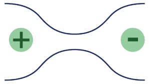
Induced Polarization

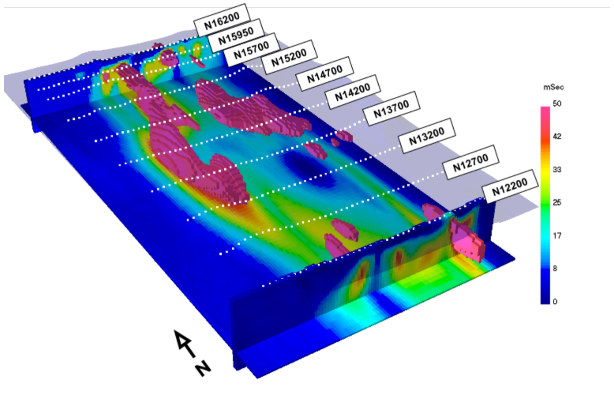
DISC 2017

Electromagnetics Fundamentals and Applications

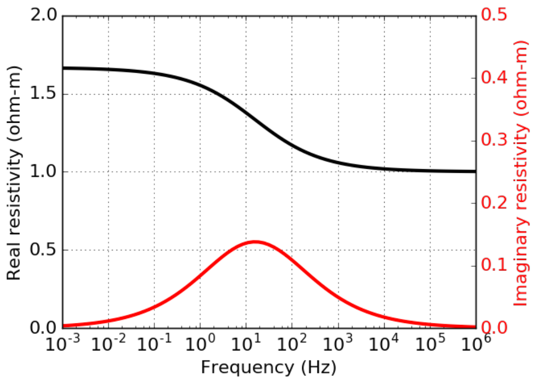


Motivation

Minerals

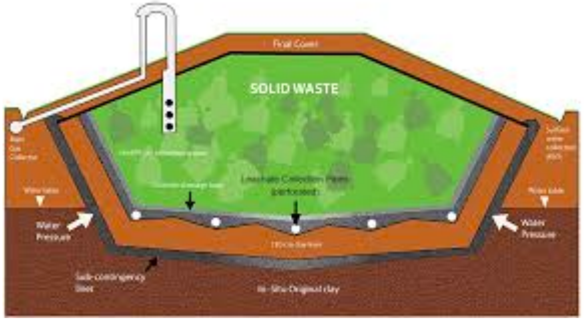


Complex resistivity

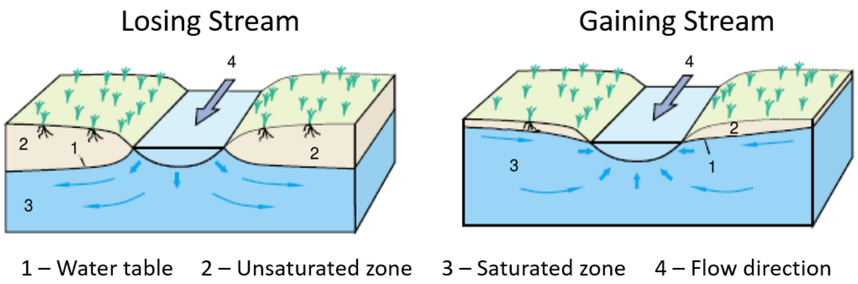


Permafrost

Geotechnical



Groundwater

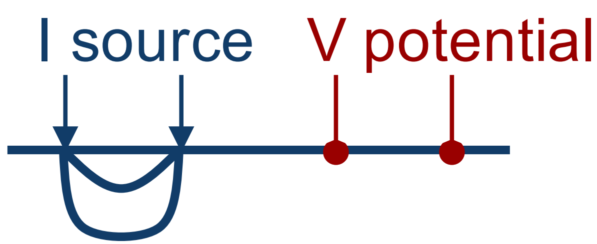


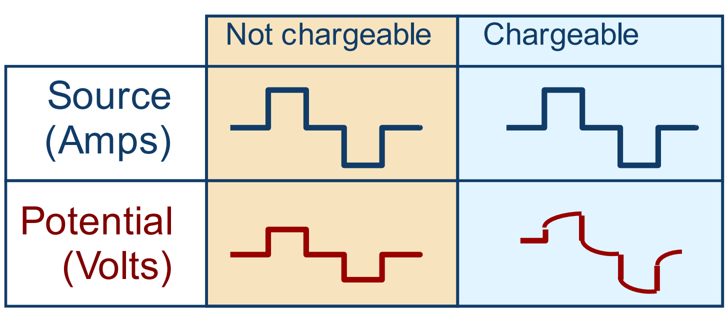
Outline

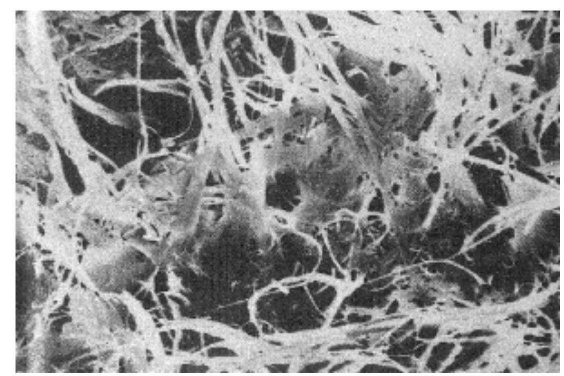
- Sources of IP
- Conceptual model of IP
- Chargeability
- IP data
- Pseudosections
- Two stage DC-IP inversion
- Case history: Mt. Isa

