Induced Polarization

Reading on the GPG:

https://gpg.geosci.xyz/content/induced_polarization/index.html

Today's Topics

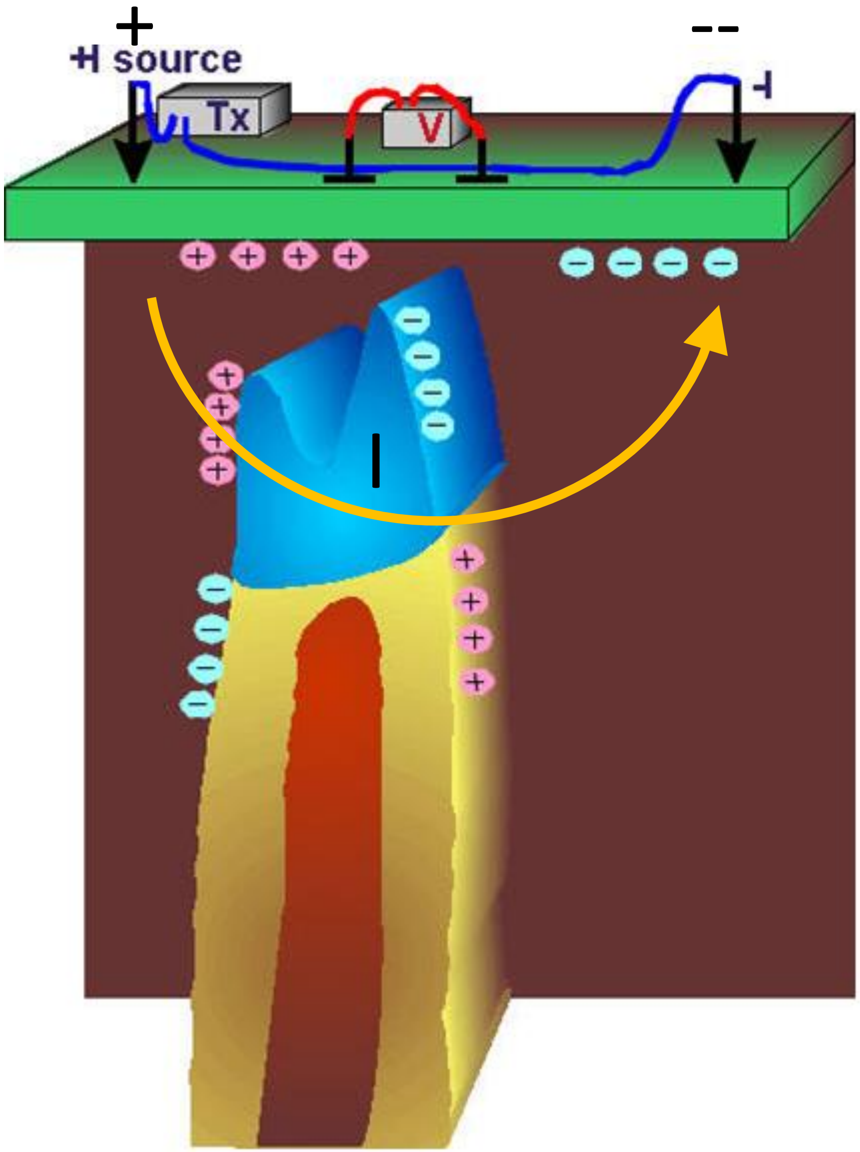
- Introduction to IP
  - DCR review
  - What is induced polarization (IP)?
  - Impact of IP on voltage measurements
- Physical Properties: Chargeability
- Survey and Data
- Processing and Interpretation
- Example: Mt Isa Revisited

Introduction

DC Resistivity Review

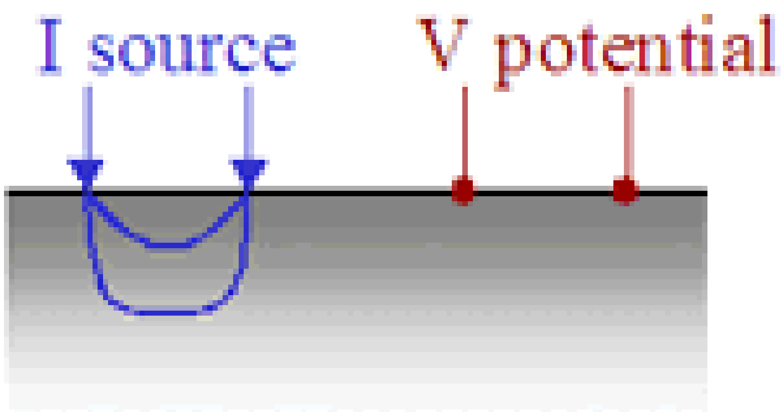
- DCR injects static current into the ground via electrodes
- Charges build up on surfaces perpendicular to current flow
- Charge build-up generates a secondary potential
- Measured potentials used to infer Earth's resistivity structure

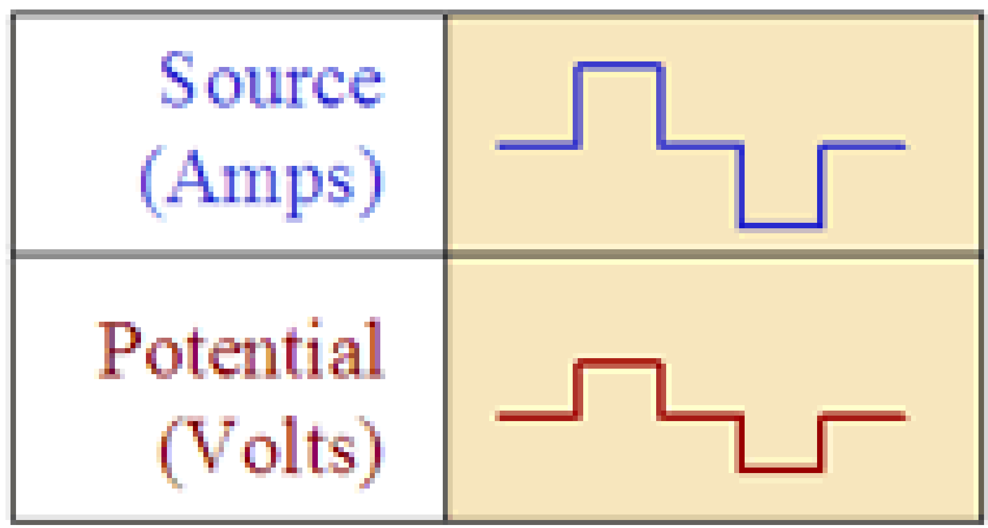
(pseudo-section or inversion)



DC Resistivity Review

- DCR measures potentials during the on-time
- Repeated measurements stacked to reduce error





Induced Polarization (IP)

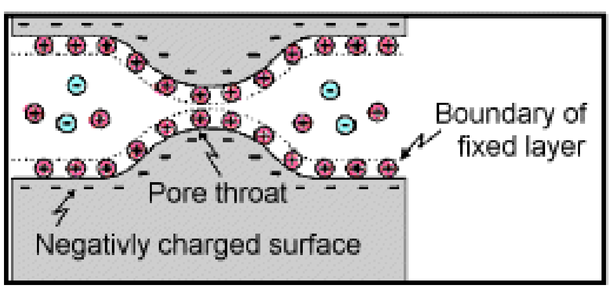
- Occurs when ionic charges accumulate within materials under an applied voltage

  → Generates a secondary potential

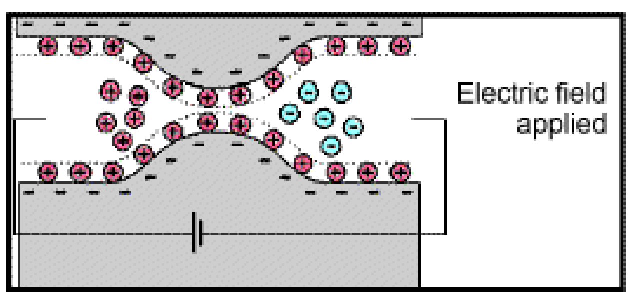
- Not an instantaneous process!

- Occurs in fluid-filled pore-spaces

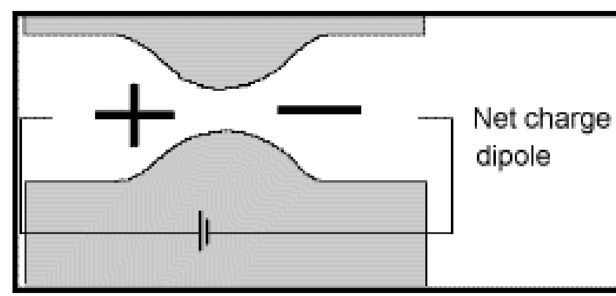
Equilibrium State



Voltage Applied



Separation of +ve and –ve ions

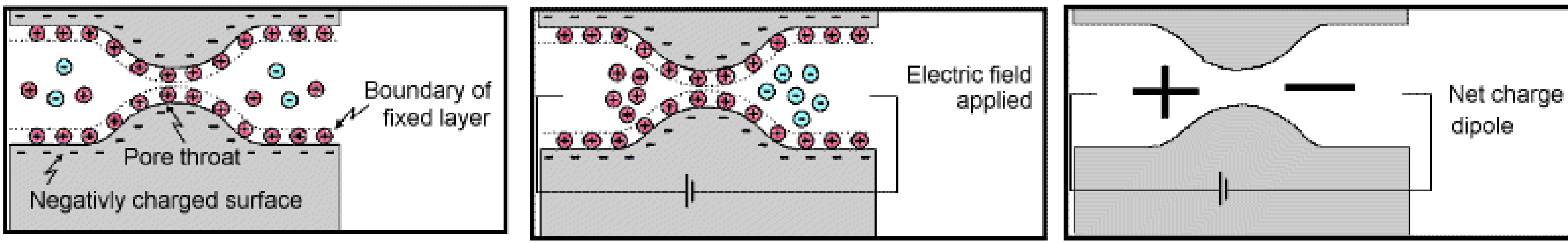


Induced Polarization (IP)

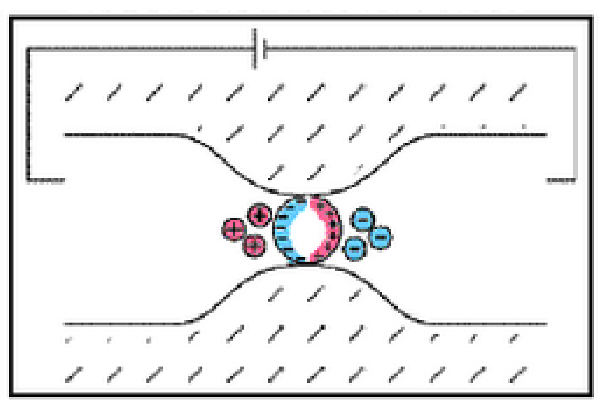
- Two types:

  1) Membrane polarization: Ions accumulate at pore throat

Equilibrium State | Voltage Applied | Separation of +ve and –ve ions



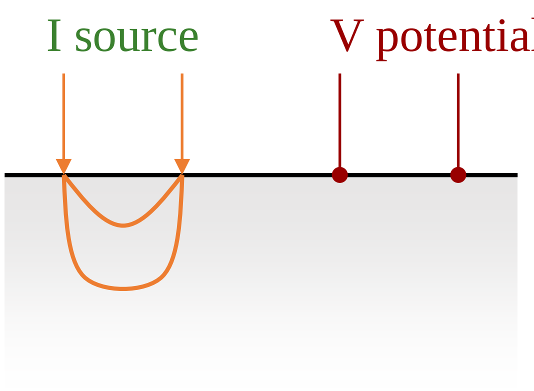
  2) Electrode polarization: Ions accumulate at metals

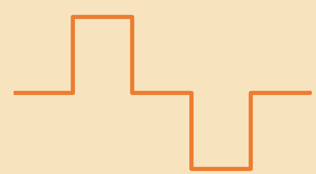
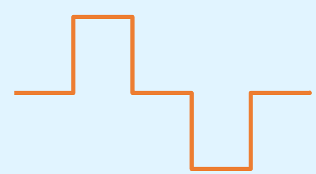
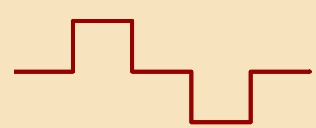
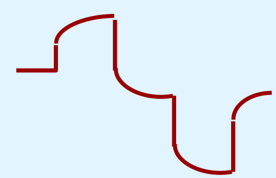


Impact on Voltage Measurements

- Charge accumulation on boundaries (change in ρ)
  → Instantaneous change in potential

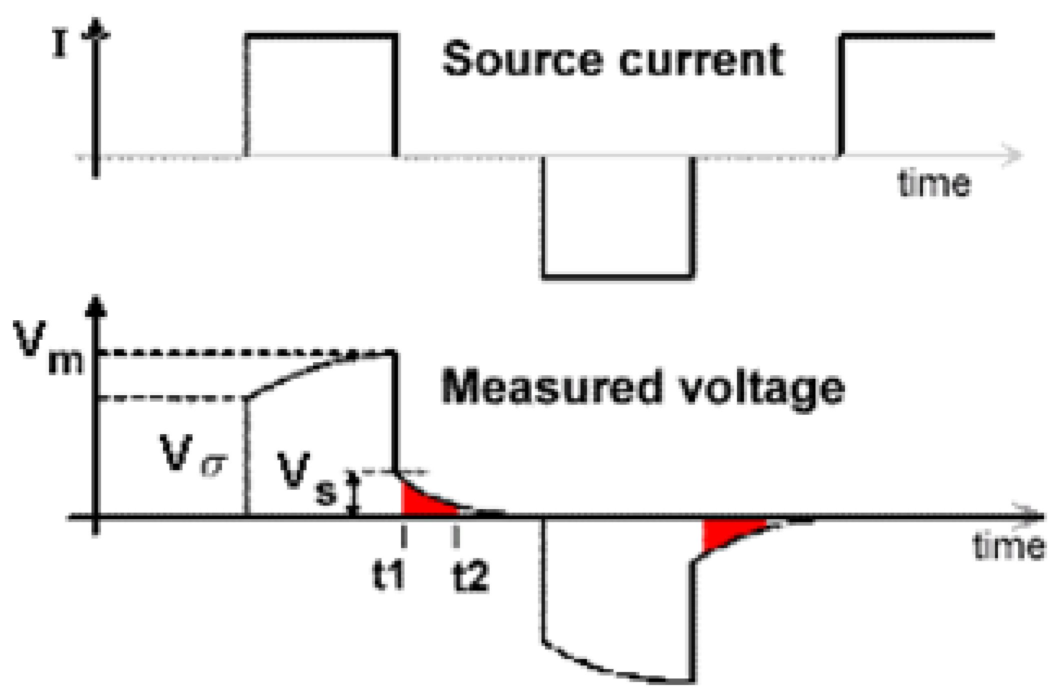
- Charge accumulation due to IP
  → Non-instantaneous change in potential
  → Reaches a saturation point
  → Measurable voltage during off-time



