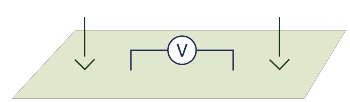
DC Resistivity

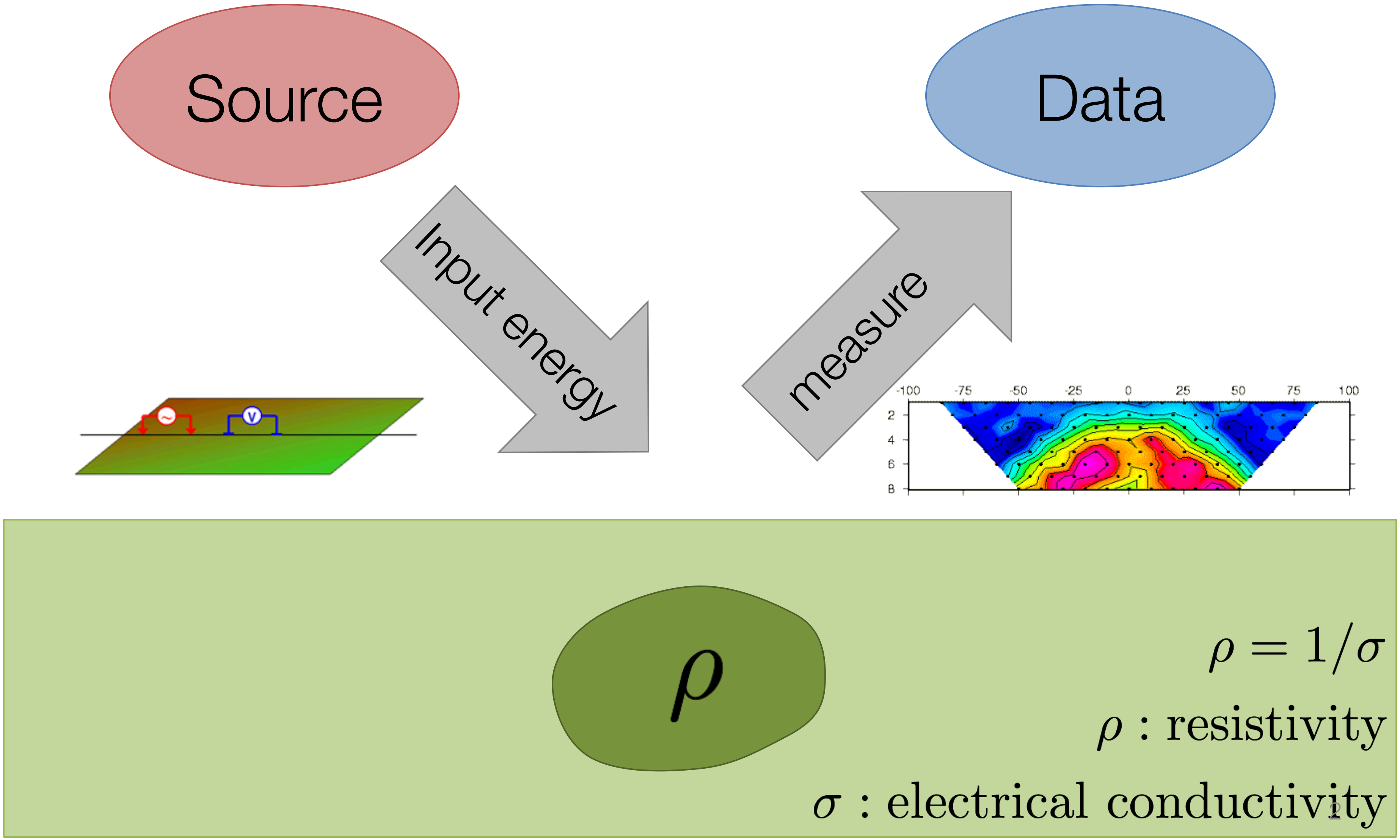
DISC

2017

Electromagnetics
Fundamentals and Applications

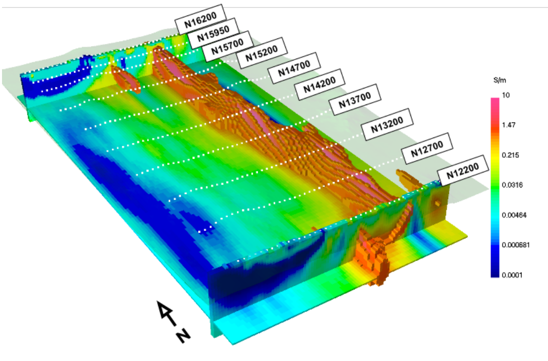


DC Resistivity Survey



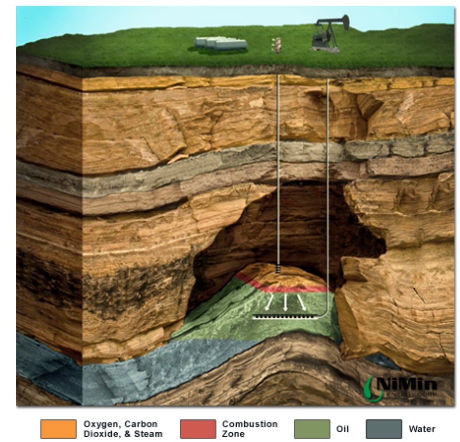
Motivation

Minerals

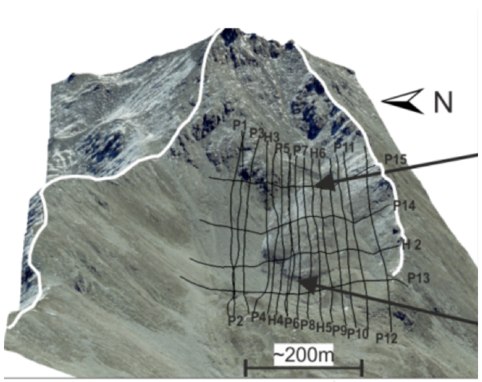


Water inflow in mine

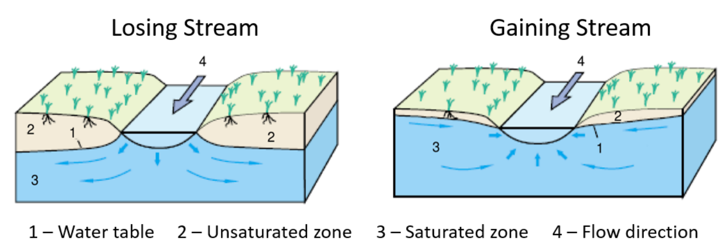
Oil and Gas



Geotechnical

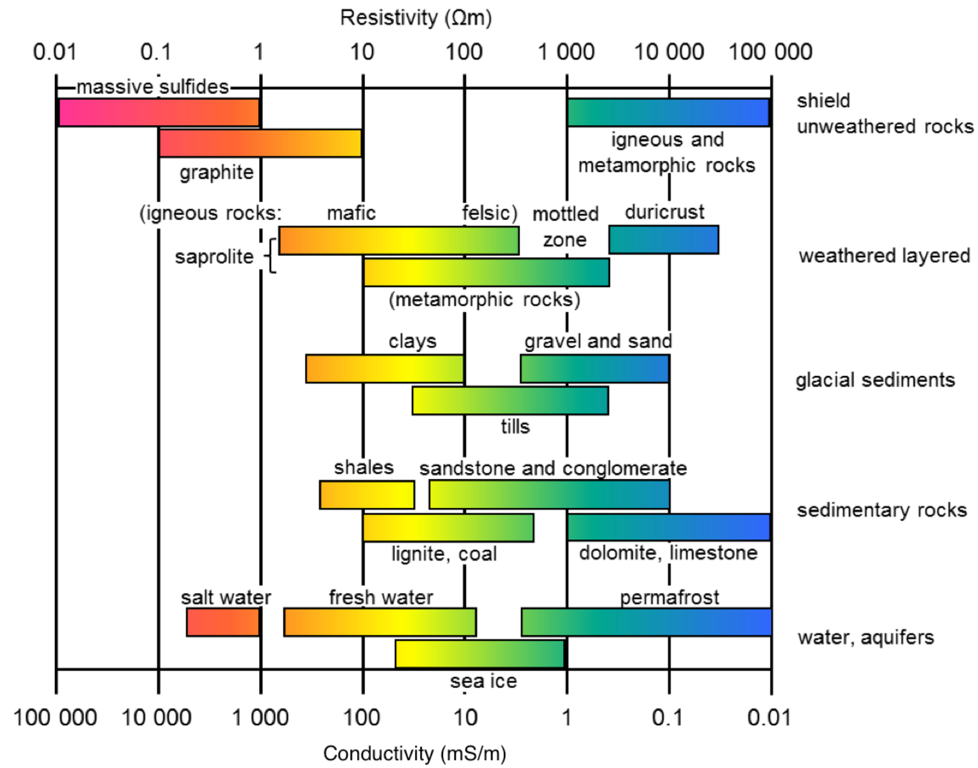


Groundwater



Electrical conductivity

- DC resistivity is sensitive to:
  - σ: Conductivity [S/m]
  - ρ: Resistivity [Ωm]
  - $\sigma = 1/\rho$
- Varies over many orders of magnitude
- Depends on many factors:
  - Rock type
  - Porosity
  - Connectivity of pores
  - Nature of the fluid
  - Metallic content of the solid matrix



Outline

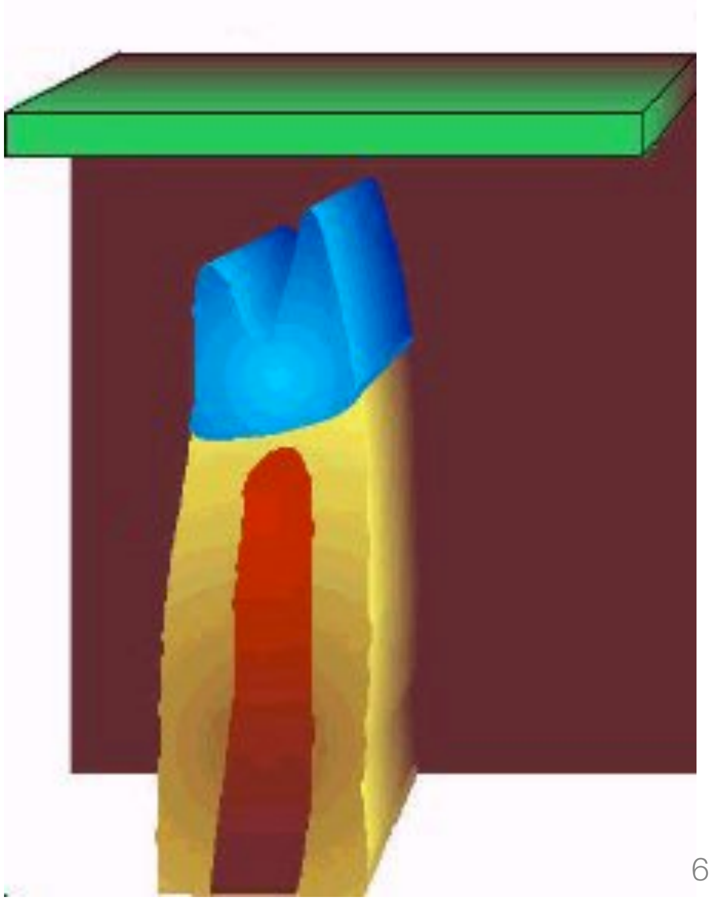
- Basic experiment
- Currents, charges, potentials and apparent resistivities
- Soundings, profiles and arrays
- Data, pseudosections and inversion
- Sensitivity
- Survey Design
- Case History – Mt Isa
- Effects of background resistivity

Basic Experiment

- **Target:**
  - Ore body. Mineralized regions less resistive than host

Elura Orebody Electrical resistivities

Rock Type	*Ohm-m*
Overburden	12
Host rocks	200
Gossan	420
Mineralization (pyritic)	0.6
Mineralization (pyrrhotite)	0.6



Basic Experiment

- **Target:**
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- **Setup:**
  - Tx: Current electrodes
  - Rx: Potential electrodes

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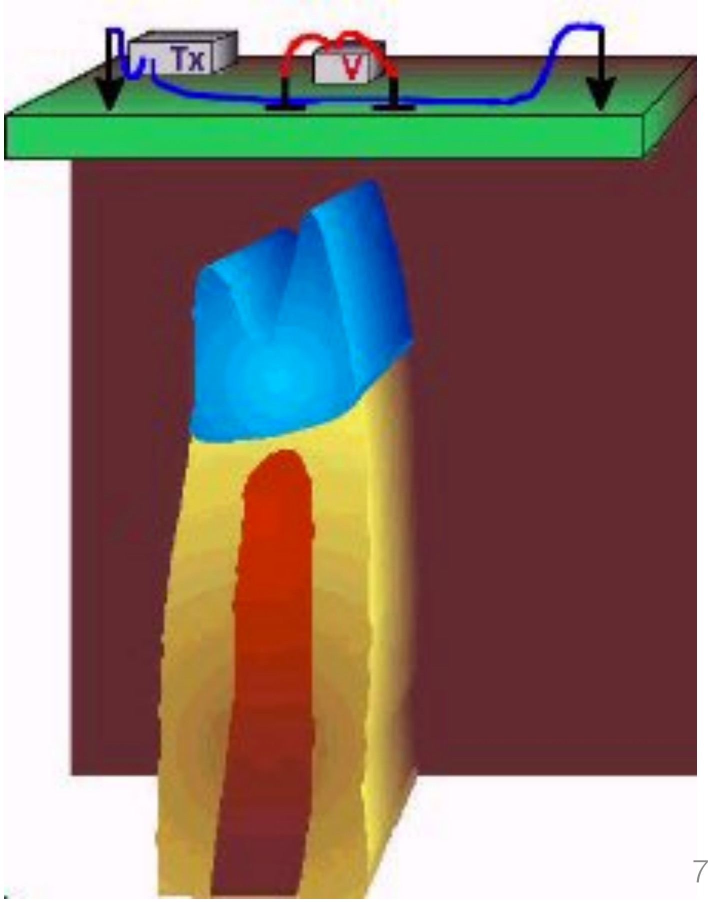

Basic Experiment

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- **Currents:**
  - Preferentially flow through conductors

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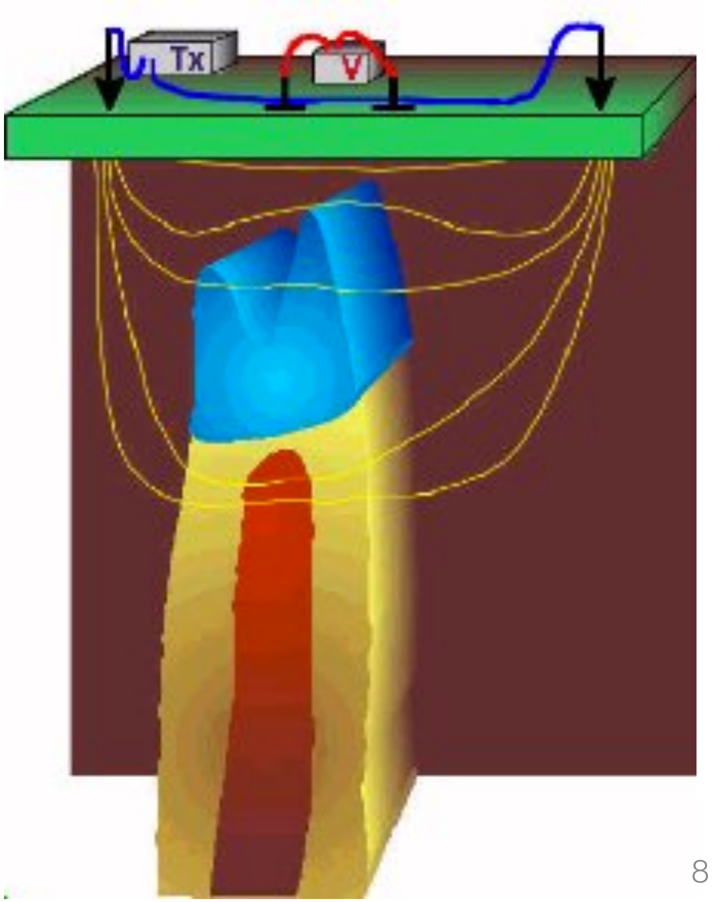

Basic Experiment

- **Target:**
  - Ore body. Mineralized regions less resistive than host
- **Setup:**
  - Tx: Current electrodes
  - Rx: Potential electrodes
- **Currents:**
  - Preferentially flow through conductors
- **Charges:**
  - Build up at interfaces

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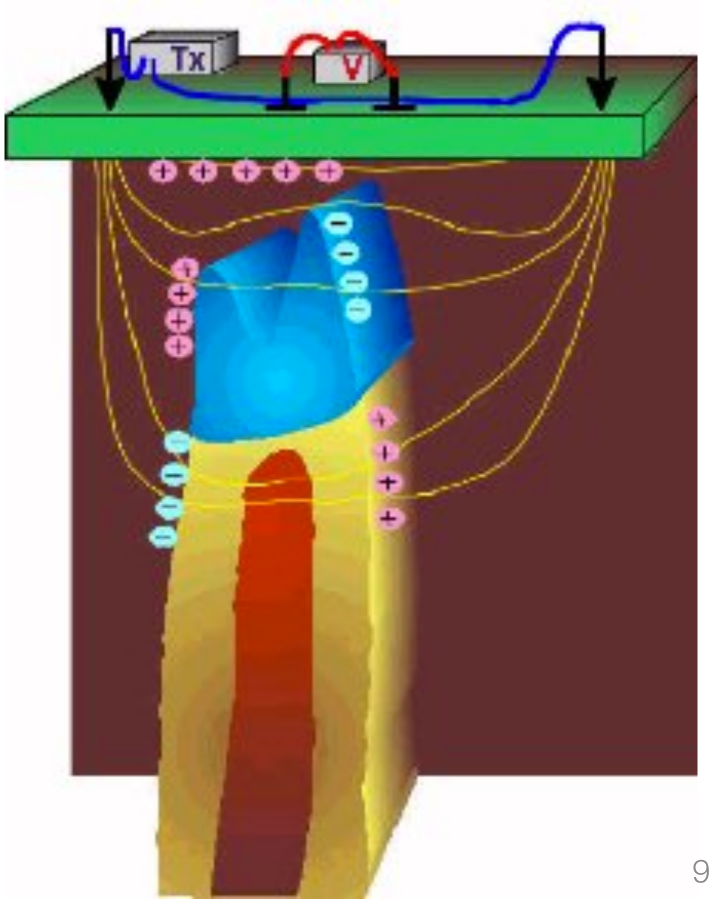

Basic Experiment

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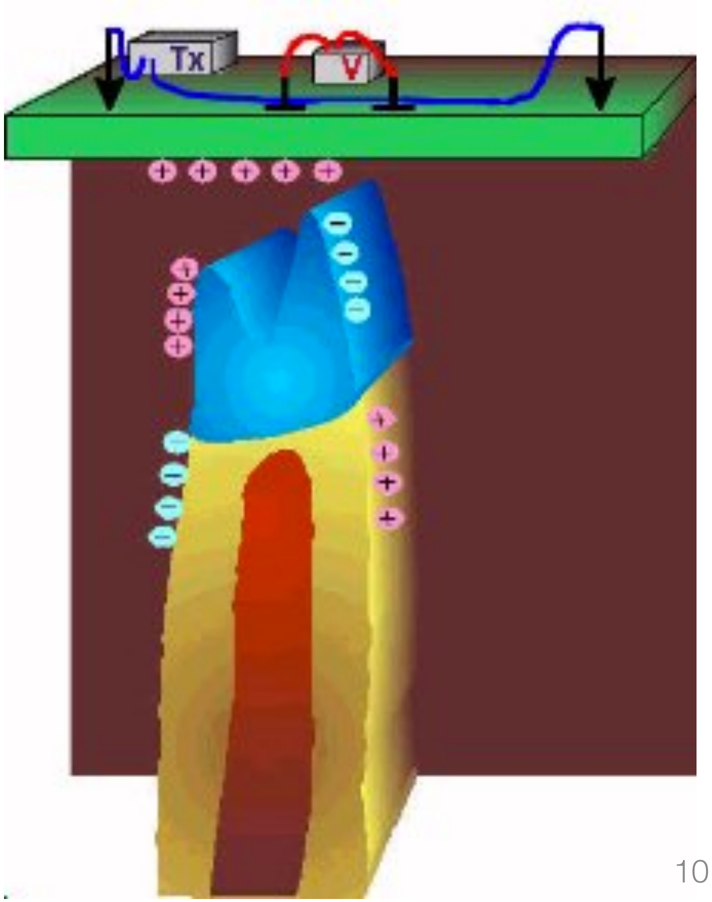
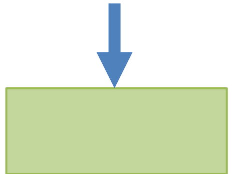
- **Target:**
  - Ore body. Mineralized regions less resistive than host
- **Setup:**
  - Tx: Current electrodes
  - Rx: Potential electrodes
- **Currents:**
  - Preferentially flow through conductors
- **Charges:**
  - Build up at interfaces
- **Potentials:**
  - Associated with the charges are measured at the surface



How do we obtain resistivity?