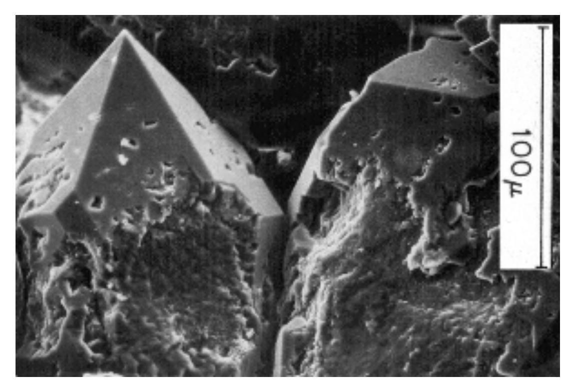
Induced Polarization

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





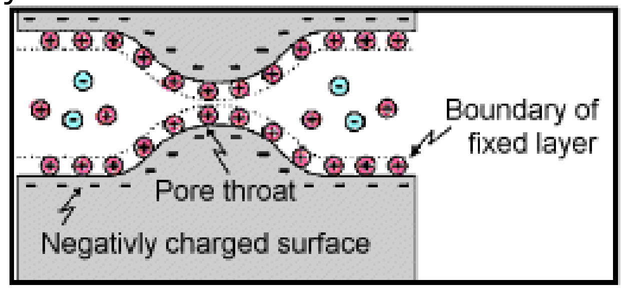




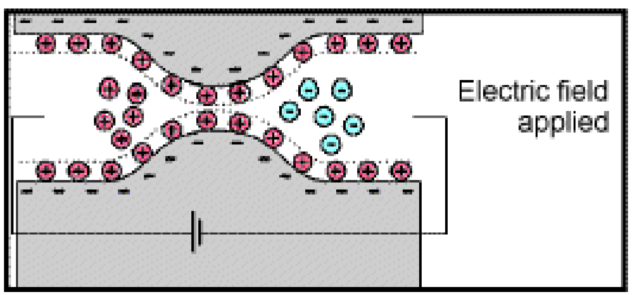
Conceptual Model of IP

Membrane polarization

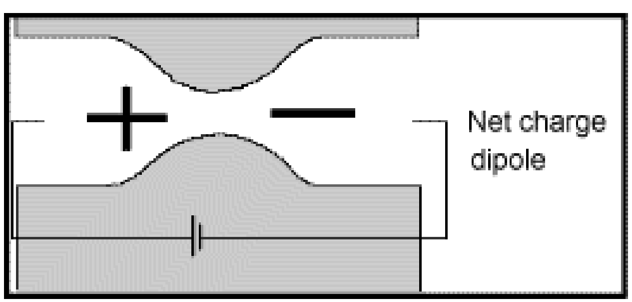
Initially - neutral



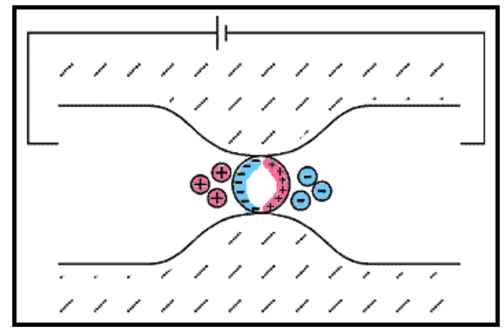
Apply electric field, build up charges

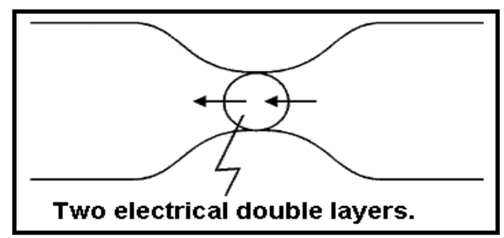


Charge polarization, Electric dipole

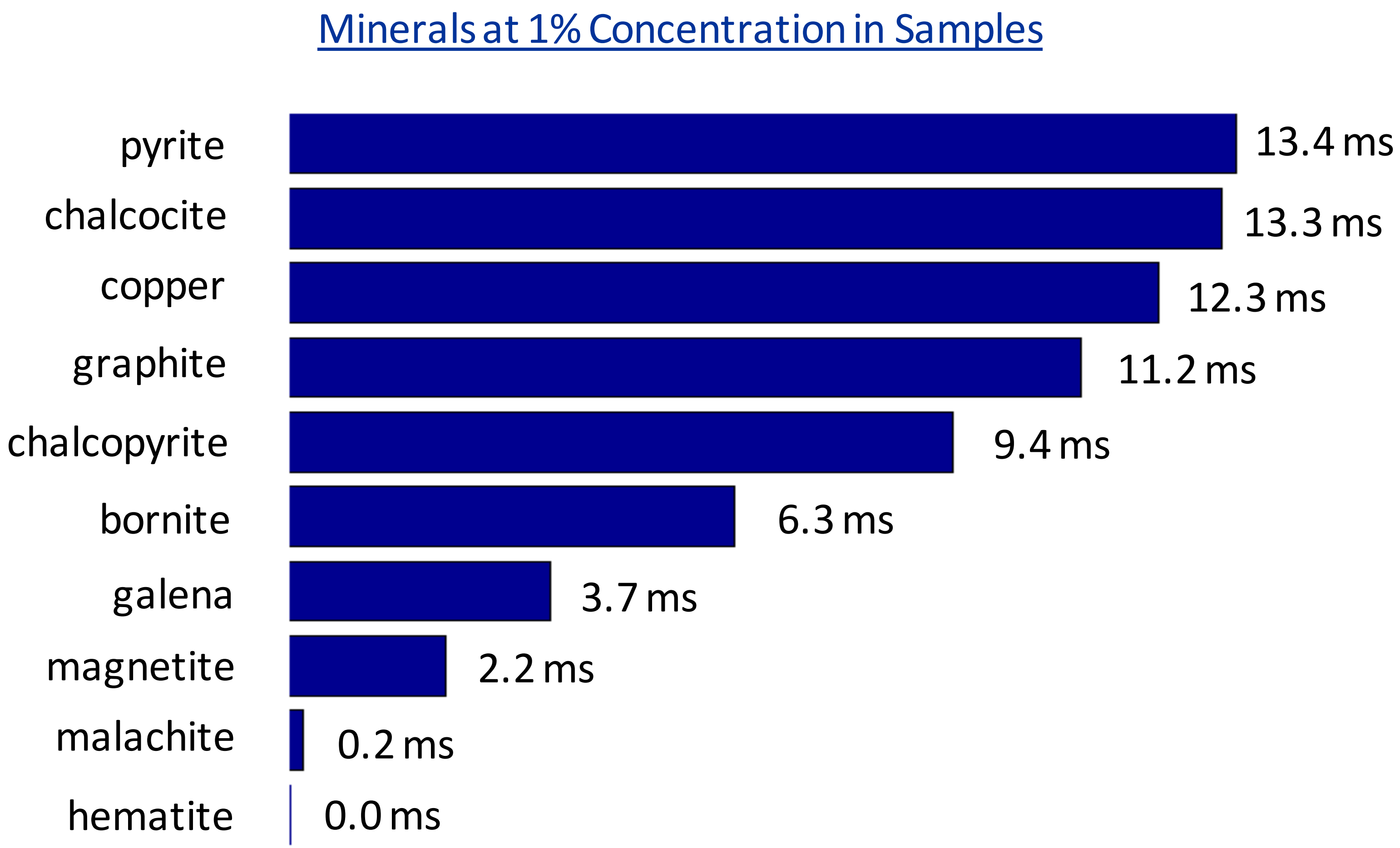


Electrode polarization

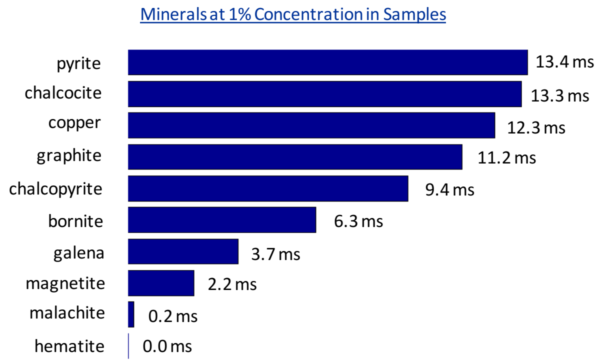




Chargeability



Chargeability

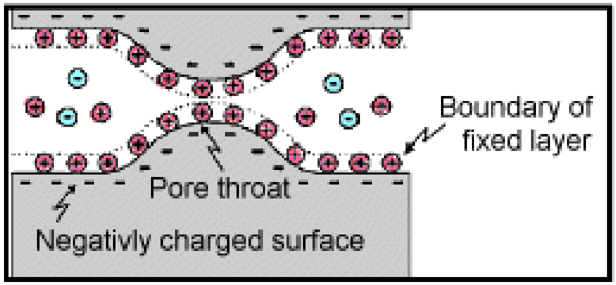


Material type	Chargeability (msec.)
20% sulfides	2000 - 3000
8-20% sulfides	1000 - 2000
2-8% sulfides	500 - 1000
volcanic tuffs	300 - 800
sandstone, siltstone	100 - 500
dense volcanic rocks	100 - 500
shale	50 - 100
granite, granodiorite	10 - 50
limestone, dolomite	10 - 20

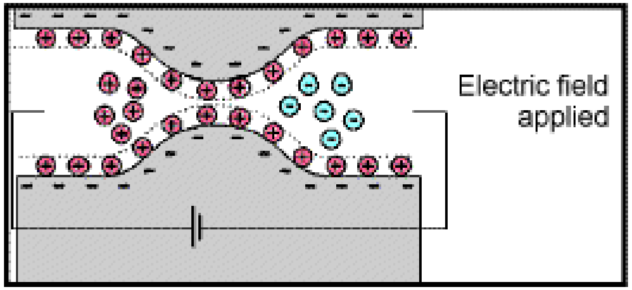
Material type	Chargeability (msec.)
ground water	0
alluvium	1 - 4
gravels	3 - 9
precambrian volcanics	8 - 20
precambrian gneisses	6 - 30
schists	5 - 20
sandstones	3 - 12

