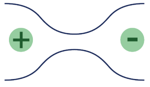
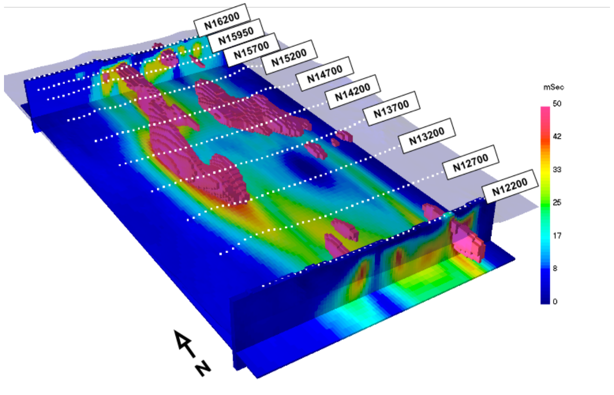
Induced Polarization

DISC
2017
Electromagnetics
Fundamentals and Applications

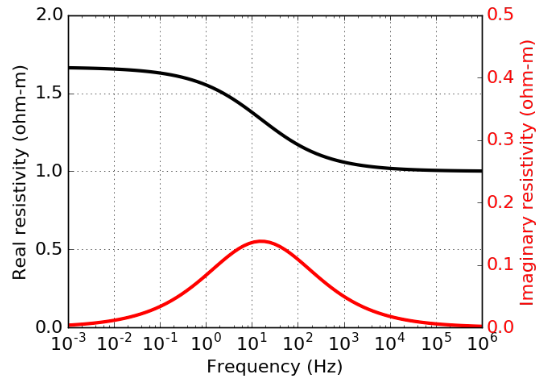


Motivation

Minerals



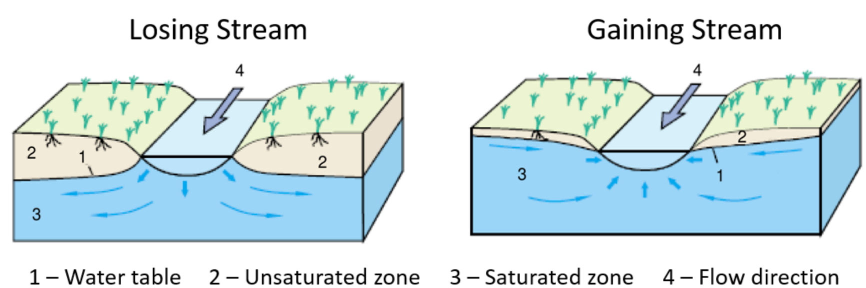
Complex resistivity



Permafrost

Geotechnical

Groundwater

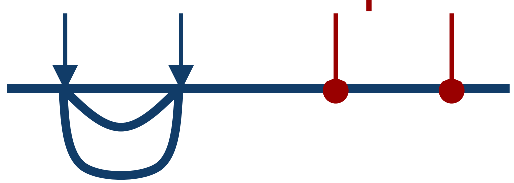


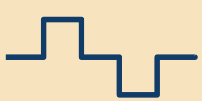
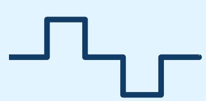
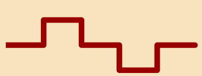
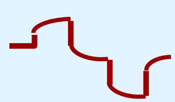
Outline

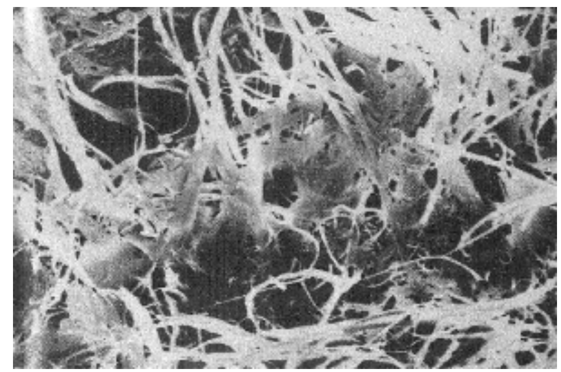
- Sources of IP
- Conceptual model of IP
- Chargeability
- IP data
- Pseudosections
- Two stage DC-IP inversion
- Case history: Mt. Isa
- Example: Landfills

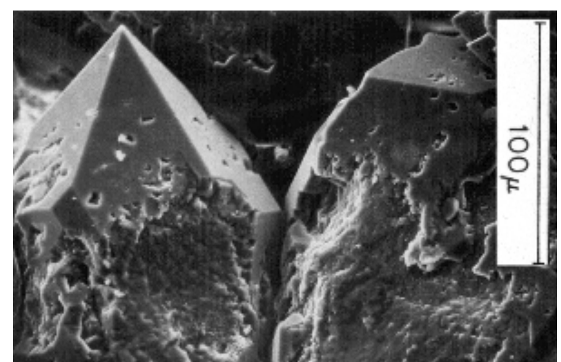
Induced Polarization

- Injected currents cause materials to become polarized
- Microscopic causes → macroscopic effect
- Phenomenon is called induced polarization



	Not chargeable	Chargeable
Source (Amps)		
Potential (Volts)		

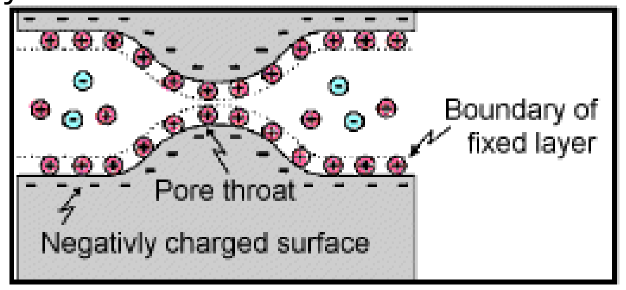




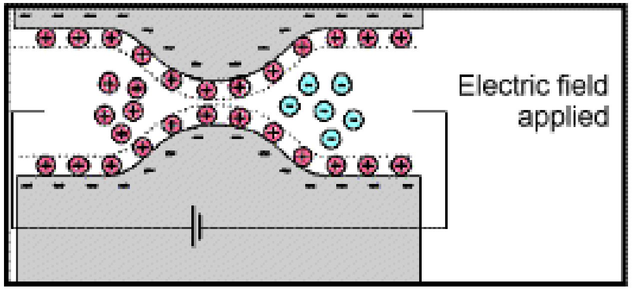
Conceptual Model of IP

Membrane polarization

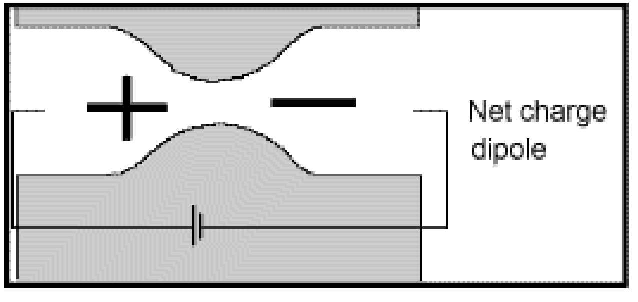
Initially - neutral



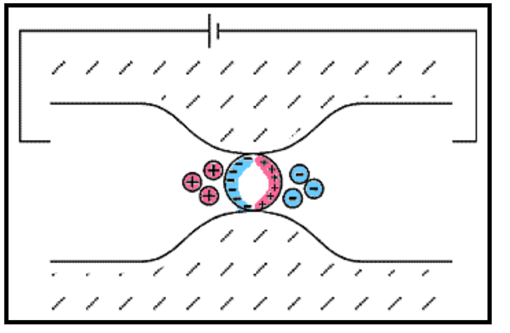
Apply electric field, build up charges

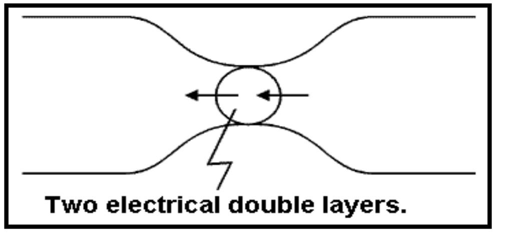


Charge polarization, Electric dipole

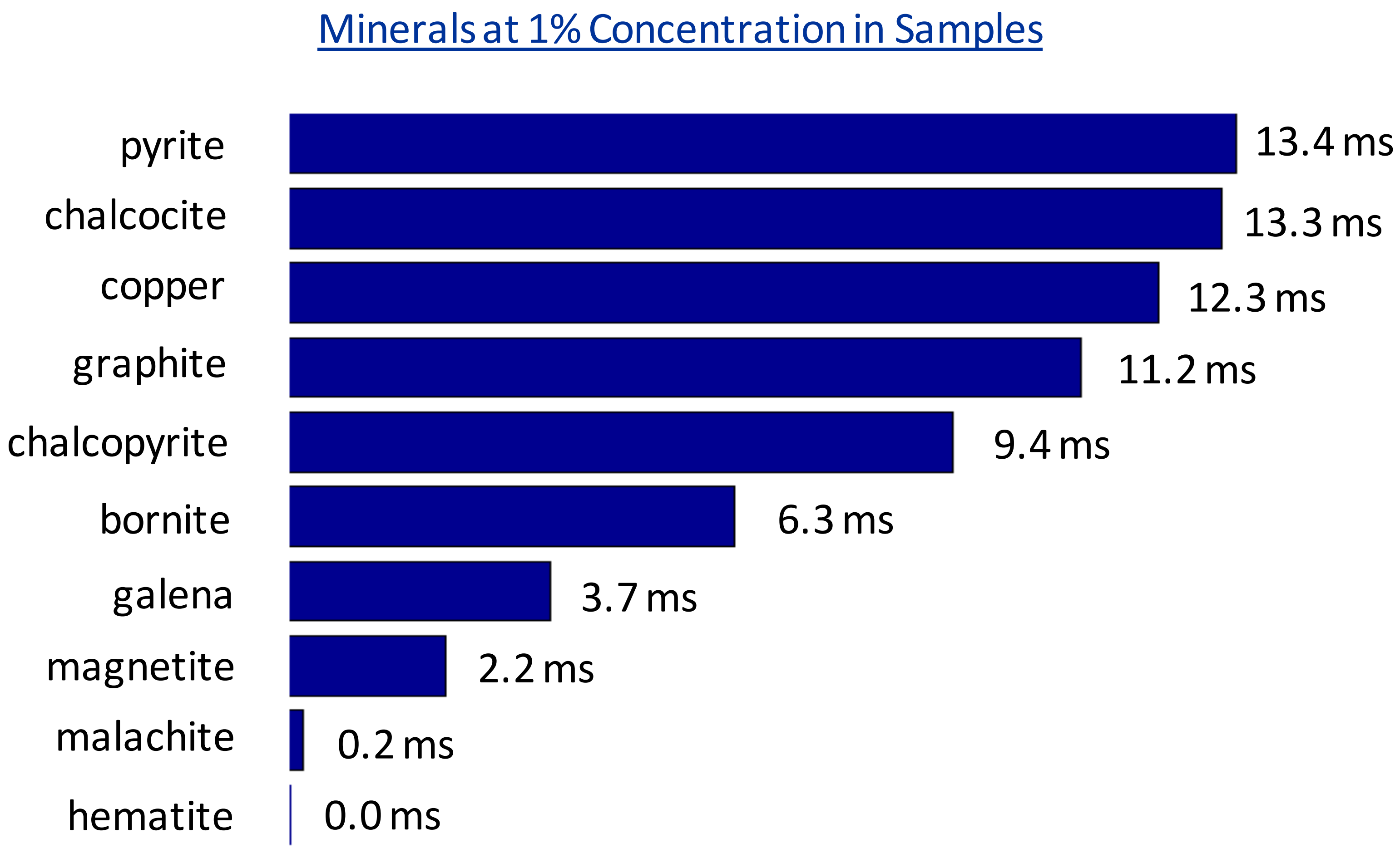


Electrode polarization

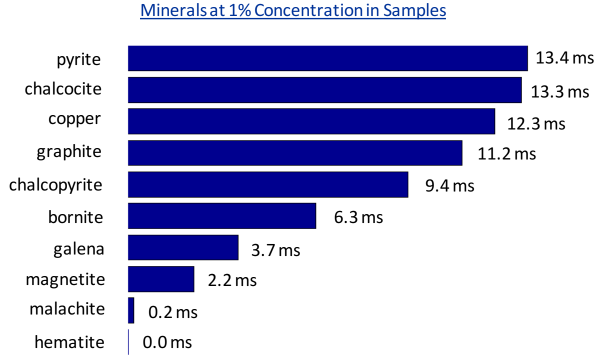




Chargeability



Chargeability

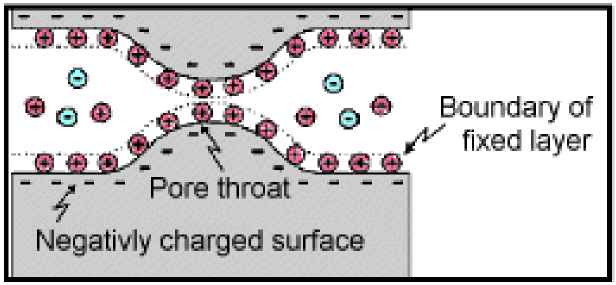


Material type	Chargeability (msec.)
20% sulfides	2000 - 3000
8-20% sulfides	1000 - 2000
2-8% sulfides	500 - 1000
volcanic tuffs	300 - 800
sandstone, siltstone	100 - 500
dense volcanic rocks	100 - 500
shale	50 - 100
granite, granodiorite	10 - 50
limestone, dolomite	10 - 20

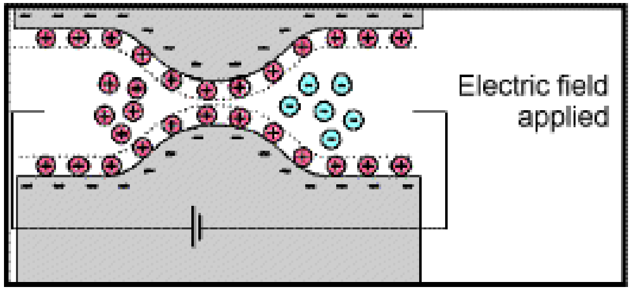
Material type	Chargeability (msec.)
ground water	0
alluvium	1 - 4
gravels	3 - 9
precambrian volcanics	8 - 20
precambrian gneisses	6 - 30
schists	5 - 20
sandstones	3 - 12