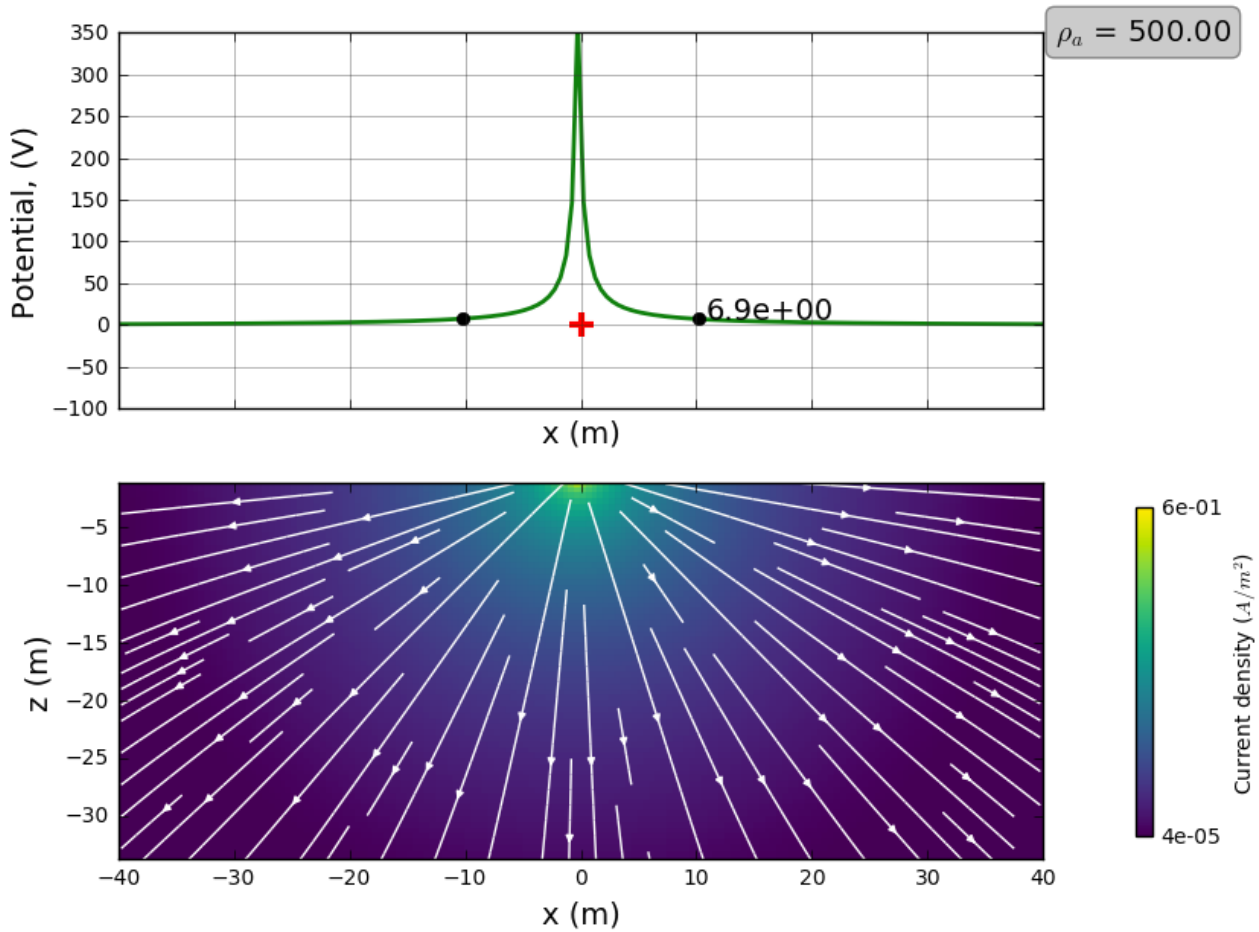
Steady State Maxwell equations

	Full	Steady State
Faraday	$\nabla \times \vec{e} = -\frac{\partial \vec{b}}{\partial t}$	$\nabla \times \vec{e} = 0 \qquad \vec{e} = -\nabla V$
Ampere	$\nabla \times \vec{h} = \vec{j} + \frac{\partial \vec{d}}{\partial t} + \vec{j}_s$	$\nabla \cdot \vec{j} = -\nabla \cdot \vec{j}_s$
Ohm's Law	$\vec{j} = \sigma \vec{e}$	
Put it together		$\nabla \cdot \sigma \nabla V = I\delta(r)$
Potential in a homogeneous halfspace	 $V = \frac{I}{2\pi\sigma}\frac{1}{r}$	$V = \frac{\rho I}{2\pi r}$

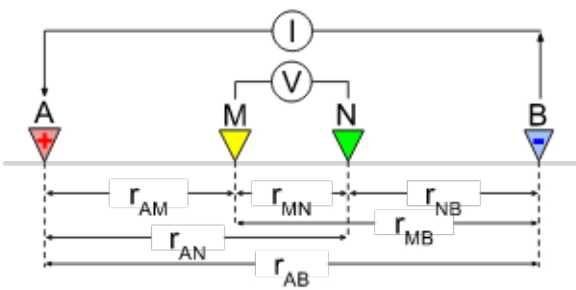
Currents and potentials: halfspace

$$V = \frac{\rho I}{2\pi r}$$

$$\rho = \frac{2\pi r V}{I}$$



Currents and potentials: 4-electrode array

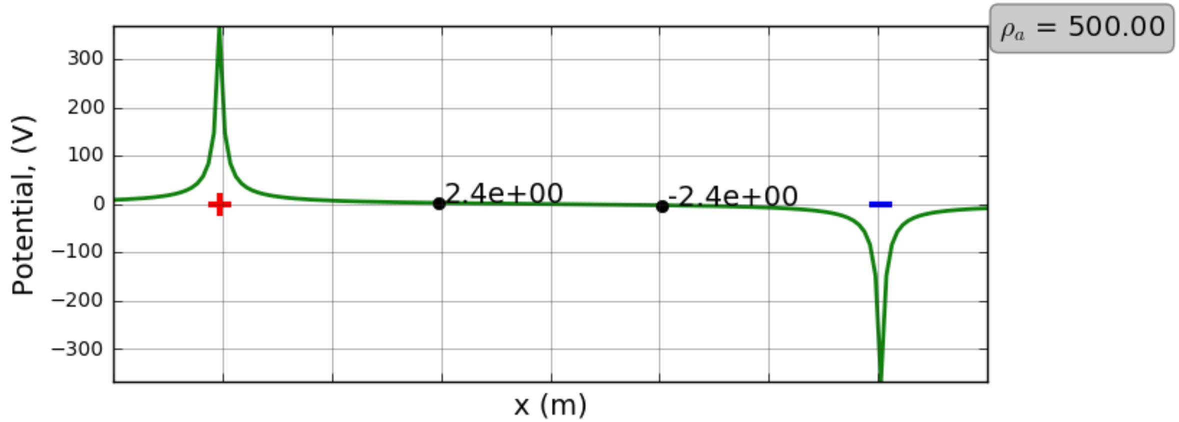


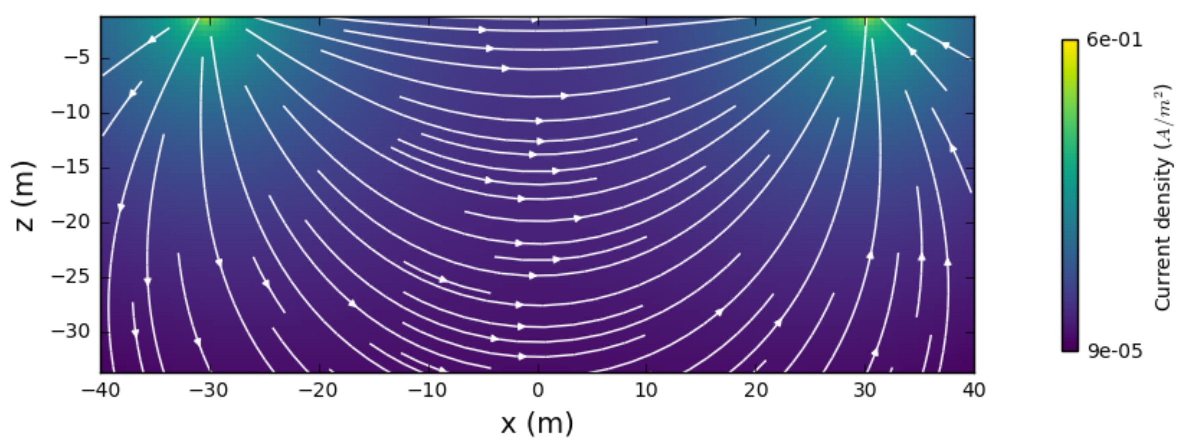
$$\Delta V_{MN} = \rho I \underbrace{\frac{1}{2\pi}\left[\frac{1}{AM} - \frac{1}{MB} - \frac{1}{AN} + \frac{1}{NB}\right]}_{G}$$

Resistivity

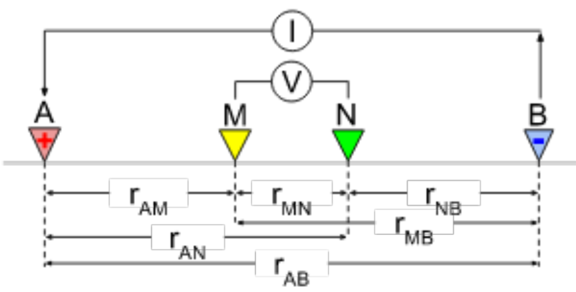
$$\rho = \frac{\Delta V_{MN}}{IG}$$

Halfspace (500 Ωm)





Currents and Apparent Resistivity

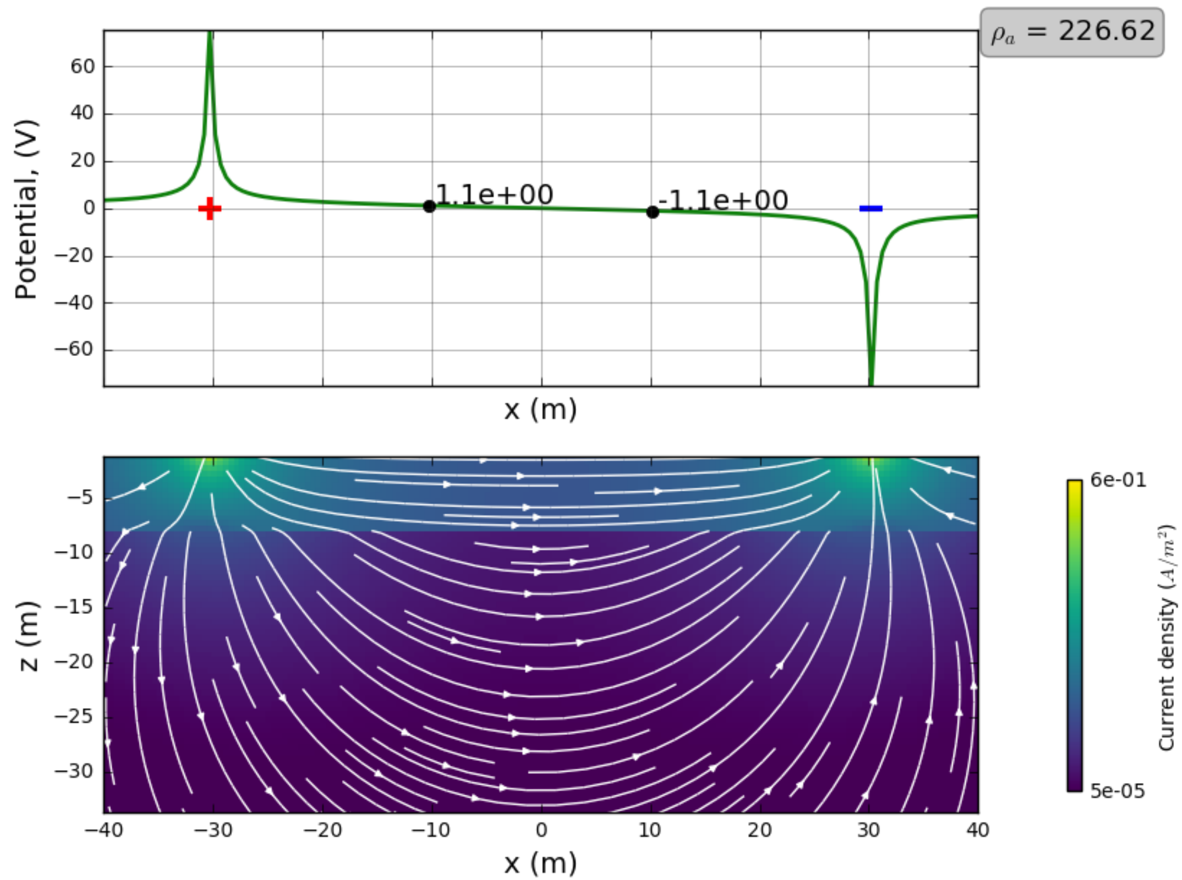


$$\Delta V_{MN} = \rho I \underbrace{\frac{1}{2\pi}\left[\frac{1}{AM} - \frac{1}{MB} - \frac{1}{AN} + \frac{1}{NB}\right]}_{G}$$

Apparent resistivity

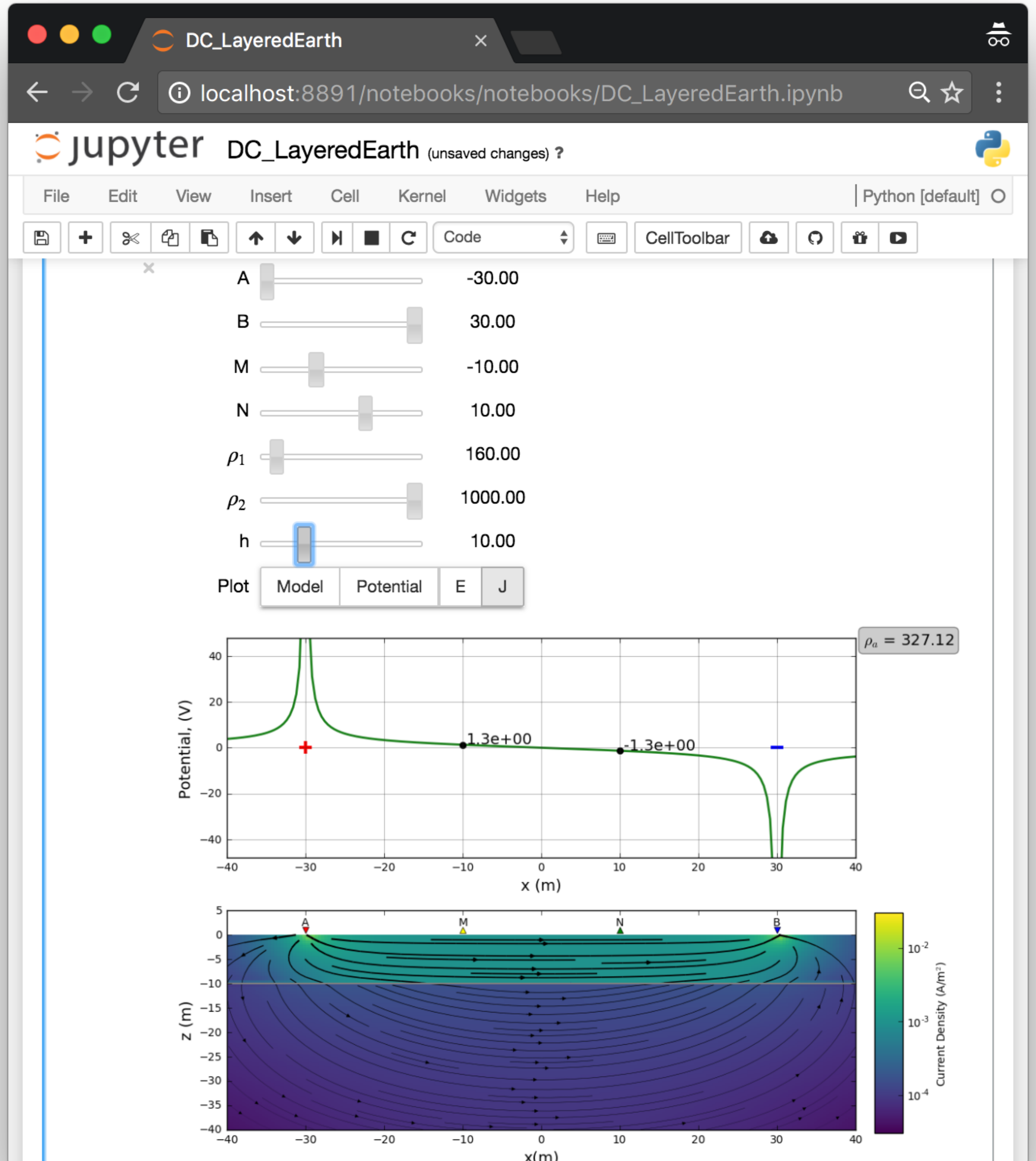
$$\rho_a = \frac{\Delta V_{MN}}{IG}$$

Conductive overburden (100 Ωm)



Why interactive apps?

- Visualization aids understanding
- Learn through interaction
  - ask questions and investigate
- Open source:
  - Free to use
  - Welcome contributions!

