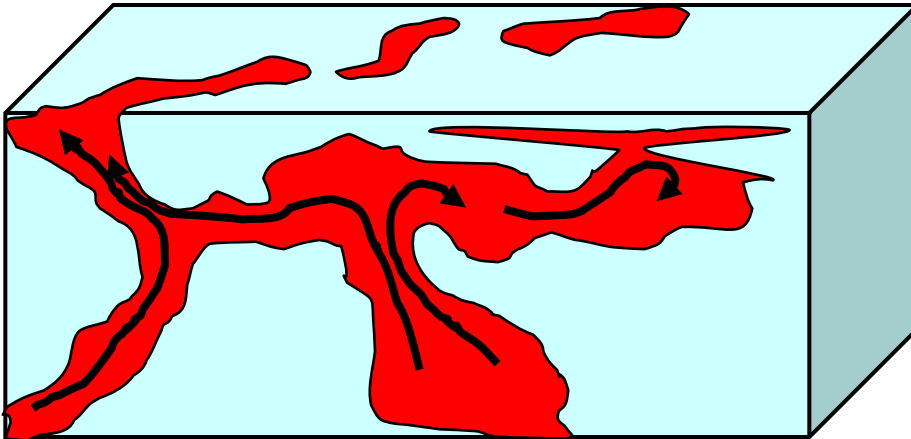
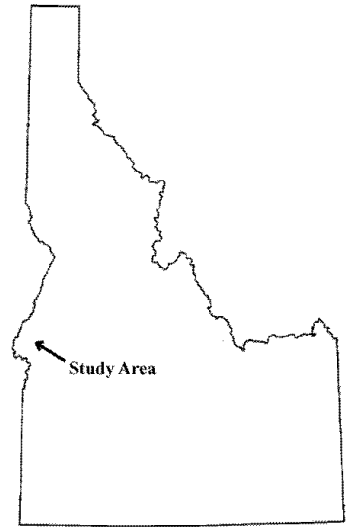
<http://www.worldoil.com/Article.aspx?id=40370>

Generally lower resolution but covers large areas quickly
Often used as a reconnaissance tool to identify areas for
detailed ground-based investigation

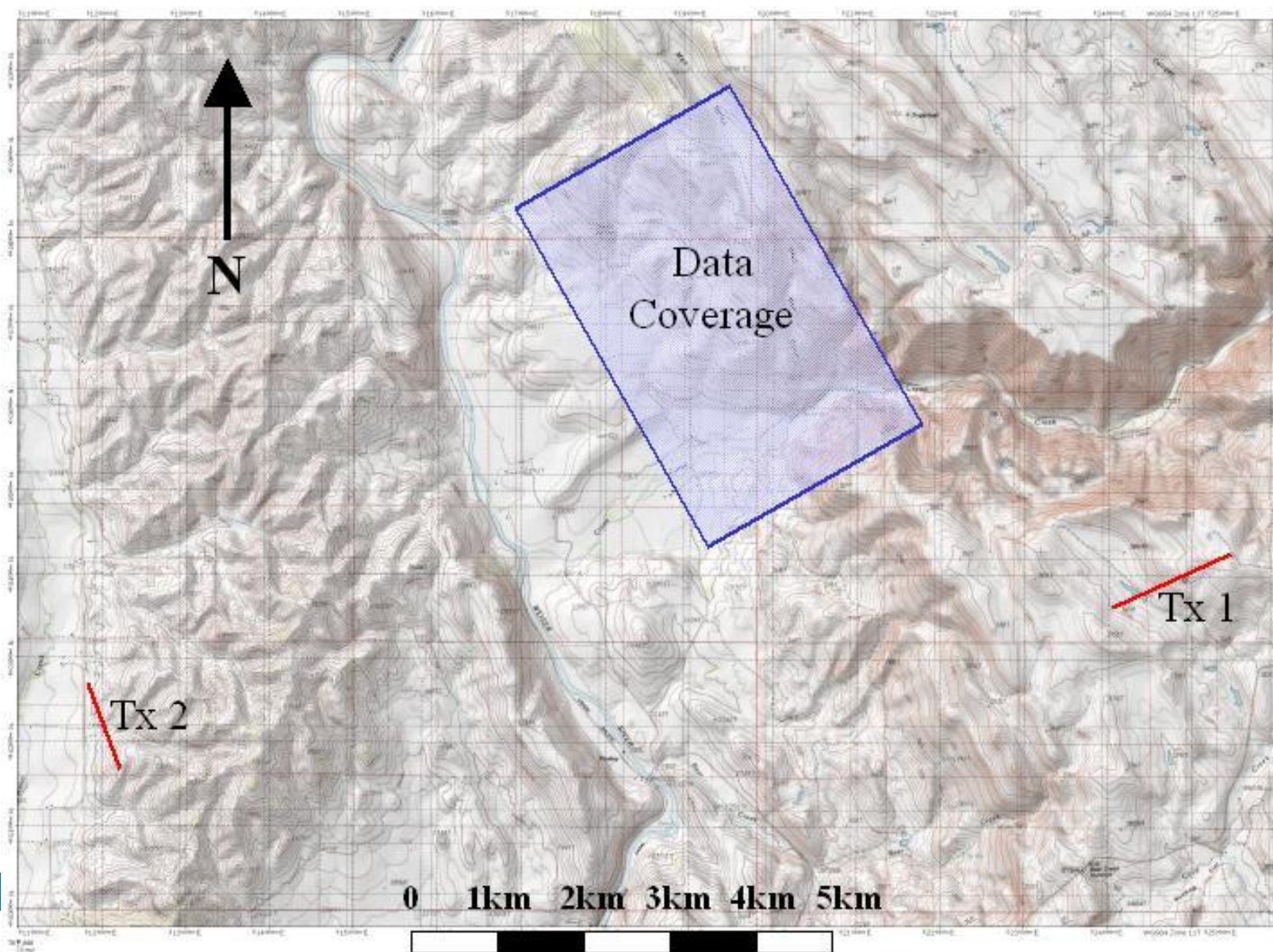
Electromagnetics Example

Goal – Characterize a geothermal resource and identify possible drilling targets

Method – Controlled source audio-frequency magnetotellurics (CSAMT)