Chargeability

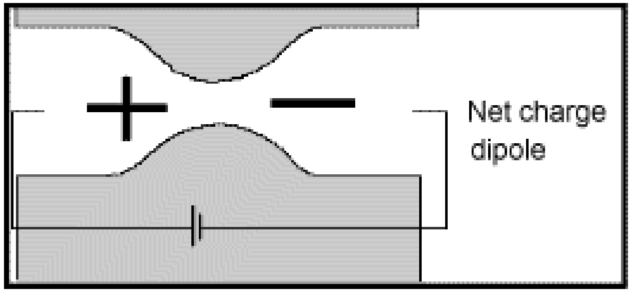
Initially - neutral



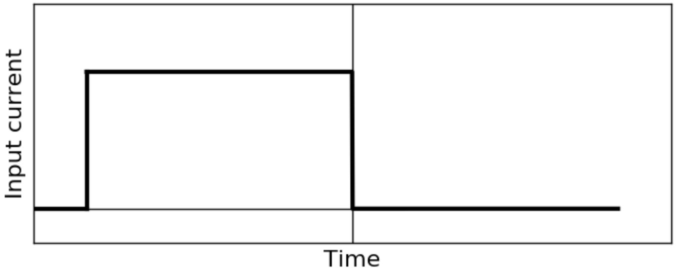
Apply electric field, build up charges



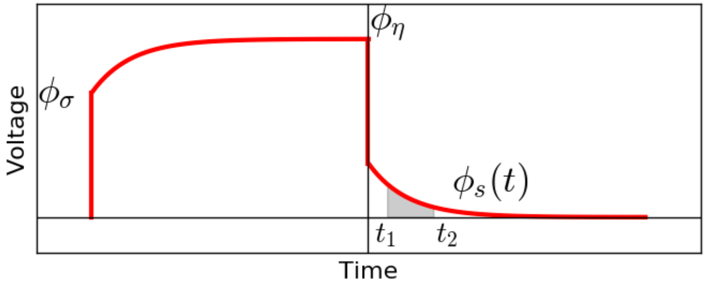
Charge polarization, Electric dipole



Input current



Measured voltage



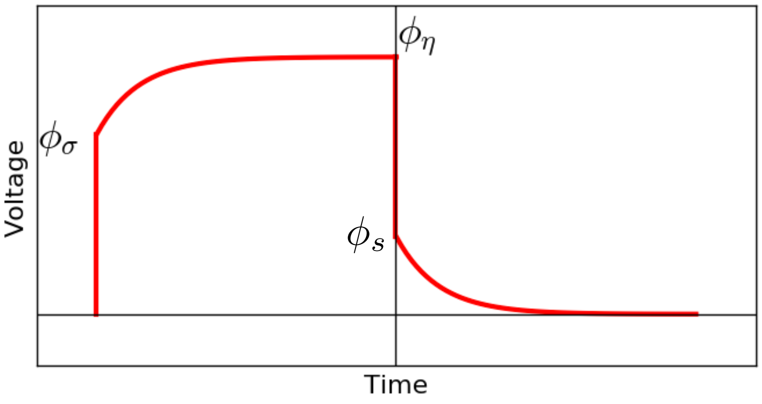
IP data

- Seigel (1959):
  - Introduced chargeability: η
  - Effect reduces conductivity

$$\sigma_\eta = \sigma(1-\eta) \qquad \eta \in [0,1)$$

- Theoretical chargeability data

$$d^{IP} = \frac{\phi_s}{\phi_\eta} = \frac{\phi_\eta - \phi_\sigma}{\phi_\eta}$$

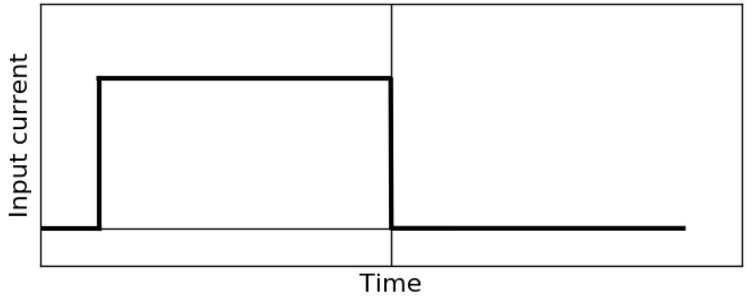


- Not directly measureable

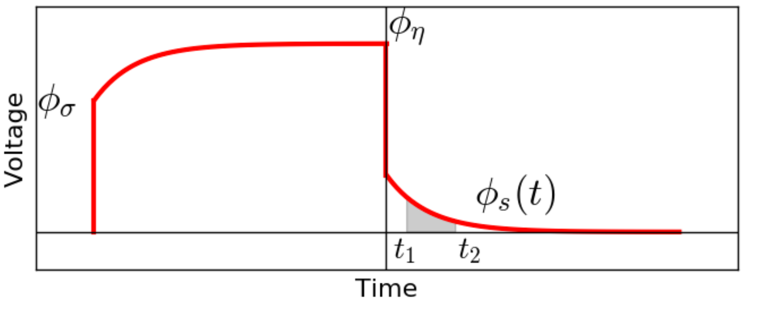
IP data: time domain

- IP decay

Input current



Measured voltage



- IP datum

Dimensionless: $\eta = \phi_s / \phi_\eta$

Value at individual time channel: $\phi_s(t)$

Area under decay curve: $M = \frac{1}{\phi_\eta} \int_{t_1}^{t_2} \phi_s(t) dt$

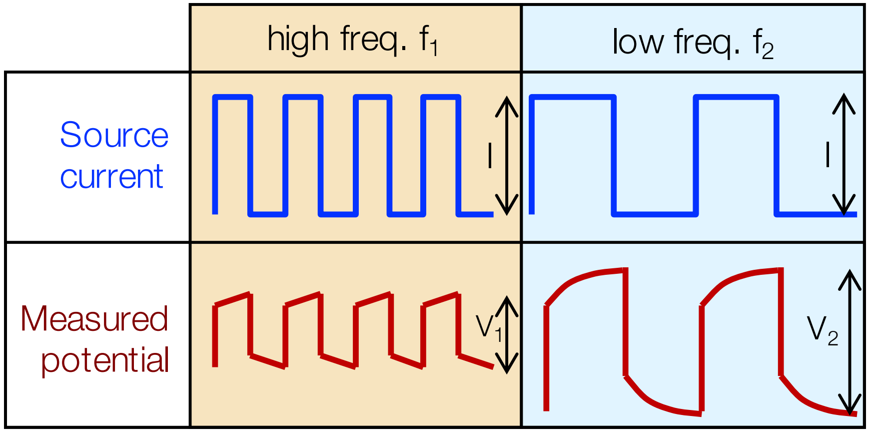
IP data: frequency domain

- Percent frequency effect:

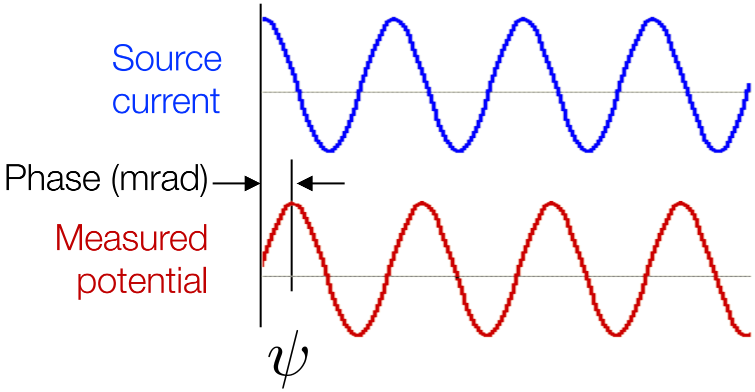
$$PFE = 100(\frac{\rho_{a2} - \rho_{a1}}{\rho_{a1}})$$

ρ_{a1}: apparent resistivity at f_1

ρ_{a2}: apparent resistivity at f_2



- Phase ψ



IP data

- IP signals due to a perturbation (small change) in conductivity

$$\sigma_\eta = \sigma(1-\eta) \qquad\qquad \eta \in [0, 1)$$

- An IP datum can be written as

$$d_i^{IP} = \sum_{j=1}^{M} J_{ij}\eta_j \qquad i = 1, \ldots, N$$

$$J_{ij} = \frac{\partial log\phi^i}{\partial log\sigma_j}$$

sensitivities for the DC resistivity problem

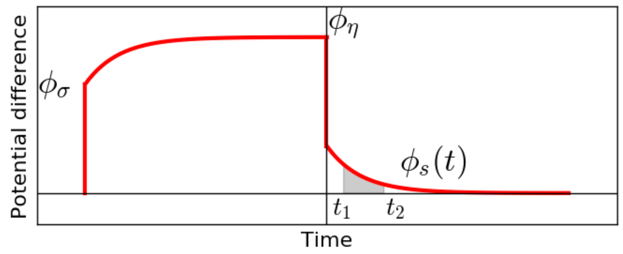
- In matrix form

$$\mathbf{d}^{IP} = \mathbf{J}\boldsymbol{\eta}$$

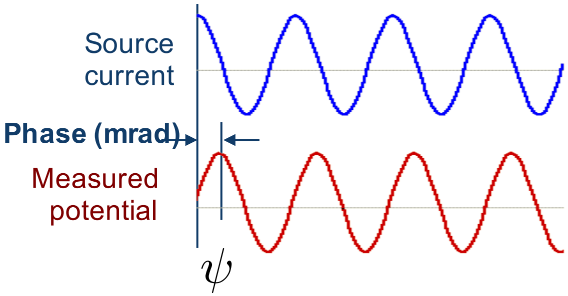
$\mathbf{J}$ is an N×M matrix

Summary of IP data

- Time domain:
  - Theoretical chargeability (dimensionless)
  - Integrated decay time (msec)



- Frequency domain:
  - PFE (dimensionless)
  - Phase (mrad)



