SUSTech Southern University of Science and Technology

南方科技大学 SOUTHERN UNIVERSITY OF SCIENCE AND TECHNOLOGY

地球与空间科学系 DEPARTMENT OF EARTH AND SPACE SCIENCES

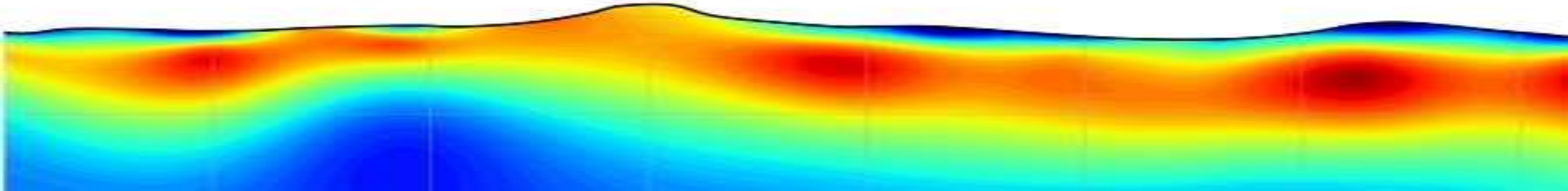
ESS302 Applied Geophysics II

Gravity, Magnetic, Electrical, Electromagnetic and Well Logging

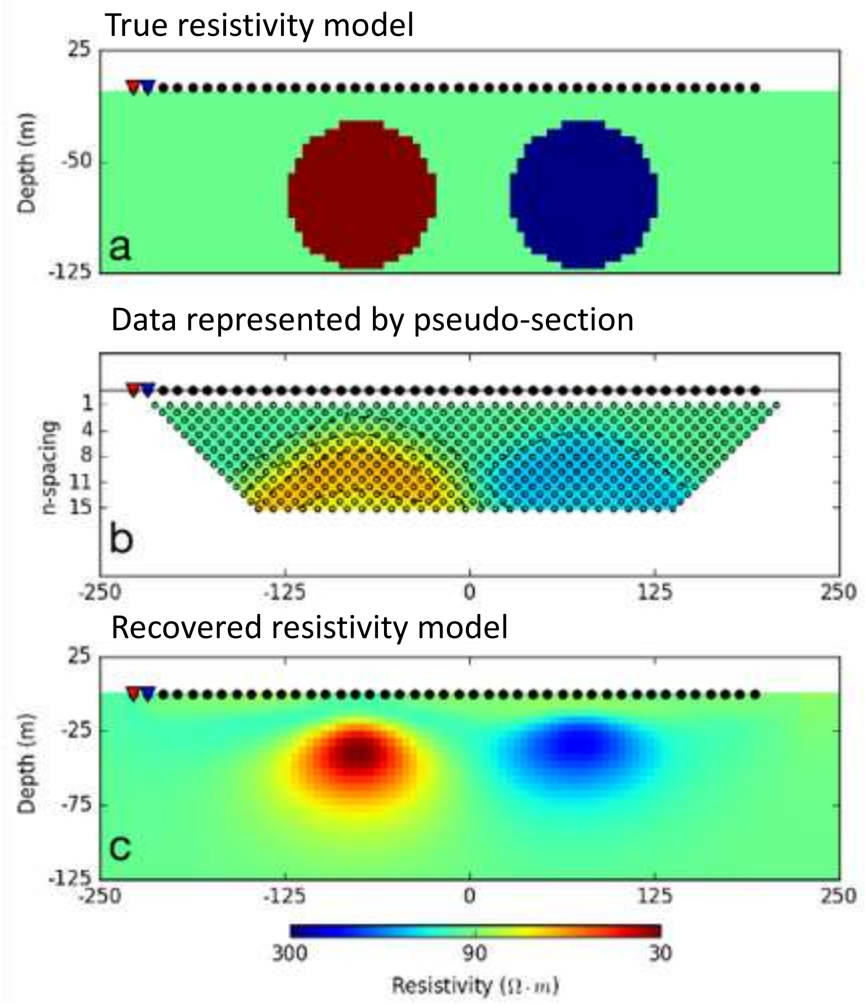
Electrical 3: Applications and IP

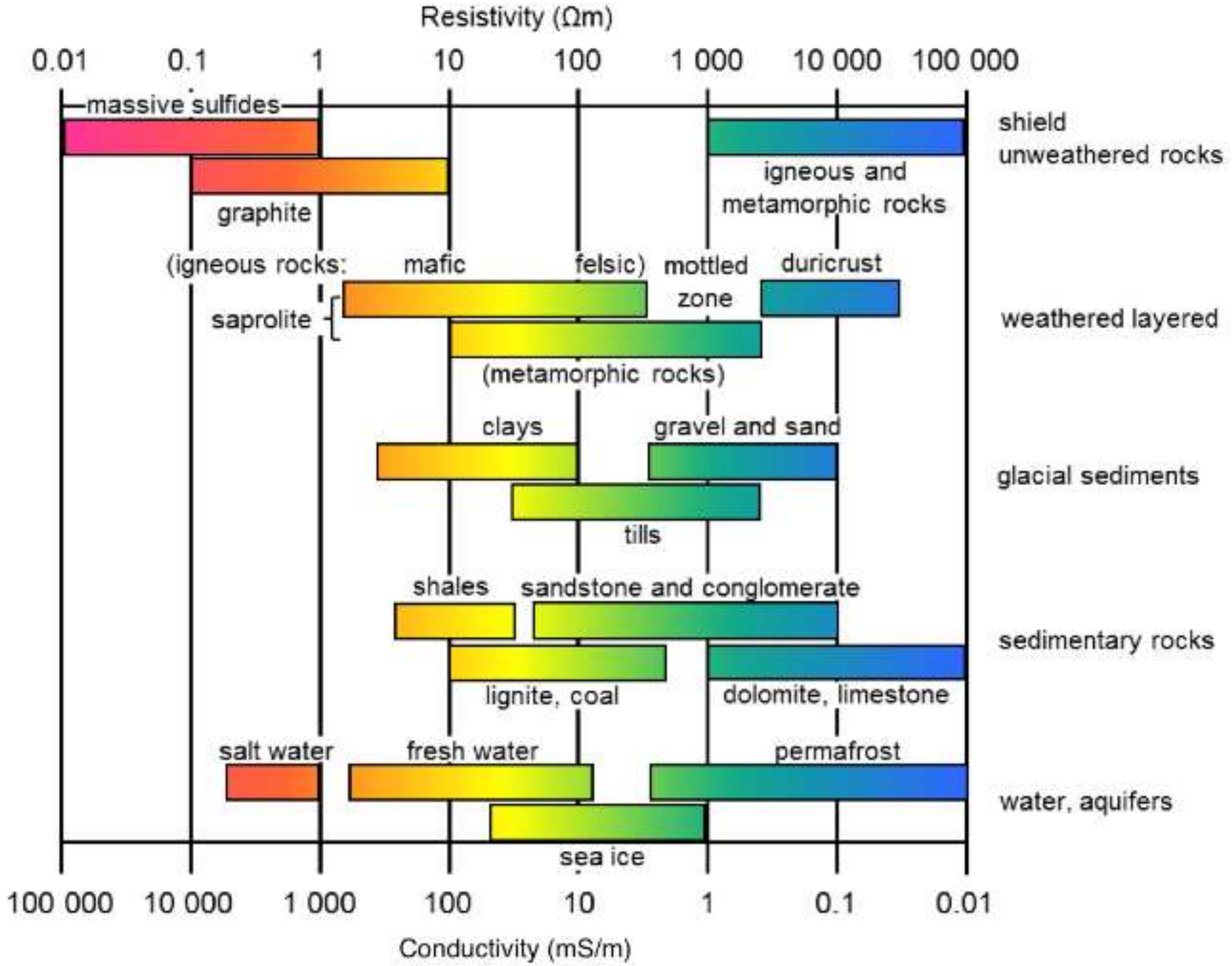
Instructor: Dikun Yang

Feb – May, 2019

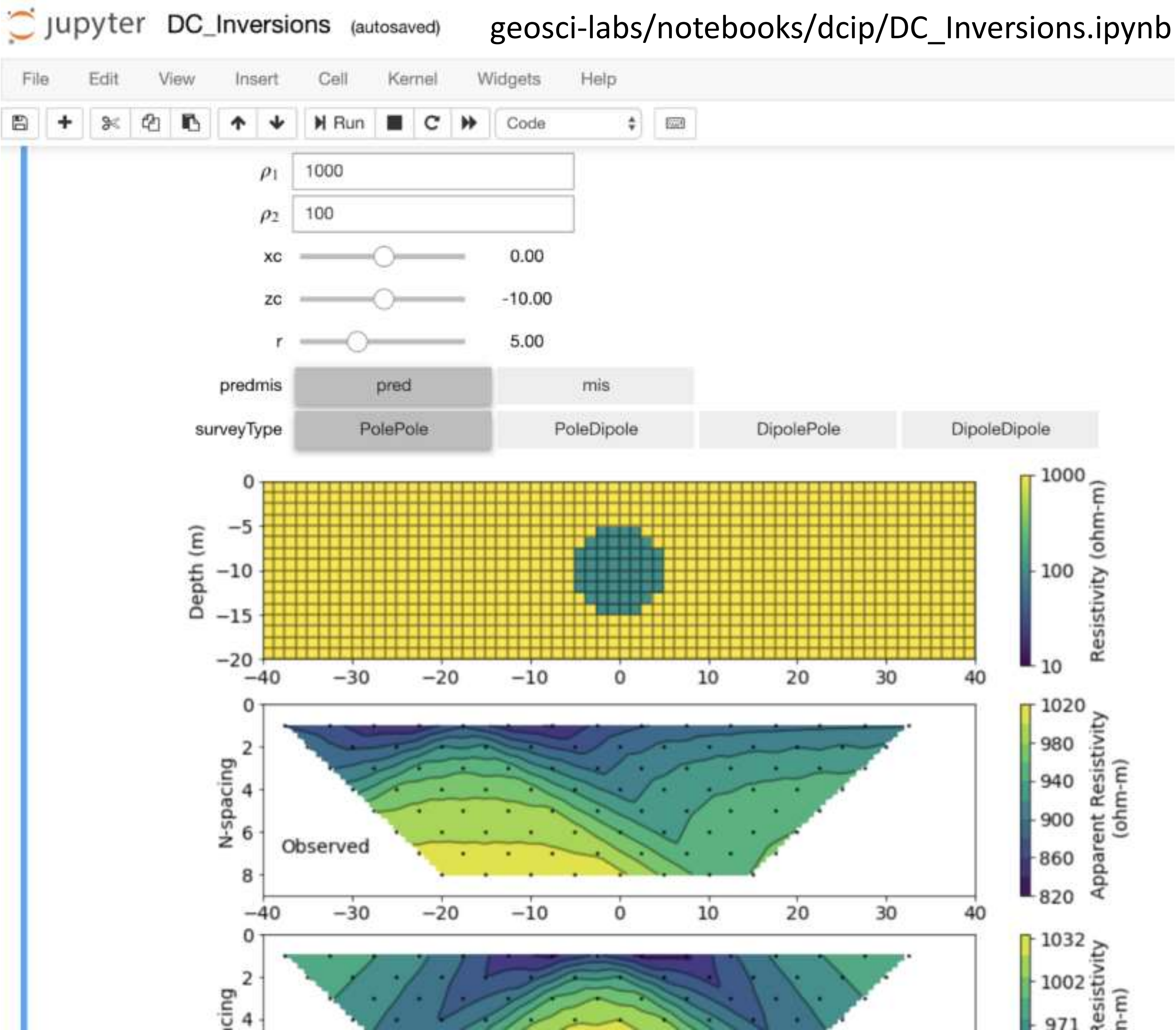


Characterization of the Earth Using Resistivity





geosci-labs/notebooks/dcip/DC_Inversions.ipynb



Exercise:

- Parameterize the model as a sphere (cylinder) in a uniform half-space
- Find a model that fits the observed data by interactive manual inversion (trial-and-error method)