	Not chargeable	Chargeable
Source (Amps)		
Potential (Volts)		

Impact on Voltage Measurements

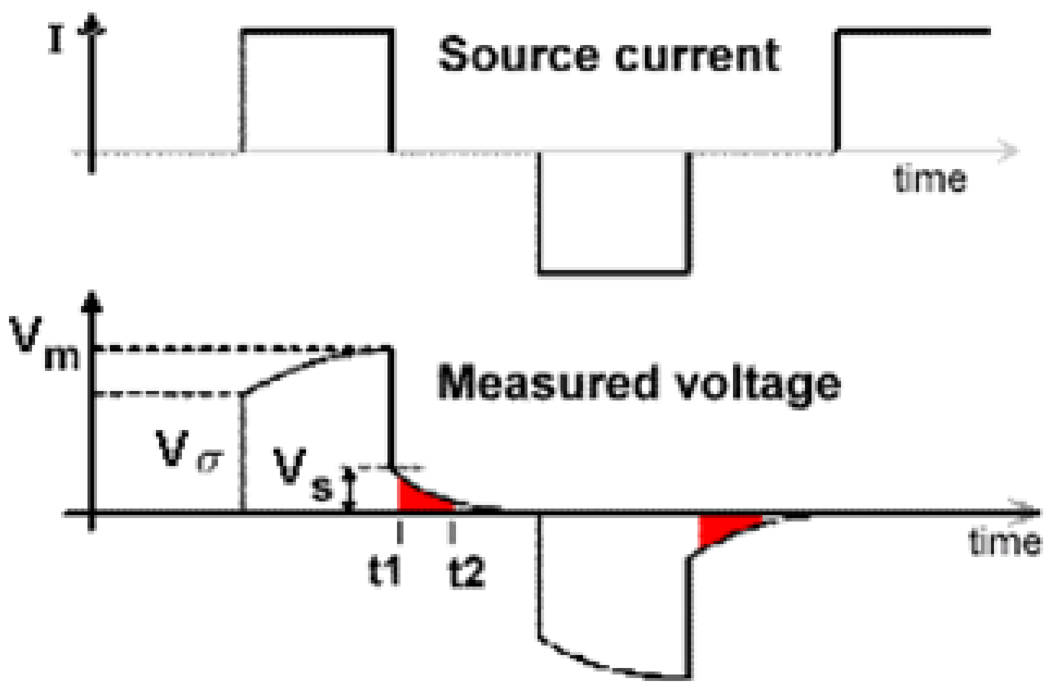
1) Voltage applied by transmitter
   → instantaneous (V_σ) increase due to ρ



Impact on Voltage Measurements

1) Voltage applied by transmitter
   → instantaneous (V_σ) increase due to ρ

2) Voltage increases as ions accumulate: $$V_{on}(t) = V_\sigma + V_s\left[1 - e^{-t/\tau}\right]$$

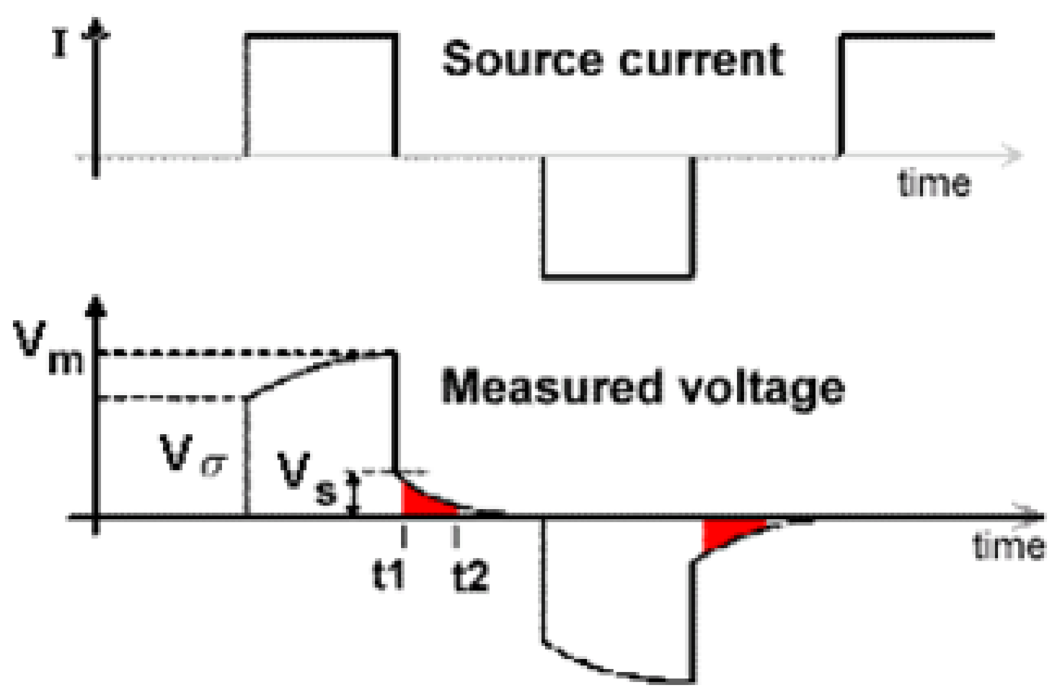


Impact on Voltage Measurements

1) Voltage applied by transmitter
   → instantaneous (V_σ) increase due to ρ

2) Voltage increases as ions accumulate: $V_{on}(t) = V_\sigma + V_s\left[1 - e^{-t/\tau}\right]$

3) Saturation of ionic charges leads to DC voltage ($V_m = V_\sigma + V_s$)



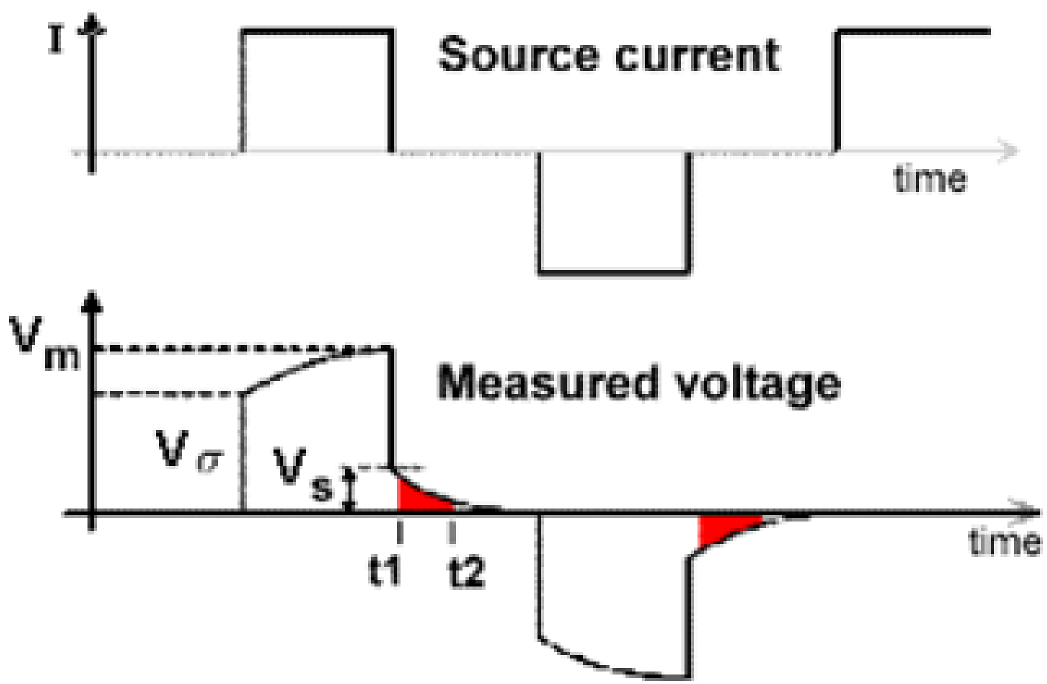
Impact on Voltage Measurements

1) Voltage applied by transmitter
   → instantaneous (V_σ) increase due to ρ

2) Voltage increases as ions accumulate: $V_{on}(t) = V_\sigma + V_s\left[1 - e^{-t/\tau}\right]$

3) Saturation of ionic charges leads to DC voltage ($V_m = V_\sigma + V_s$)

4) Voltage from transmitter removed
   → instantaneous loss in secondary potential (equal to V_σ)



Impact on Voltage Measurements

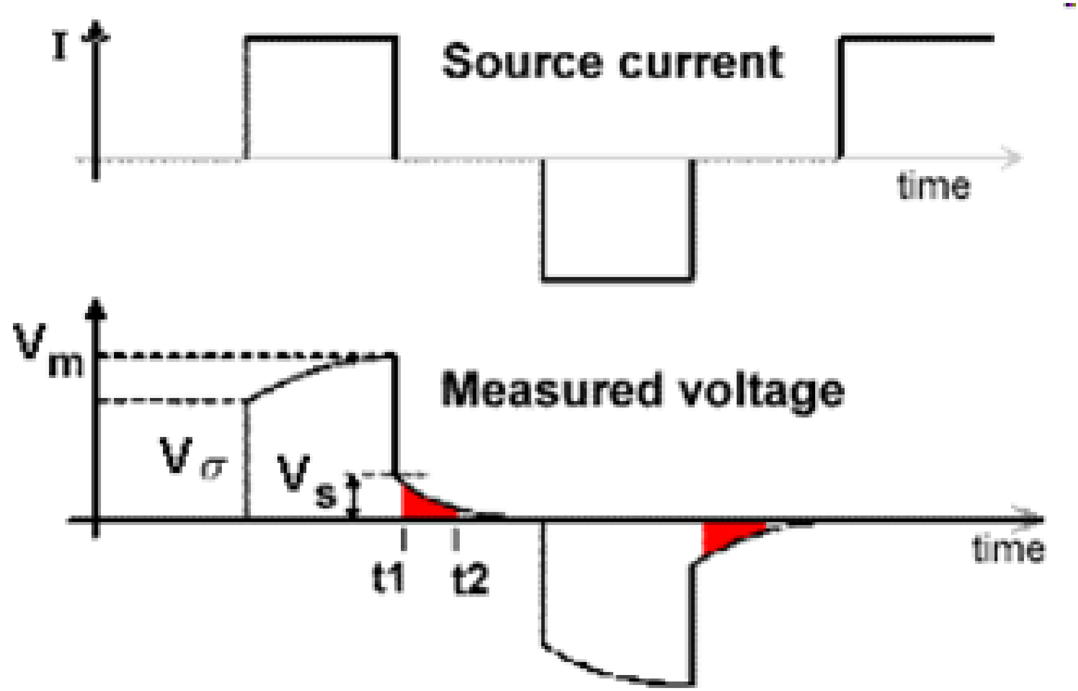
1) Voltage applied by transmitter
   → instantaneous (V_σ) increase due to ρ

2) Voltage increases as ions accumulate: $$V_{on}(t) = V_\sigma + V_s\left[1 - e^{-t/\tau}\right]$$

3) Saturation of ionic charges leads to DC voltage ($V_m = V_\sigma + V_s$)

4) Voltage from transmitter removed
   → instantaneous loss in secondary potential (equal to V_σ)

5) IP voltage discharges during off-time:
   $$V_{off}(t) = V_s\, e^{-t/\tau}$$



Physical Properties

Chargeability

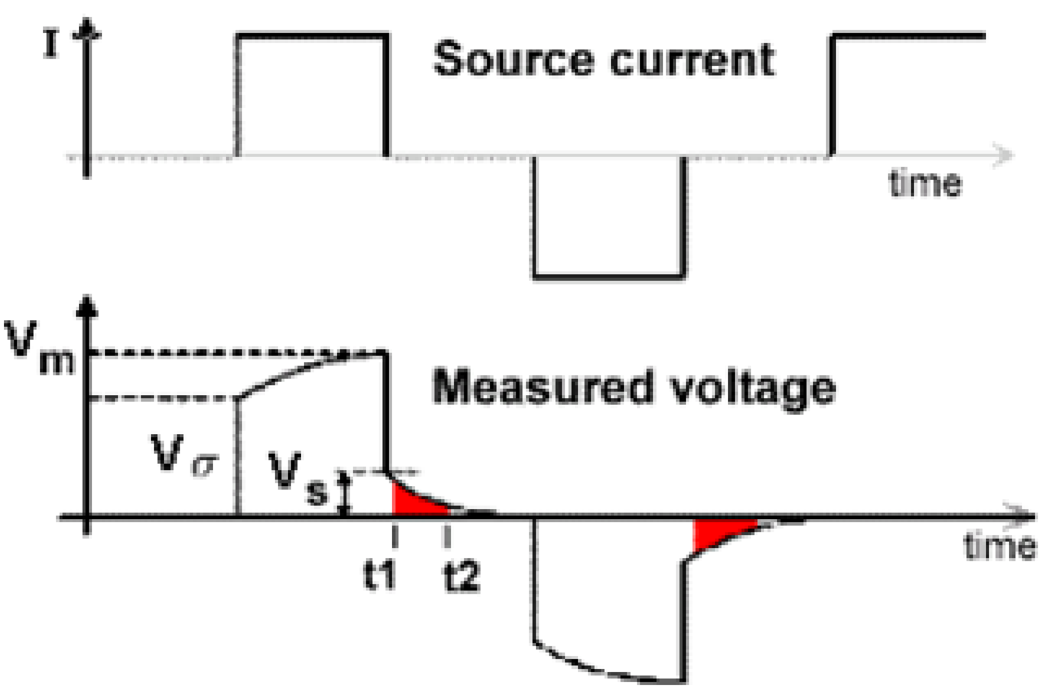
- Strength of material's IP signature represented by chargeability
- Intrinsic Chargeability (over-voltage/DC voltage)

$$\eta = \frac{V_s}{V_m}$$

(in mV/V)

- Integrated chargeability

$$d_{IP} = \frac{1}{V_m}\int_{t_1}^{t_2} V_s(t)dt$$



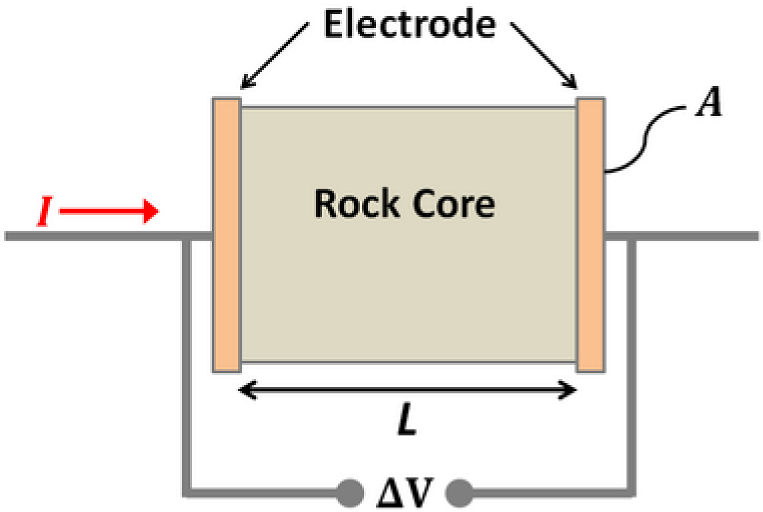
Chargeability in Frequency Domain

Measure impedance:

$$Z(\omega) = \frac{\Delta V(\omega)}{I(\omega)}$$

Compute resistivity:

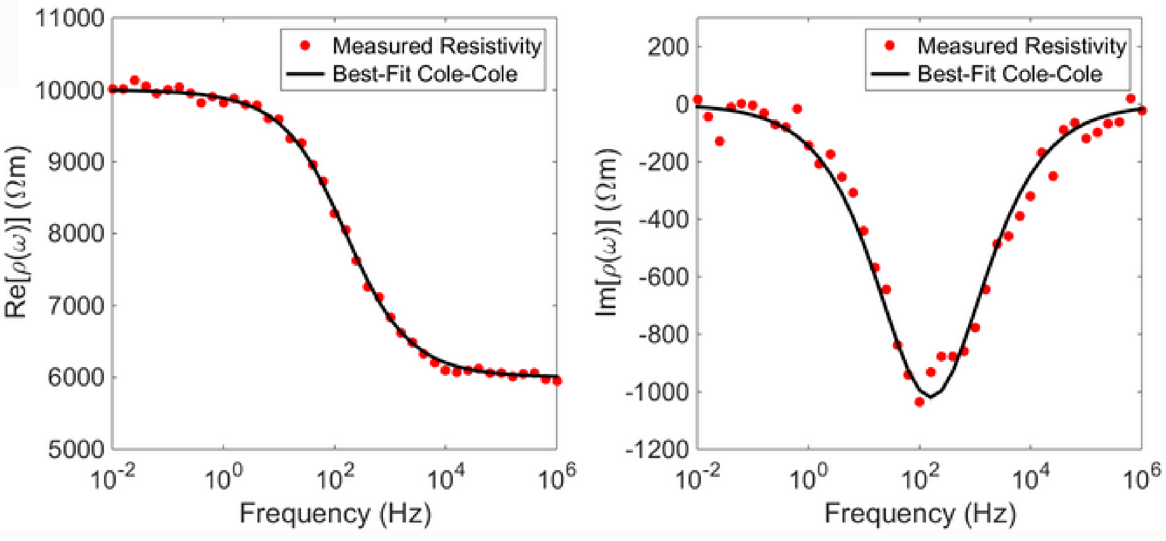
$$\rho(\omega) = \frac{Z(\omega)A}{L}$$



Fit Cole-Cole model:

$$\rho(\omega) = \rho_0 \left[1 - \eta \left(1 - \frac{1}{1 + (i\omega\tau)^C} \right) \right]$$

where $\eta = \frac{\rho_0 - \rho_\infty}{\rho_0}$



Chargeability of Rocks

- Some rocks are chargeable (sulfides, volcanic tuffs, clays)
- More aren't (igneous, sandstones, limestones etc…)

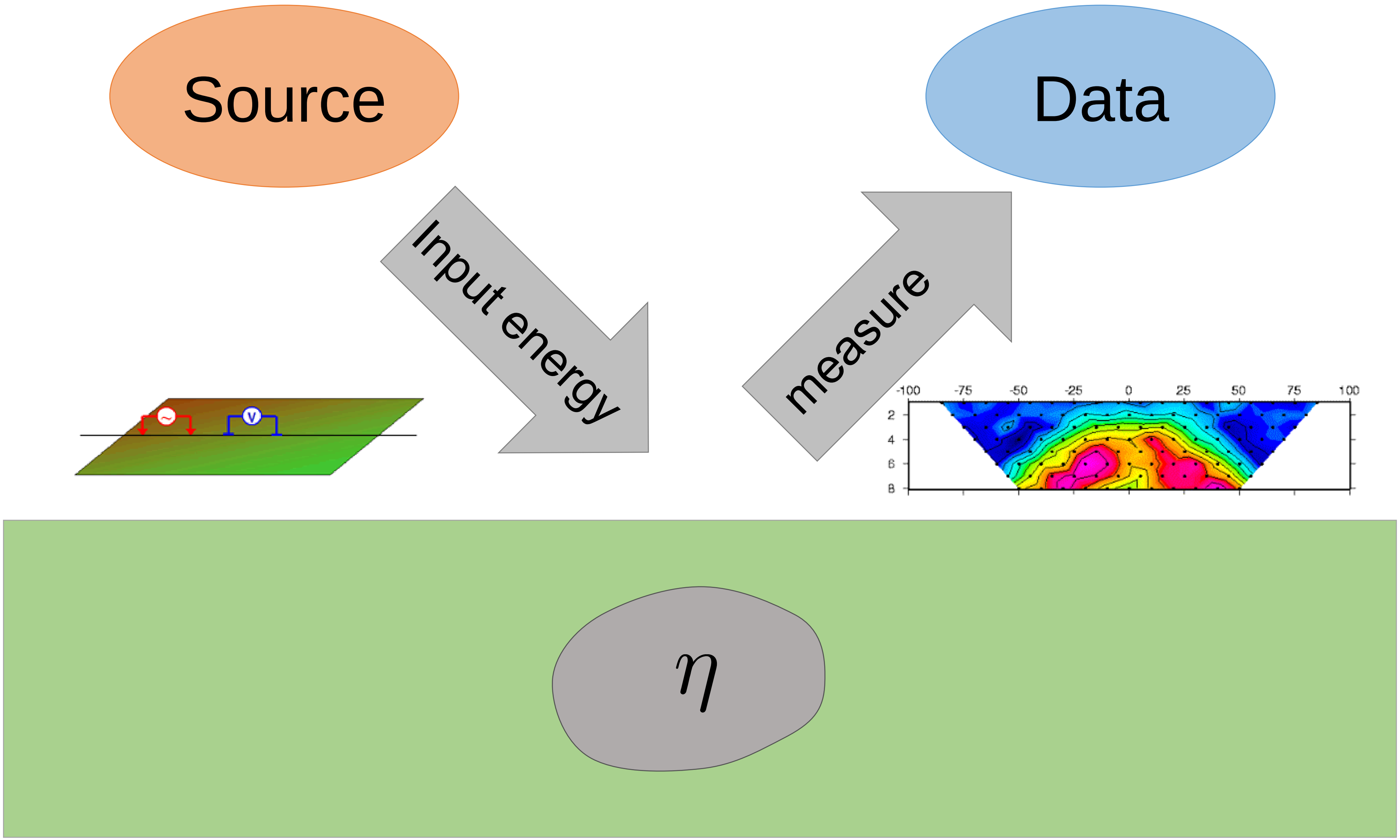
Material type	Chargeability (msec.)
20% sulfides	2000 - 3000
8-20% sulfides	1000 - 2000
2-8% sulfides	500 - 1000
volcanic tuffs	300 - 800
sandstone, siltstone	100 - 500
dense volcanic rocks	100 - 500
shale	50 - 100
granite, granodiorite	10 - 50
limestone, dolomite	10 - 20

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

Impacts on Chargeability

- Abundance of sulfide mineralization
- Porewater salinity (# ions)
- Clay content
- Tortuosity
- Chargeability strongly correlated with conductivity

DC-IP Survey


Source
Data
Input energy
measure
-100 -75 -50 -25 0 25 50 75 100
2
4
6
8
η

Motivational Problems

Exploration for Sulfide Minerals

Landfills

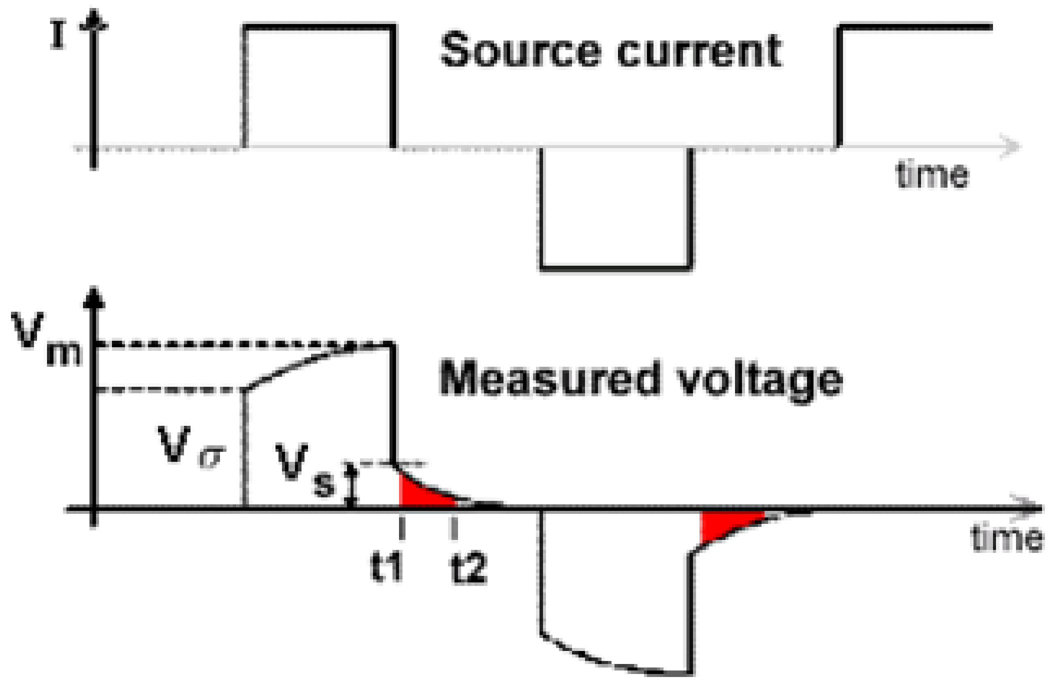
Used when:

1) Insufficient resistivity contrast

2) Sufficient chargeability contrast

Recap

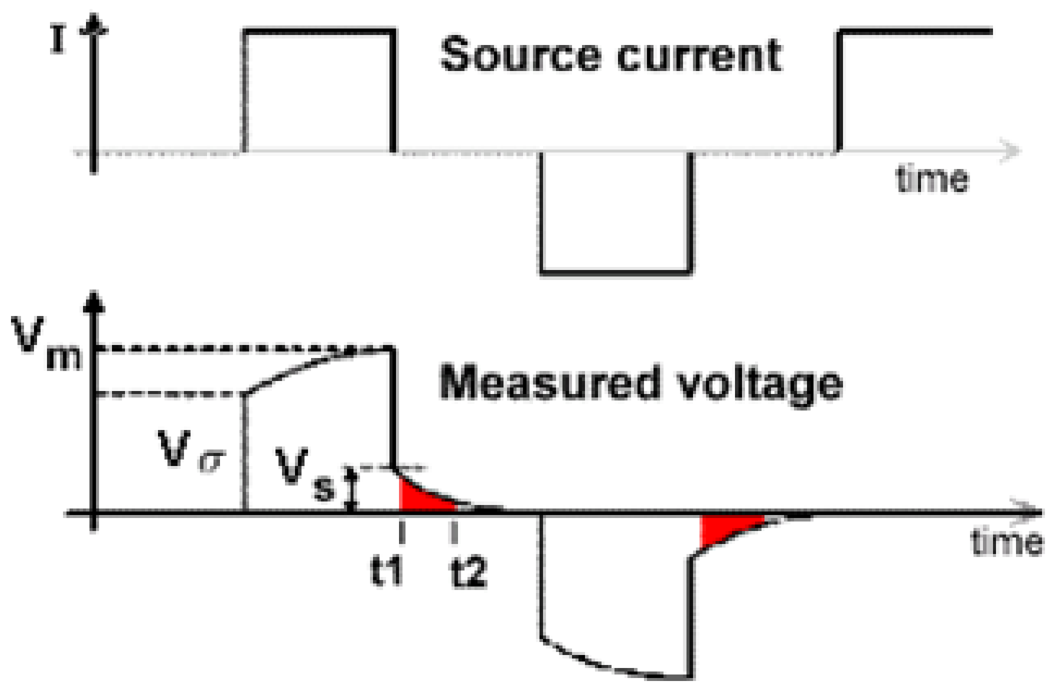
- DCR → accumulation of charges on boundaries due to ρ
  IP → accumulation of ions in chargeable materials
- DCR → instant change in secondary potential
  IP → non-instant change in secondary potential
  → secondary potential during off-time
- Only some rocks are chargeable (exhibit IP)



Recap: Questions

Q: If the Earth is chargeable, is there a secondary potential when the current electrodes are turned off?

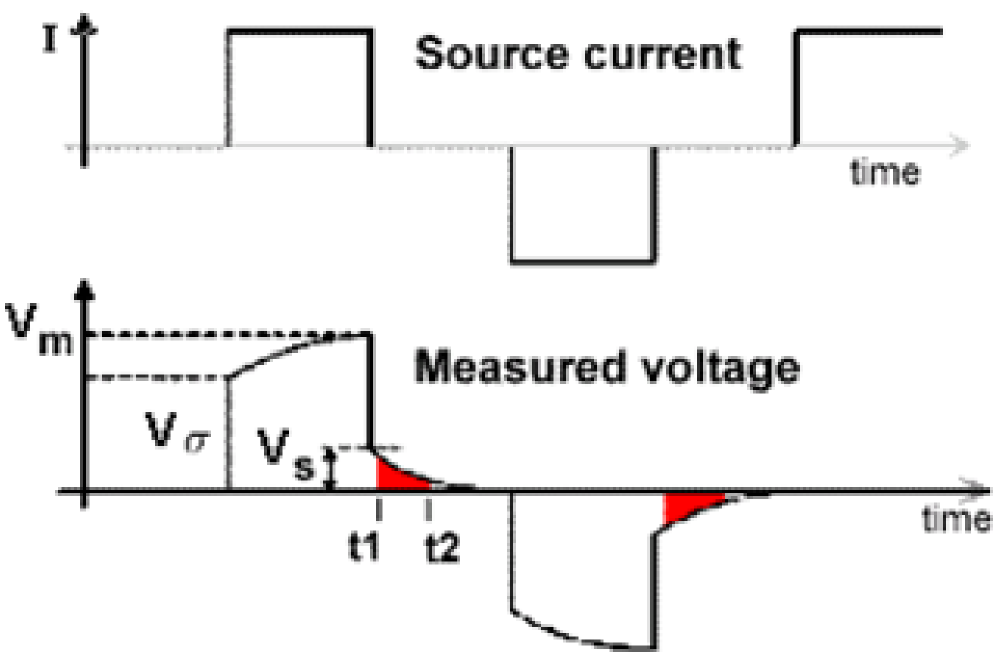
Q: What type(s) or rocks are chargeable?