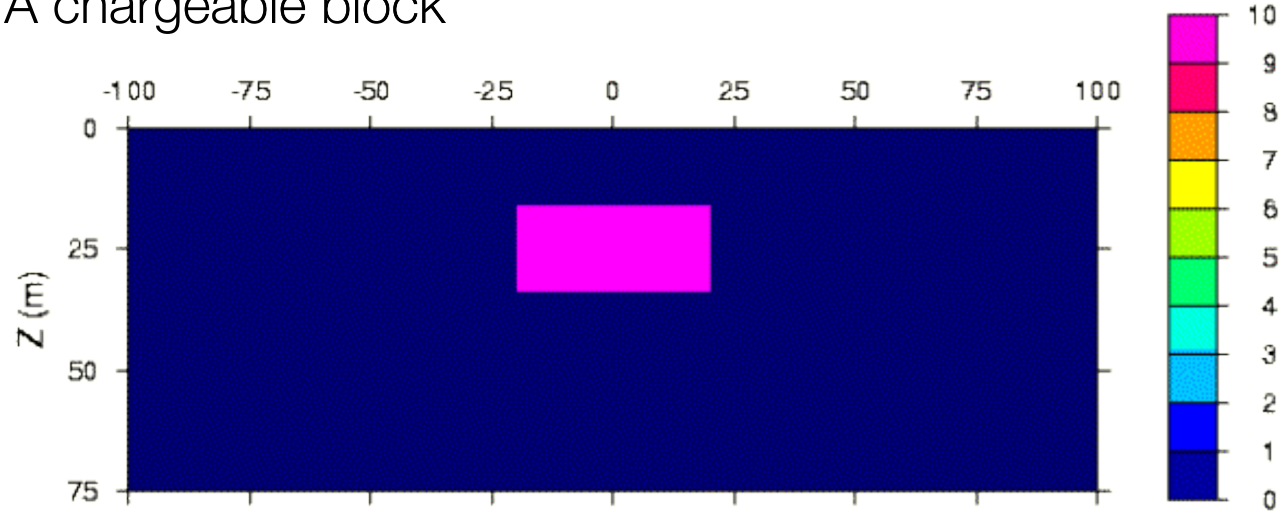
- For all data types: linear problem

$$\mathbf{d}^{IP} = \mathbf{J}\boldsymbol{\eta}$$

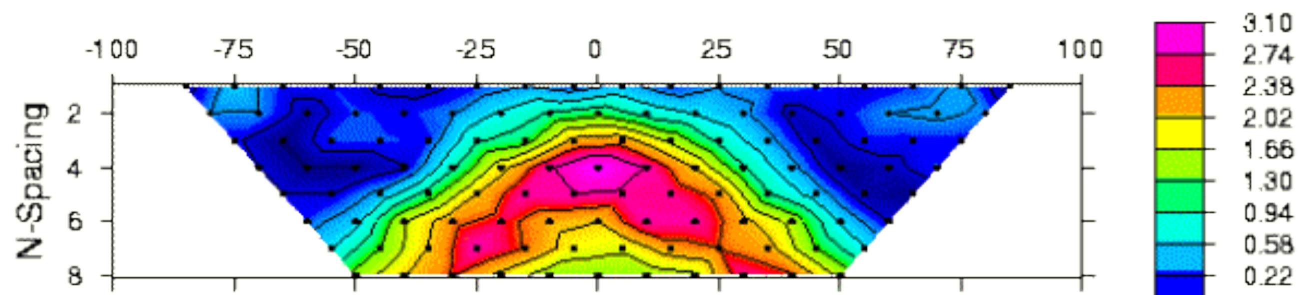
$\mathbf{J}$ is an N×M matrix

IP pseudosections

1) A chargeable block

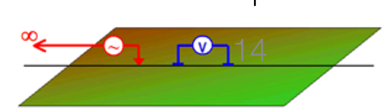


Chargeability model



Observed apparent chargeability

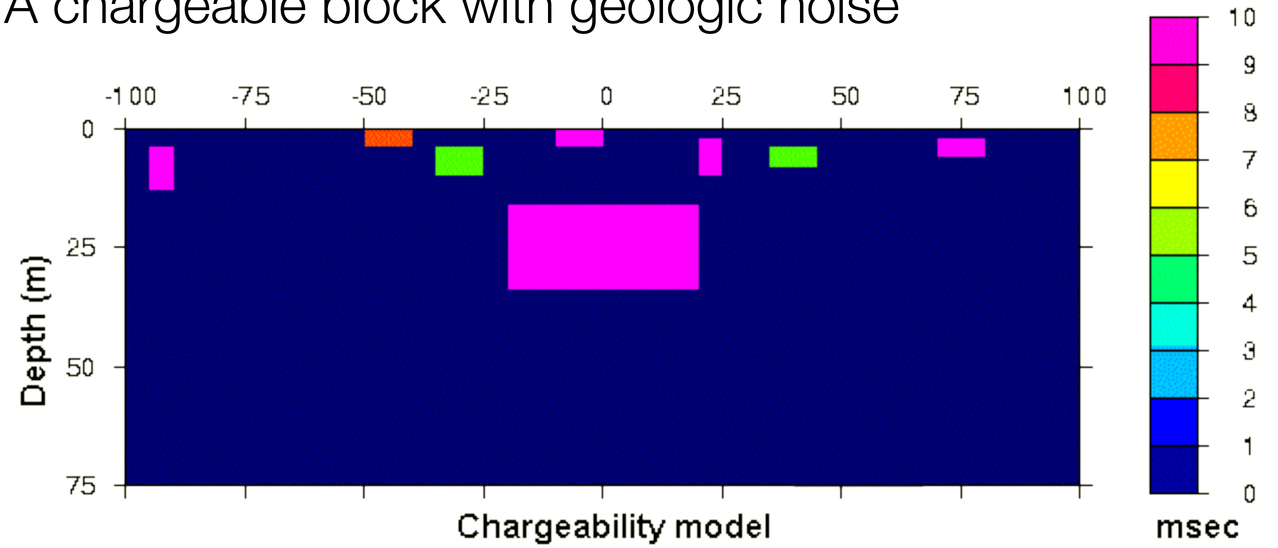
Pole-Dipole

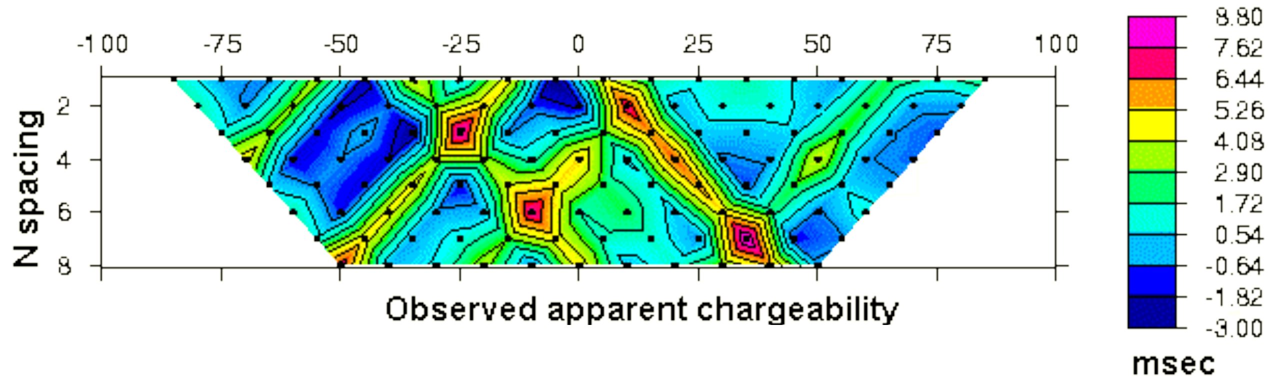


- Pole-dipole; n=1,8; a=10m; N=316

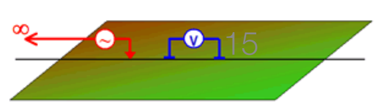
IP pseudosections

2) A chargeable block with geologic noise





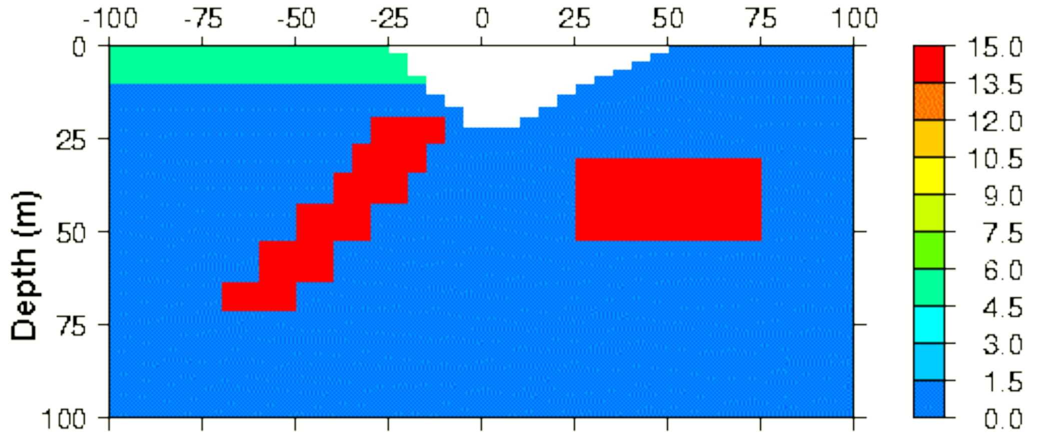
Pole-Dipole



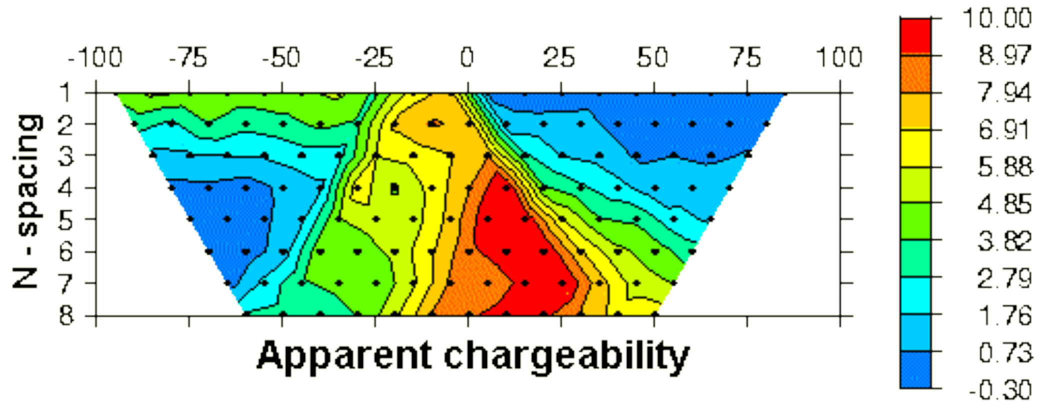
- Pole-dipole; n=1,8; a=10m; N=316

IP pseudosections

3) The "UBC-GIF model"

