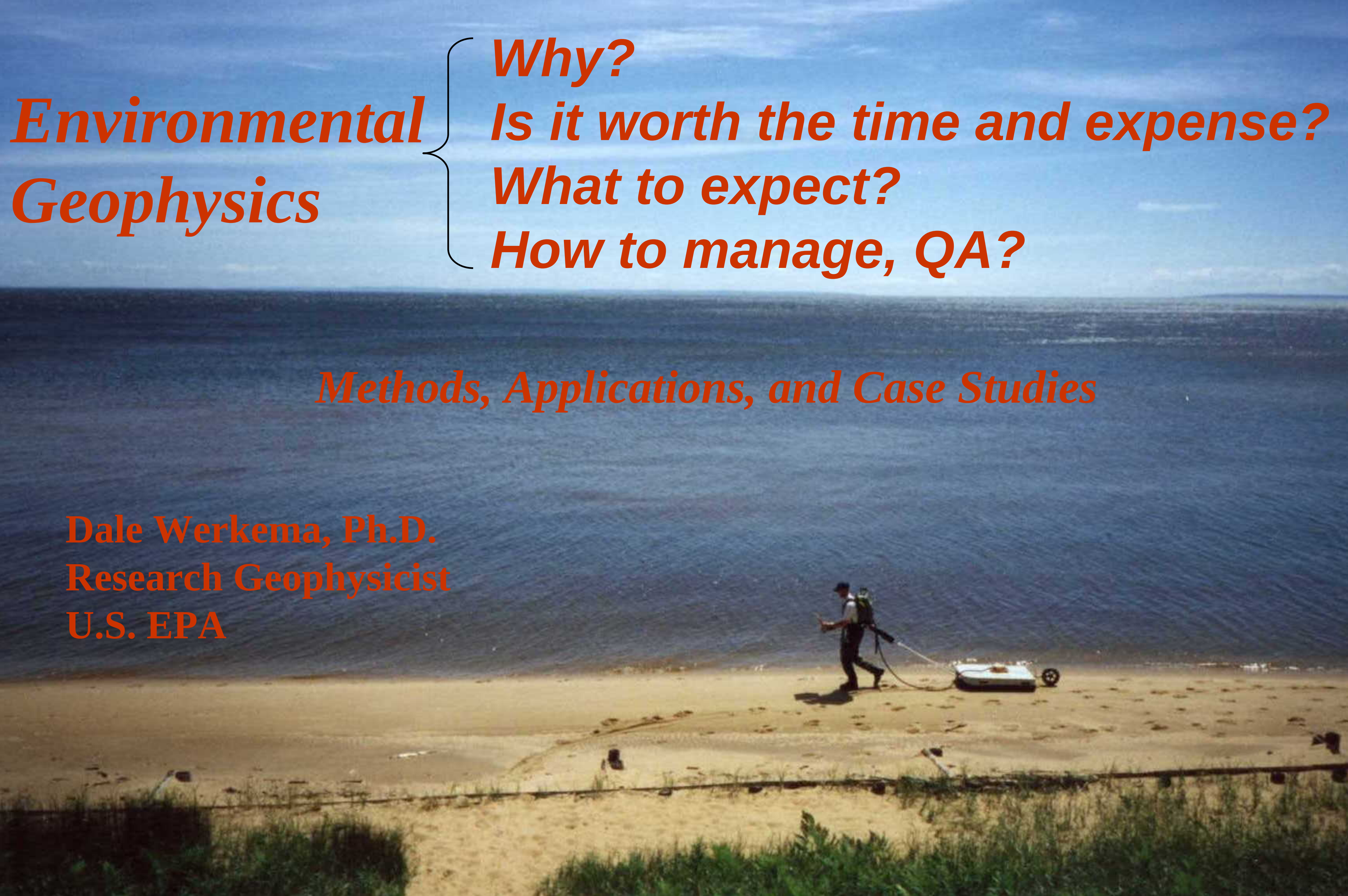
Environmental Geophysics

- *Why?*
- *Is it worth the time and expense?*
- *What to expect?*
- *How to manage, QA?*

Methods, Applications, and Case Studies

Dale Werkema, Ph.D.
Research Geophysicist
U.S. EPA



Outline

- Typical environmental geophysical methods:
  - *Detection capabilities: detect what? At what concentration?*
  - *Limitations*
  - *What are the best practices for these methods?*
  - *What are the QA/QC considerations?*
  - *Expected products or deliverables*
  - *Is additional data needed? If so, what?*
  - *What are reasonable expectations?*
  - *Cost/value*

- Can geophysical methods aid conceptual site model (CSM)?
- Are geophysical methods capable of Long-Term remediation monitoring (see earlier talk)?
- Lessons learned/pitfalls?
- Questions to ask a geophysical contractor

Typical (surface) Environmental Geophysical Methods

1. **Electrical Methods**
2. **Magnetic Methods**
3. **Seismic Methods**
4. **Gravimetric**
5. **Borehole specific methods (not covered)**

Electrical Methods

- ***Resistivity***
- ***Induced Polarization (IP)***
- ***Spectral Induced Polarization (SIP)***
- ***Self-Potential (SP)***
- ***Electromagnetic Induction (EMI)***
- ***Ground Penetrating Radar (GPR)***

Properties measured:

•electrical resistivity/cond.

•magnetic permeability

•oxidation potential/ion conc.

applications:

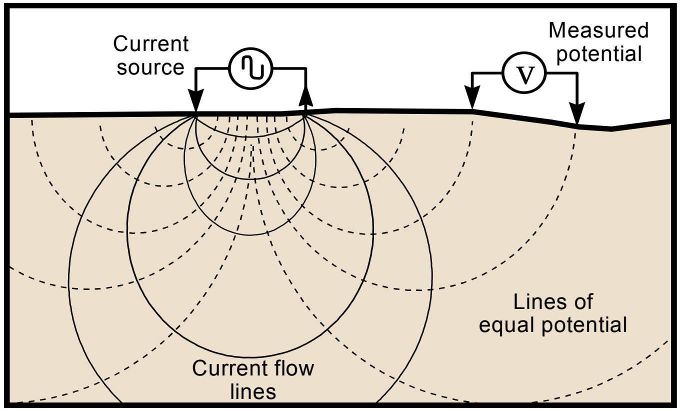
•CSM

•Subsurface mapping

•Bulk electrical property contrasts

•Long-term monitoring

Direct Current (DC) Resistivity



Archie's Law for Porous Media w/o clay

$$\rho_e = a\,\phi^{-m}\,S^{-n}\,\rho_w$$

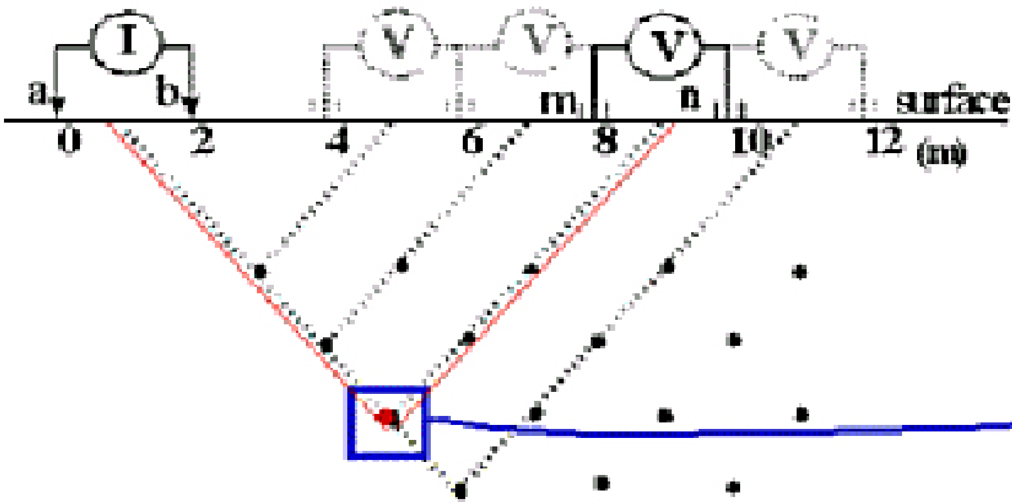
ρ_e = resistivity of the earth

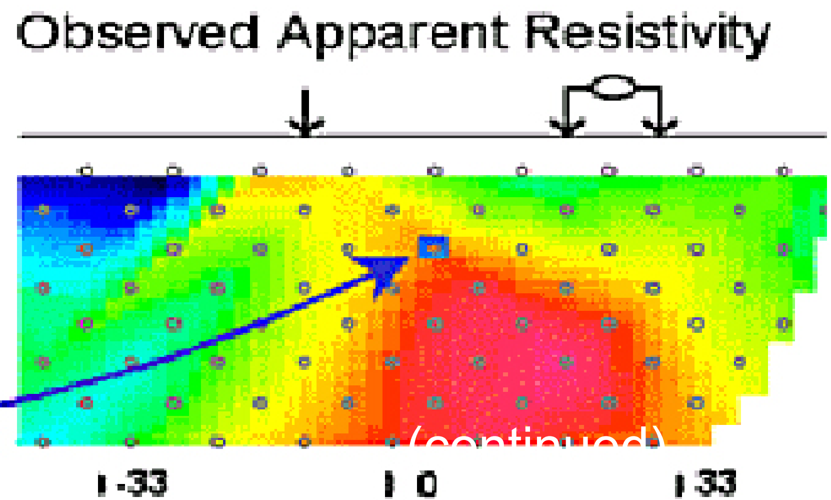
ϕ = fractional pore volume (porosity)

S = fraction of the pores containing fluid

ρ_w = the resistivity of the fluid

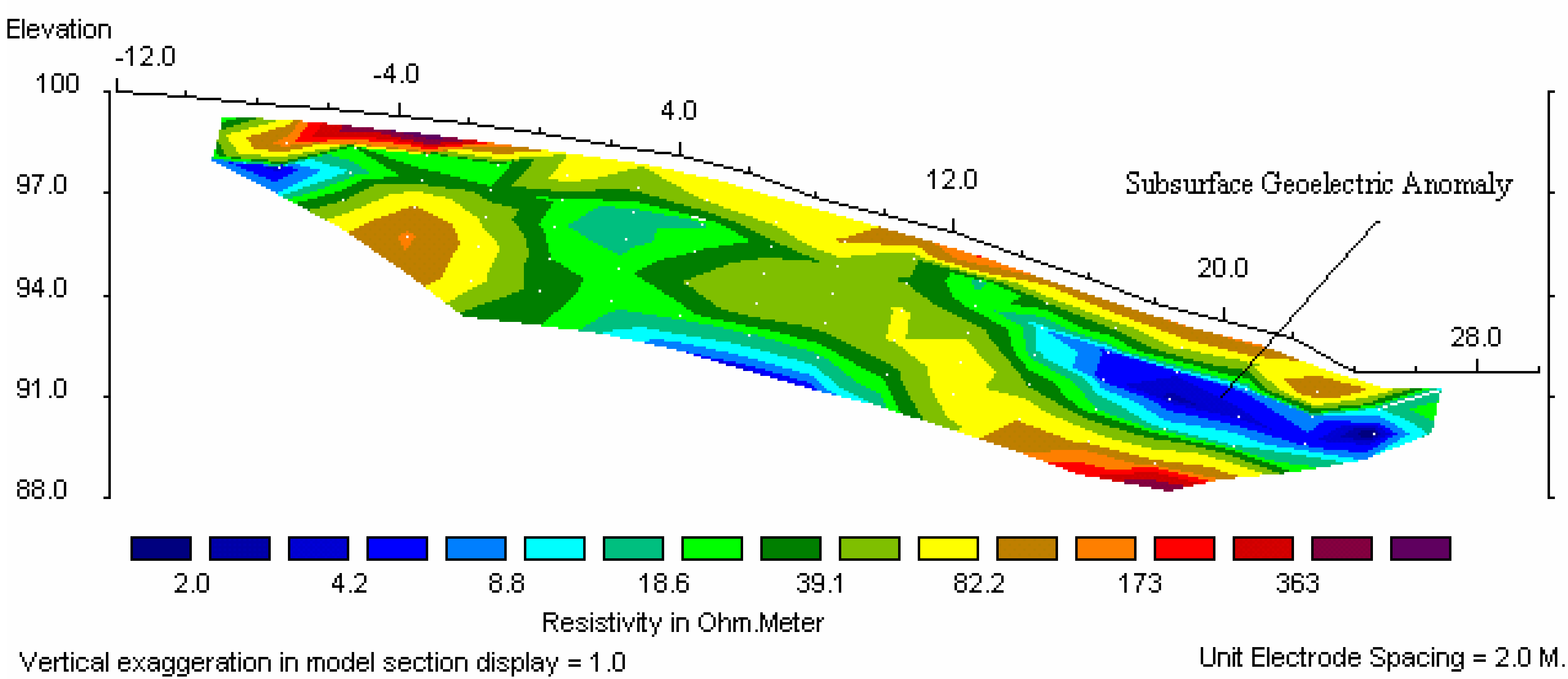
n, a and m are empirical constants



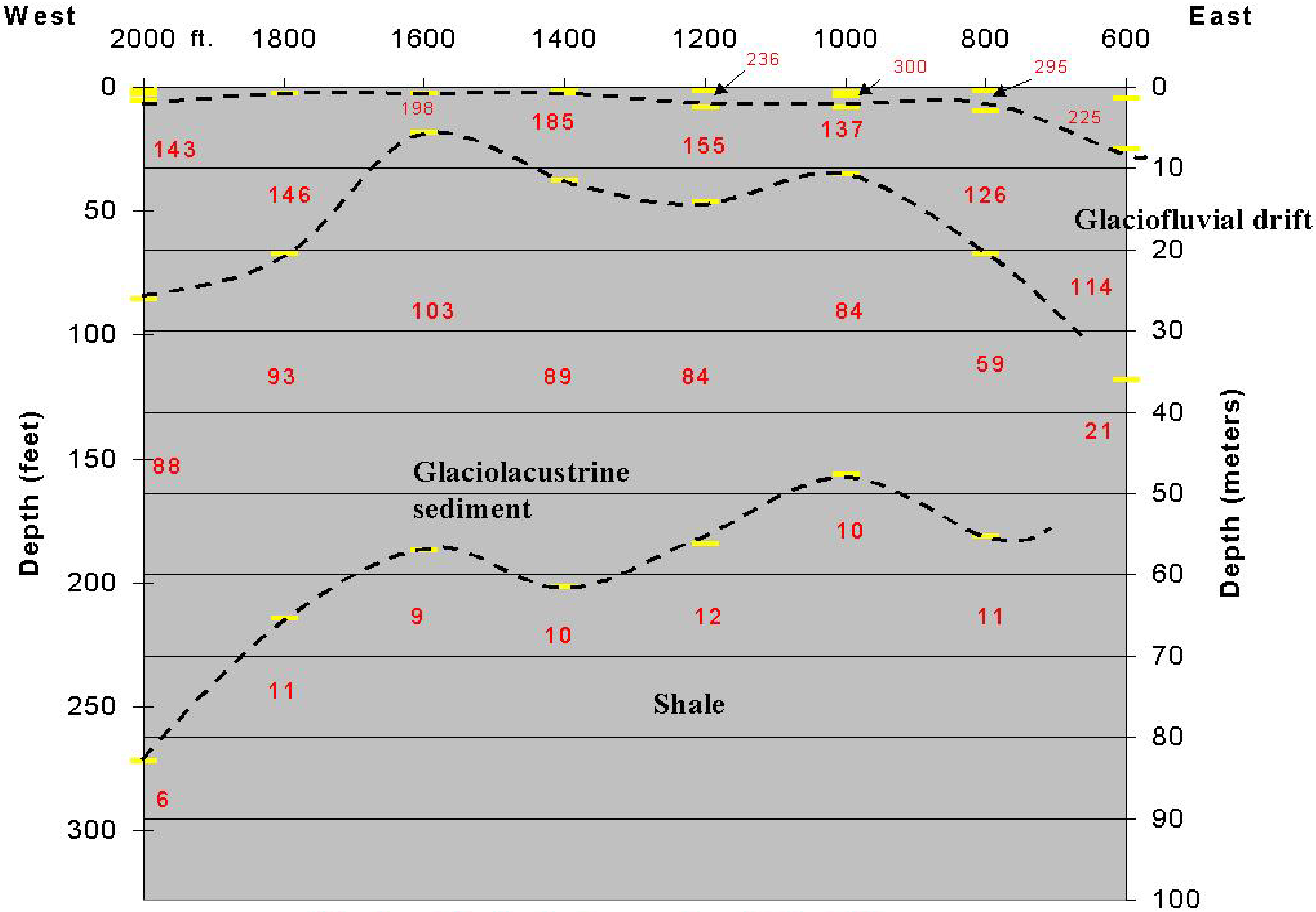


(continued)