Chargeability

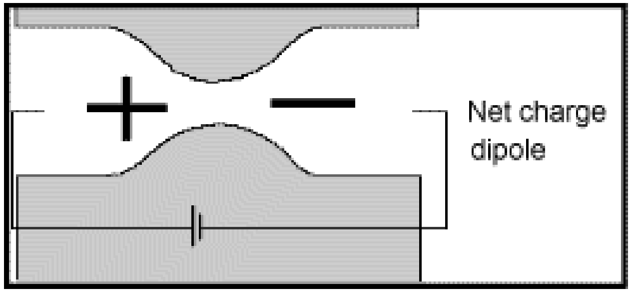
Initially - neutral



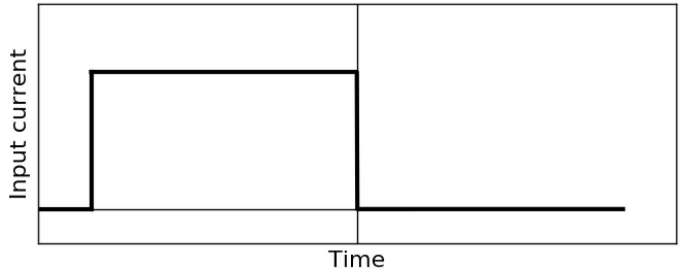
Apply electric field, build up charges



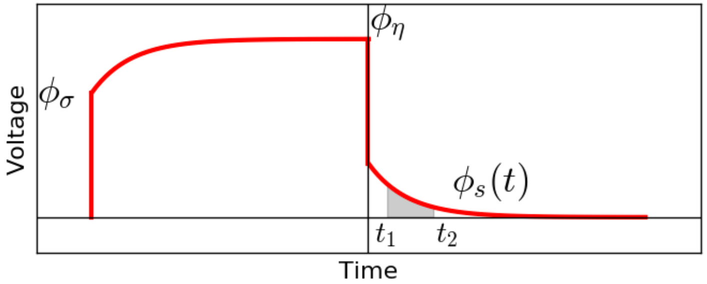
Charge polarization, Electric dipole



Input current



Measured voltage



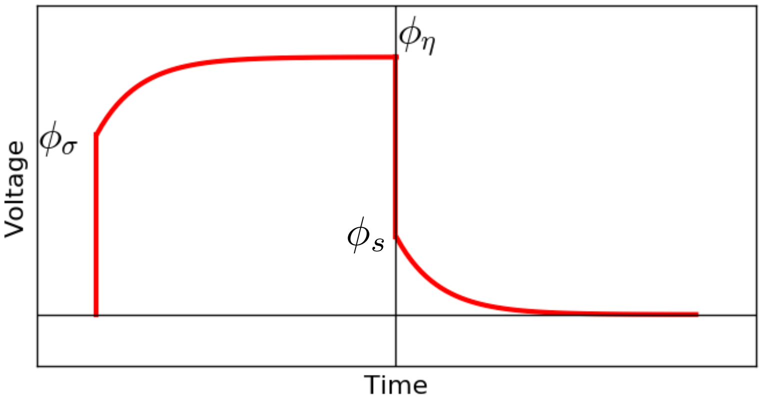
IP data

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

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

- Theoretical chargeability data

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

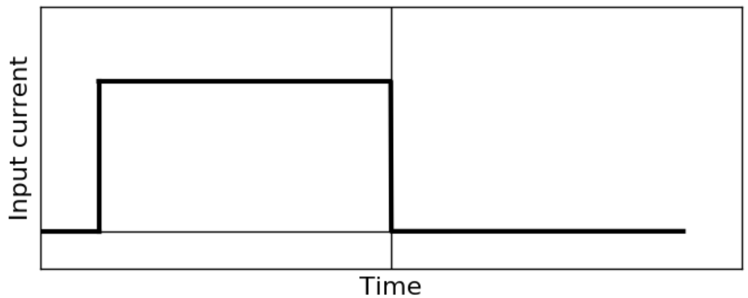


- Not directly measureable

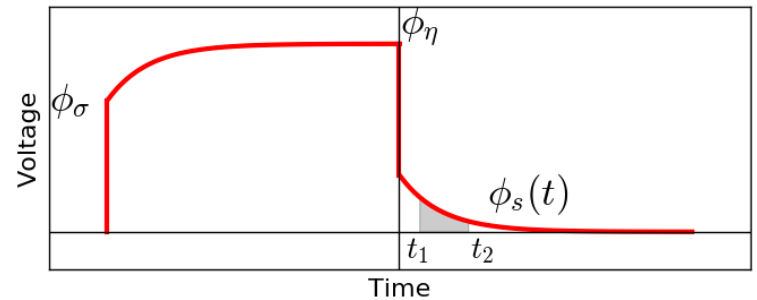
IP data: time domain

- 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:	$M = \dfrac{1}{\phi_\eta} \displaystyle\int_{t_1}^{t_2} \phi_s(t) dt$

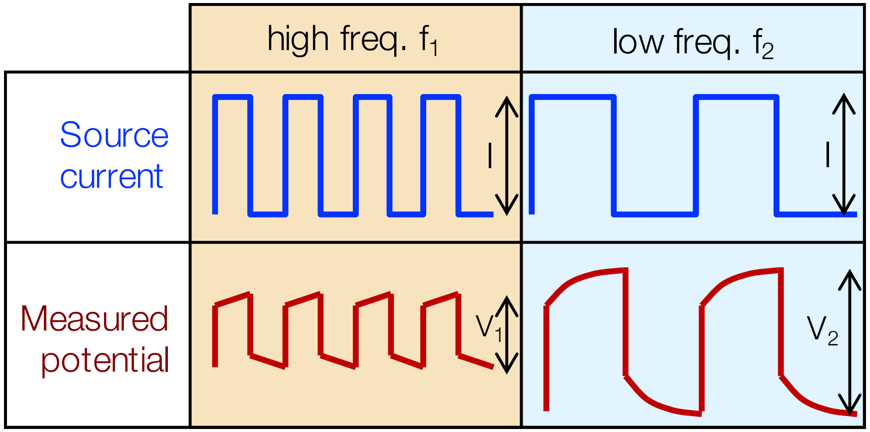
IP data: frequency domain

- Percent frequency effect:

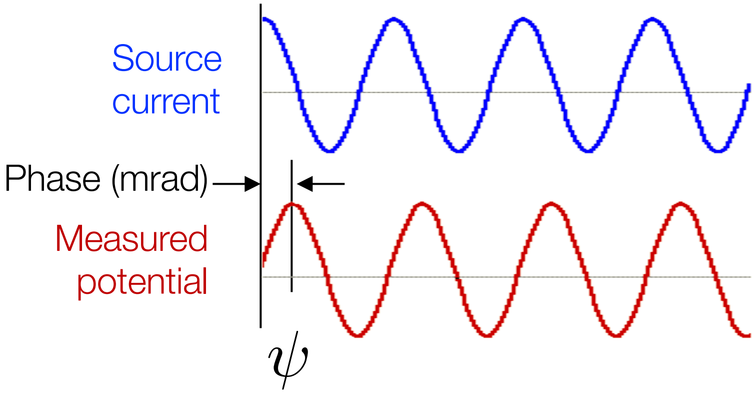
$$PFE = 100\left(\frac{\rho_{a2} - \rho_{a1}}{\rho_{a1}}\right)$$