Model section

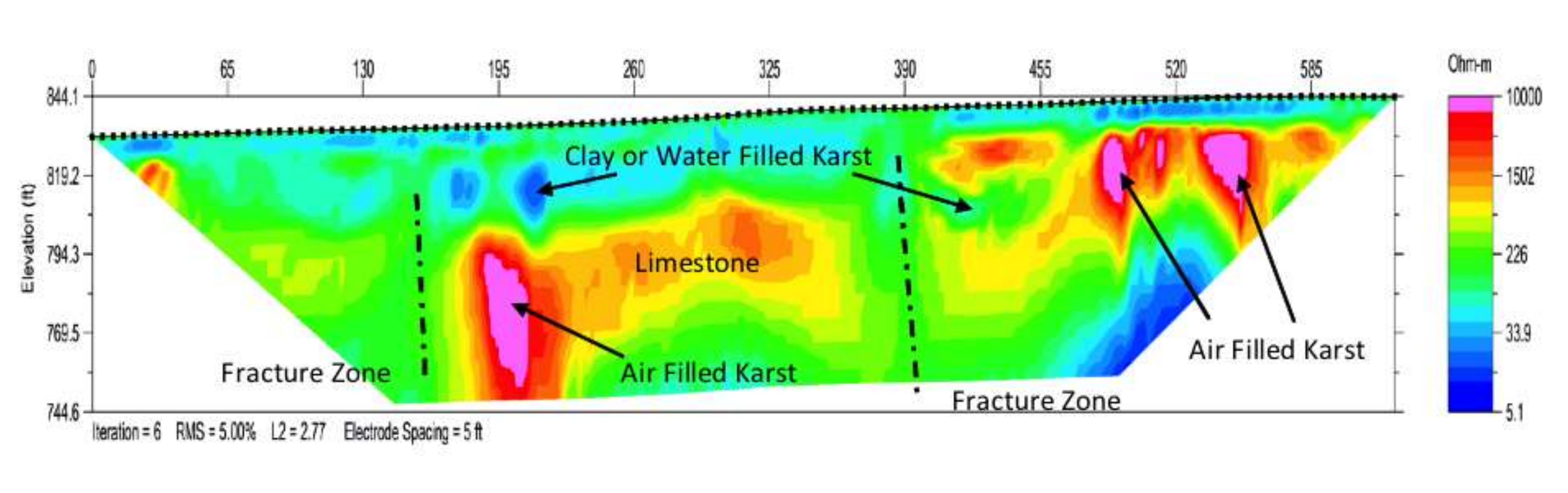
Observed data

Predicted or simulated data

Environmental

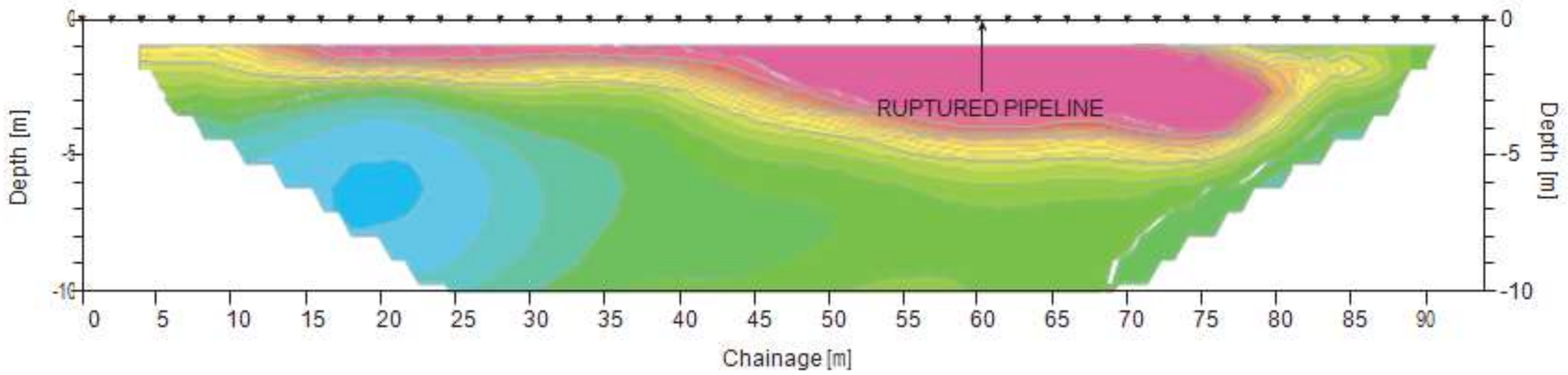
Karst

- Air-filled
- Water-filled

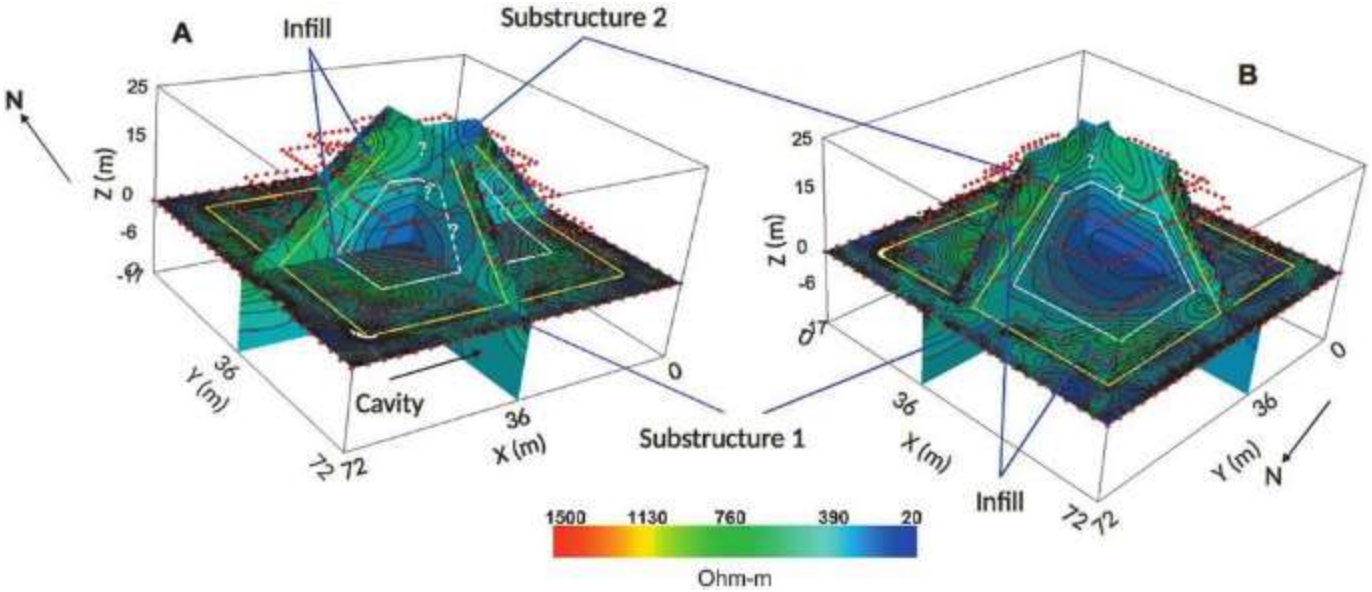


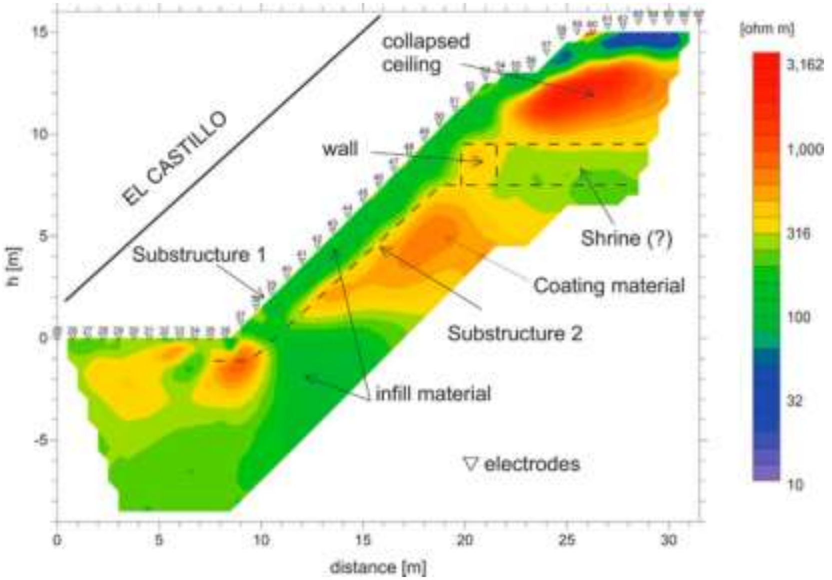
Oil spill

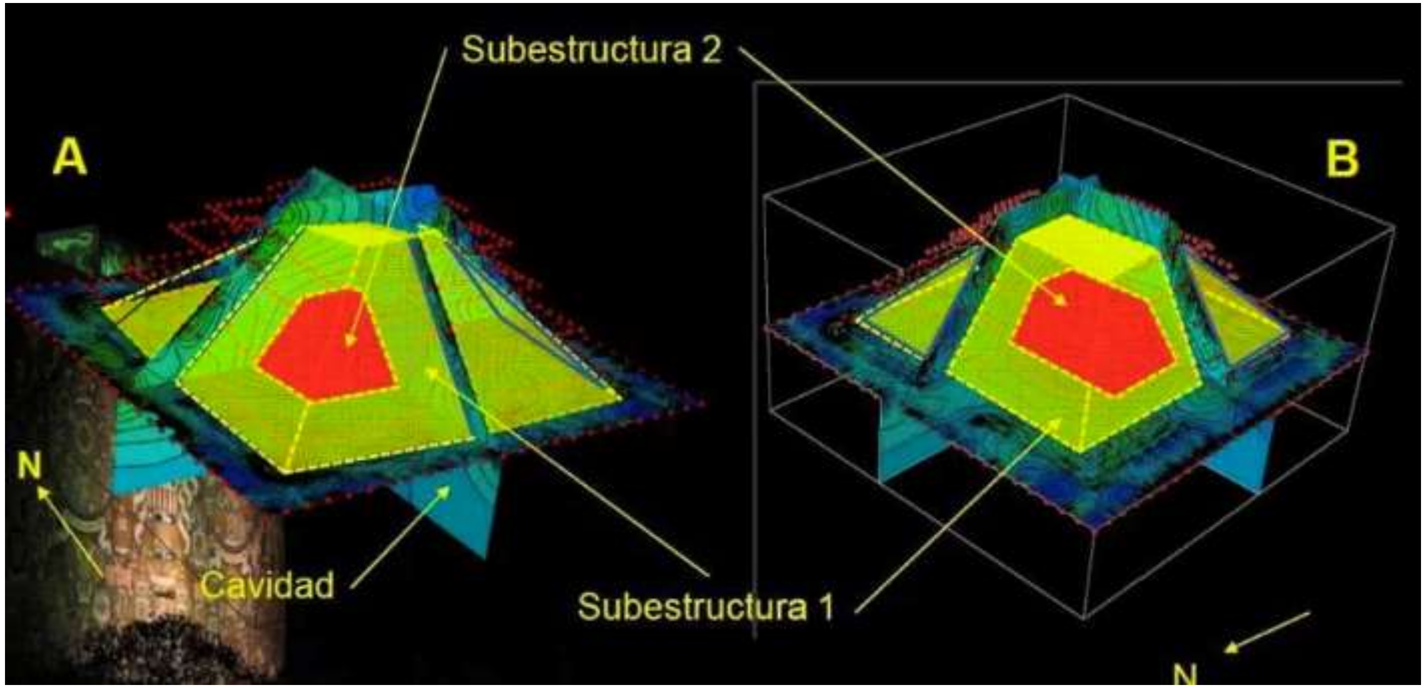
- Hydrocarbon: resistive



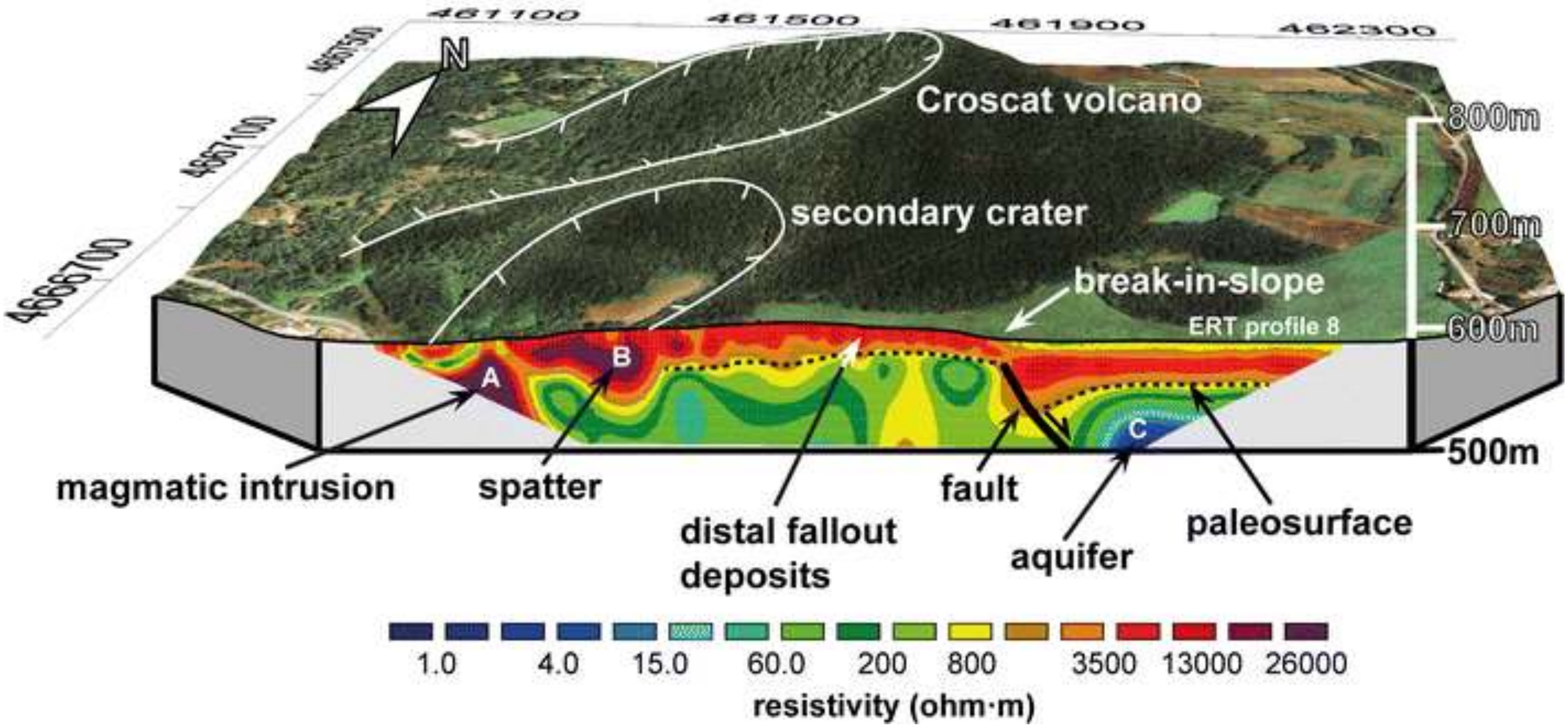
Archaeology