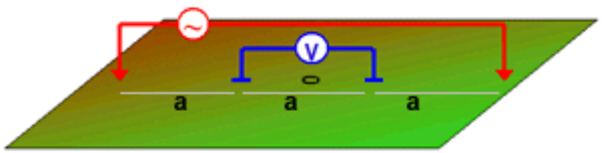


http://em.geosci.xyz/apps.html

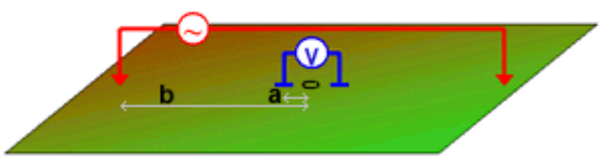
Soundings and Arrays

Geometry

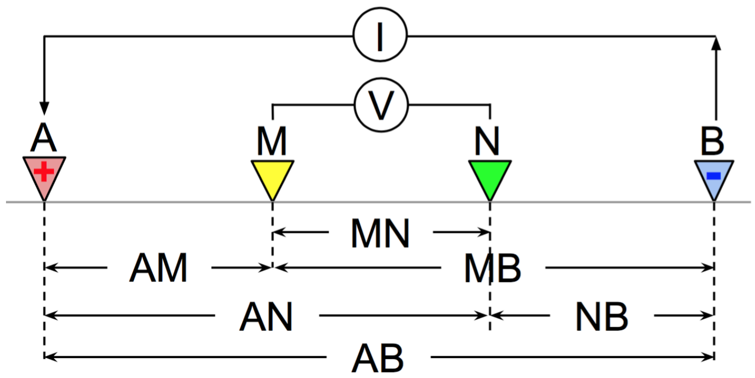
Wenner



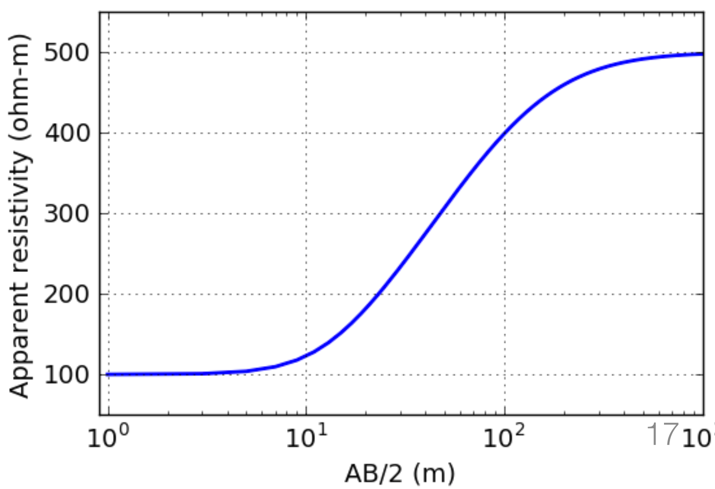
Schlumberger



4 electrode Array

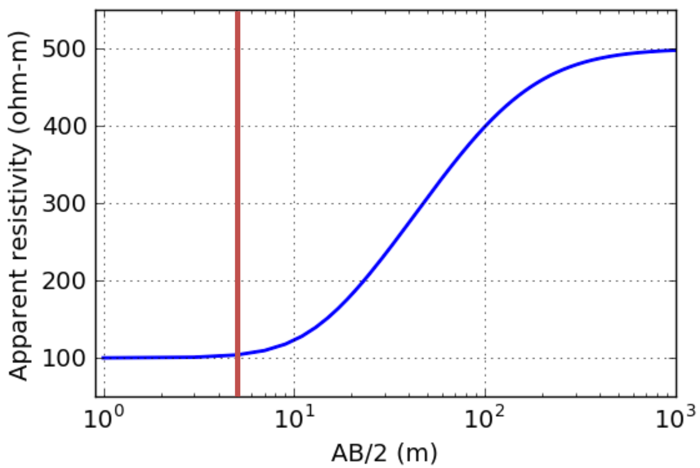


Sounding

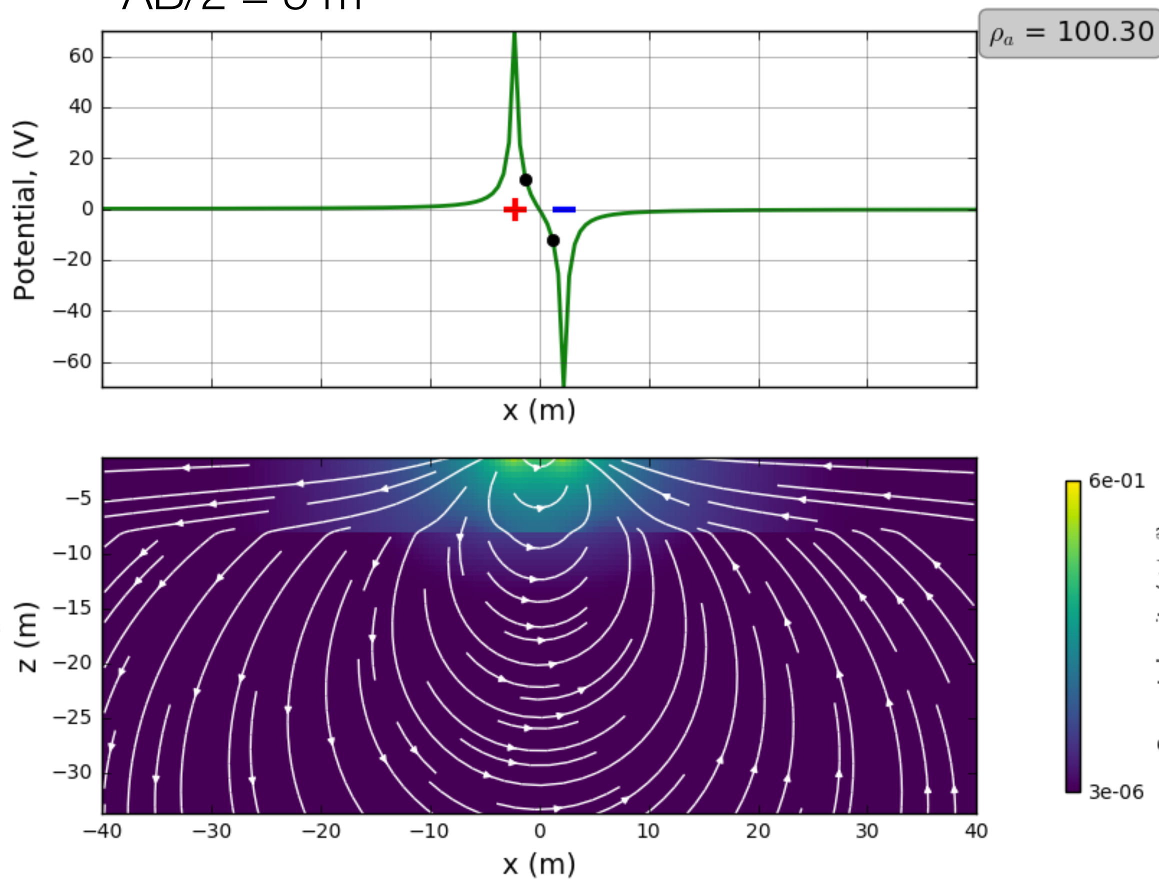


Soundings

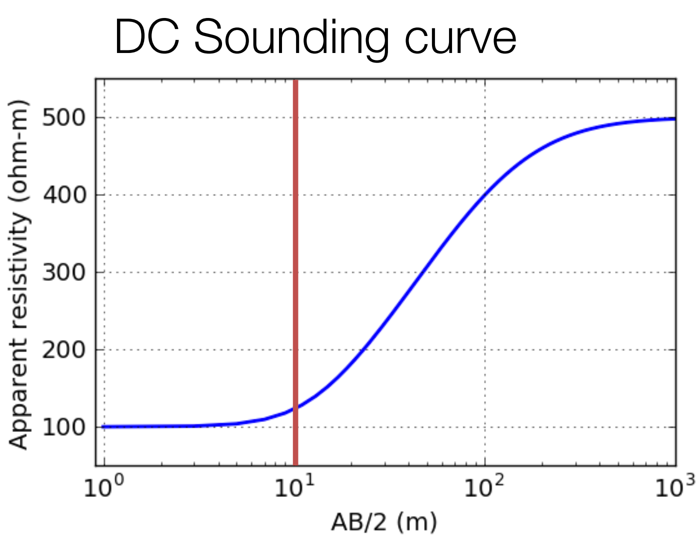
DC Sounding curve

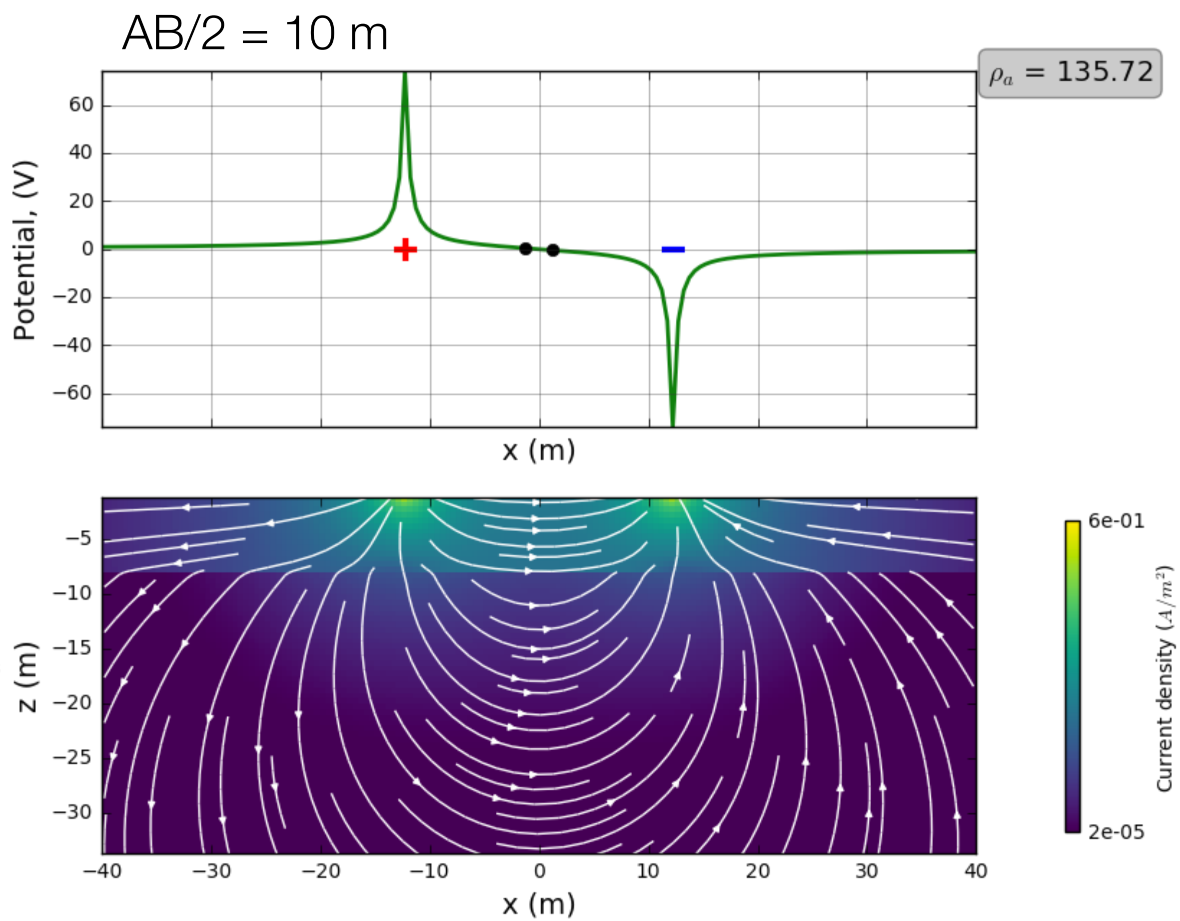


AB/2 = 5 m



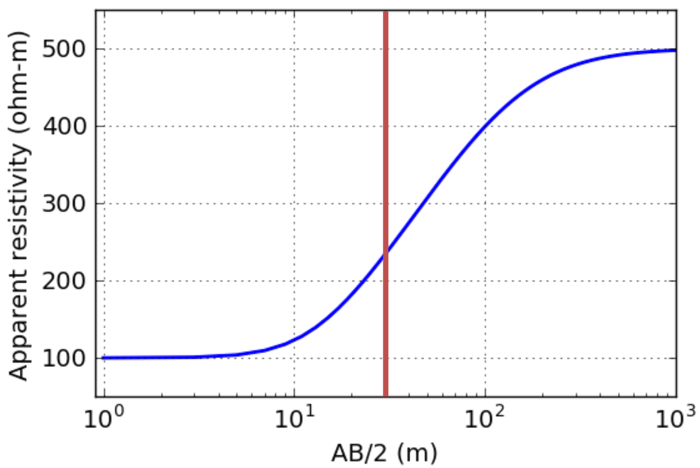
Soundings


DC Sounding curve
Apparent resistivity (ohm-m)
500
400
300
200
100
10^0
10^1
10^2
10^3
AB/2 (m)

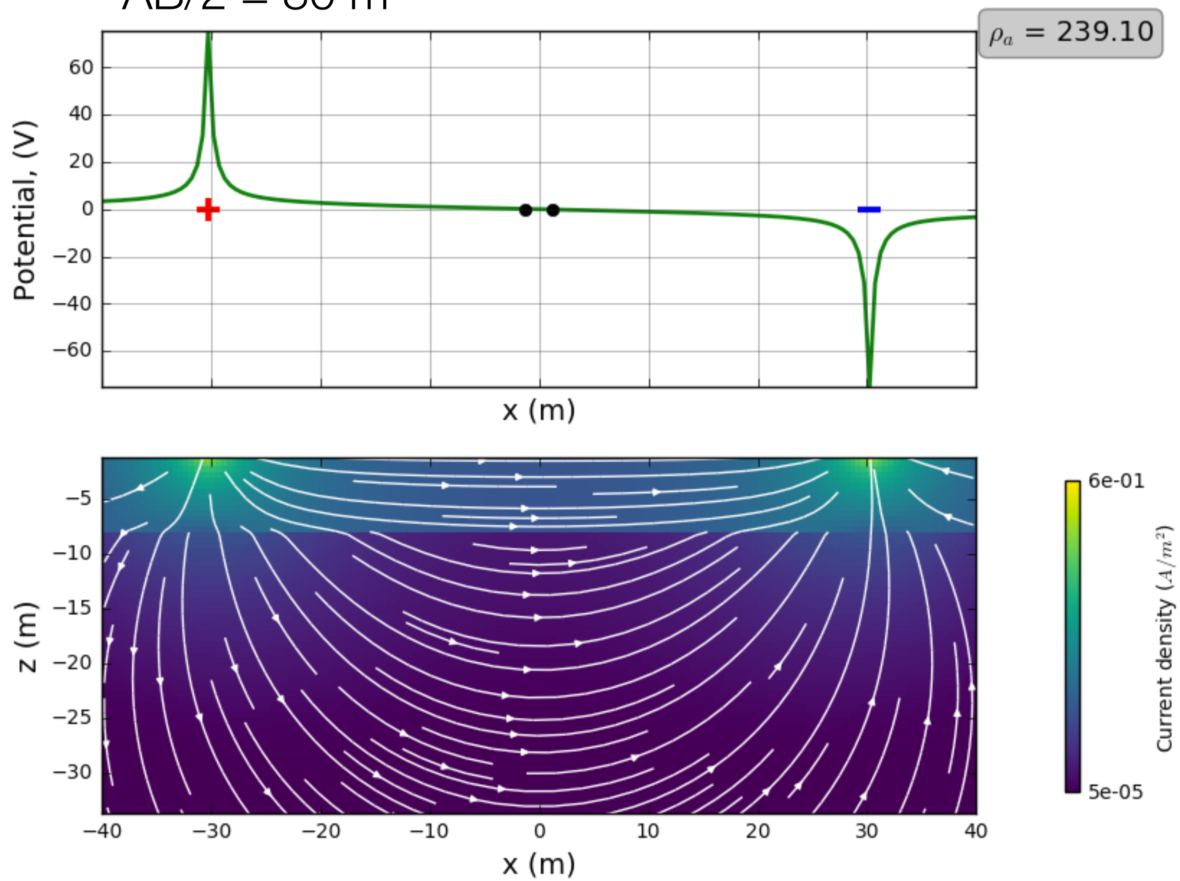

AB/2 = 10 m
ρ_a = 135.72
Potential, (V)
60
40
20
0
−20
−40
−60
x (m)
z (m)
−5
−10
−15
−20
−25
−30
−40
−30
−20
−10
0
10
20
30
40
x (m)
6e-01
2e-05
Current density (A/m^2)

Soundings

DC Sounding curve

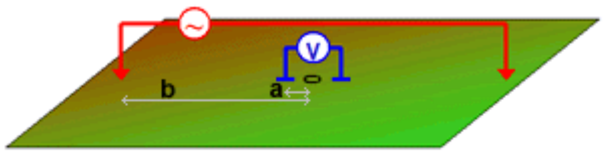


AB/2 = 30 m

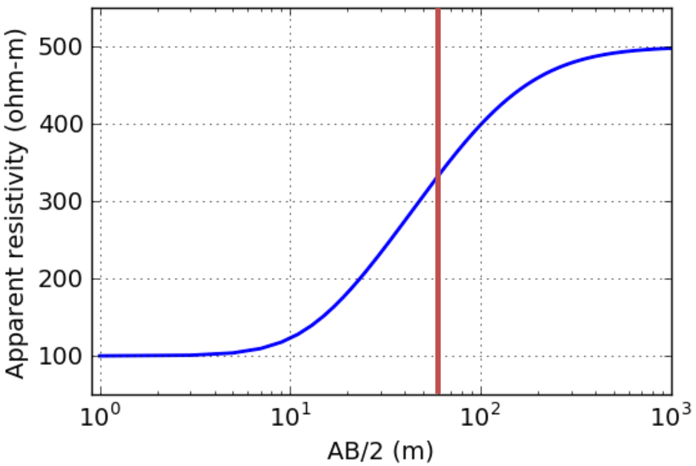


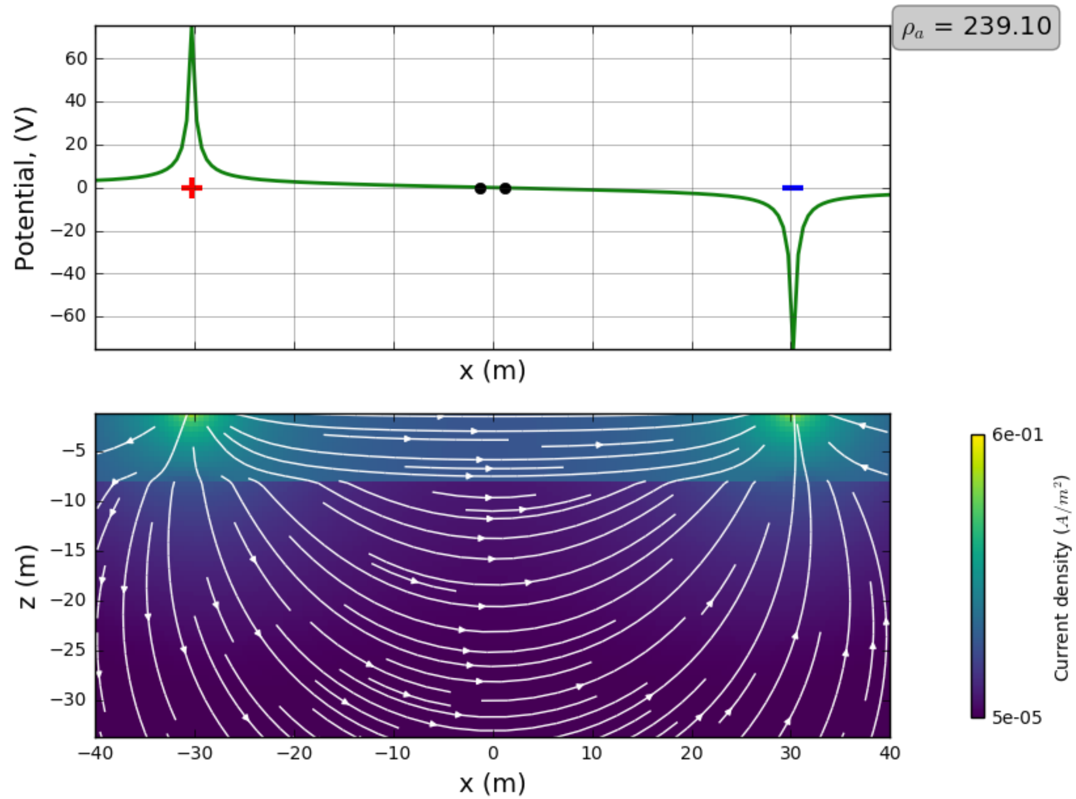
Summary: soundings

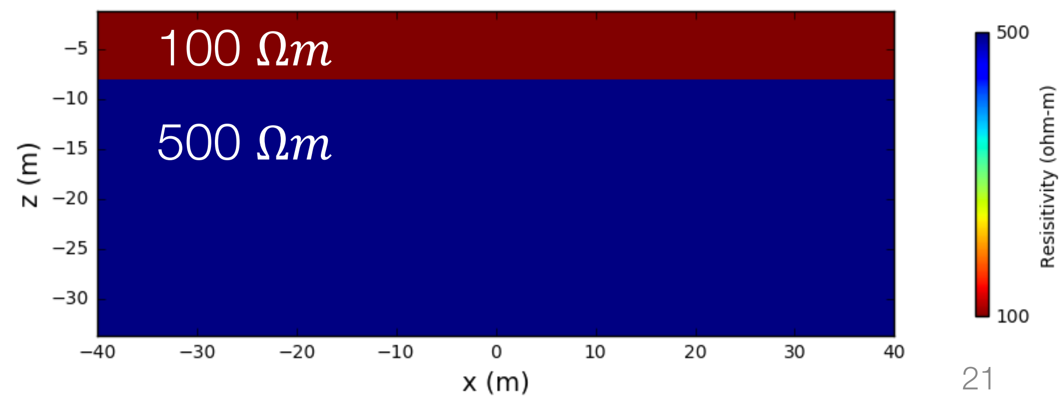
Schlumberger array



DC **Sounding** curve

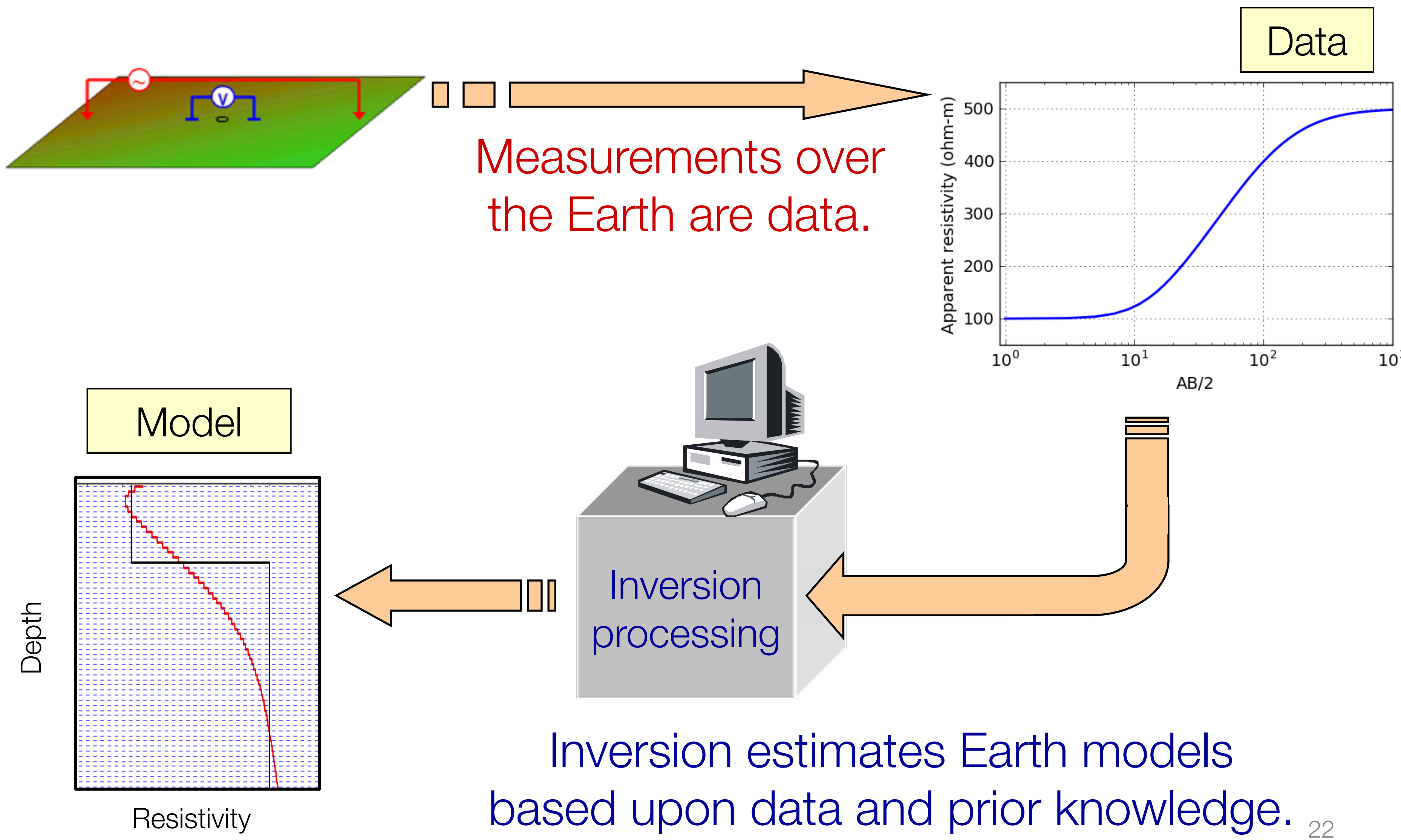






Scale length of array must be large to see deep

Inversion


Data
Measurements over the Earth are data.
Apparent resistivity (ohm-m)
500
400
300
200
100
10^0
10^1
10^2
10^3
AB/2
Model
Depth
Resistivity
Inversion processing
Inversion estimates Earth models based upon data and prior knowledge.

DCR for a confined body

- Useful to formally bring in the concept of charges

Normal component of current density is continuous

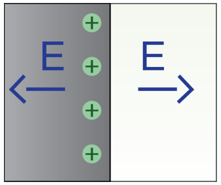
$$J_{1n} = J_{2n}$$

$$\sigma_1 E_{1n} = \sigma_2 E_{2n}$$

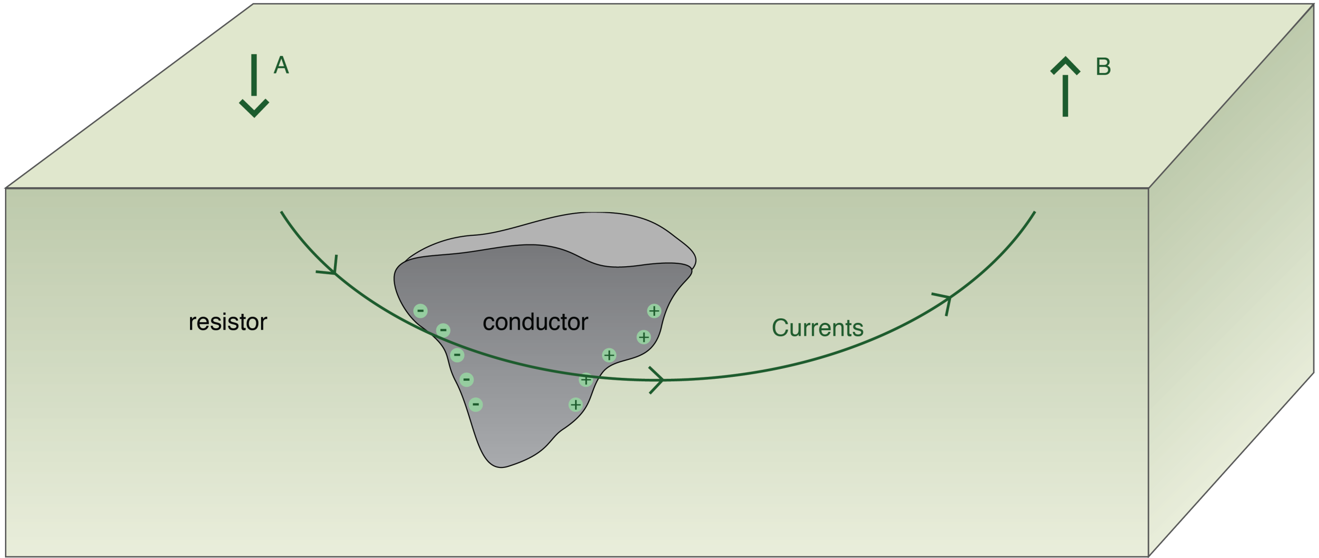
Conductivity contrast

$$\sigma_1 \neq \sigma_2$$

- Electric field discontinuous
- Charge build-up

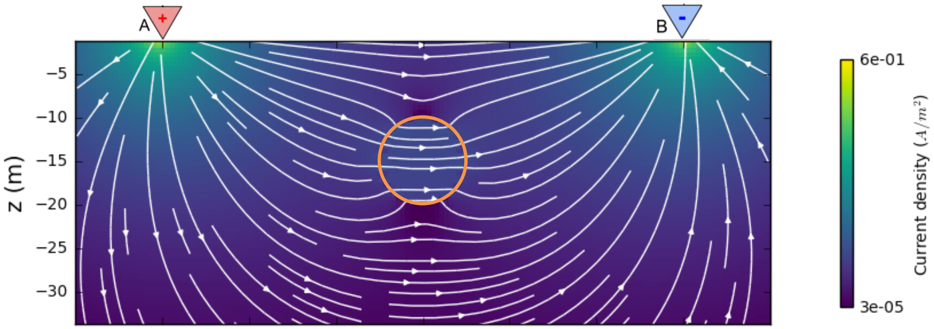


$$\mathbf{E} = \frac{Q}{4\pi\varepsilon_0 |\mathbf{r} - \mathbf{r}'|^2}\hat{\mathbf{r}}$$