ρ_{a1}: apparent resistivity at f_1

ρ_{a2}: apparent resistivity at f_2

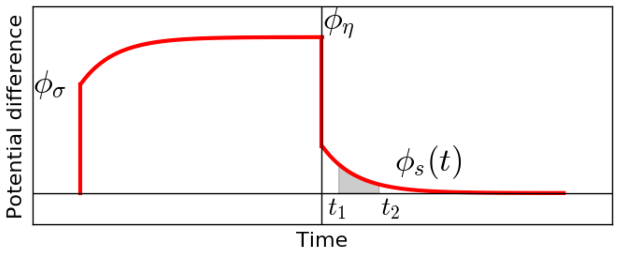


- Phase ψ

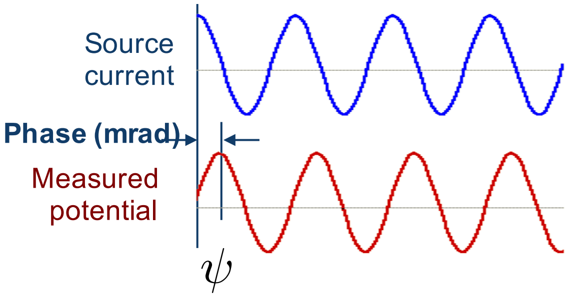


Summary of IP data types

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



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



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

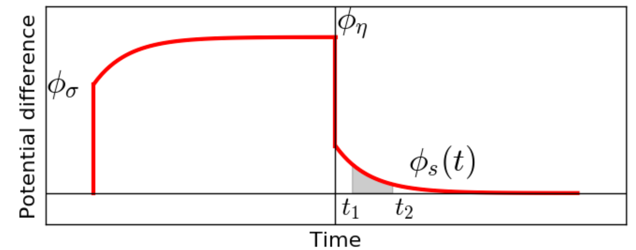
- In matrix form

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

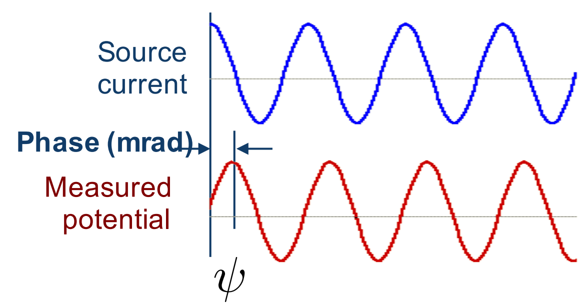
$\mathbf{J}$ is an N×M matrix

Summary of IP data

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



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



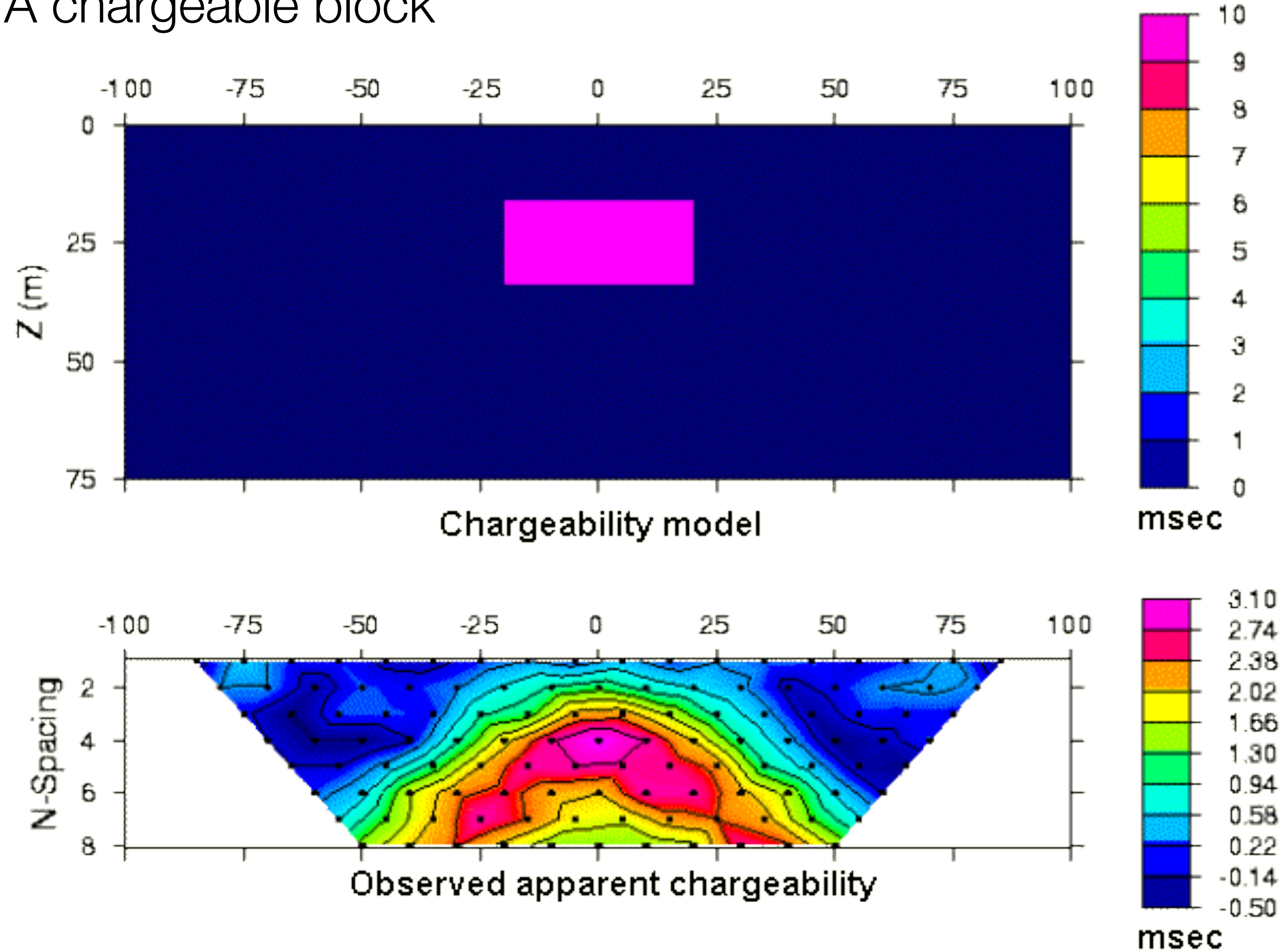
- For all data types: linear problem

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

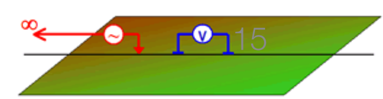
$\mathbf{J}$ is an N×M matrix

IP pseudosections

1) A chargeable block



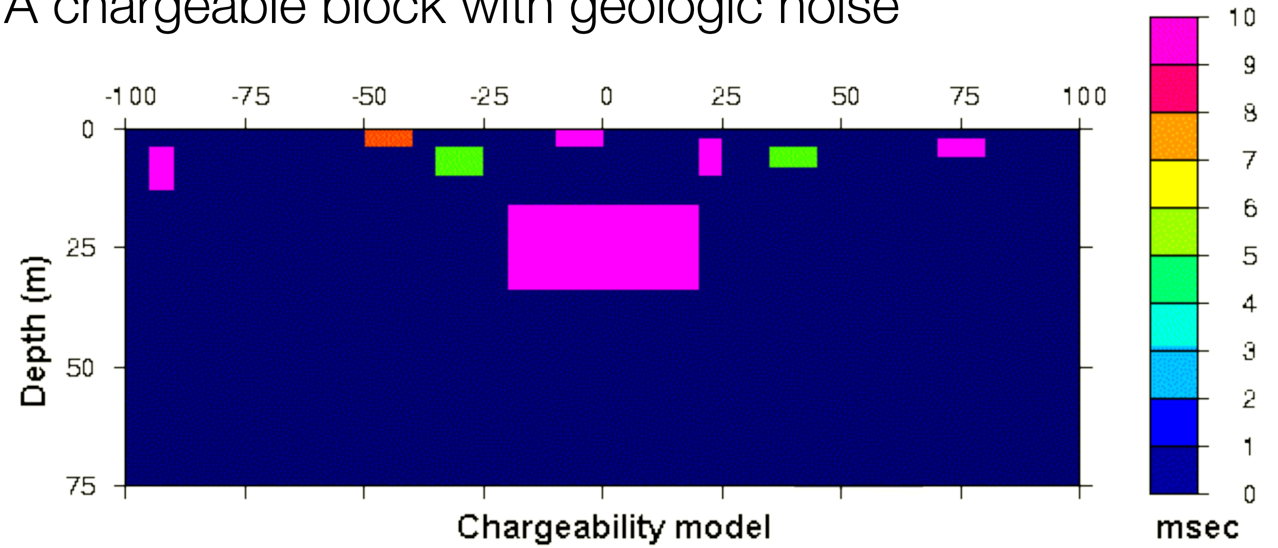
Pole-Dipole

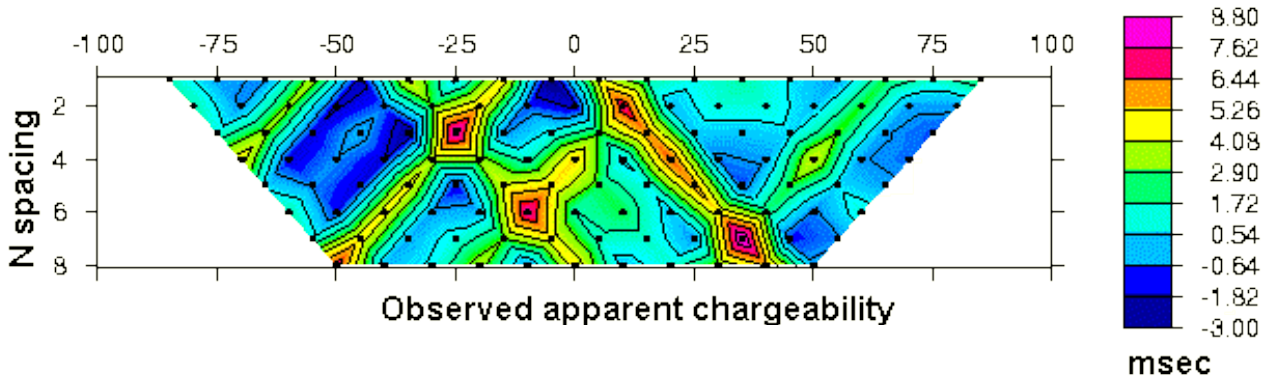


- Pole-dipole; n=1,8; a=10m; N=316

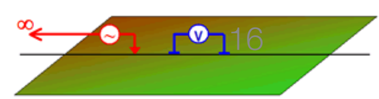
IP pseudosections

2) A chargeable block with geologic noise





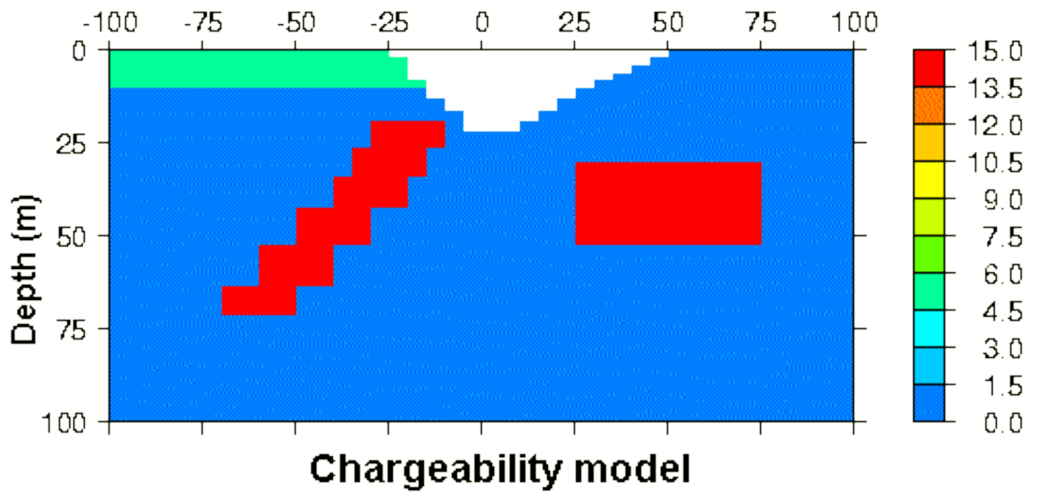
Pole-Dipole

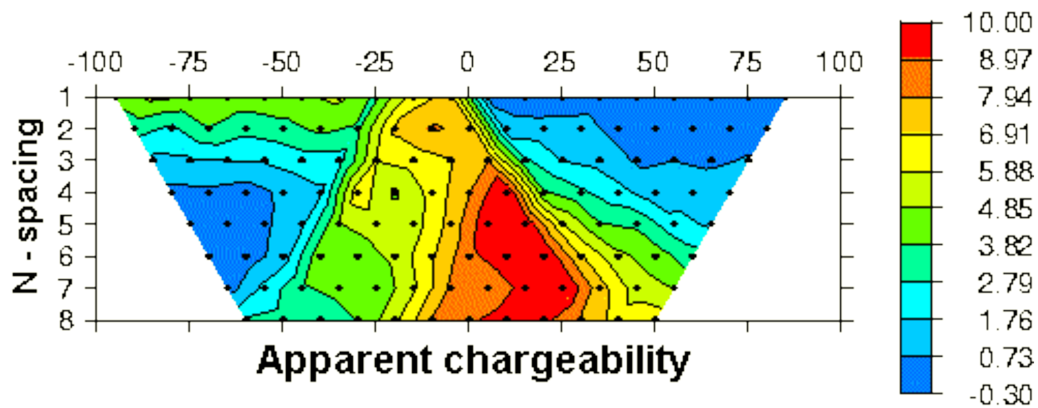


- Pole-dipole; n=1,8; a=10m; N=316

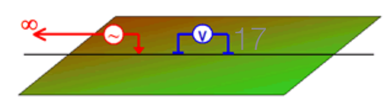
IP pseudosections

3) The “UBC-GIF model”