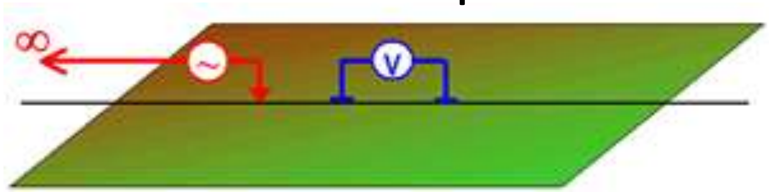
Volcano

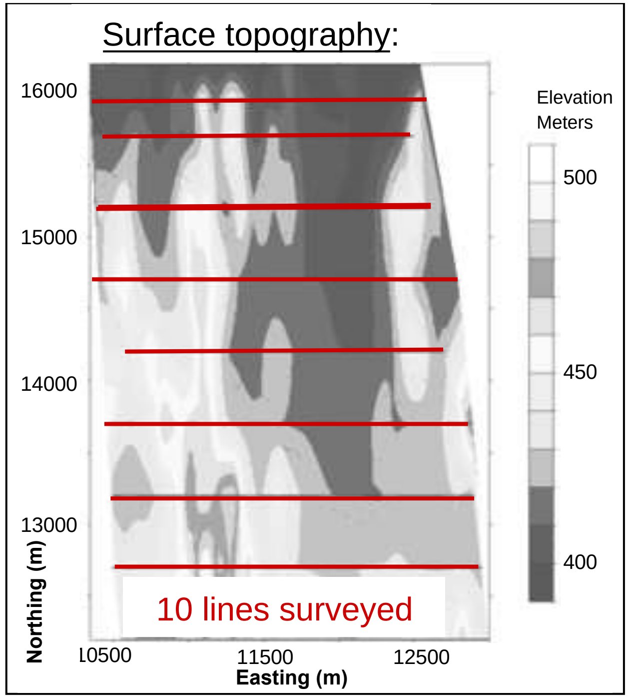


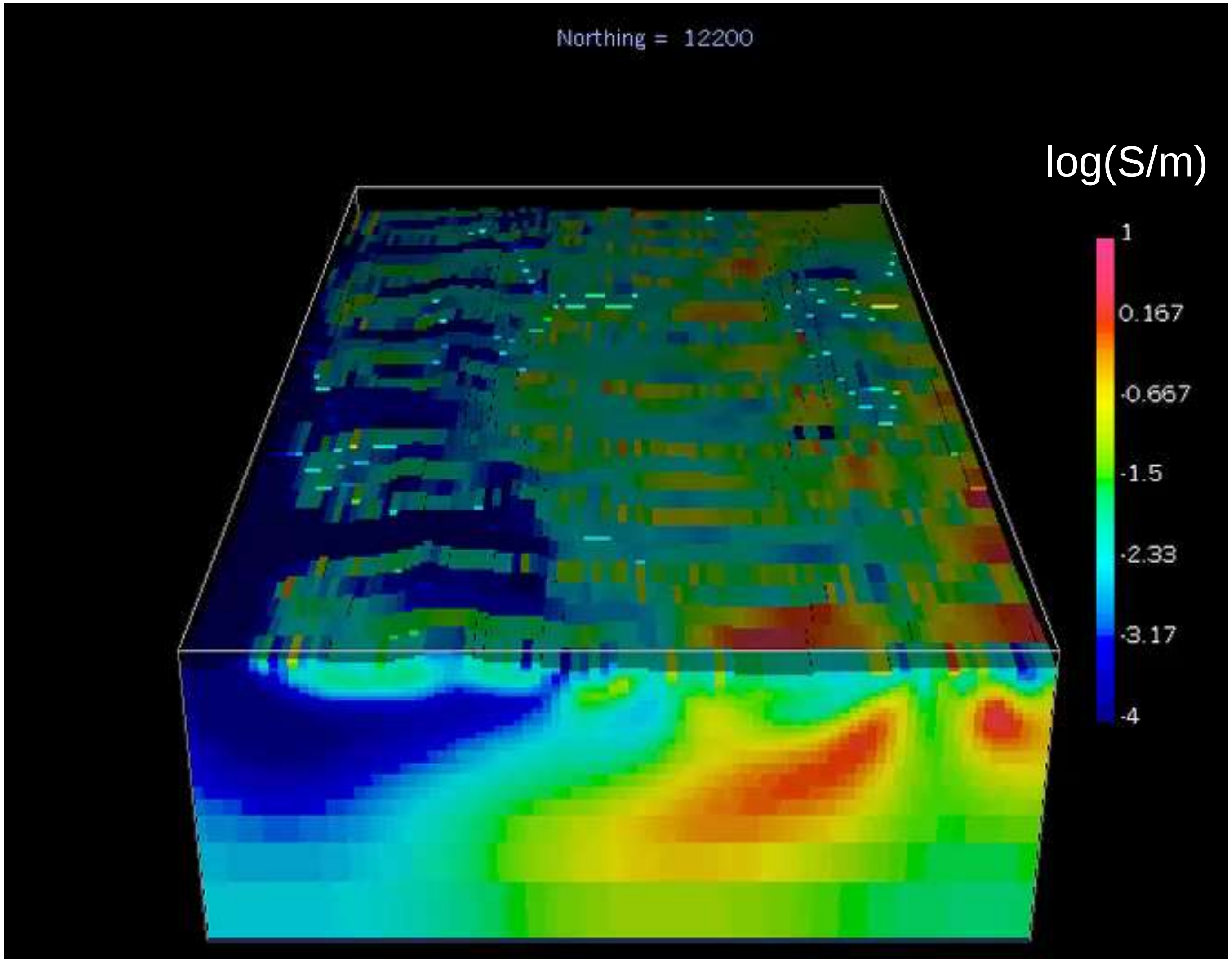
461100
461500
461900
462300
4667500
4667100
4666700
N
Croscat volcano
secondary crater
break-in-slope
ERT profile 8
800m
700m
600m
500m
A
B
C
magmatic intrusion
spatter
distal fallout deposits
fault
aquifer
paleosurface
1.0
4.0
15.0
60.0
200
800
3500
13000
26000
resistivity (ohm·m)