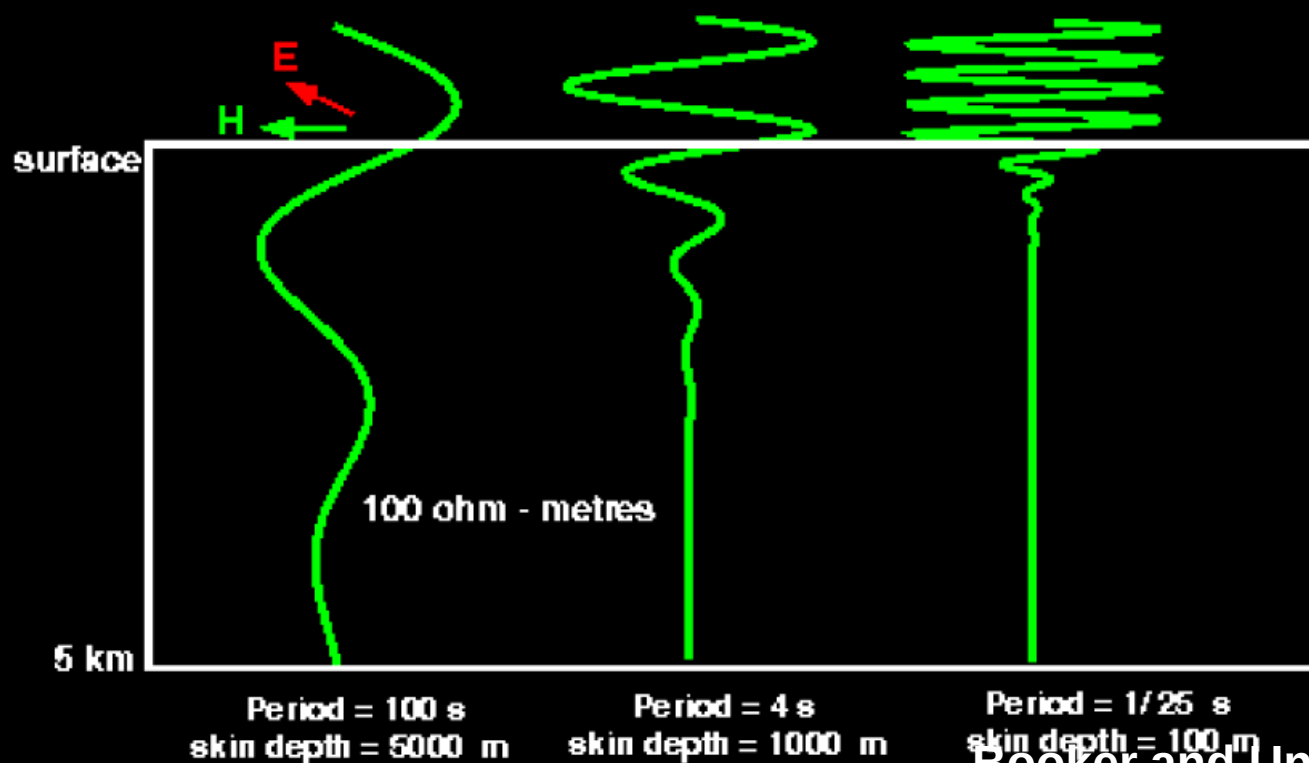
Survey Layout



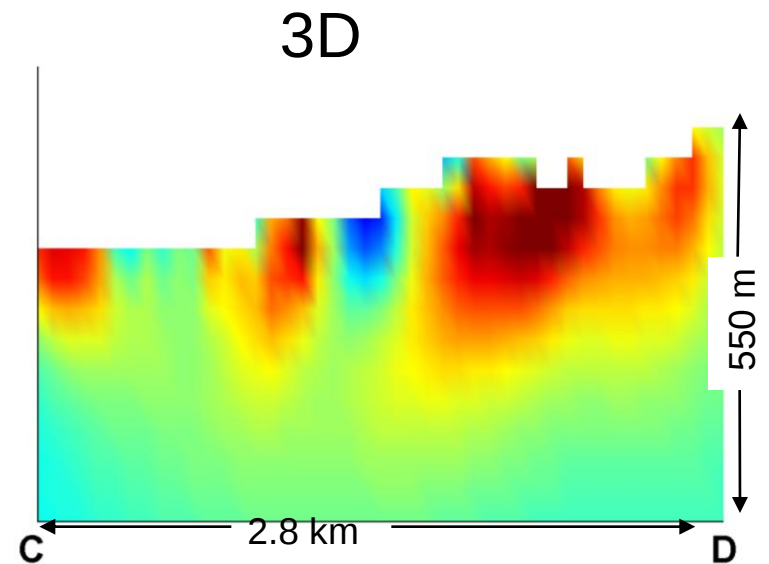
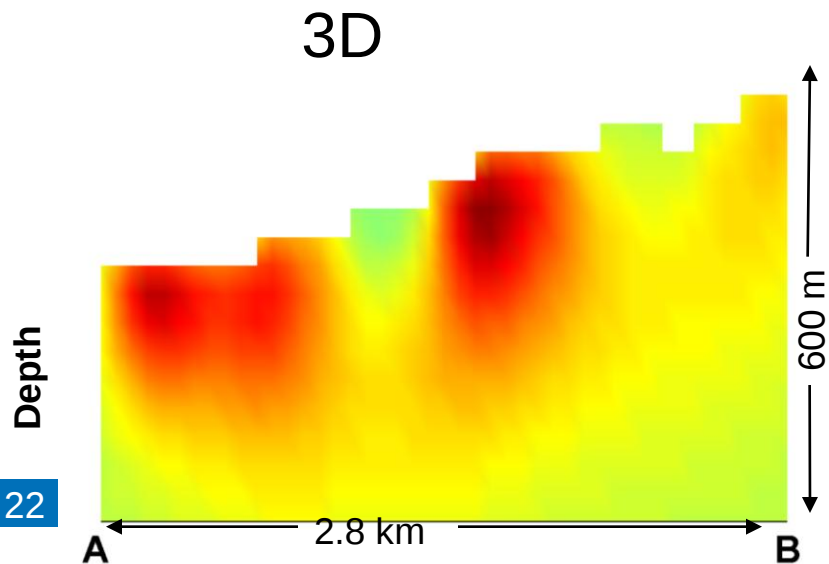
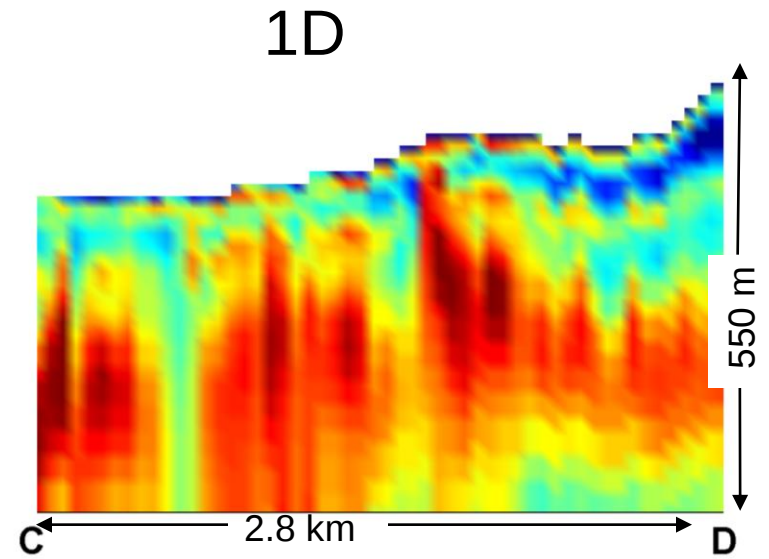
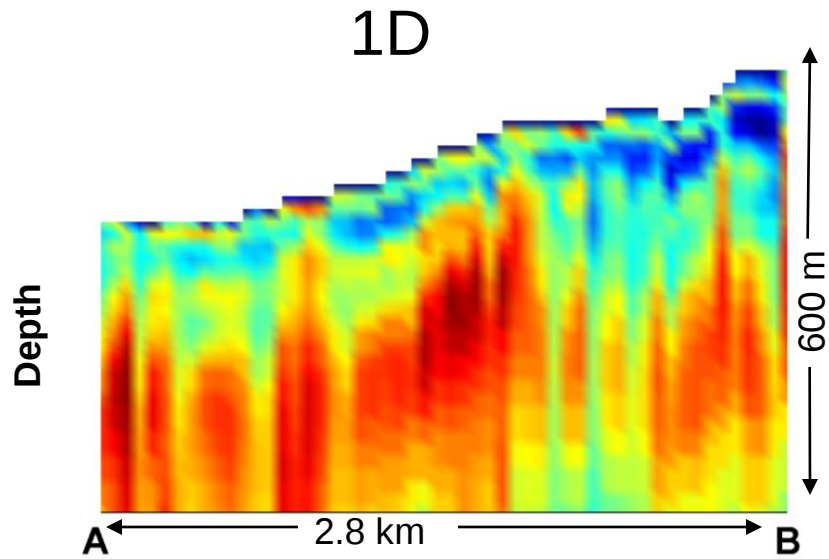
Multi-Frequency Data

