DC Resistivity

DC Resistivity Survey
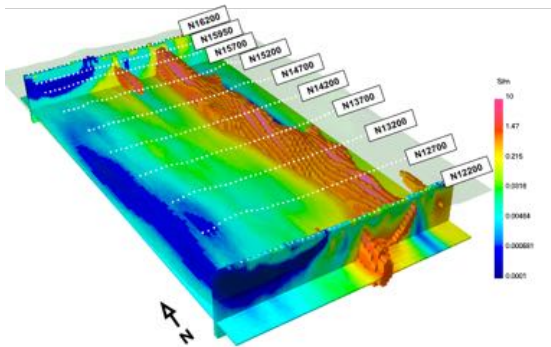

Source

Data

Input energy

measure

ρ

$\rho = 1/\sigma$
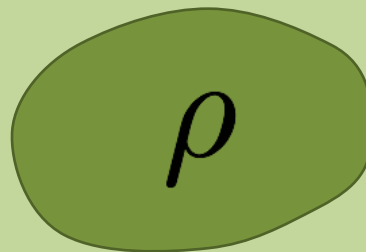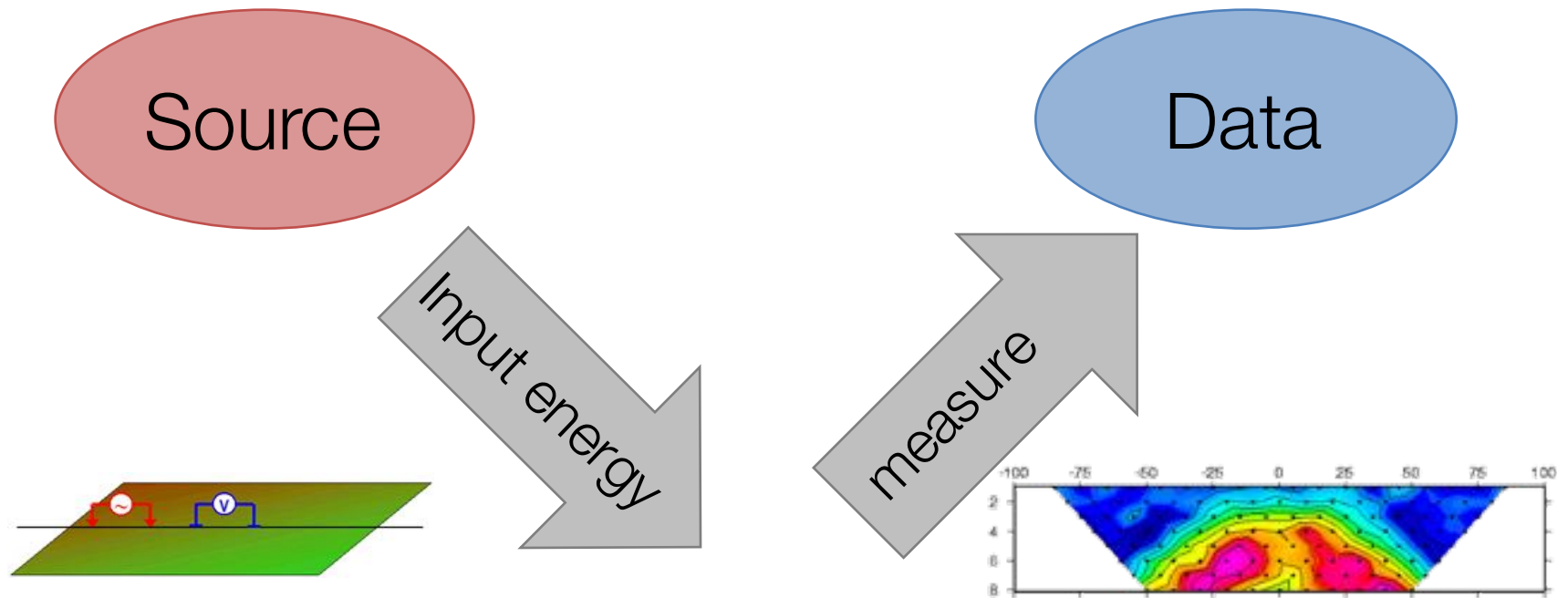
ρ : resistivity

σ : electrical conductivity
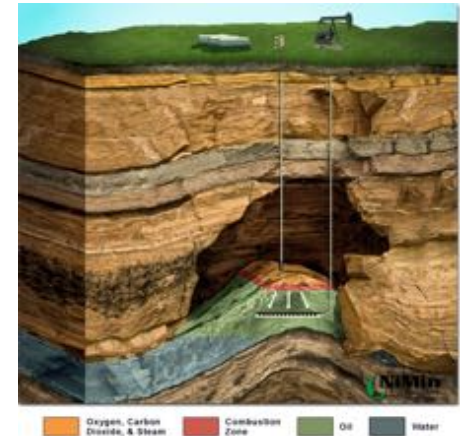
Motivation

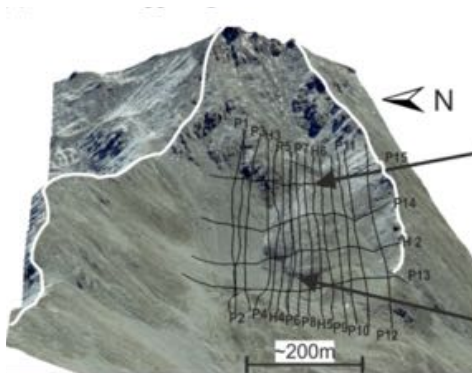## Minerals
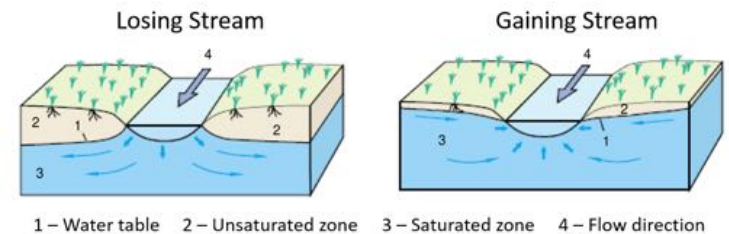