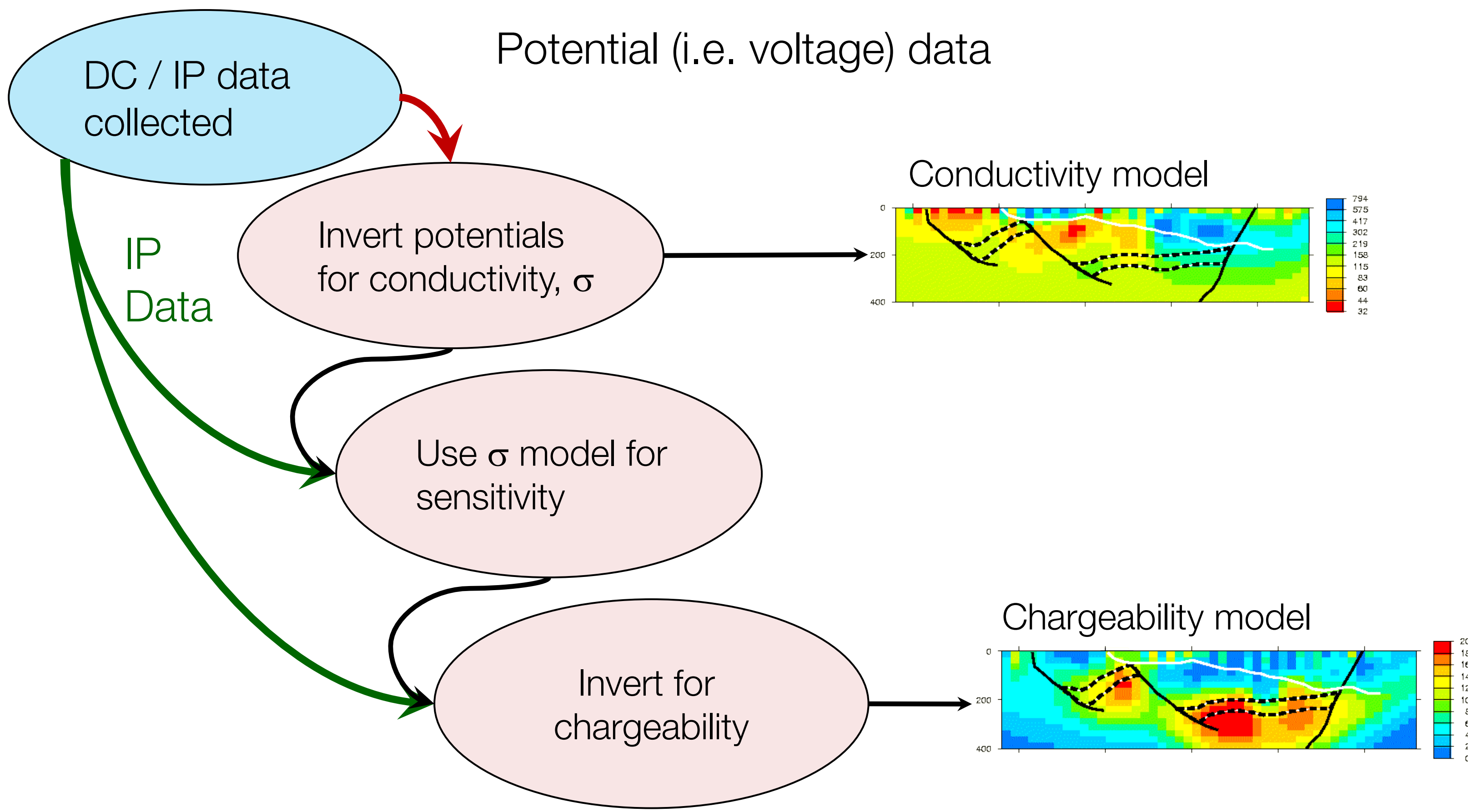




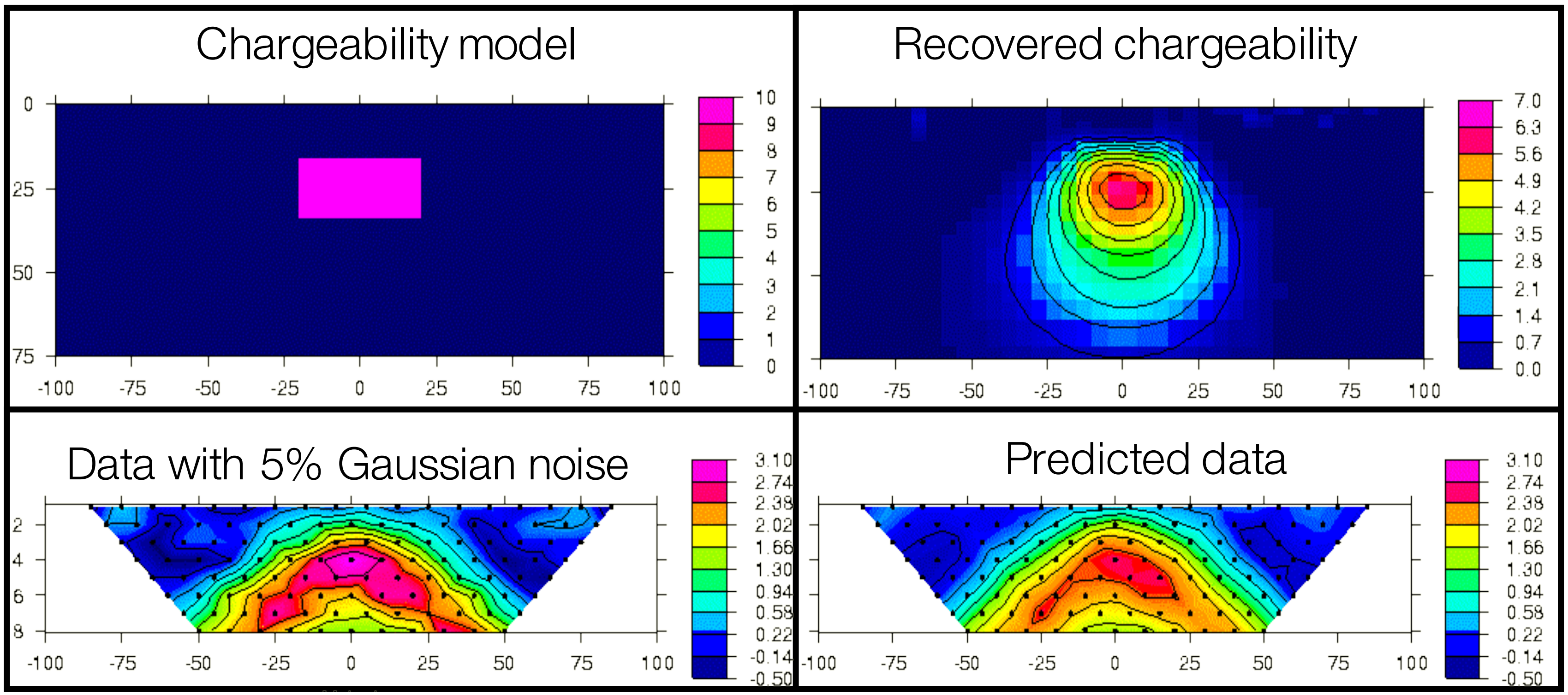
Pole-Dipole



IP Inversion

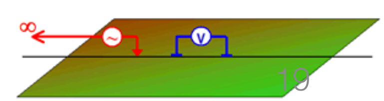


Example 1: buried prism

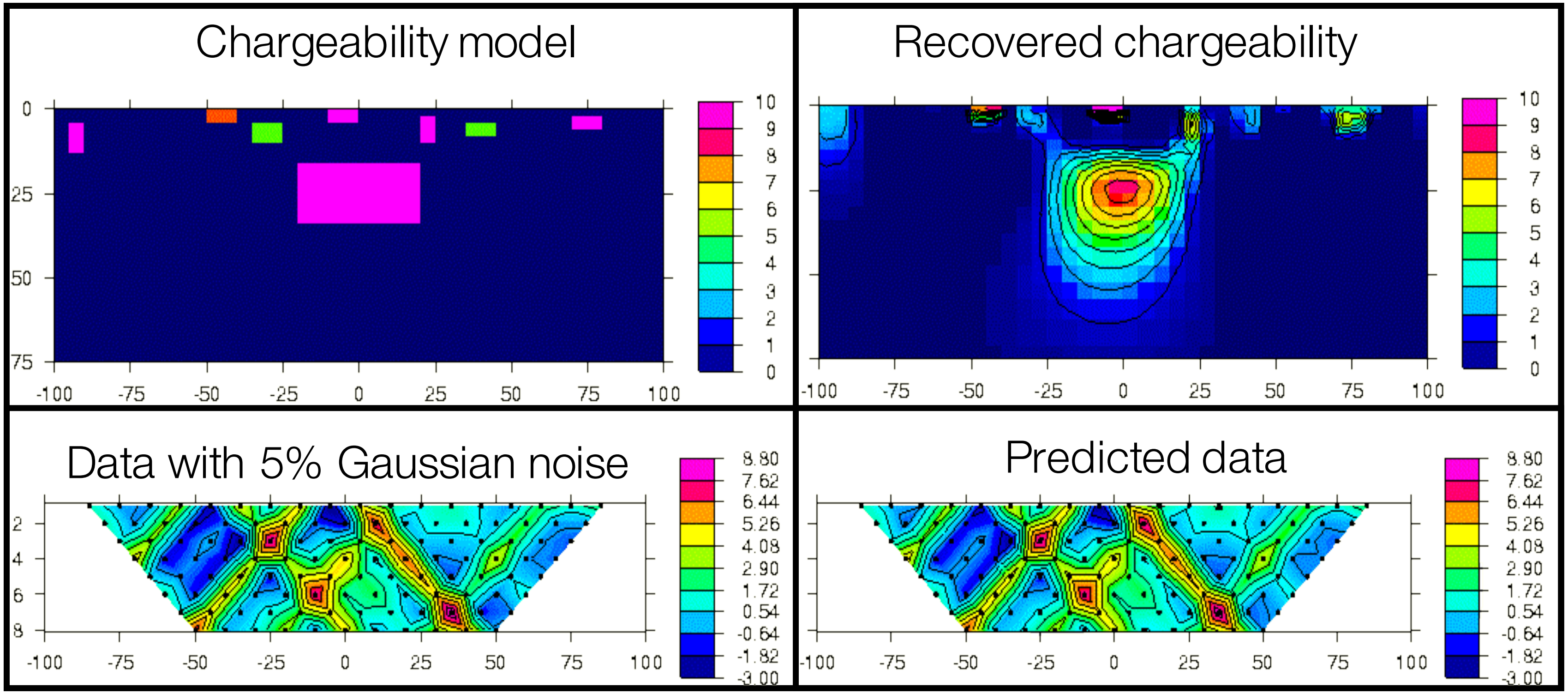


- Pole-dipole; n=1,8; a=10m; N=316; $(\alpha_s, \alpha_x, \alpha_z)$=(.001, 1.0, 1.0)