Dipole-Dipole Resistivity mapping
Type II vs. Type III Landfill

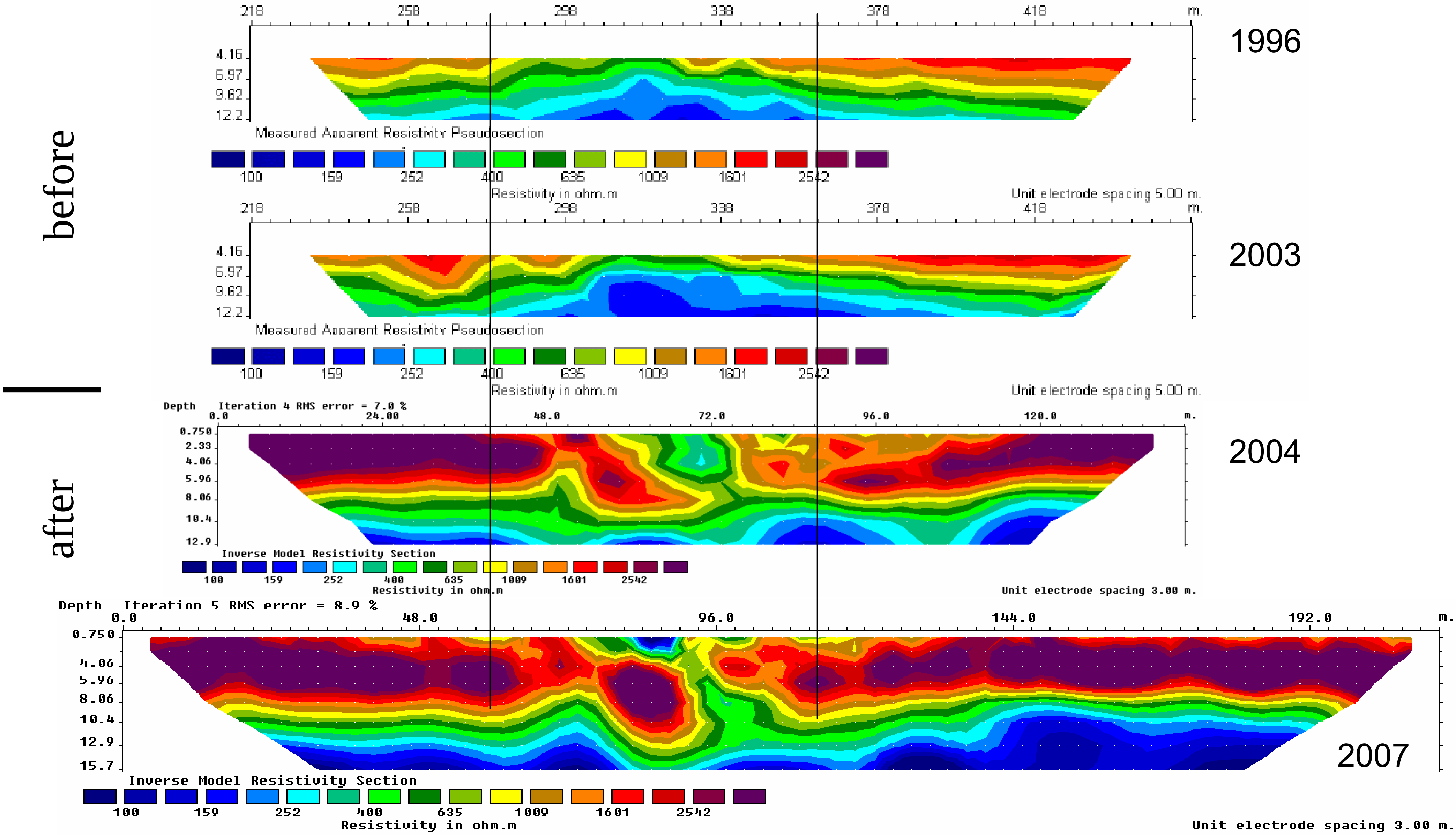


Schlumberger Vertical Electric Sounding Results



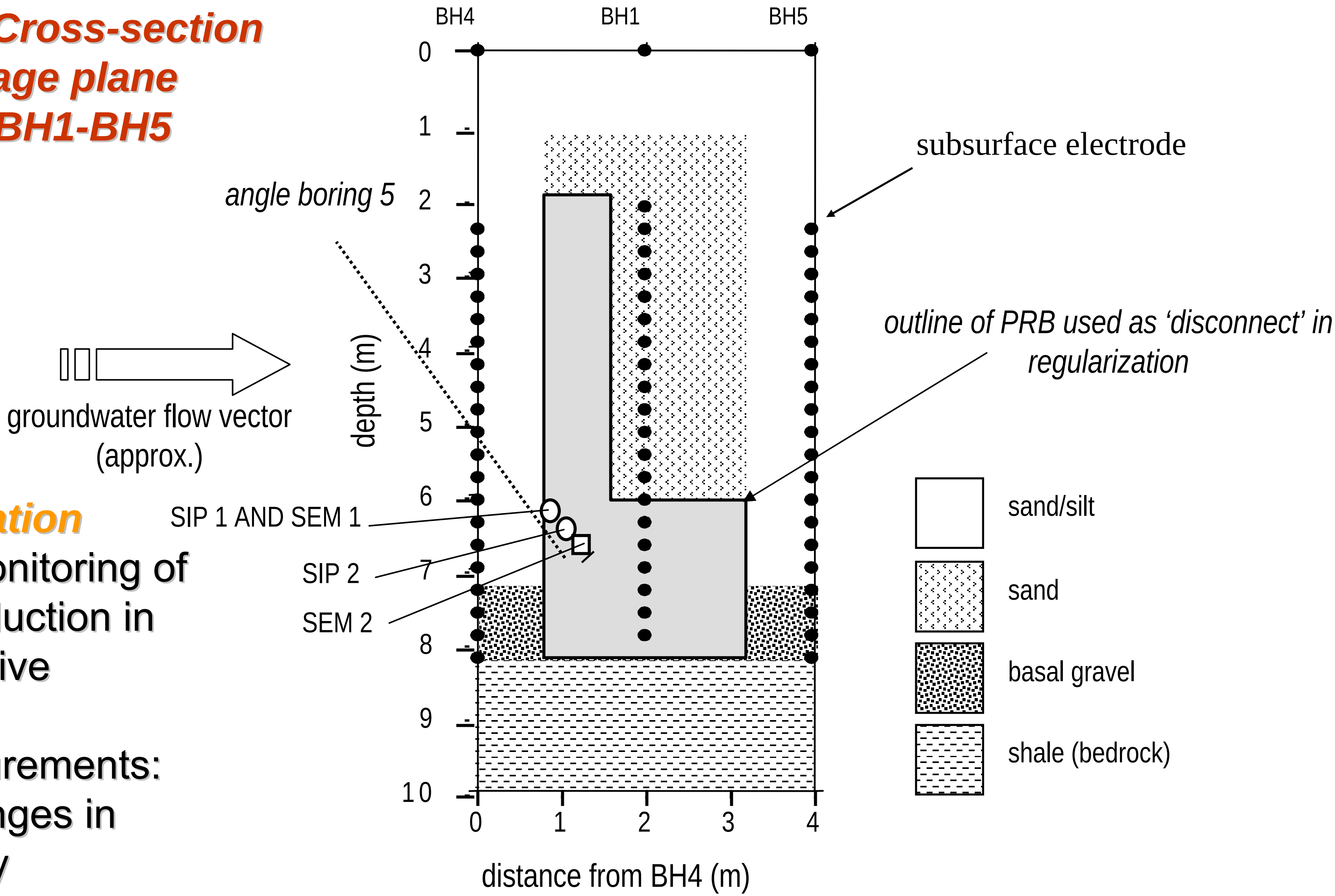
Numbers in Red indicate apparent resistivity in Ohm.m

Resistivity showing vapor extraction effects



Electrical methods to monitor permeable reactive barriers

Idealized Cross-section of image plane BH4-BH1-BH5



•Project Motivation

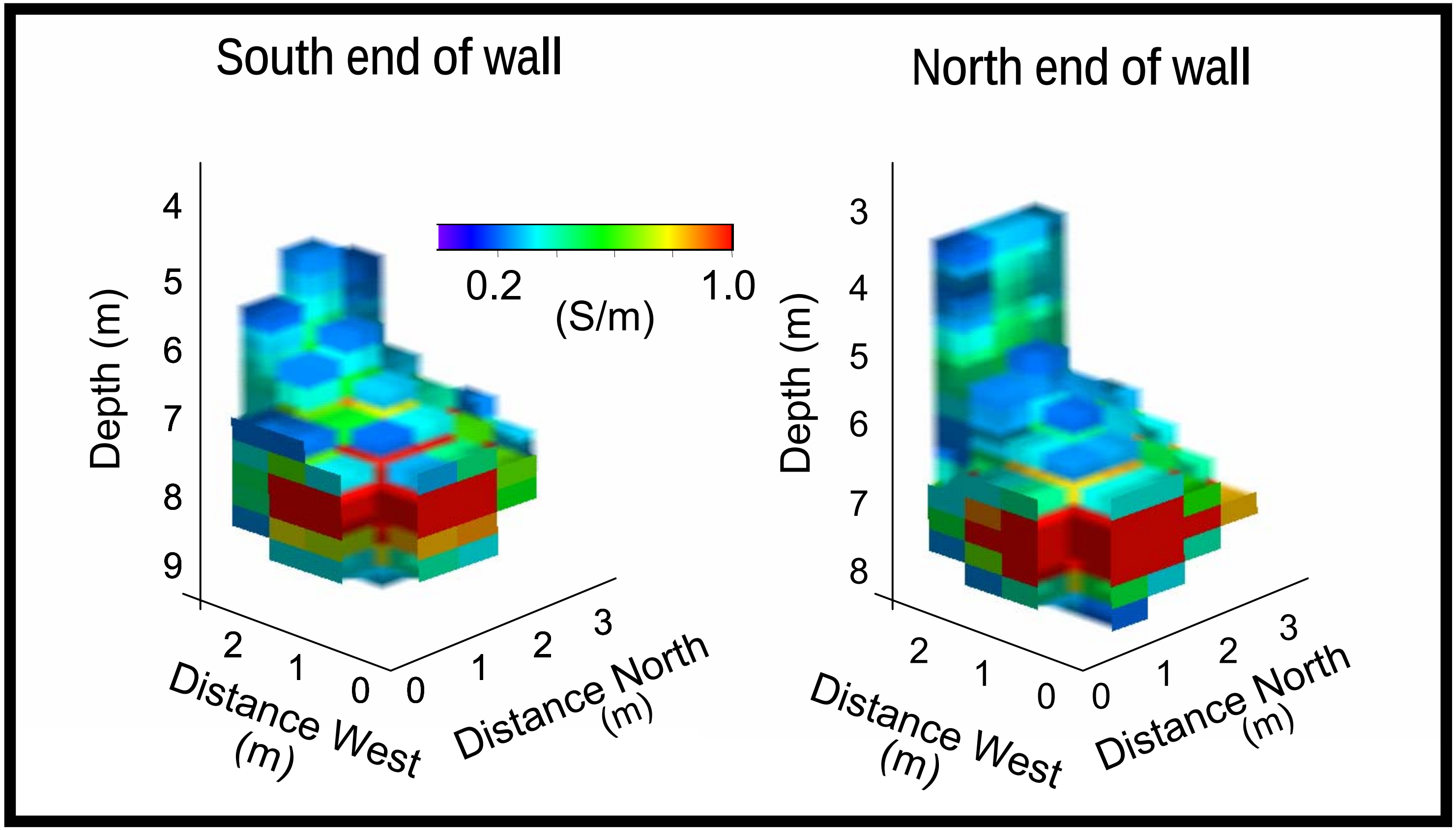
Non-invasive monitoring of performance reduction in permeable reactive barriers

Electrical measurements: sensitive to changes in surface reactivity (corrosion and precipitation)