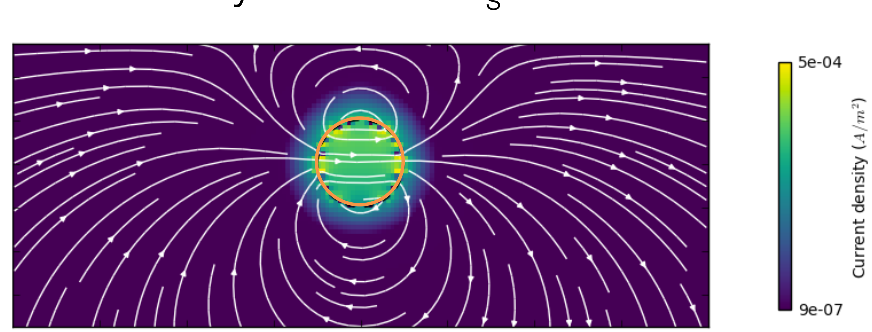


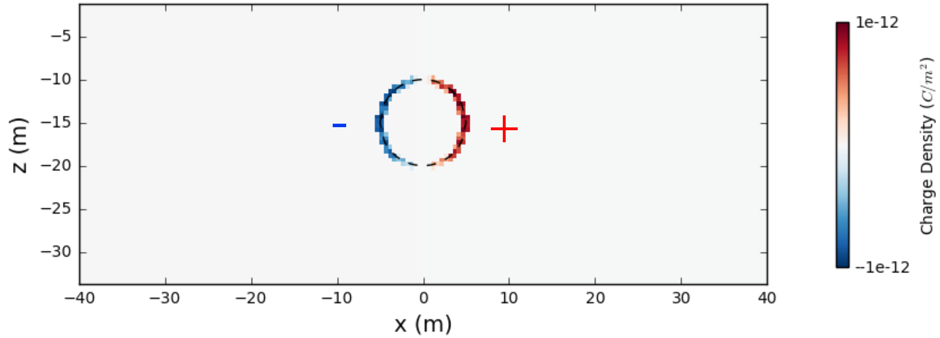
Currents, charges, and potentials

Total currents: J

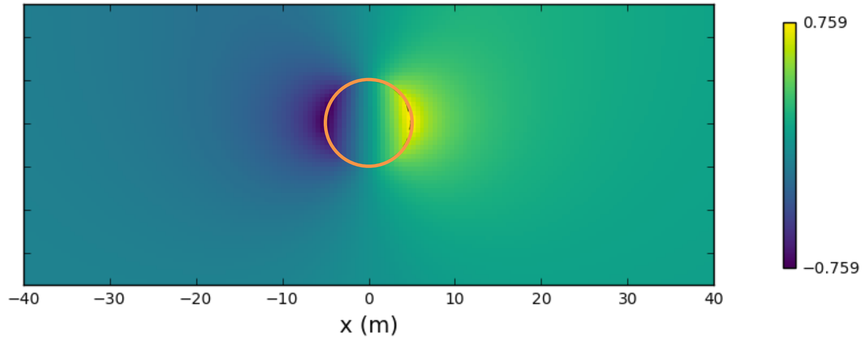


Secondary currents: J_s





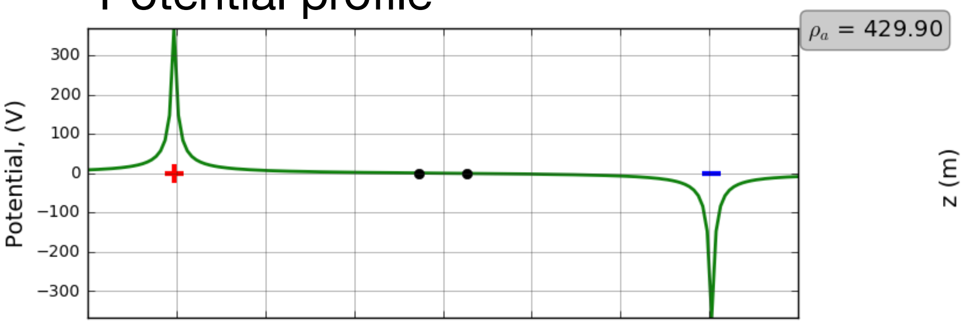
Secondary charges: Q_s



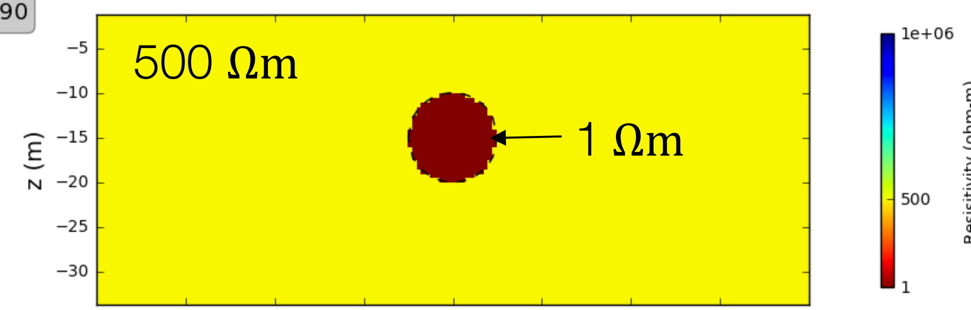
Secondary potential: ϕ_s

Measurements of DC data: gradient array

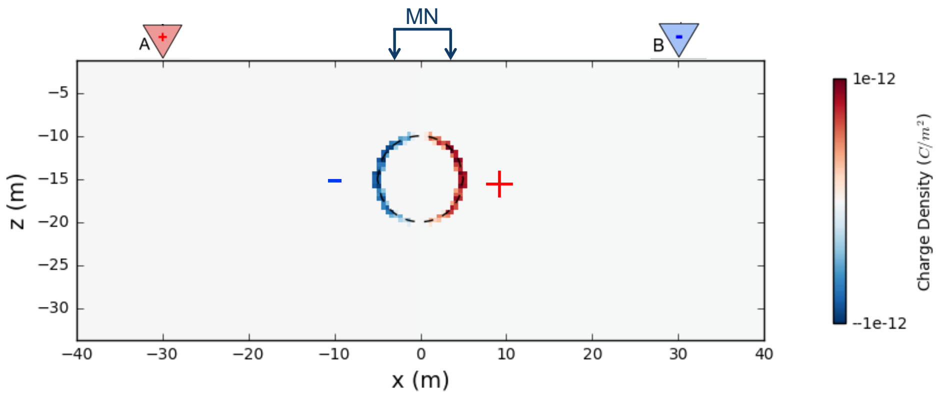
Potential profile



Resistivity model

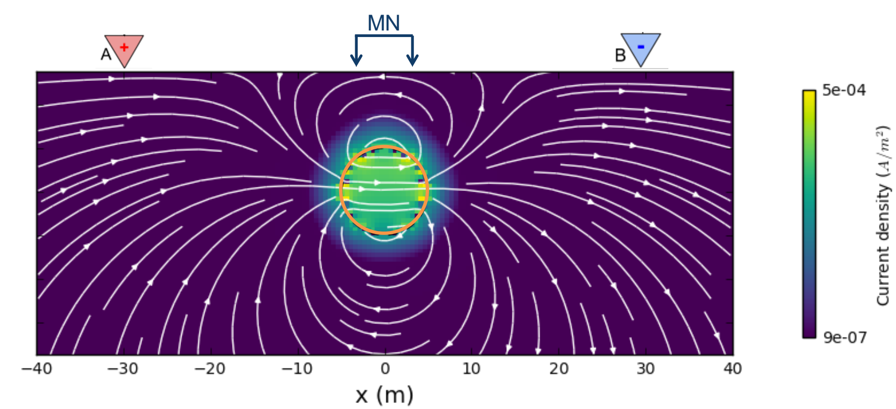


ρ_a = 430



Secondary charges: Q_s

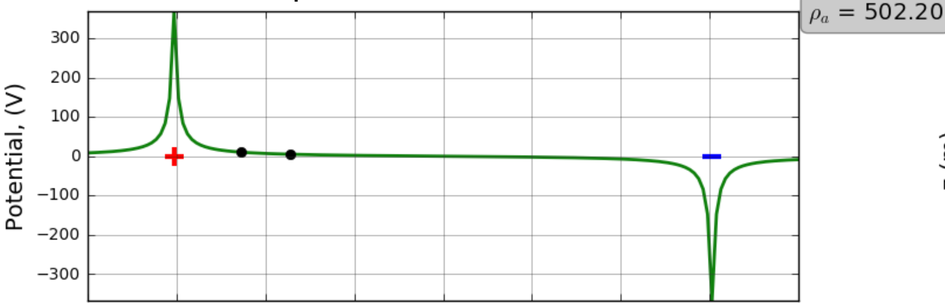
ρ_a = 430



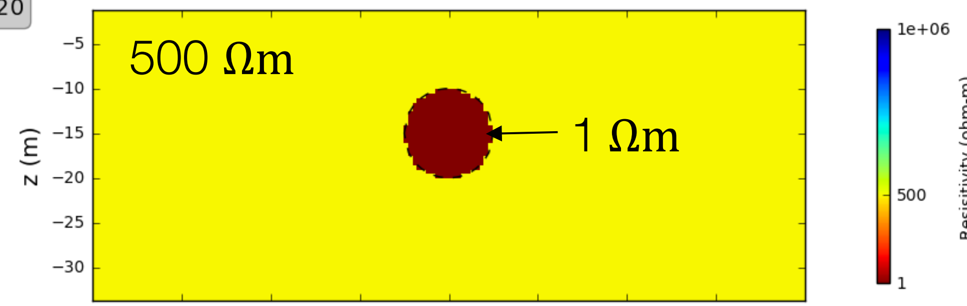
Secondary currents: J_s

Measurements of DC data: gradient array

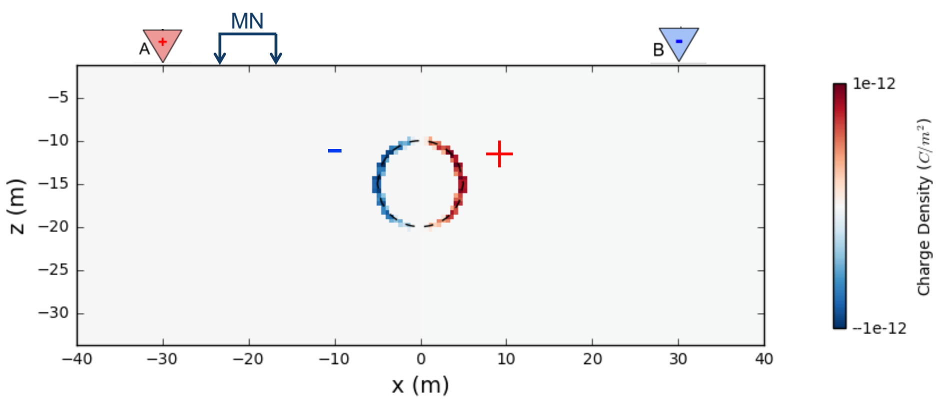
Potential profile



Resistivity model

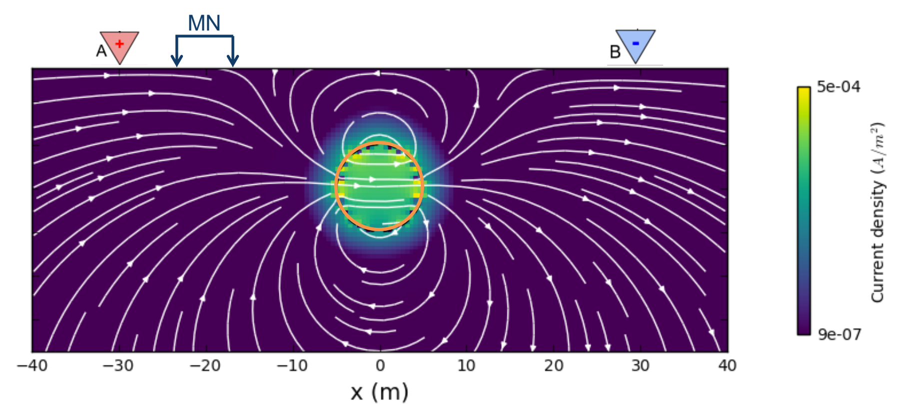


ρ_a = 502



Secondary charges: Q_s

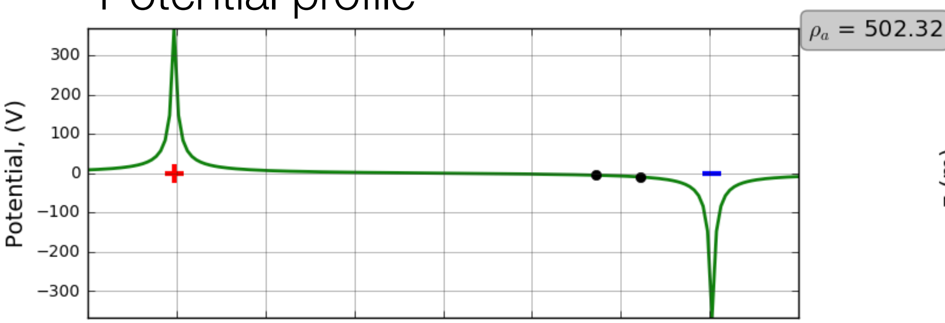
ρ_a = 502



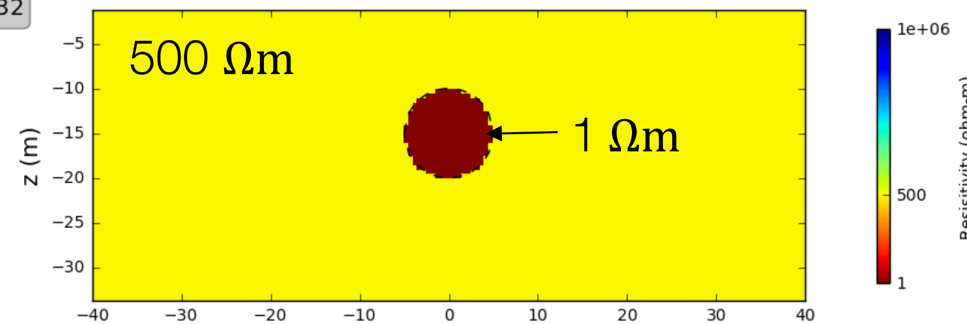
Secondary currents: J_s

Measurements of DC data: gradient array

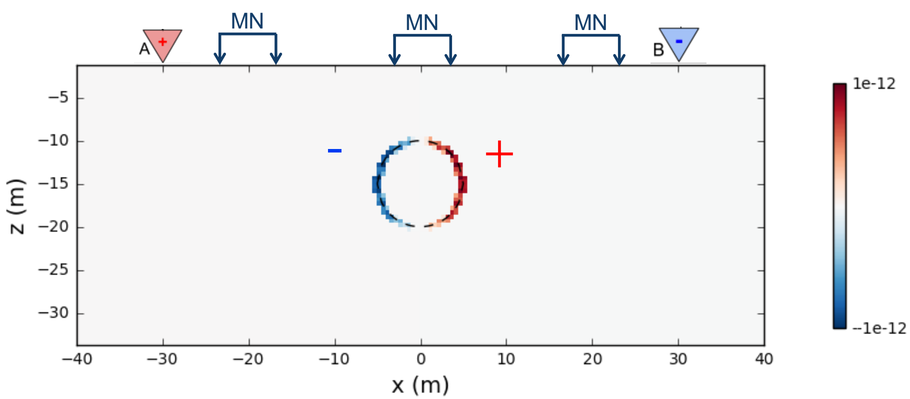
Potential profile



Resistivity model

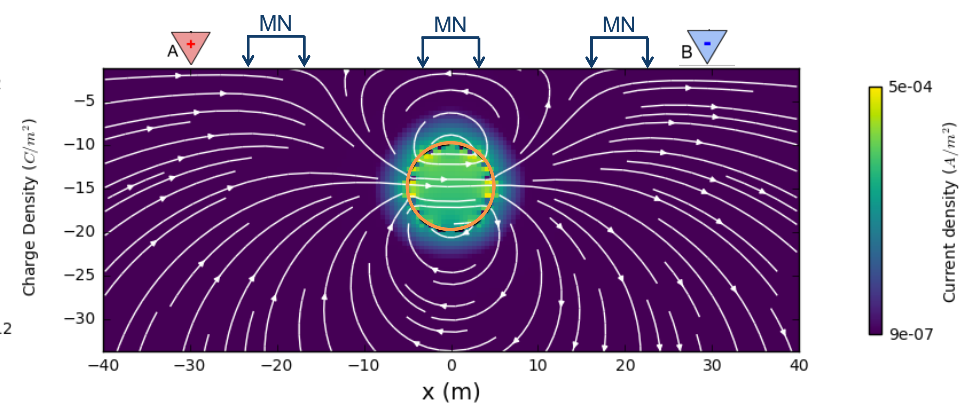


ρ_a = 502 ρ_a = 430 ρ_a = 502



Secondary charges: Q_s

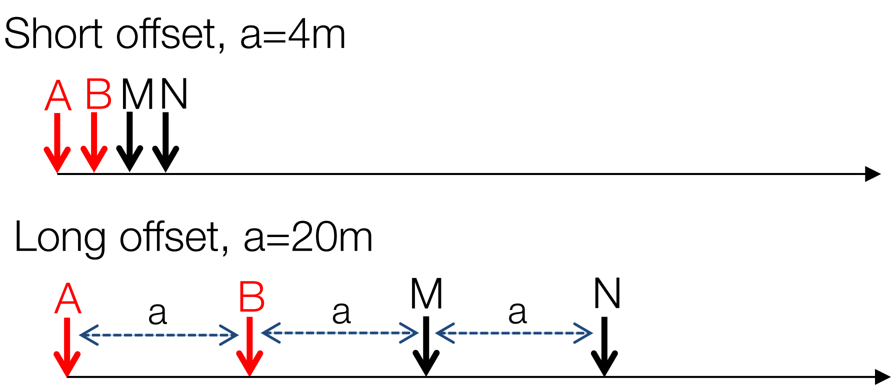
ρ_a = 502 ρ_a = 430 ρ_a = 502

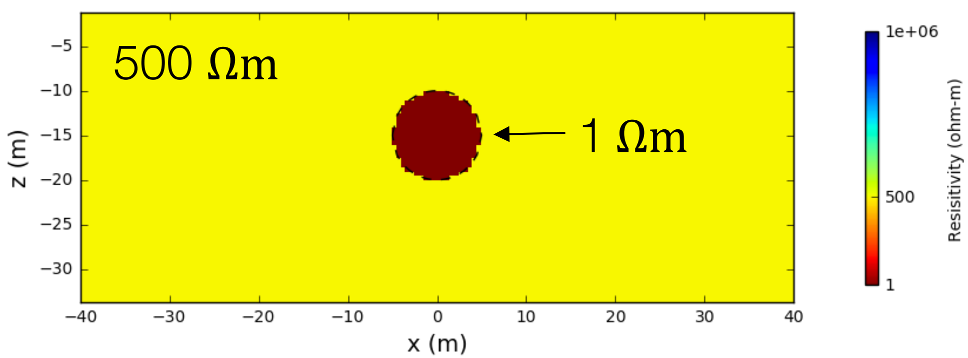


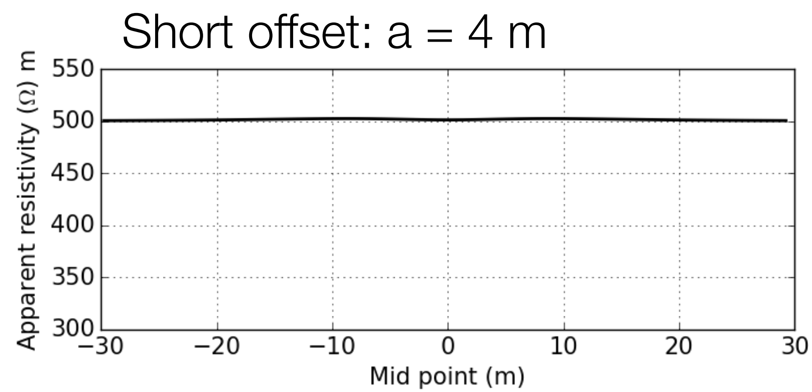
Secondary currents: J_s

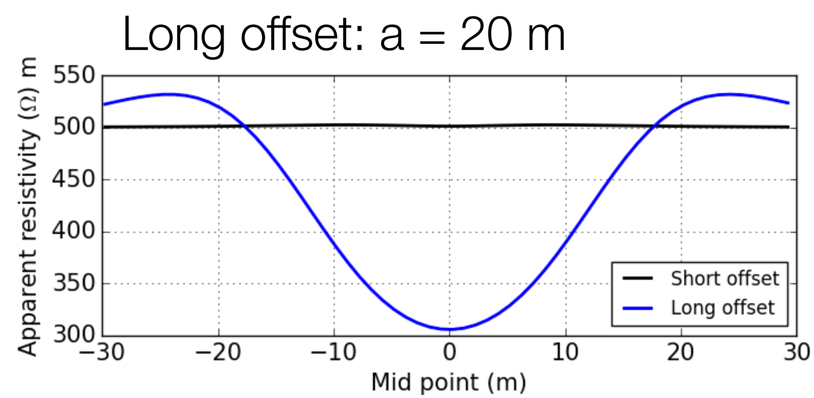
Profiling

Fixed geometry: Move laterally





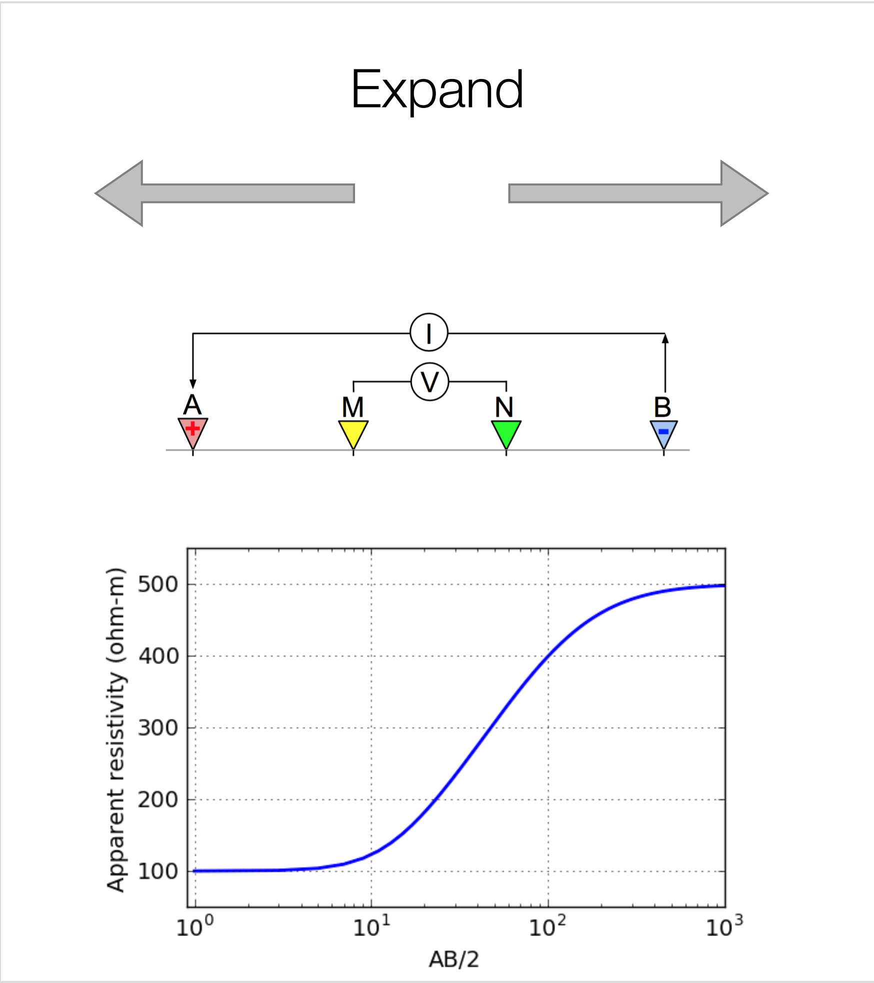




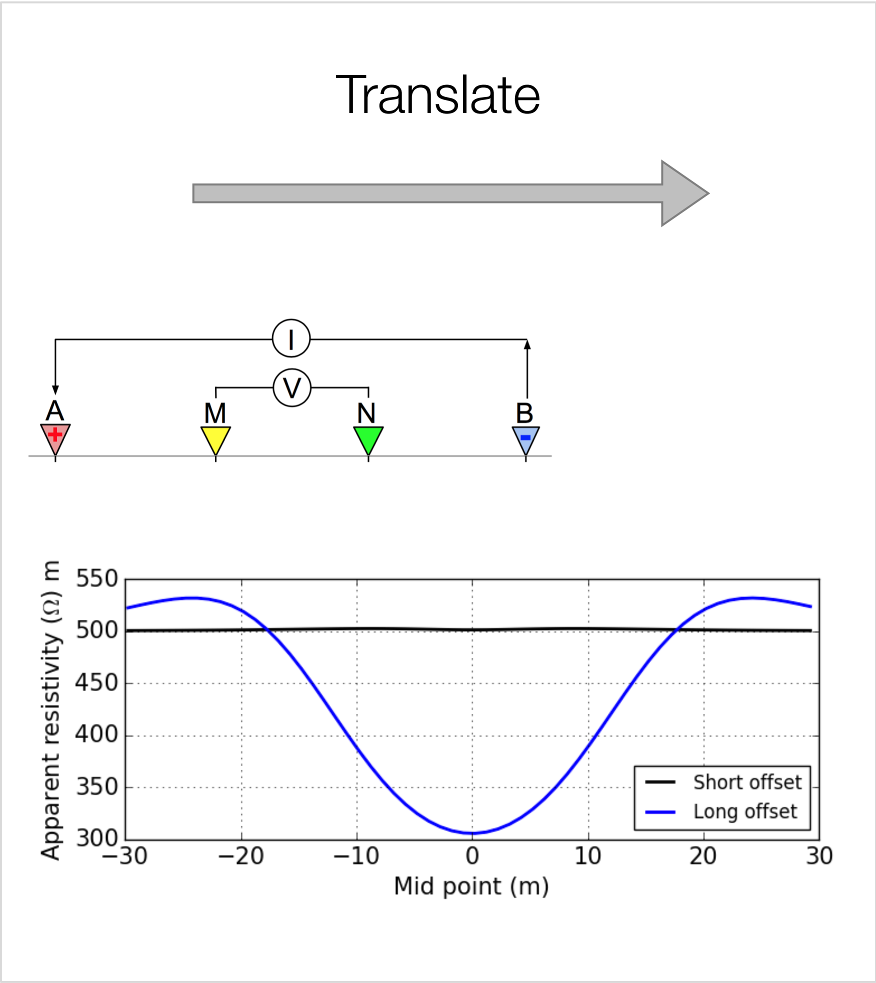
Depth of investigation depends upon offset or array length