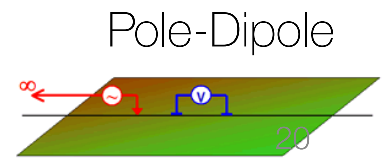
Pole-Dipole



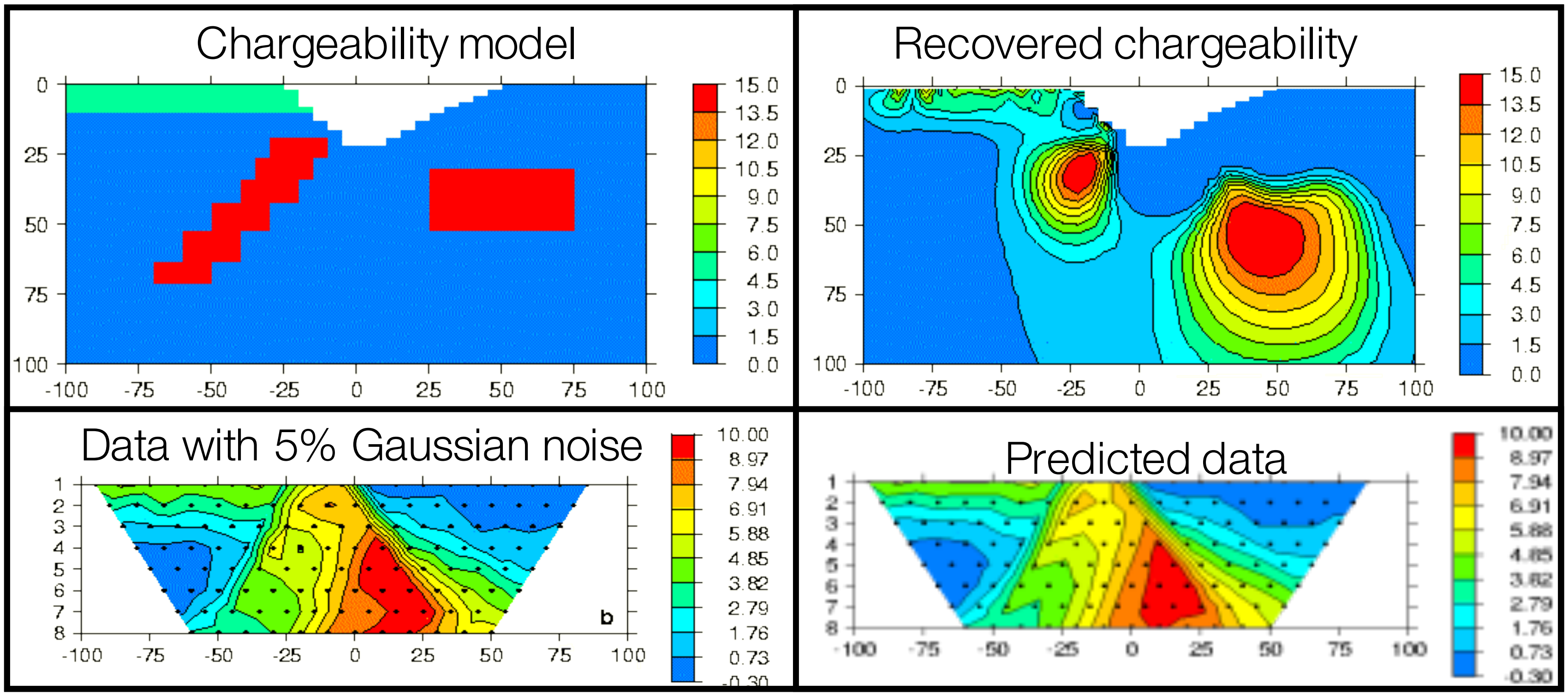
Example 2: prism with geologic noise



- Pole-dipole; n=1,8; a=10m; N=316; (α_s, α_x, α_z)=(.001, 1.0, 1.0)

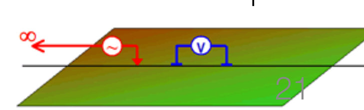


Example 3: UBC-GIF model



- 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
- Case history: Mt. Isa

- Questions

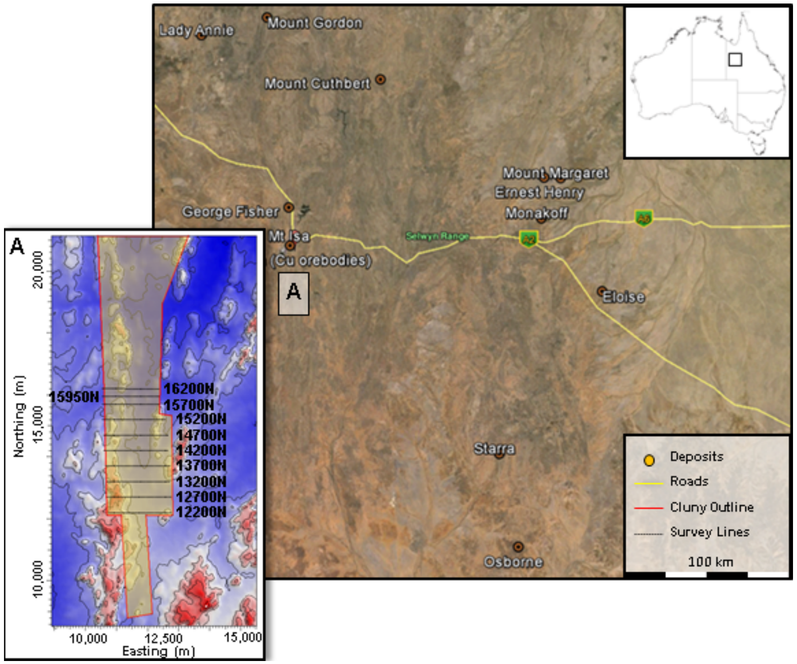
- Case history: Mt. Isa

Case history: Mt. Isa

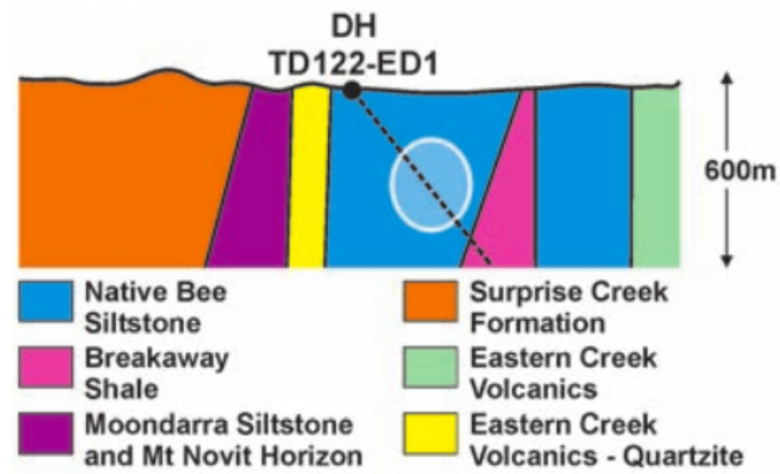
Rutley et al., 2001

Setup

- Mt. Isa (Cluny propect)