Water inflow in mine

Oil and Gas
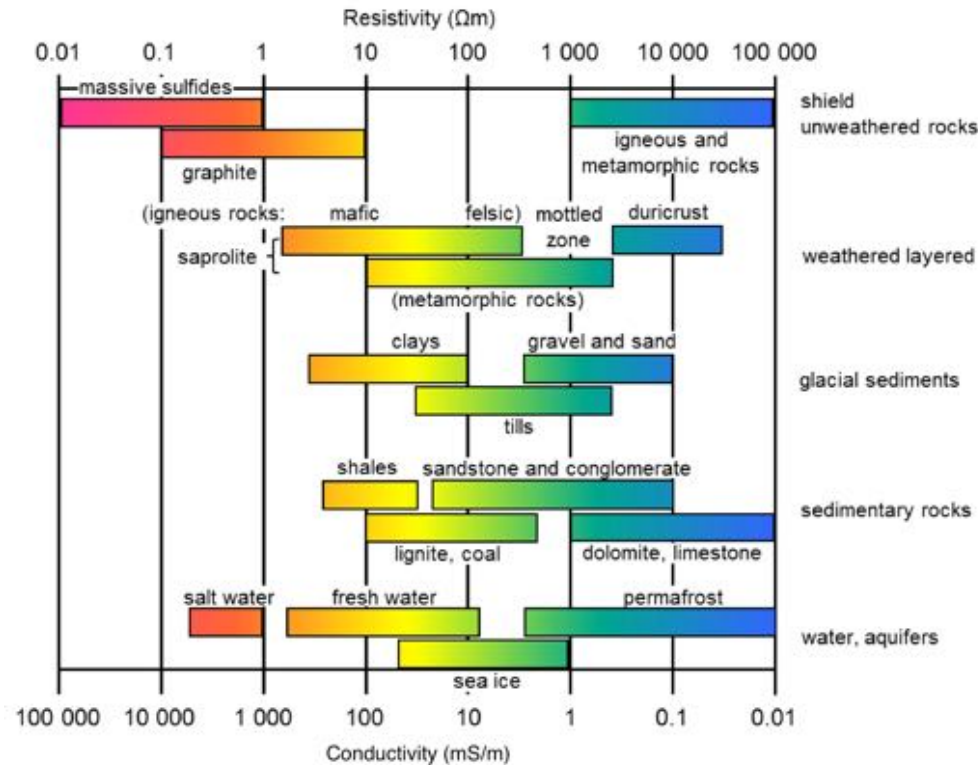

Geotechnical

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

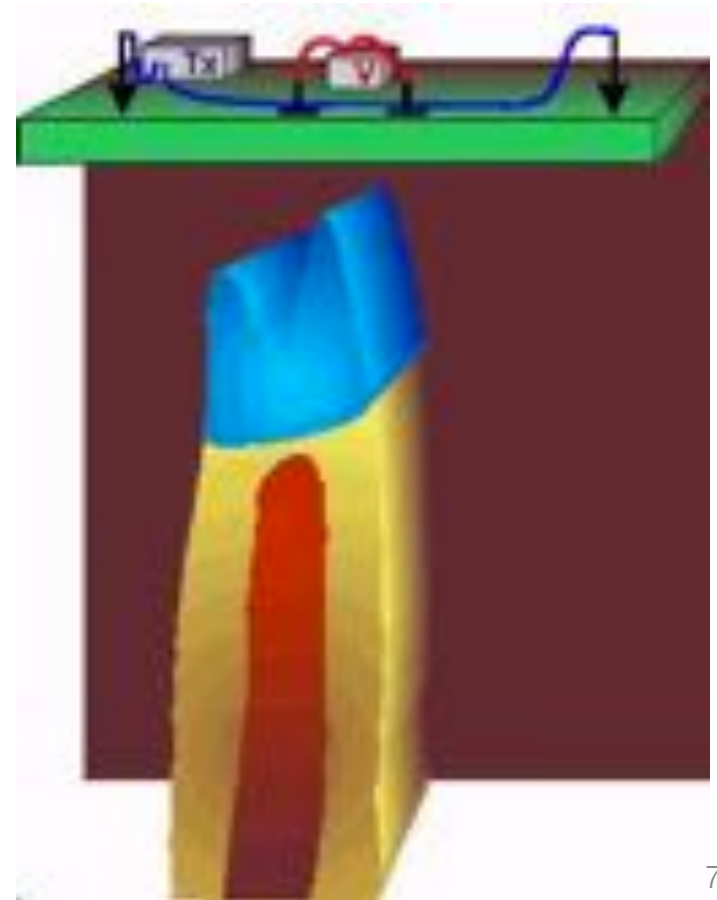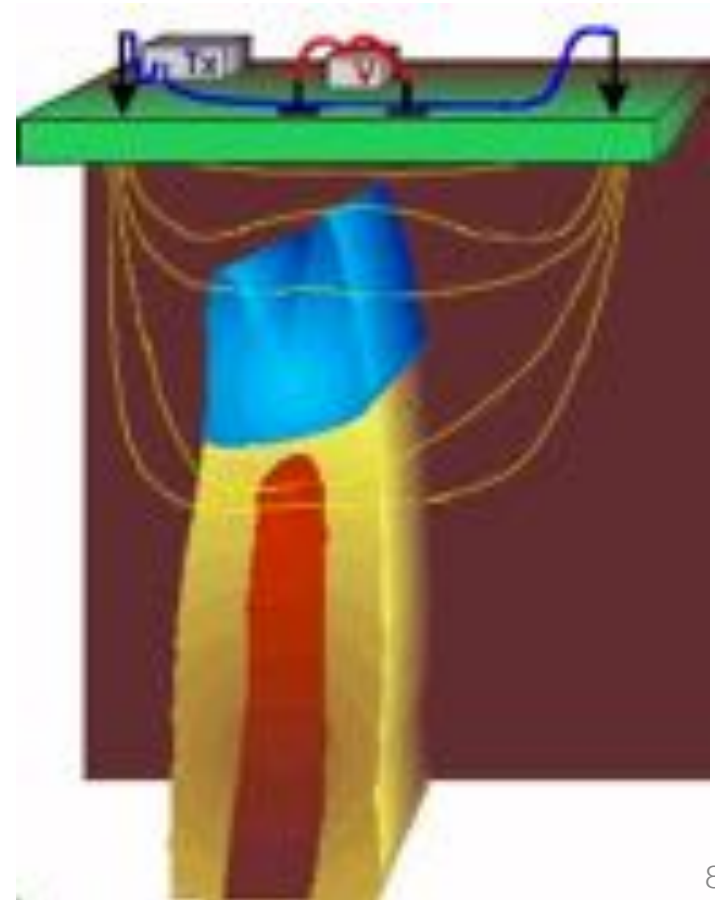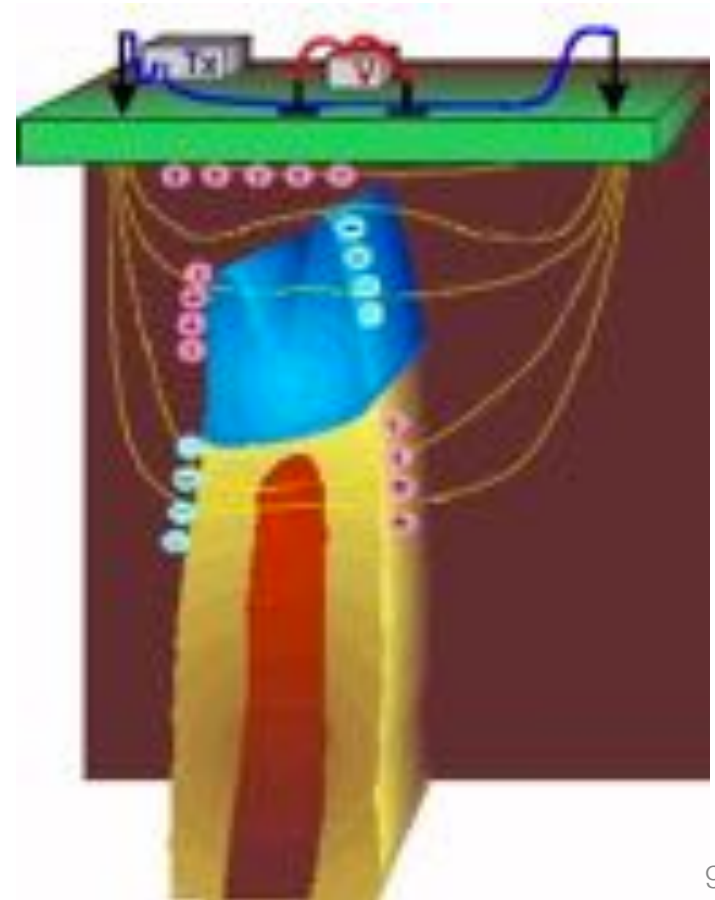| Rock Type	Ohm-m
Overburden	12
Host rocks	200
Gossan	420
Mineralization (pyritic)	0.6
Mineralization (pyrrhotite)	0.6
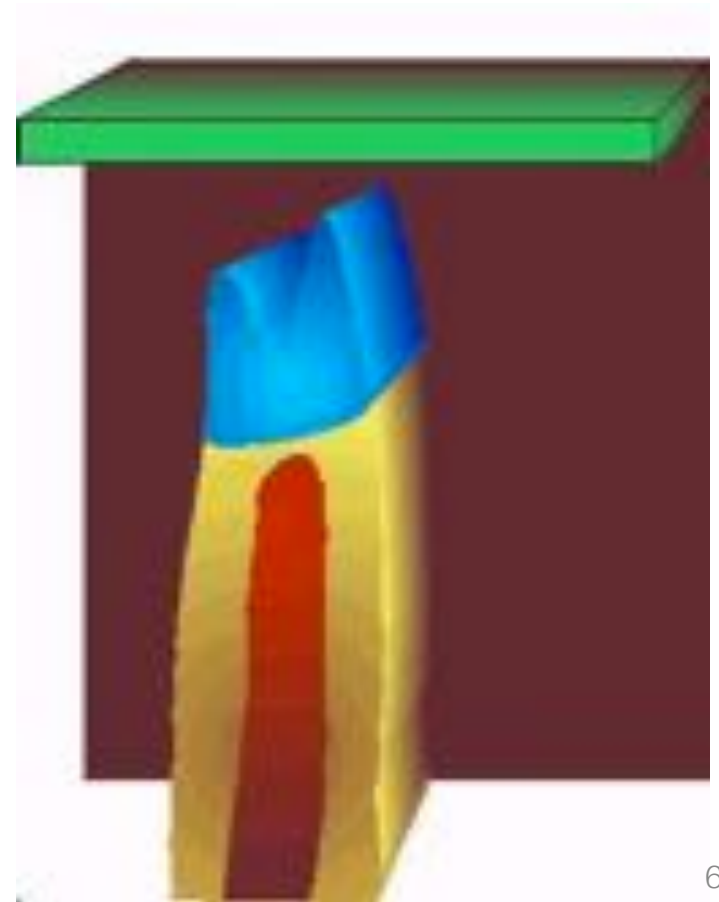
Basic Experiment

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

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

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

Elura Orebody Electrical resistivities

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

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

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

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

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

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

Elura Orebody Electrical resistivities

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

- **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
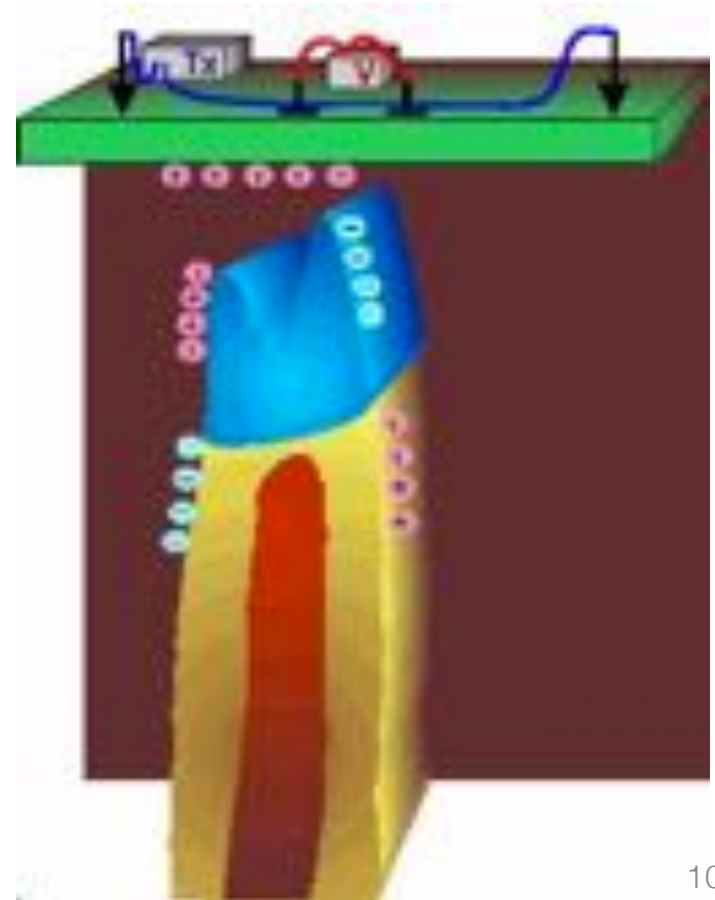
How do we obtain resistivity?

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
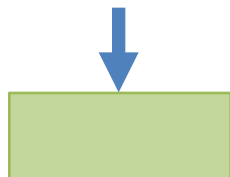
$$V = \frac{I}{2\pi\sigma}\frac{1}{r} \qquad V = \frac{\rho I}{2\pi r}$$

Currents and potentials: halfspace

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

$$\rho = \frac{2\pi r V}{I}$$
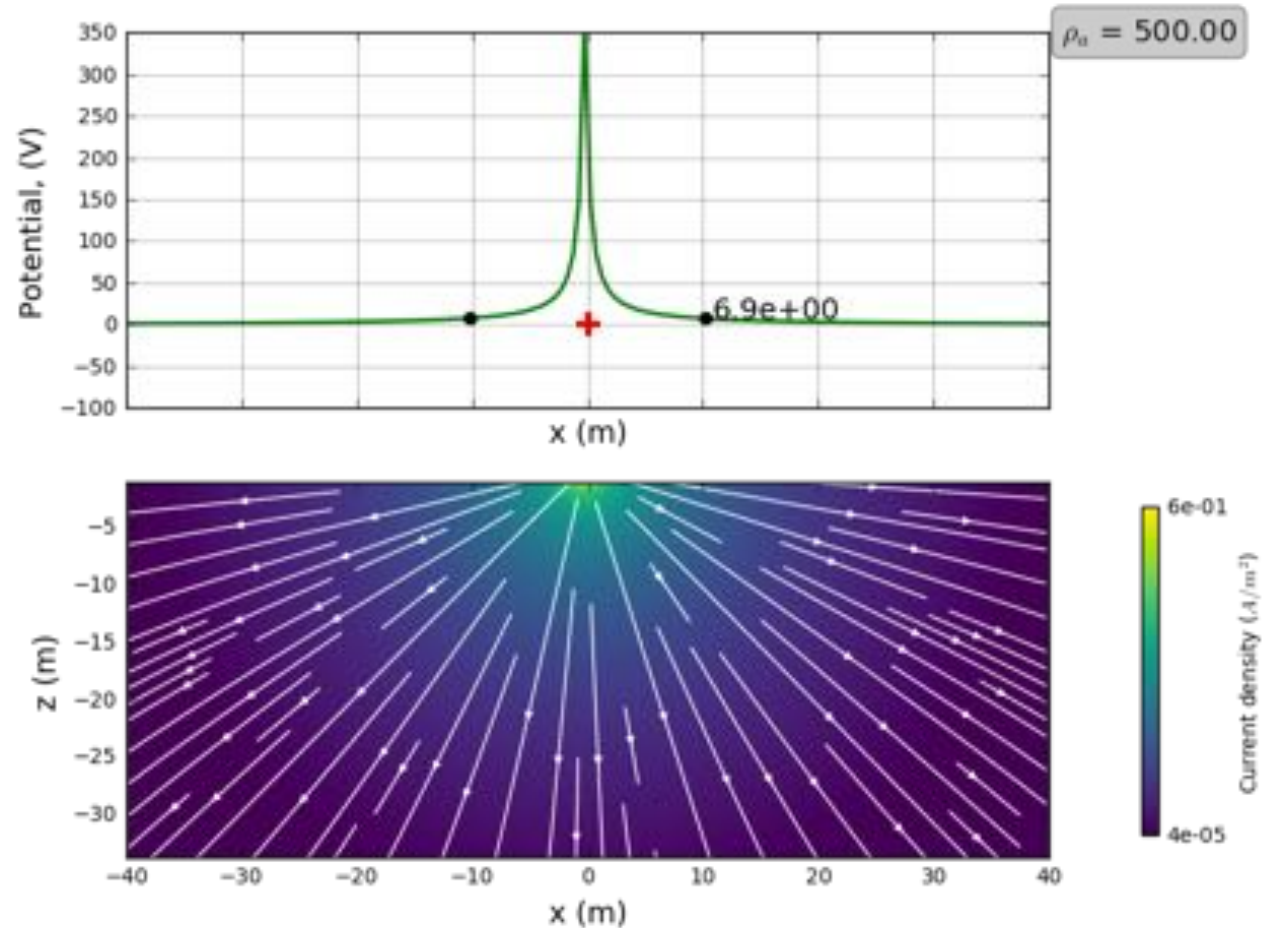
Currents and potentials: 4-electrode array
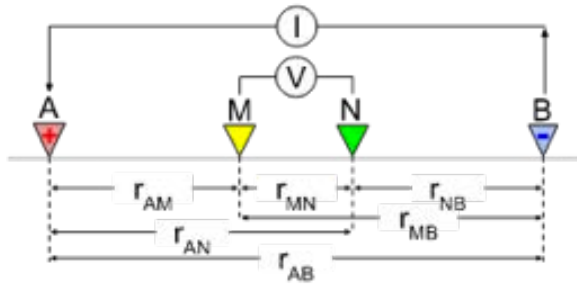
Halfspace (500 Ωm)