Summary: Soundings and Profiles

Sounding

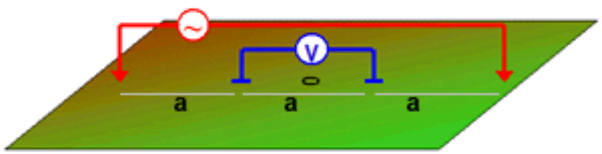


Profiling

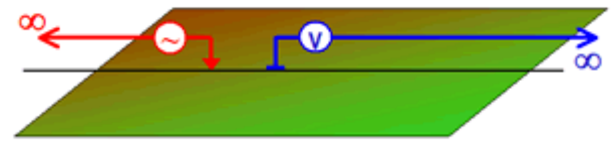


Basic Survey Setups

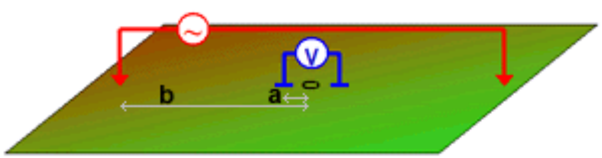
Wenner



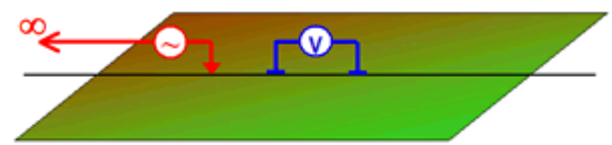
Pole-Pole



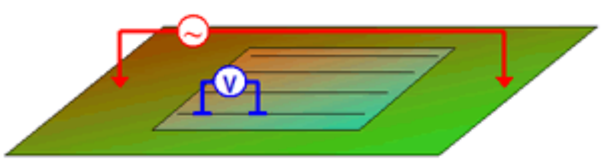
Schulmberger



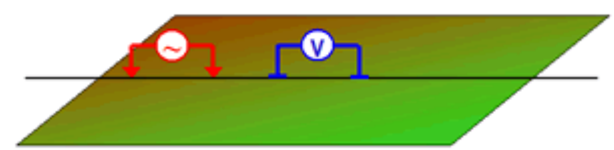
Pole-Dipole



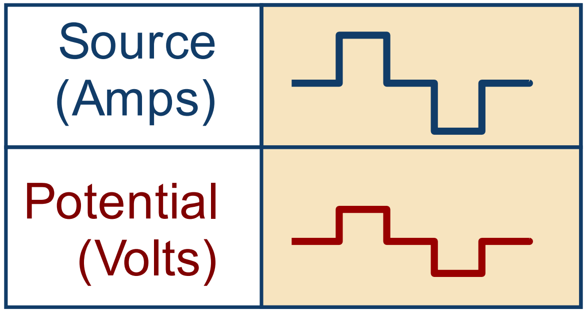
Gradient

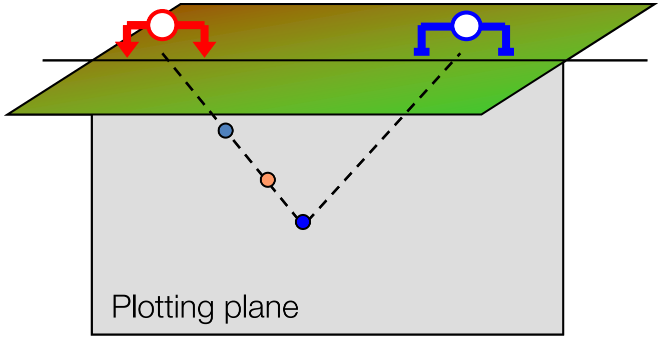


Dipole-Dipole



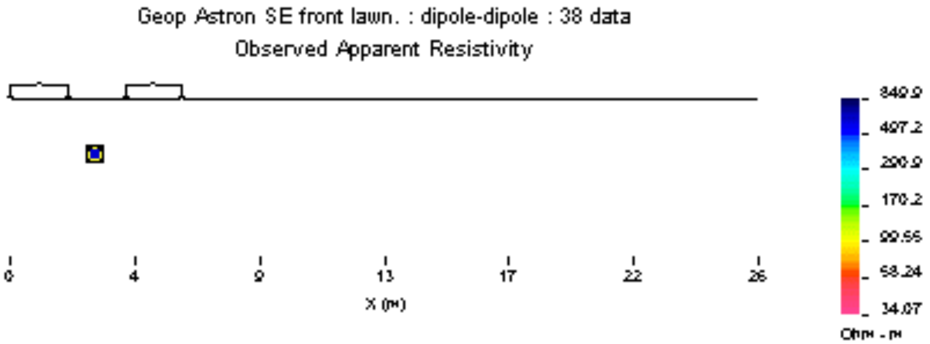
DC resistivity data





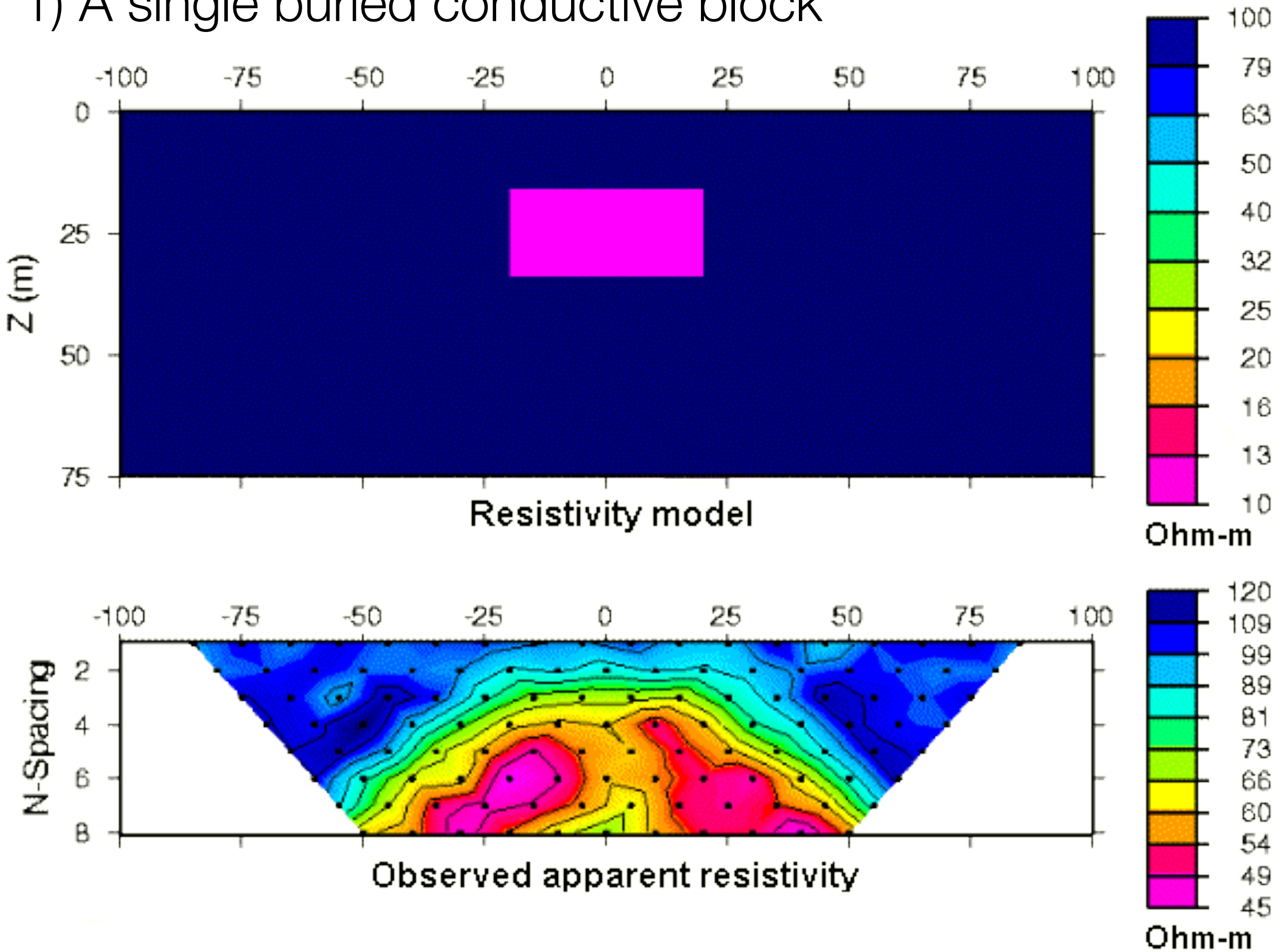
Each data point is an apparent resistivity:

$$\rho_a = \frac{2\pi \Delta V}{IG}$$

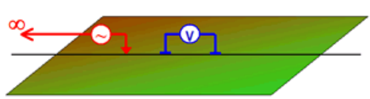


Example pseudosections

1) A single buried conductive block



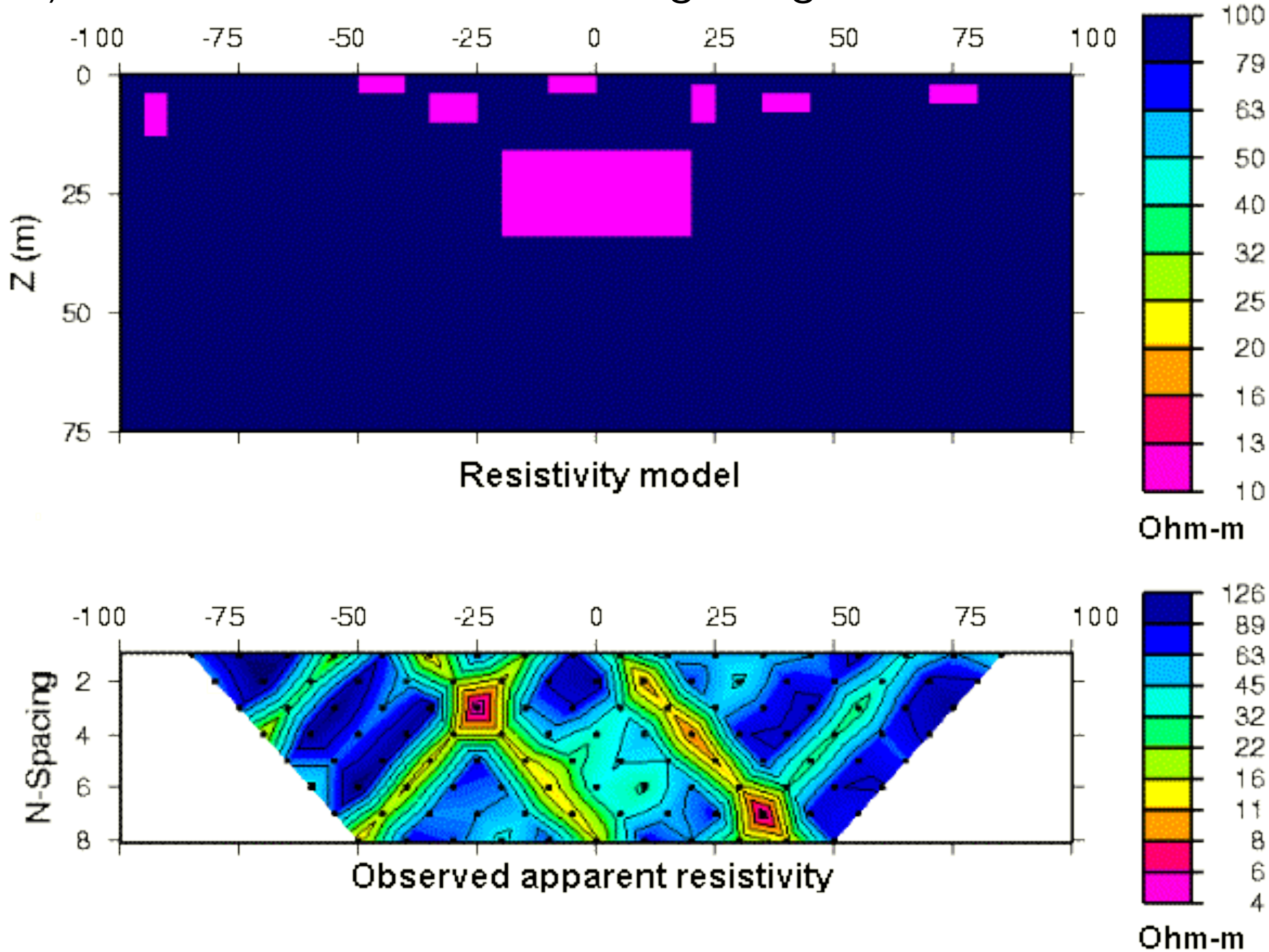
Pole-Dipole



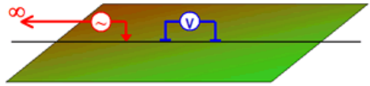
- Pole-dipole; n=1,8; a=10m; N=316

Example pseudosections

2) The conductive block with geologic noise.



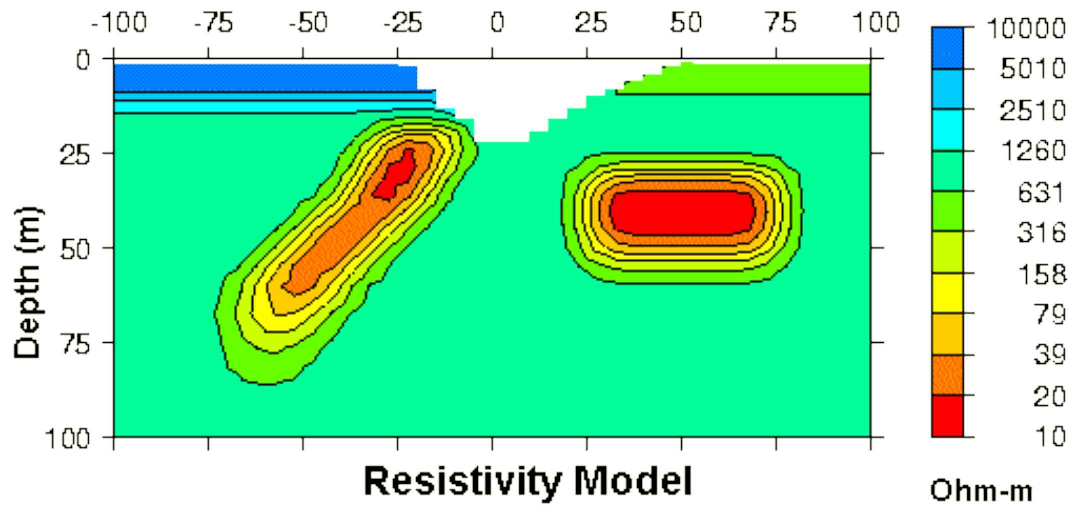
Pole-Dipole

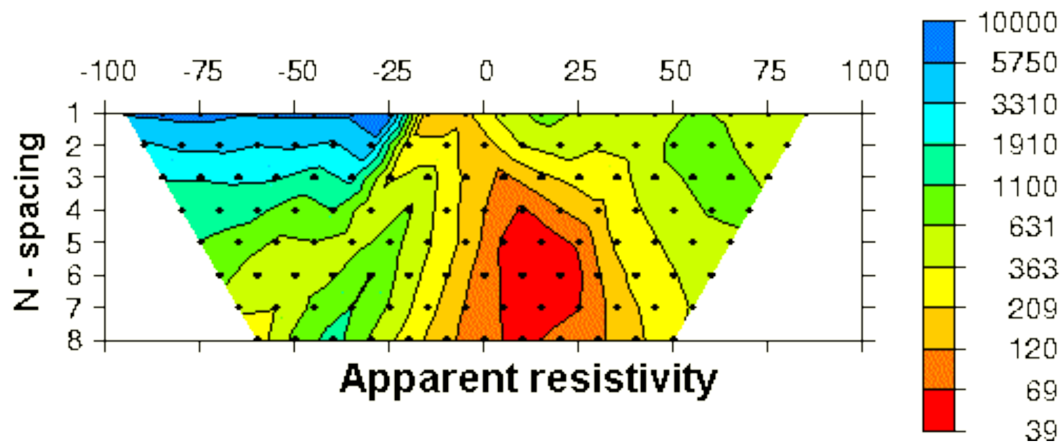


- Pole-dipole; n=1,8; a=10m; N=316

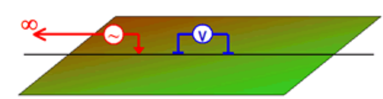
Example pseudosections

3) The “UBC-GIF model”