- Geologic model

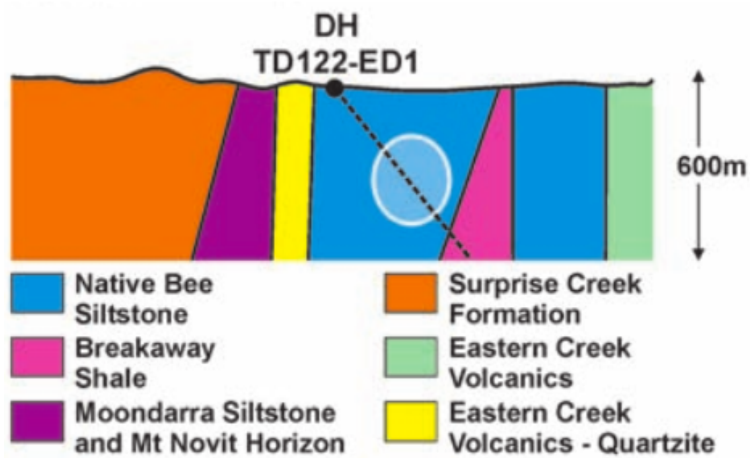


Question

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

Properties

Geologic model



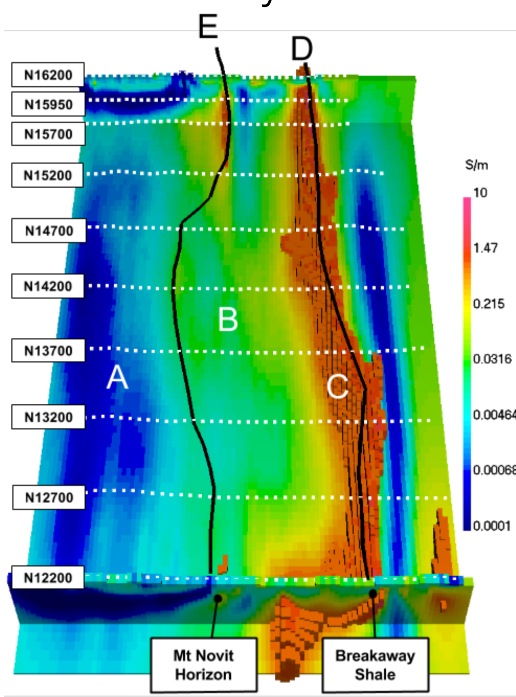
Resistivity and Chargeability

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

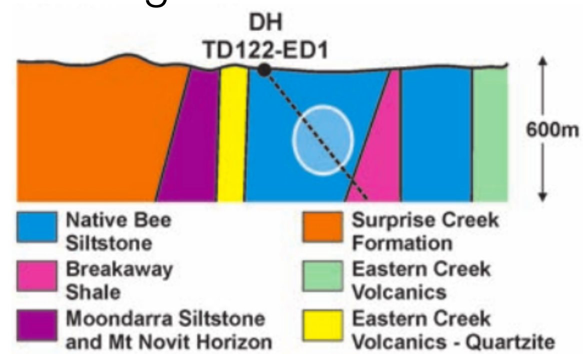
Recap: Synthesis from DC

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

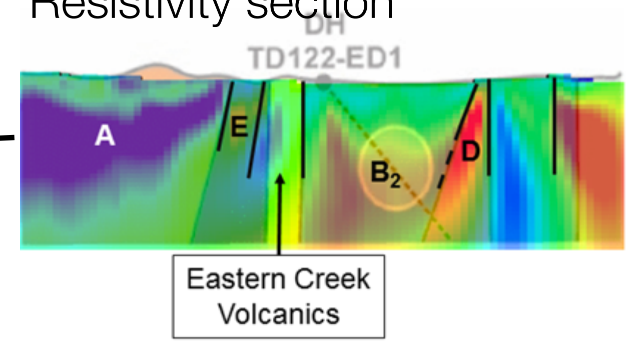
3D resistivity model



Geologic section



Resistivity section

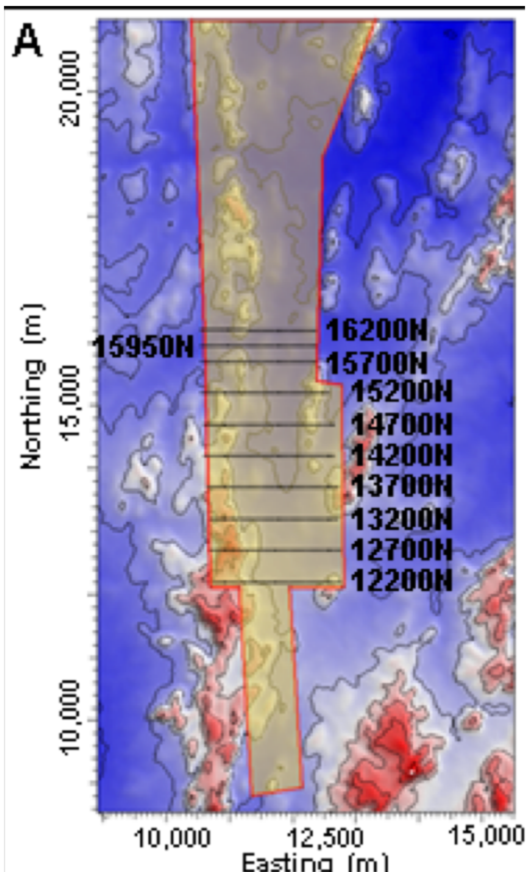


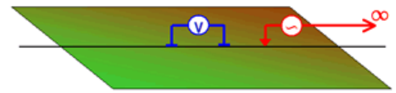
Can a **chargeable**, moderate conductor in the siltstones be identified?

Survey and data

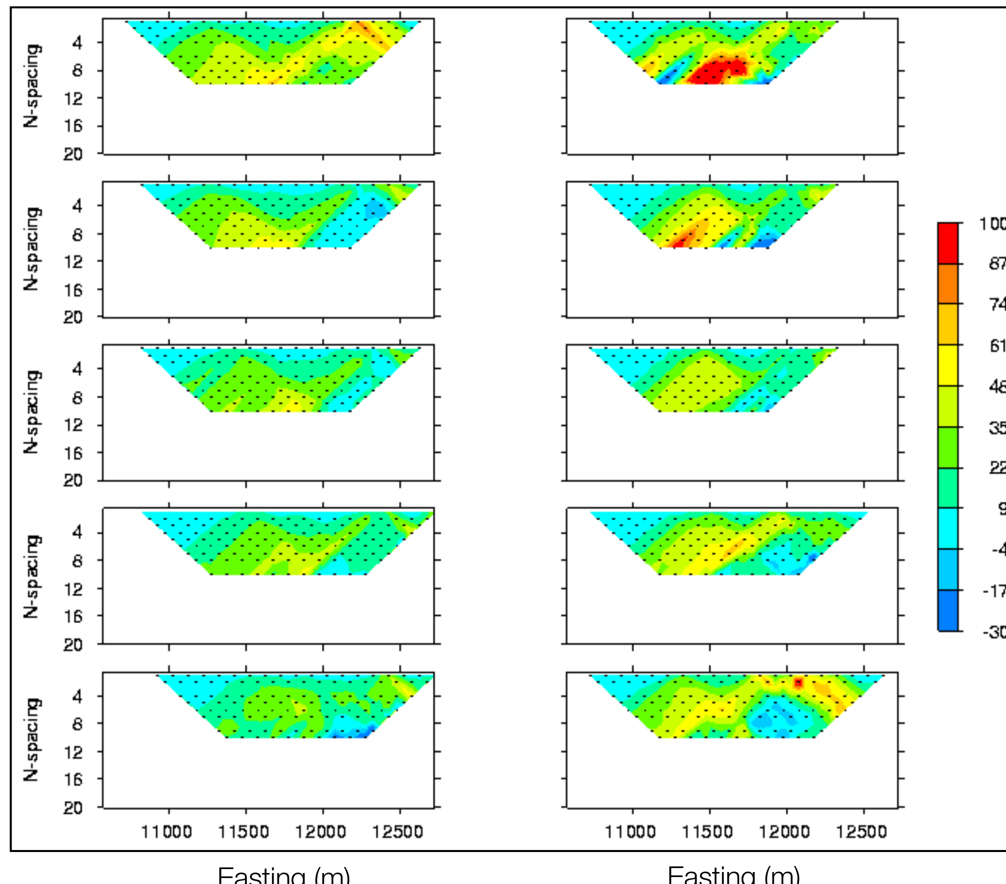
- Eight survey lines
- Two configurations

Surface topography



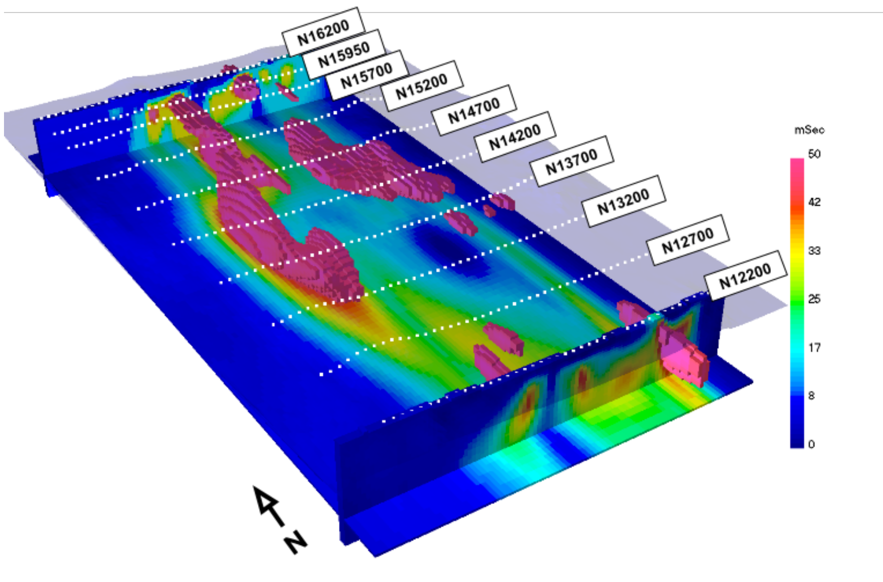


Apparent chargeability, dipole- pole.