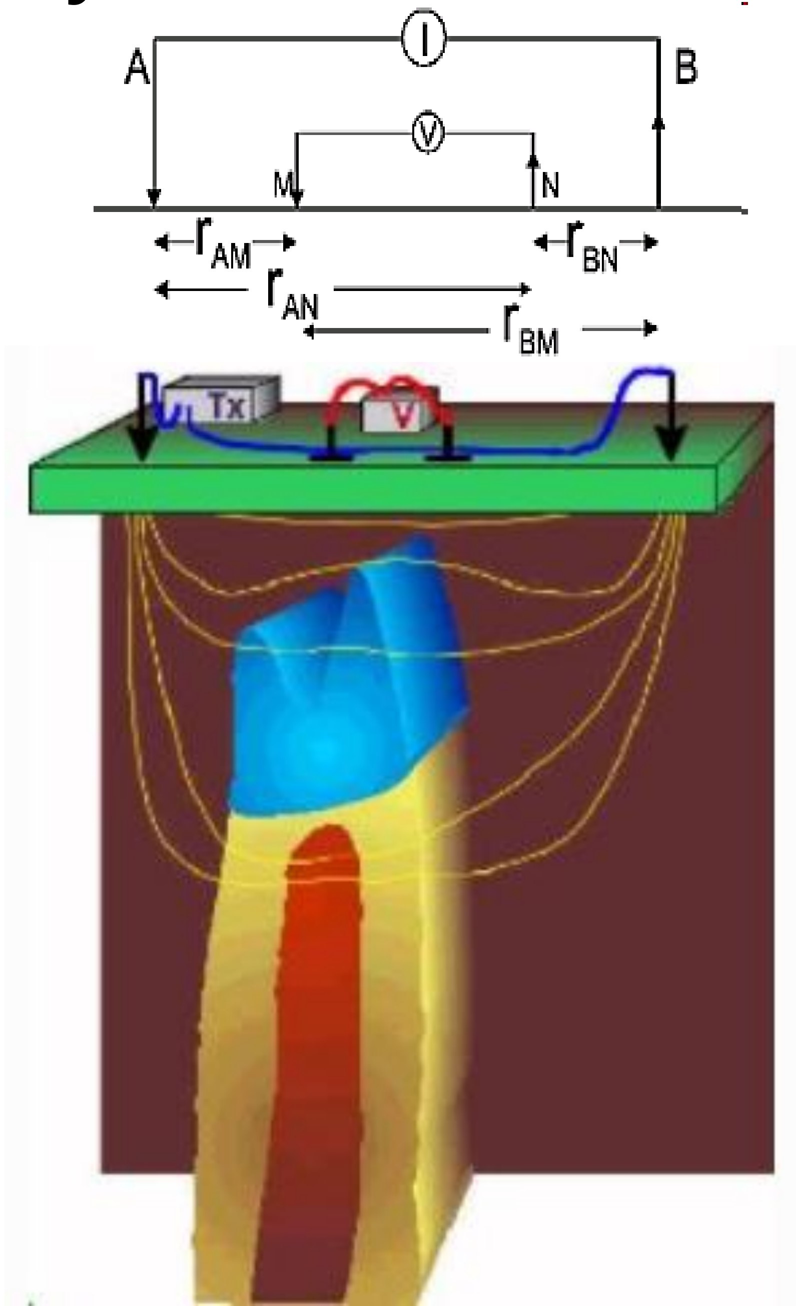


Survey and Data

DCIP Survey

- DCIP survey same as DCR
- Measured potential difference (ΔV) now time-dependent





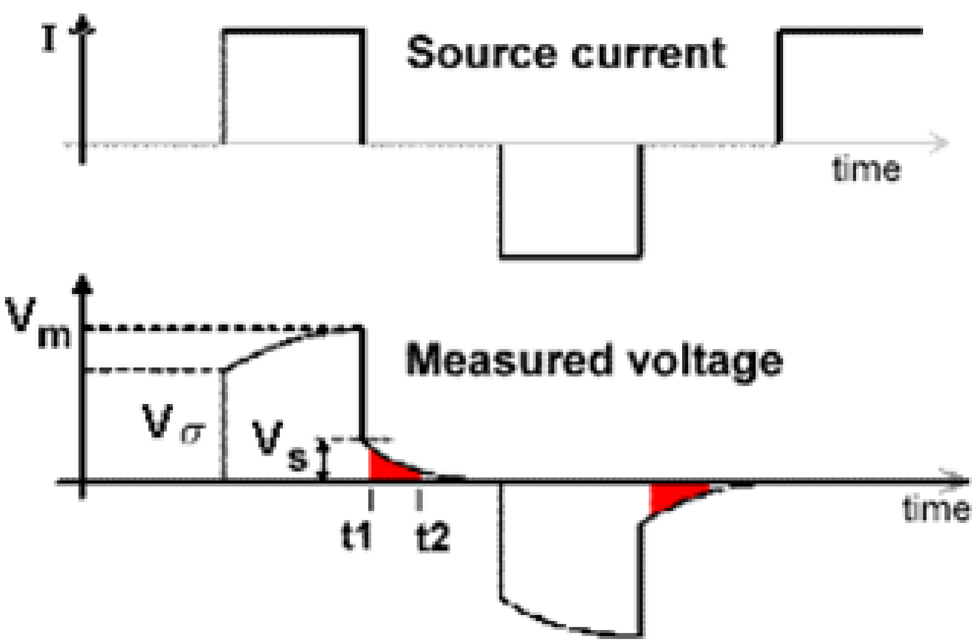
DCIP Field Data

DC Data

- Measure during on-time

  → DC voltage (ΔV_m)

  → $\rho_a = \frac{\Delta \mathbf{V}_m}{\mathbf{IG}}$



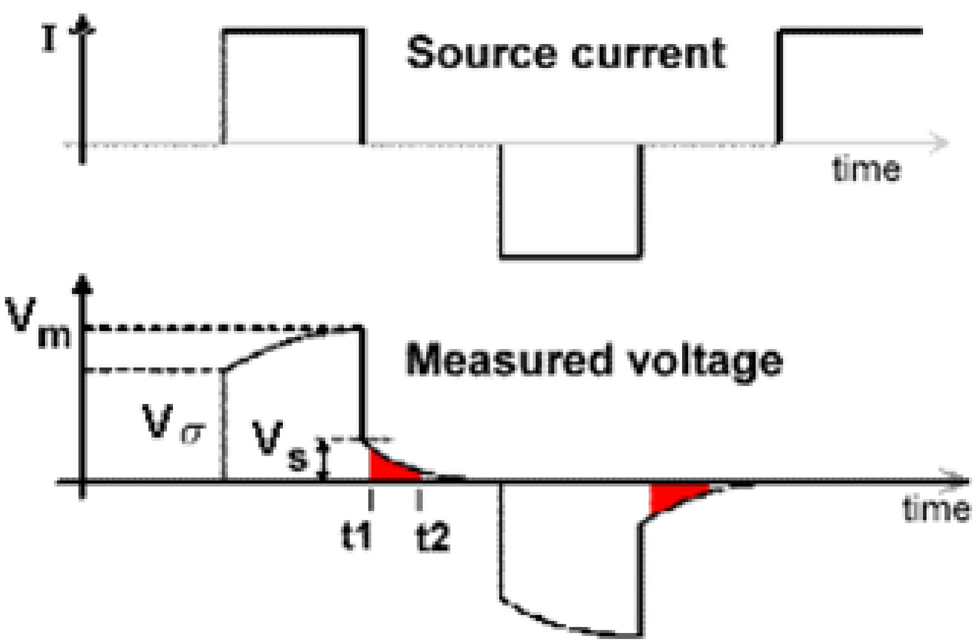
DCIP Field Data

DC Data

- Measure during on-time

→ DC voltage (ΔV_m)

→ $\rho_a = \dfrac{\Delta \mathbf{V}_m}{\mathbf{IG}}$



IP Data

- Measure during off-time
- Integrate over curve

$$d_{IP} = \frac{1}{V_m}\int_{t_1}^{t_2} V_s(t)dt$$

(integrated chargeability)

- Plot on pseudo-section (geometry accounted for)

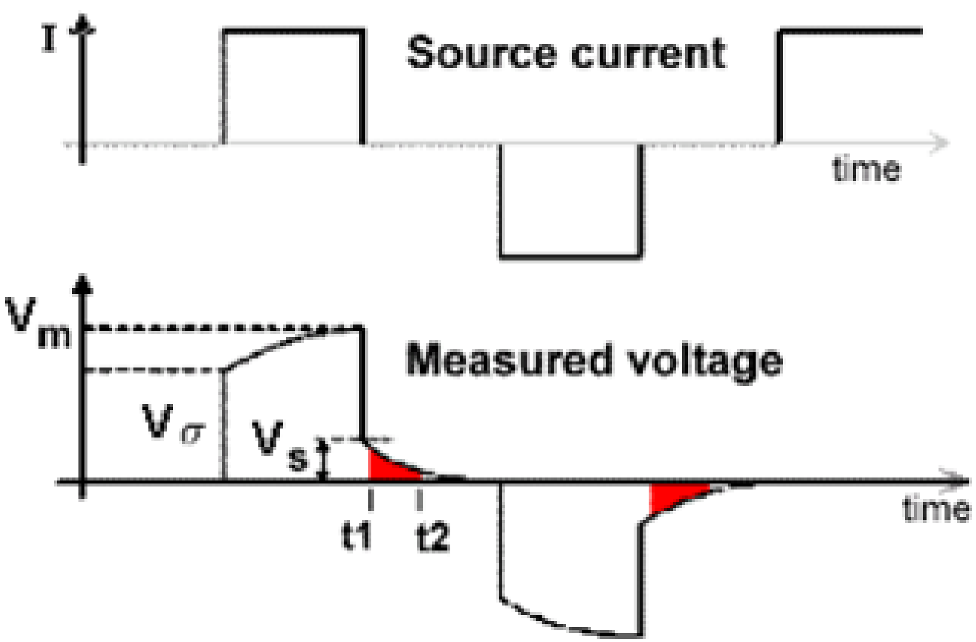
DCIP Field Data

DC Data

- Measure during on-time

→ DC voltage (ΔV_m)

→ $\rho_a = \dfrac{\Delta \mathbf{V}_m}{\mathbf{IG}}$



IP Data

- Measure during off-time
- Integrate over curve

$$d_{IP} = \frac{1}{V_m}\int_{t_1}^{t_2} V_s(t)dt$$

(like an apparent integrated chargeability)

- Plot on pseudo-section (geometry accounted for)

Can collect both during same survey!!!

IP Data with Intrinsic Chargeability

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

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

- An IP datum can also be written as

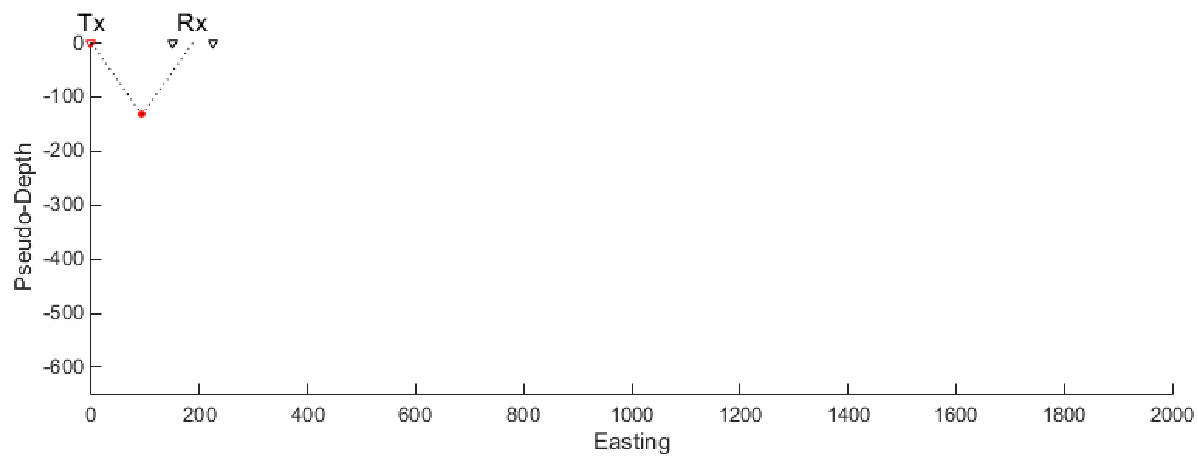
$$d_i^{IP} = \sum_{j=1}^{M} J_{ij}\eta_j \qquad i = 1, \ldots, N$$

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

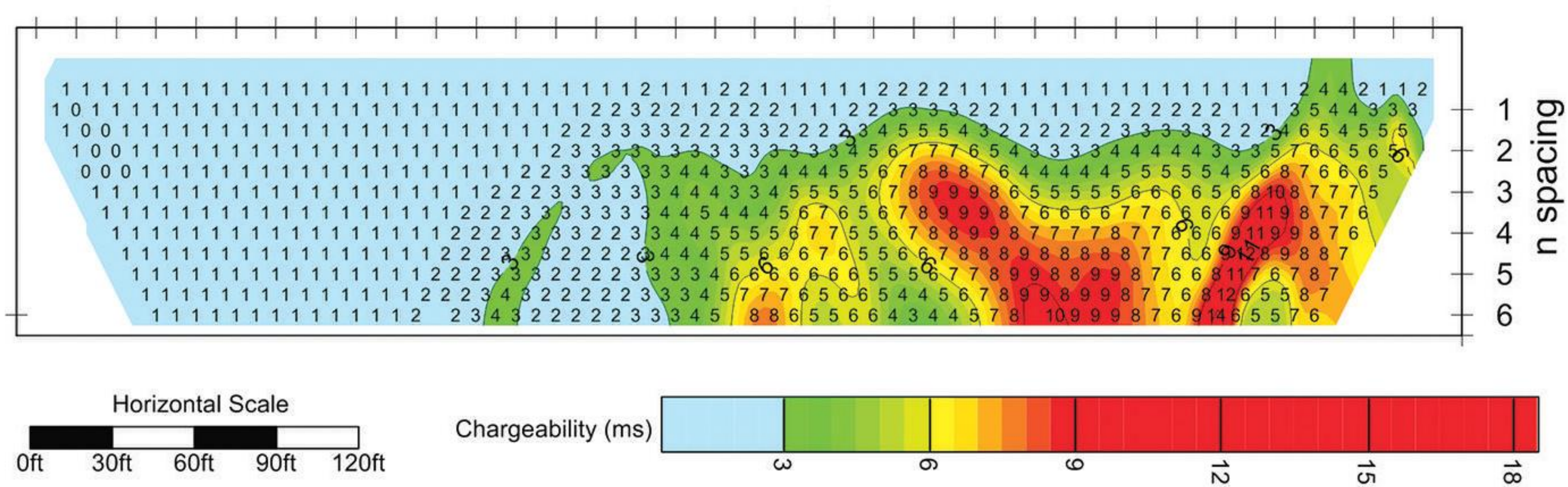
sensitivities for the DC resistivity problem

- In matrix form $\quad \mathbf{d}^{IP} = \mathbf{J}\boldsymbol{\eta}$ $\quad \mathbf{J}$ is an N×M matrix