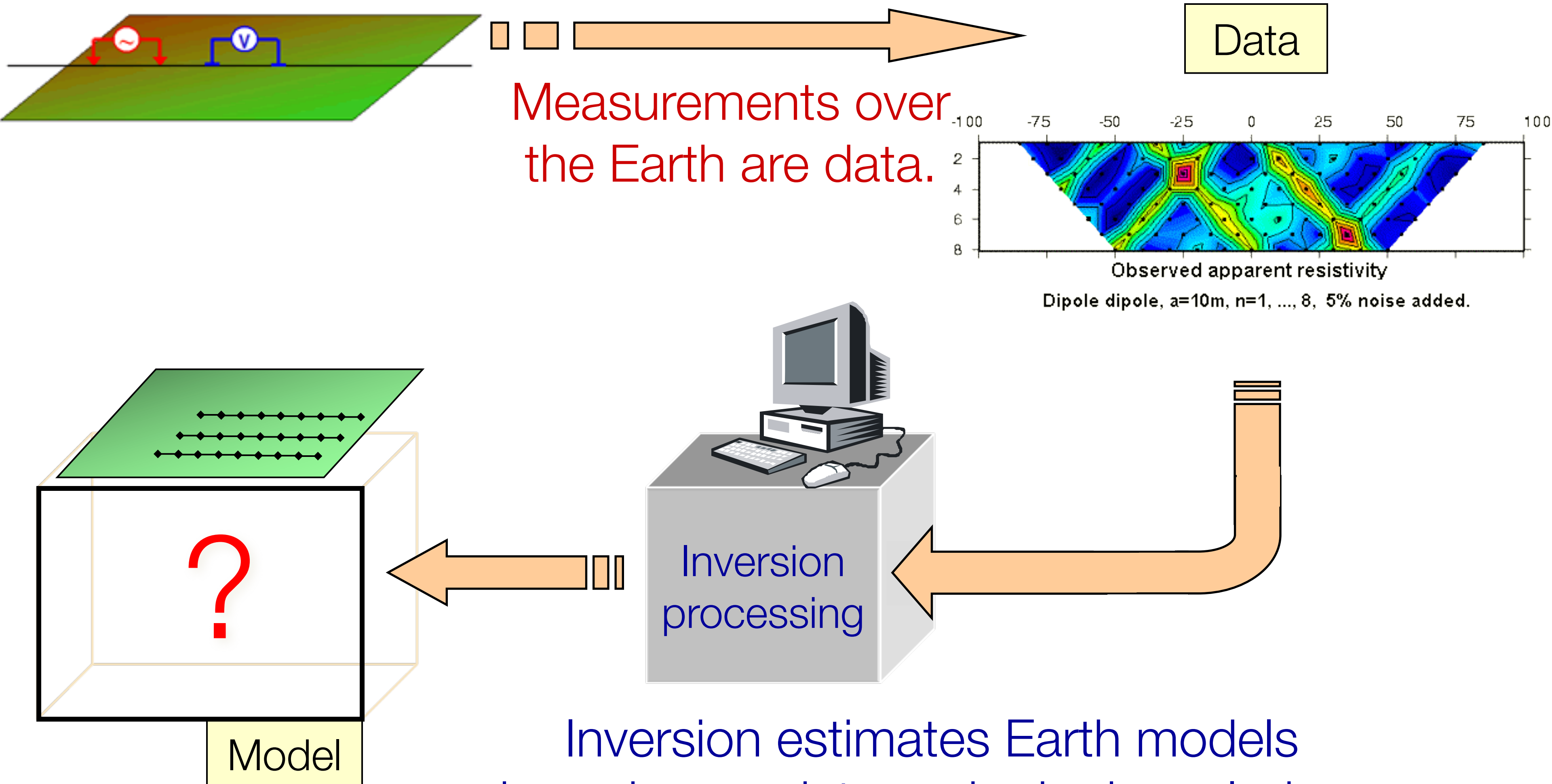




Pole-Dipole

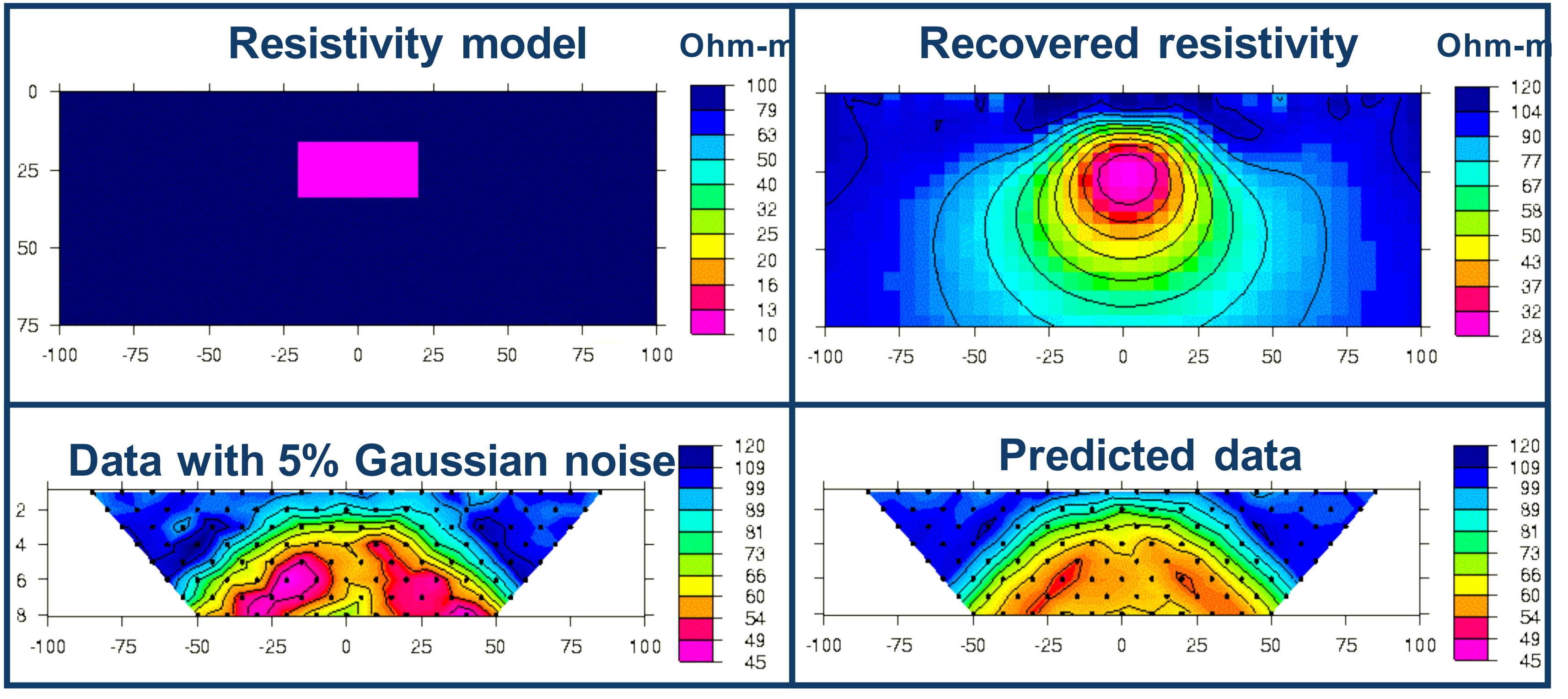


Inversion



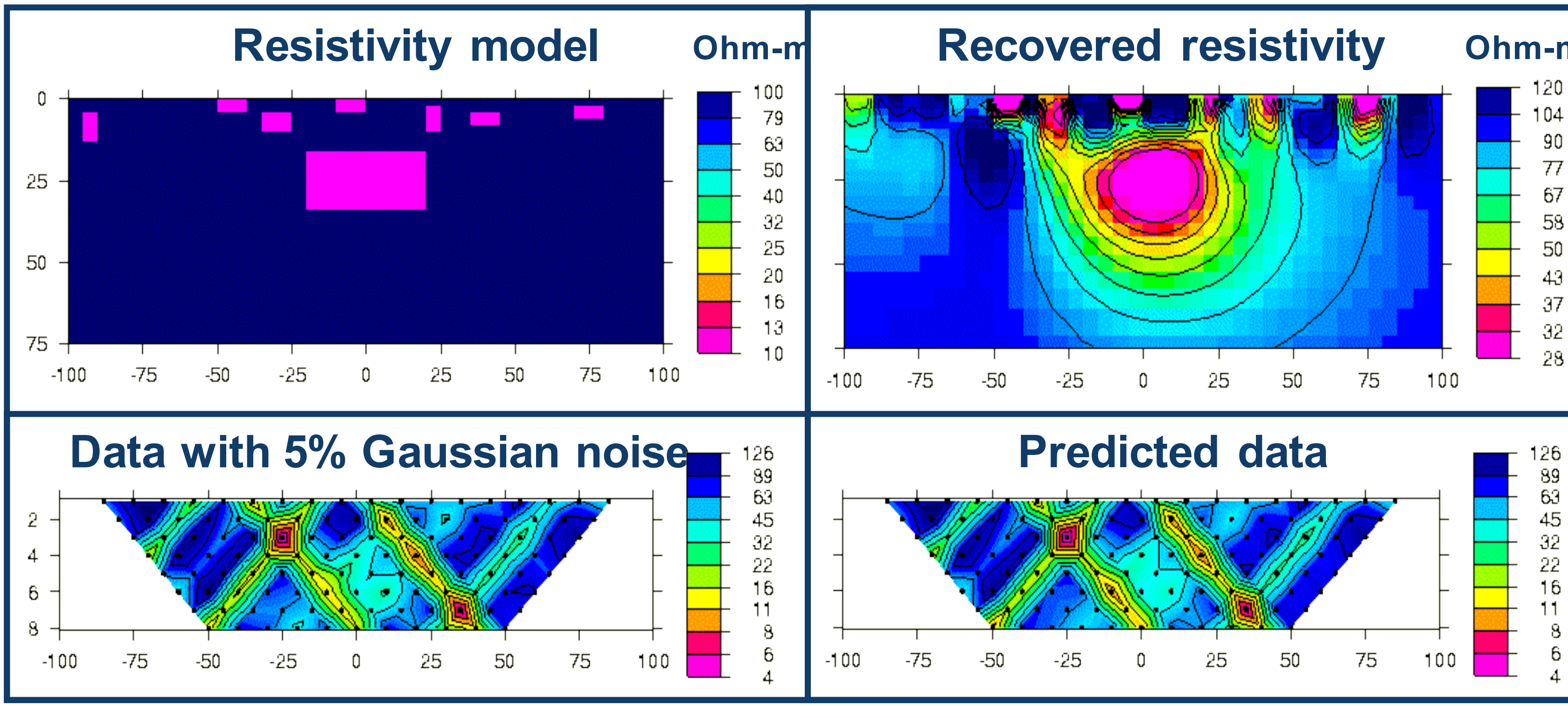
Inversion estimates Earth models based upon data and prior knowledge.

Example 1: buried prism



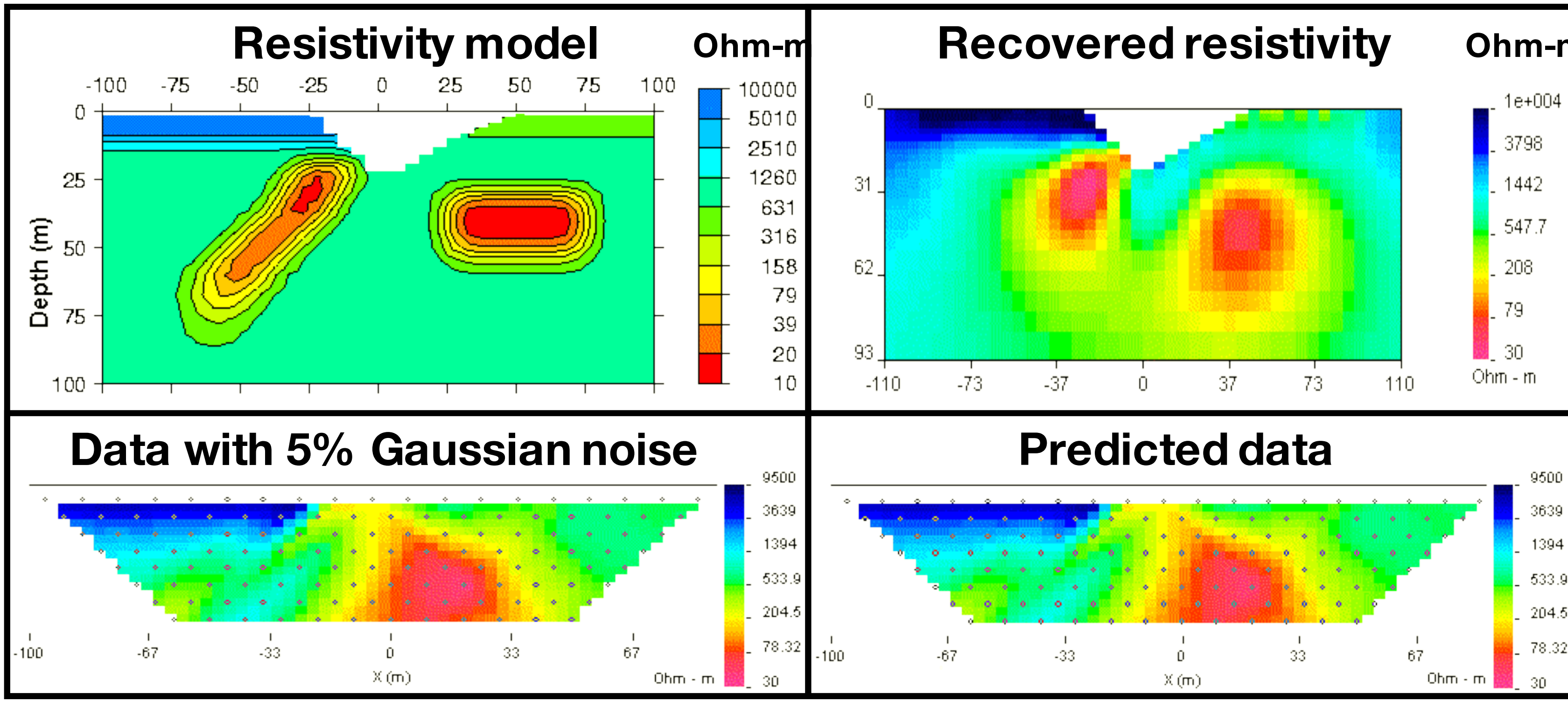
- Pole-dipole; n=1,8; a=10m; N=316; $(\alpha_s, \alpha_x, \alpha_z)$=(.001, 1.0, 1.0)

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)

Example 3: UBC-GIF model



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

The world is 3D

- Target
  - Size, shape, depth
- Background
  - Variable resistivity

- Questions
  - Where to put currents? 2D acquisition? 3D?
  - Where to make measurements?
  - Which measurements?
  - Effects of topography?

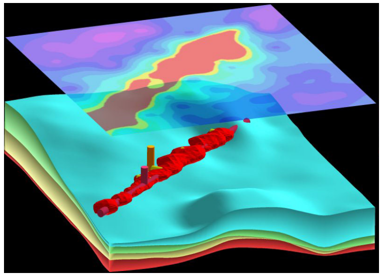
- These are survey design questions

- Crucial element is the **sensitivity**

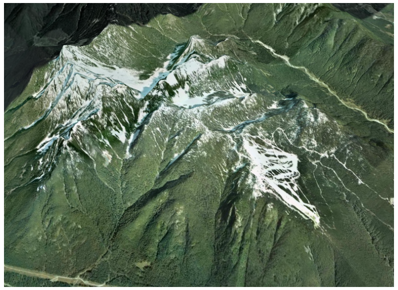
Host

Water underground

Ore body

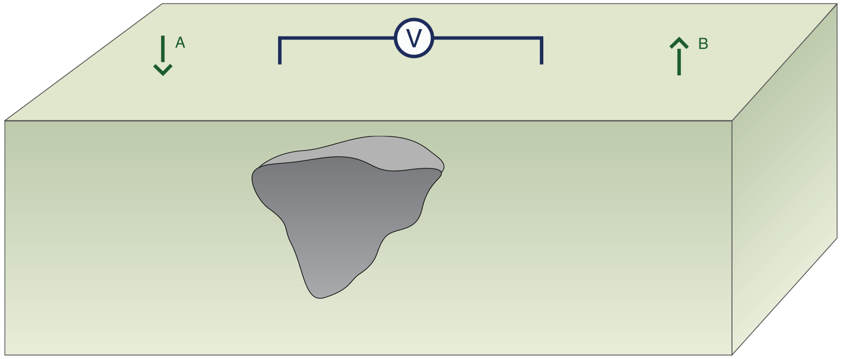


Topography



Sensitivity

Sensitivity Function



Is the measured potential *sensitive* to the target?

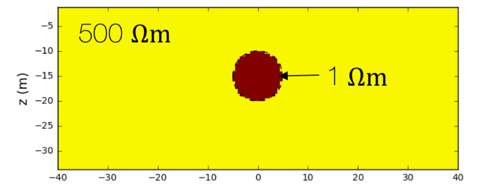
Quantified by the sensitivity

$$G = \frac{\Delta d}{\Delta p} = \frac{\text{change in data}}{\text{change in model}}$$

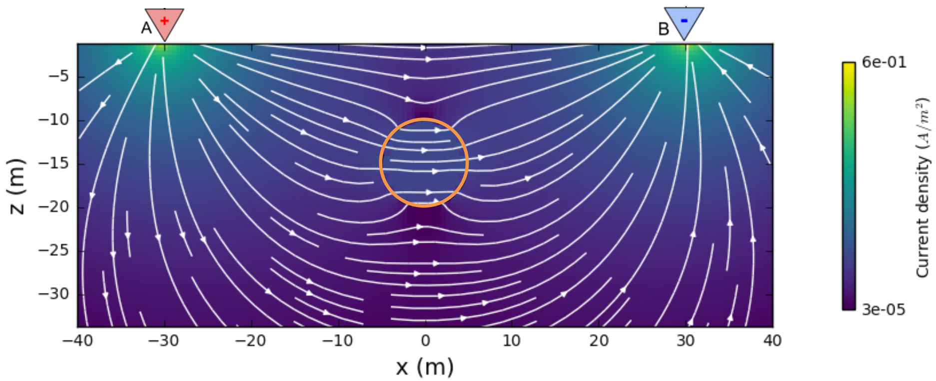
- Collect the data that are sensitive to the target
  - Need to **excite** the target
  - Need to have sensor **close** to the target

Exciting the target

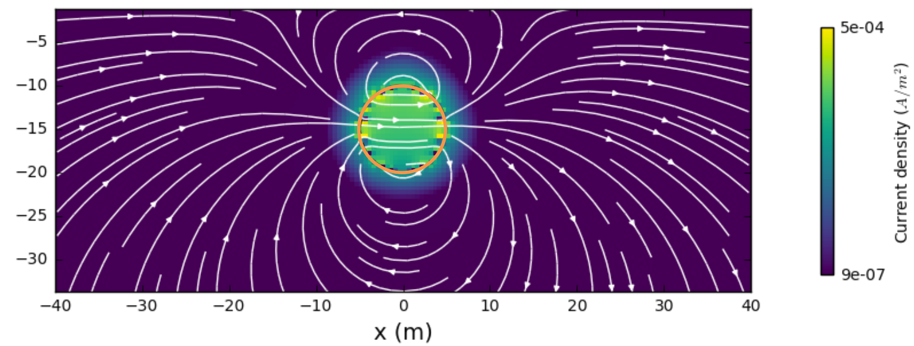
Resistivity model



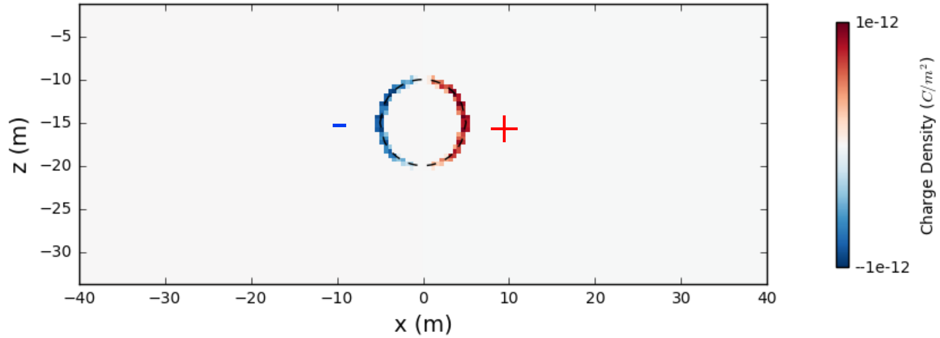
Total currents: **J**



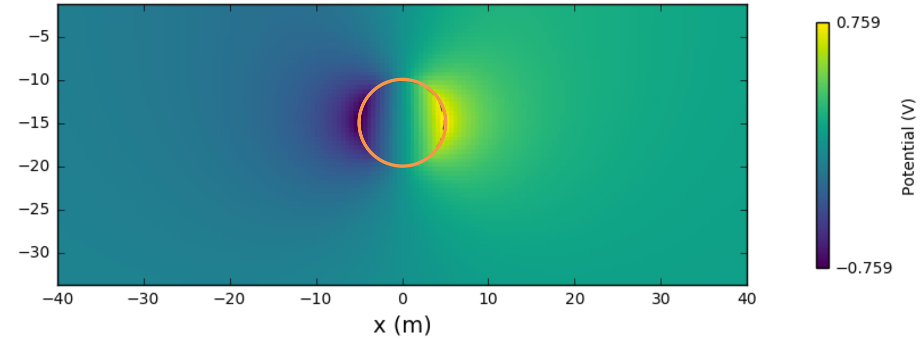
Secondary currents: $\mathbf{J}_s$



Secondary charges: Q_s

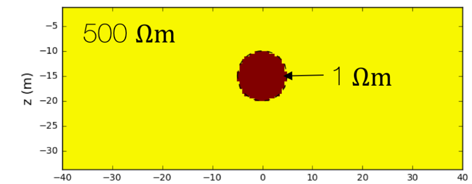


Secondary potential: ϕ_s

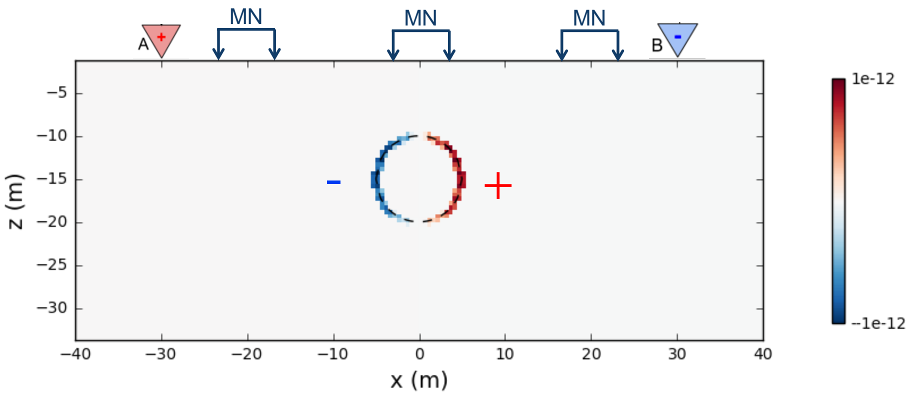


Measurements

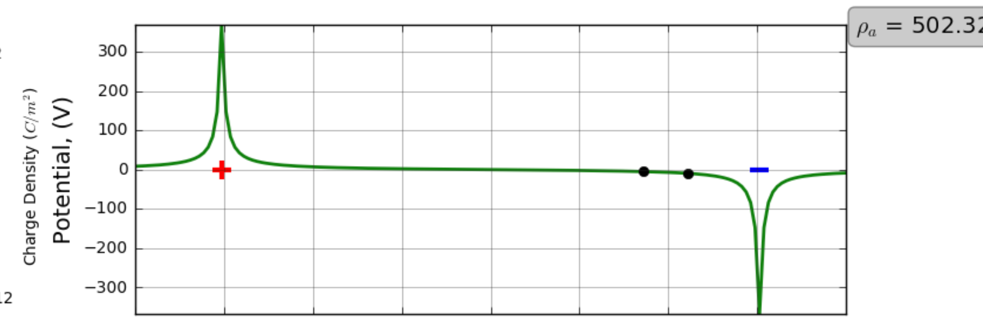
Resistivity model



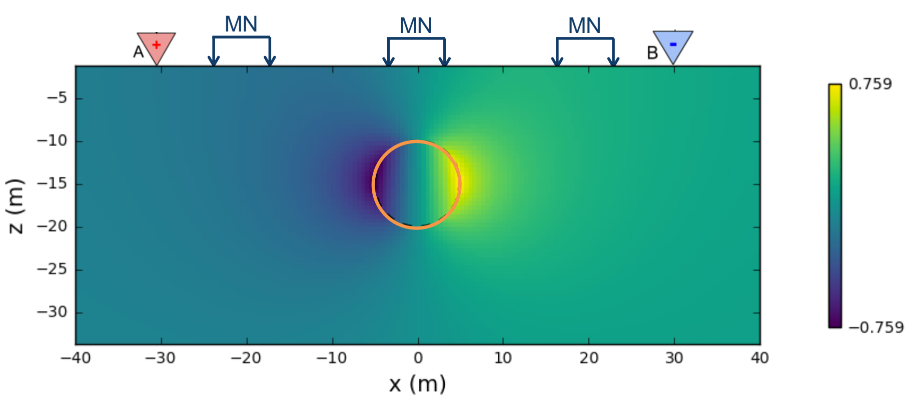
Secondary charges: Q_s



Potential profile

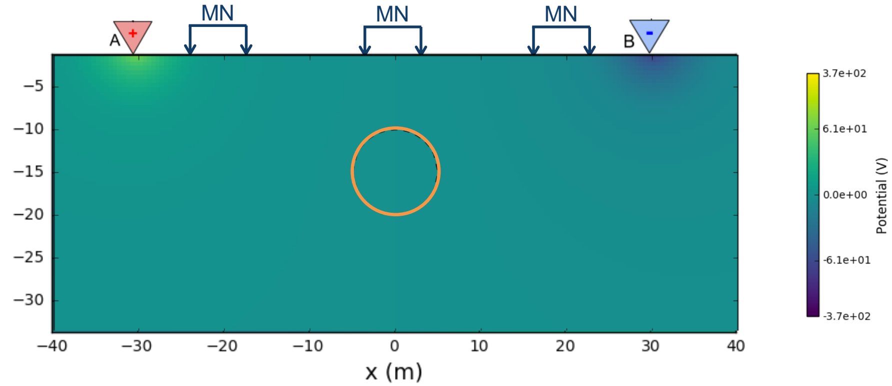


Secondary potential: ϕ_s



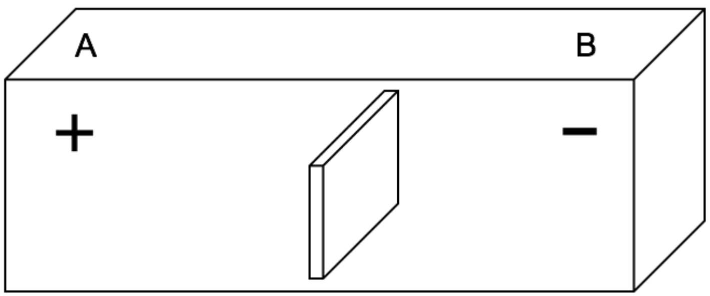
Total potential: ϕ

$\rho_a = 502$ $\rho_a = 430$ $\rho_a = 502$

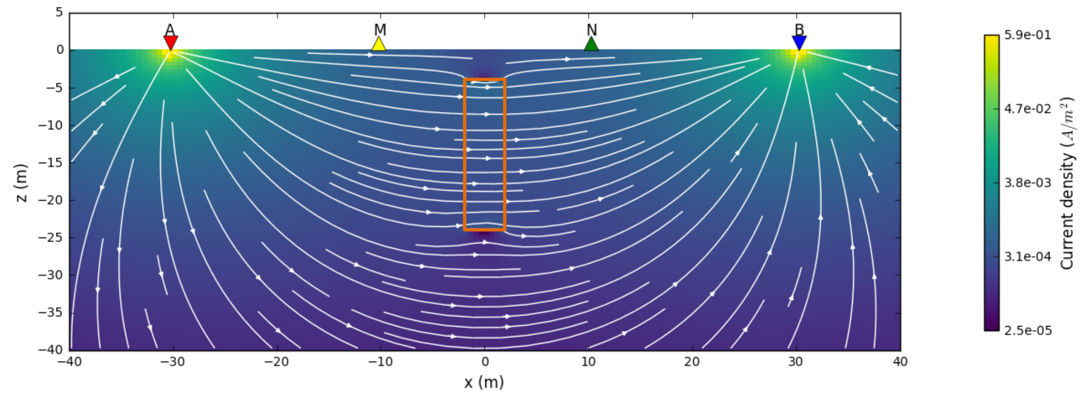


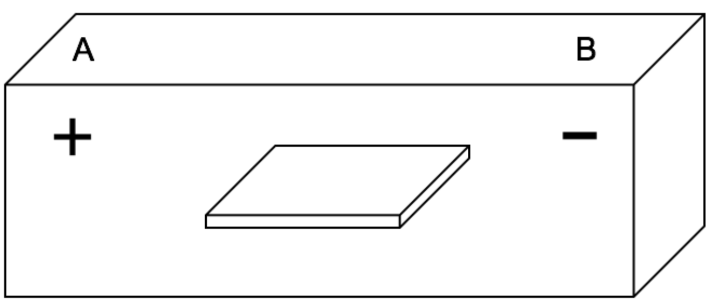
Coupling

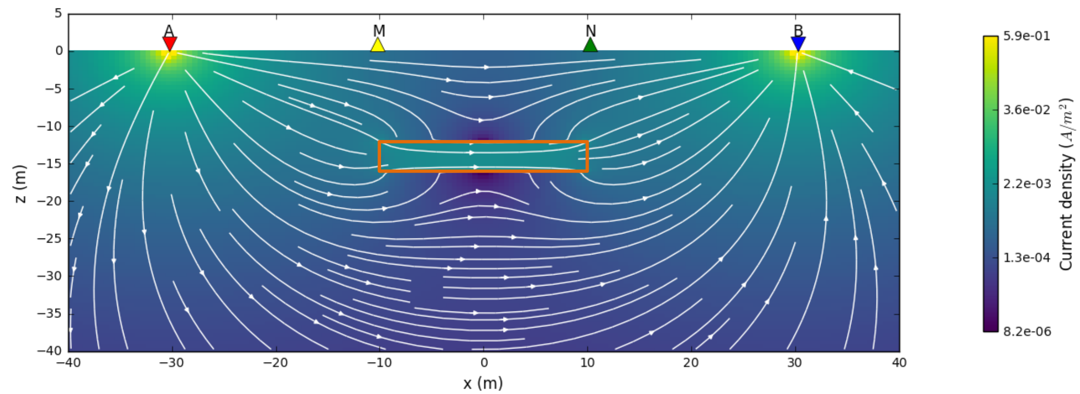
- Thin plate – different orientations
  → different data