3D Electrical Imaging for Mining Exploration

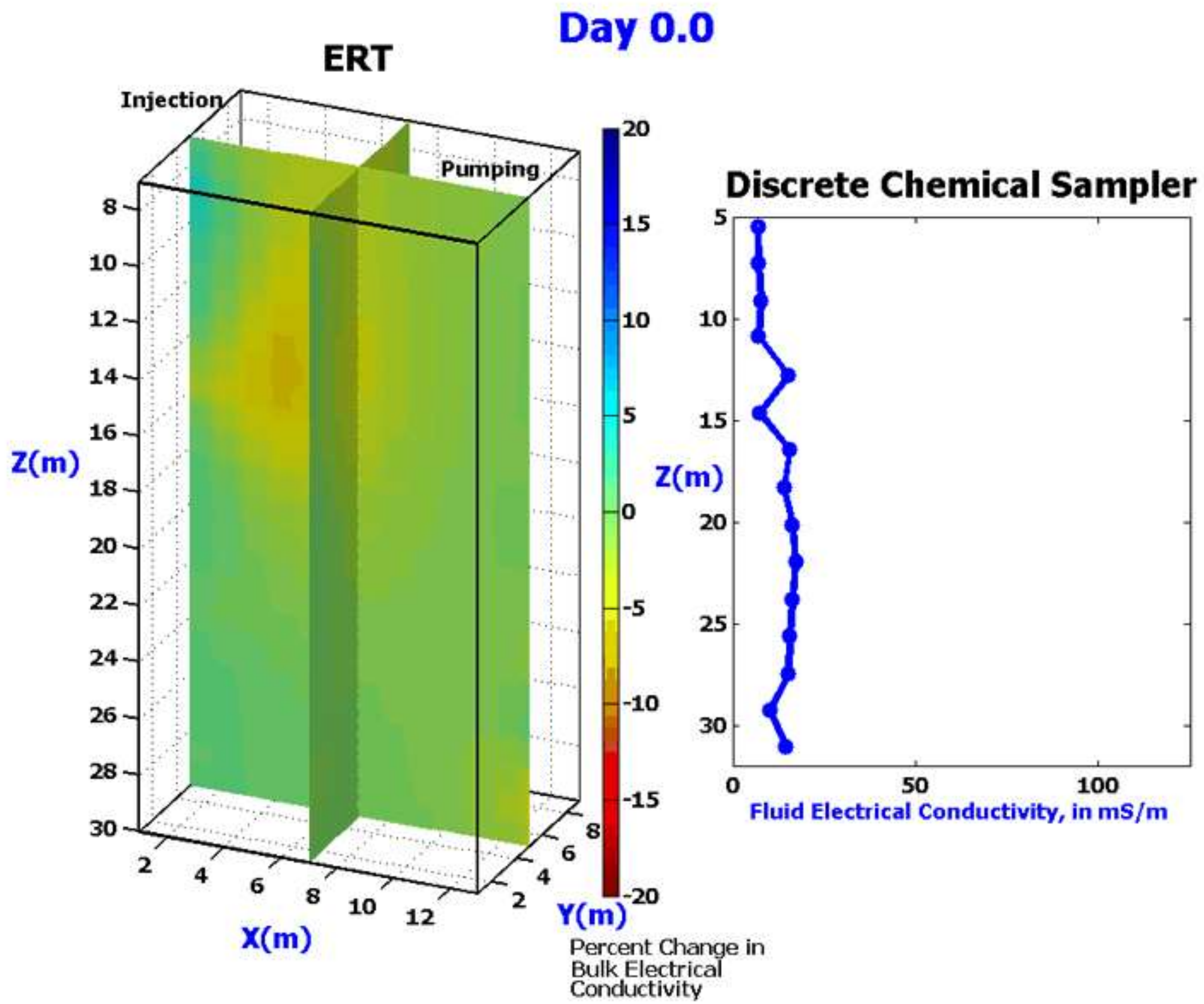
Pole-dipole



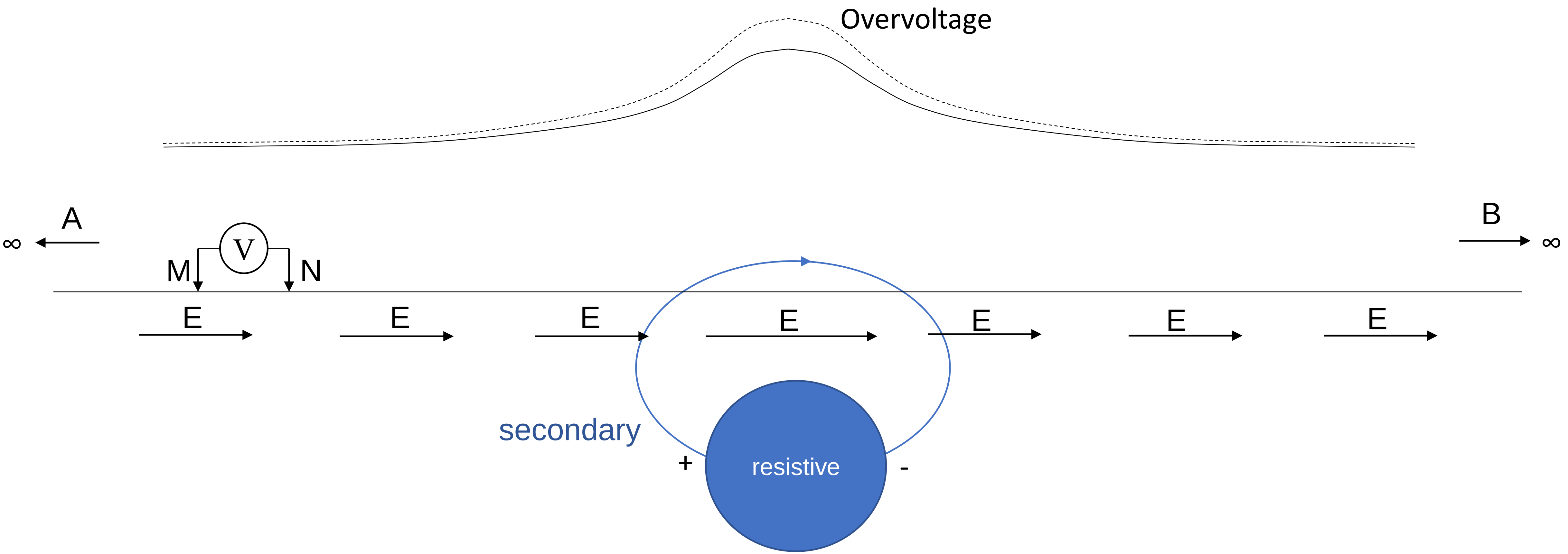




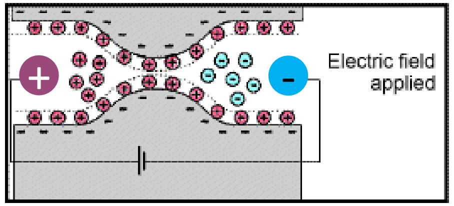
4D ERT for Hydrological Monitoring



Induced Polarization (IP)



- If narrow pore throats exist
- Ions accumulate at narrows in response to external field
- Additional electrical dipole moment
- Cause overvoltage in measured potentials



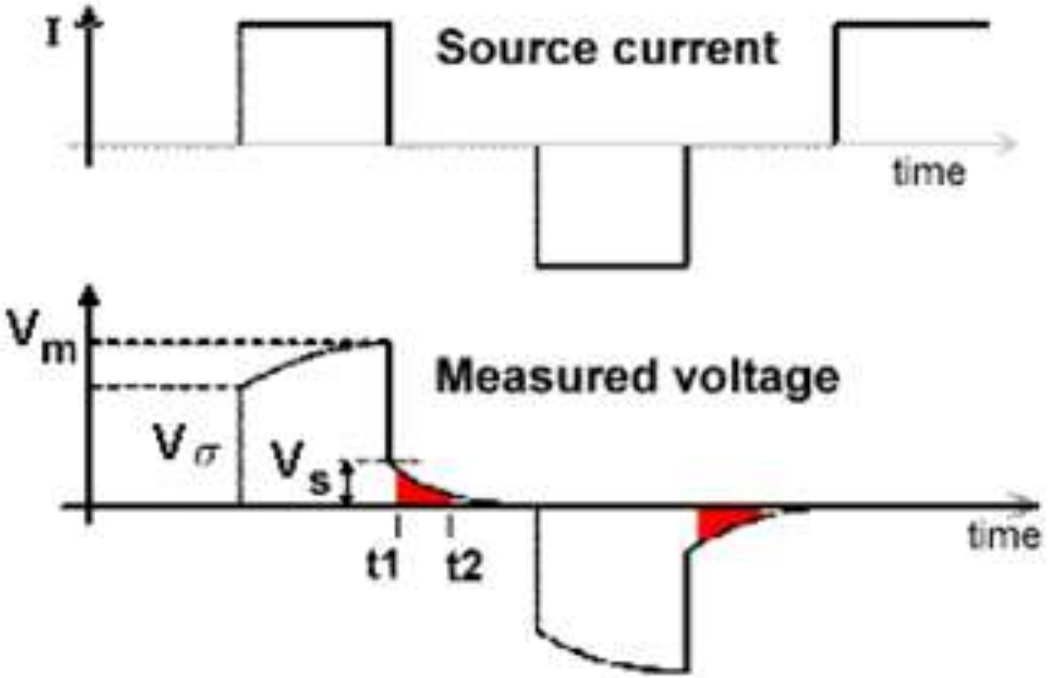
IP Effect in DC Data

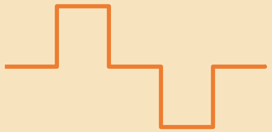
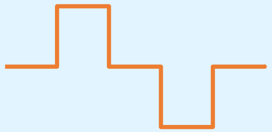
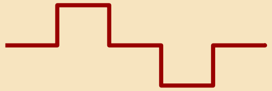
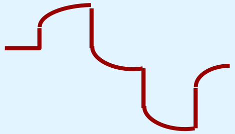
1) Voltage applied by transmitter
   → instantaneous (V_σ) increase due to ρ
2) Voltage increases as ions accumulate:

$$V_{off}(t) = V_s\, e^{-t/\tau}$$

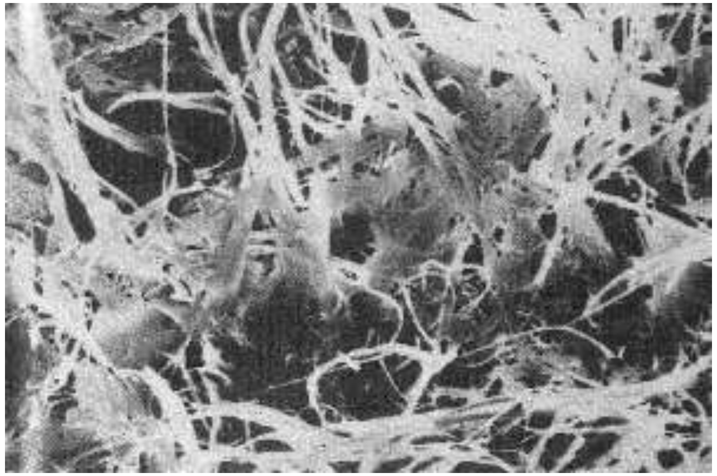
3) Saturation of ionic charges
   → DC voltage ($V_m = V_\sigma + V_s$)
4) Voltage from transmitter removed
   → instantaneous loss in secondary potential (equal to V_σ)
5) IP voltage discharges during off-time

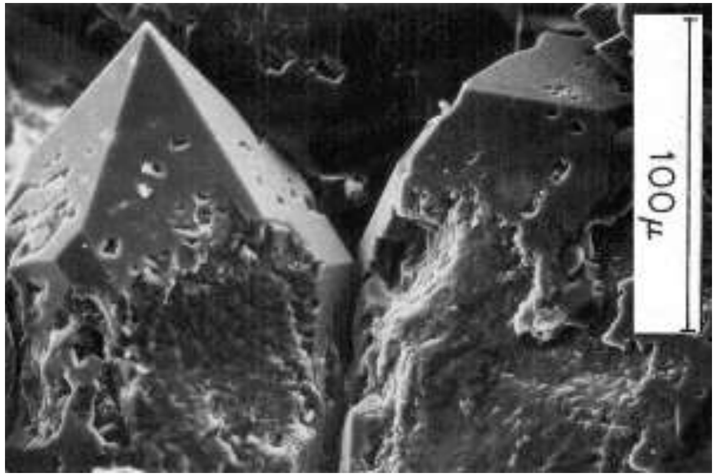
$$V_{on}(t) = V_\sigma + V_s\left[1 - e^{-t/\tau}\right]$$



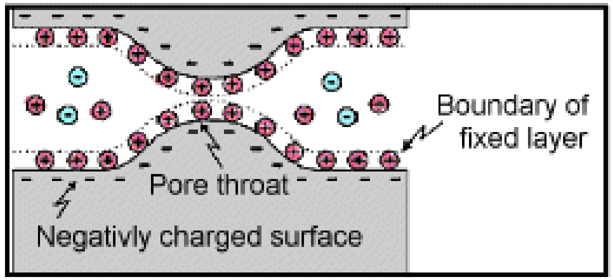
	Not chargeable	Chargeable
Source (Amps)		
Potential (Volts)		

Chargeability – Capability of Holding Charges

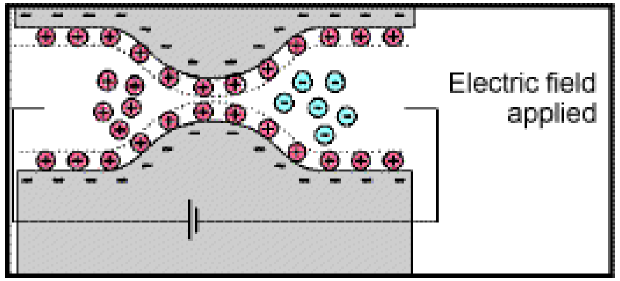




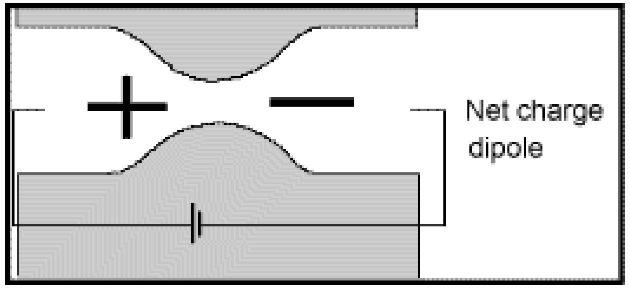
Type 1: Membrane polarization - ions accumulate at pore throat