Slater & Binley, Geophysics, 2006

Tomographic Application: Images of PRB integrity from 3D resistivity inversion

3D electrical conductivity image of the Kansas City PRB



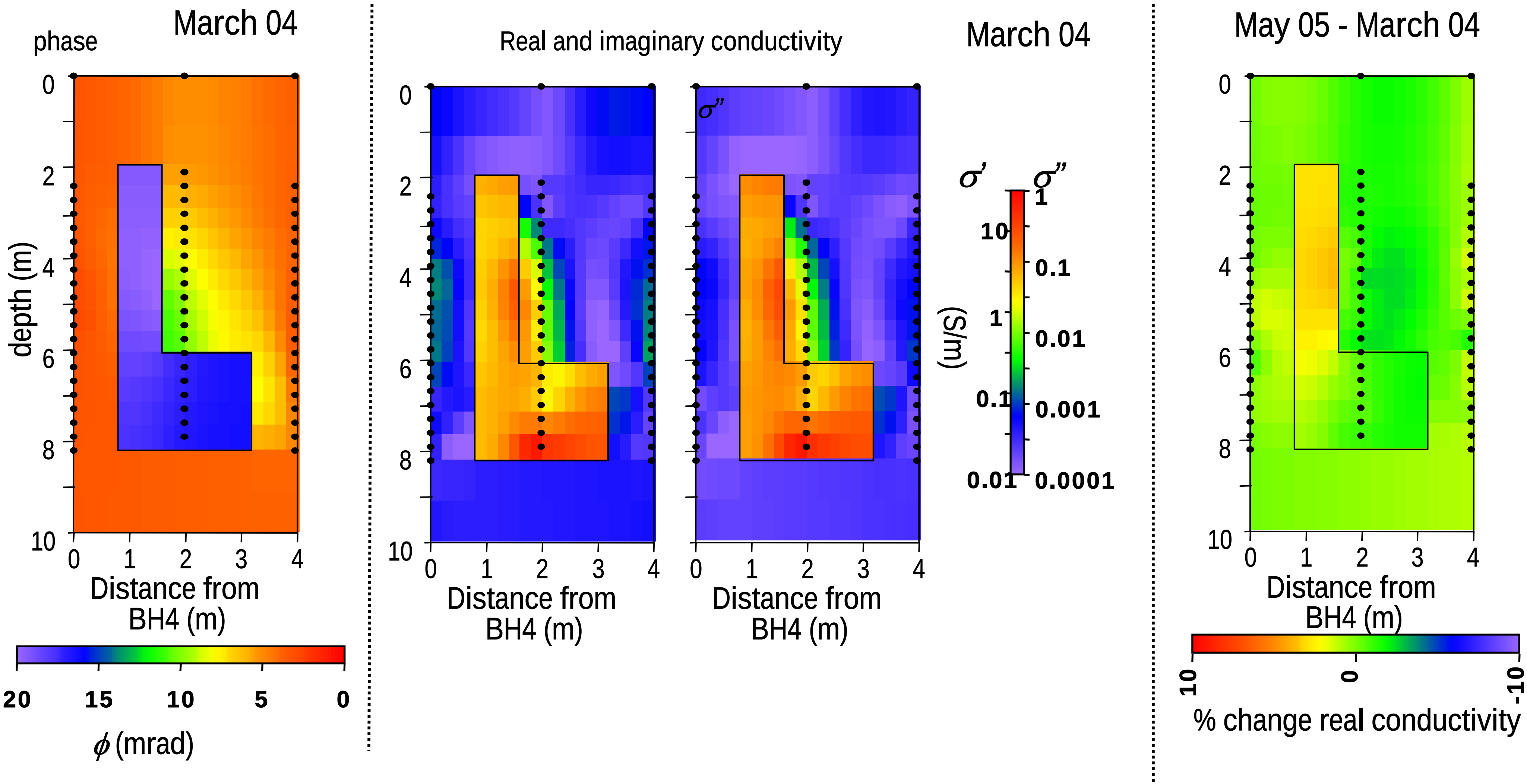
- Highly conductive granular iron.
- Cross borehole images effective at defining a 3D image of the barrier in-situ.

➢Imaginary conductivity (S/m) images depict the barrier geometry mostly due to the large contrast in electrical properties between the granular iron of the PRB and the in-situ material.

➢Demonstrates non-invasive (i.e. the PRB is not invaded) tool for geoelectrical monitoring/measurement/characterization of PRB

(Slater & Binley, Geophysics, 2003)

Field datasets



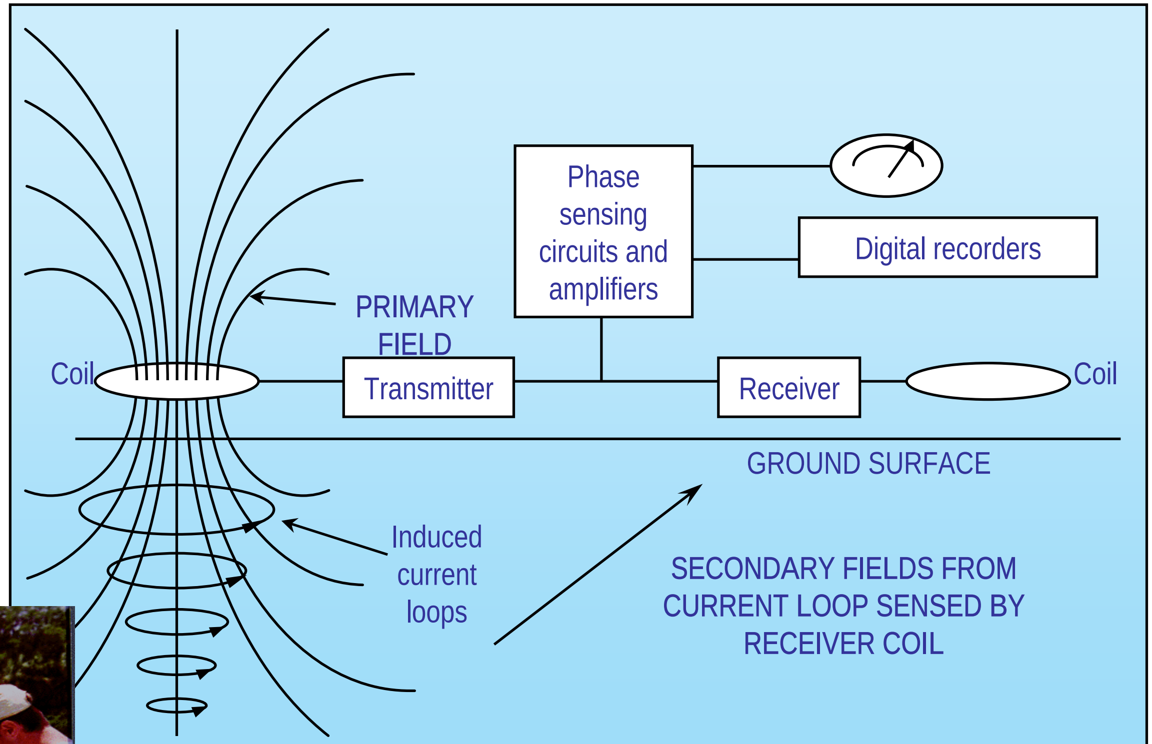
Electrical imaging is a viable technology for monitoring the long-term decadal scale changes in the electrical properties of a PRB that result from corrosion and precipitation.

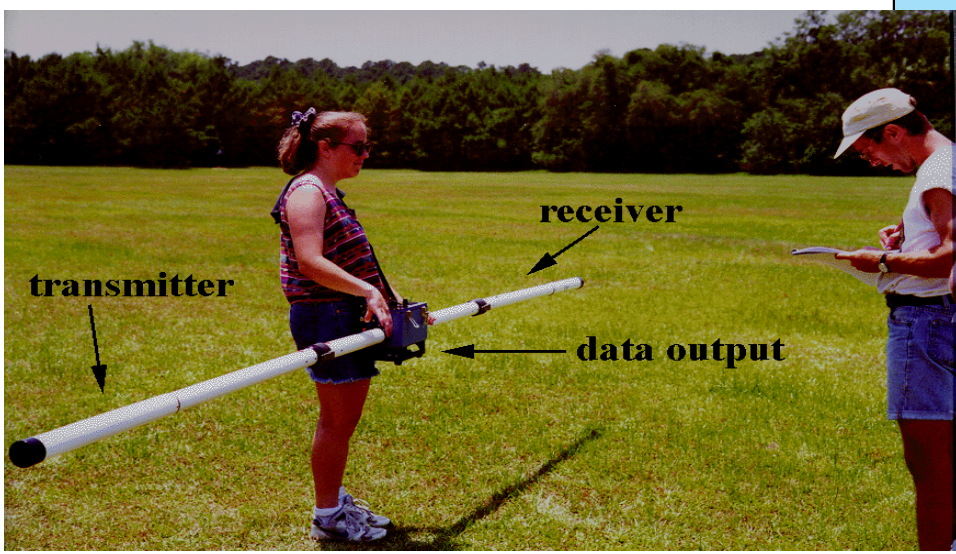
Slater & Binley, Geophysics, 2006

	Resistivity	IP/SIP/CR	SP
Limitations	Surface, clear site, metallic objects	Time, surface	Surface, cultural noise
Best practice	Pilot study/trial, QA data	→	→
QA	Per instrument, repeat a line section	→	→
Deliverables	Raw and inverse model with interpretations	→	→
Additional Data	Borehole, water or subsurface data	→	→
Expectations	Cross section, 3D, 4D Bulk electrical resistivity of subsurface	→	→
Cost/Value	~$1600/day Varied – site specific ¼ to 1 mile/day	~$2000/day Varied – site specific ¼ to 1 mile/day	~$1200/day Varied – site specific ¼ to 1 mile/day

Electromagnetic Induction (EMI) Surveys

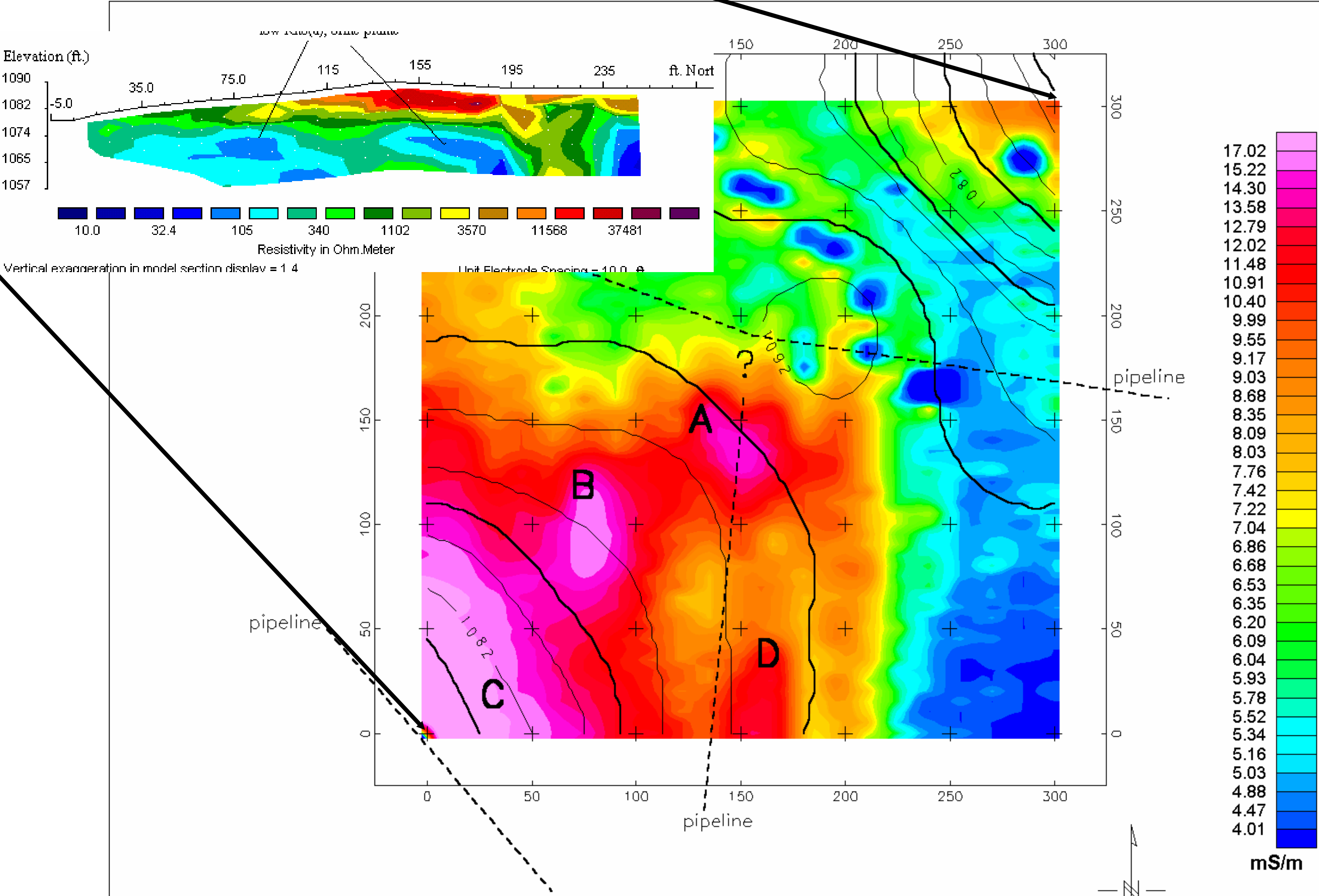
- Active electromagnetic induction techniques
- Applications
  - Profiling
  - Sounding