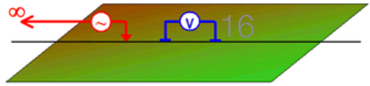


Chargeability model

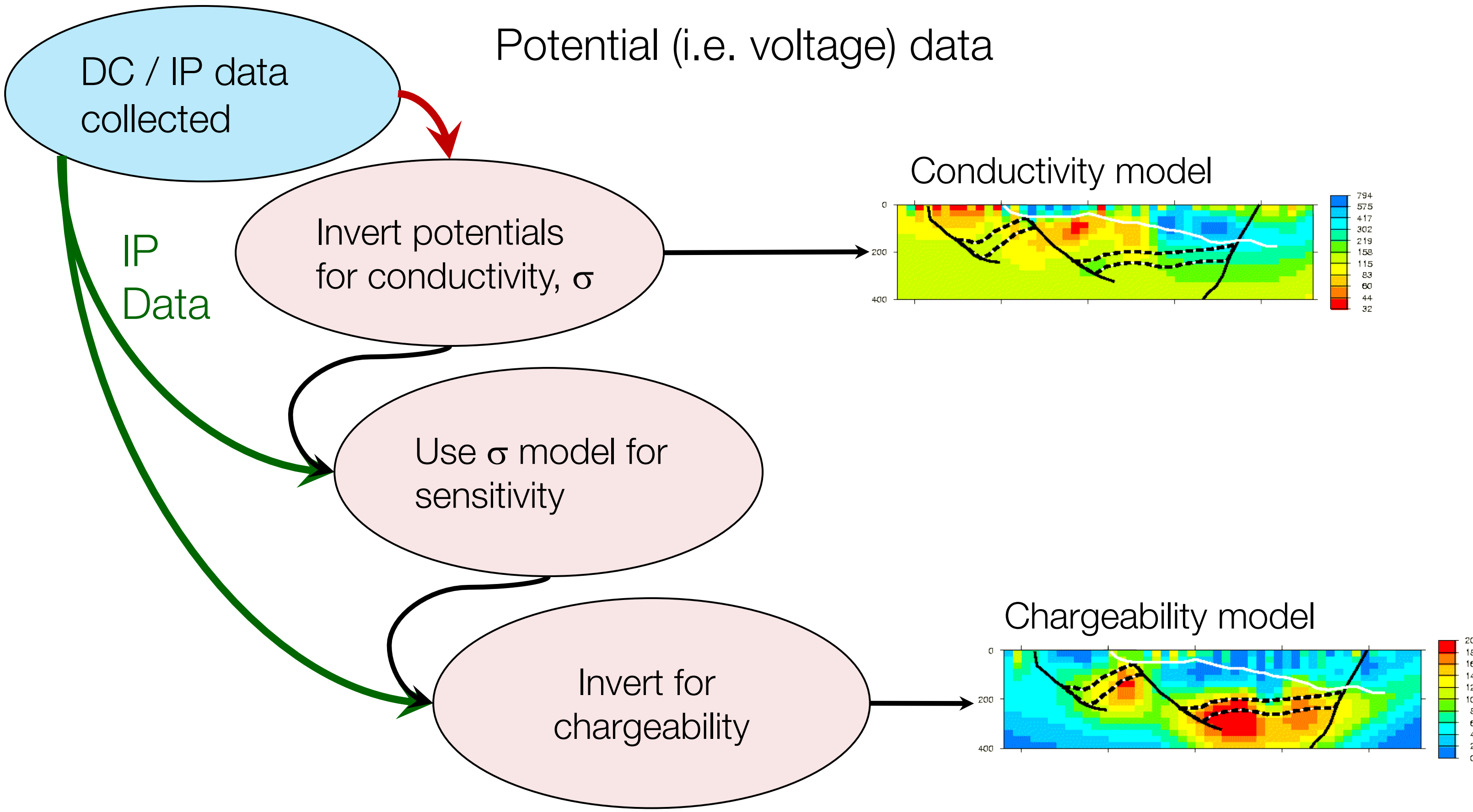


Apparent chargeability

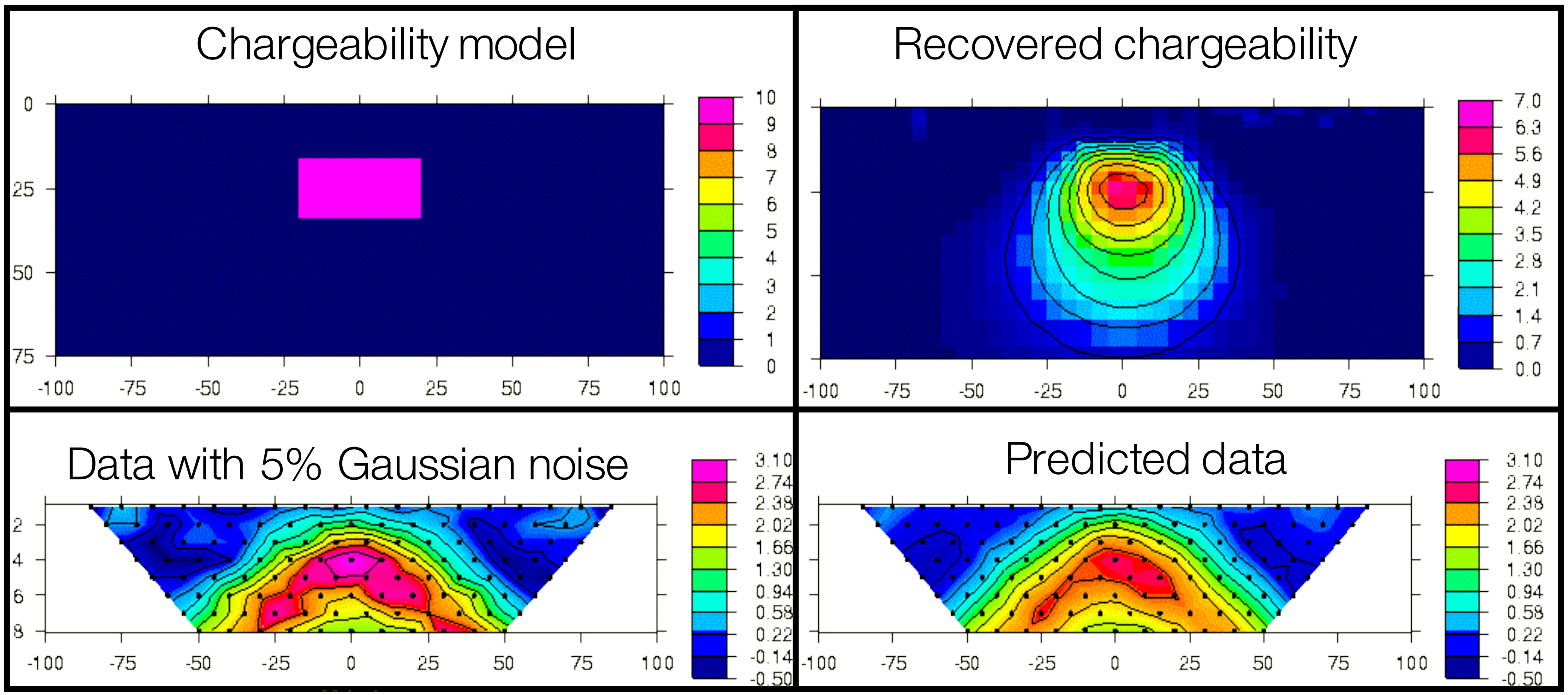
Pole-Dipole



IP Inversion

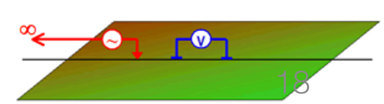


Example 1: buried prism

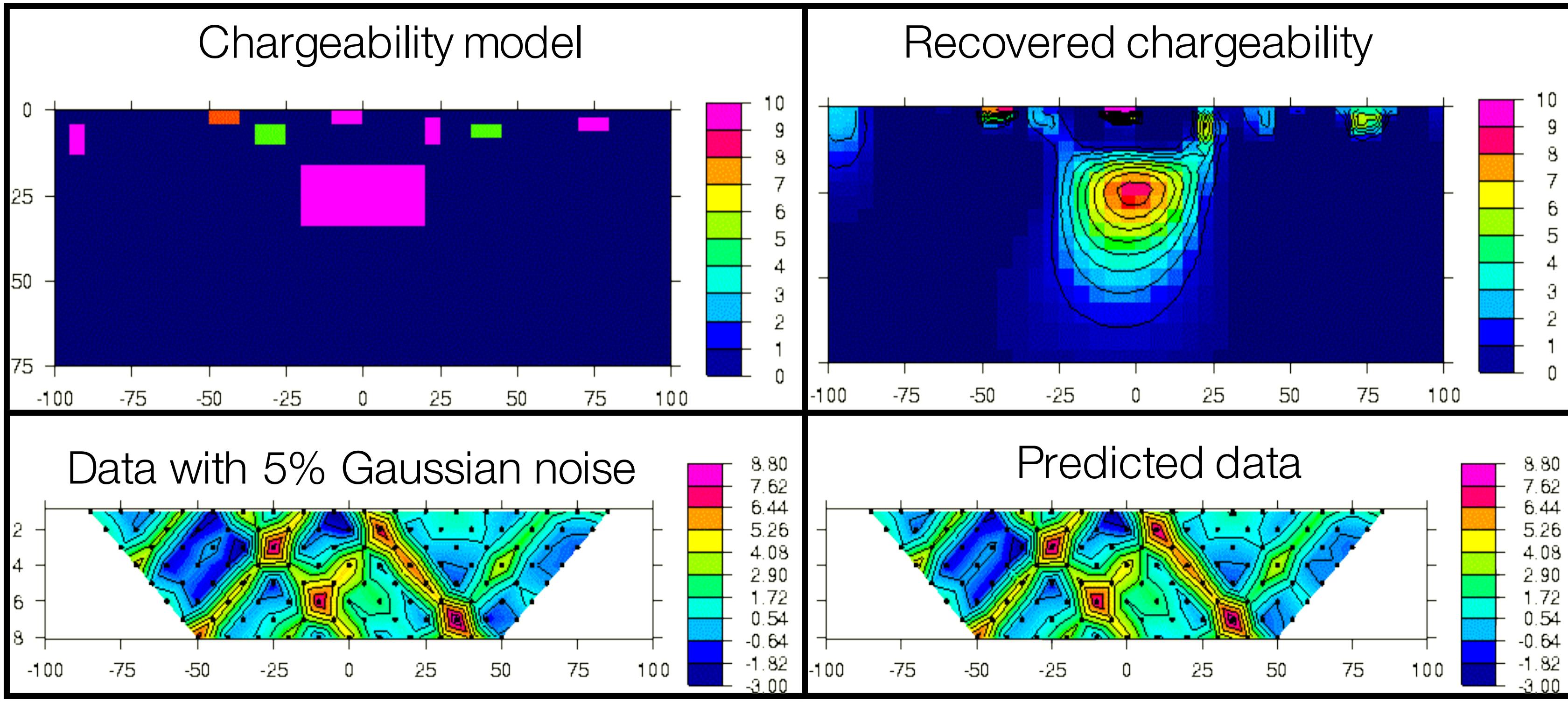


- Pole-dipole; n=1,8; a=10m; N=316; $(\alpha_s, \alpha_x, \alpha_z)$=(.001, 1.0, 1.0)

Pole-Dipole

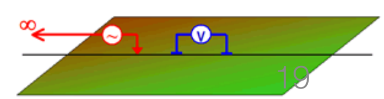


Example 2: prism with geologic noise

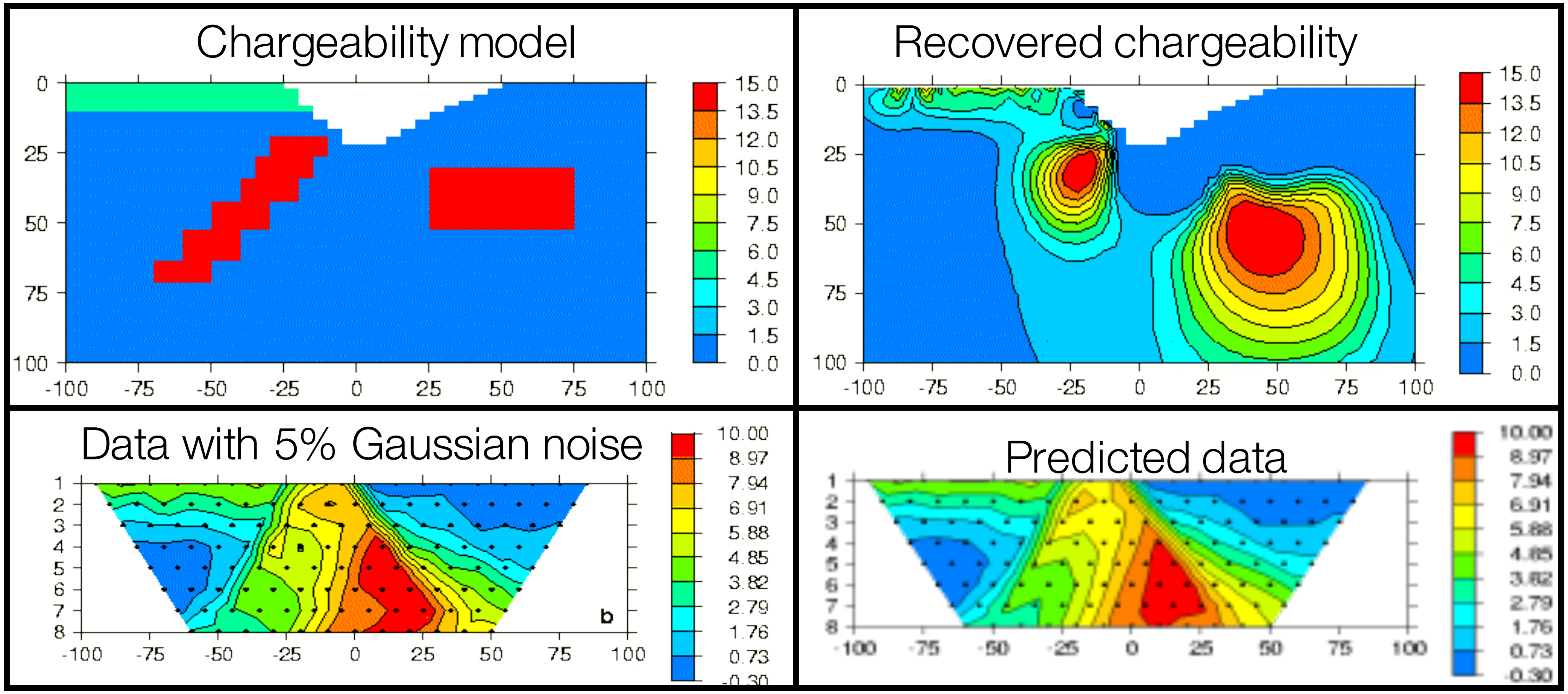


- Pole-dipole; n=1,8; a=10m; N=316; $(\alpha_s, \alpha_x, \alpha_z)$=(.001, 1.0, 1.0)

Pole-Dipole

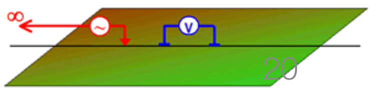


Example 3: UBC-GIF model



- Pole-dipole; n=1,8; a=10m

Pole-Dipole



Induced Polarization: Summary

- Sources of IP
- Conceptual model of IP
- Chargeability
- IP data
- Pseudosections
- Two stage DC-IP inversion

- Questions

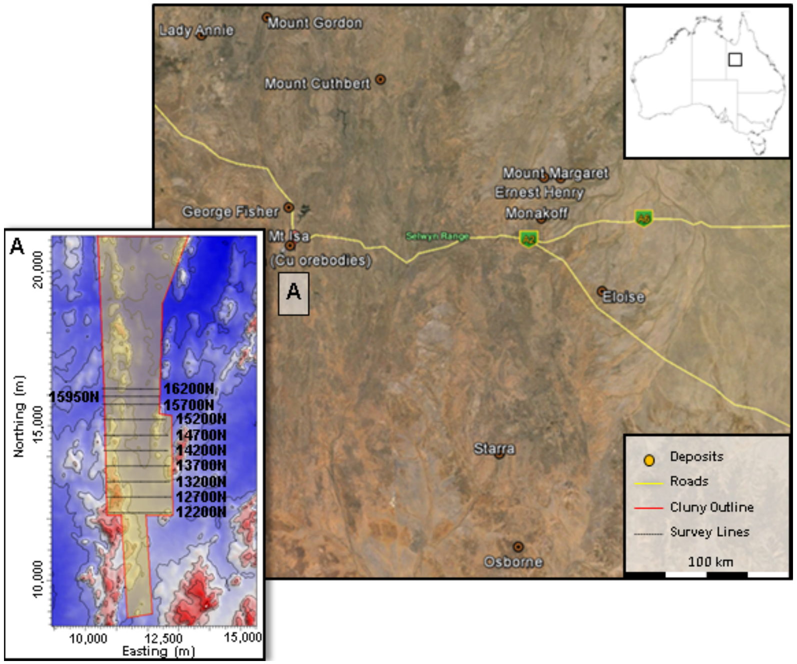
- Case history: Mt. Isa
- Example: Landfills

Case history: Mt. Isa

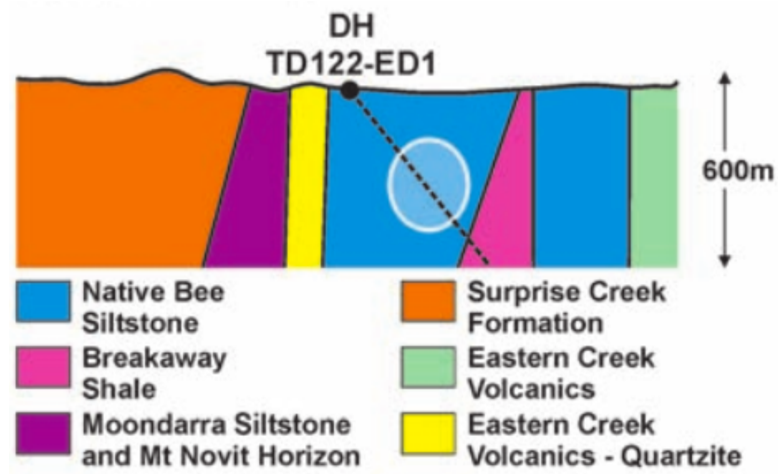
Rutley et al., 2001

Setup

- Mt. Isa (Cluny propect)



- Geologic model

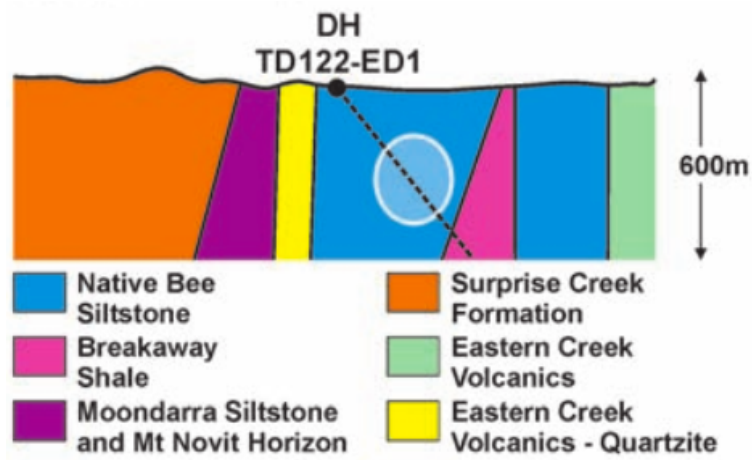


Question

- Can conductive, chargeable units, which would be potential targets within the siltstones, be identified with DC / IP data?

Properties

Geologic model



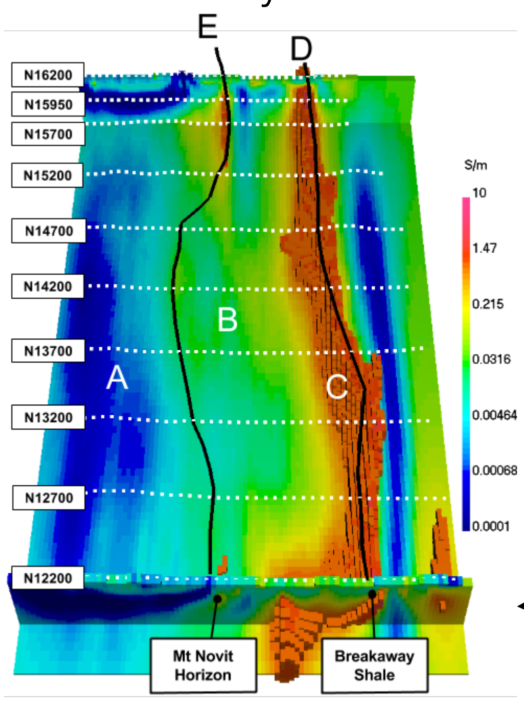
Resistivity and Chargeability

Rock Unit	Conductivity	Chargeability
Native Bee Siltstone	Moderate	Low
Moondarra Siltstone	Moderate	Low
Breakaway Shale	Very High	Low-None
Mt Novit Horizon	High	High
Surprise Creek Formation	Low	None
Eastern Creek Volcanics	Low	None

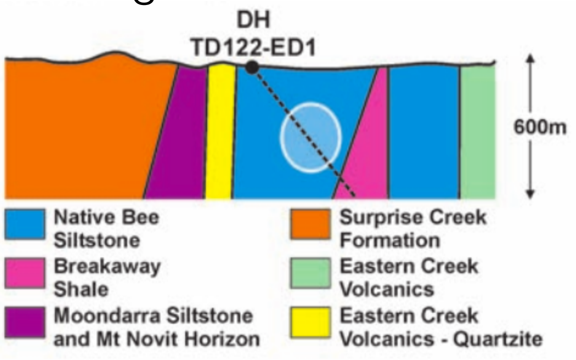
Recap: Synthesis from DC

- Identified a major conductor → black shale unit
- Some indication of a moderate conductor

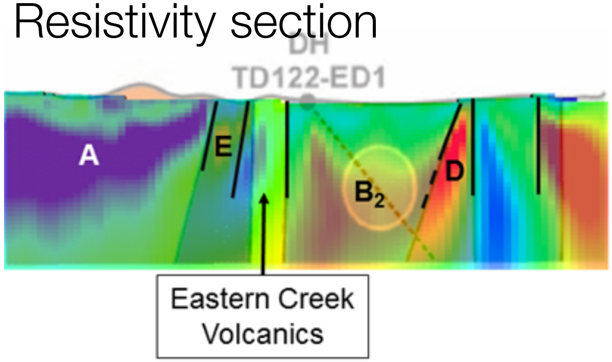
3D resistivity model



Geologic section



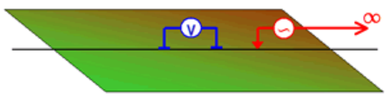
Resistivity section



Can a **chargeable**, moderate conductor in the siltstones be identified?