Equilibrium State

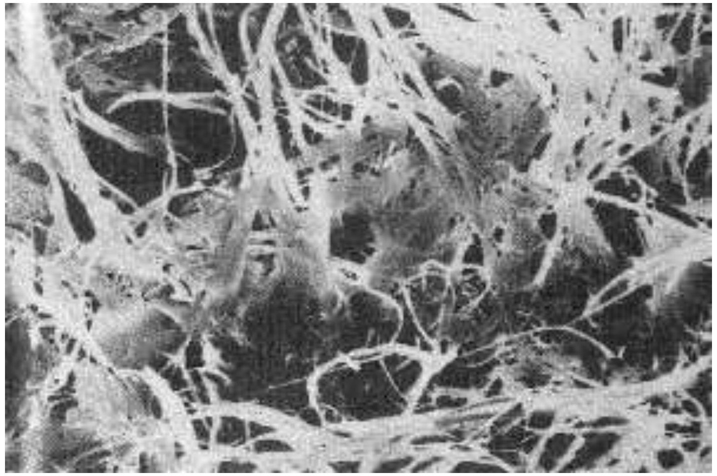


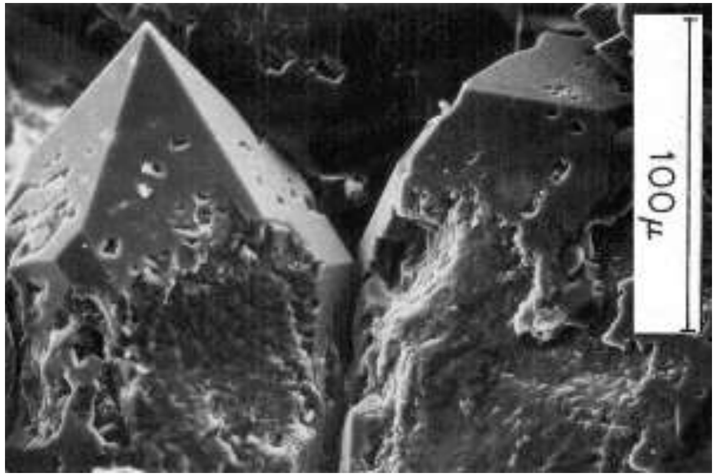
Voltage Applied



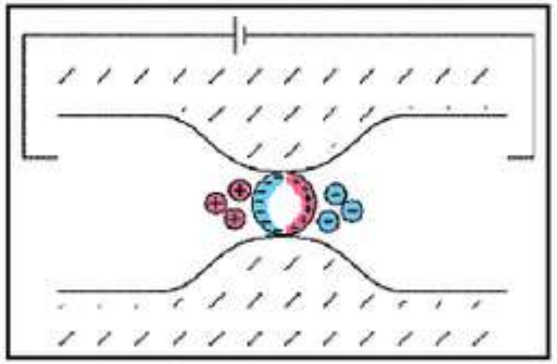
Separation of +ve and –ve ions

Chargeability – Capability of Holding Charges



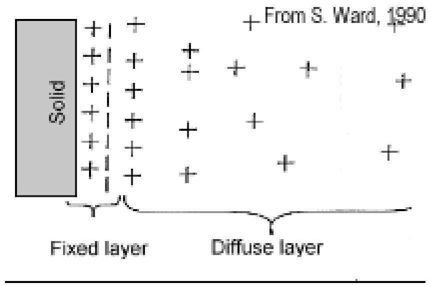


Type 2: Electrode polarization: Ions accumulate at metals



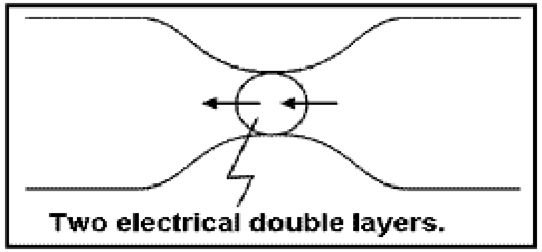
- Pore space is blocked by metallic particles
- Metallic particles become electrically charged and attract nearby ions
- This is why the waveform of dc survey switches polarity

Electric double layer



Hypothetical anomalous ion distribution near a solid-liquid interface.

Net electric dipole moment

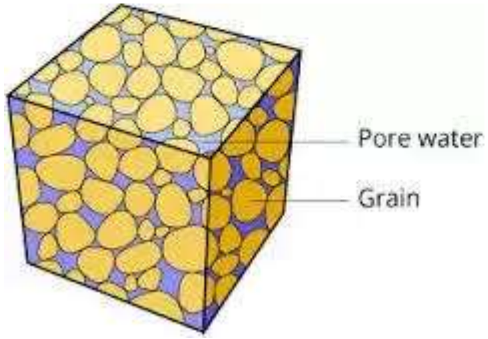


Chargeability – A Diagnostic Physical Property

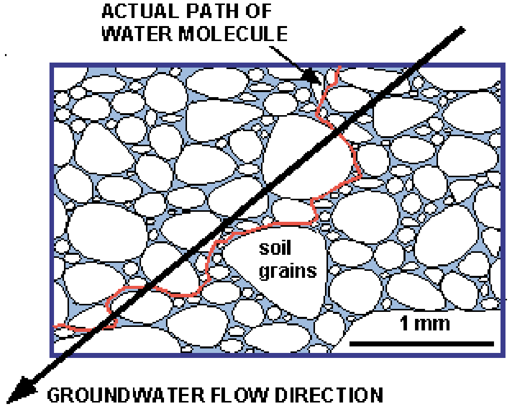
Chargeability is not thoroughly understood in theory but it is often related to:

Sulphide Mineralization

Clays



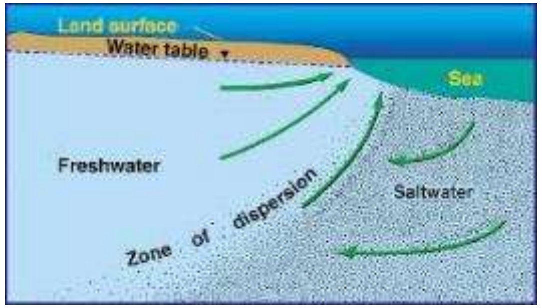
Pore-Water Salinity



Tortuosity

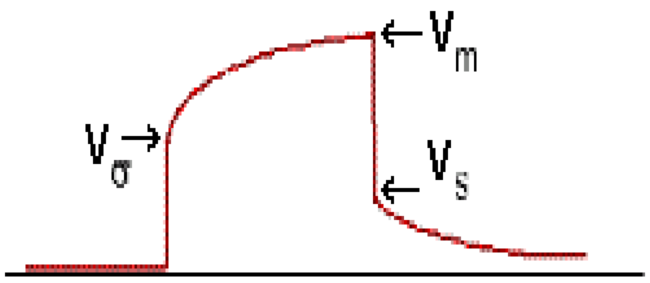
Use chargeability to characterize the earth:

- Environmental: Contamination, groundwater…
- Mining: Disseminated sulphides (porphyry)
- Oil/gas:



Time-domain IP Data

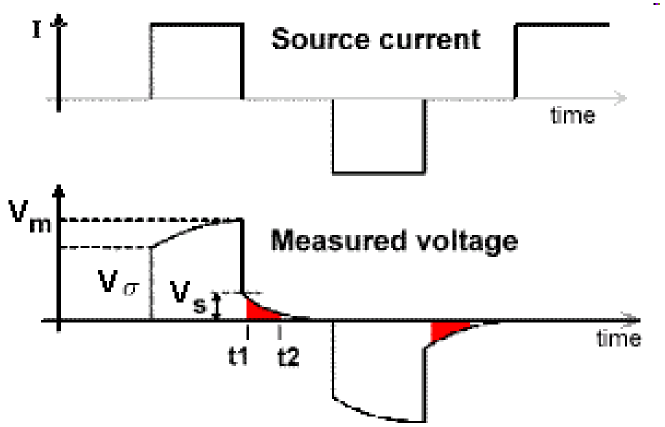
Intrinsic chargeability (dimensionless) $$\eta = \frac{V_s}{V_m}$$



$$d_{IP} = \frac{V_s(t)}{V_m}$$ mV/V

Integrate over the decay (discharge period)

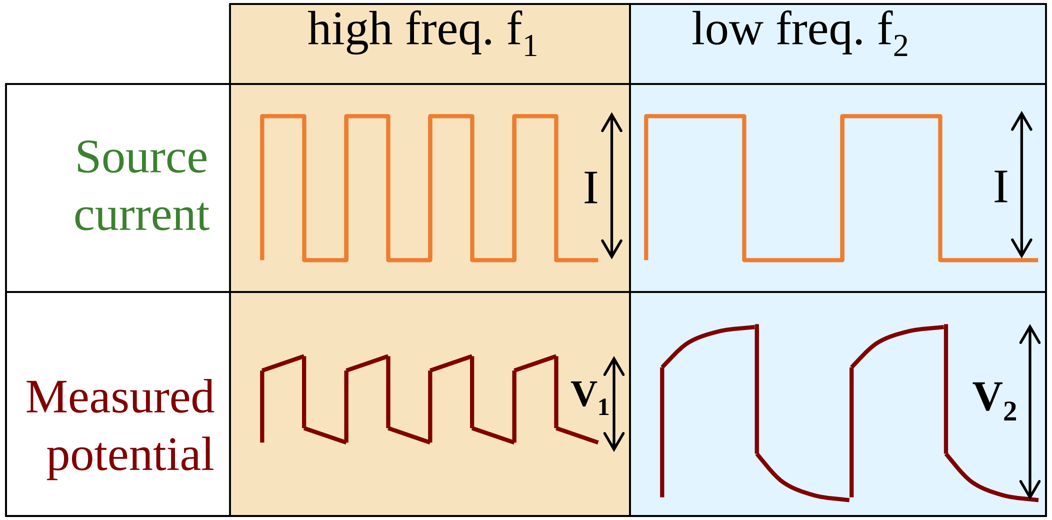
$$d_{IP} = \frac{1}{V_m}\int_{t_1}^{t_2} V_s(t)dt$$ (msec)



Frequency-domain IP Data

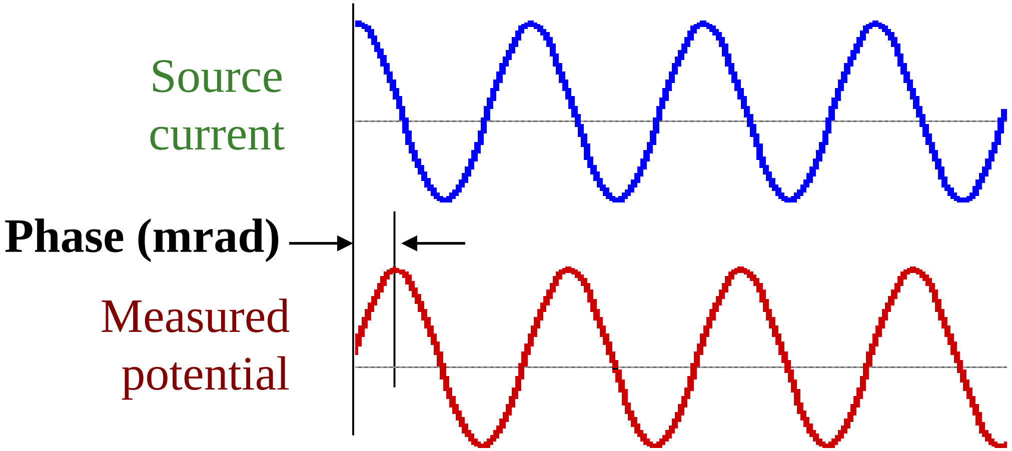
Percent frequency effect:

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

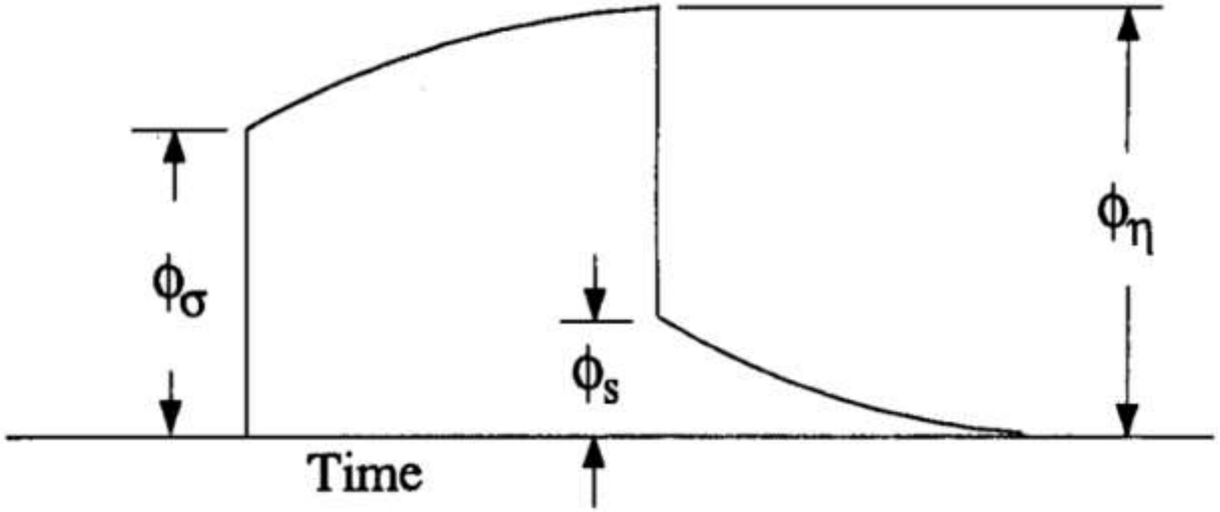


Phase:

$$d_{IP} = \textbf{phase (mrad)}$$



IP Modeling



Chargeability: alter conductivity

$$\sigma = \sigma(1 - \eta)$$

$$\phi_\eta = \mathcal{F}_{dc}[\sigma(1 - \eta)]$$

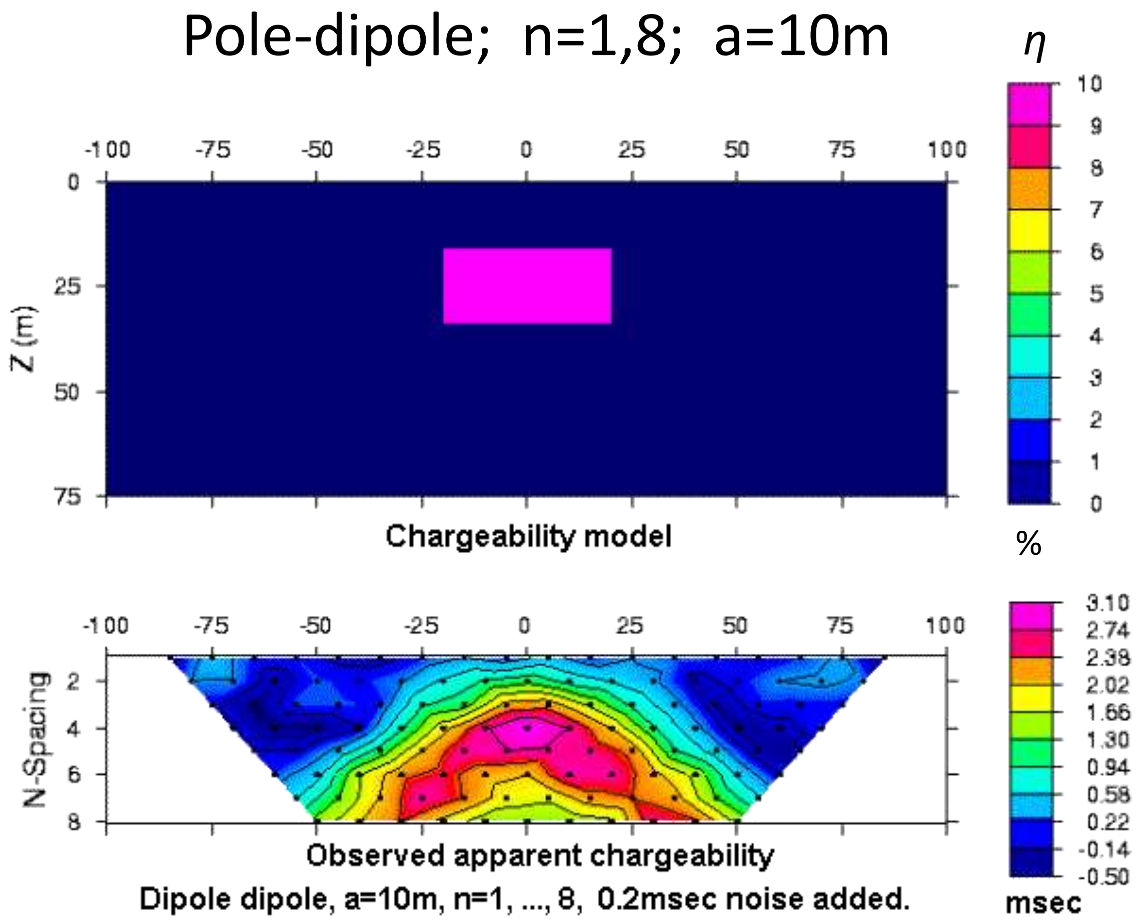
Apparent chargeability

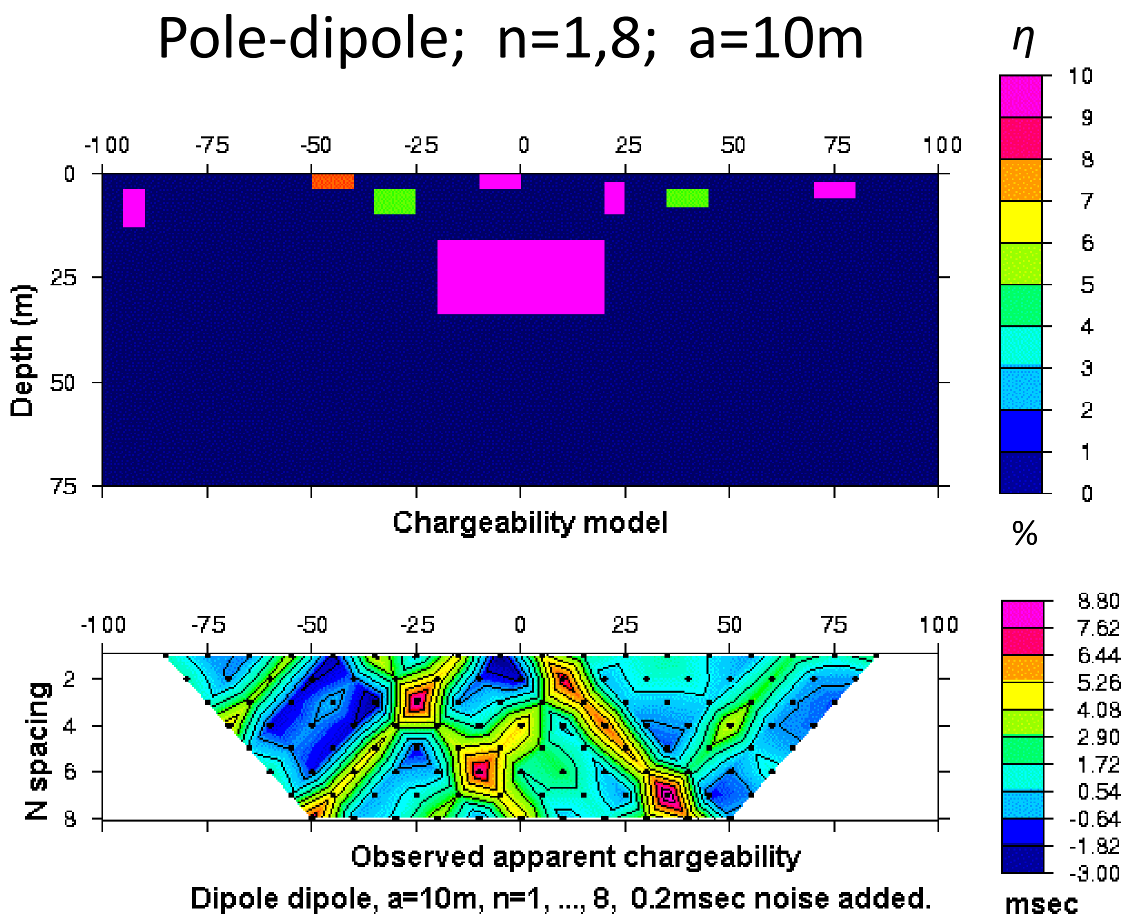
$$\eta_a = \frac{\phi_s}{\phi_\eta} = \frac{\phi_\eta - \phi_\sigma}{\phi_\eta}$$

$$\eta_a = \frac{\mathcal{F}_{dc}[\sigma(1 - \eta)] - \mathcal{F}_{dc}[\sigma]}{\mathcal{F}_{dc}[\sigma(1 - \eta)]}$$

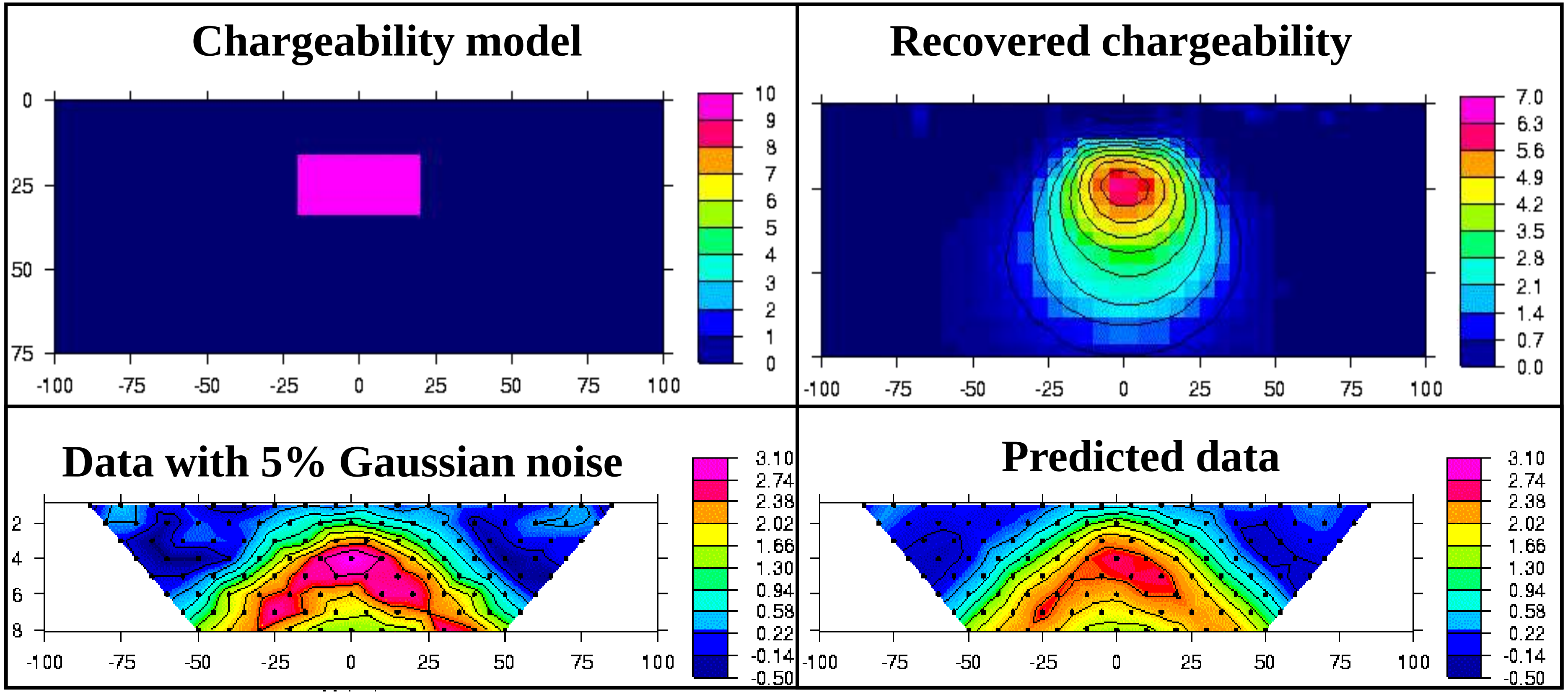
Oldenburg, D. W., and Y. Li, 1994, Inversion of induced polarization data: Geophysics, **59**, 1327-1341.