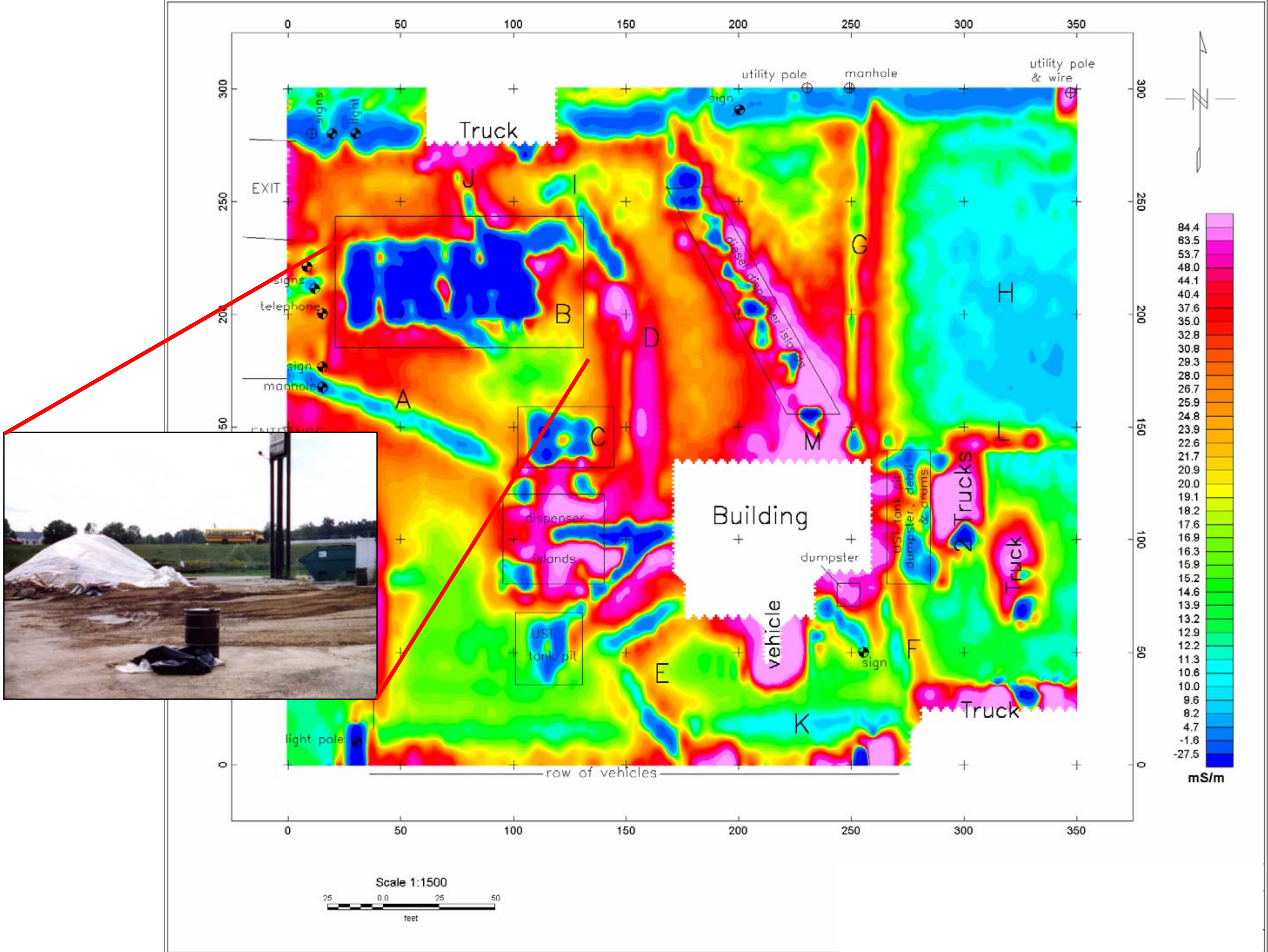


EM-31

EM-34



EM-31 Quadrature Component (bulk conductivity)
with contoured Topography Overlay, CI=2 ft.

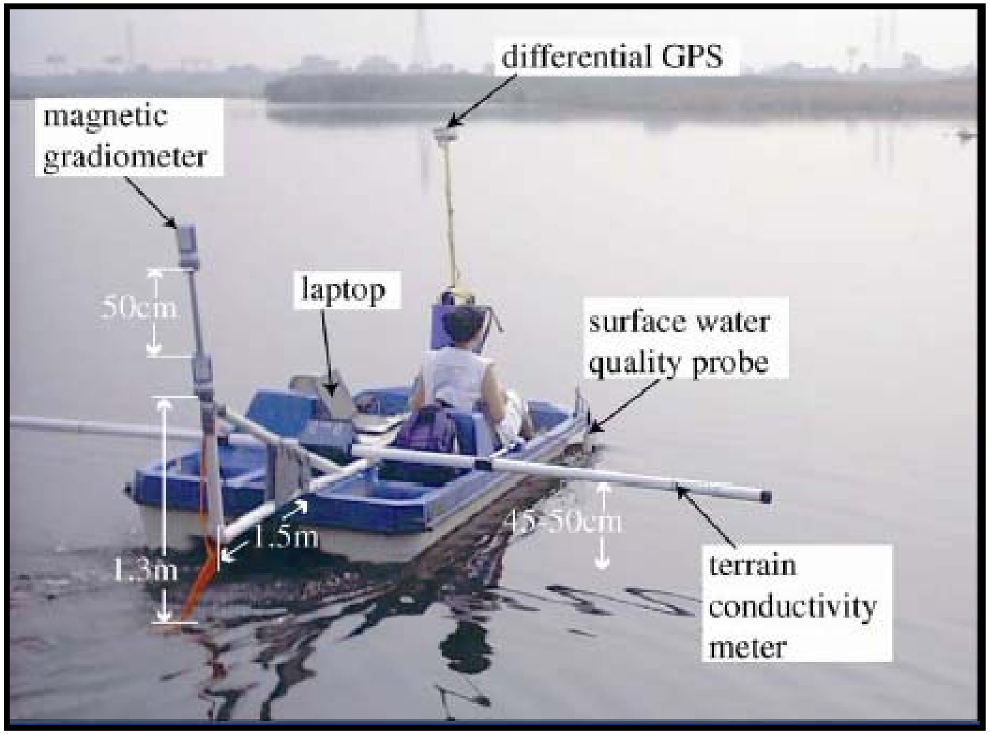


utility pole
manhole
utility pole & wire
sign
signs
light
Truck
EXIT
J
I
B
signs
telephone
sign
manhole
A
C
D
diesel dispenser islands
G
H
M
L
Building
dumpster
vehicle
dispenser
islands
UST
tank pit
E
K
F
sign
2 Trucks
Truck
Truck
light pole
row of vehicles
84.4
63.5
53.7
48.0
44.1
40.4
37.6
35.0
32.8
30.8
29.3
28.0
26.7
25.9
24.8
23.9
22.6
21.7
20.9
20.0
19.1
18.2
17.6
16.9
16.3
15.9
15.2
14.6
13.9
13.2
12.9
12.2
11.3
10.6
10.0
9.6
8.2
4.7
-1.6
-27.5
mS/m
Scale 1:1500
feet

Electrical Methods for Wetlands

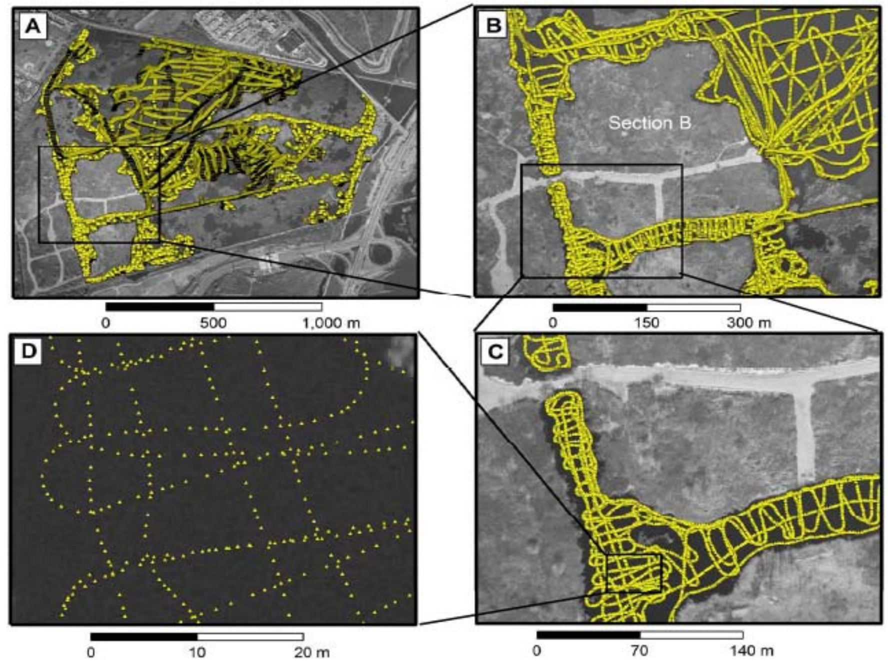
- Aquatic geophysics from shallow water boats
  Spatially rich data
  Shallow draft (< 0.75 m)
  0.25 m location accuracy
  Continuous data logging