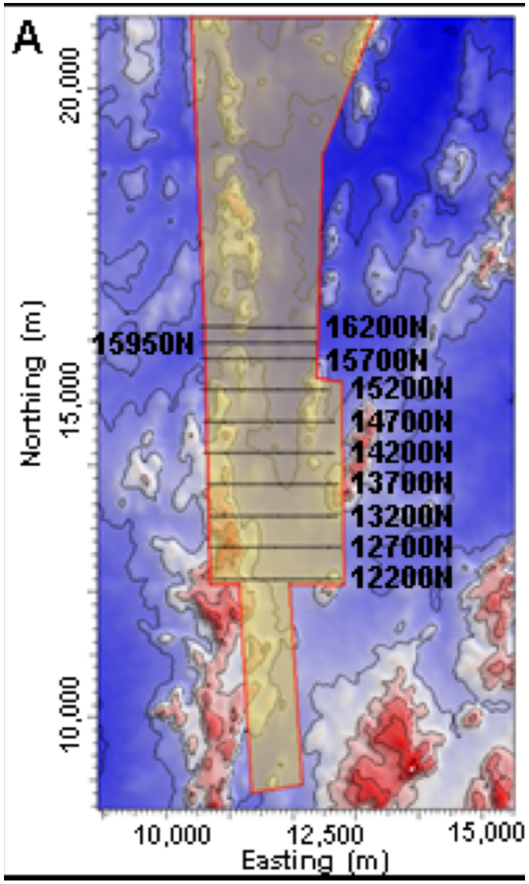
Survey and data

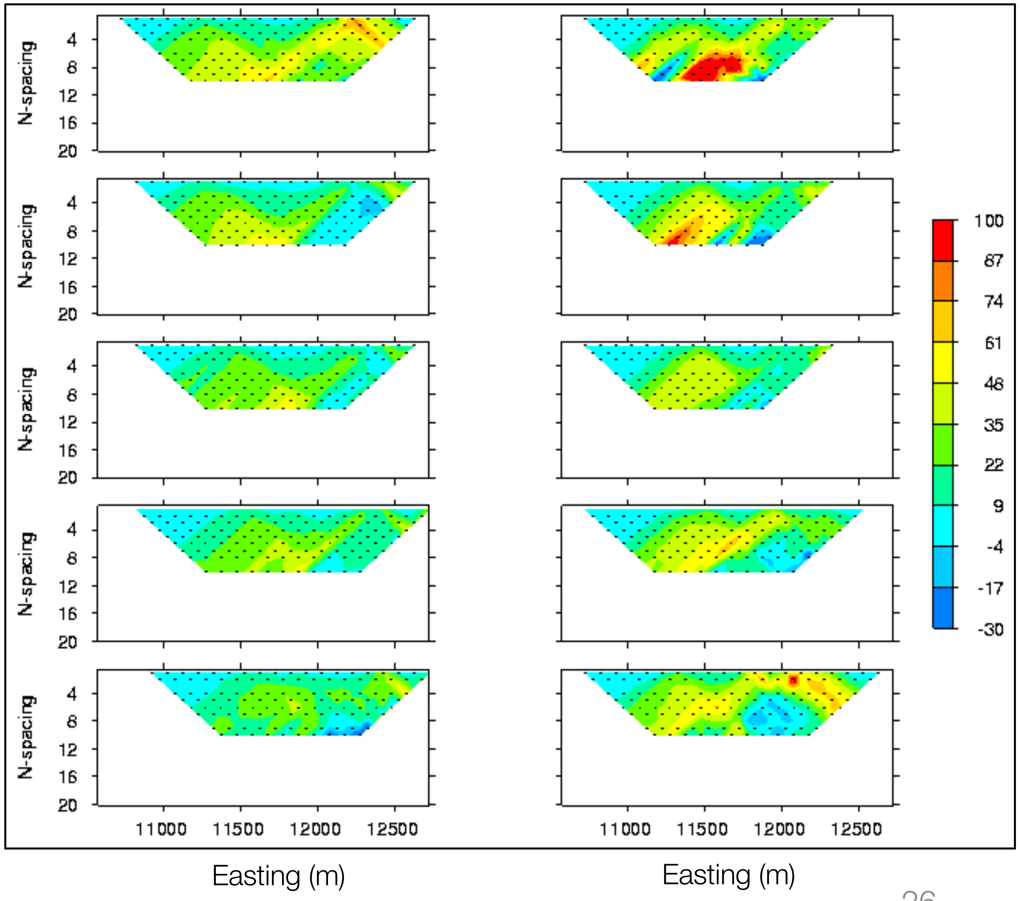
- Eight survey lines
- Two configurations



Apparent chargeability, dipole- pole.

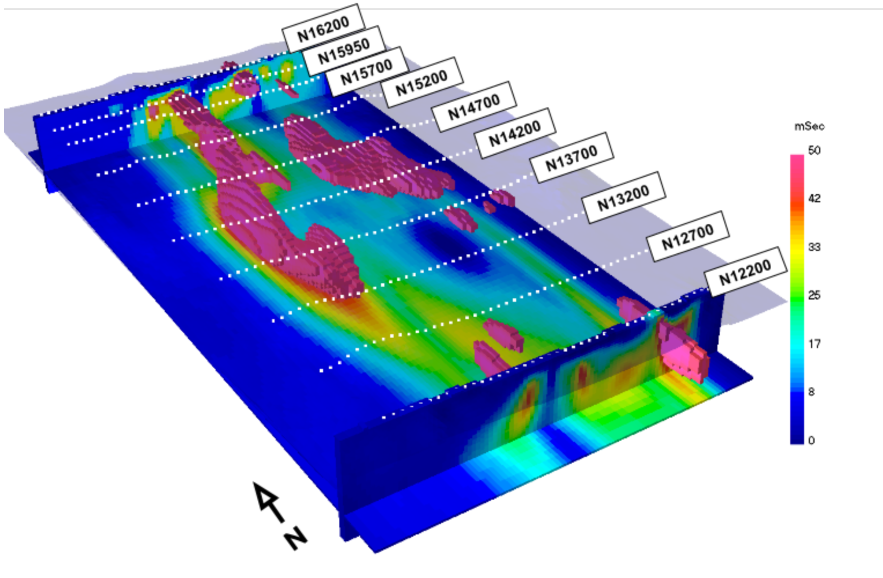
Surface topography



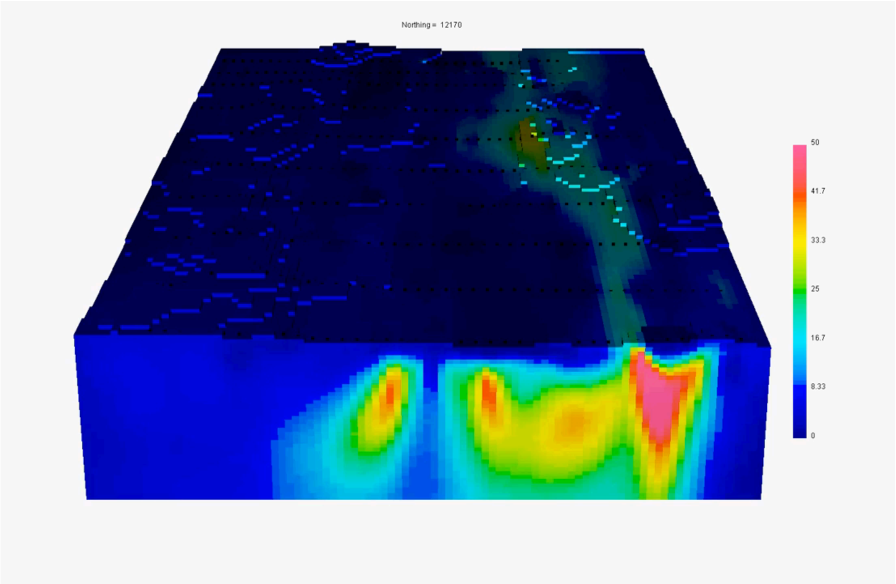


Processing

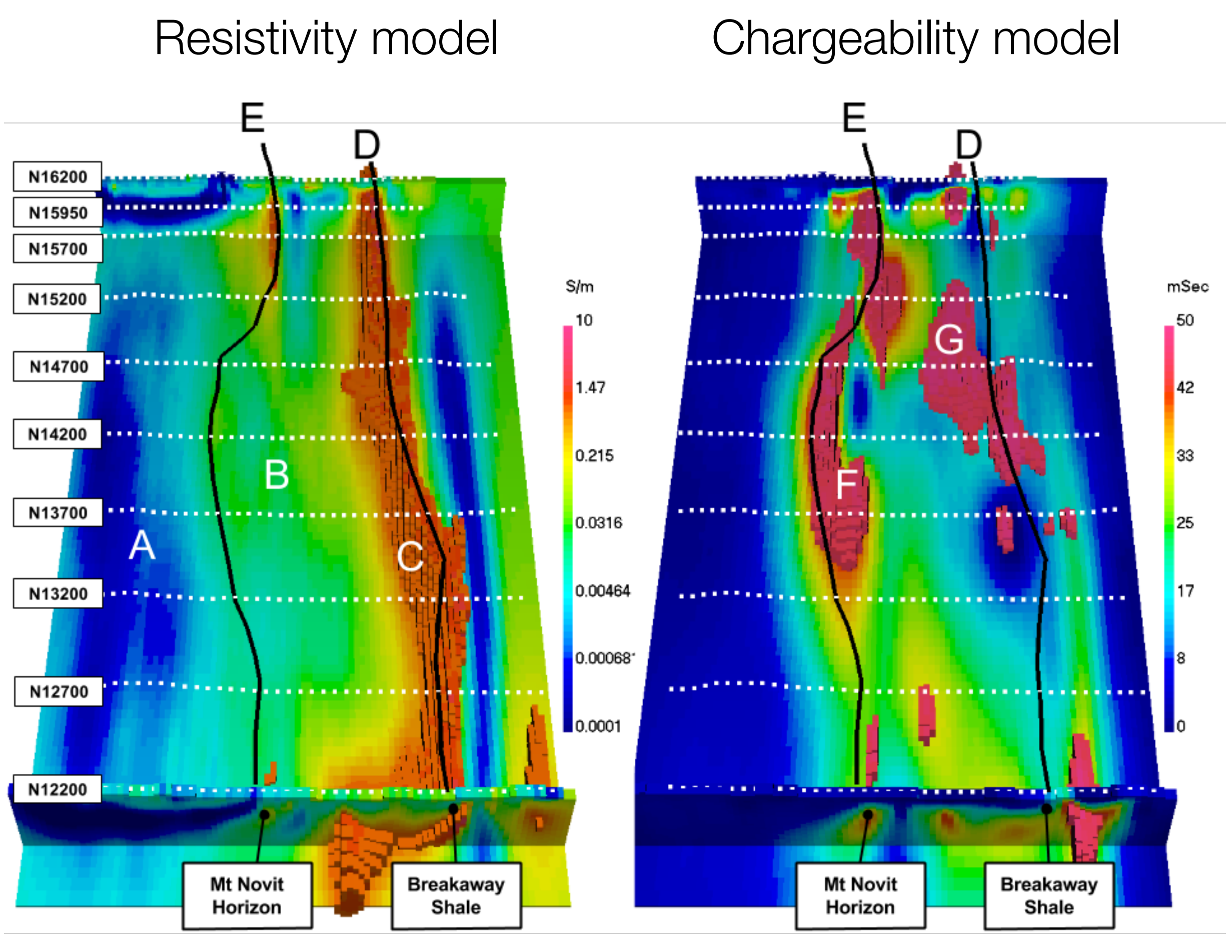
3D chargeability model



Animation



Interpretation



A: Resistive, Non-chargeable

B: Moderate conductivity; low chargeabilty

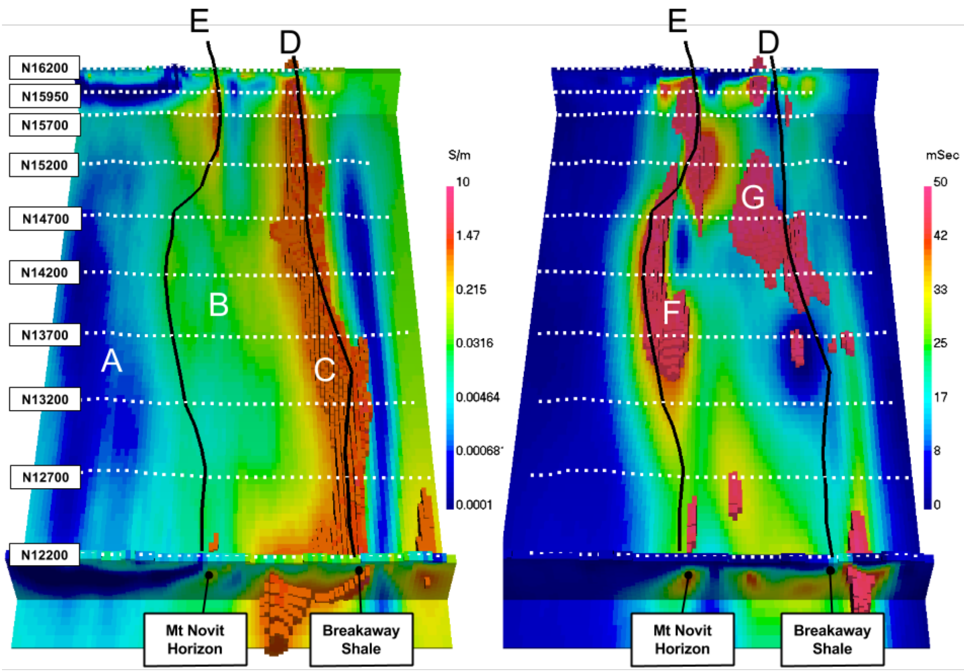
C: Very high conductivity (> 10 S/m)