IP Data of Chargeable Blocks

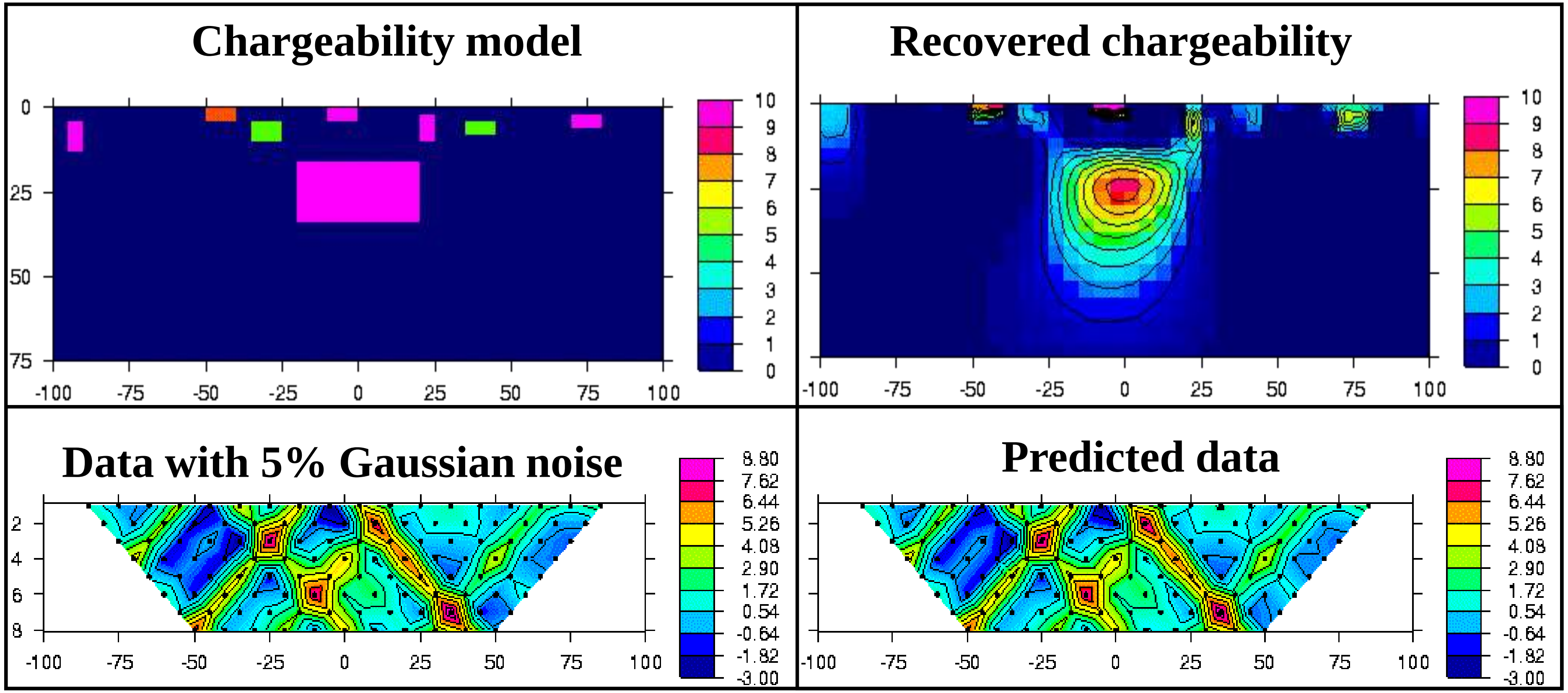




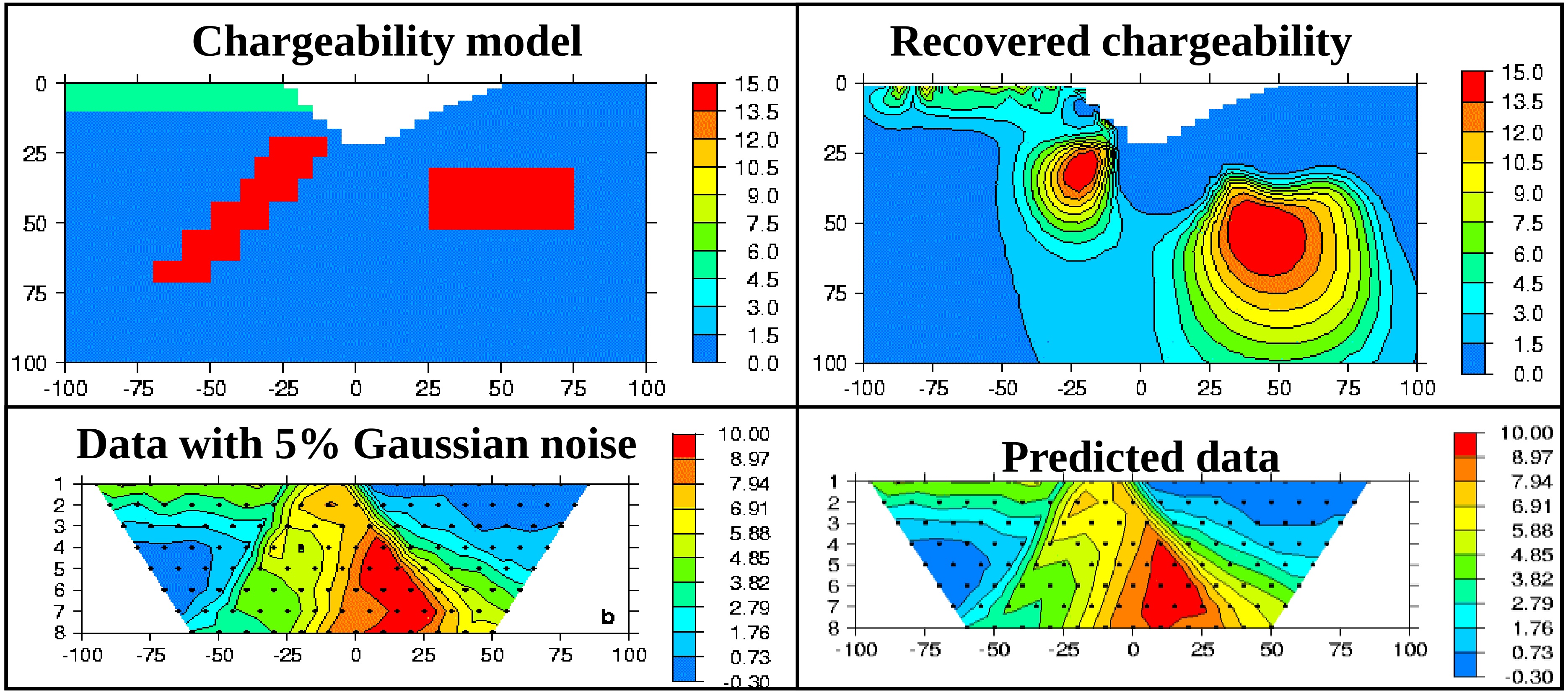
IP Inversion for Chargeability



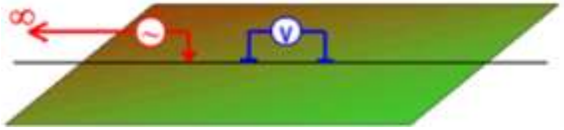
IP Inversion for Chargeability

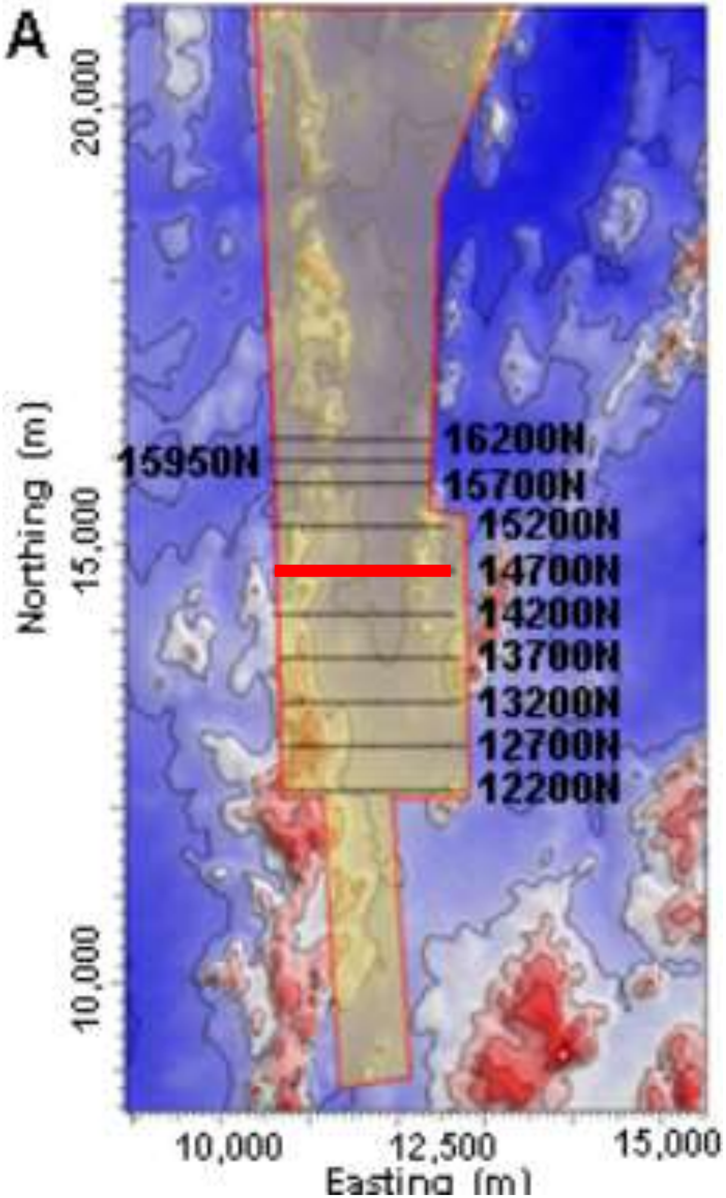


IP Inversion for Chargeability

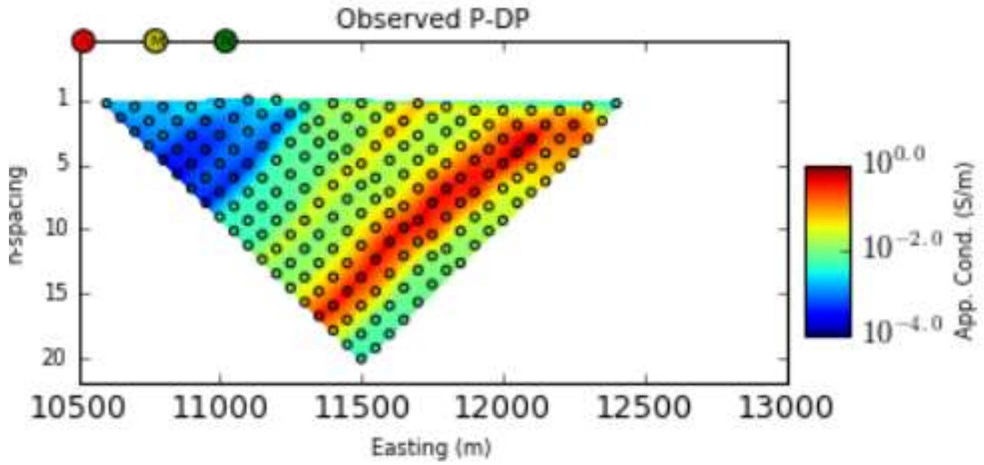


Mt. Isa Mineral Exploration

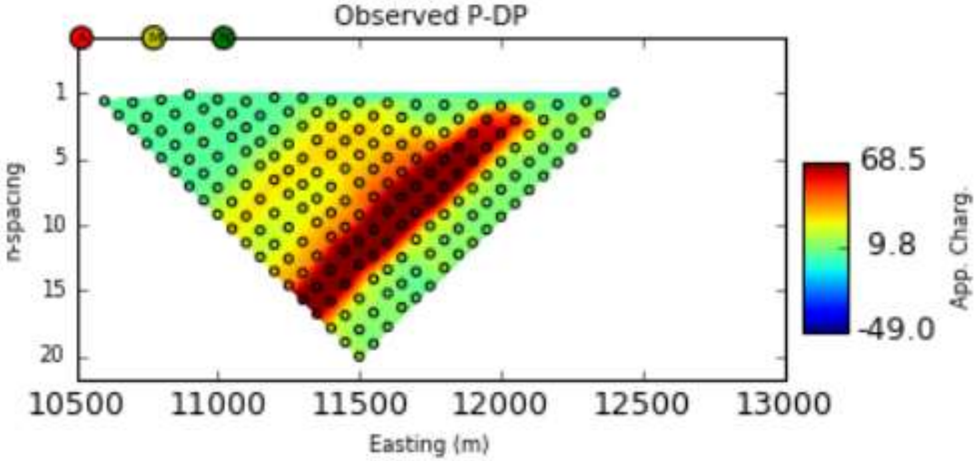




Conductivity pseudo-section



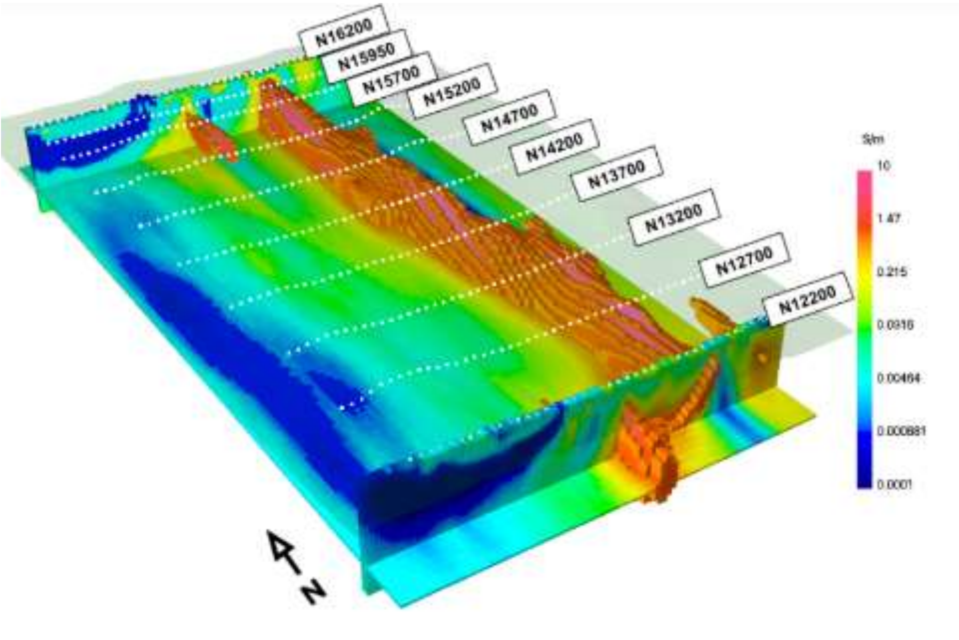
Chargeability pseudo-section



3D DC/IP Inversion

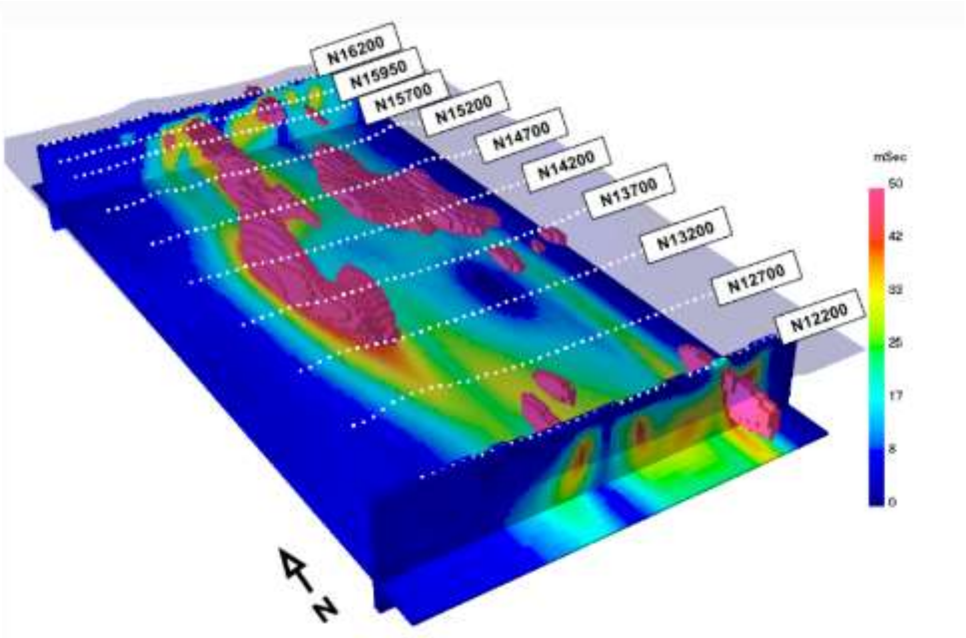