Low Frequency: Deeper Penetration

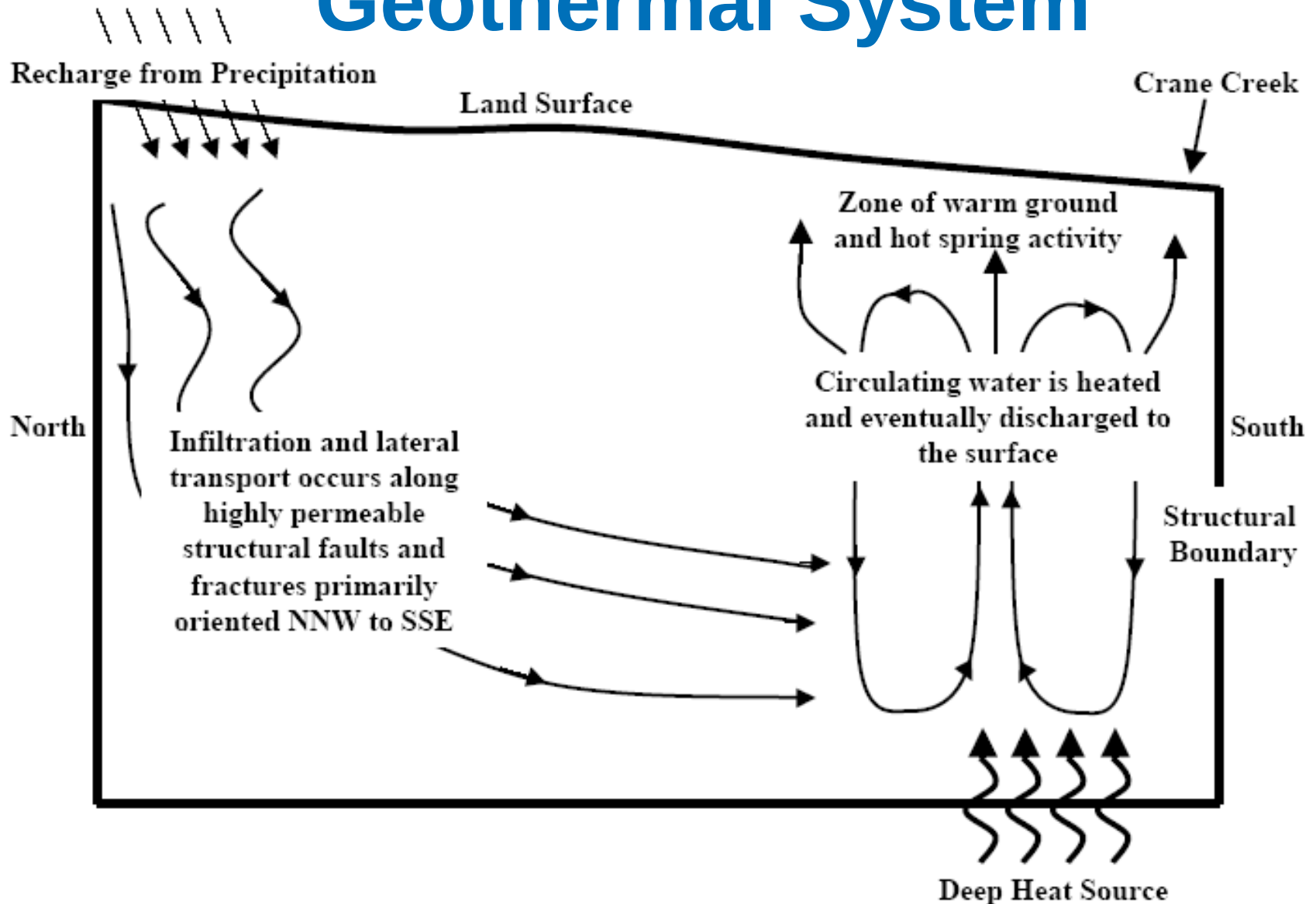
Higher Frequency: Shallow Penetration



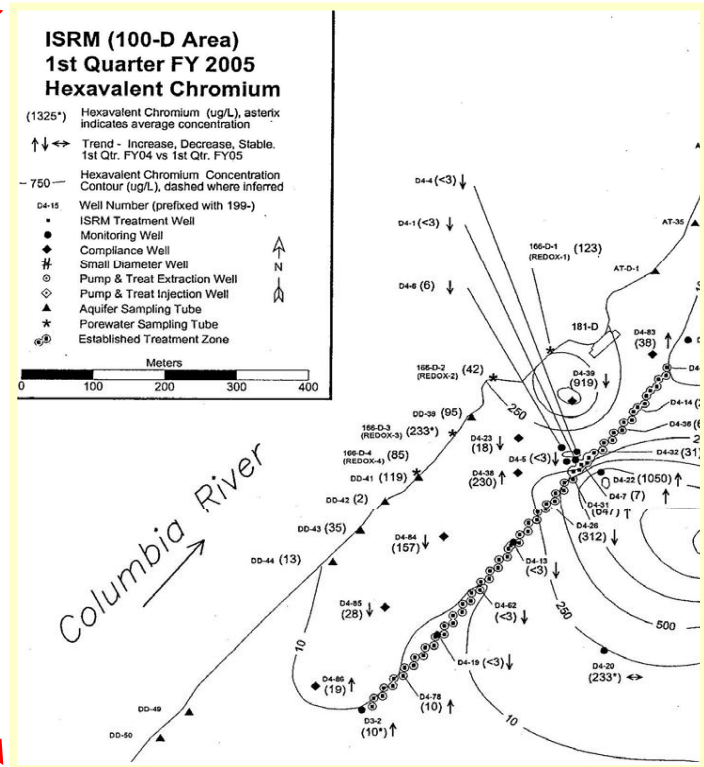
Model Slices



Conceptual Model of Geothermal System

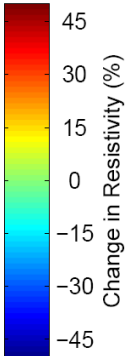
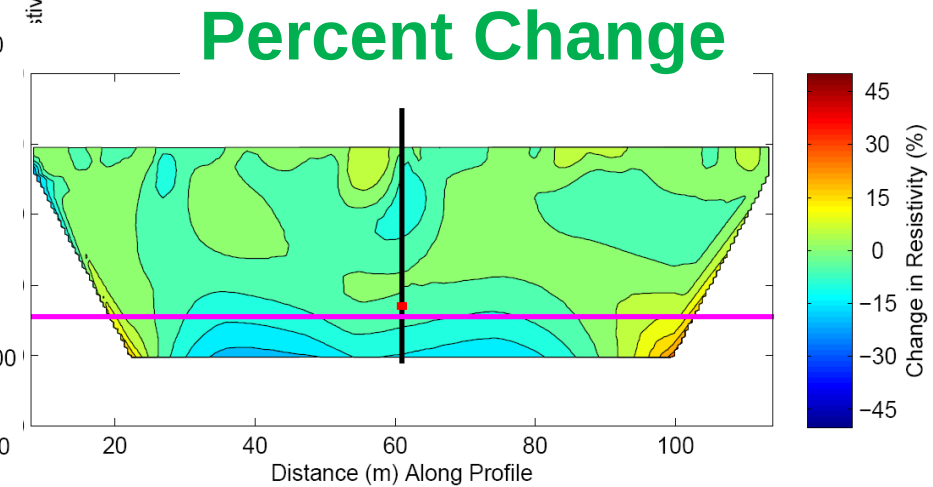
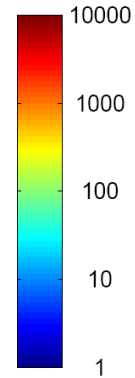
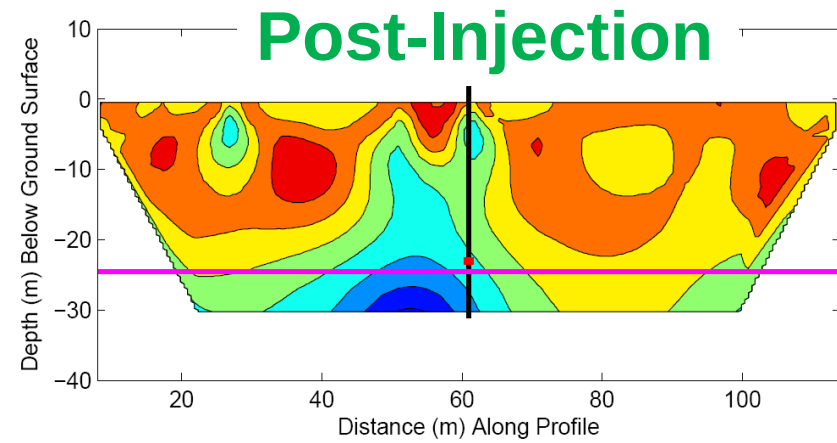
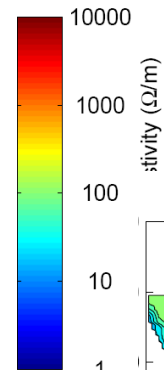
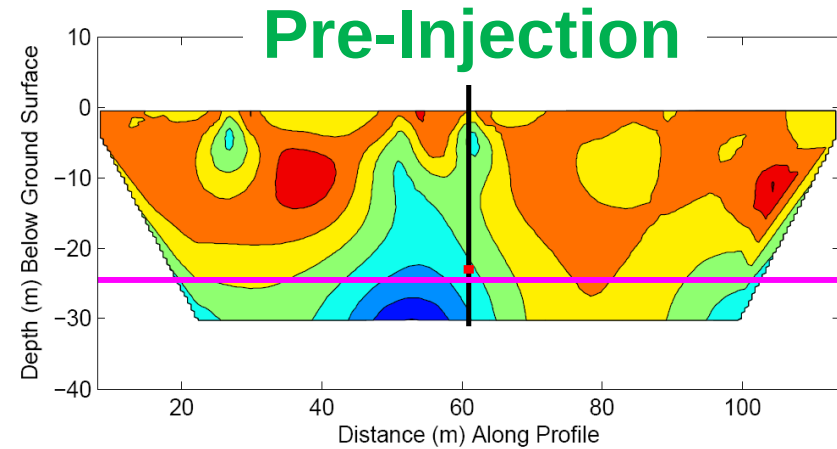


Methods – Electrical resistivity, Induced polarization, Borehole logging

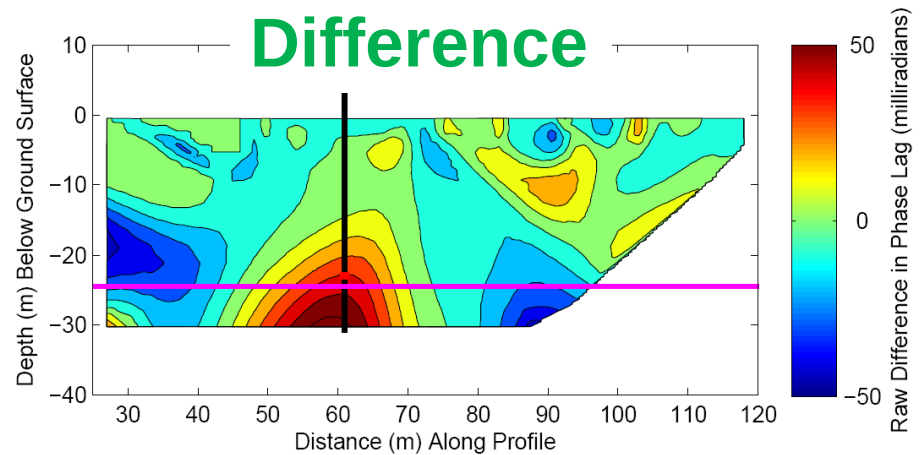
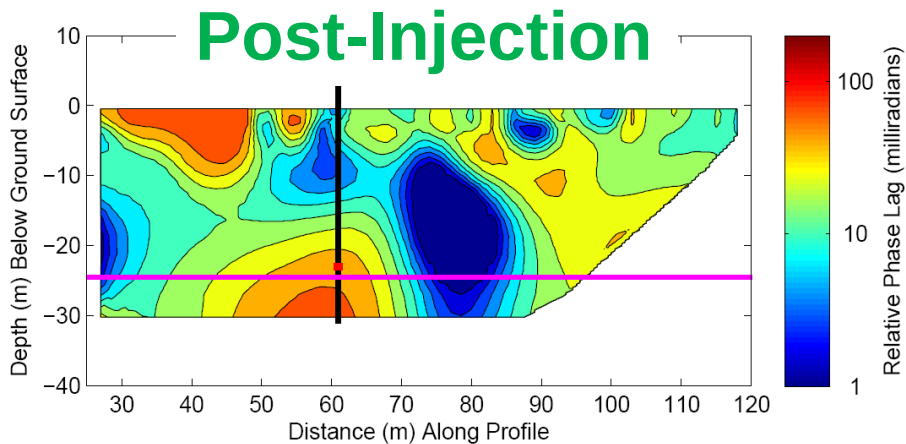
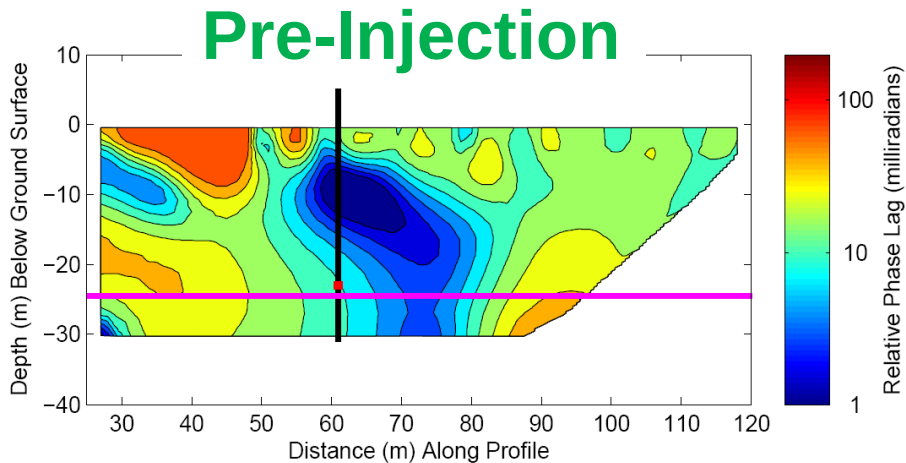