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

Resistivity

$$\rho = \frac{\Delta V_{MN}}{IG}$$
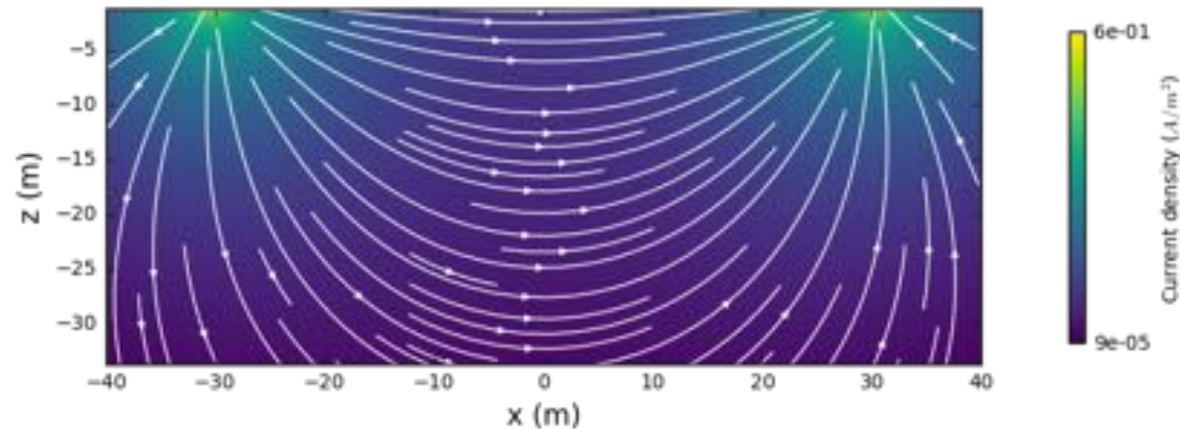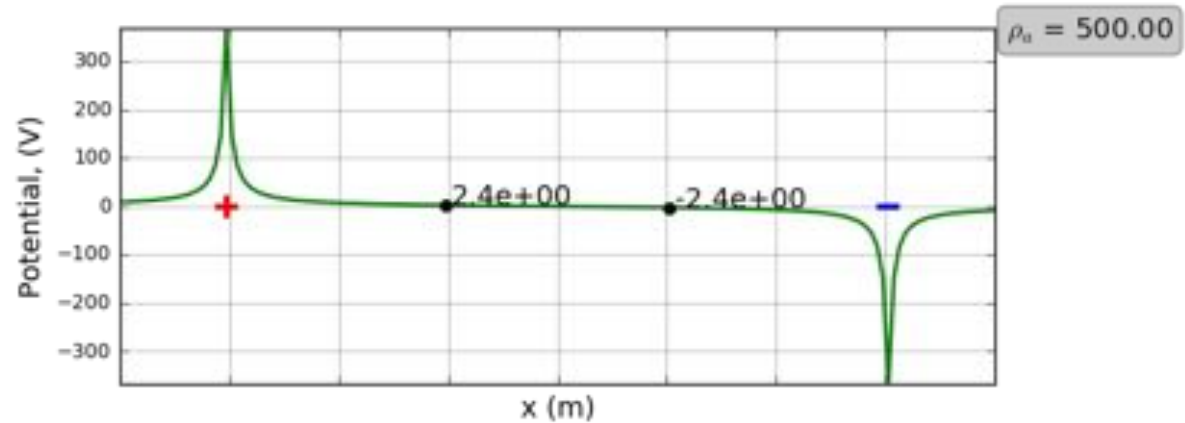
Currents and Apparent Resistivity

Conductive overburden (100 Ωm)
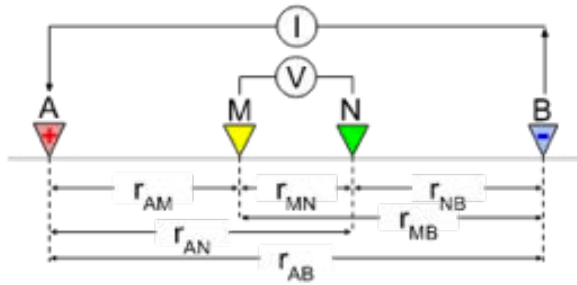
$$\Delta V_{MN} = \rho I \frac{1}{2\pi} \underbrace{\left[\frac{1}{AM} - \frac{1}{MB} - \frac{1}{AN} + \frac{1}{NB} \right]}_{G}$$

Apparent resistivity

$$\rho_a = \frac{\Delta V_{MN}}{IG}$$
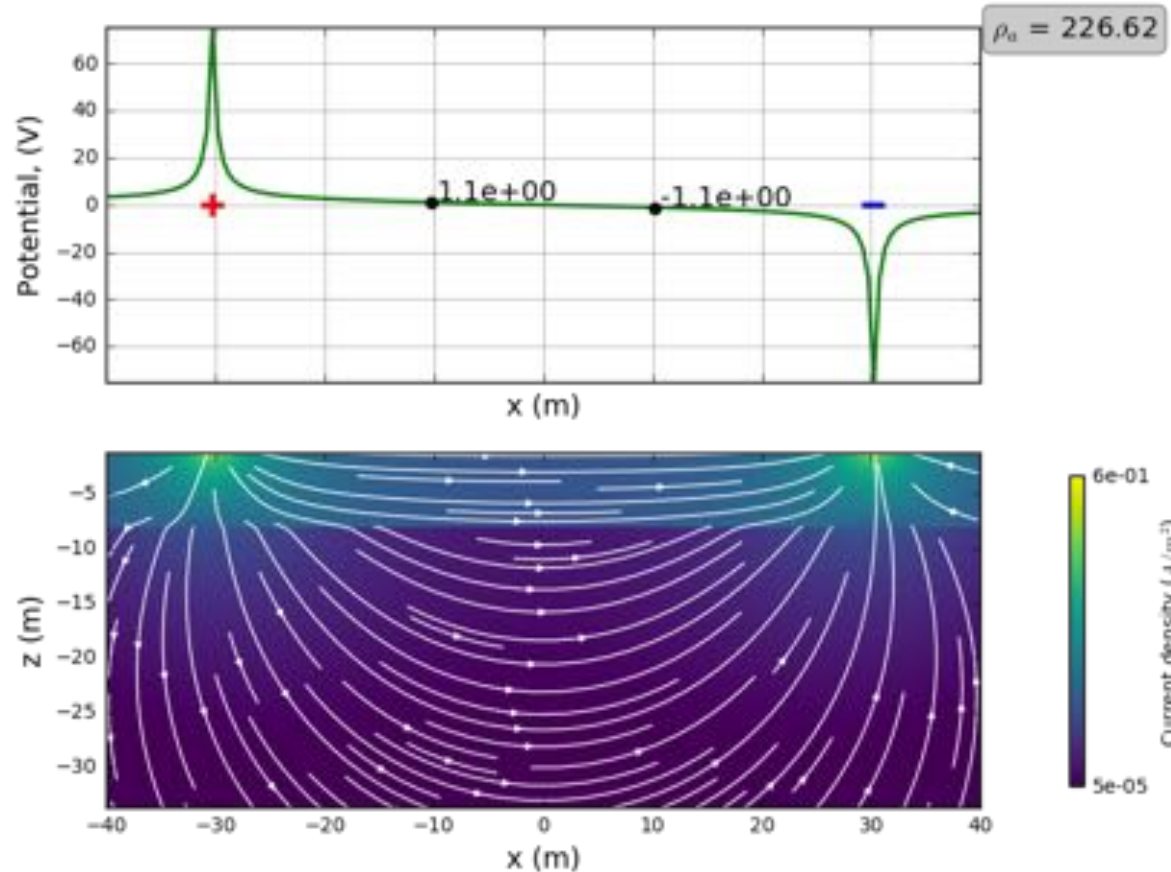
Why interactive apps?

- Visualization aids understanding

- Learn through interaction
  - ask questions and investigate

- Open source:
  - Free to use
  - Welcome contributions!

http://em.geosci.xyz/apps.html
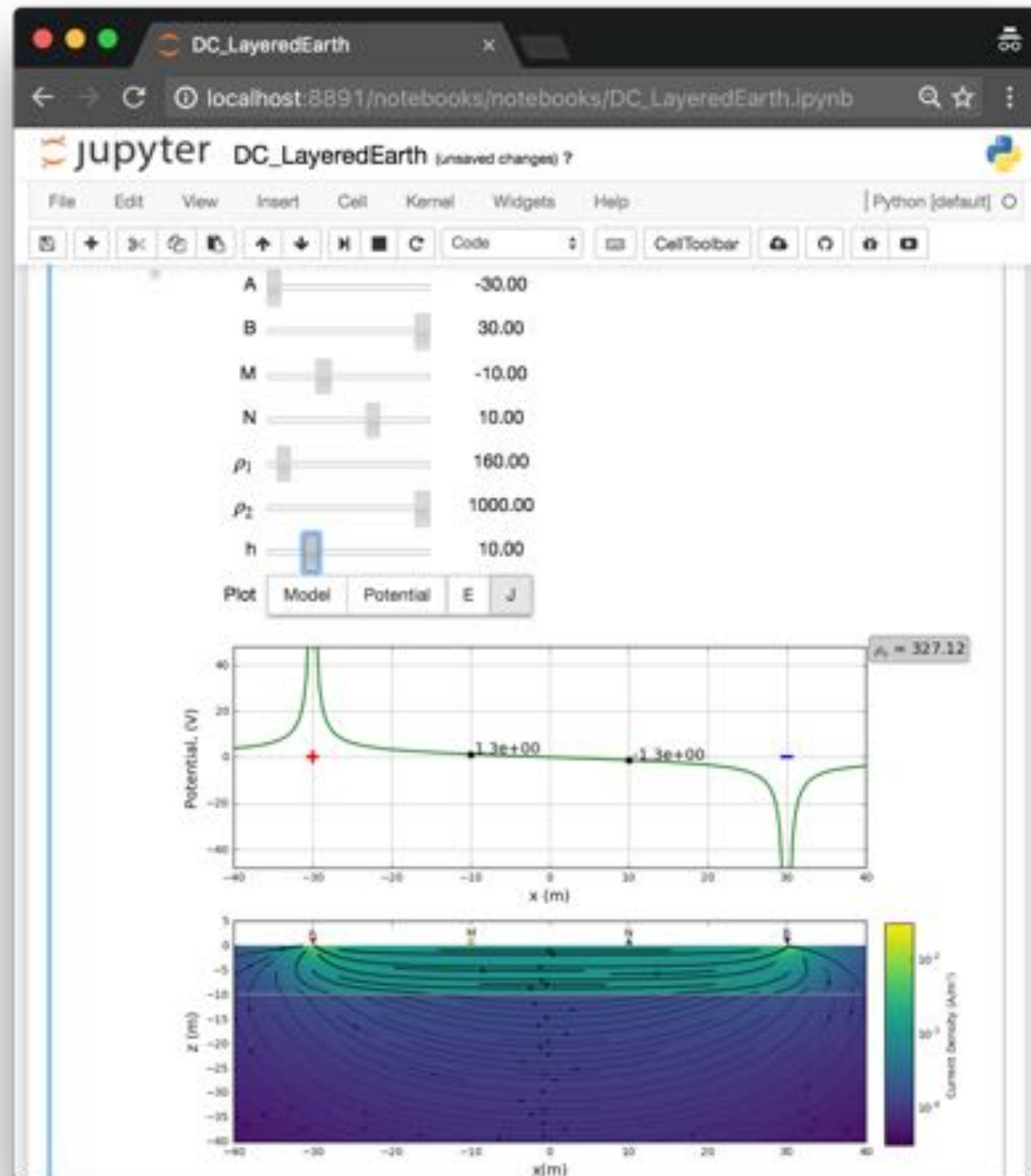
Soundings and Arrays