Apparent resistivity data ($\boldsymbol{\rho_a}$)

Resistivity model (ρ)



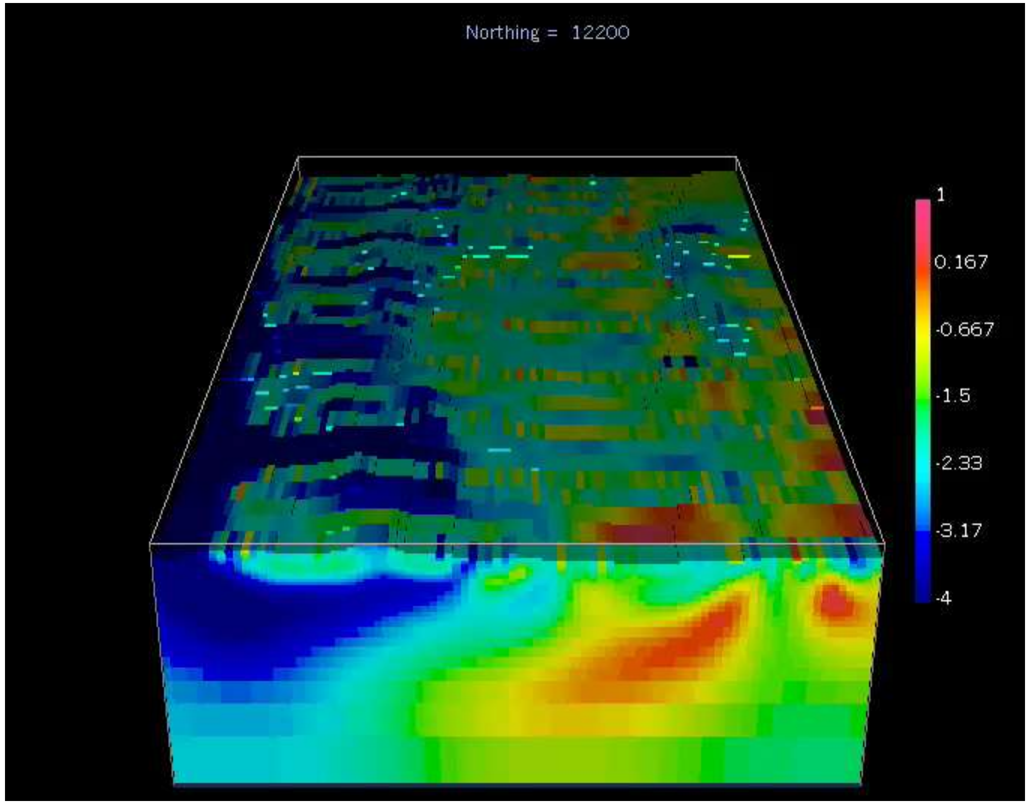
Integrated chargeability data ($\boldsymbol{d_{IP}}$)

Chargeability model (η)

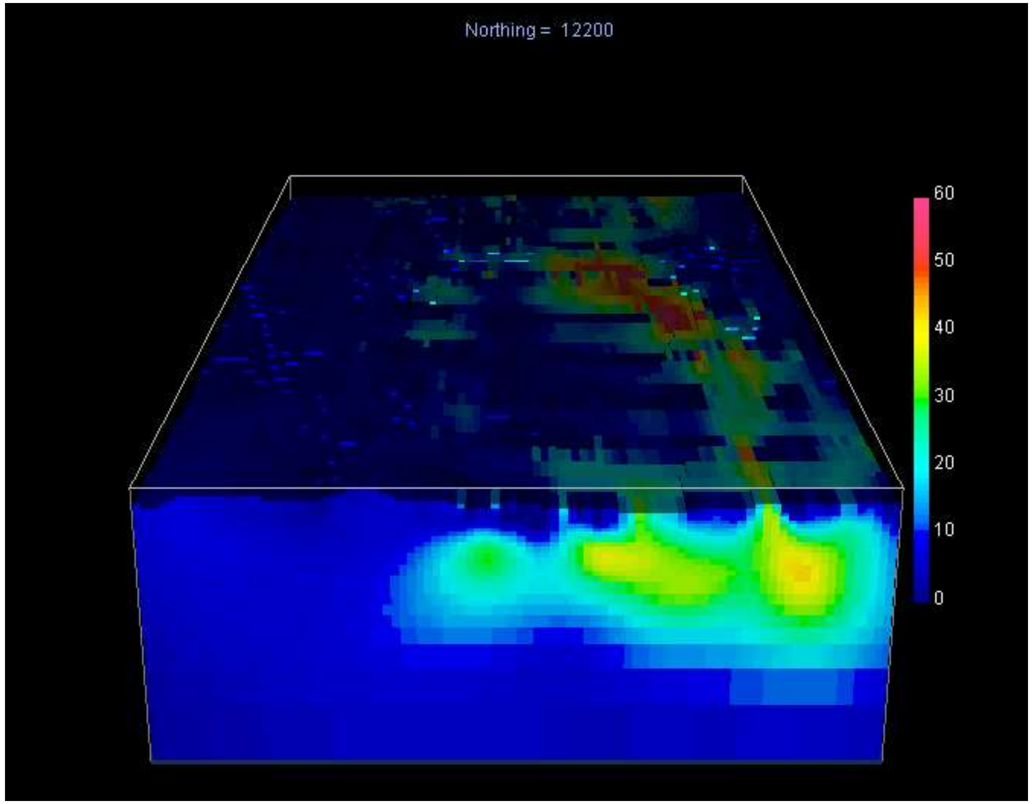


Consistent Models?

Volume rendered resistivity model



Volume rendered chargeability model



Summary

- ERT applications
  - Environmental
  - Archaeology
  - Volcano
  - Mining
  - Hydrological
- IP effect
  - Physical intuition
  - Mechanism of IP
  - IP effect in data
  - Chargeability inversion