Location – DOE Hanford Site,
Washington State

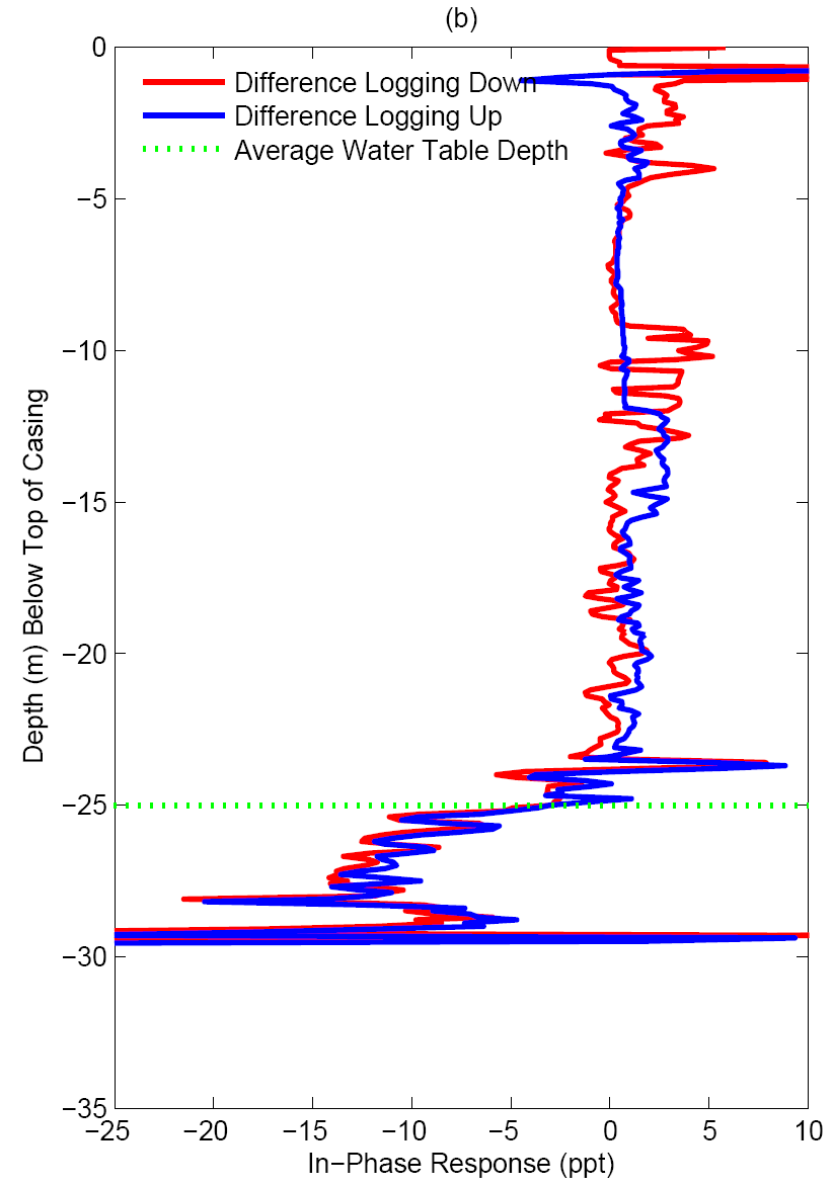
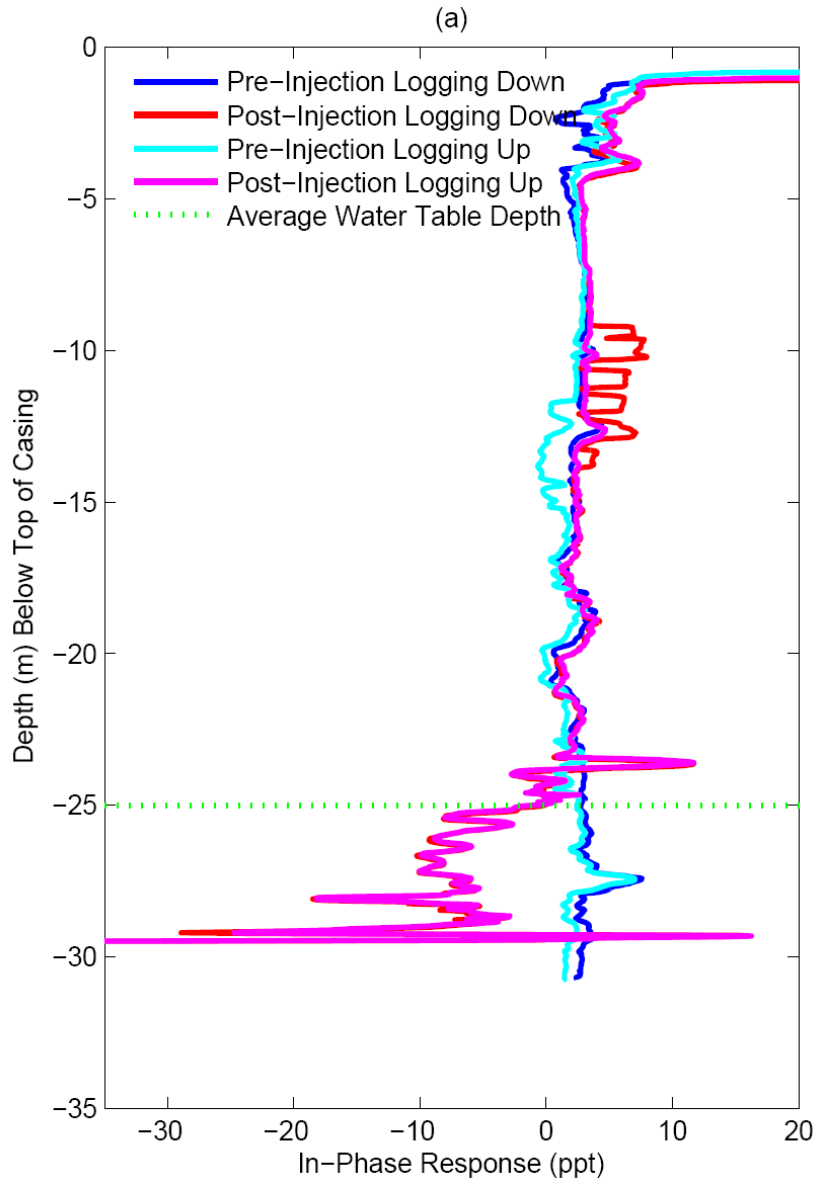
Resistivity Models