Geometry

Wenner
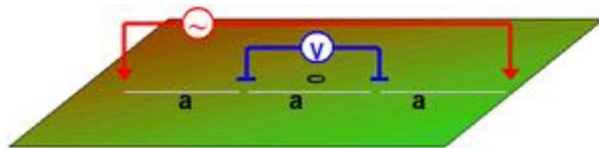
Schlumberger

4 electrode Array
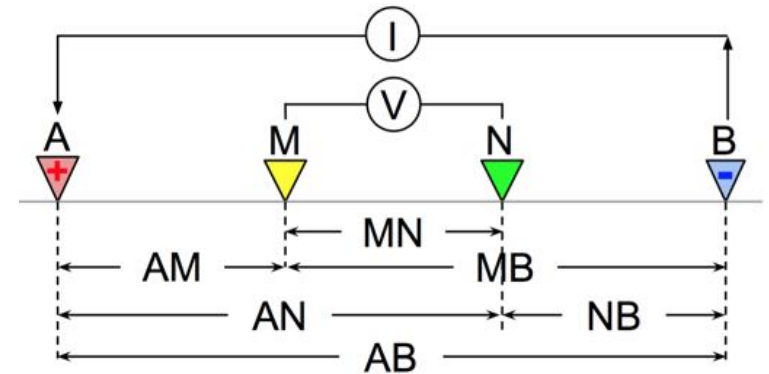
Sounding
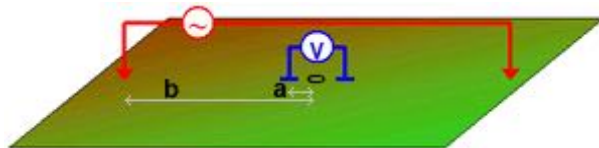
Soundings

DC Sounding curve

AB/2 = 5 m

$\rho_a = 100.30$

Soundings

DC Sounding curve

AB/2 = 10 m

$\rho_a = 135.72$

Soundings

DC Sounding curve

AB/2 = 30 m

$\rho_a = 239.10$
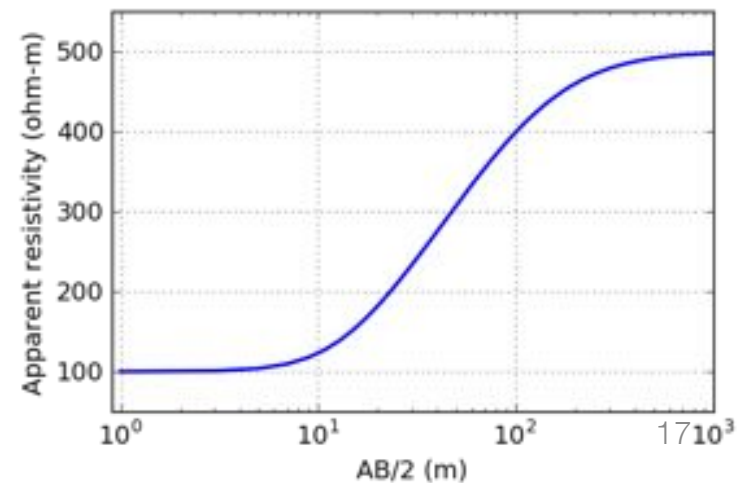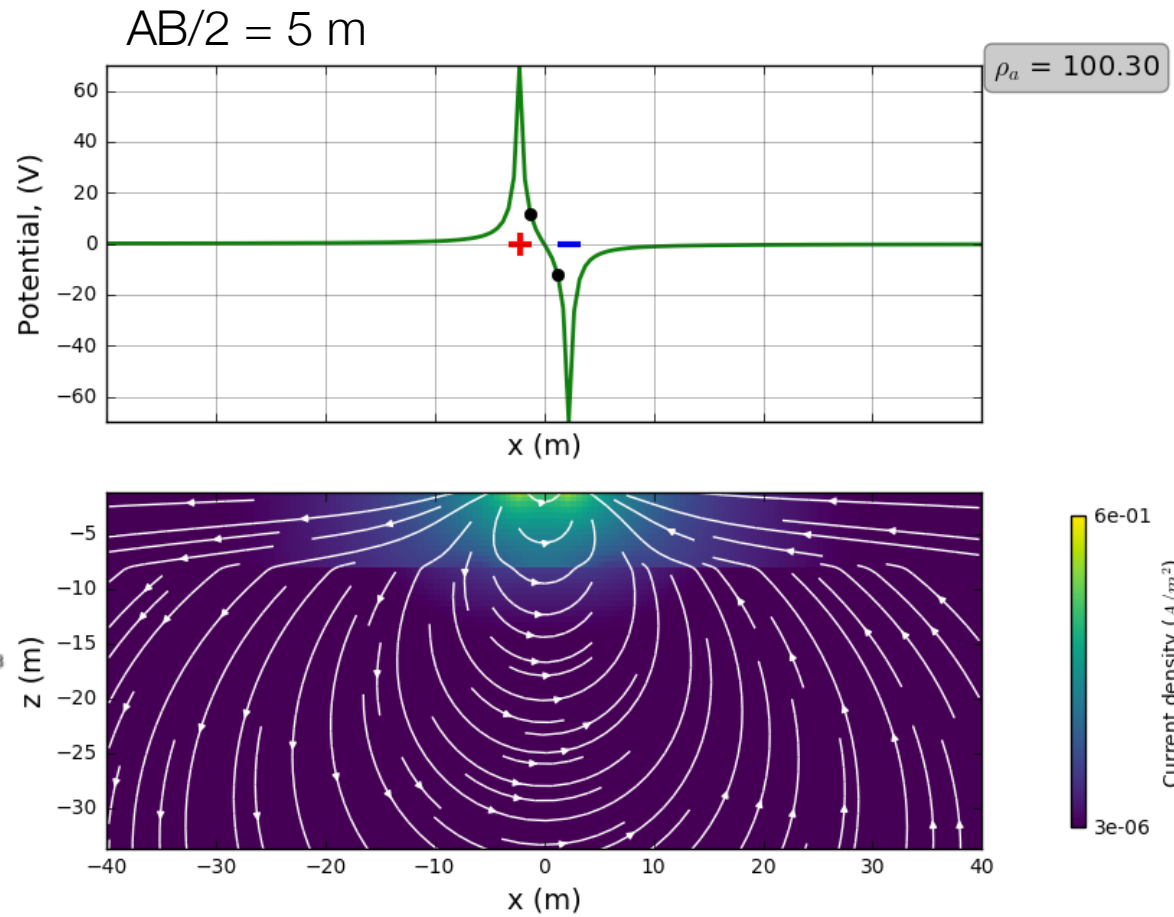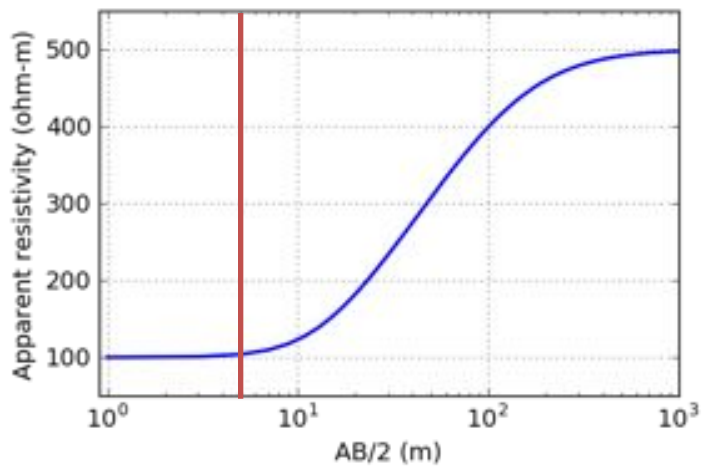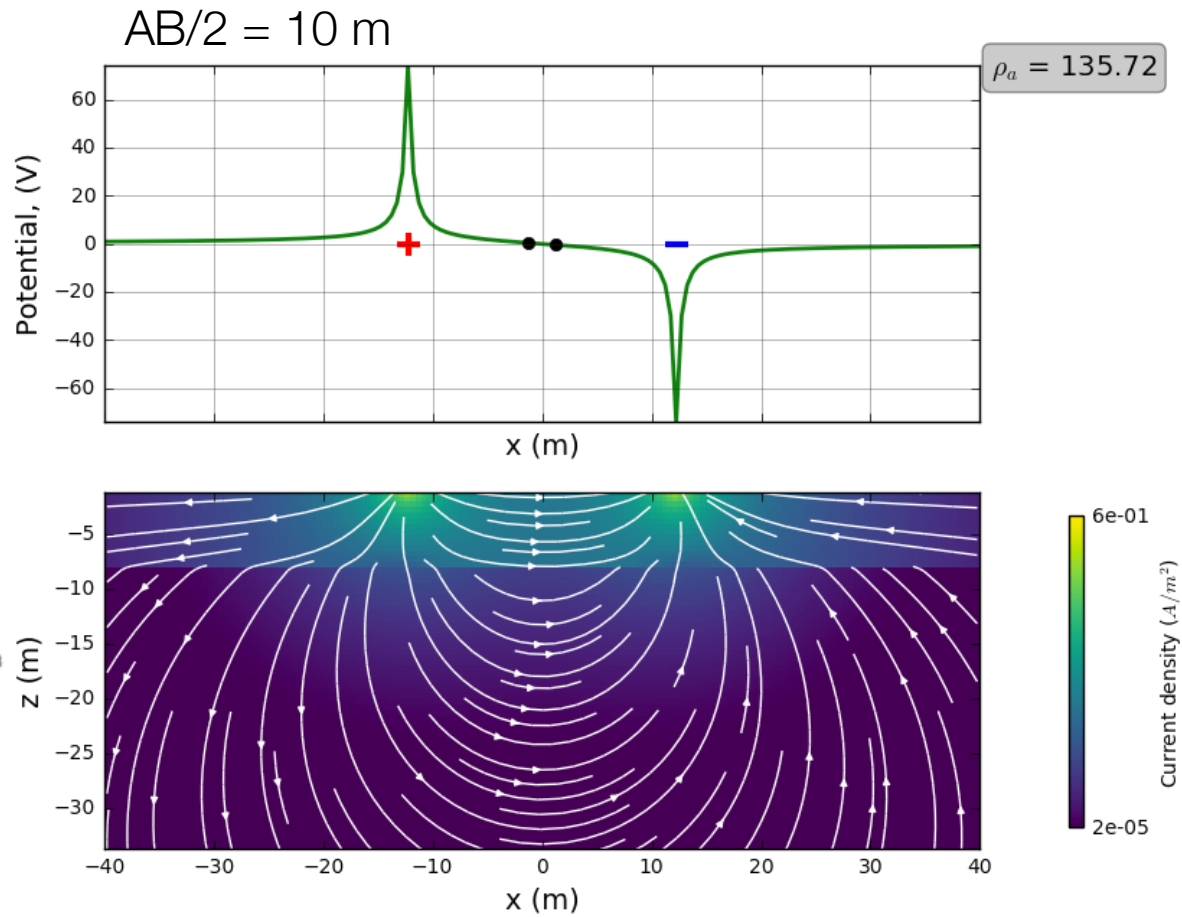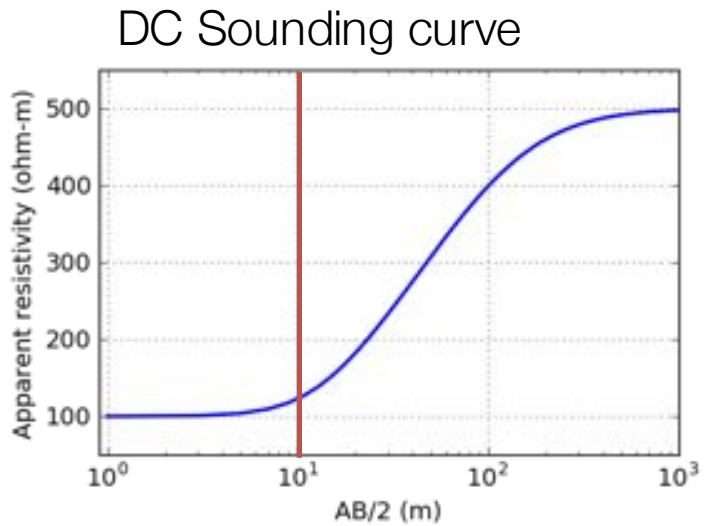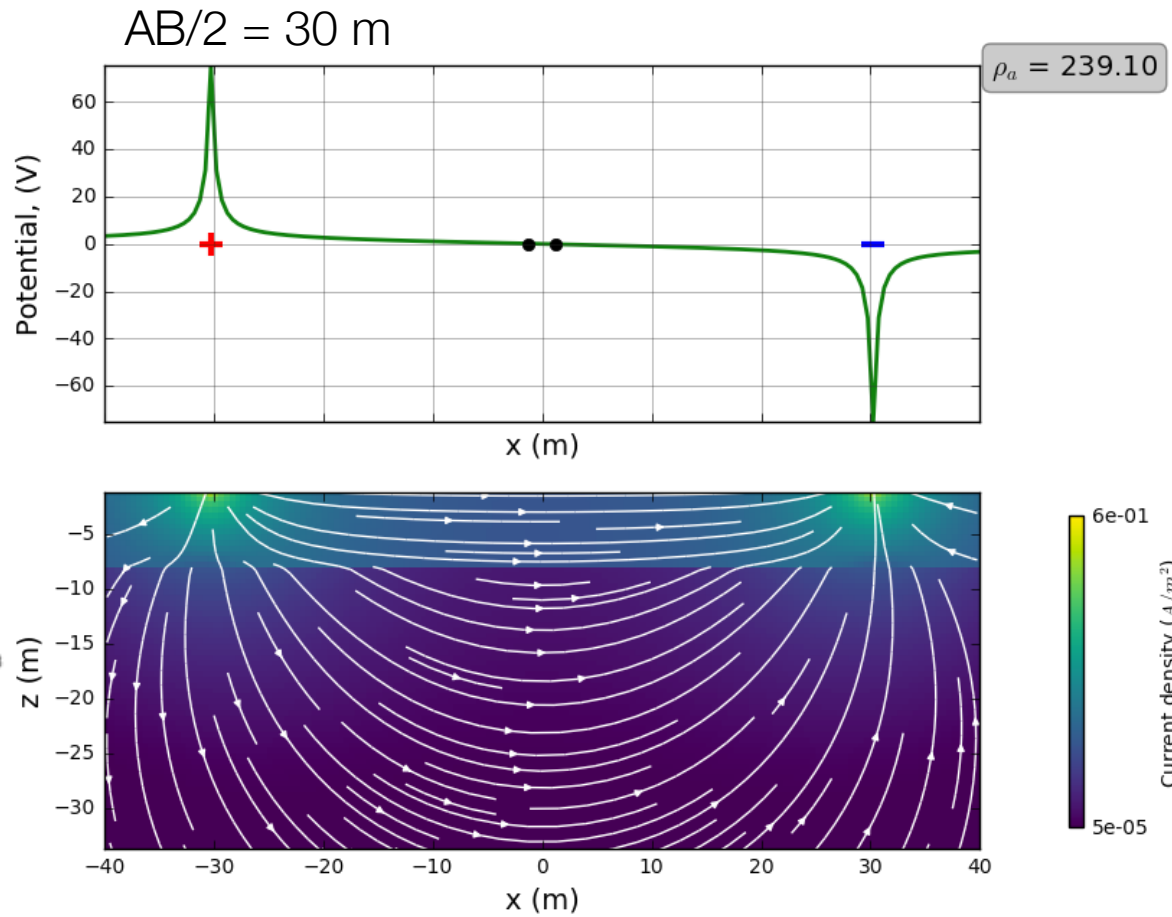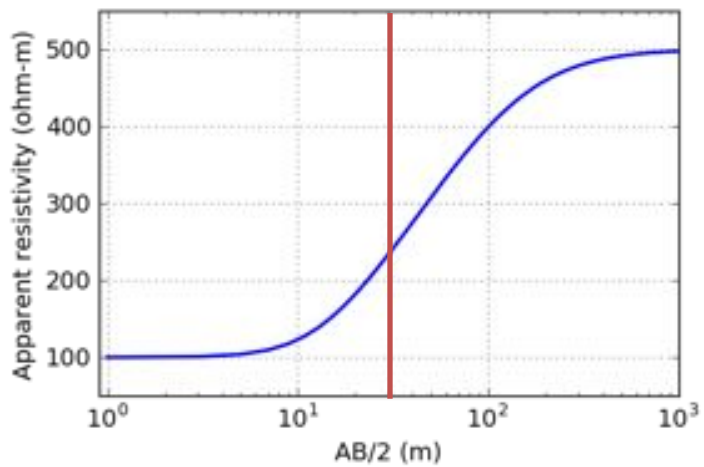
Summary: soundings