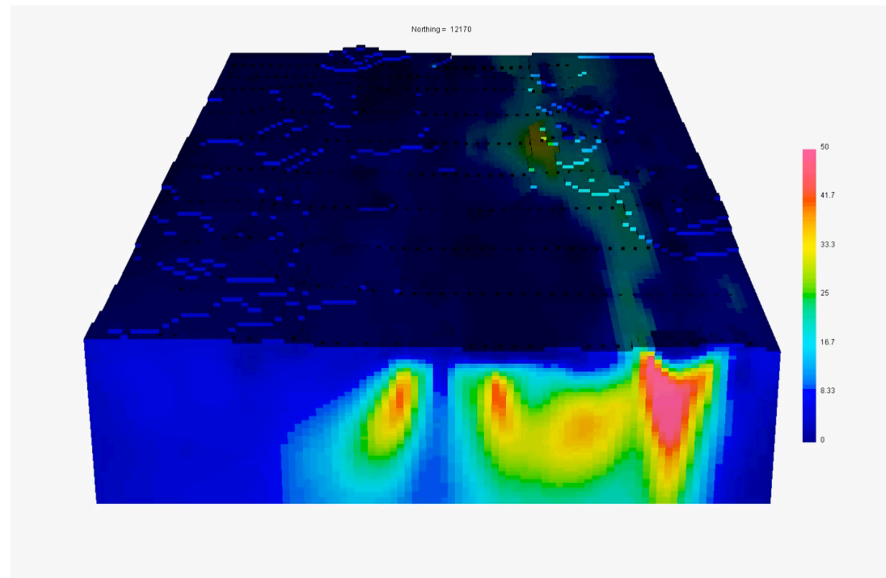


Processing

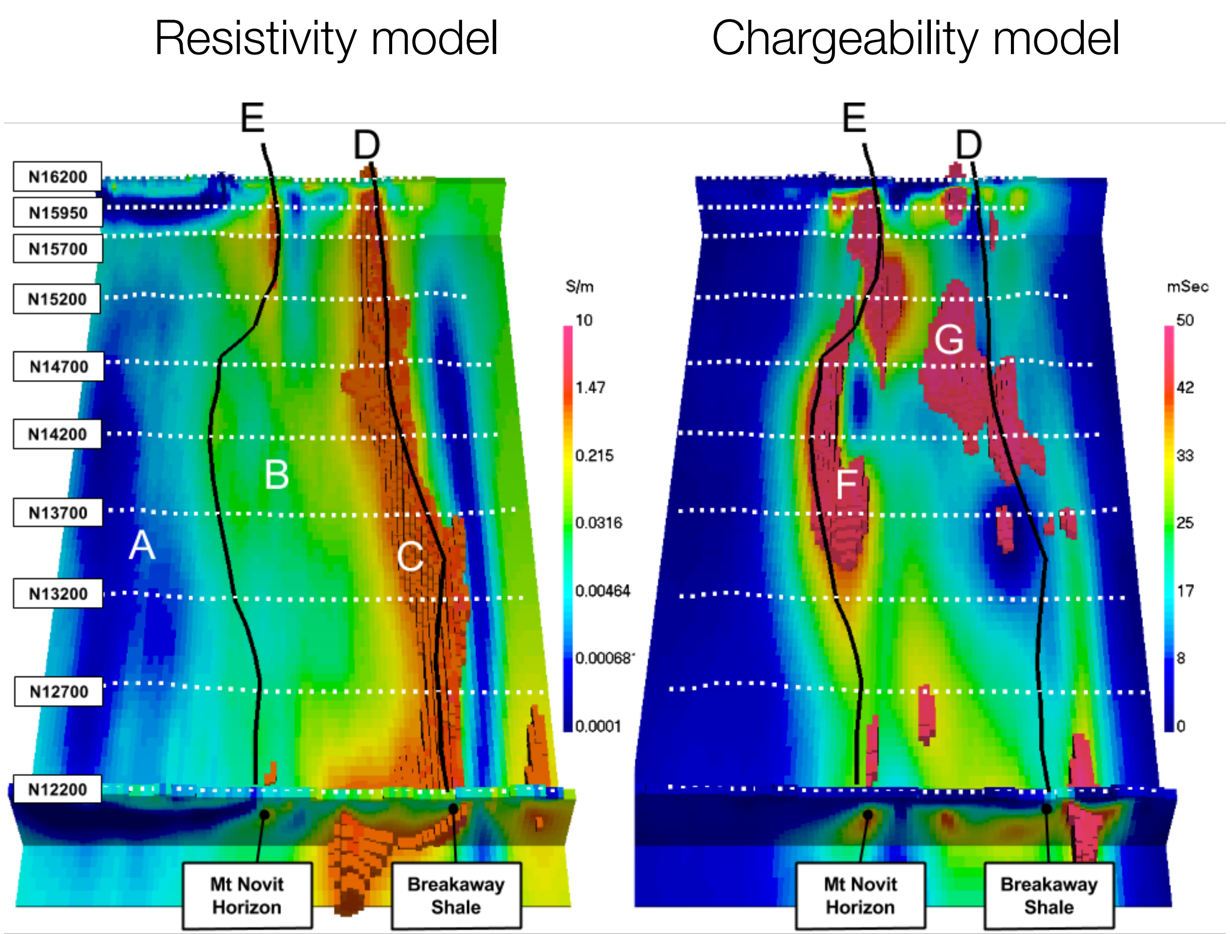
3D chargeability model



Animation



Interpretation



A: Resistive, Non-chargeable

B: Moderate conductivity; low chargeabilty

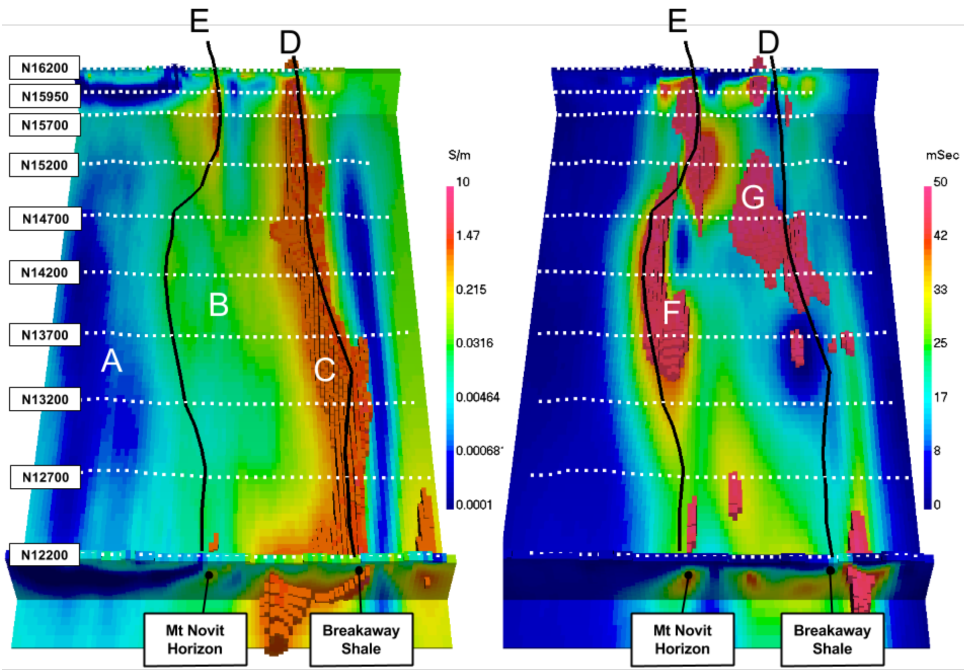
C: Very high conductivity (> 10 S/m)

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

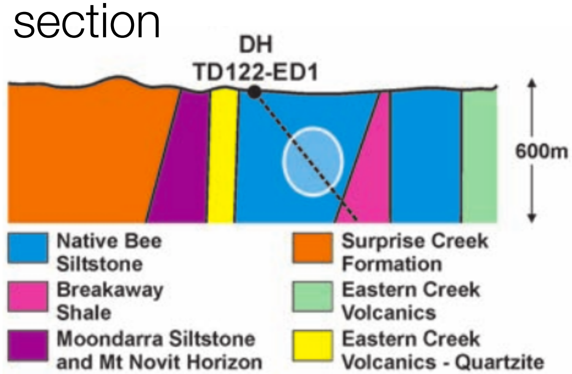
- Very high conductivity

E and F: Mt Novit Horizon

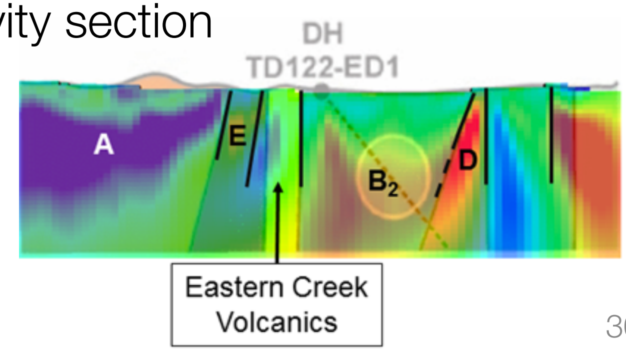
- High conductivity and high chargeability

G: Other chargeable regions within siltstone complex

Geologic section



Resistivity section



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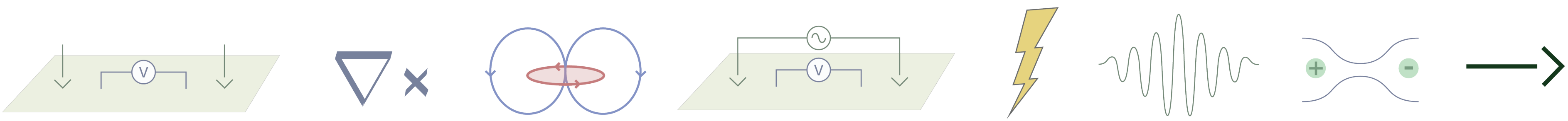
End of IP

Next up



DC Resistivity

EM Fundamentals

Inductive Sources

Grounded Sources

Natural Sources

GPR

Induced Polarization

The Future

Lunch: Play with apps