Chargeability (IP) Models



Borehole EM

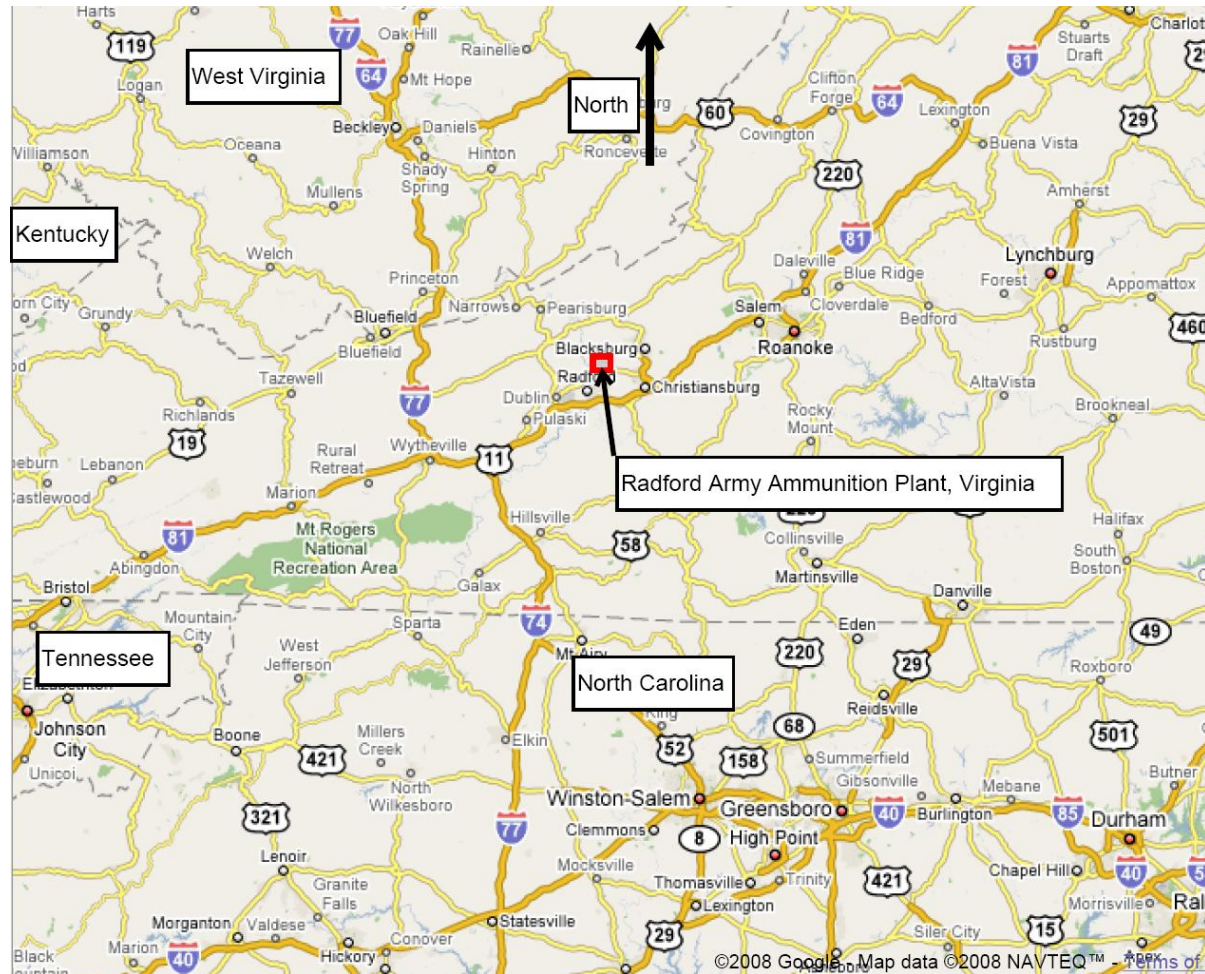


Seismic Refraction

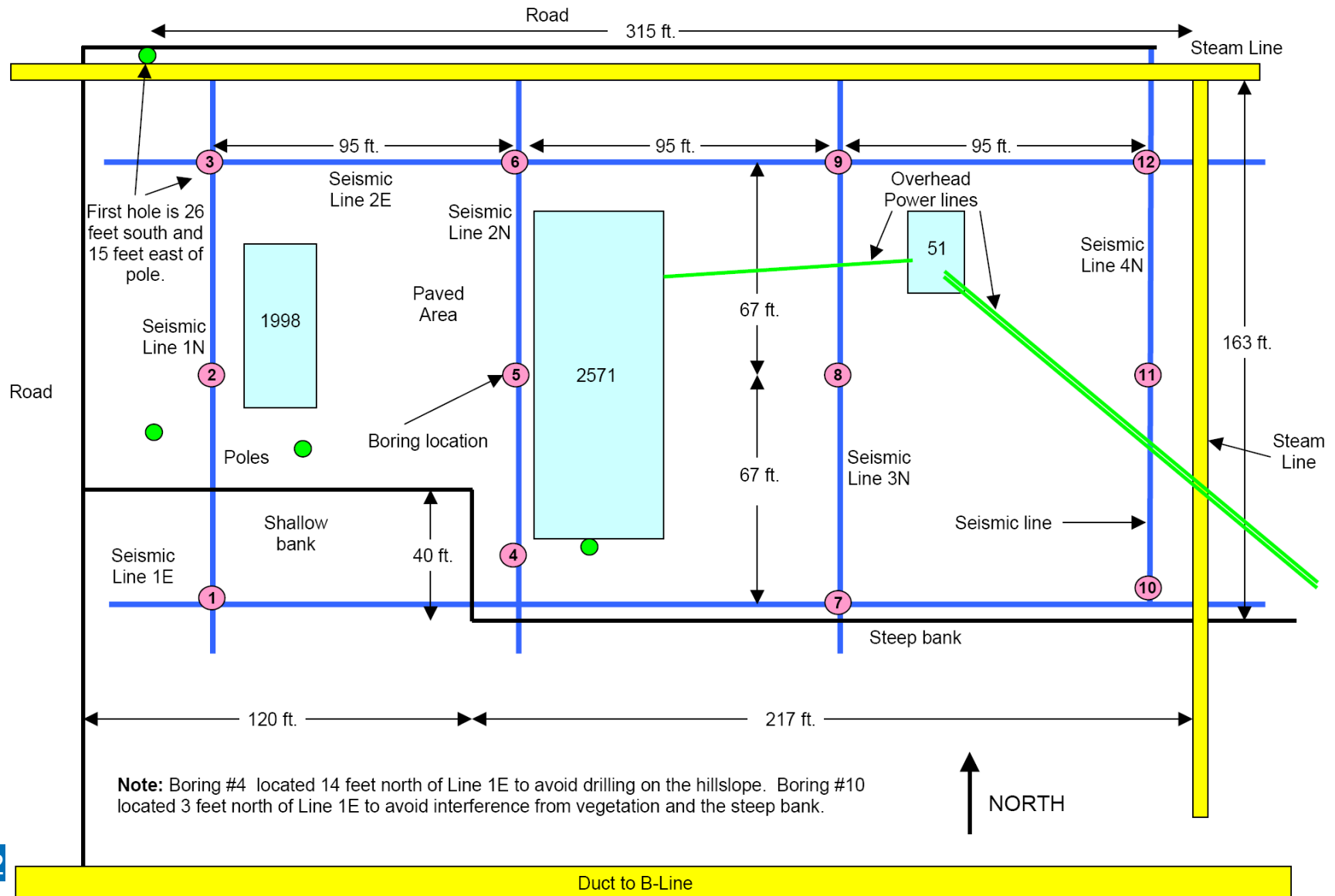
Goal – Characterize a construction site and identify possible karst sinkhole features or other hazards

Method – Seismic Refraction

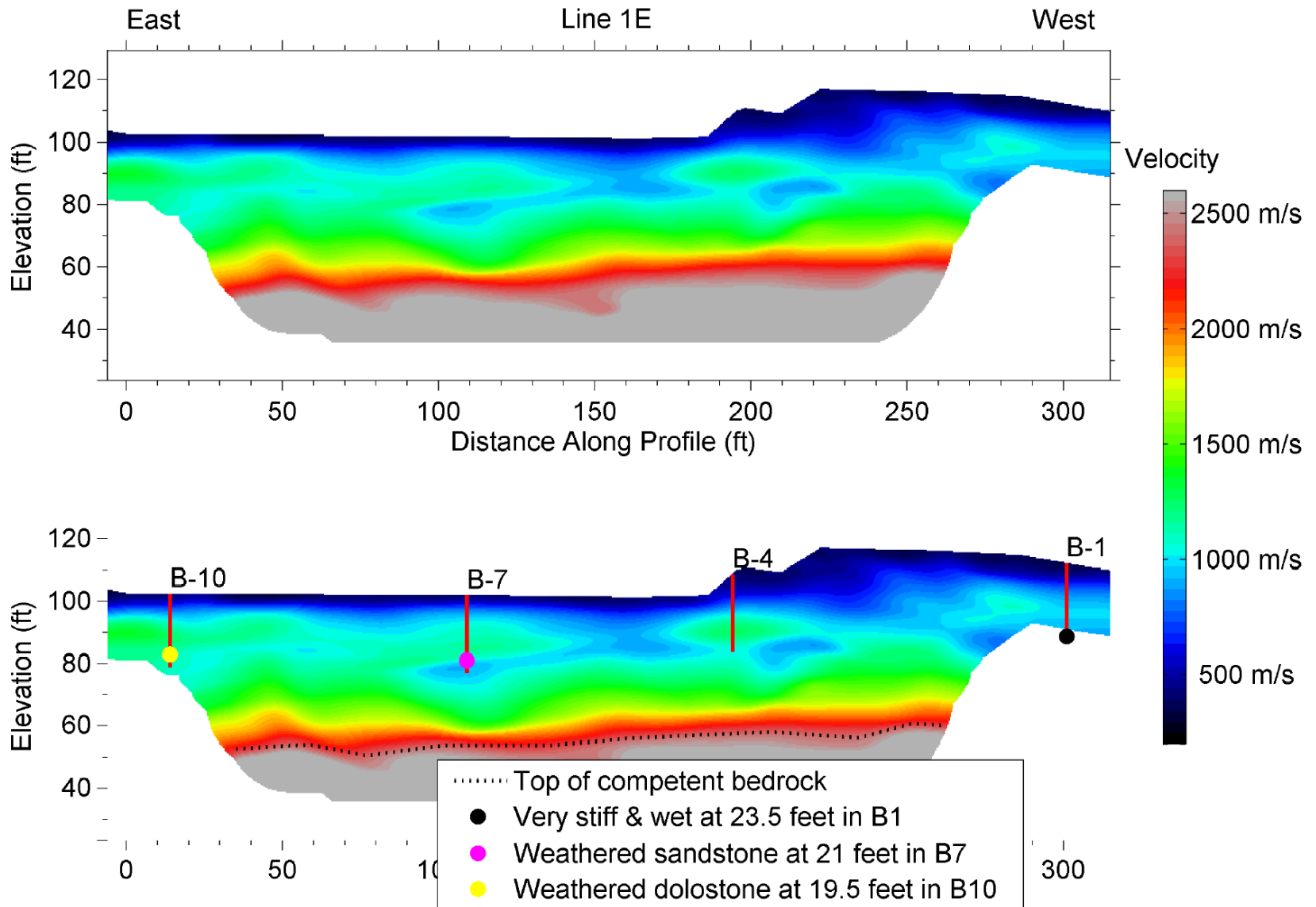
Location – Radford Army Ammunition Plant, Virginia