Schlumberger array

$\rho_a = 239.10$

DC **Sounding** curve

$100\ \Omega m$

$500\ \Omega m$
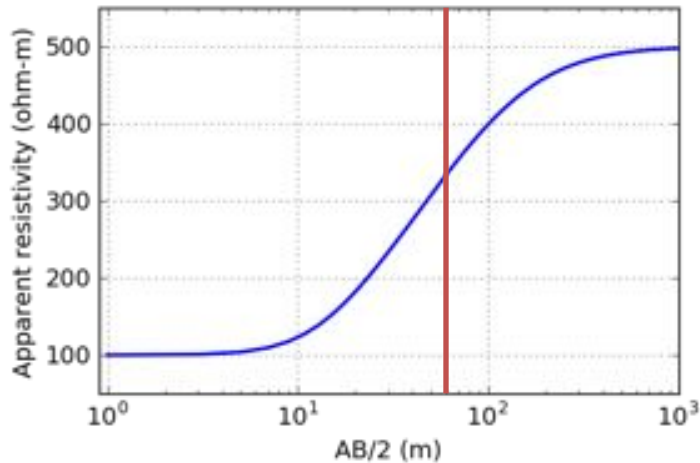
Scale length of array must be large to see deep

Inversion

Data

Measurements over the Earth are data.

Model

Depth

Resistivity

Inversion processing

Inversion estimates Earth models based upon data and prior knowledge.
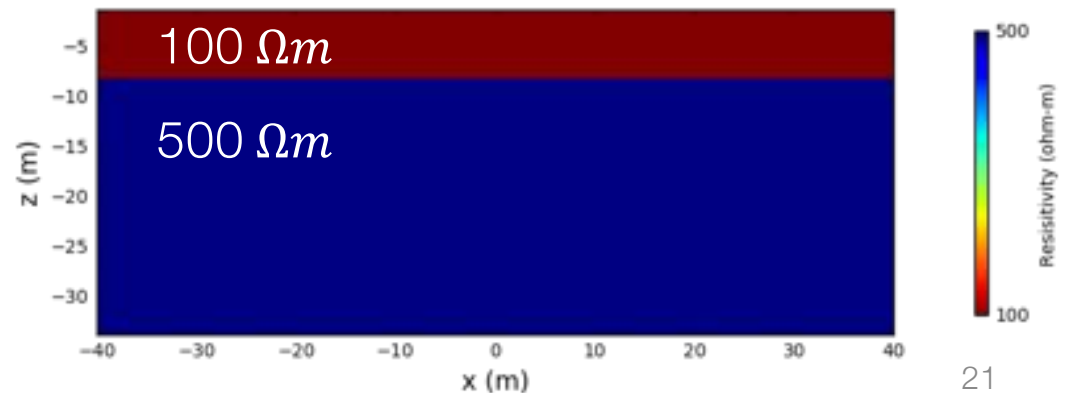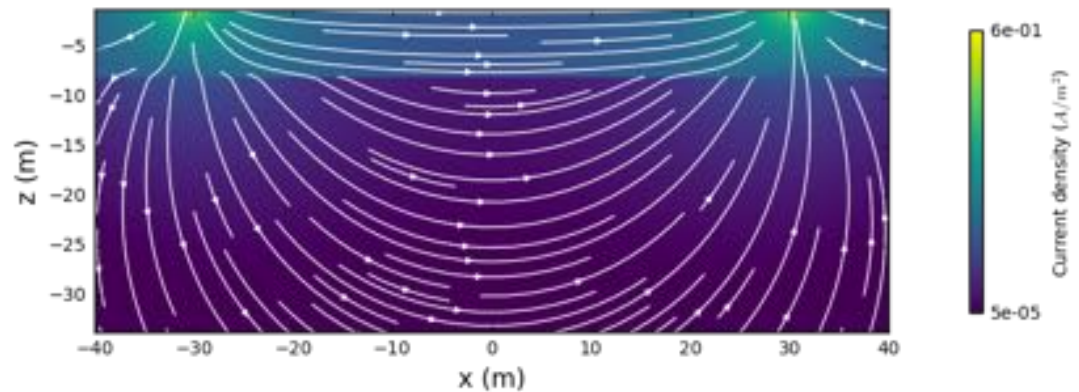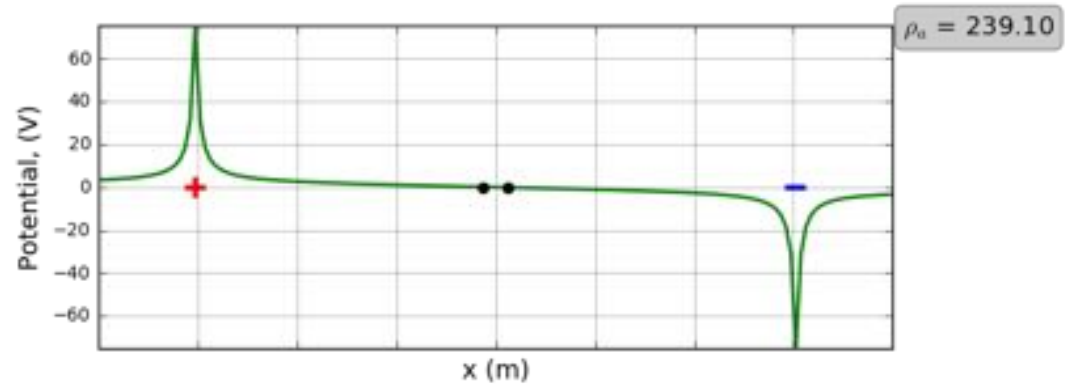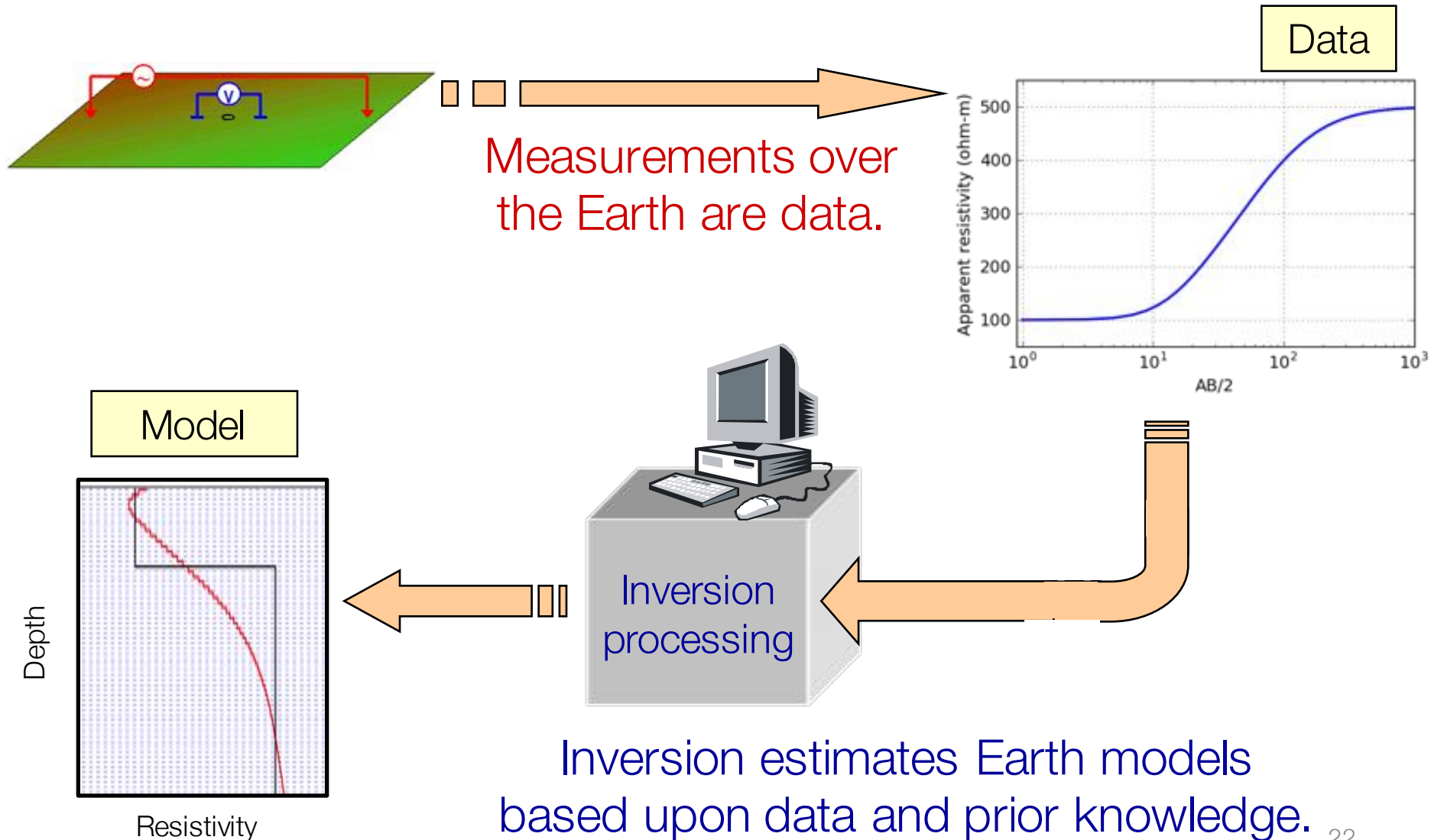
DCR for a confined body