E and F: High conductivity and high chargeability

G: Other chargeable regions

Synthesis

Resistivity model   Chargeability model



A: Surprise Creek Formation

- Resistive, non-chargeable

B: Moondarra and Native Bee siltstones

C: Breakaway Shales

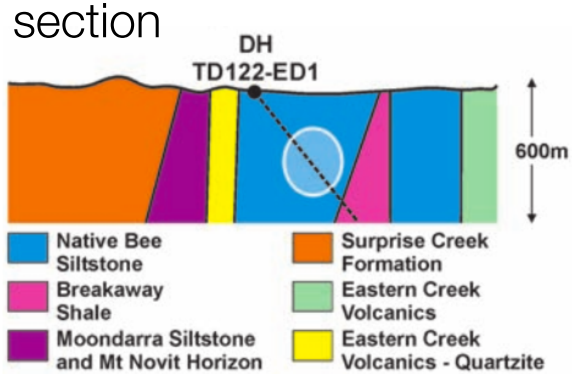
- Very high conductivity

E and F: Mt Novit Horizon

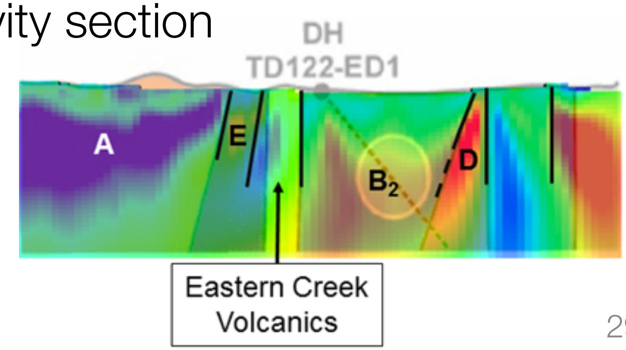
- High conductivity and high chargeability

G: Other chargeable regions within siltstone complex

Geologic section



Resistivity section



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- IP data
- Pseudosections
- Two stage DC-IP inversion
- Case history: Mt. Isa

- Questions

- Example: Landfills

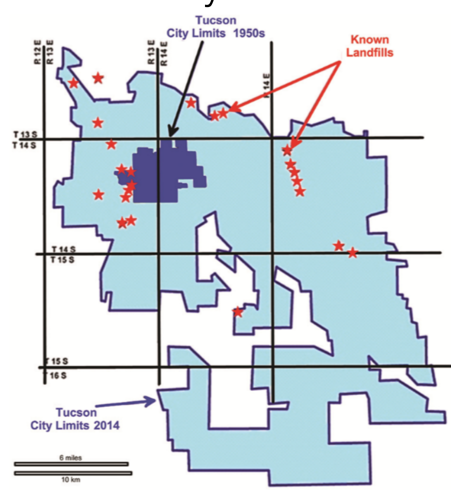
IP over Landfills

Landfills: Hazards and Goals

- Pollutants
  - Toxic leachates (mercury, arsenic, cadmium, lead, PVC, solvents)
  - Methane and other gases
- Concerns
  - Health
  - Water contamination
  - Construction hazard
  - Devalues property
- Goals
  - Locate abandoned landfills
  - Assess size
  - Characterize the waste
  - Monitor reclamation

Nearmont and Congress landfills, Tucson, Arizona

Tucson city limits and regional landfills



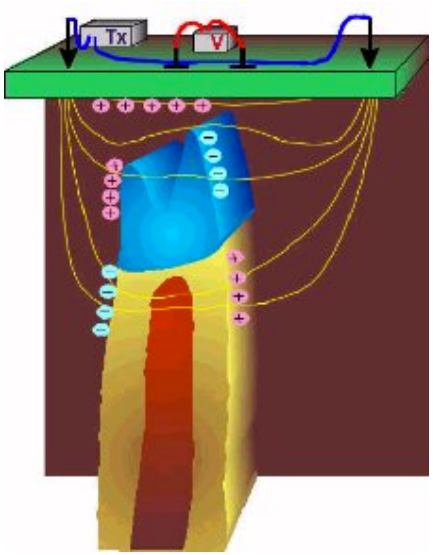
Physical Properties

Waste Type	Description	Resistivity	Susceptible	Chargeable
Electronic/ Technological	Metallic objects, heavy metals in solution	Low	Yes	Yes
Methane/ Carbon-Dioxide	Wood, cement, iron rebar, wall board, asbestos, glass, plastics	Very High	No	No
Construction Debris	anaerobic decomposition of organic materials to methane, CO2	High	Frequently	Weakly
Earth Materials	Clays, various fill	Low/Moderate	Occasionally	Yes
Green waste	trees, wood clippings etc	Very High	No	Possibly

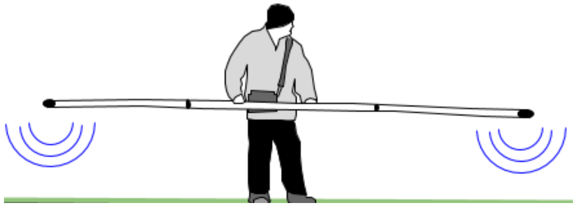
Traditional Landfill Surveys

Magnetic

DC Resistivity



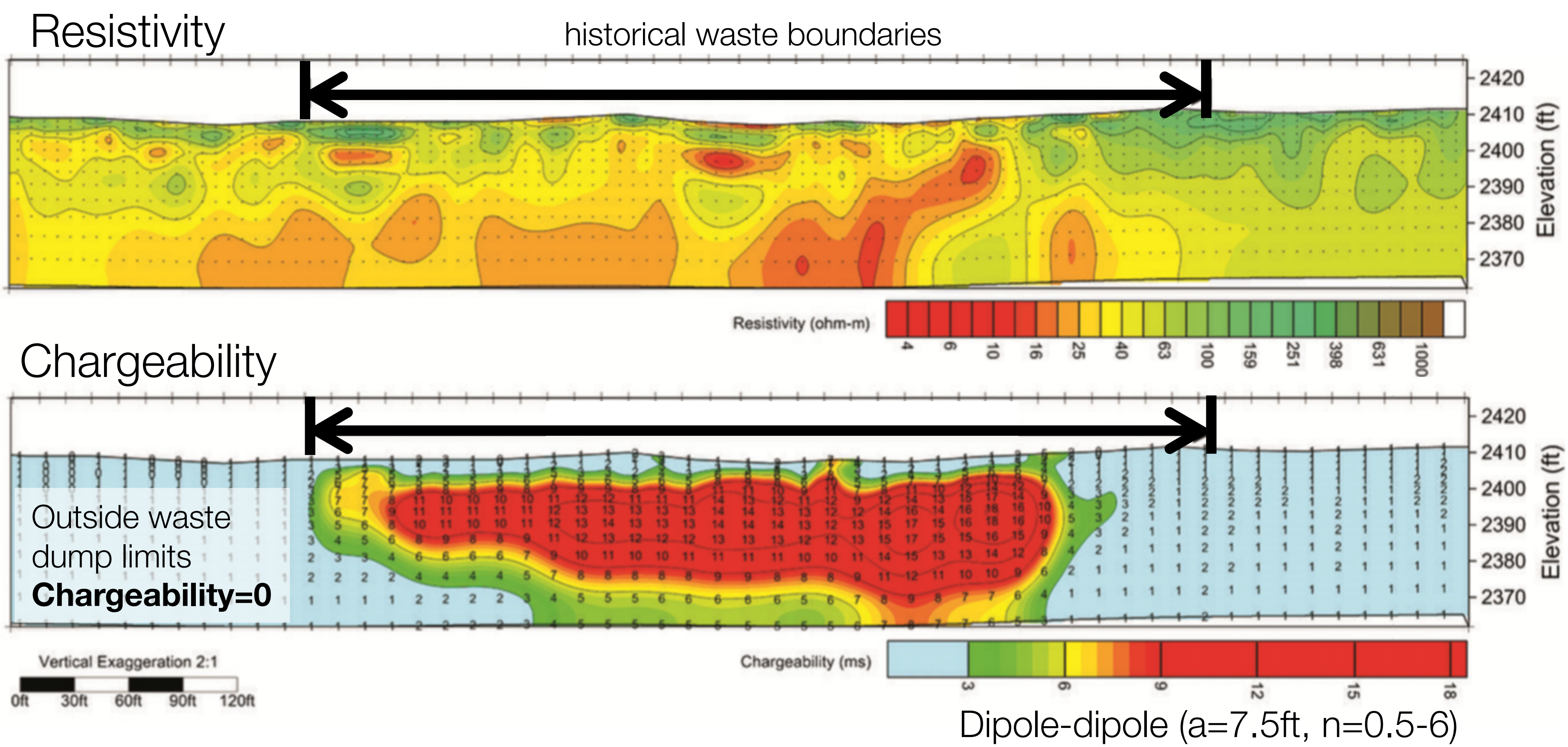
Near-Surface Electromagnetic



- Most popular surveys have limited success
- IP might be a better diagnostic
- Responsive to: metallic debris, green waste, organic matter, some construction materials

Ryan Airfield (Eastern Pit)

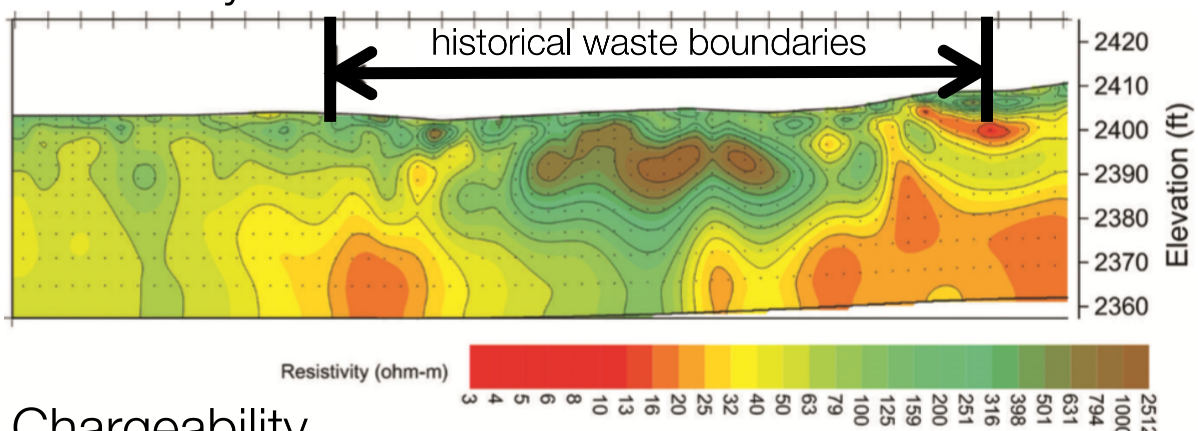
- Waste material: Mixed solid waste (MSW)
- Observations:
  - Resistivity not correlated with pit margins (non-diagnostic)
  - Chargeability (IP) correlates well with historical pit margins (diagnostic)



Ryan Airfield (Western Pit)

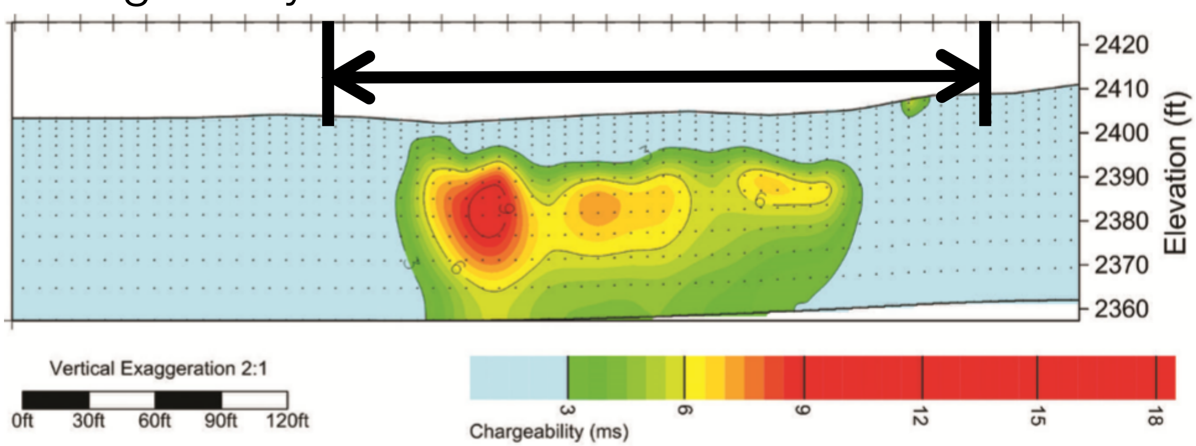
- Waste material: Construction / demolition
- Observations:
  - Waste correlates with region of high resistivity
  - Waste correlates with chargeable region (significant IP anomaly).