- Terrain conductivity/magnetics mode

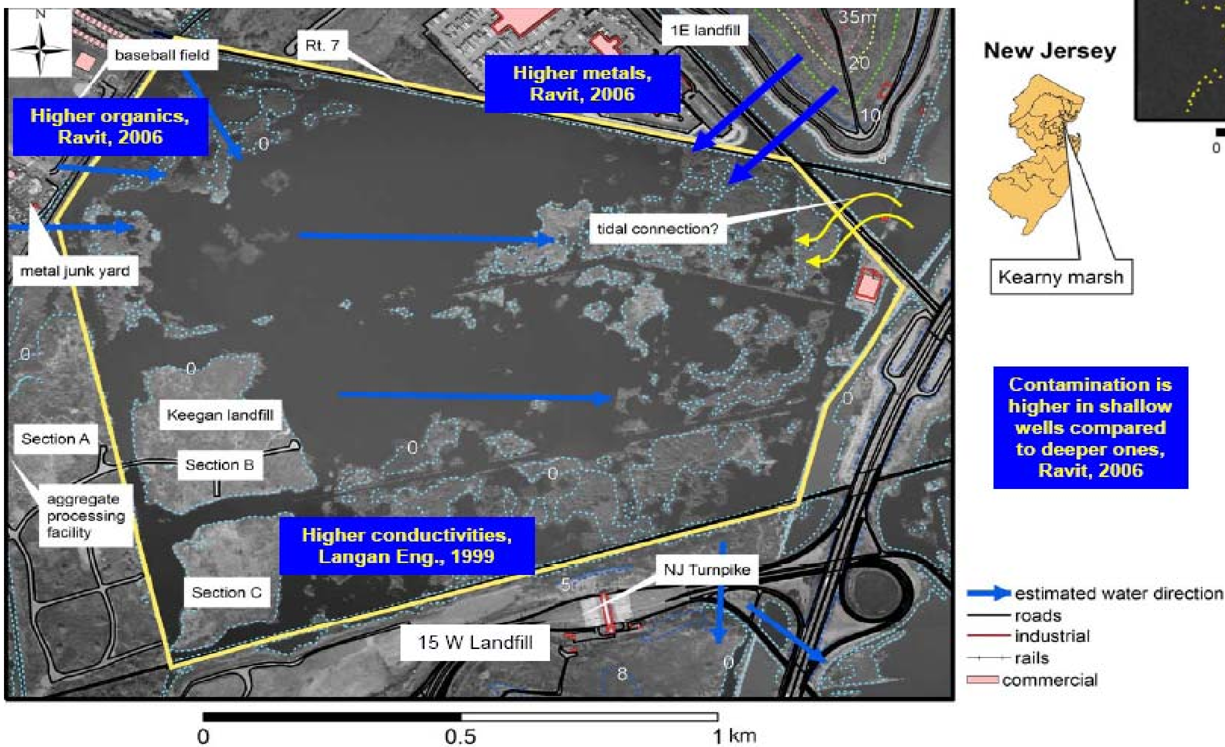


Mansoor et al. 2006

Study Site: Kearny Freshwater Marsh

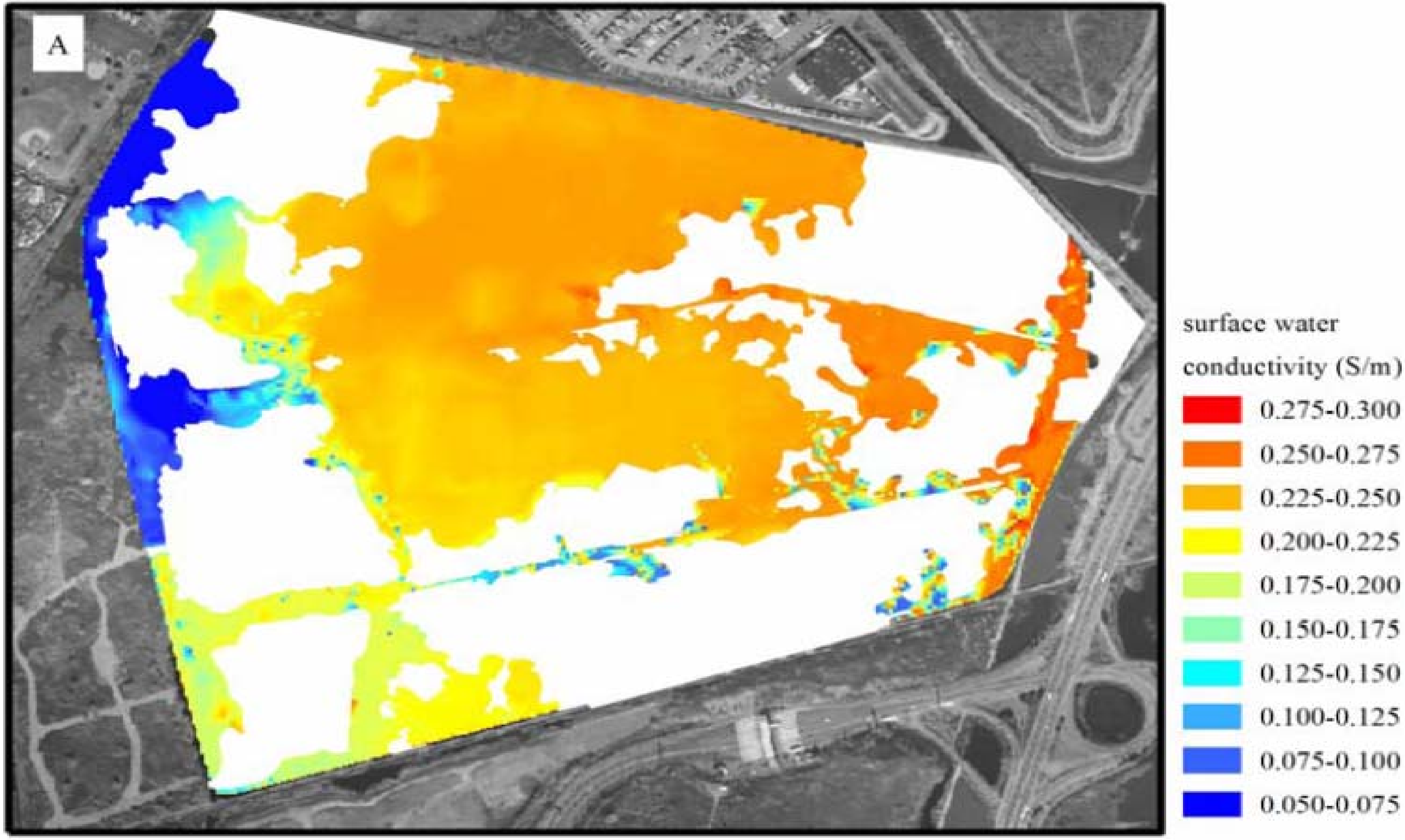


Data density



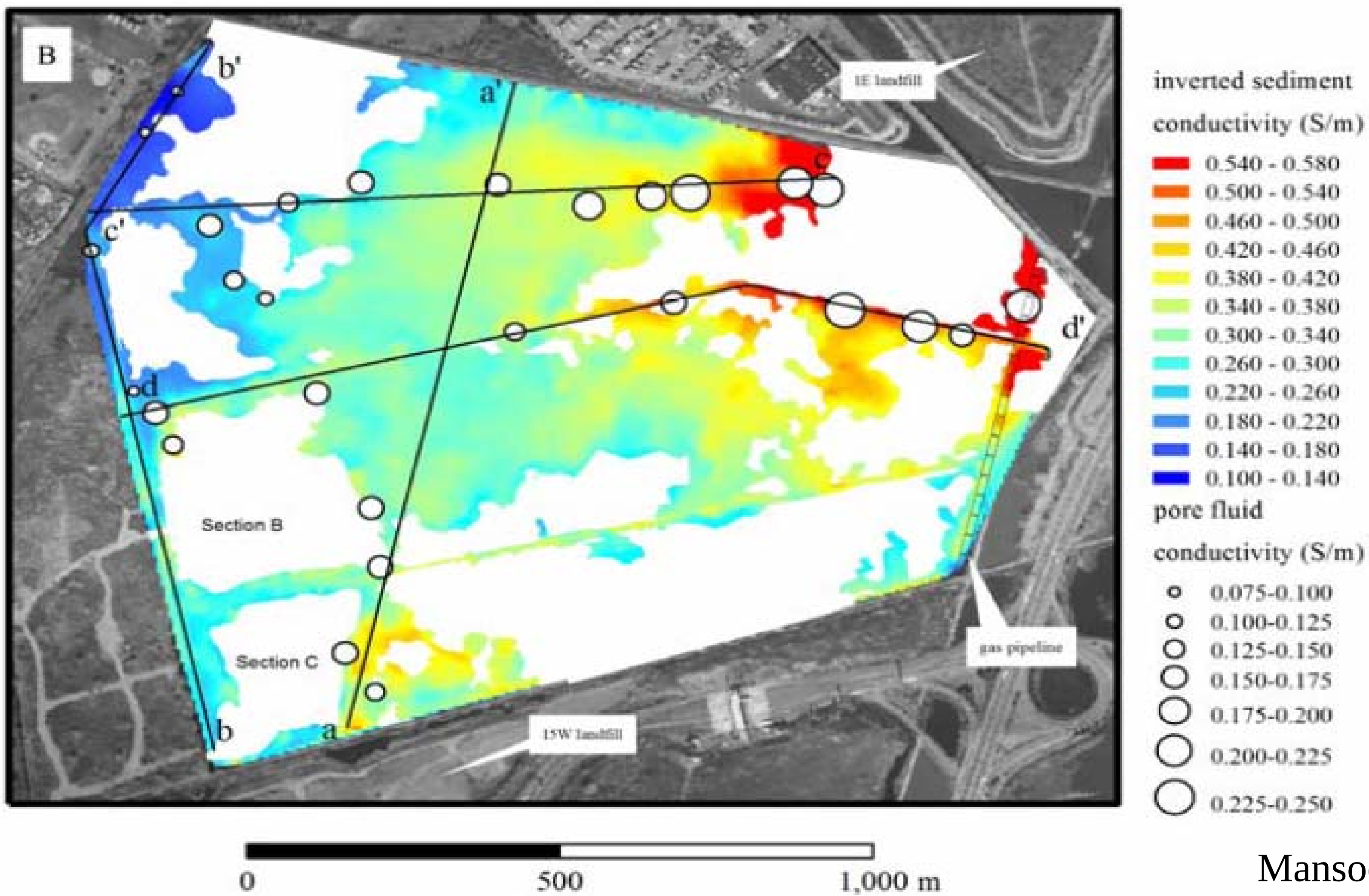
Mansoor et al. 2006

Surface water conductivity (σ_w)



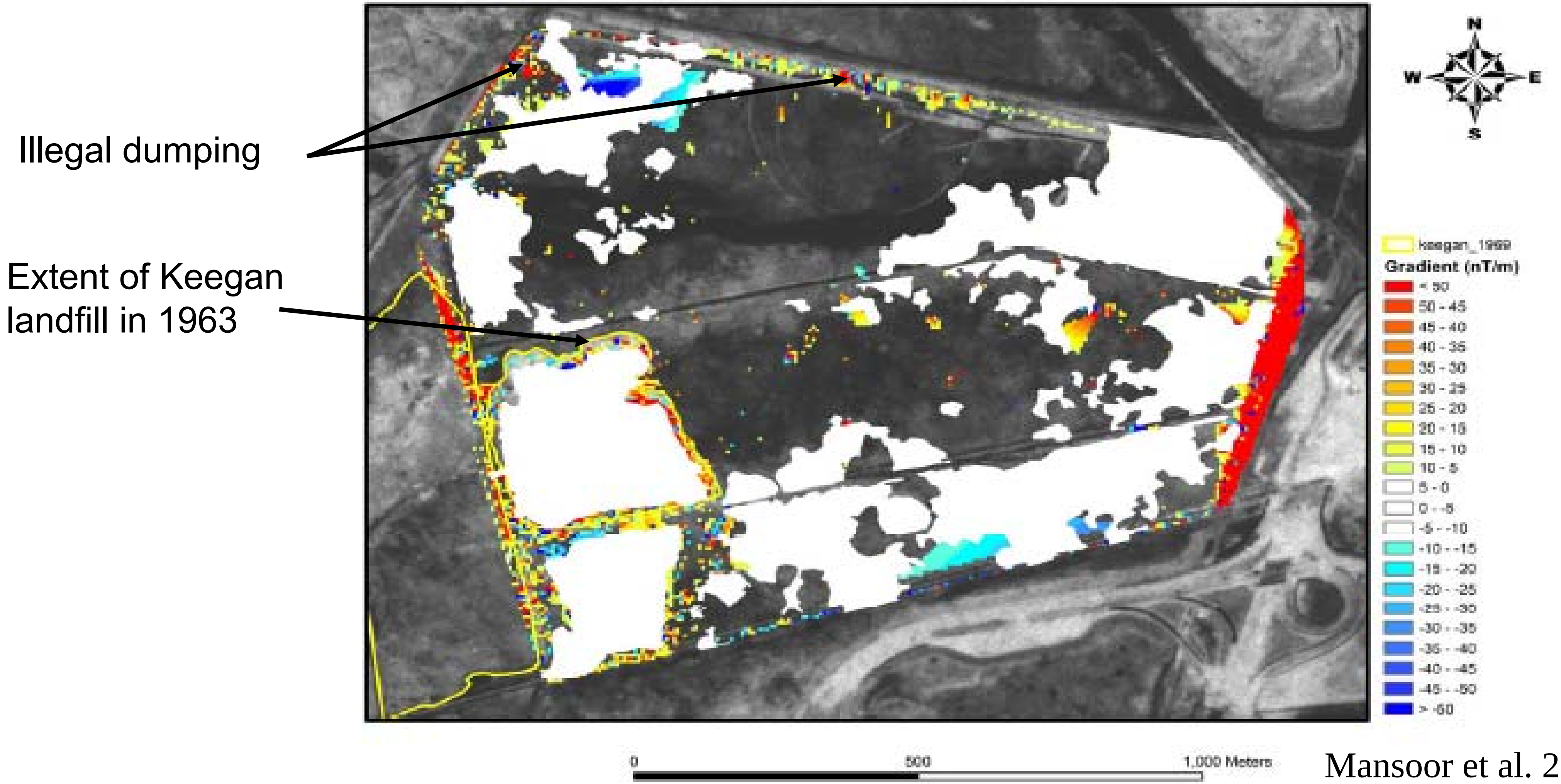
Mansoor et al. 2006

Wetland sediment conductivity (σ_{earth})



Mansoor et al. 2006

Geophysics reflects land use history



Mansoor et al. 2006

Geonics EM-61 Time-domain EM
Great metal detector (ferrous and non-ferrous)

Geonics EM-61-HH
(Hand-Held)