IP Pseudo-Section



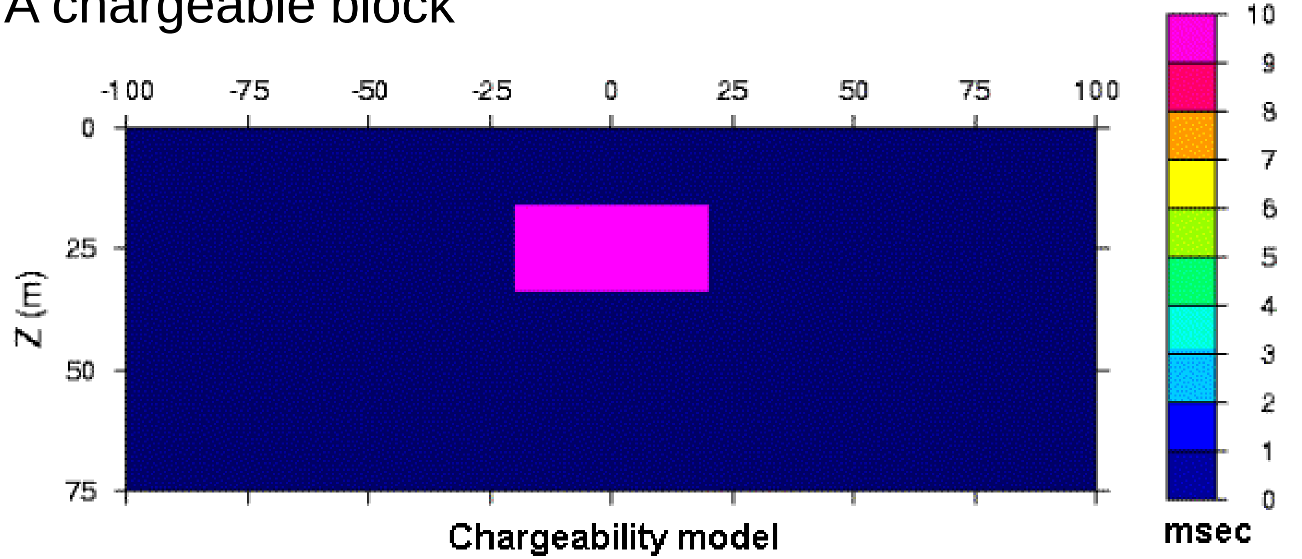
Apparent chargeability pseudo-section (plotted same way)

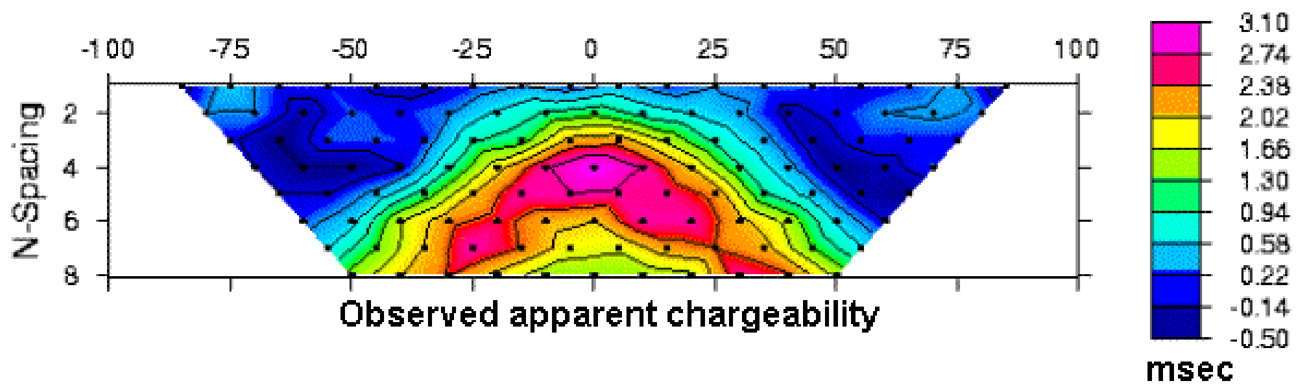


Q: What does pseudo-section tell us about chargeability distribution?

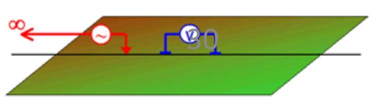
IP Pseudo-Section

1) A chargeable block





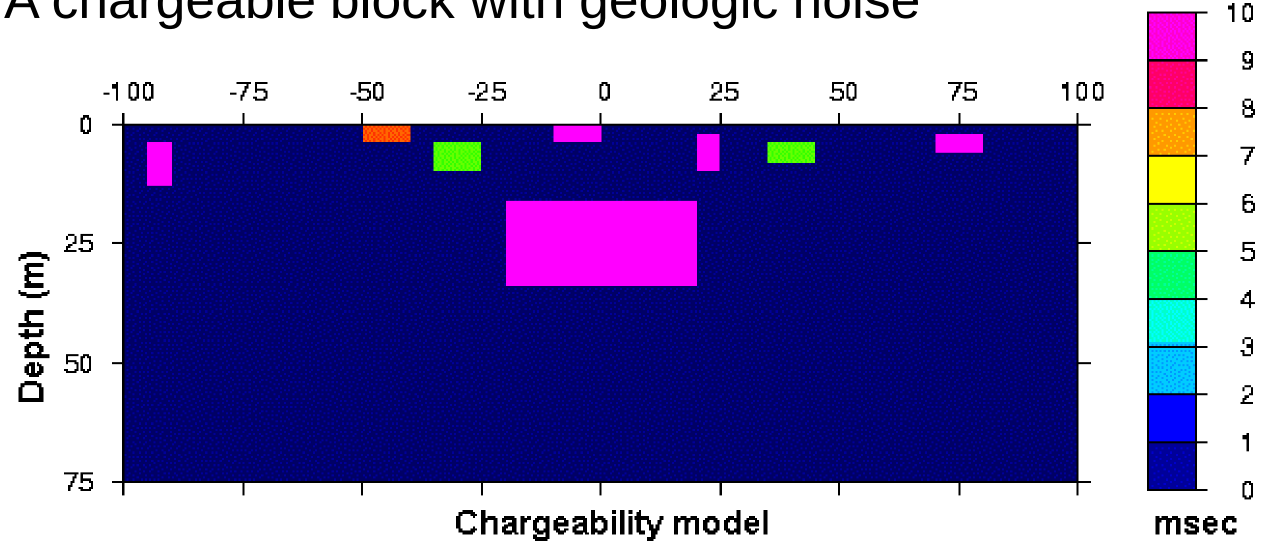
Pole-Dipole

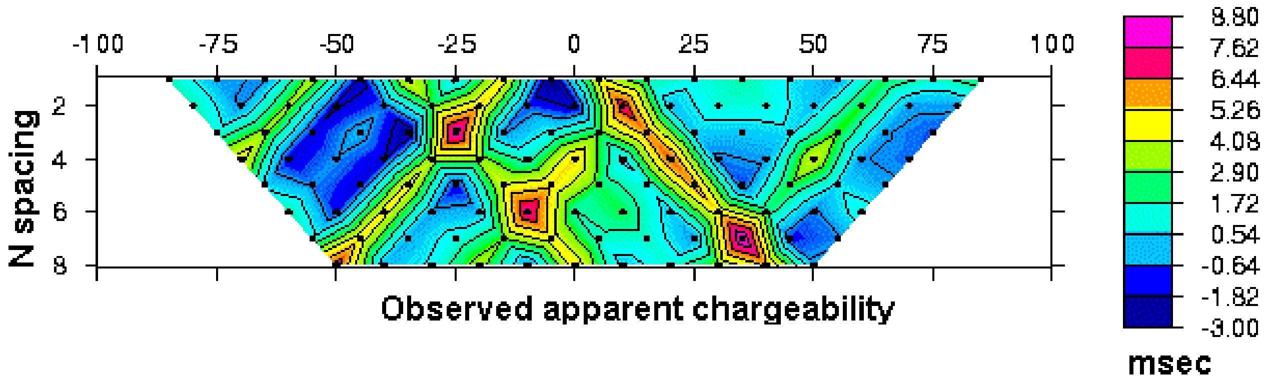


- Pole-dipole; n=1,8; a=10m; N=316

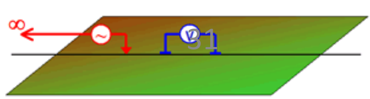
IP Pseudo-Section

2) A chargeable block with geologic noise





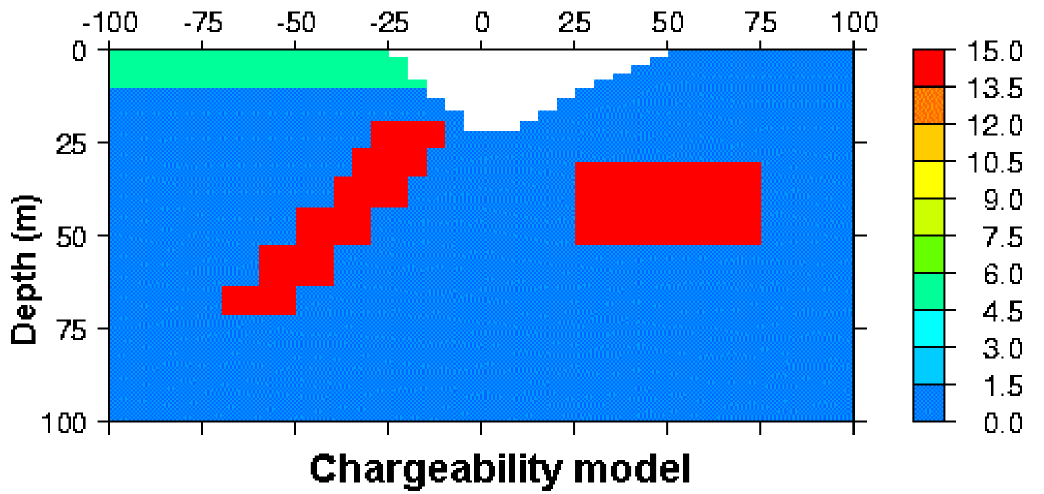
Pole-Dipole

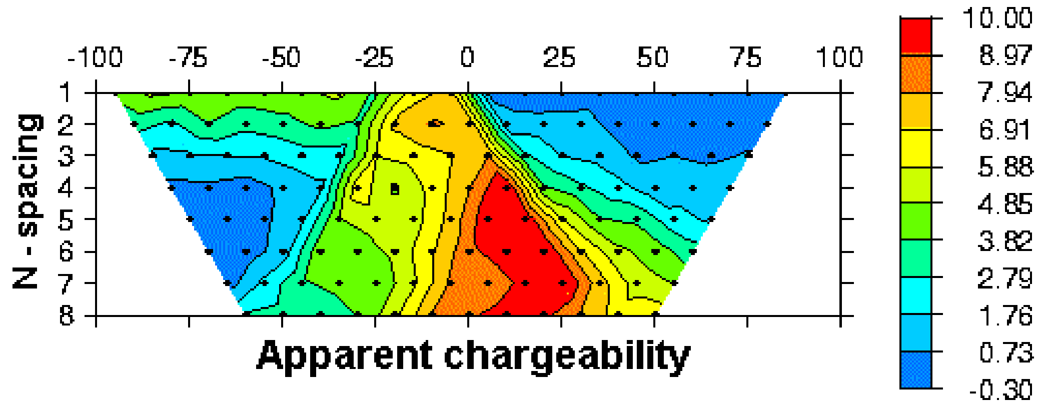


- Pole-dipole; n=1,8; a=10m; N=316

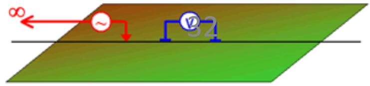
IP Pseudo-Section

3) The “UBC-GIF model”





Pole-Dipole

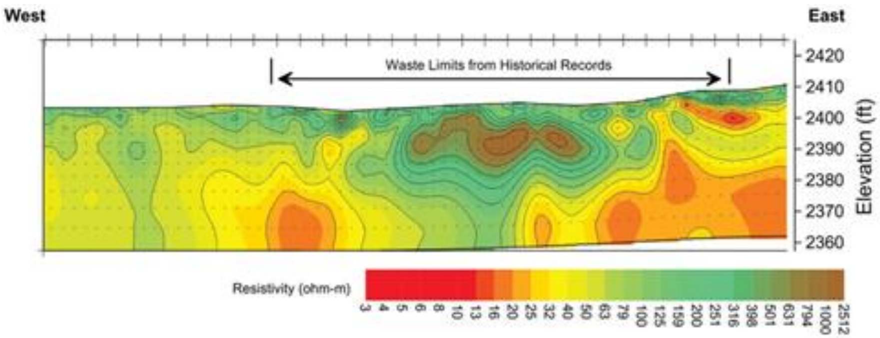


Processing and Interpretation

Inversion

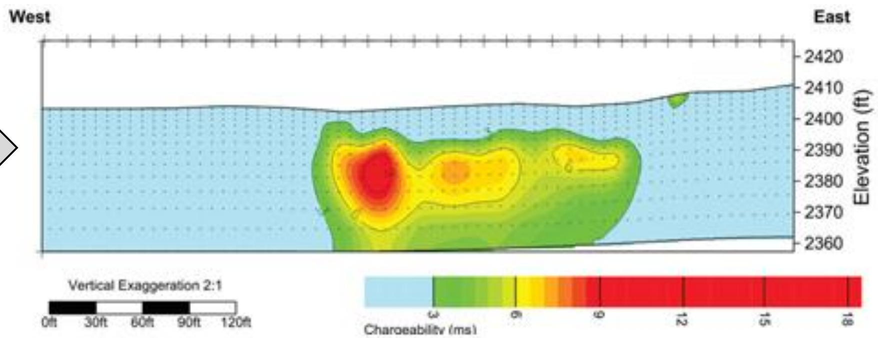
Apparent resistivity data ($\boldsymbol{\rho_a}$)

Resistivity model (ρ)



Chargeability data ($\boldsymbol{d_{IP}}$)