- 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

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

resistor   conductor   Currents
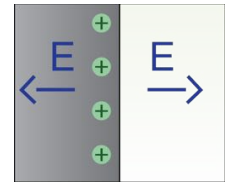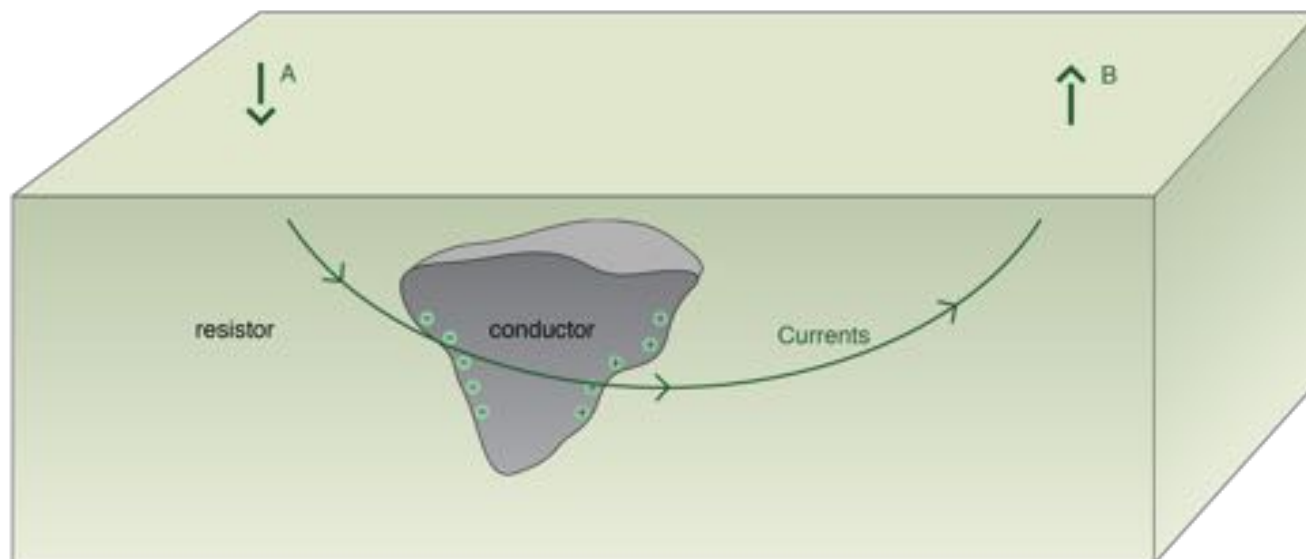
Currents, charges, and potentials

Total currents: J
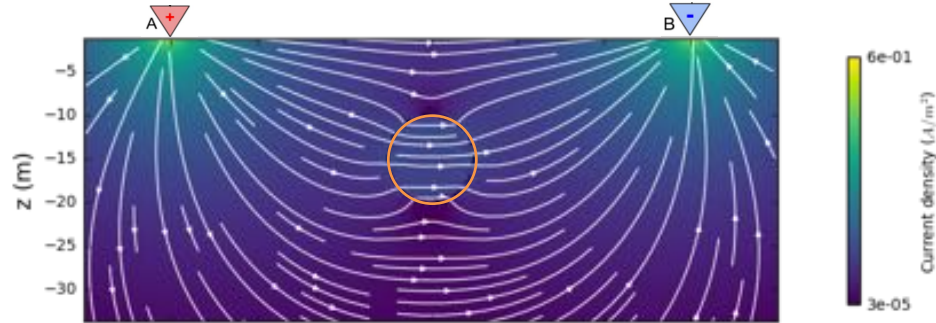
Secondary currents: J_s
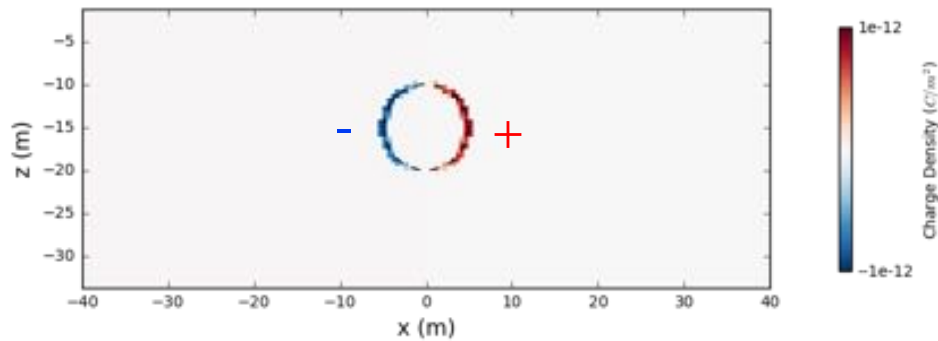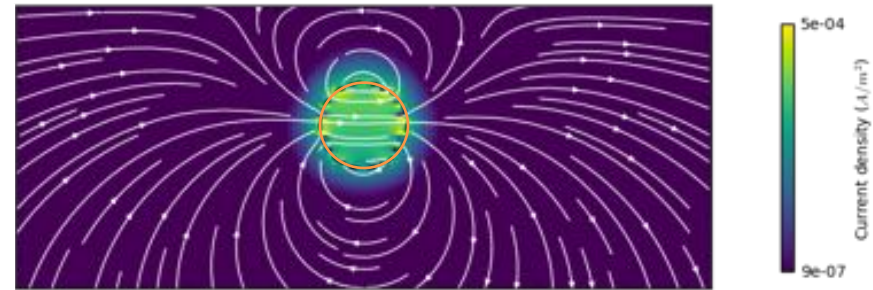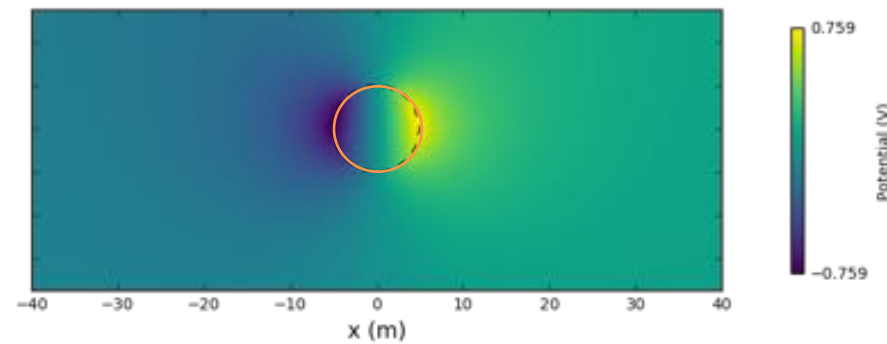
Secondary charges: Q_s