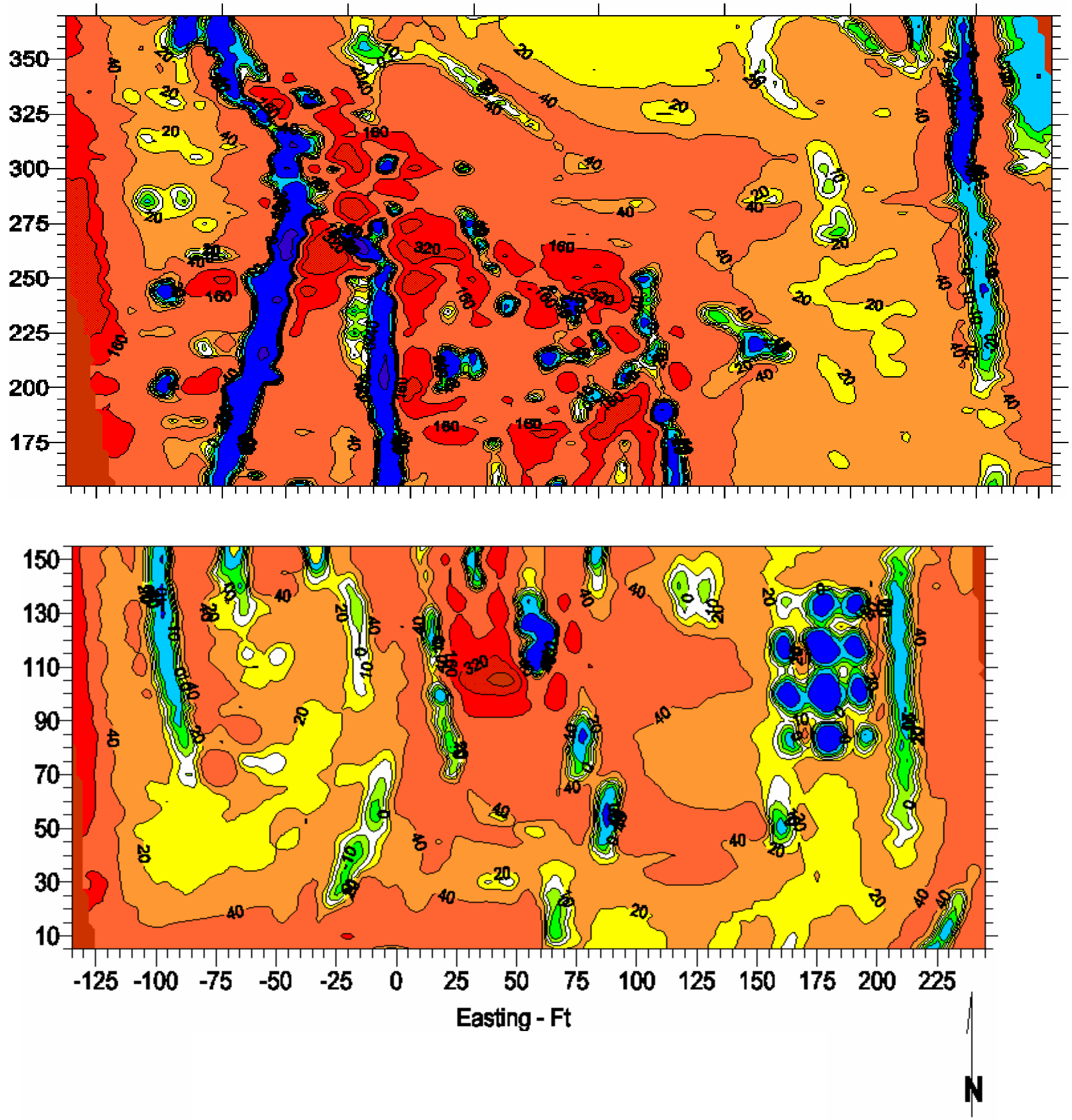
Geonics EM-61

0.5 m x 1.0 m coils

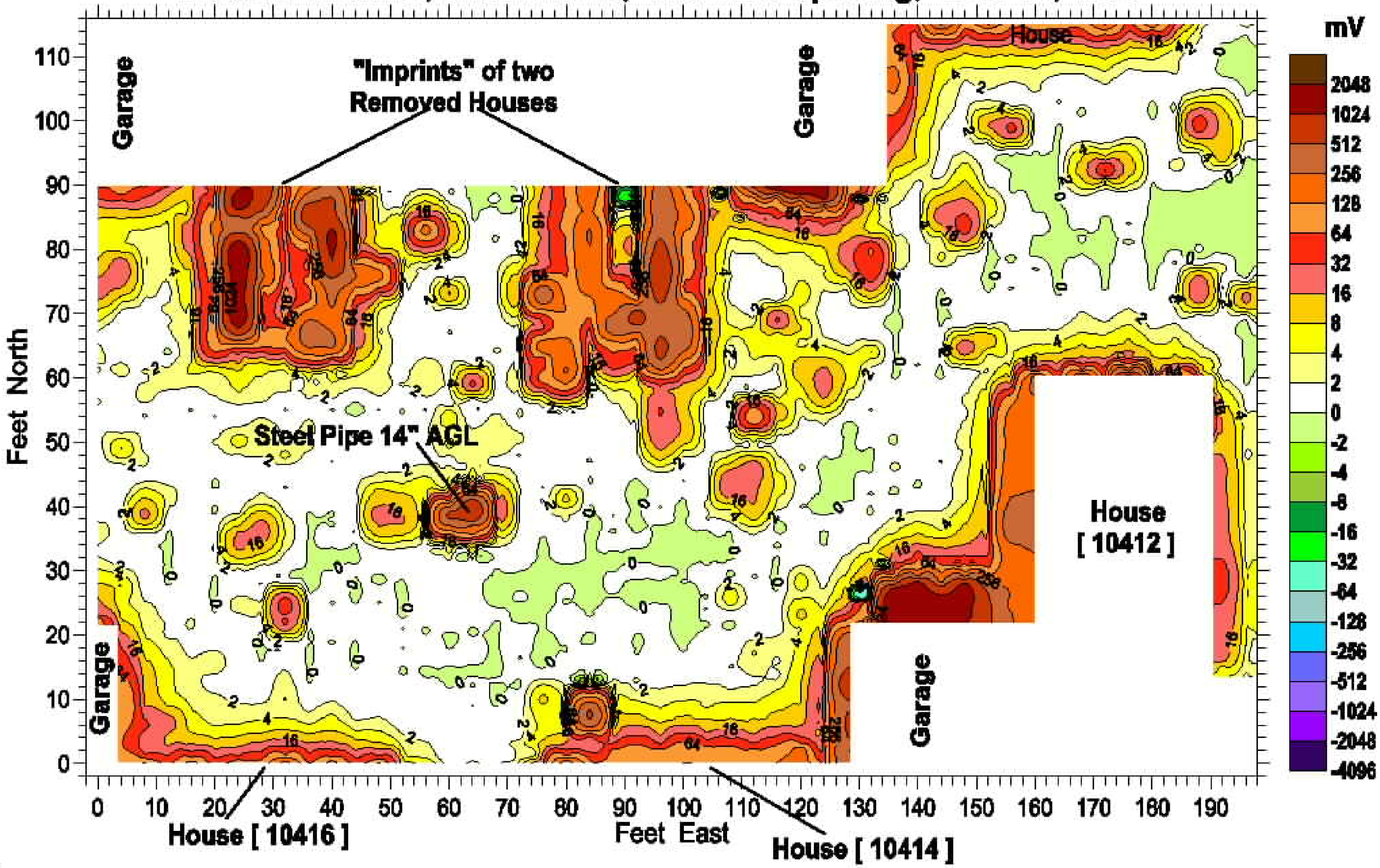
1.0 m x 1.0 m coils

Former Oil Refinery

A great deal of metal debris was left buried below the former refinery

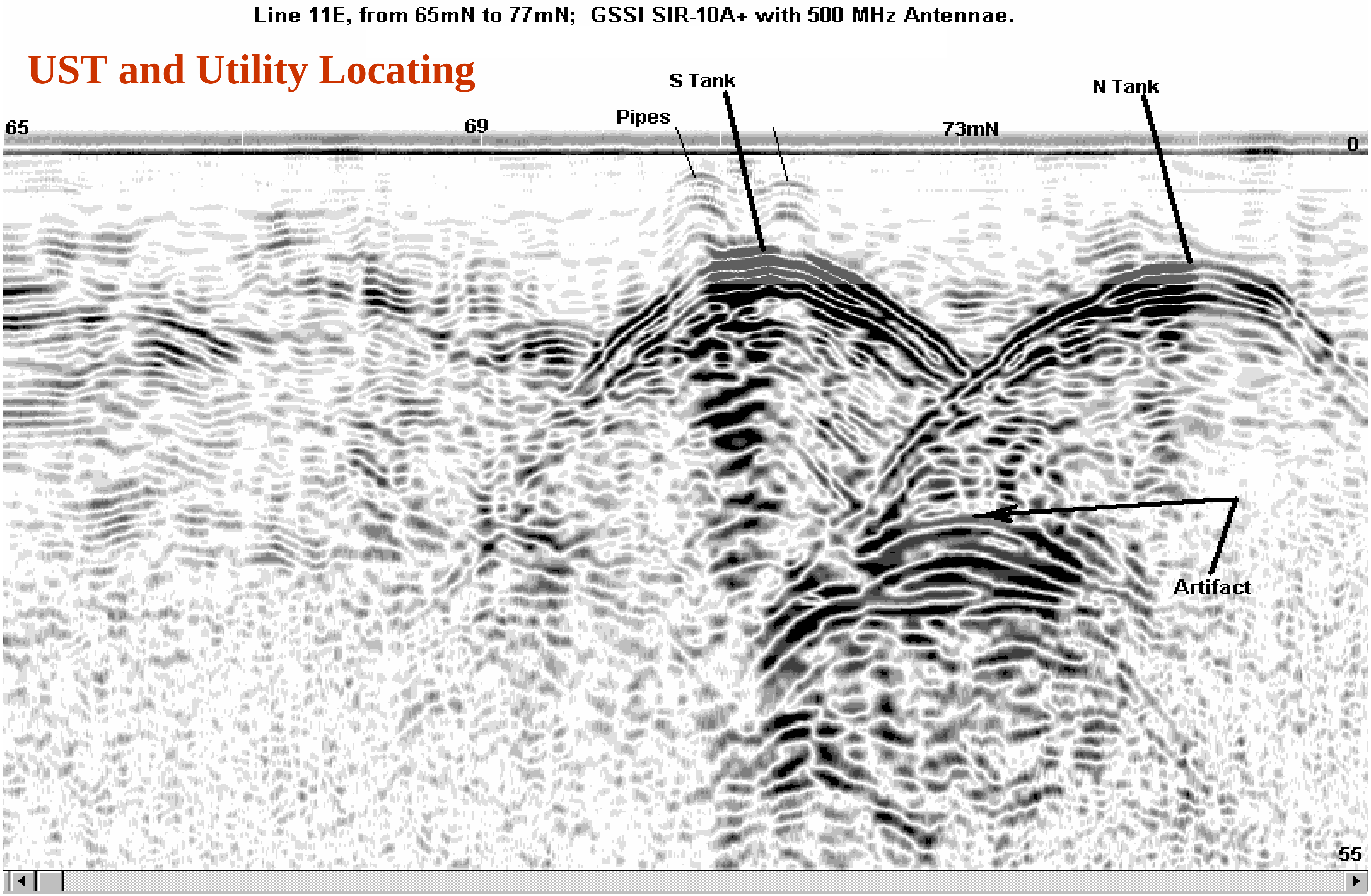


Geonics EM61 with 0.5 x 1.0 m Coils,
Bottom Channel, in milliVolts; 4 ft. Line Spacing;

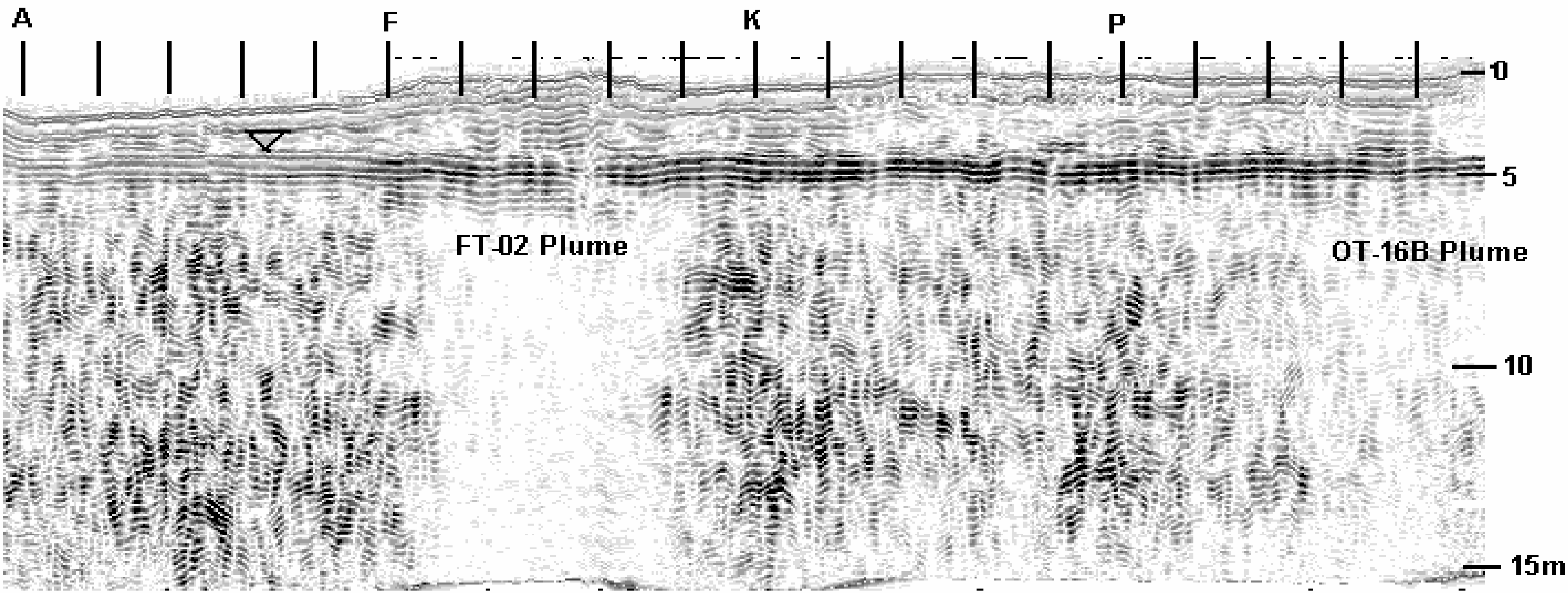


Ground Penetrating Radar (GPR)

UST and Utility Locating

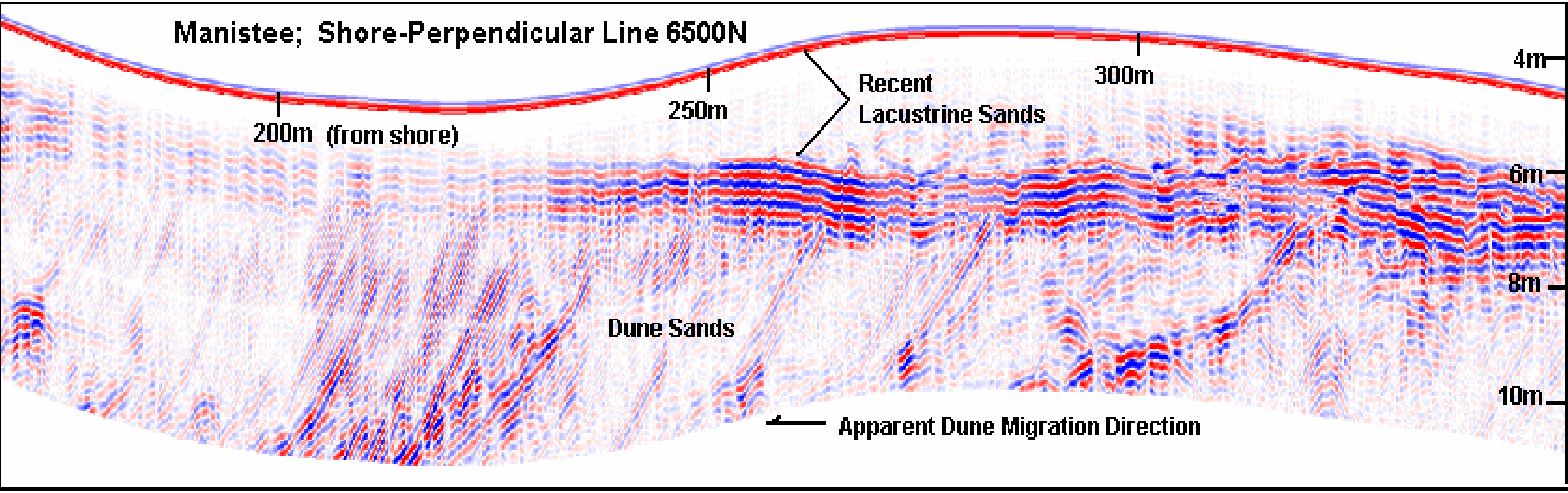


Plume Mapping



GSSI SIR-10A with Bistatic 100 MHz Antennae; 400 ns

Off-Shore Underwater Radar (GPR)



WNW ⇨

	EMI EM-31,EM-34	EMI EM-61	GPR
Limitations	Surface obstructions, Anthro. objects, resolution per depth	Surface obstructions Limited depth < 10 m	Surface conductive layer, obstructions
Best practice	Good georeference	→	→,pilot study
QA	Repeat first and last line	→	→
Deliverables	Map or profile of bulk conductivity	Map or profile of mV α to metallic content	Labeled profiles, interp.
Additional Data	Any subsurface info	Known subsurface objects	wt., objects
Expectations	Only measures bulk conductivity of a volume of earth	Ferrous and non-ferrous metals	Stratigraphy
Cost/Value	~$1400/day 1 to 8 line miles/day	~$1400/day 1 to 3 acres/day	~$1200-1500/day ¼ to 20 mi./day