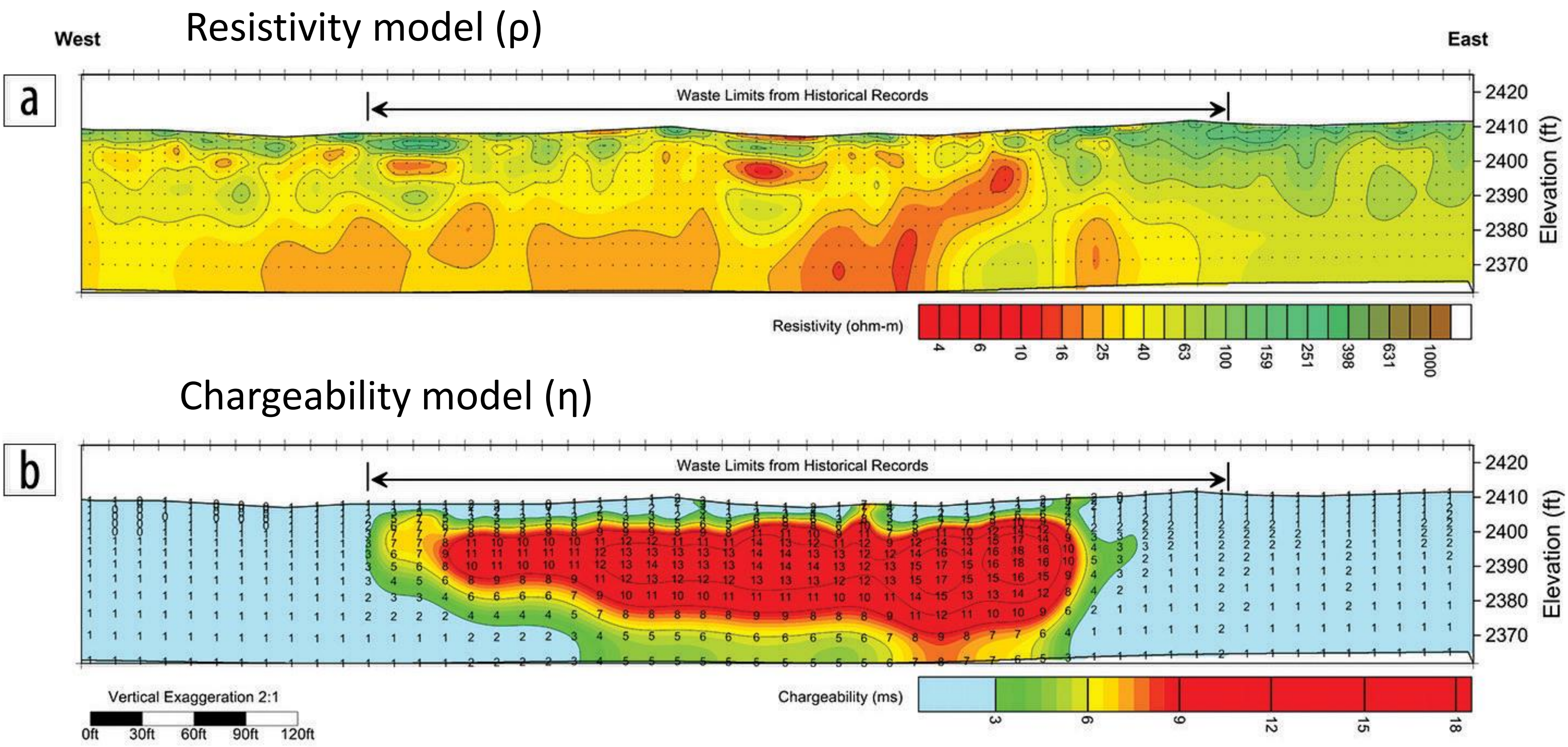
Chargeability model (η)



- DCIP data provides 2 models
- One or both can be used for interpretation
- Resistivity model required to recover chargeability model

Interpretation Example

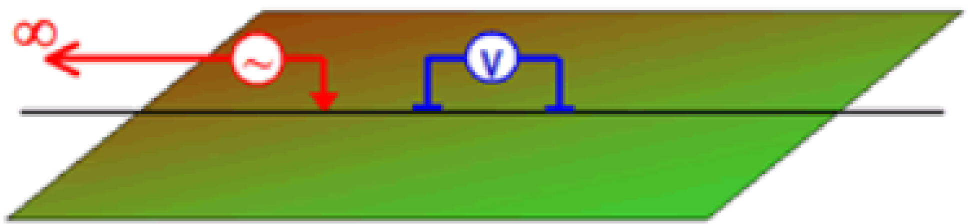
- Finding margins of an old waste deposit

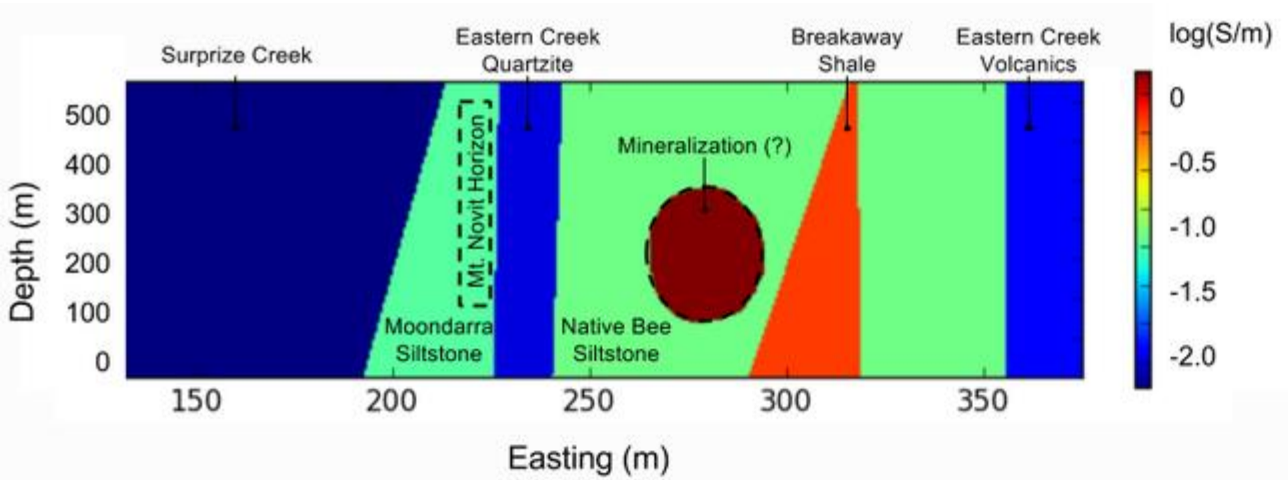


Example: Mt Isa Revisited

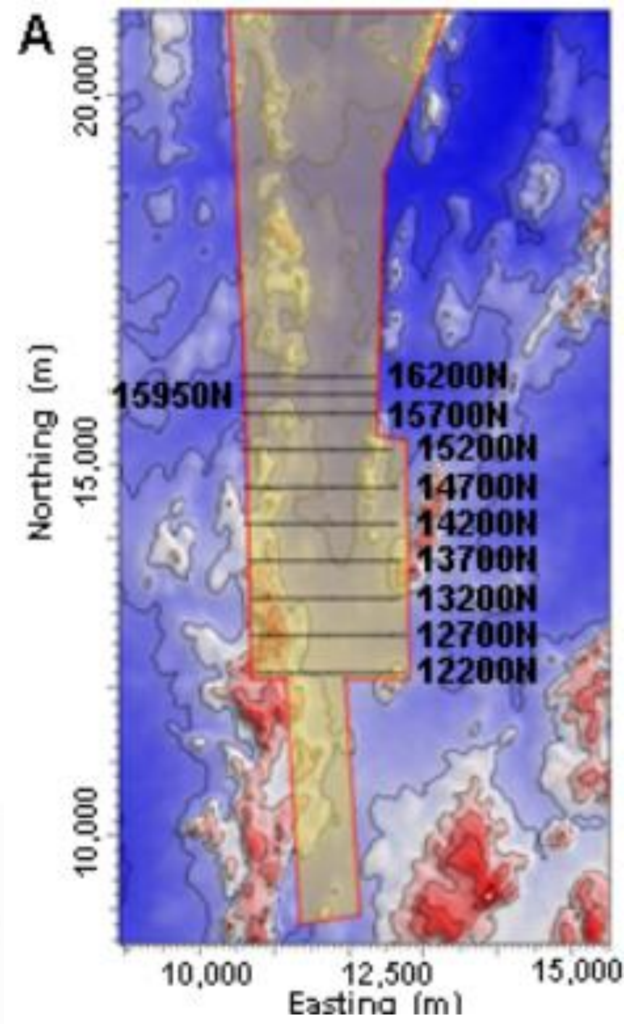
Mt. Isa (Setup)

- Potential ore deposit (lead, zinc, silver, copper, gold?)
- Survey with pole-dipole and dipole-pole config.

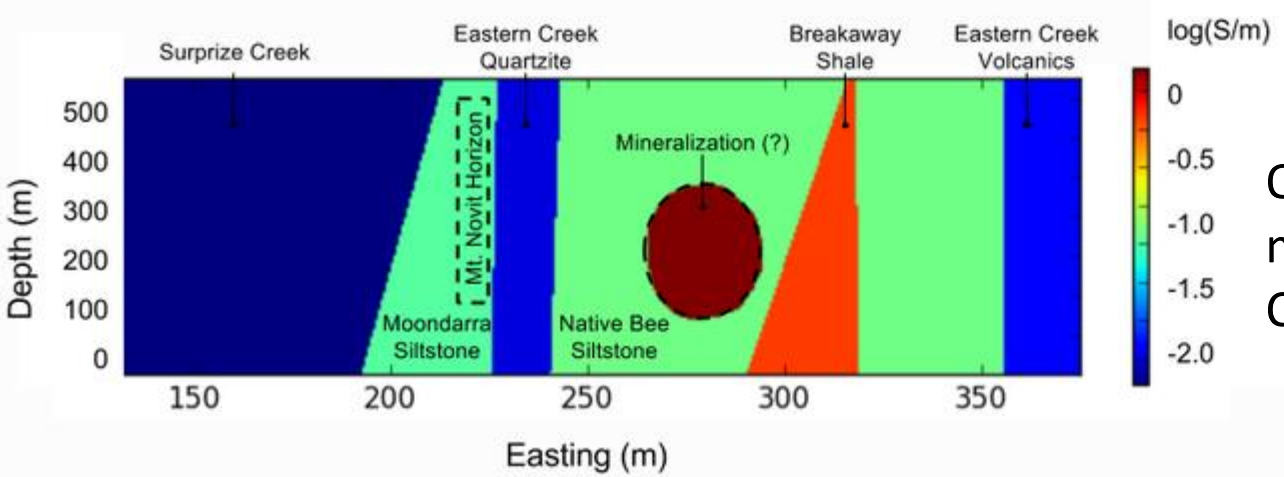




Simplified (log) conductivity distribution expected at Mount Isa (N:12200m).



Mt. Isa (Properties)

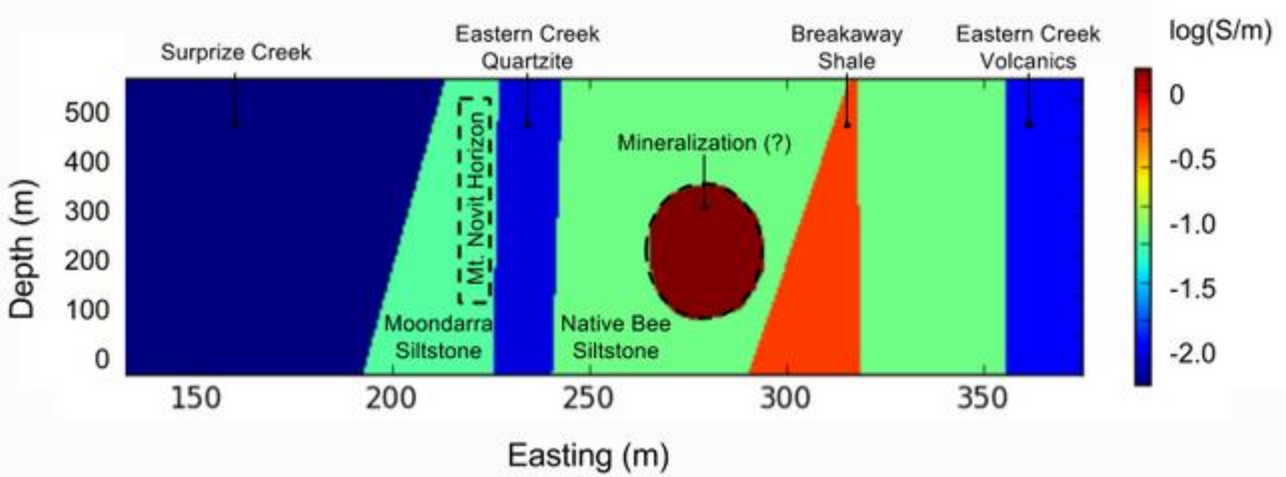


Simplified (log) conductivity distribution expected at Mount Isa (N:12200m).

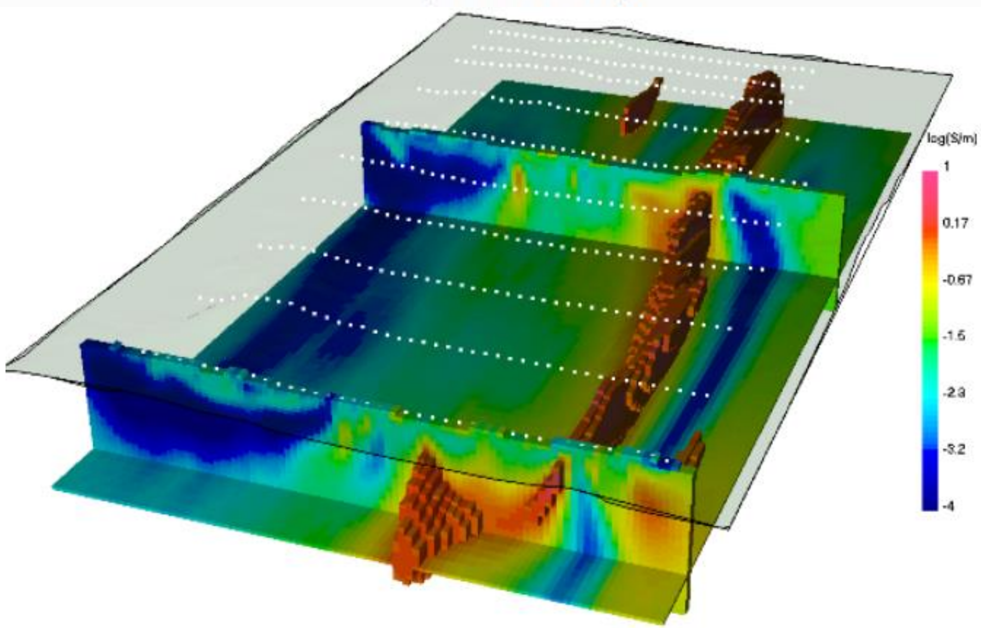
Q: Do you expect mineralization to be Chargeable?

Rock Unit	Conductivity	Resistivity ($\Omega \cdot m$)	Chargeability
Native Bee Siltstone	Moderate	Moderate (~10)	Low
Moondarra Siltstone	Moderate	Moderate (~10)	Low
Breakaway Shale	Very High	Very Low (~0.1)	Low-None
Mt Novit Horizon	High	Low (~1)	High
Surprise Creek Formation	Low	High (~1000)	None
Eastern Creek Volcanics	Low	High (~1000)	None

Mt. Isa (From last time)



Simplified (log) conductivity distribution expected at Mount Isa (N:12200m).