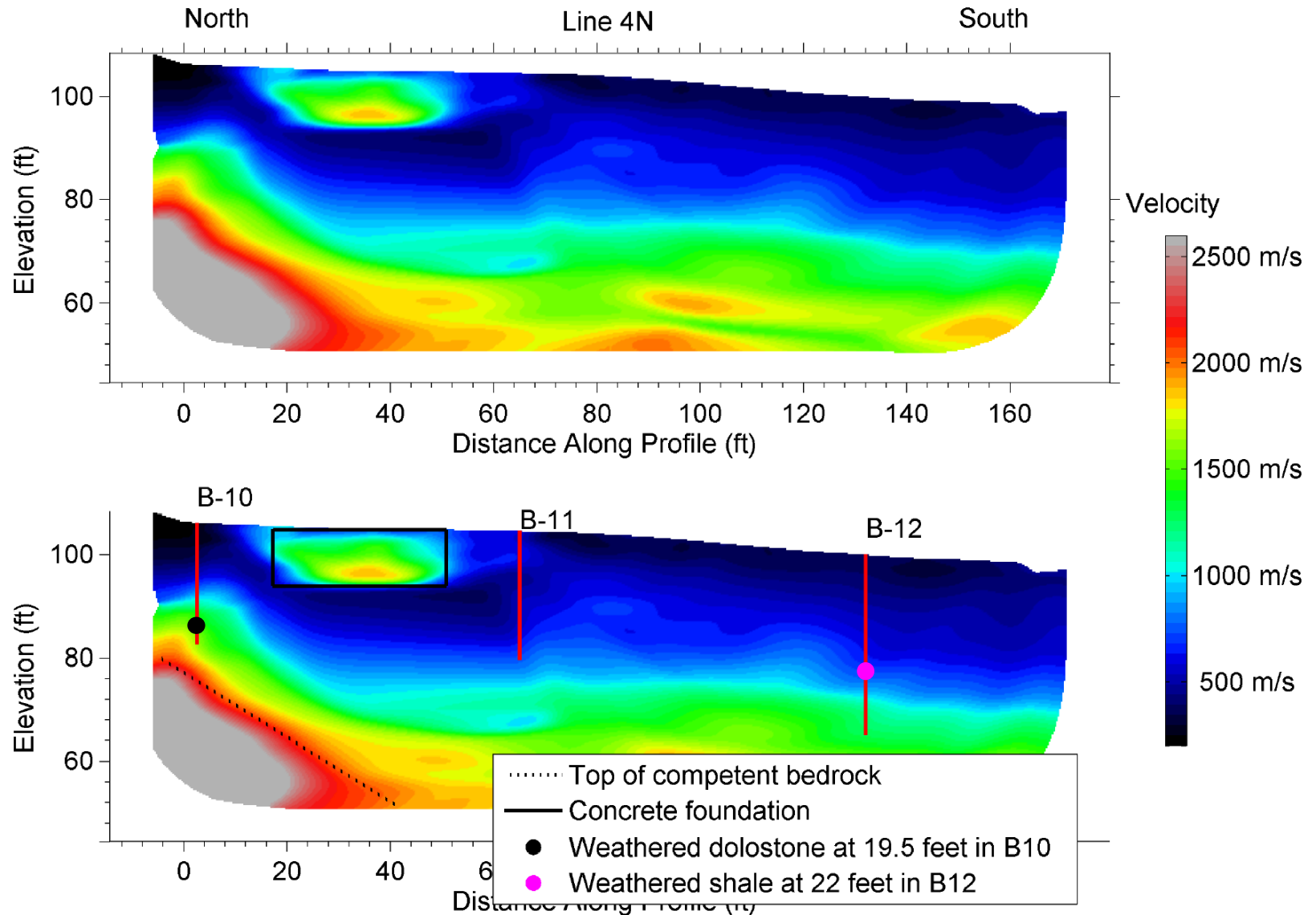
Site Plan



Velocity Model



Velocity Model

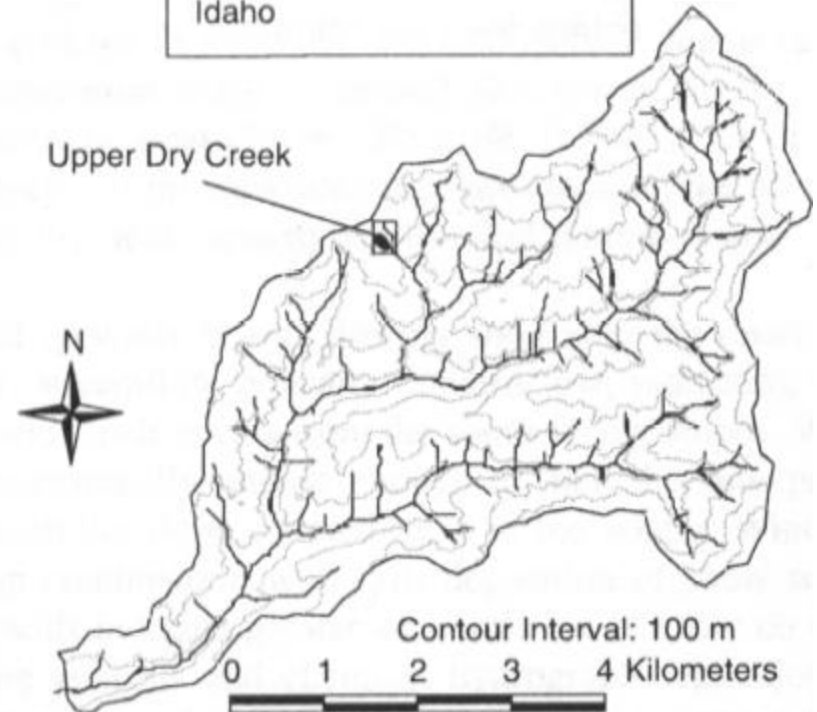


Time Lapse Resistivity

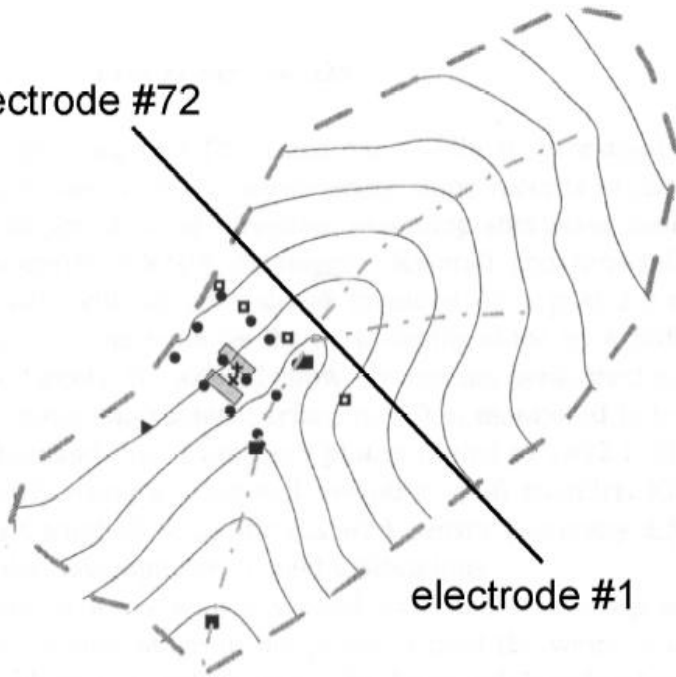
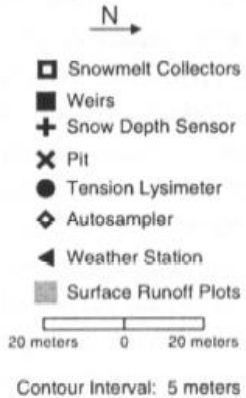
Goal – Determine seasonal variability in water storage for a small watershed