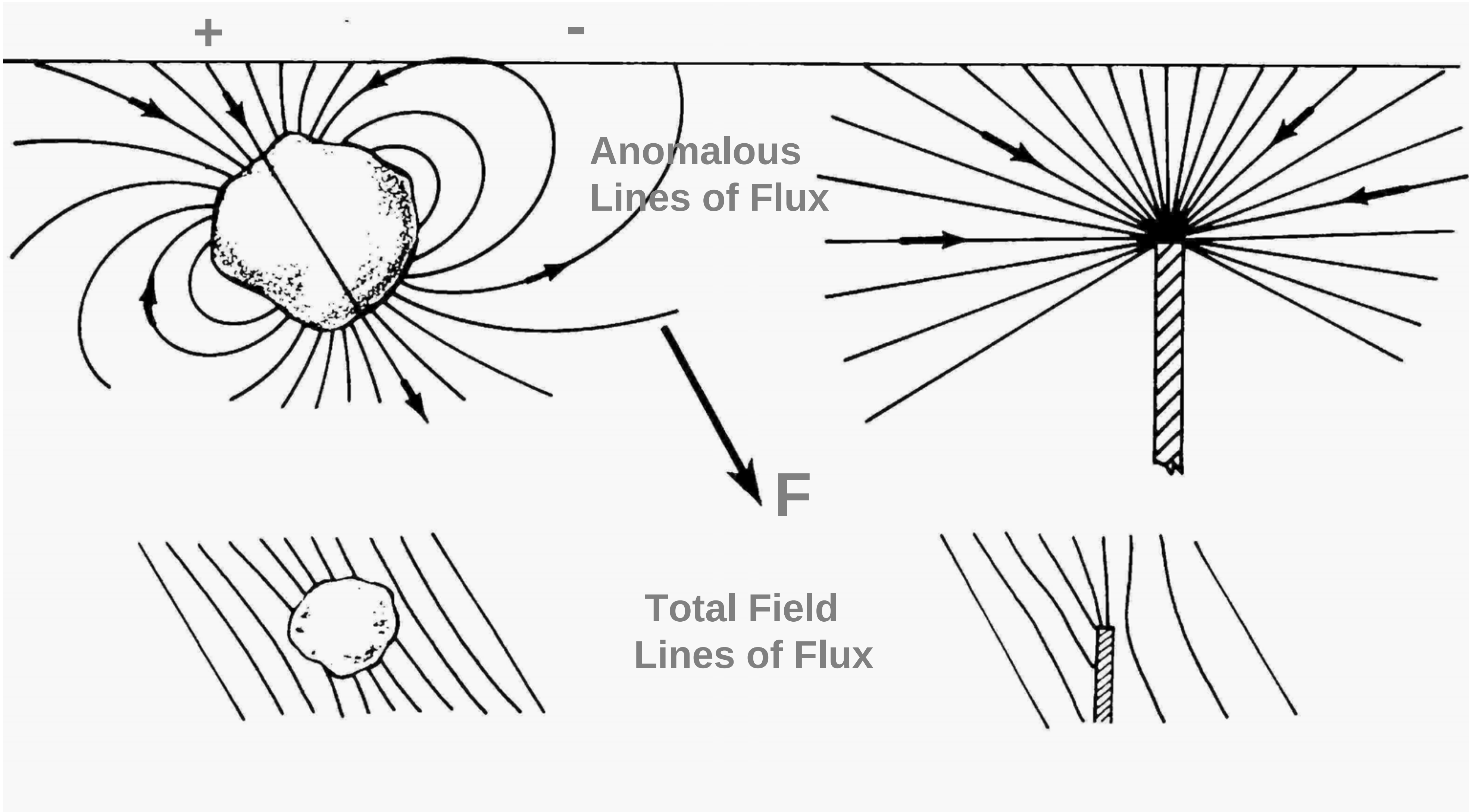
Magnetic

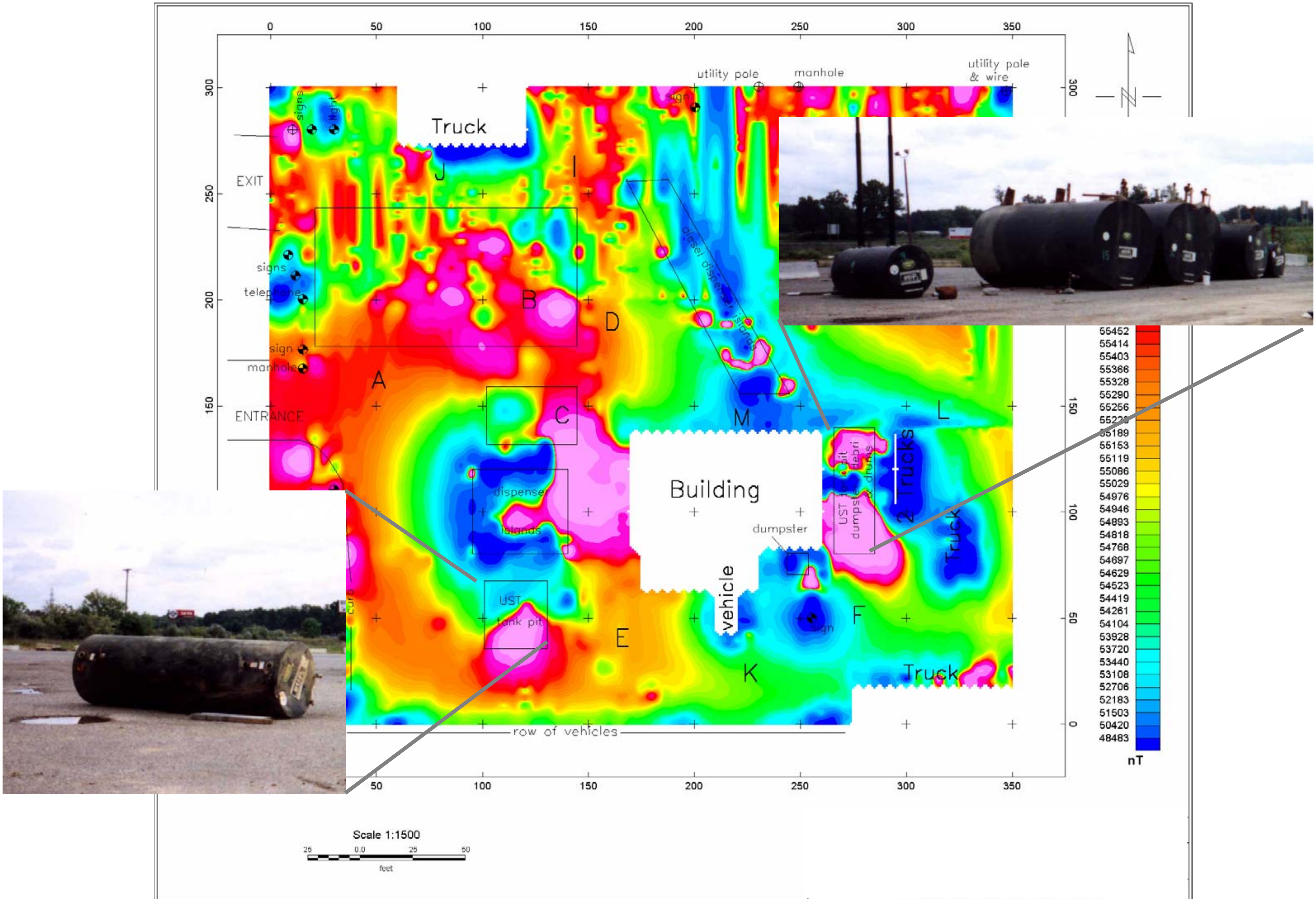
- ***measures spatial variations in natural magnetic field intensity***
- ***Intensity due to magnetic susceptibility***
- ***applications:***
    - ***fossil fuel exploration***
    - ***mineral deposit exploration***
    - ***engineering/construction site investigation***
    - ***environmental***

Modification of Magnetic Field by Ferrous Objects

Equi-Dimensional Object: Dipole Response

Long, Vertical Pipe: Monopole Response

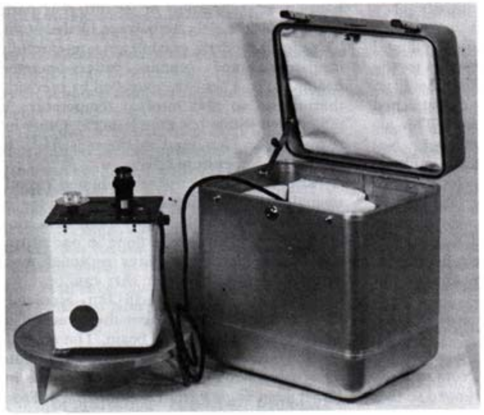


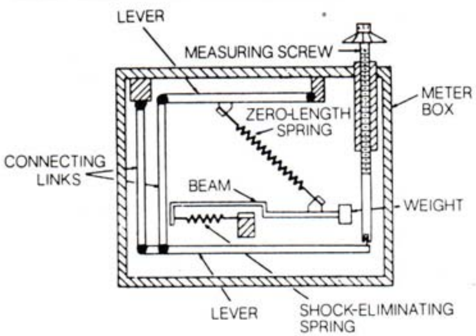


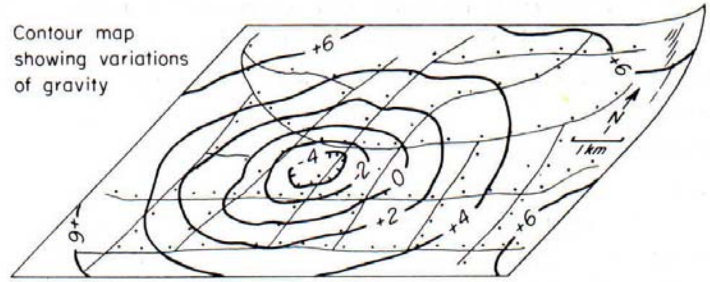
Truck
EXIT
ENTRANCE
signs
light
telephone
sign
manhole
utility pole
manhole
utility pole & wire
sign
A
B
C
D
E
F
I
J
K
L
M
diesel dispenser islands
dispenser islands
UST tank pit
Building
dumpster
vehicle
sign
UST tank pit dumpster debri & drums
2 Trucks
Truck
Truck
curb
row of vehicles
55452
55414
55403
55366
55328
55290
55256
55189
55153
55119
55086
55029
54976
54946
54893
54818
54768
54697
54629
54523
54419
54261
54104
53928
53720
53440
53108
52706
52183
51503
50420
48483
nT
Scale 1:1500
feet

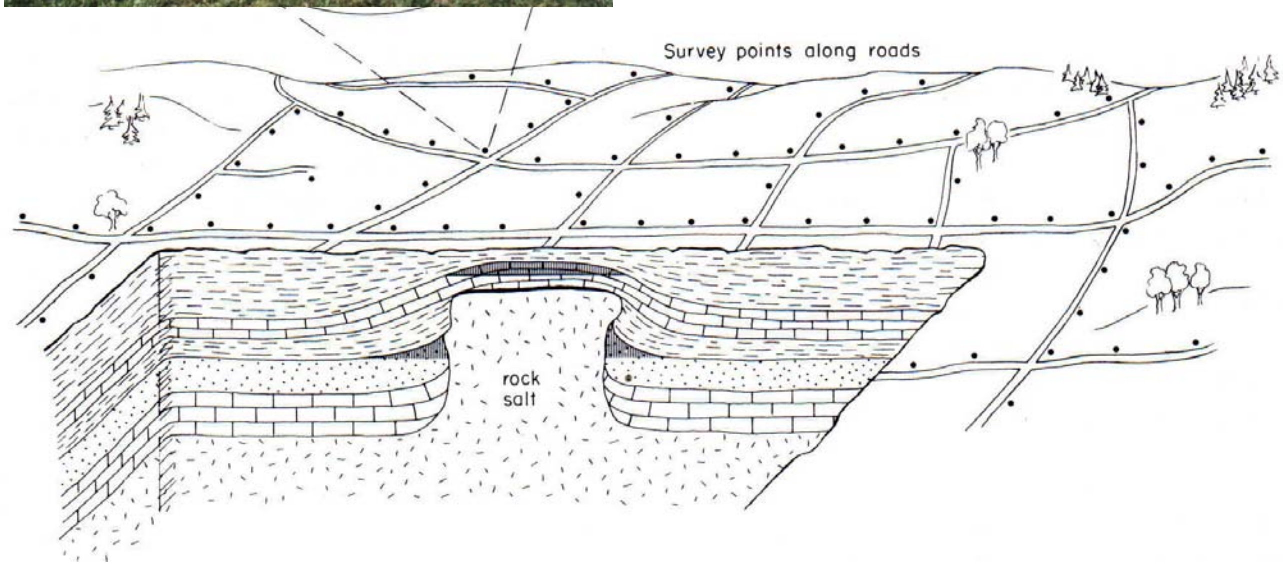
Gravimetric

- ***Gravity***
  - *measures spatial variations in natural gravity field*
  - *results reveal subsurface density variability*
  - *applications include:*
    - *fossil fuel exploration*
    - *mineral deposit exploration*
    - *groundwater*
    - *engineering/construction site investigation*
    - *environmental*