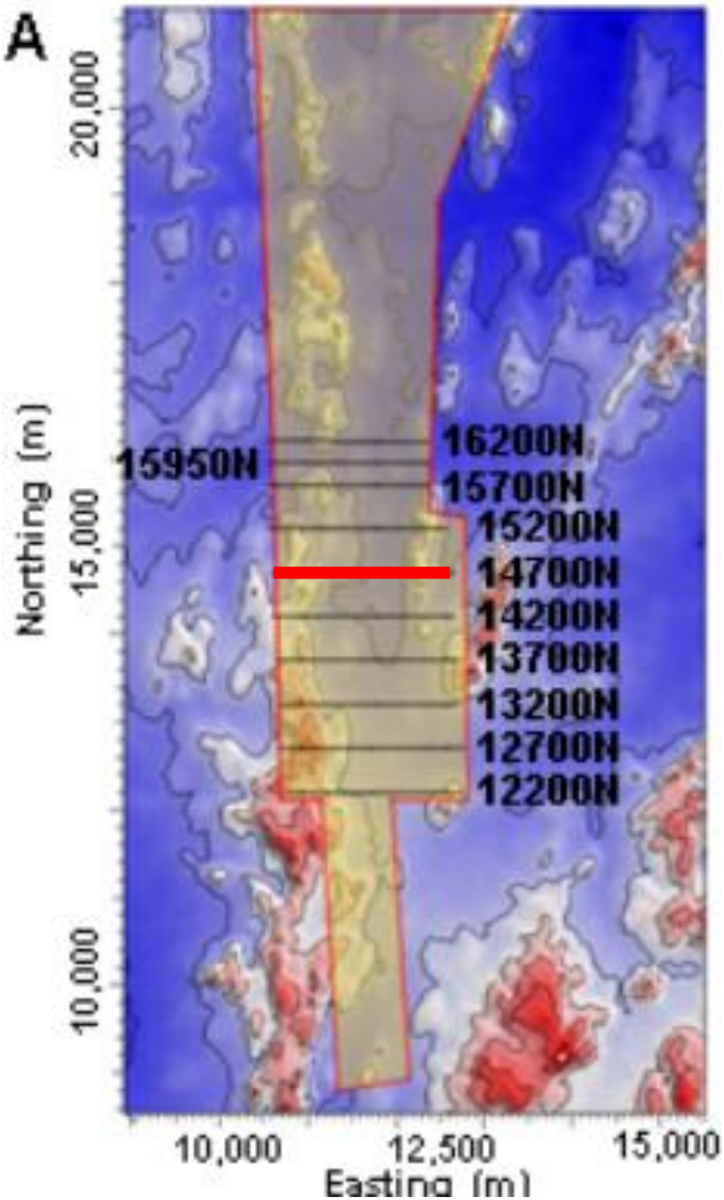


Mineralization and other units are conductive

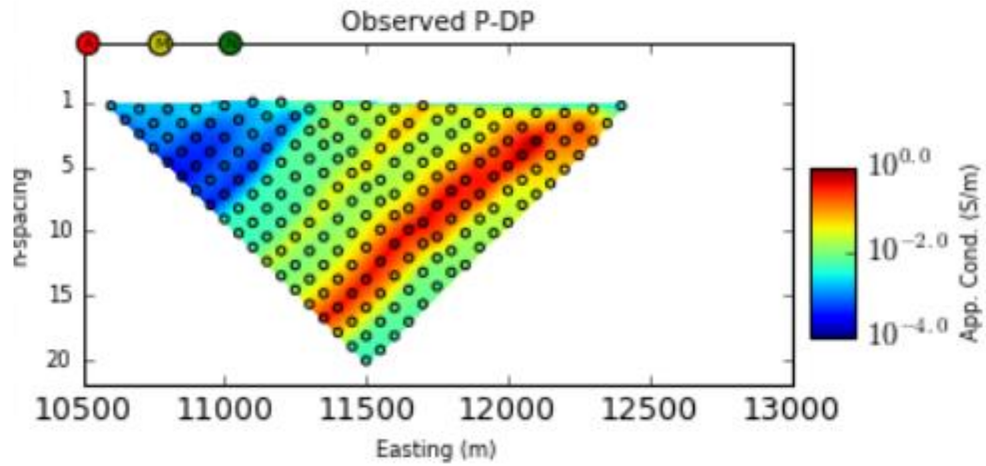
→ Hard to differentiate with conductivity

→ Differentiate by chargeability

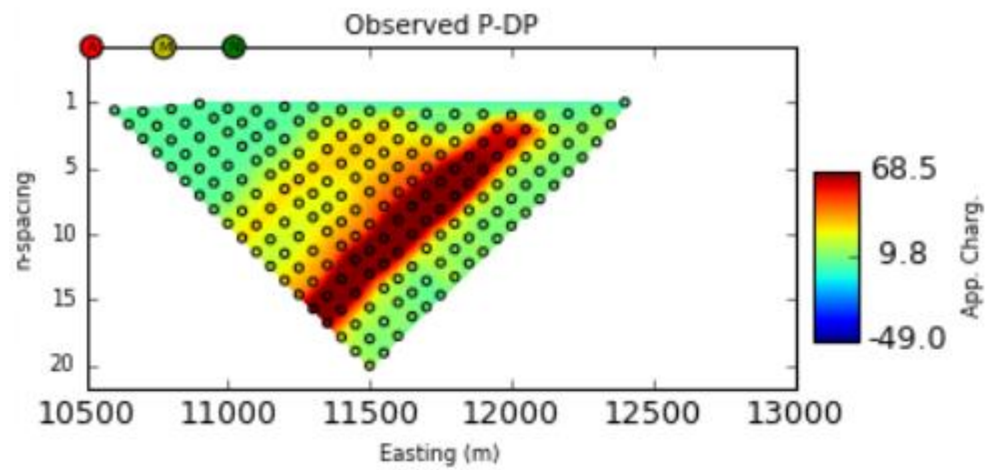
Mt. Isa (Survey and Data)



Conductivity pseudo-section



Chargeability pseudo-section



Q: What trends seen in data?

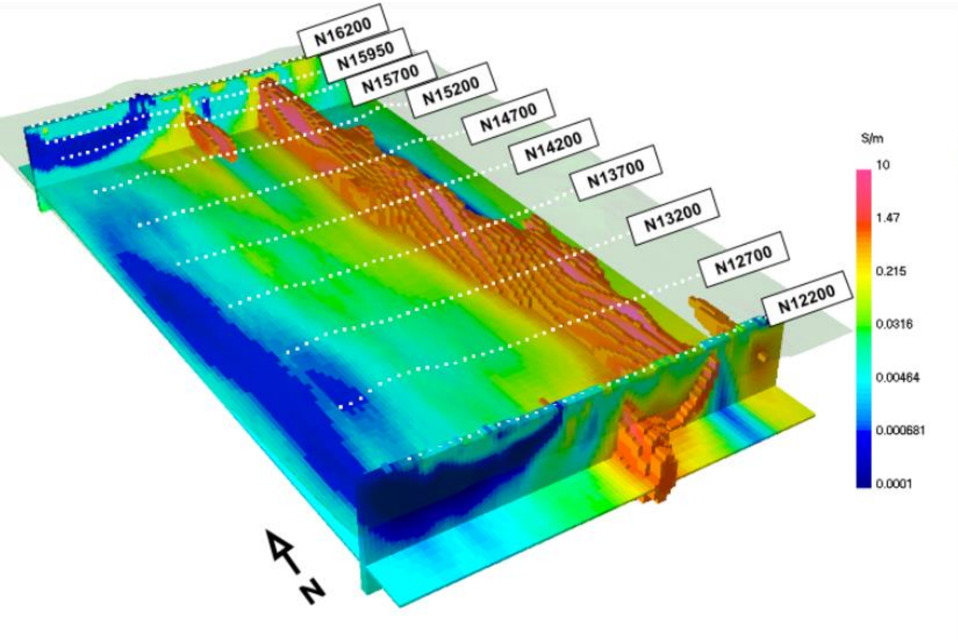
Mt. Isa (Processing)

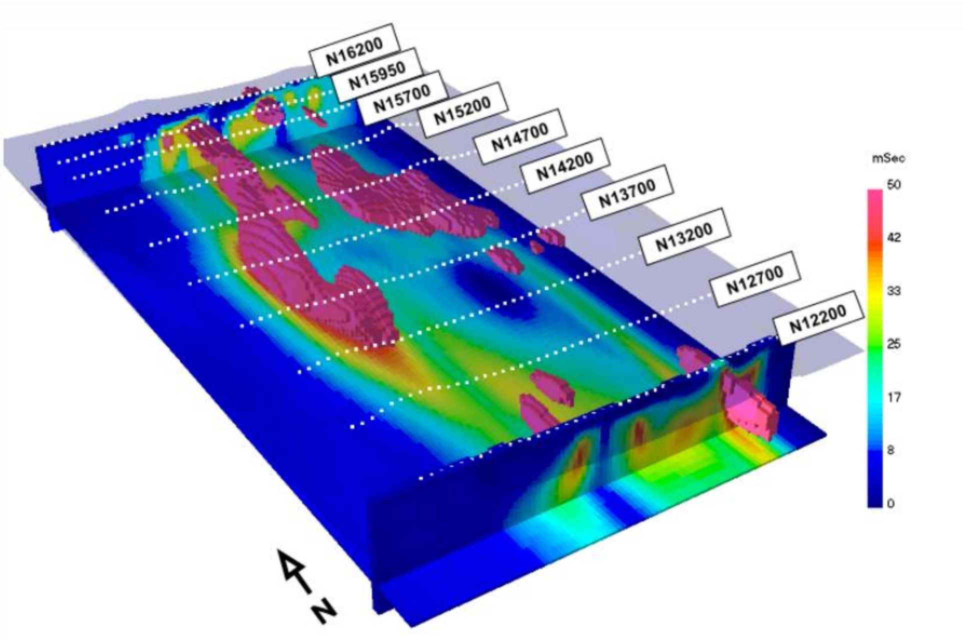
Apparent resistivity data ($\boldsymbol{\rho_a}$)

Resistivity model (ρ)

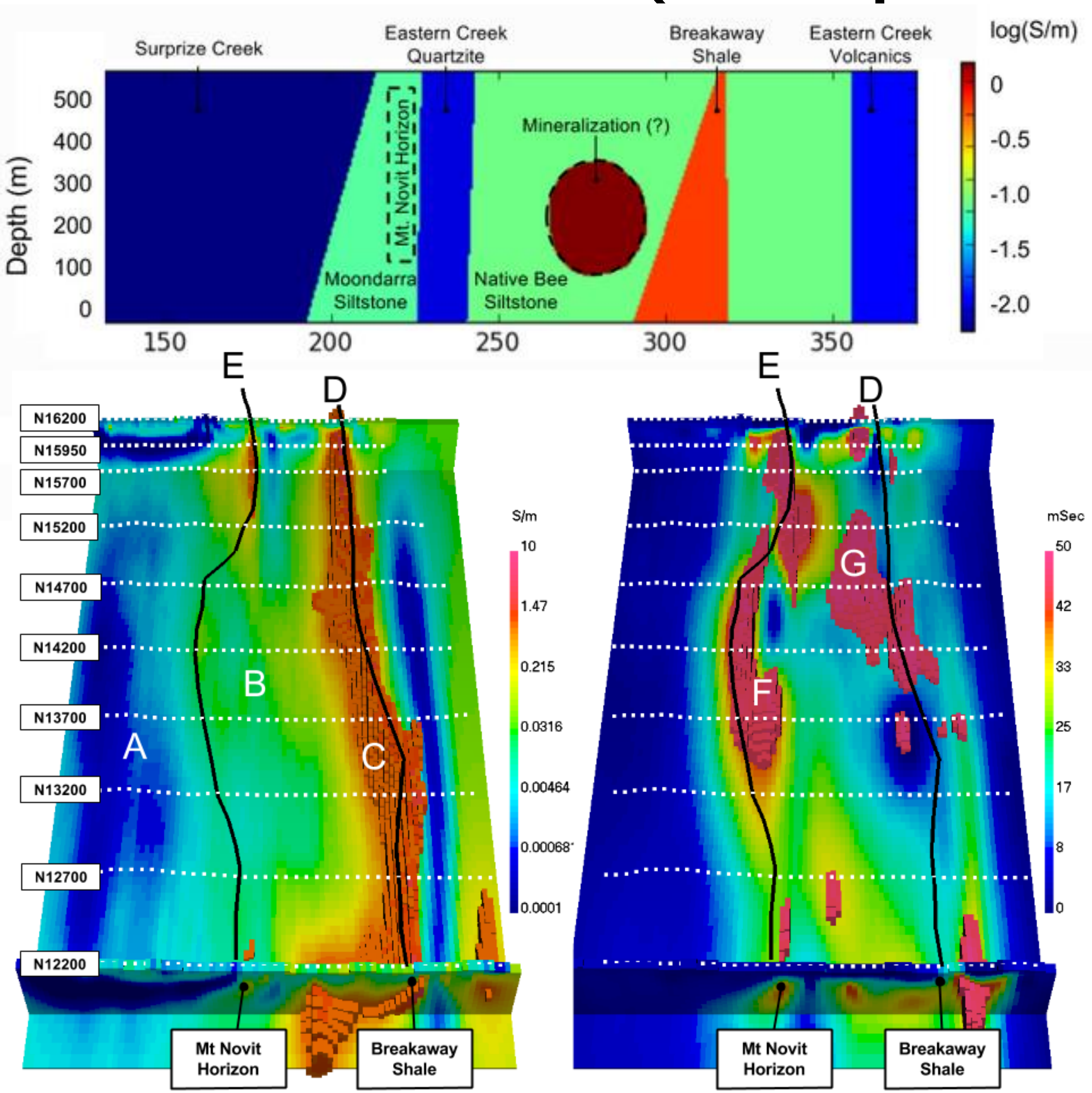
Integrated chargeability data ($\boldsymbol{d_{IP}}$)

Chargeability model (η)