Resistivity



Resistive waste within landfill

Chargeability

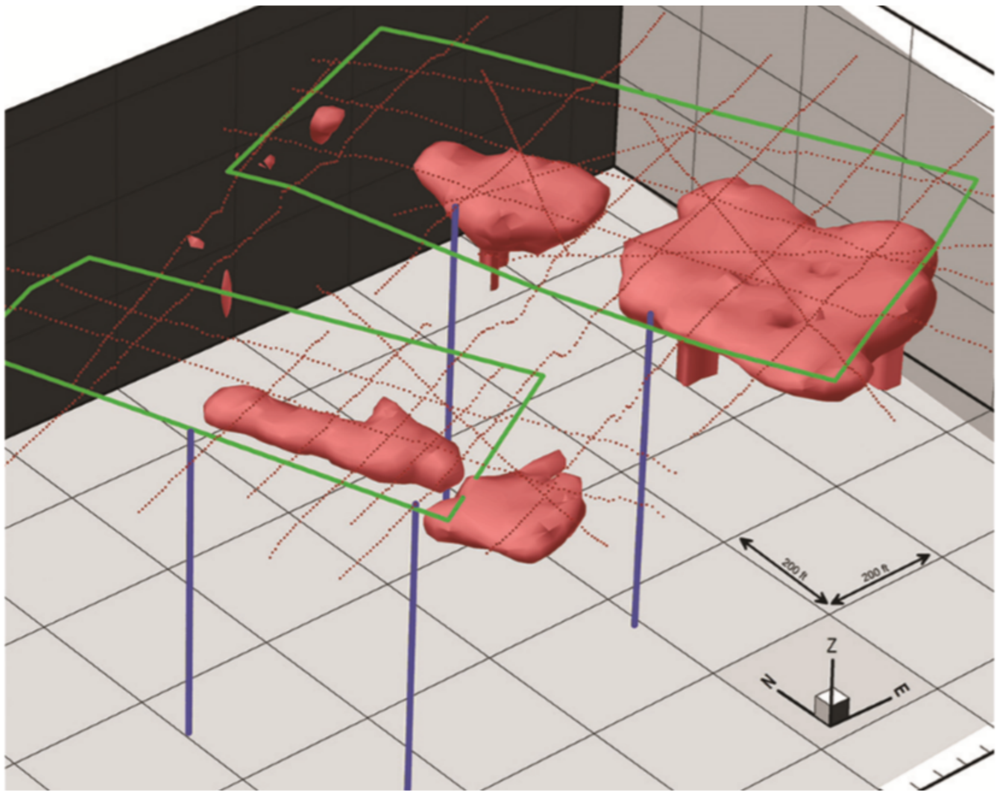


IP correlates with landfill

Dipole-dipole (a=7.5ft, n=0.5-6)

Ryan Airfield (Composite)

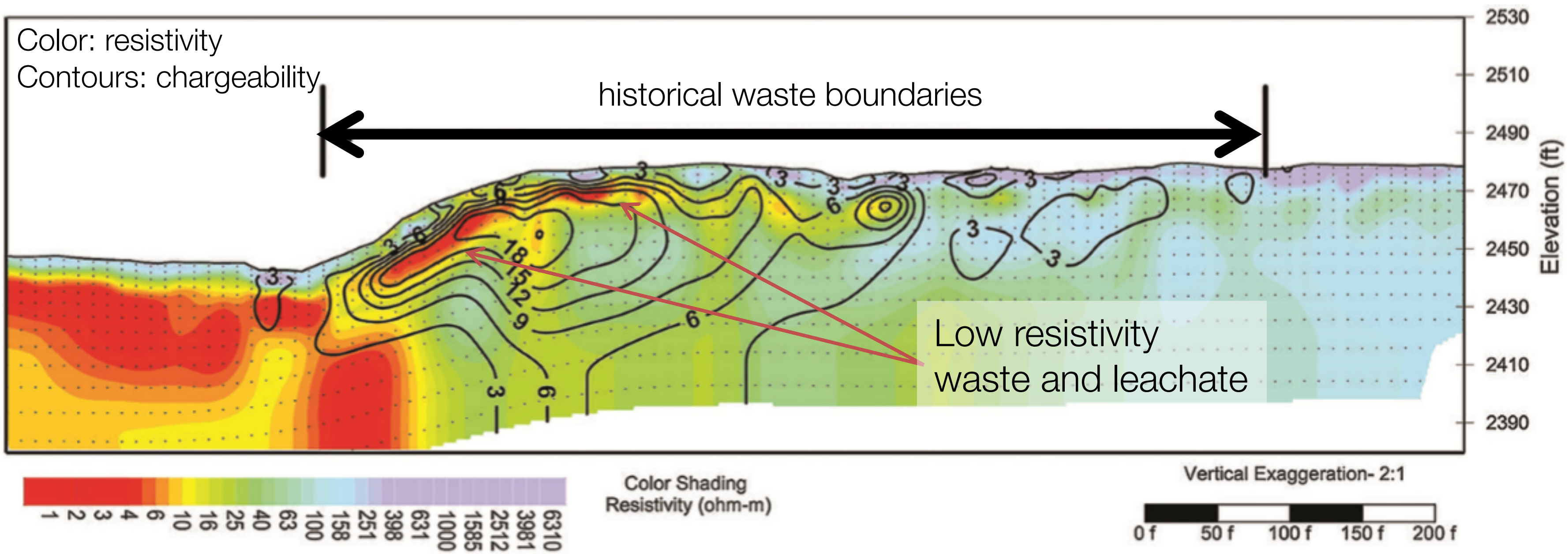
Chargeability isosurface



- Waste material:
  - MSW and construction / demolition
- Observations:
  - Well locations picked with aim of **not** intercepting waste
  - Verified by drilling

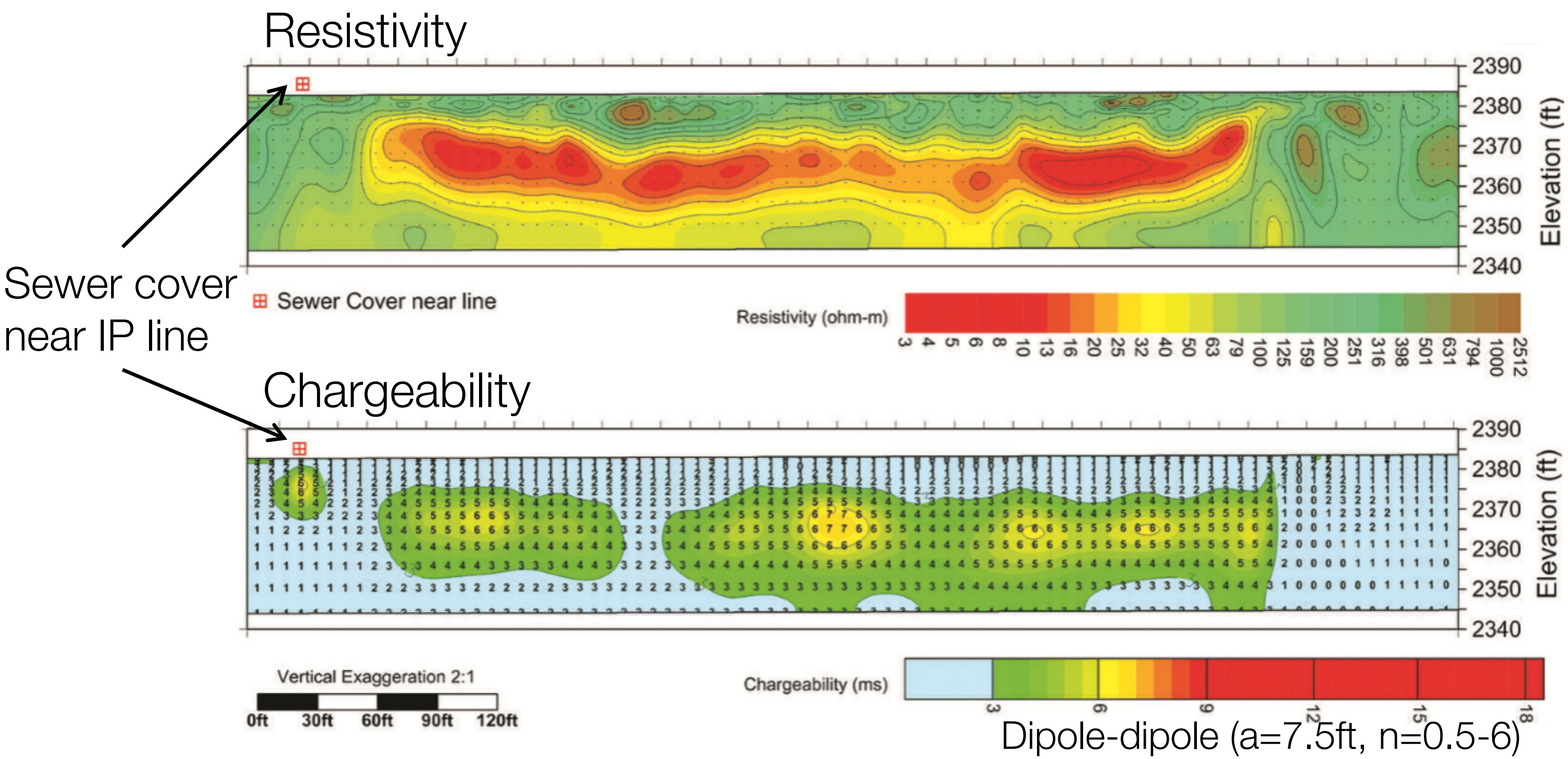
Tumamoc Landfill

- Waste material: Construction / demolition
- Observations:
  - Low resistivities down-gradient from waste → likely conductive leachate
  - Low resistivity and IP offset from one another
  - IP falls within historic landfill boundaries



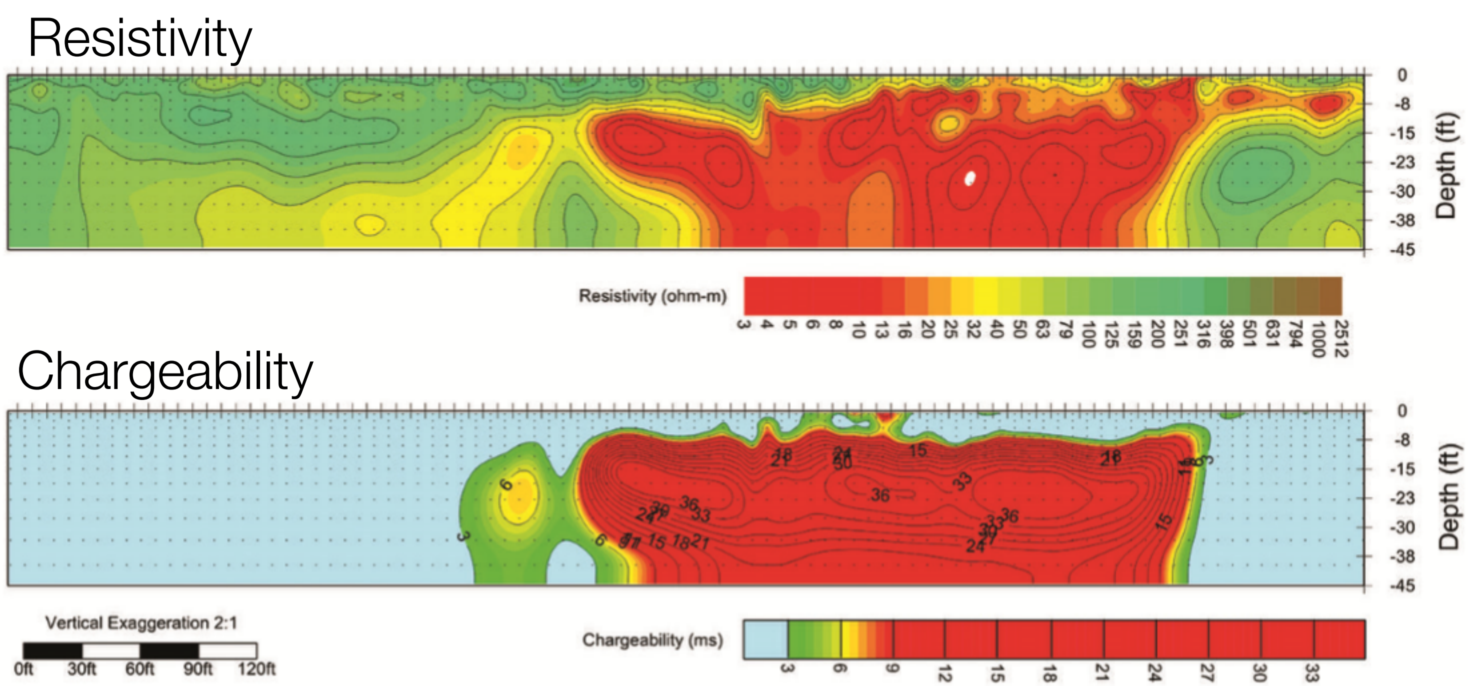
Tucson region: Organic material

- Waste material: green-waste, trees, clippings
- Observations:
  - Resistivity low
  - Weak but elevated IP signature



Nearmont Landfill

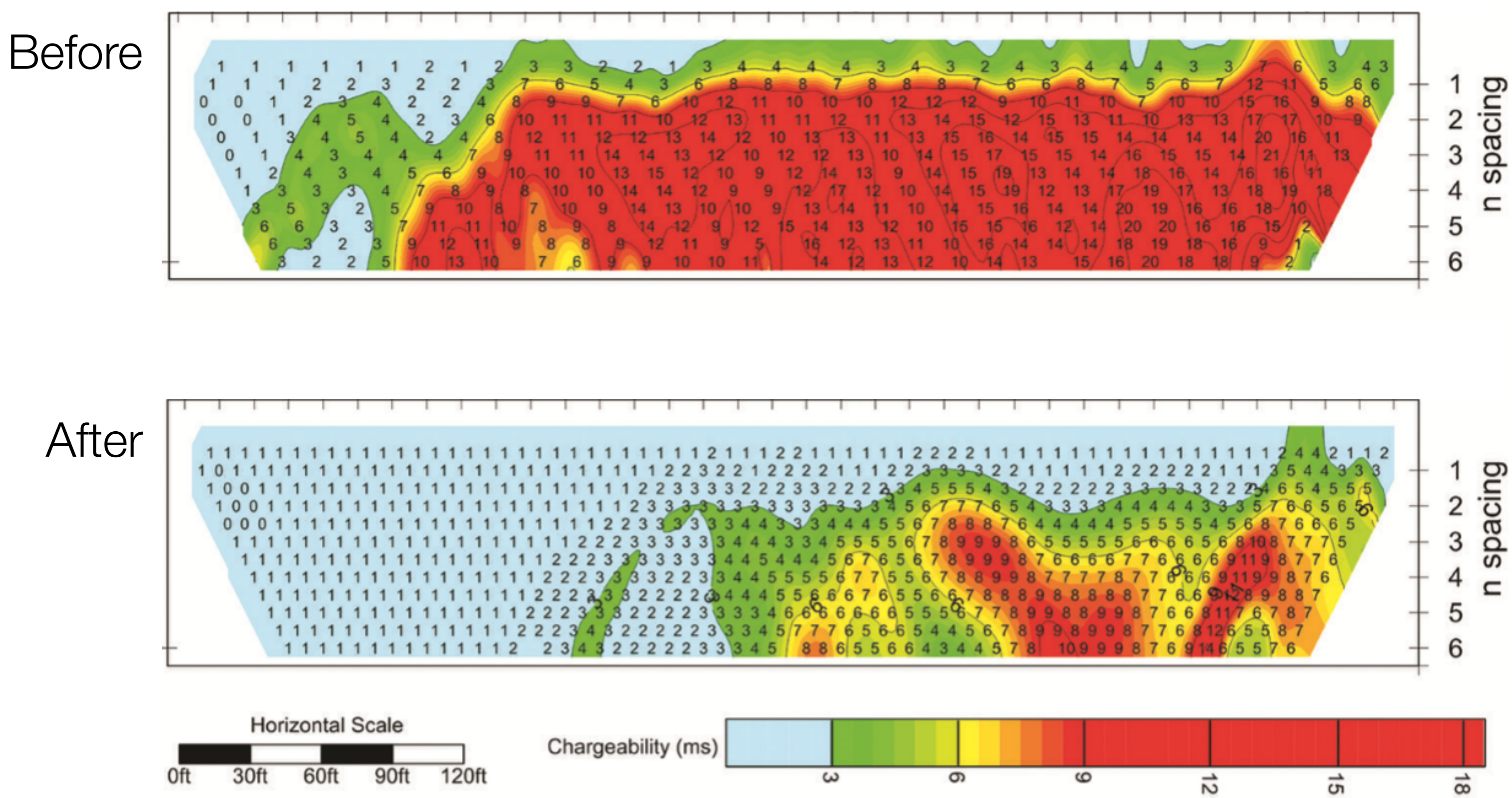
- Waste material: Municipal solid waste (MSW)
- Observations:
  - low resistivity + high IP (ideal “fingerprint”)
  - MSW waste confirmed with drilling