Total currents: **J**



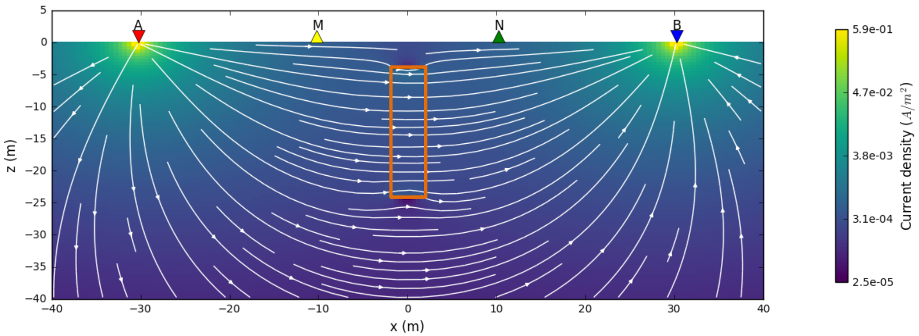




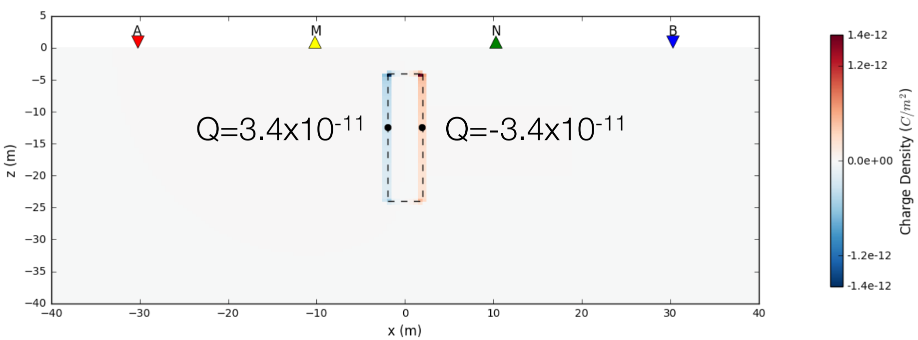
Conductive vs. Resistive Target

Conductive Target

Total currents: **J**

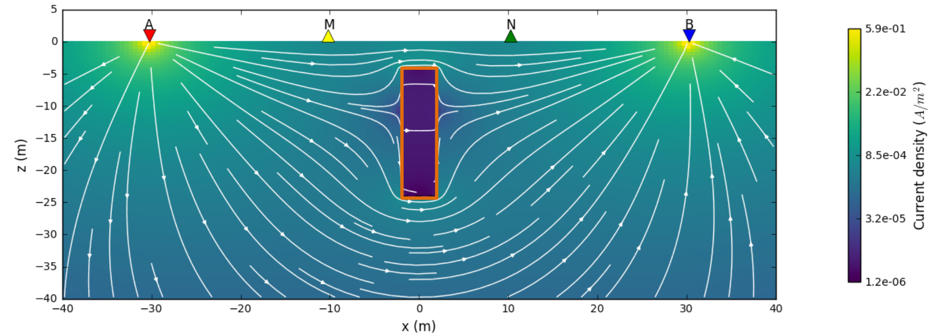


Secondary charges: Q_s

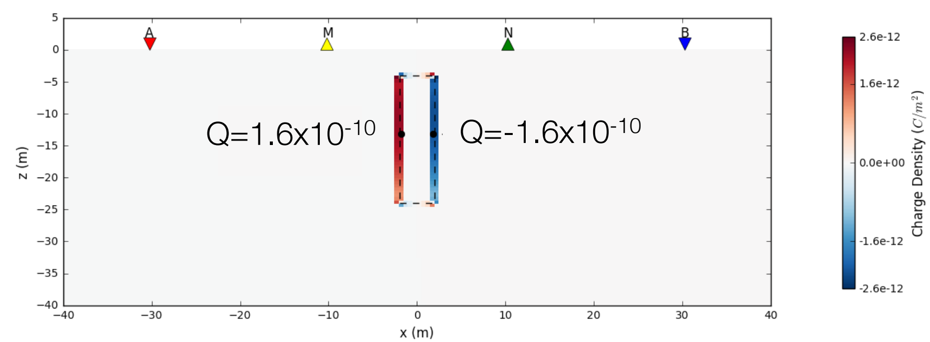


Resistive Target

Total currents: **J**



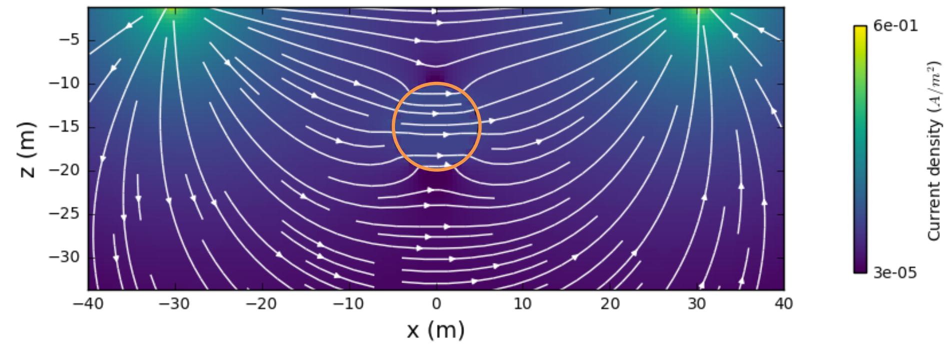
Secondary charges: Q_s



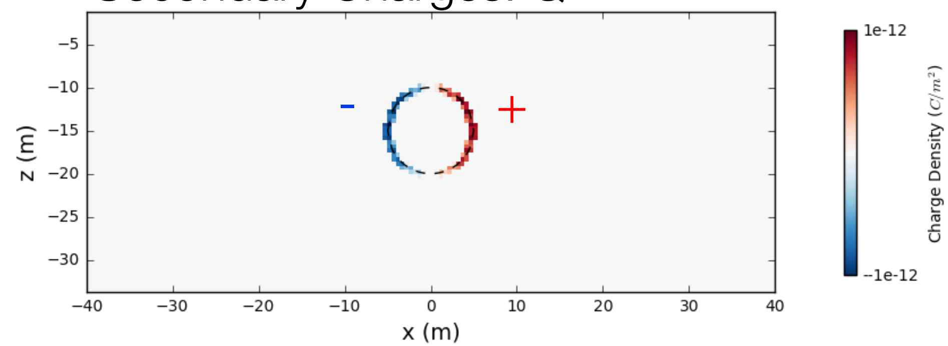
Summary: Sensitivity

- “Excite” the target
  - Drive currents to target
  - Need good coupling with target
- Measuring a datum
  - Proximity to target
  - Electrode orientation and separation
- Background resistivity is important

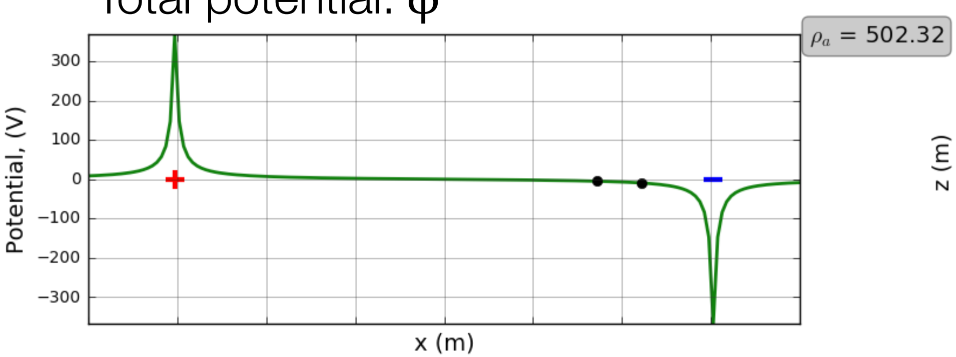
Total currents: **J**



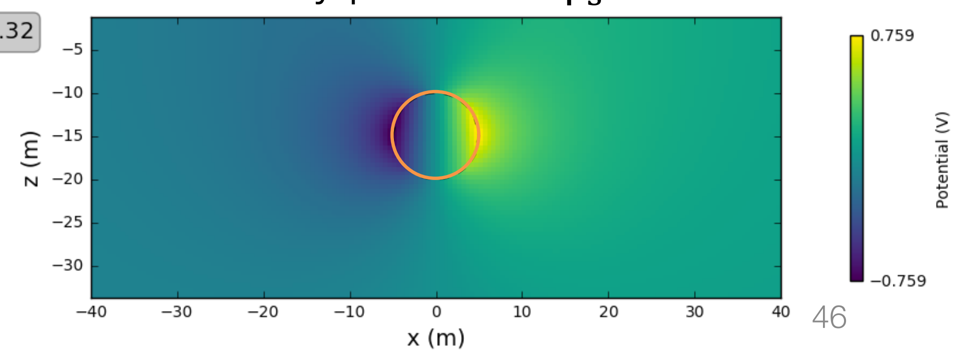
Secondary Charges: Q



Total potential: ϕ

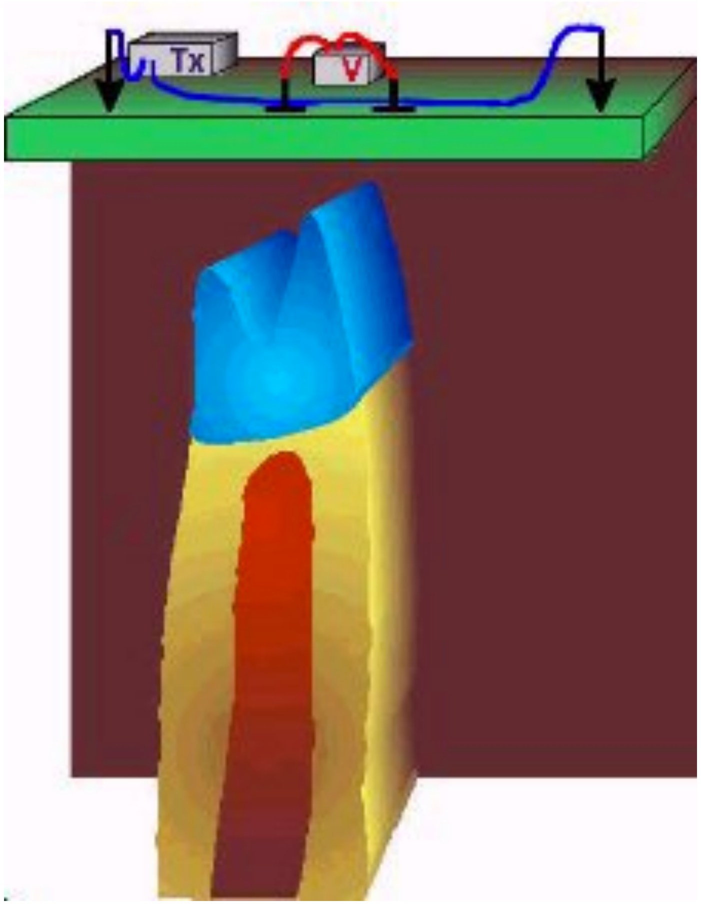


Secondary potential: ϕ_s

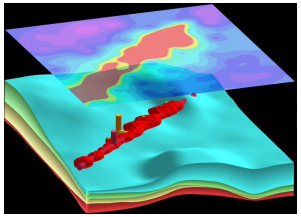


Survey Design: Questions

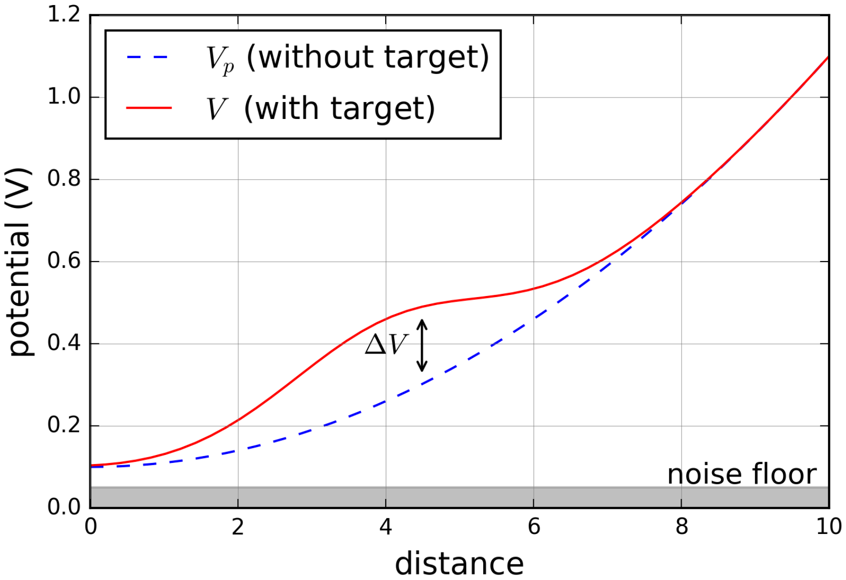
- What is objective?
  - Layered earth (1D)
    → do a sounding
  - Target body (2D)
    → profile, sounding perpendicular to geology
  - Target body (3d)
    → need 3D coverage
- What is the background resistivity?
- What are the noise sources? fences, power lines, …



Survey Design: in general



- Numerical simulation – can we **see** the target?
- Steps:
  - Define a geologic model
  - Assign physical properties
  - Select a survey
  - Simulate with (V) and without (V_p) target
- Best practice
  - Assign uncertainties to simulated data
  - Invert with code you will use for the field data



Signal from target

$$\Delta V = V - V_p$$

Need

$$\Delta V > floor$$

$$\frac{\Delta V}{V_p} > \%|V|$$

Outline

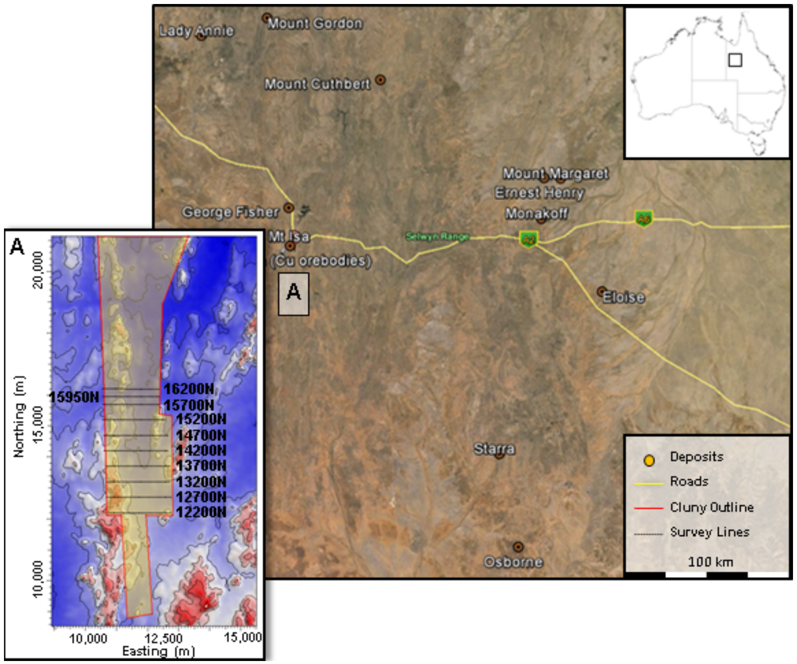
- Basic experiment
- Currents, charges, potentials and apparent resistivities
- Soundings, profiles and arrays
- Data, pseudosections and inversion
- Sensitivity
- Survey Design
- What have we learned? (DC app)

- Questions

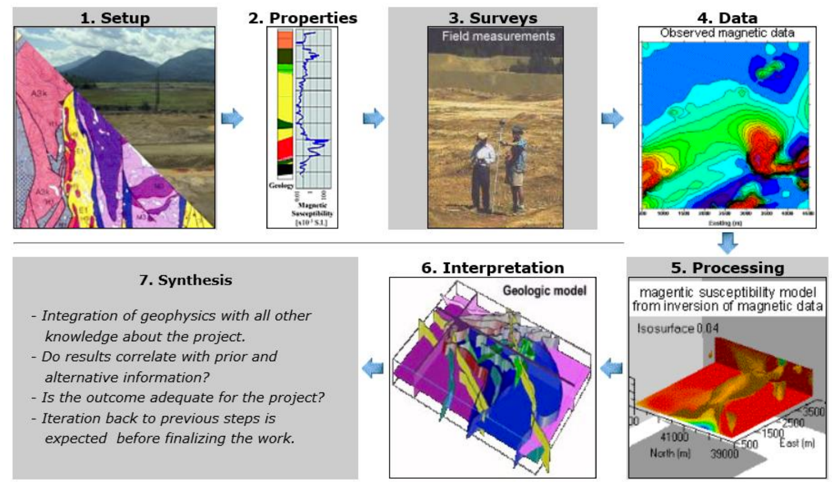
- Case History – Mt Isa
- Effects of background resistivity

Mt. Isa

Mt. Isa (Cluny prospect)

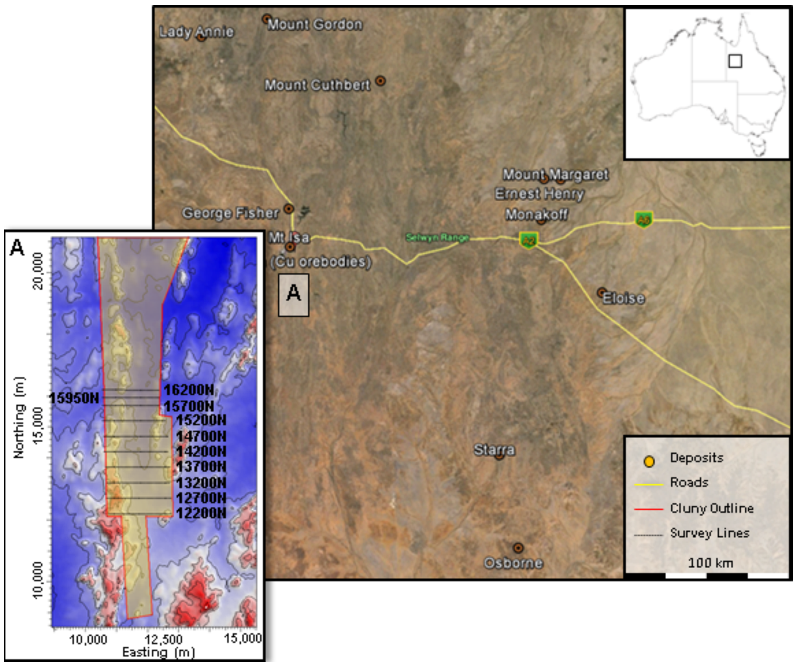


Seven Steps

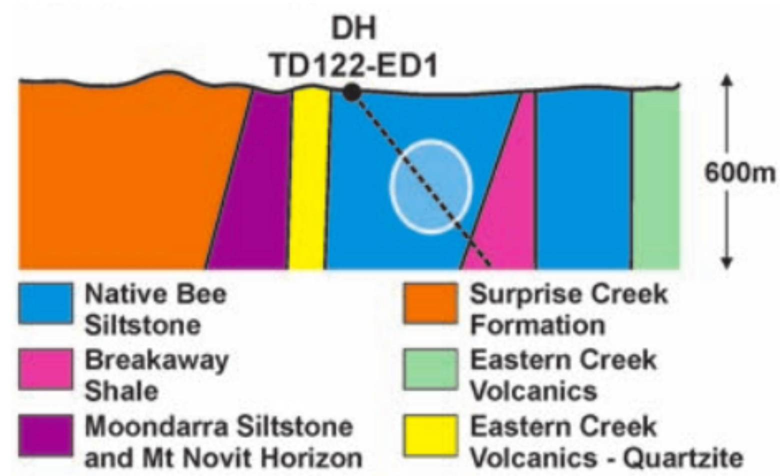


Setup

Mt. Isa (Cluny prospect)



Geologic model

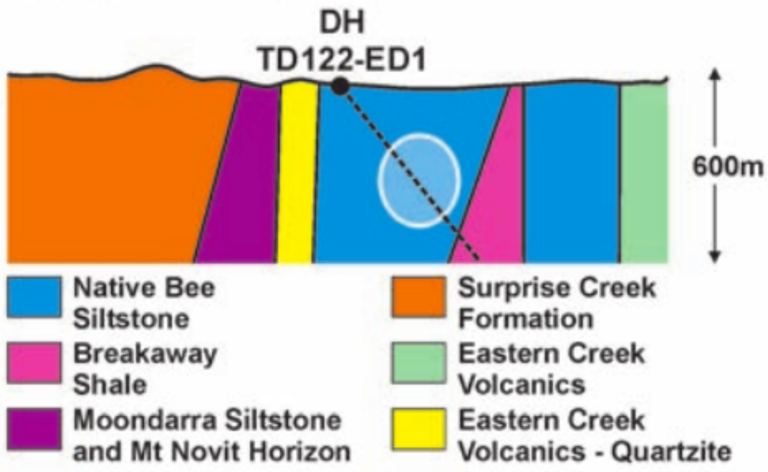


Question

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

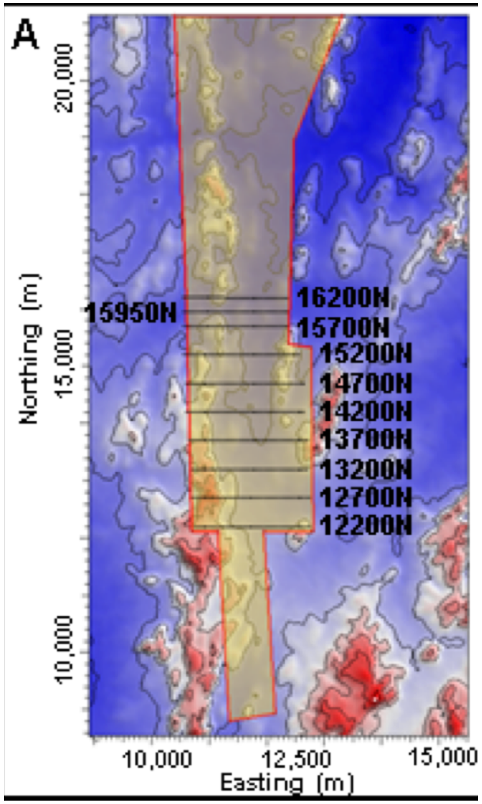
Properties

Geologic model



Rock Unit	Conductivity
Native Bee Siltstone	Moderate
Moondarra Siltstone	Moderate
Breakaway Shale	Very High
Mt Novit Horizon	High
Surprise Creek Formation	Low
Eastern Creek Volcanics	Low

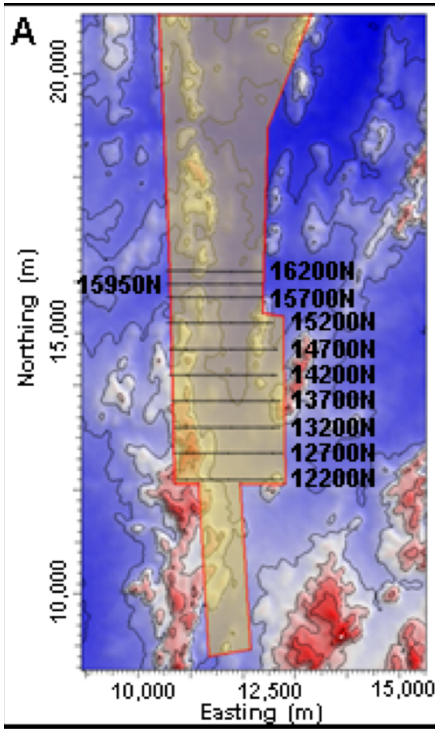
Surface topography



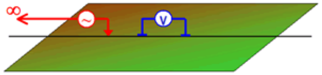
Survey and Data

- Eight survey lines
- Two survey configurations.