Method – Time lapse resistivity

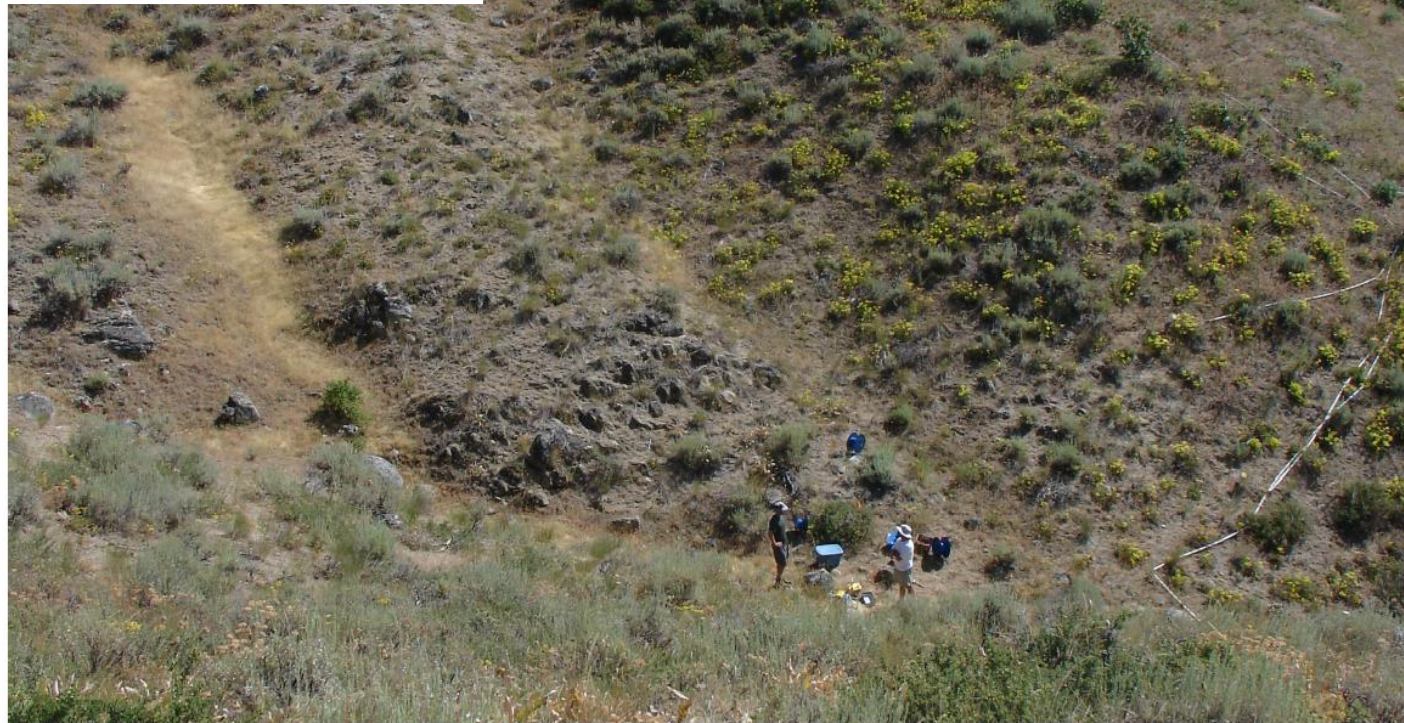
Location – North of Boise, Idaho



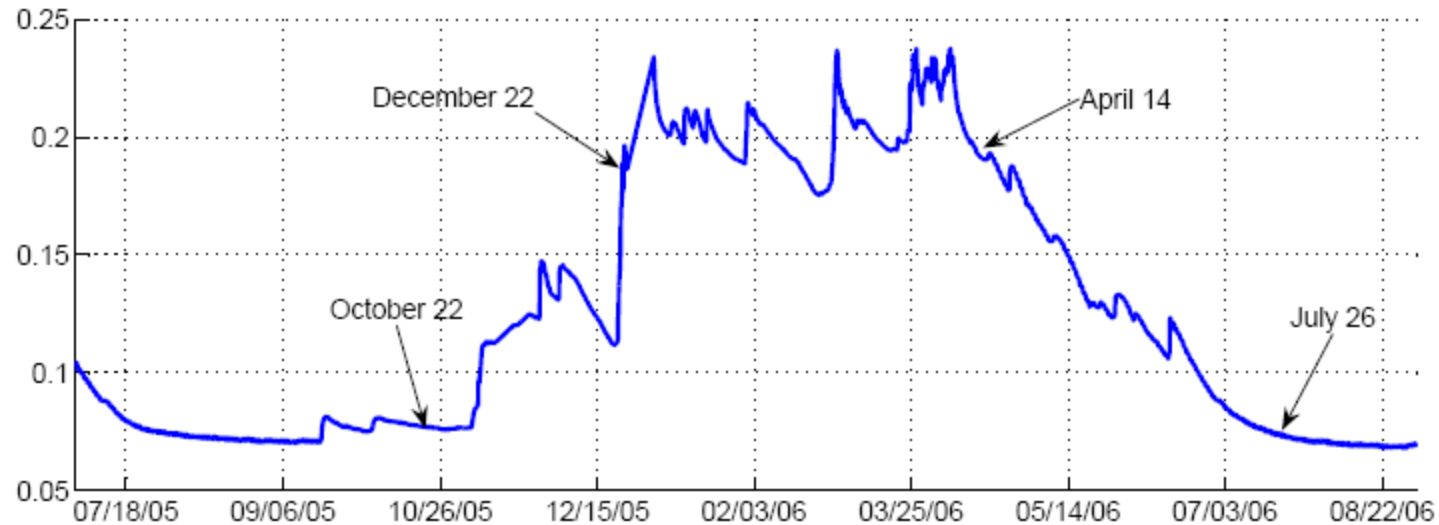
electrode #72



Survey Layout



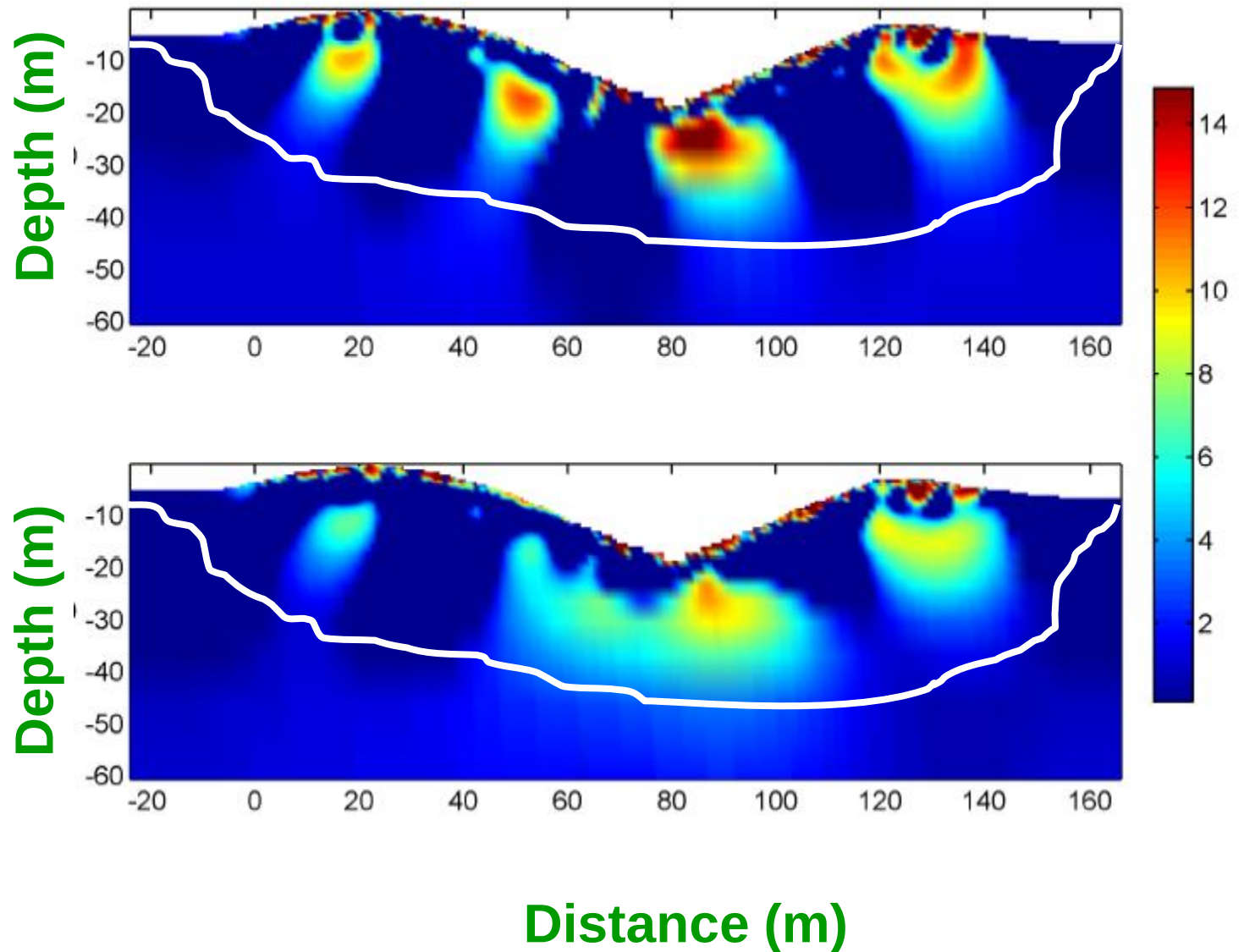
Survey Timing



Soil moisture sensors buried 5, 15, 30, 45, and 60 cm deep

Data acquisition was timed to capture two dry periods and two wet periods

Saturation Changes



Magnetics

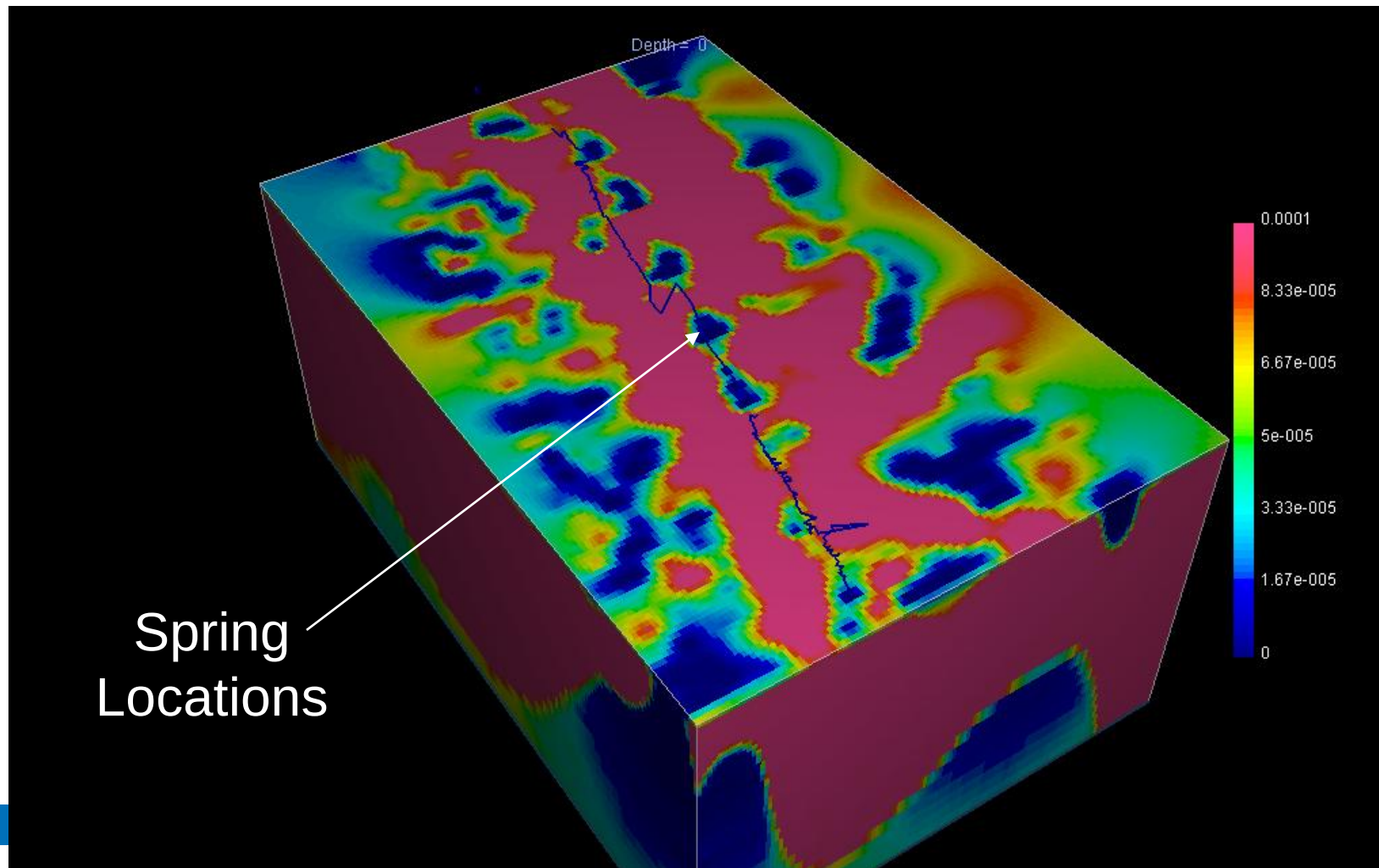
Goal – Characterize a geothermal system

Method – Magnetics

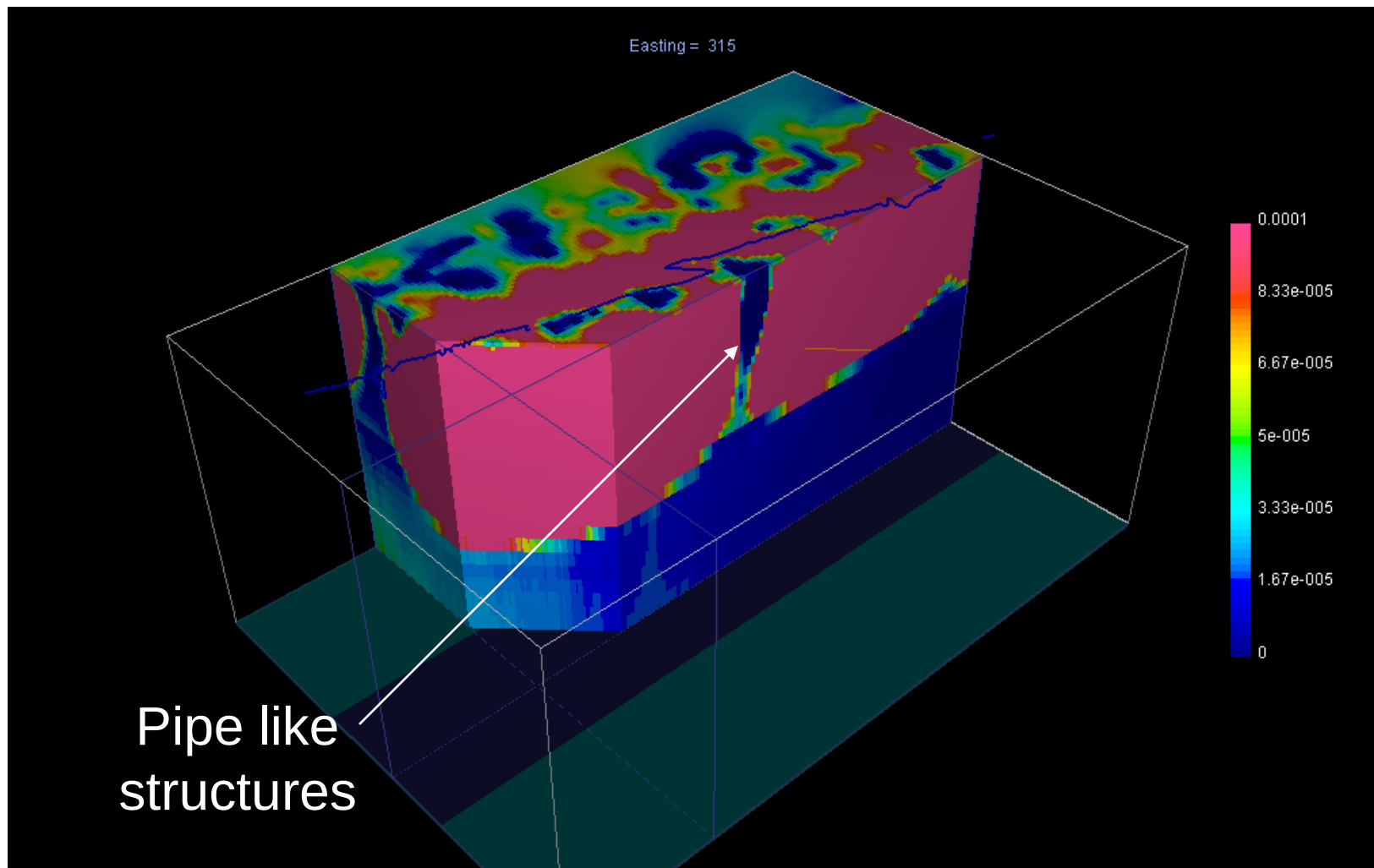


Location – Alvord Desert,
Eastern Oregon

Susceptibility Model



Slice Through Model



Questions?



Contact Info:
Miller.Carlyle@epa.gov
(580)-436-8950

Near Surface EM Tools

System	Description	Horizontal Resolution	Vertical Resolution	Frequency/ Time Domain/ Static
EM31	Vertical Loop/ Horizontal Loop. Coil separation 3.7m	Few meters	Between 1-6m.	Frequency domain. Operates at 9.8 KHz
EM 34-3	Vertical Loop/ Horizontal Loop. Coil separation 10,20,40 m	Tens of meters	Between 4-60m.	Frequency domain. 0.4,1.6,6.4 kHz.
EM 61	Coincident Loop	1m	3-5m	Time Domain
Protem	Loop TX: 5m-100m, RX: 60cm	Wider than TX Loop	Few to hundreds of meters	Time domain: with time gates 6microsec-32ms
Syscal	Multi-Channel Resistivity system	Depends on electrode spacing	Cm to 100s of meters	DC potentials measured
OhmMapper	Capacitively coupled system at 17 kHz	Depends on electrode spacing	Cm to 100s of meters	Electric Field measured