Dipole-dipole (a=7.5ft, n=0.5-6)

Example: Landfill Monitoring

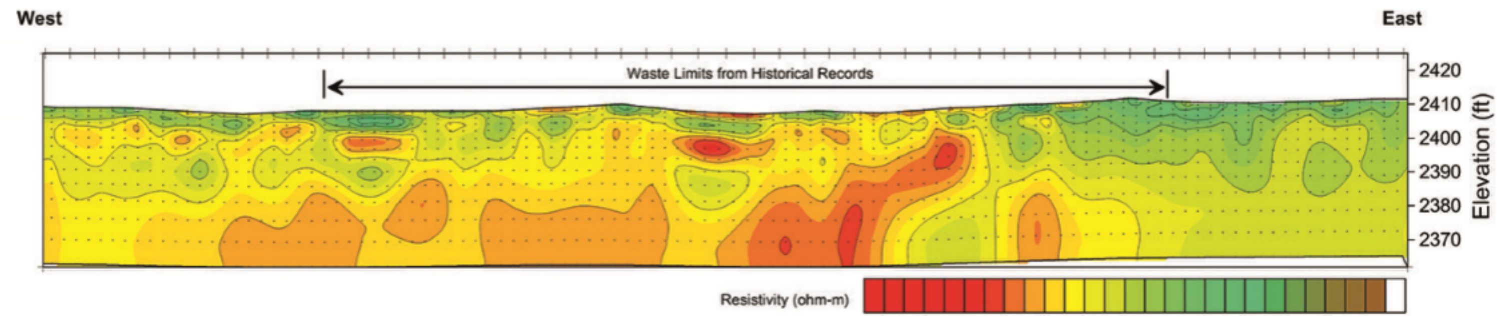
- Waste material: municipal solid waste (MSW)
- Surveys:
  - 2003: IP survey
  - 2003-2007: 4 year biodegrediation program
  - 2009: Repeat IP survey
- Observations:
  - Reduction in IP anomaly indicates the effectiveness of biodegredation



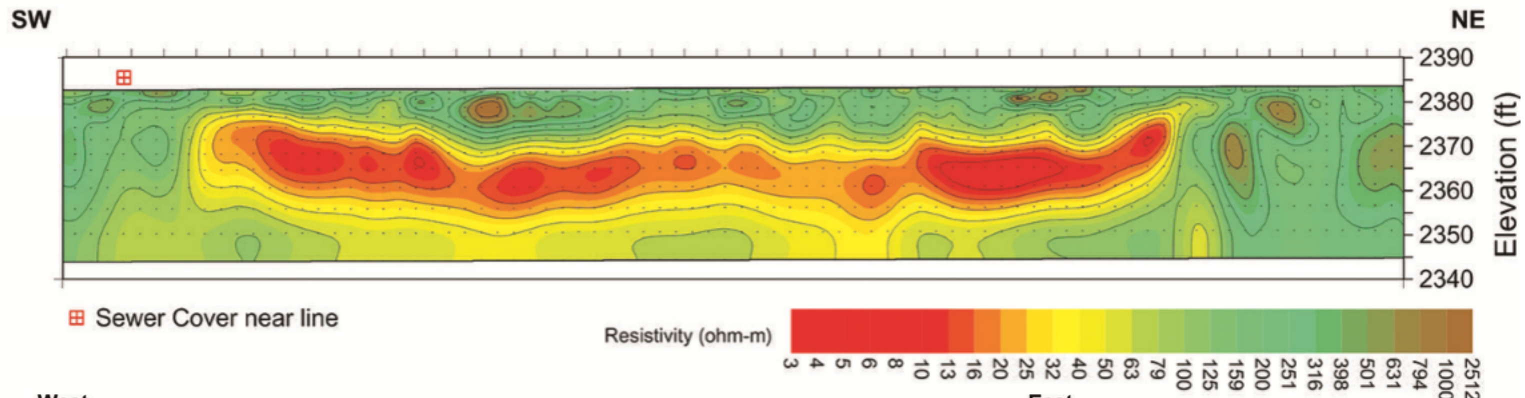
Summary

- Resistivity may not be a good indicator of waste

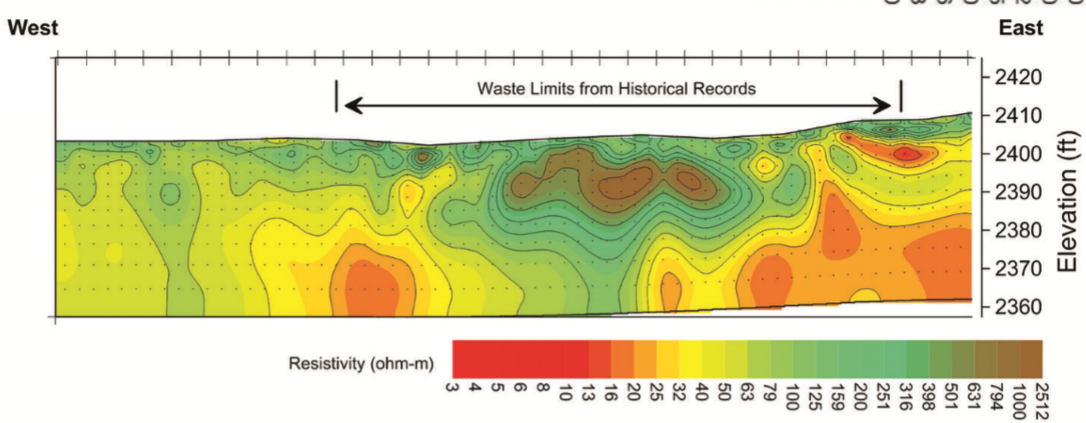
Mixed Waste



Green Waste



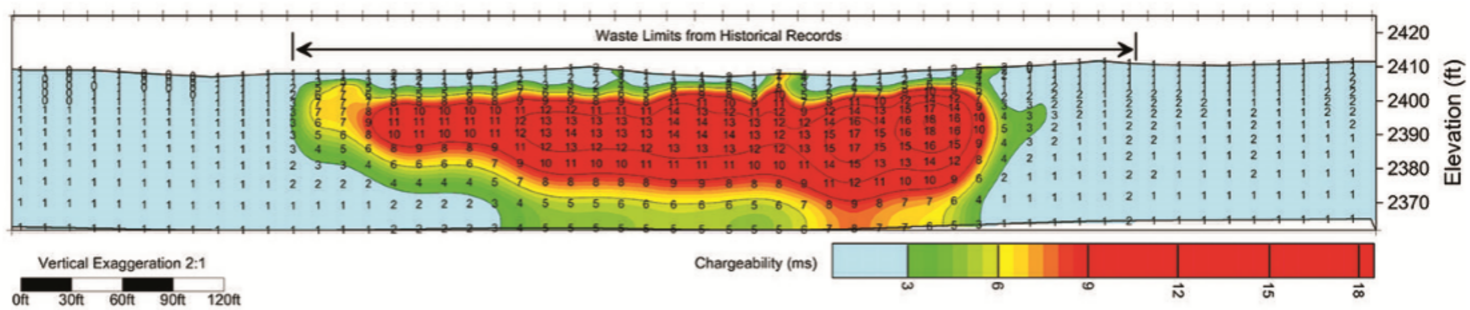
Construction/ Demolition Waste



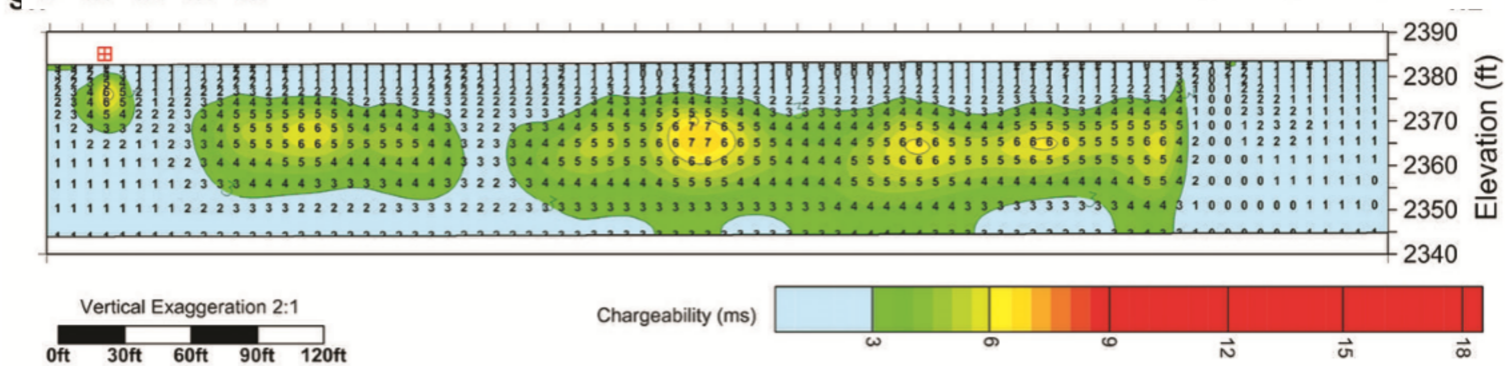
Summary

- Chargeability may be a more consistent indicator of waste

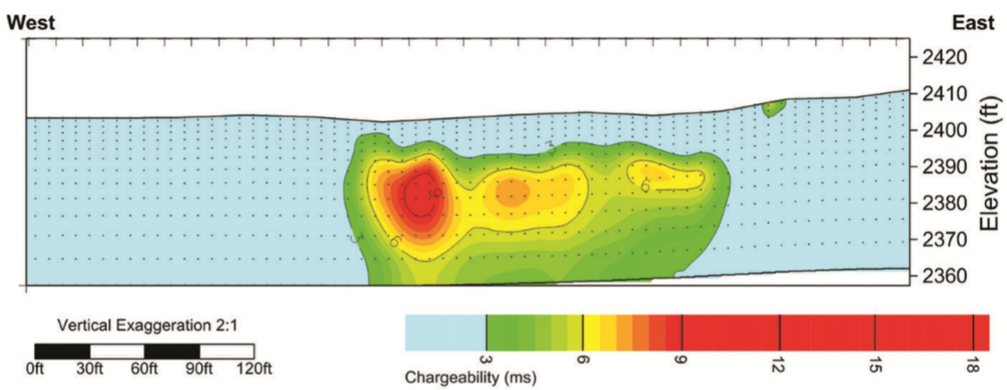
Mixed Waste



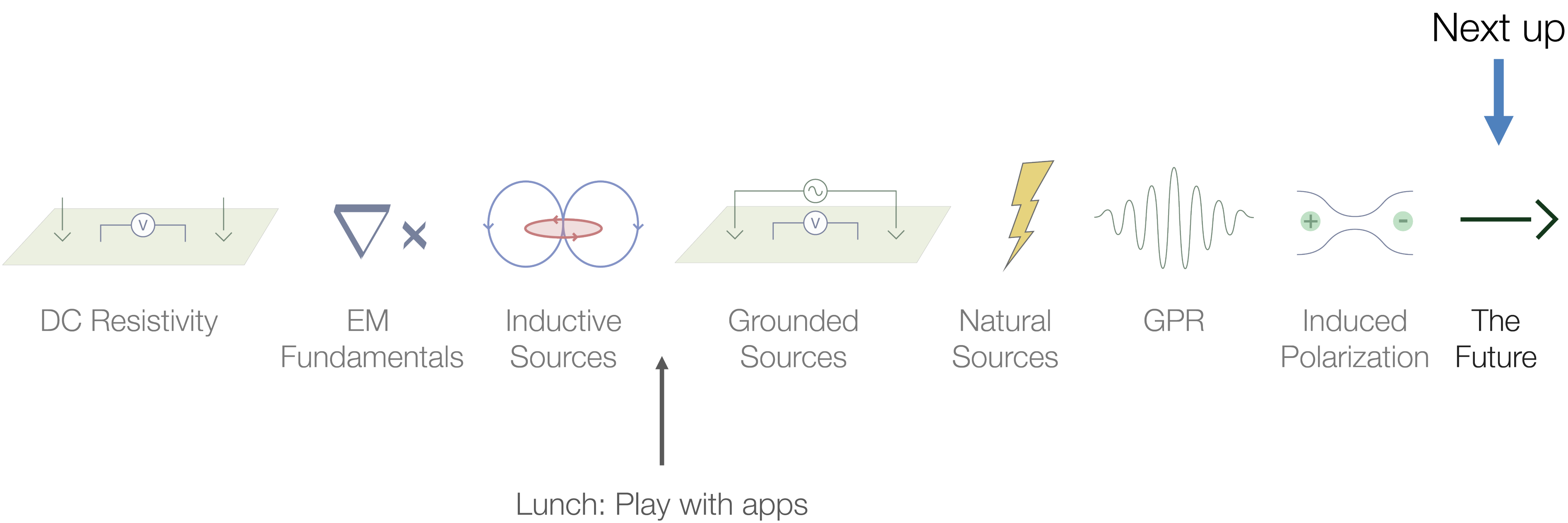
Green Waste



Construction/ Demolition Waste



End of IP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EM Fundamentals
Inductive Sources
Grounded Sources
Natural Sources
GPR
Induced Polarization
The Future
Lunch: Play with apps