Secondary potential: ϕ_s

Measurements of DC data: gradient array

Potential profile

$\rho_a = 429.90$
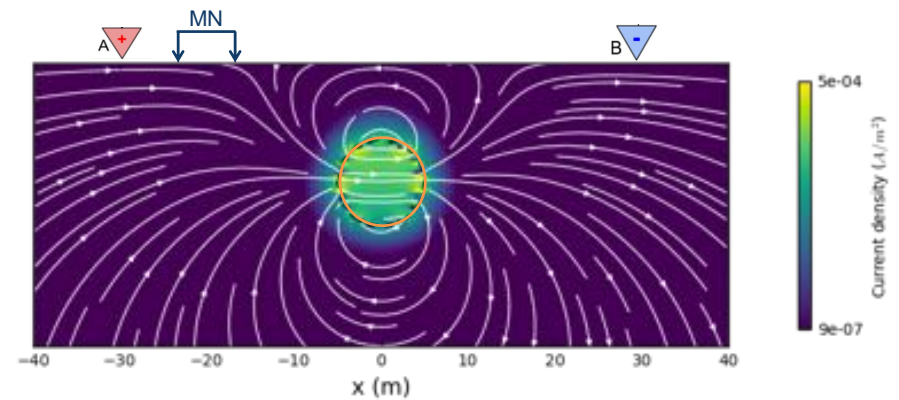
Resistivity model

500 Ωm

1 Ωm
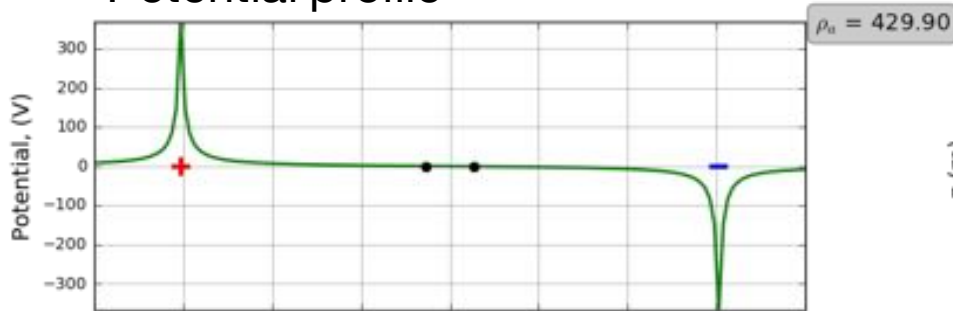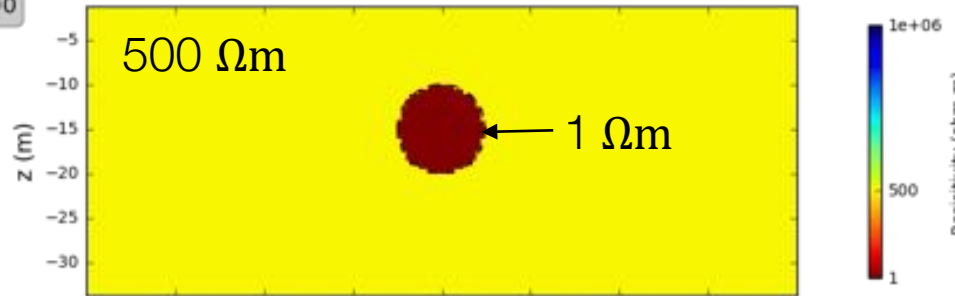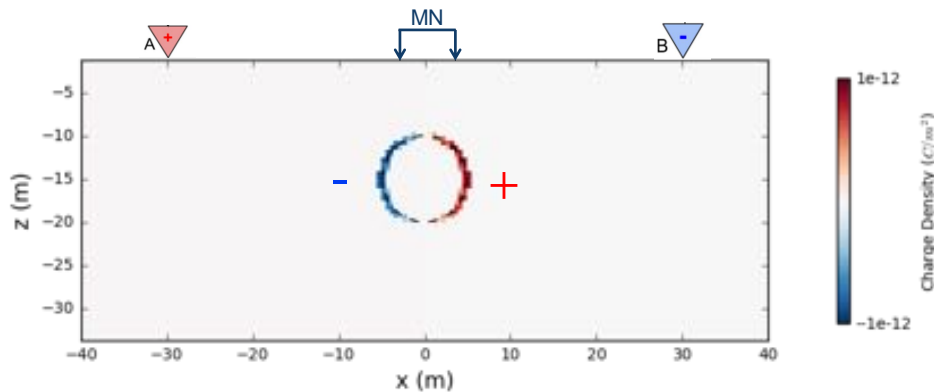
$\rho_a = 430$

Secondary charges: Q_s

$\rho_a = 430$

Secondary currents: J_s

25

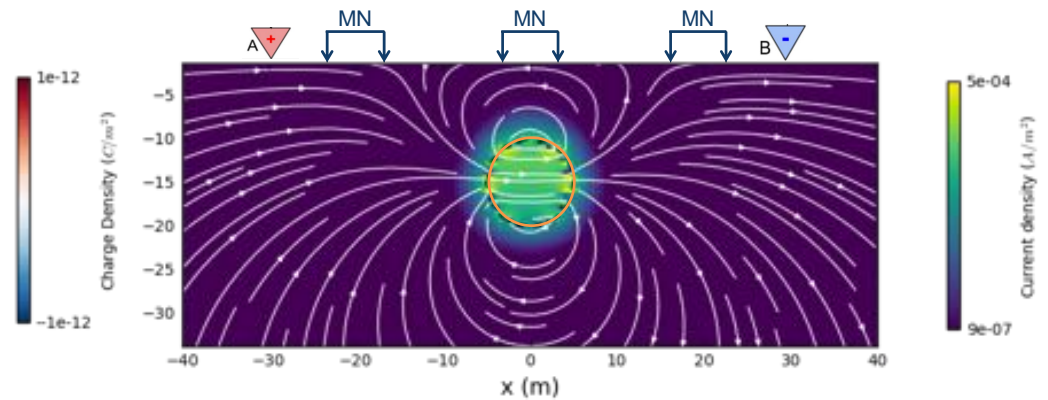# Measurements of DC data: gradient array

Potential profile

$\rho_a = 502.20$

Resistivity model

500 Ωm

1 Ωm

$\rho_a = 502$

$\rho_a = 502$

Secondary charges: Q_s
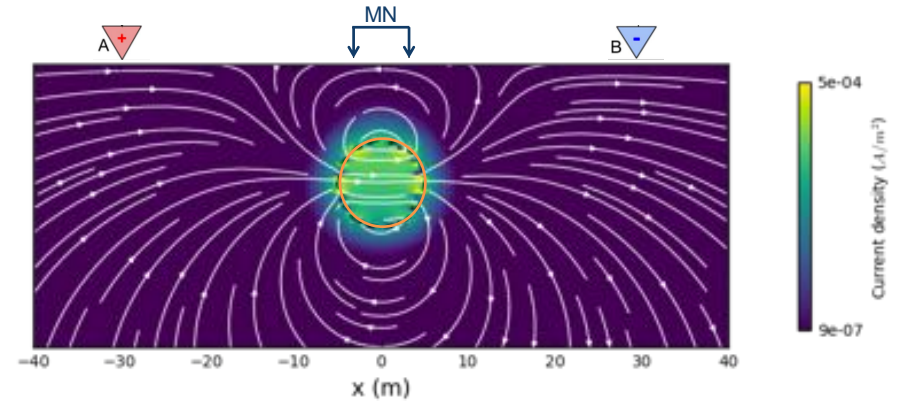
Secondary currents: J_s

Measurements of DC data: gradient array

Potential profile

$\rho_a = 502.32$

Resistivity model

500 Ωm

1 Ωm
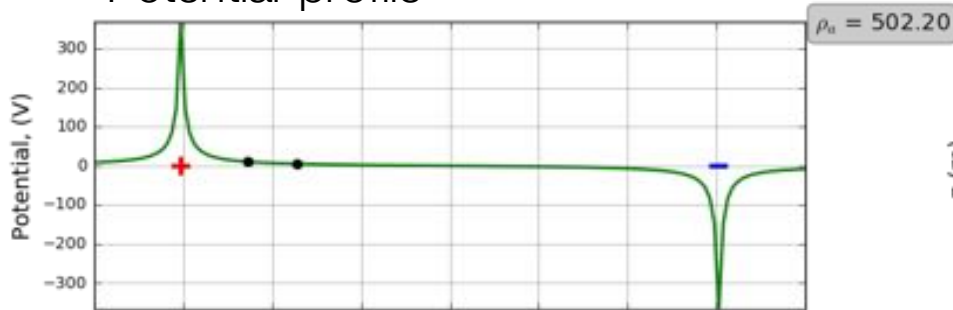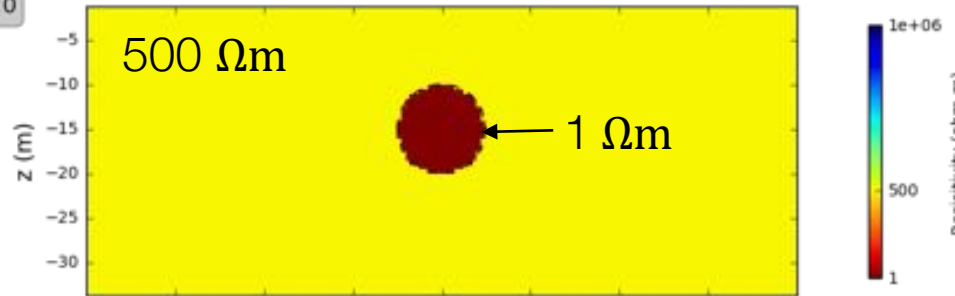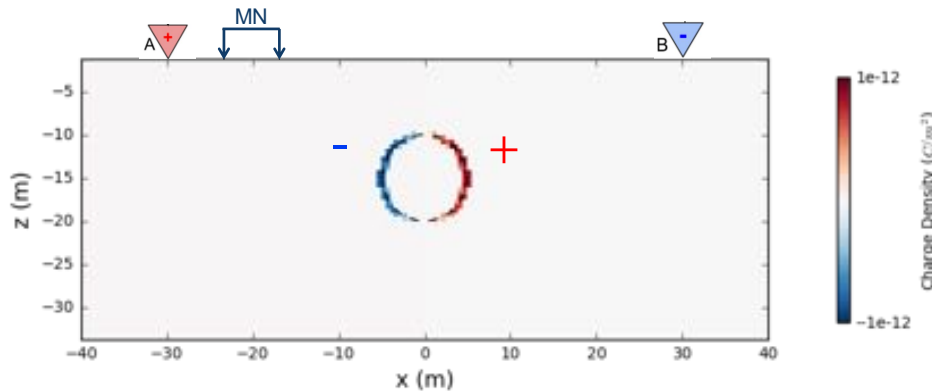
$\rho_a = 502\,\rho_a = 430\,\rho_a = 502$

Secondary charges: Q_s

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

Secondary currents: J_s
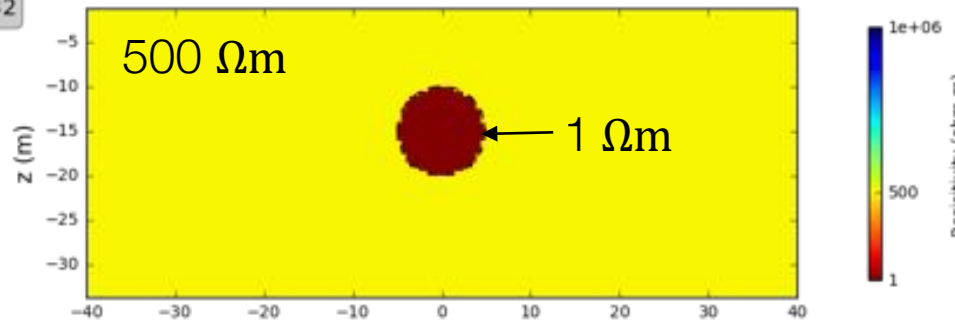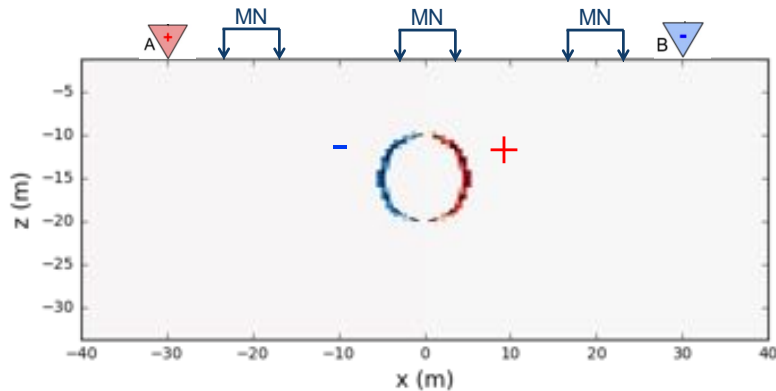
Profiling