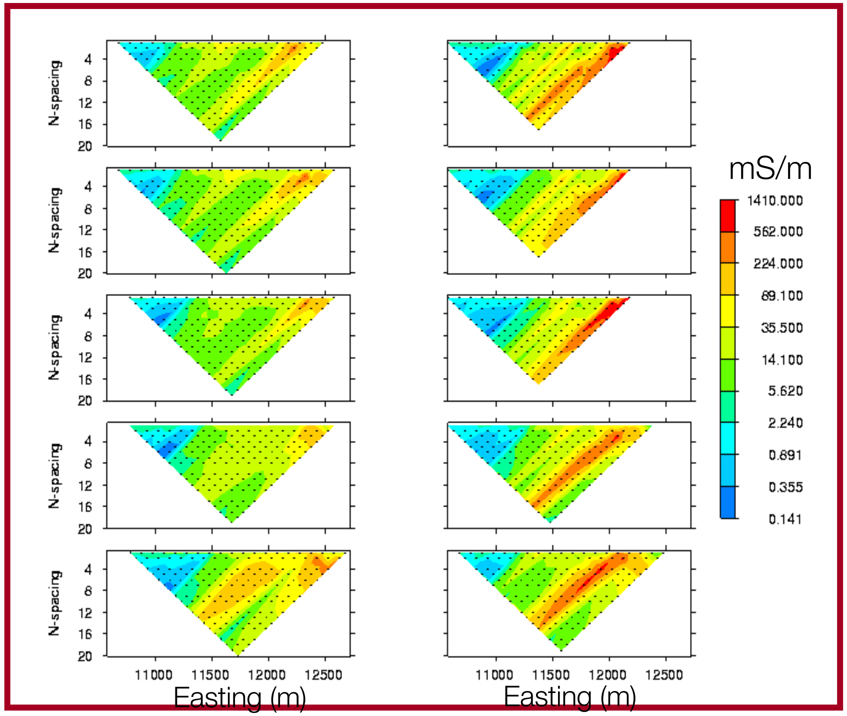
Surface topography



Data set #1:



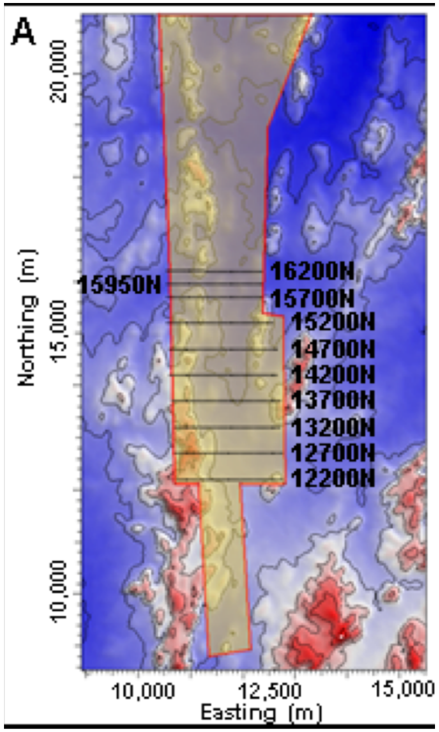
Apparent resistivity, pole - dipole.



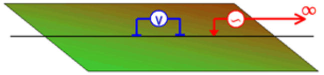
Survey and Data

- Eight survey lines
- Two survey configurations.

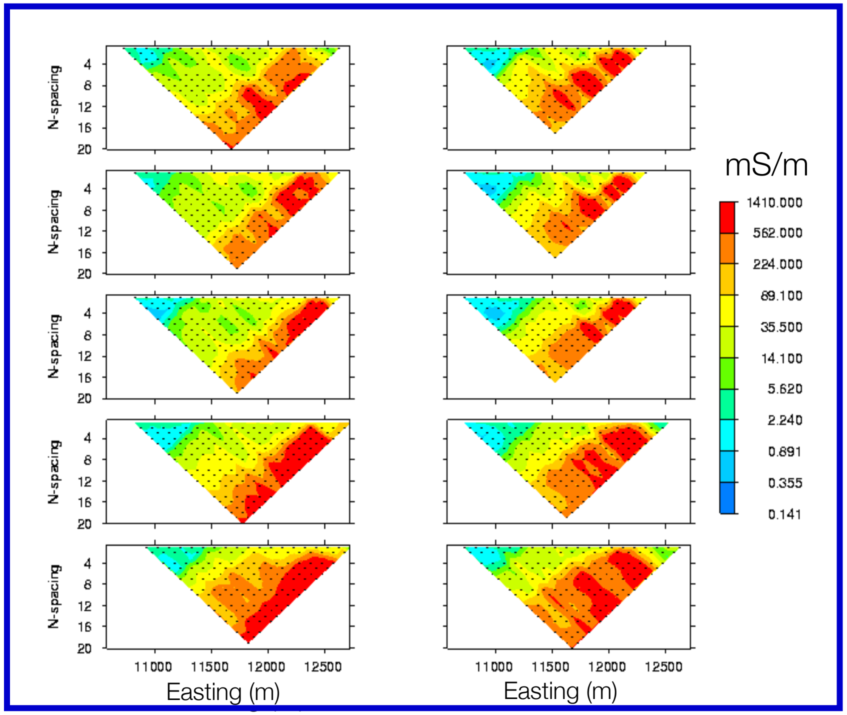
Surface topography



Data set #2:

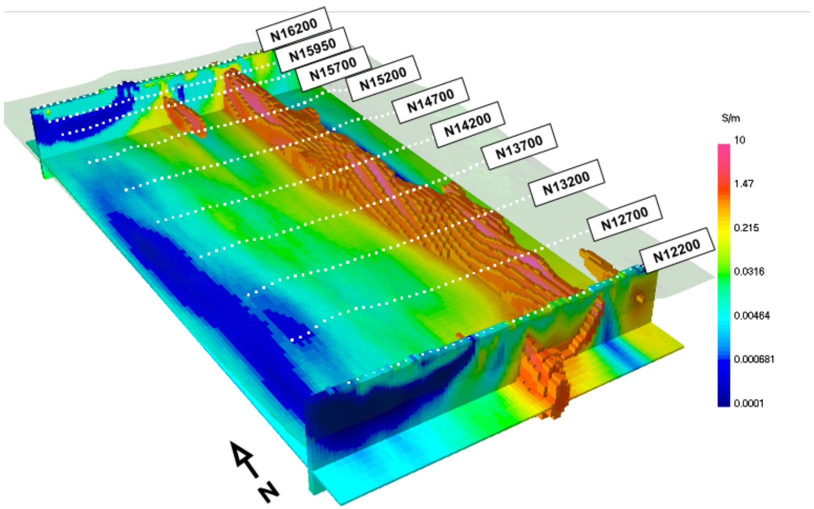


Apparent resistivity, dipole - pole

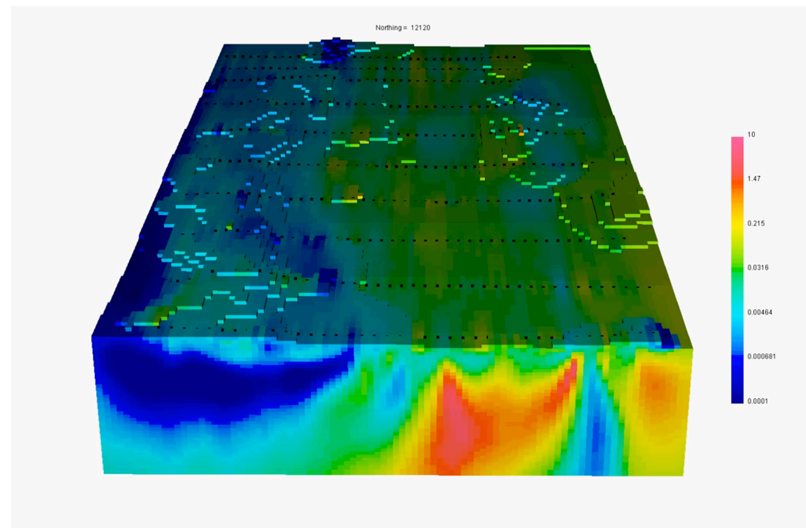


Processing and interpretation

3D resistivity model



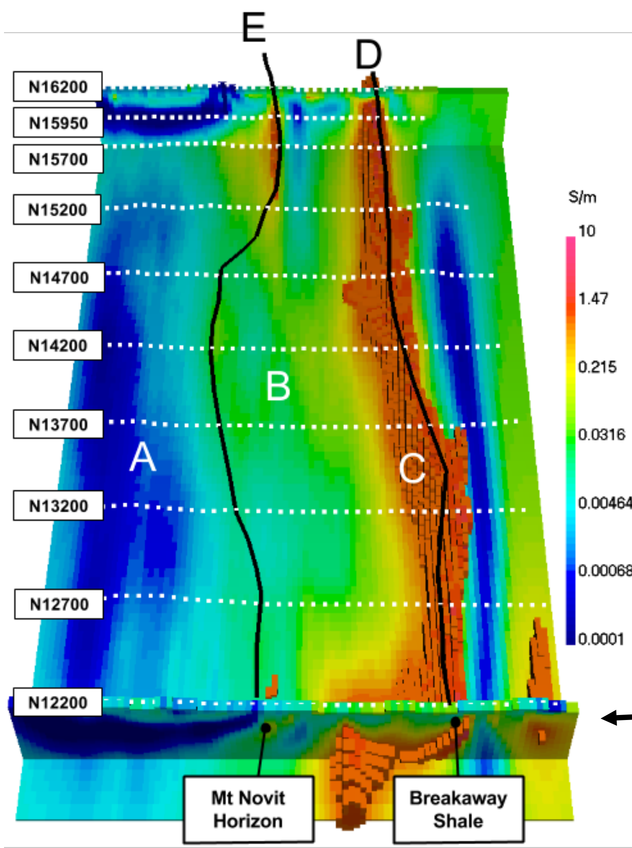
Animation



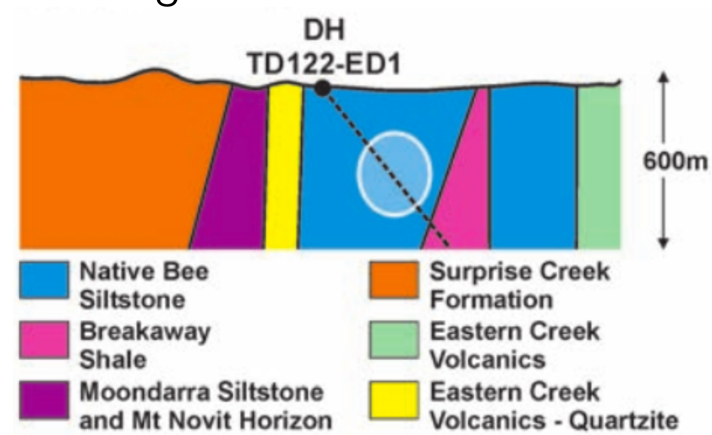
Synthesis

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

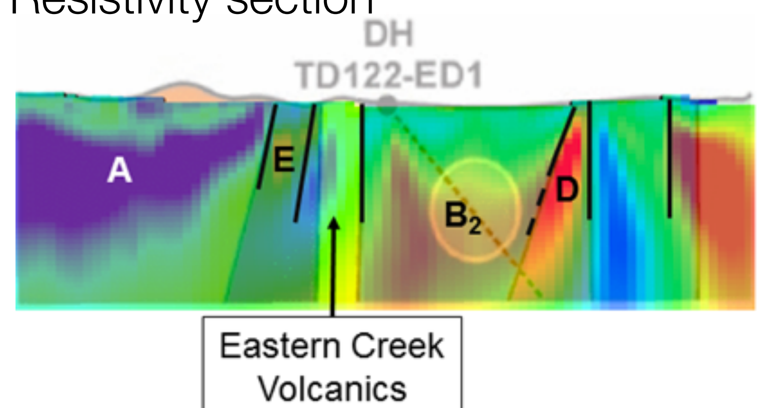
3D resistivity model



Geologic section



Resistivity section



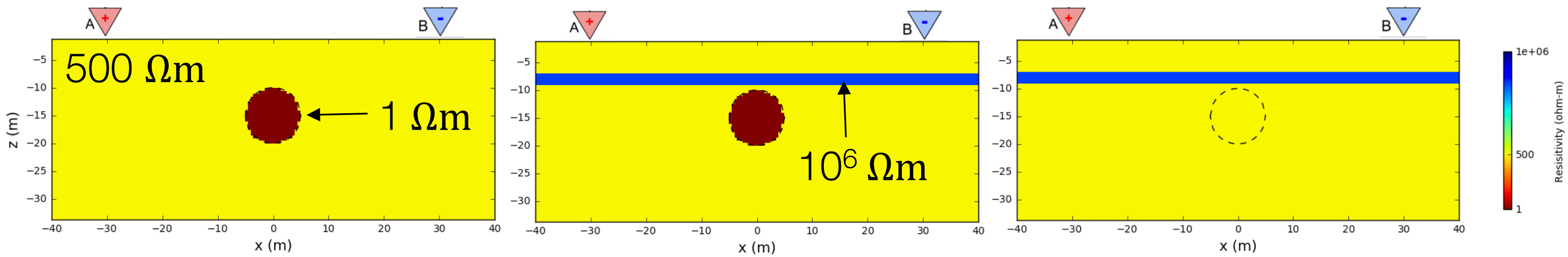
Outline

- Basic experiment
- Currents, charges, potentials and apparent resistivities
- Soundings, profiles and arrays
- Data, pseudosections and inversion
- Sensitivity
- Survey Design
- Case History – Mt Isa

- Effects of background resistivity

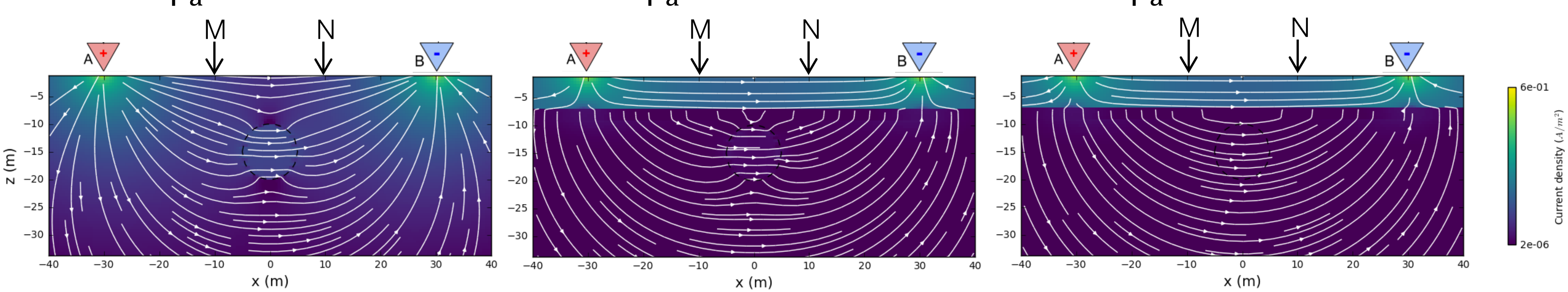
Effects of background resistivity

Resistivity models (thin resistive layer)



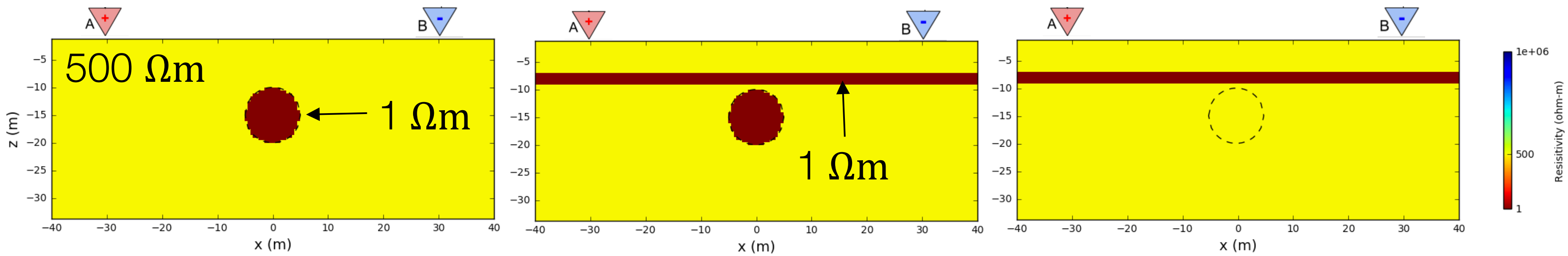
Currents and measured data at MN

ρ_a = 430 Ωm ρ_a = 1652 Ωm ρ_a = 1654 Ωm

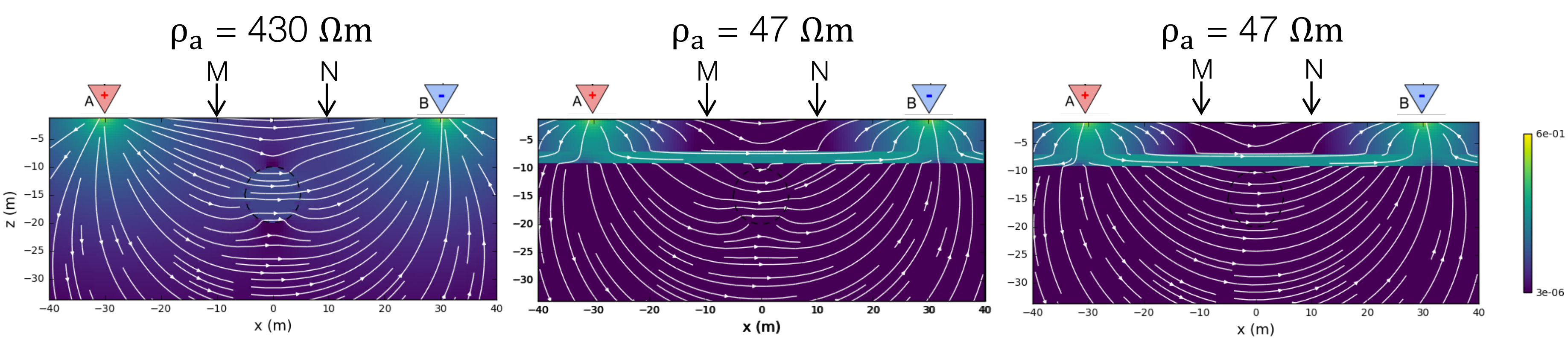


Effects of background resistivity

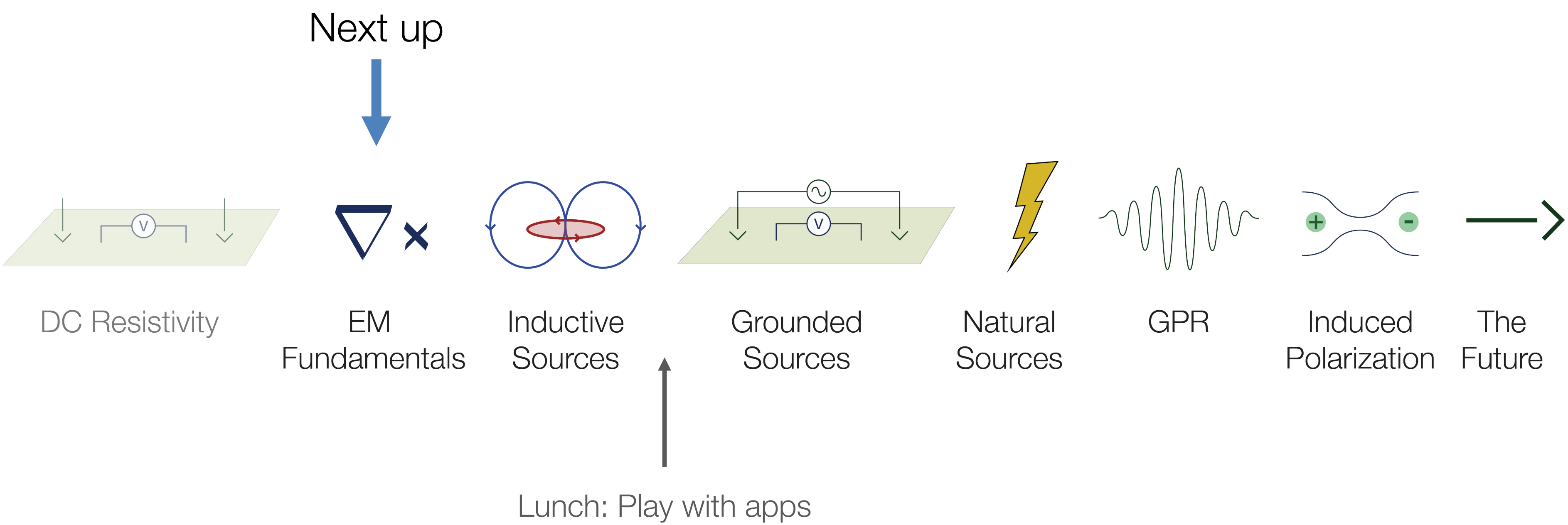
Resistivity models (thin conductive layer)



Currents and measured data at MN



End of DCR


Next up
DC Resistivity
EM Fundamentals
Inductive Sources
Grounded Sources
Natural Sources
GPR
Induced Polarization
The Future
V
Lunch: Play with apps