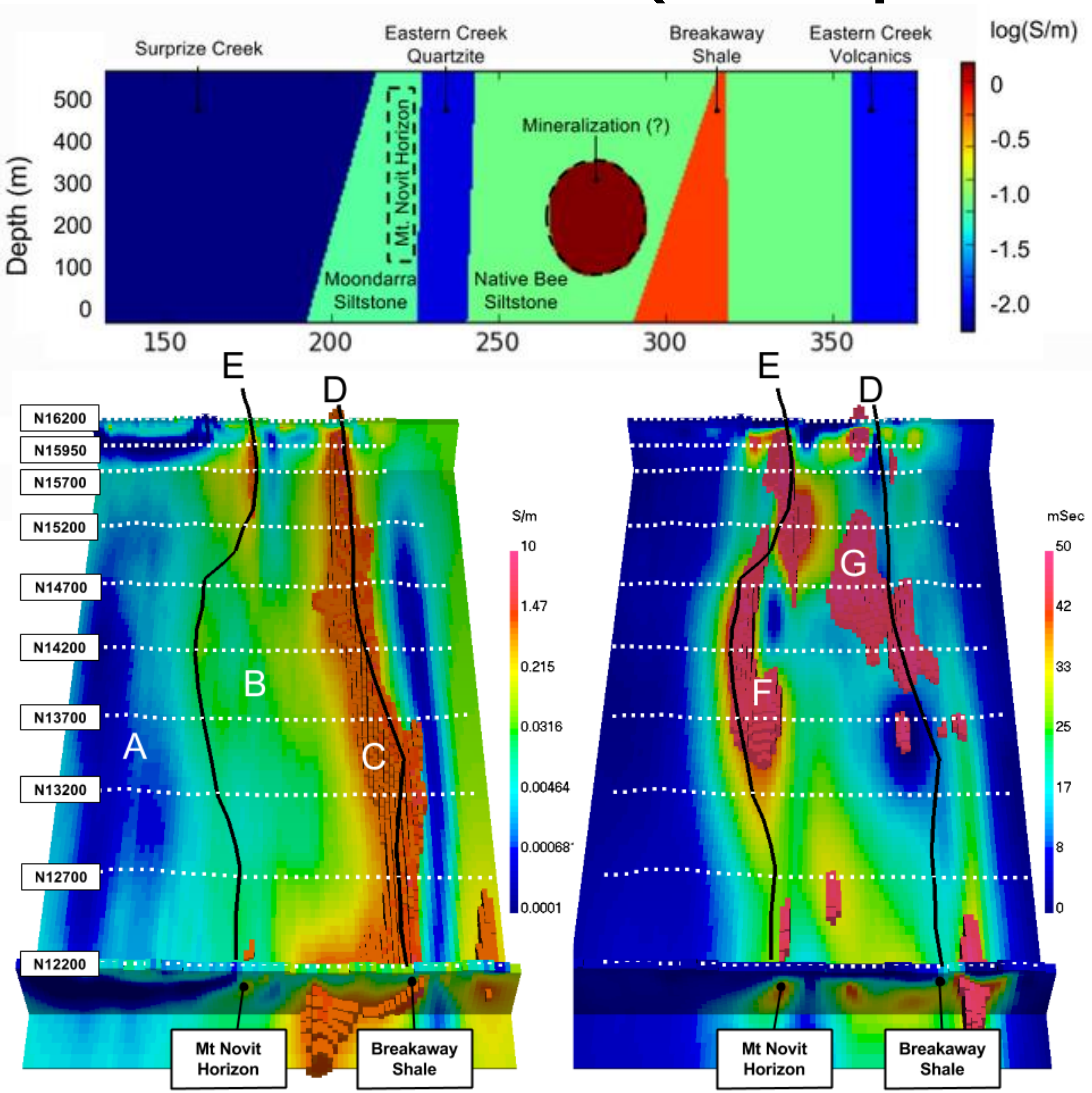


Mt. Isa (Interpretation)



A: Surprise creek
(low σ, low η)

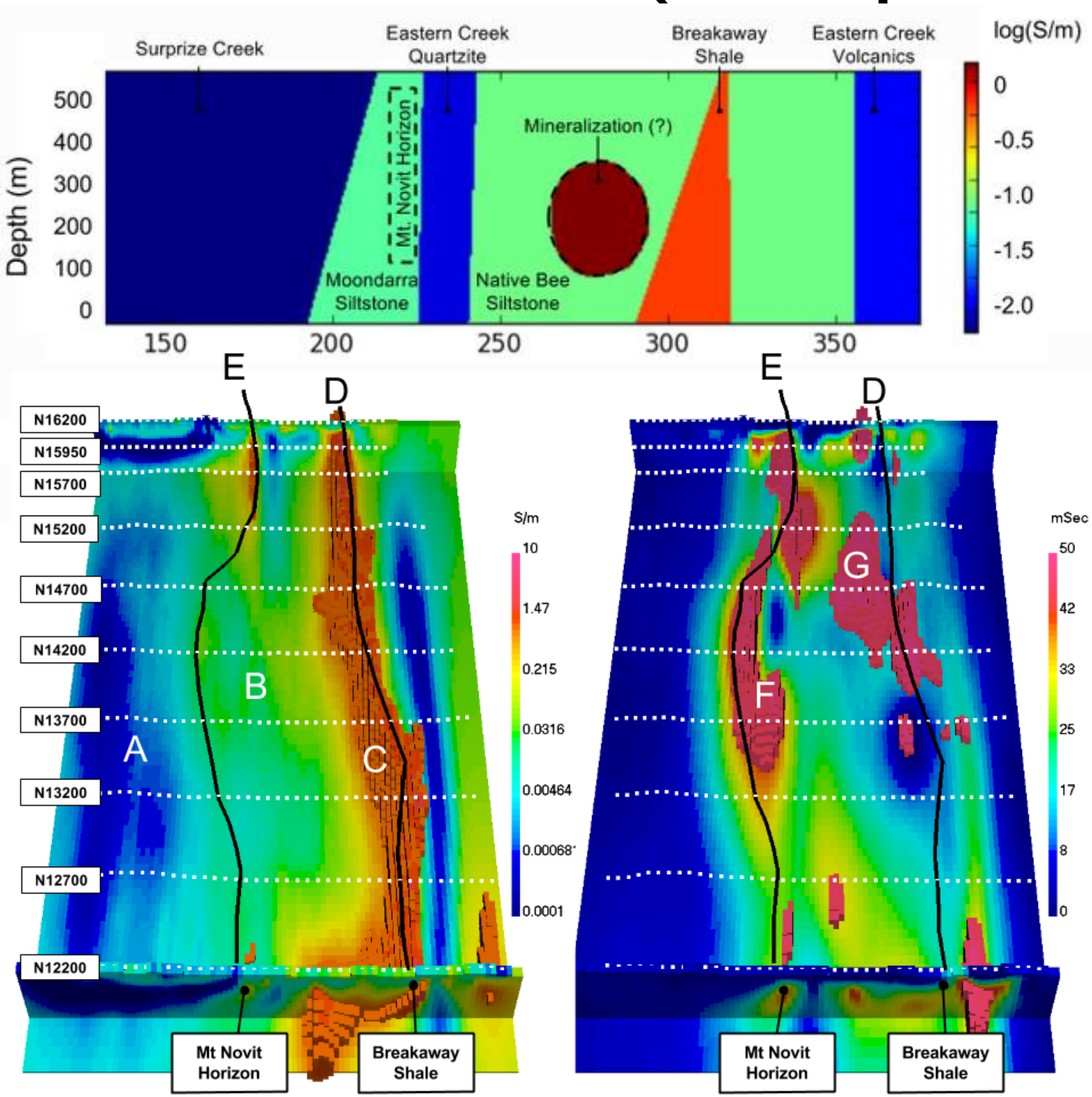
Mt. Isa (Interpretation)



A: Surprise creek
(low σ, low η)

B: Moondarra and Native Bee siltstones
(moderate σ, low η)

Mt. Isa (Interpretation)

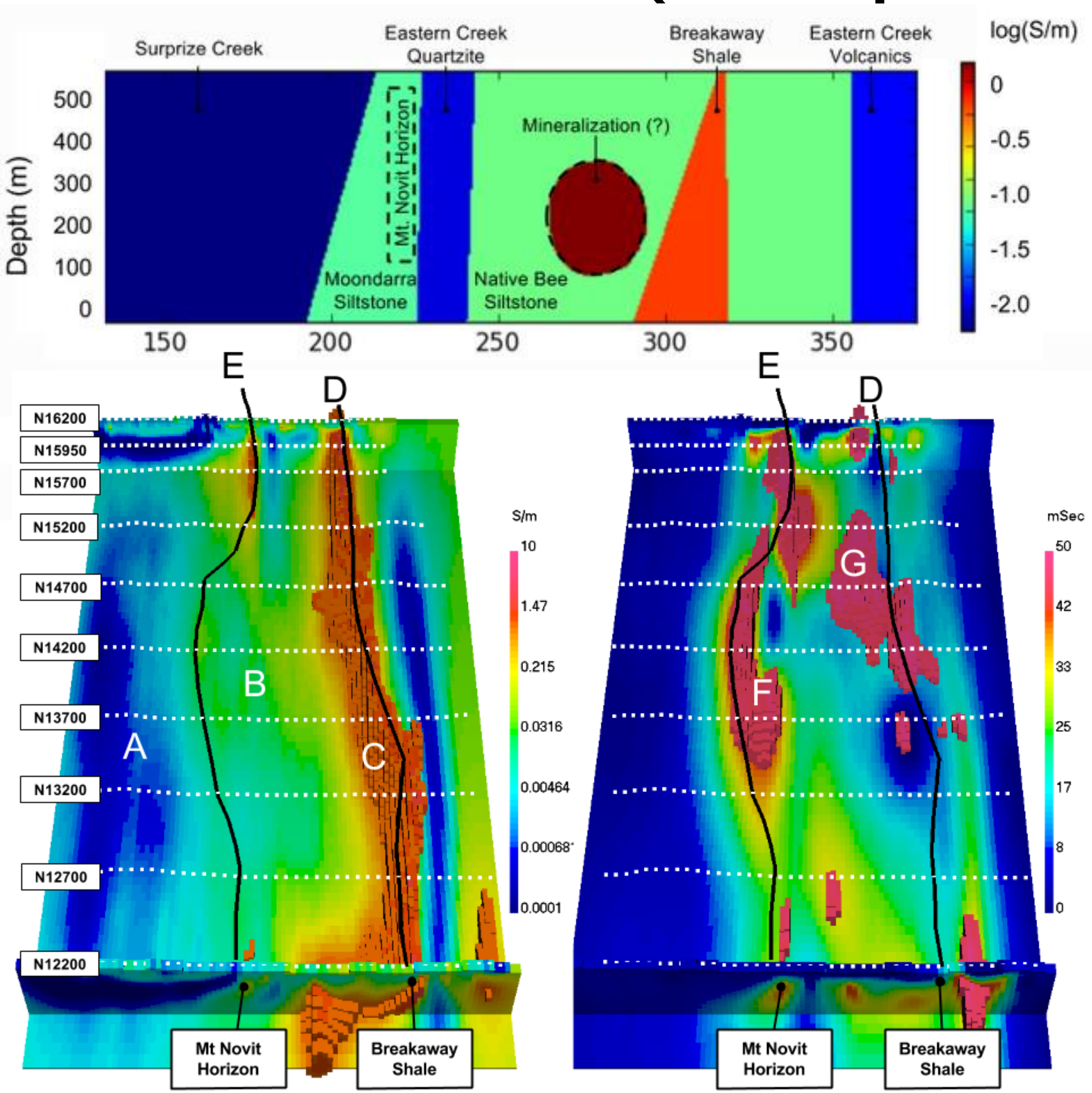


A: Surprise creek
(low σ, low η)

B: Moondarra and Native Bee siltstones
(moderate σ, low η)

C and D: Breakaway shales
(high σ, low η)

Mt. Isa (Interpretation)



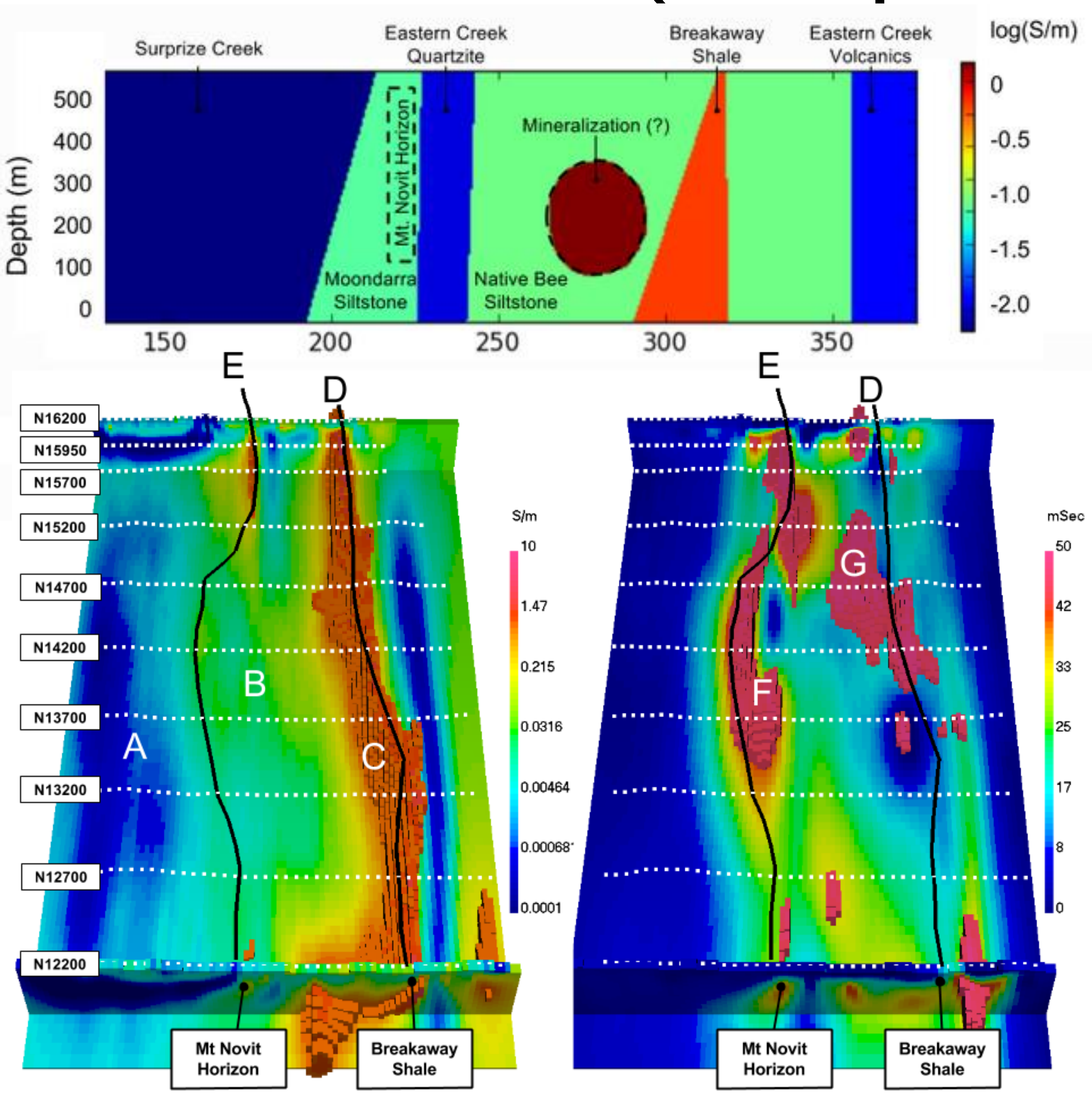
A: Surprise creek
(low σ, low η)

B: Moondarra and Native Bee siltstones
(moderate σ, low η)

C and D: Breakaway shales
(high σ, low η)

E and F: Mt. Novit horizon
(high σ, high η)

Mt. Isa (Interpretation)



A: Surprise creek (low σ, low η)

B: Moondarra and Native Bee siltstones (moderate σ, low η)

C and D: Breakaway shales (high σ, low η)

E and F: Mt. Novit horizon (high σ, high η)

G: Possible mineralization (high σ, high η)

Mt. Isa (Synthesis)

- Chargeability delineates region of interest from background
- Mt. Novit horizon is chargeable
- Chargeability delineates Breakaway shale (high σ, low η) from mineralization (high σ, high η)

Questions About Material?

Unit Activities

- **Labs: None**
- **TBL:**
  - Wednesday, November 20th
- **Quiz: None**