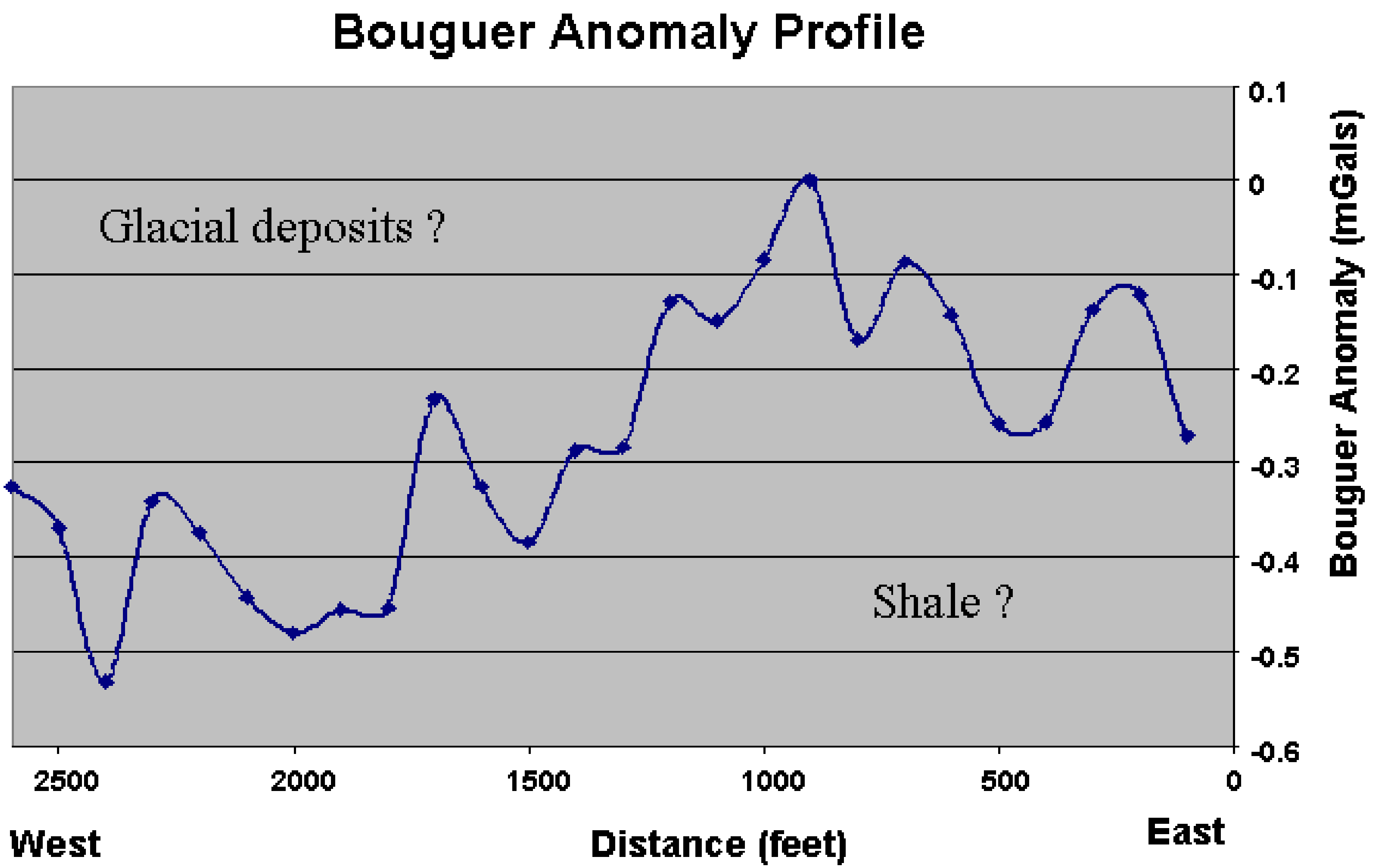




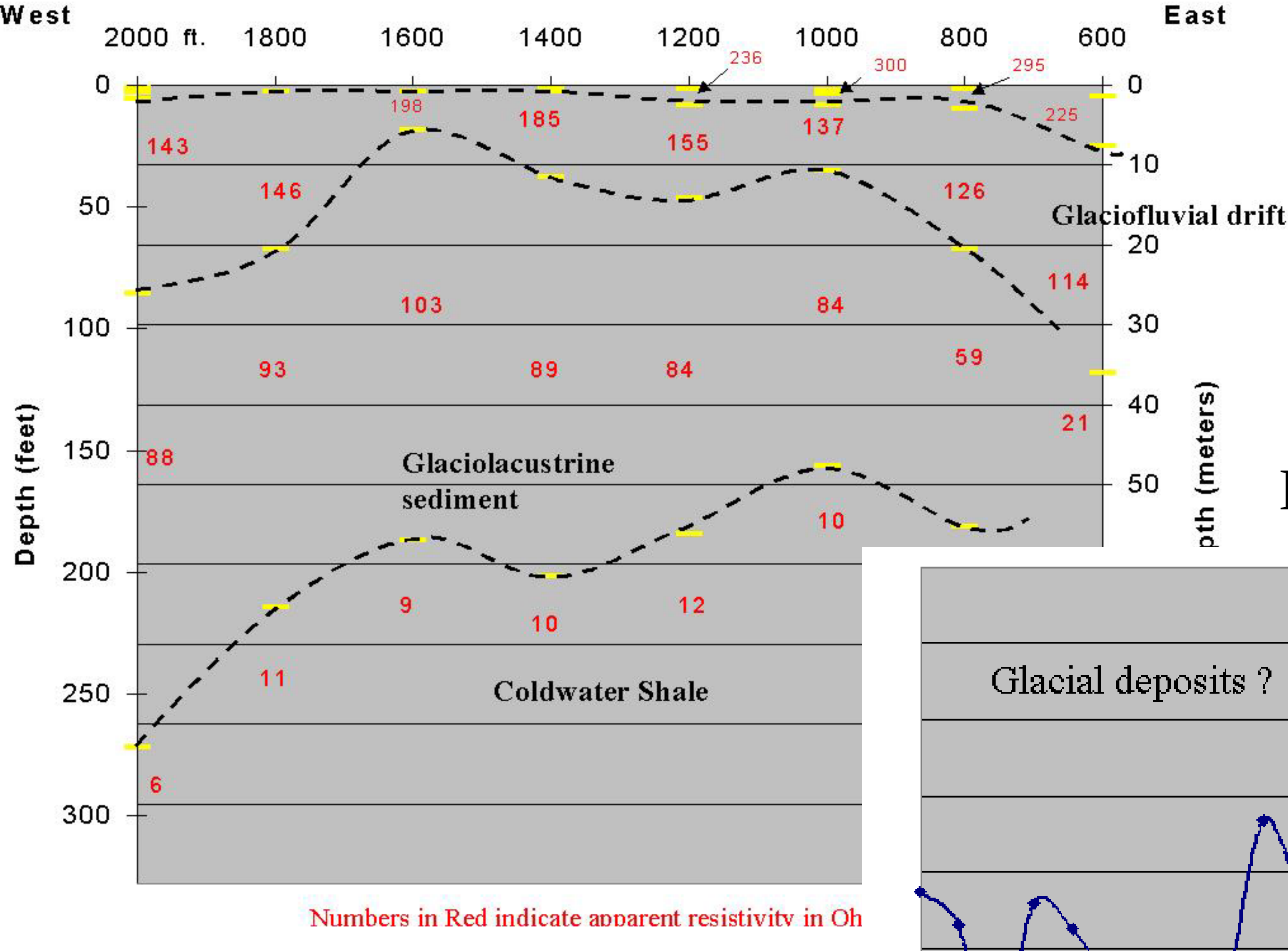




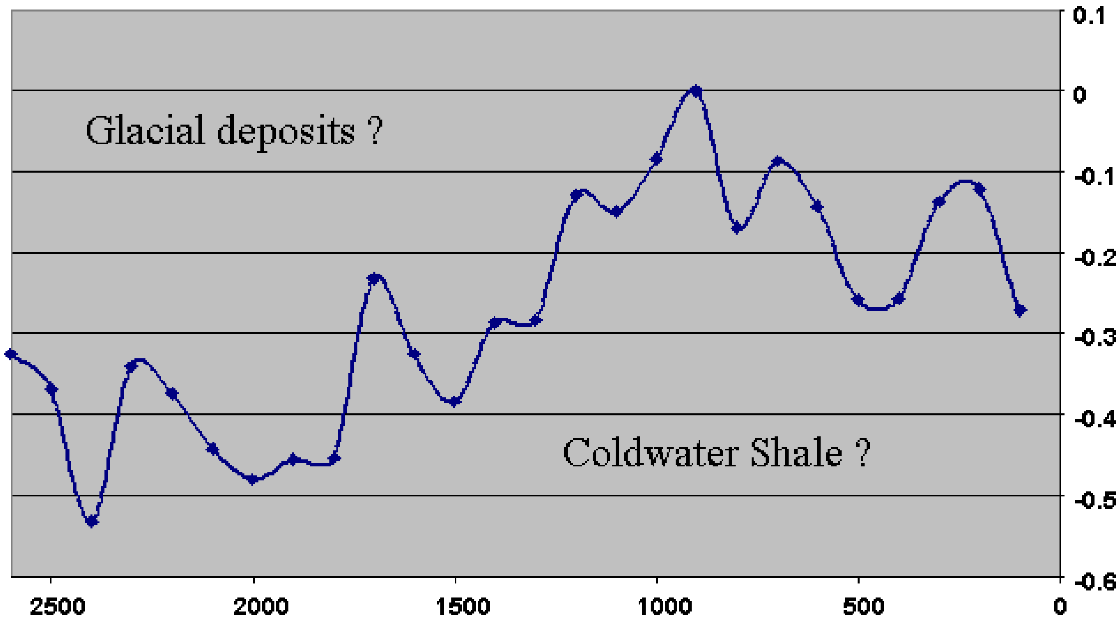
(Adopted from Robinson, 1988)


Bouguer Anomaly Profile
Glacial deposits ?
Shale ?
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
Bouguer Anomaly (mGals)
2500
2000
1500
1000
500
0
West
Distance (feet)
East

Schlumberger Vertical Electric Sounding Results



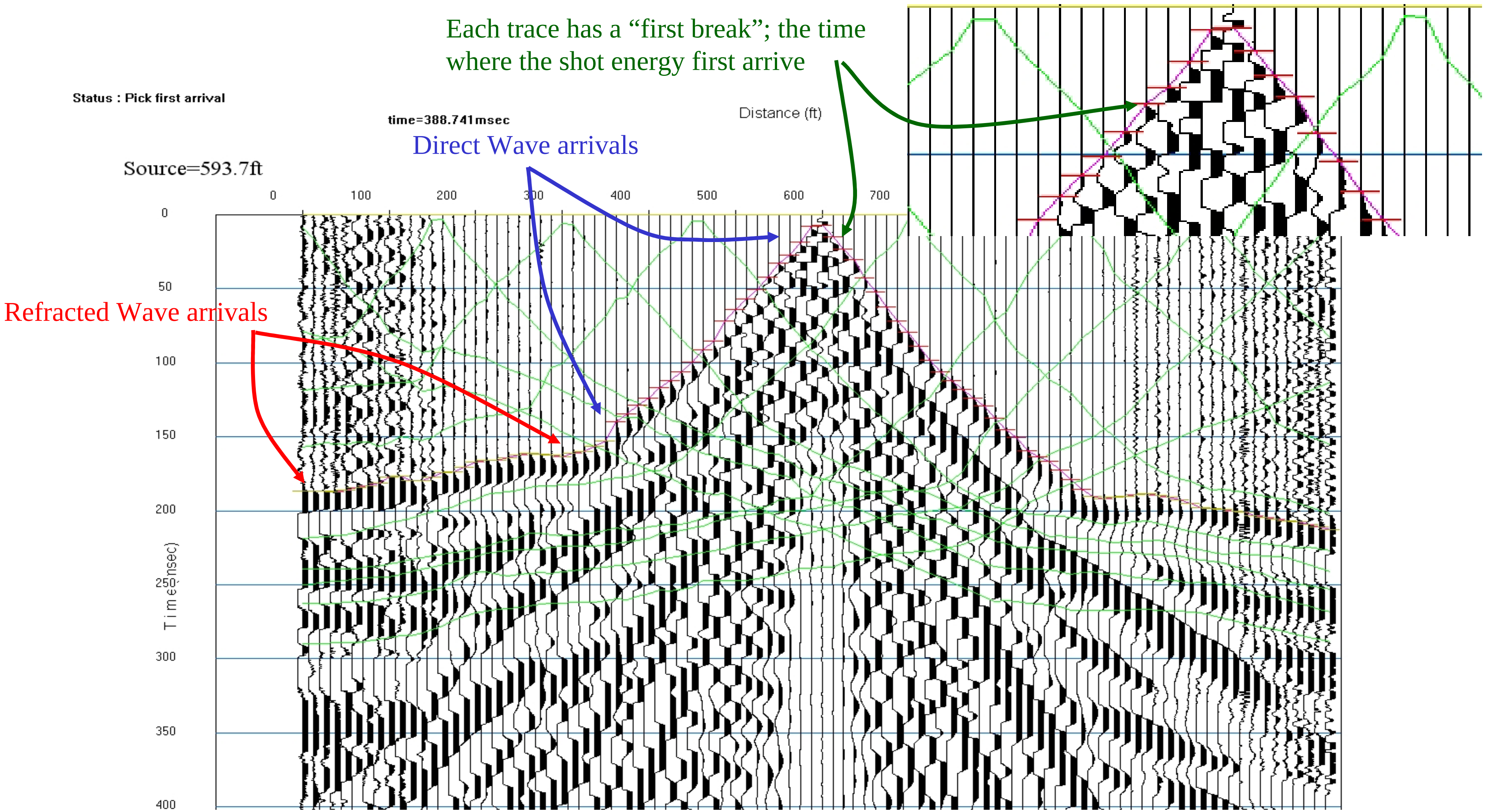
Bouguer Anomaly Profile



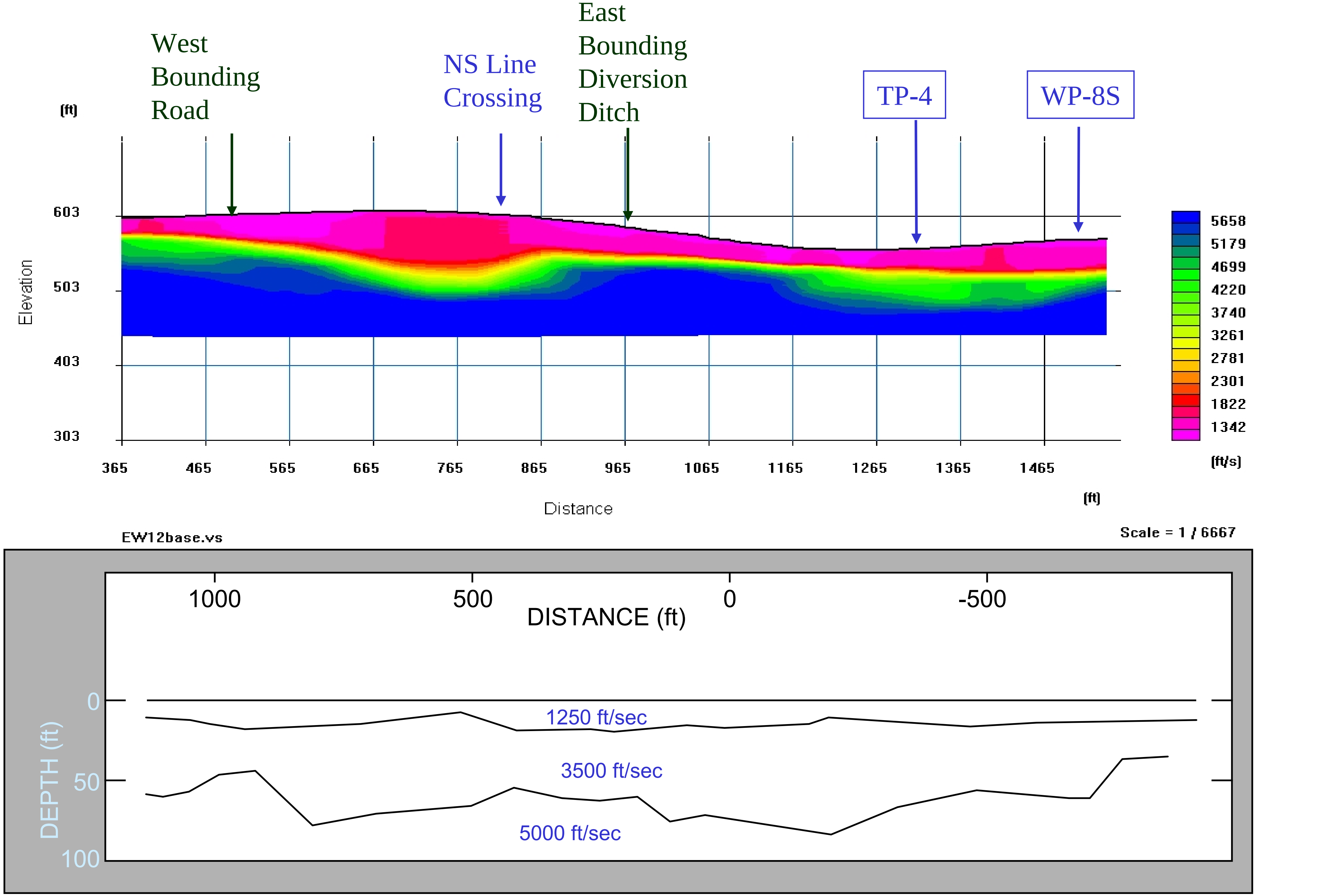
Seismic

- Refraction & Reflection
- Measures the acoustic velocity contrast (predominantly due to density contrasts)
- Great for CSM development

Example of first break picking



Adopted from Scott INEEL presentation



Adopted from Scott INEEL presentation

	Magnetic	Gravimetric	Seismic
Limitations	Only ferrous objects (anthropogenic or natural) Rebar, close surface objects Map is a spatial statistic	Scale of investigation	Surface conditions, velocity inversion
Best practice	3-5 foot line spacing	Base station, georeference	Experienced crew and interpreter
QA	Repeat first line at end of day	Document corrections	Reciprocity
Deliverables	Map, QA plot, report w/interpretations	Map with interpretation	Profile with interpretation
Additional Data	Surface conditions, clear site	Known subsurface characteristics	→
Expectations	Map of the magnetic field strength of the site	Map of density variations	Stratigraphy due to acoustic properties
Cost/Value	$1500/day 3 – 6 acres/day		~$3500 - $5000/day ¼ to miles/day

Geophysics and CSMs

- Map or delineate preferential flow
- Id. Possible sources
- Initial site investigation to guide next steps
- Can guide drilling: where and how deep
- High value for limited cost
- Nonintrusive or limited intrusive
- Map bedrock surface

Summary

What to do:

- get a qualified geophysicist
- develop an acceptable QAPP
- www.eegs.org
- www.seg.org

More info:

werkema.d@epa.gov

OSRTI

"Geophysical Technologies and Triad Innovations in Site Characterization: Geophysical Investigation at Hazardous Waste Sites"

Conclusions

- ⌧*Remember the fundamentals*
- ⌧*Know the limitations and what questions can be asked of geophysics*
- ⌧*Near surface geophysical methods measure the physical properties of the subsurface*
- ⌧*Different methods measure specific physical properties*
- ⌧*Depending on the target of investigation, multiple geophysical methods are prudent for accurate interpretations*