Fixed geometry: Move laterally

Short offset, a=4m

A B M N

Long offset, a=20m

A   a   B   a   M   a   N

500 Ωm
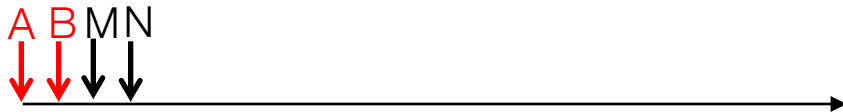
1 Ωm

Short offset: a = 4 m
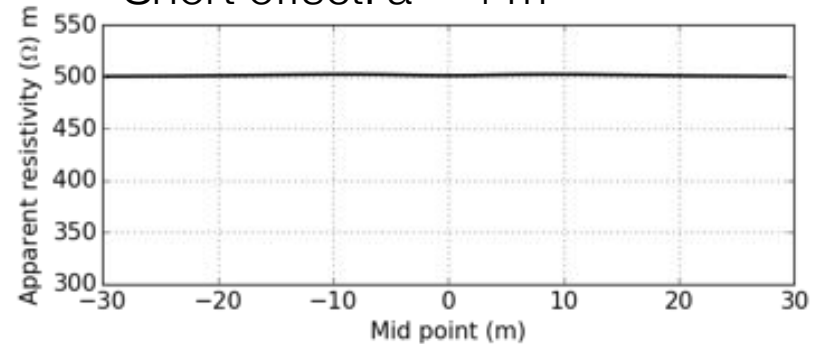
Long offset: a = 20 m
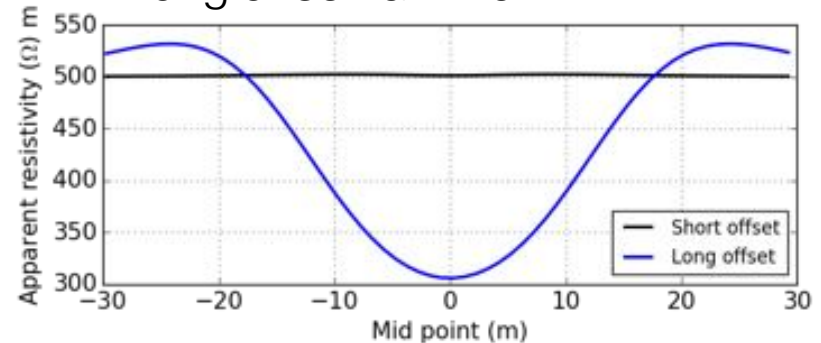
Depth of investigation depends upon offset or array length
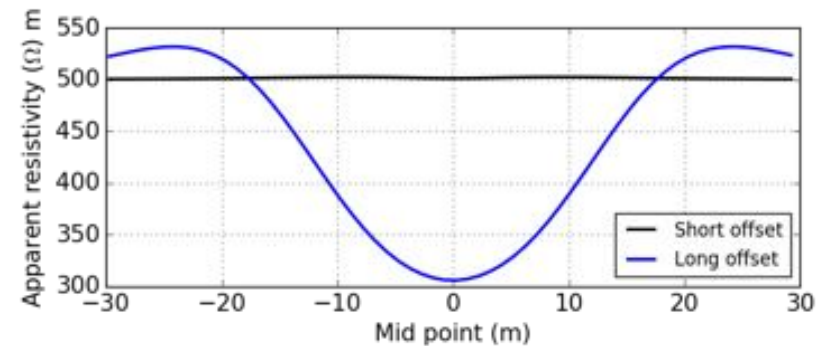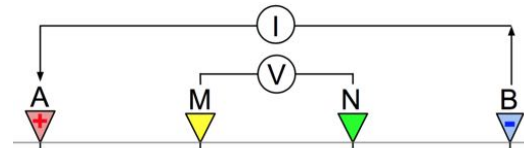
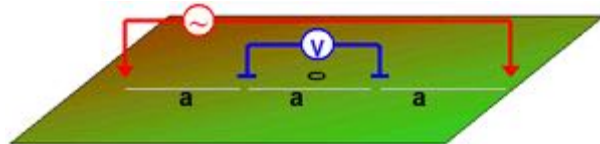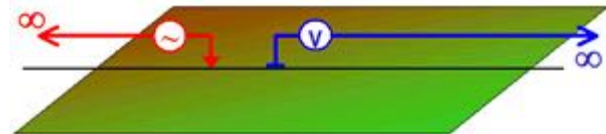# Summary: Soundings and Profiles

Sounding
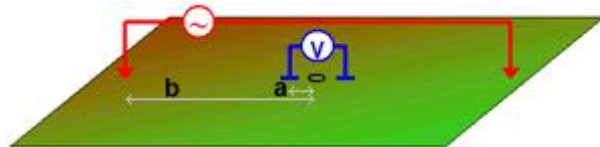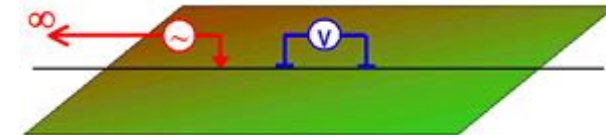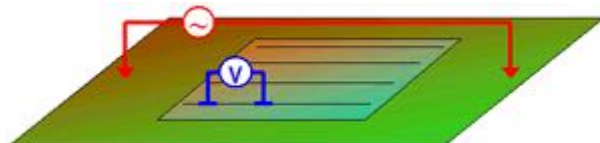

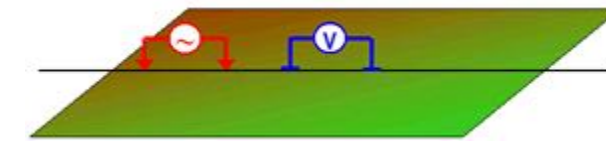Expand
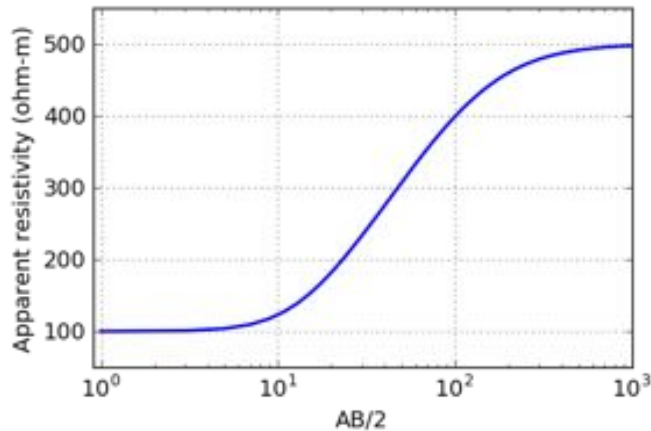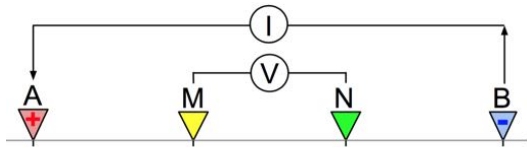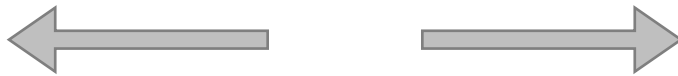
Profiling

Translate

Basic Survey Setups

Wenner

Pole-Pole

Schulmberger

Pole-Dipole

Gradient

Dipole-Dipole

DC resistivity data

Source (Amps)	
Potential (Volts)	

Plotting plane
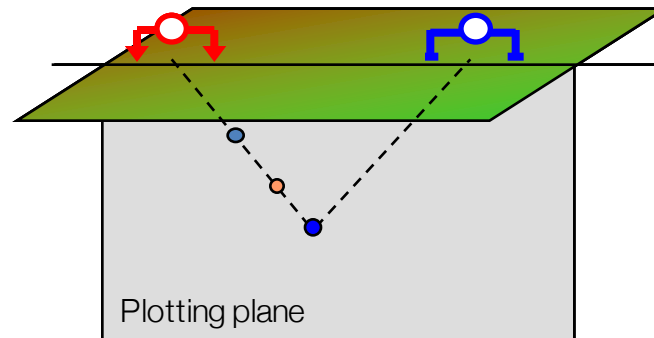
Each data point is an apparent resistivity:

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

Geop Astron SE front lawn. : dipole-dipole : 38 data
Observed Apparent Resistivity
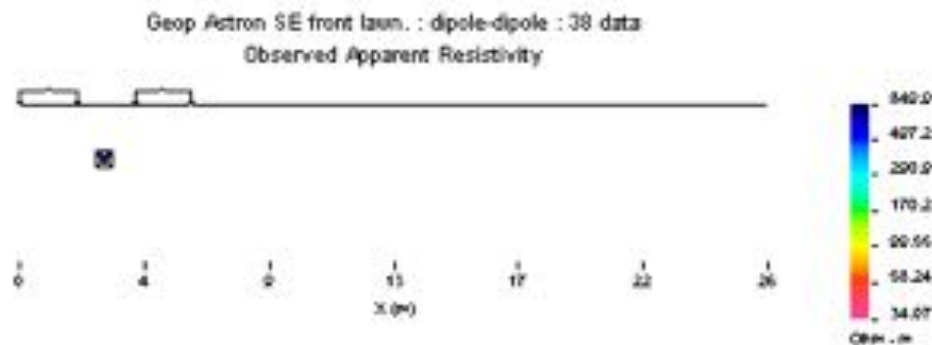
Example pseudosections

1) A single buried conductive block

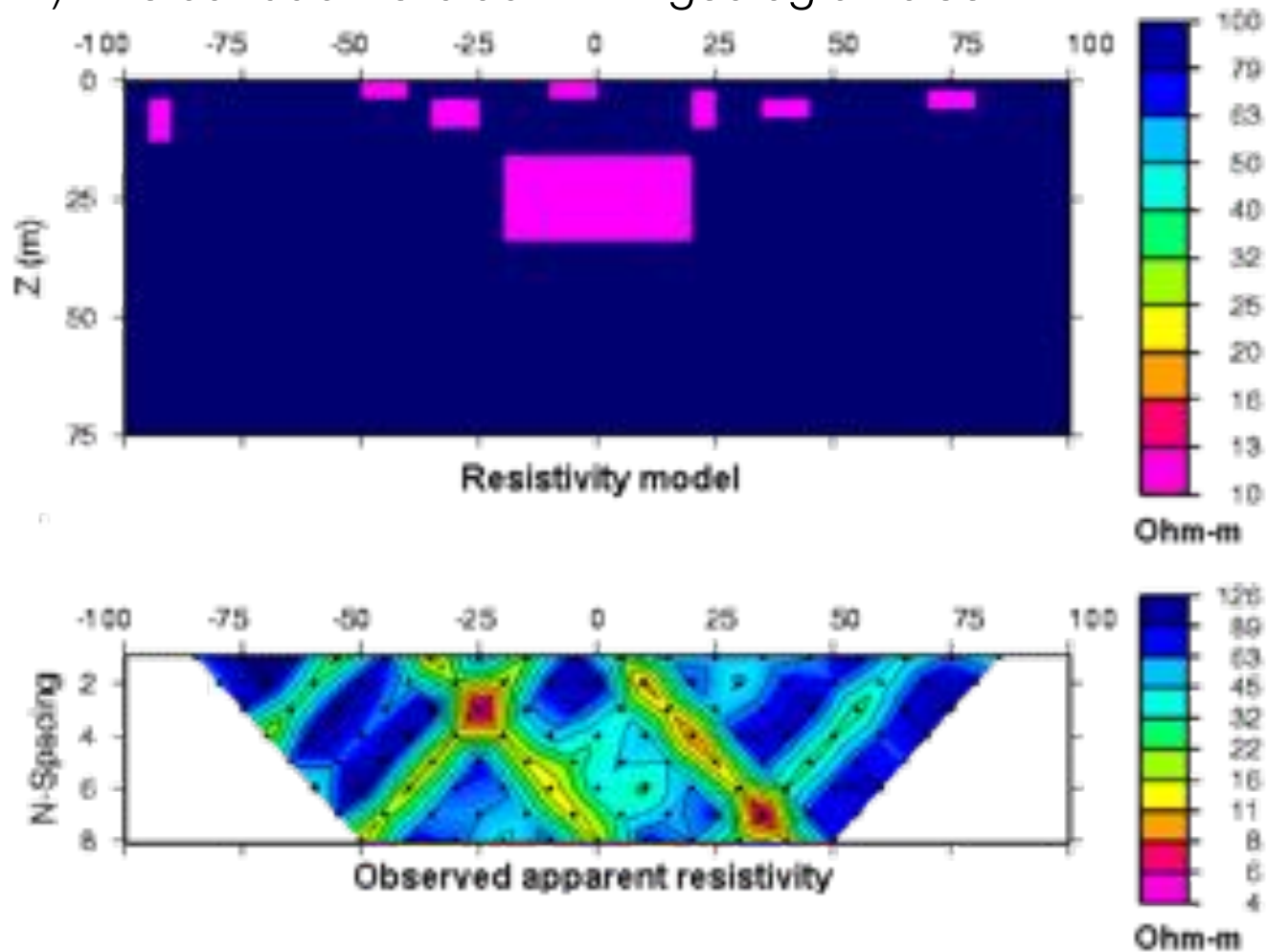

Resistivity model

Observed apparent resistivity
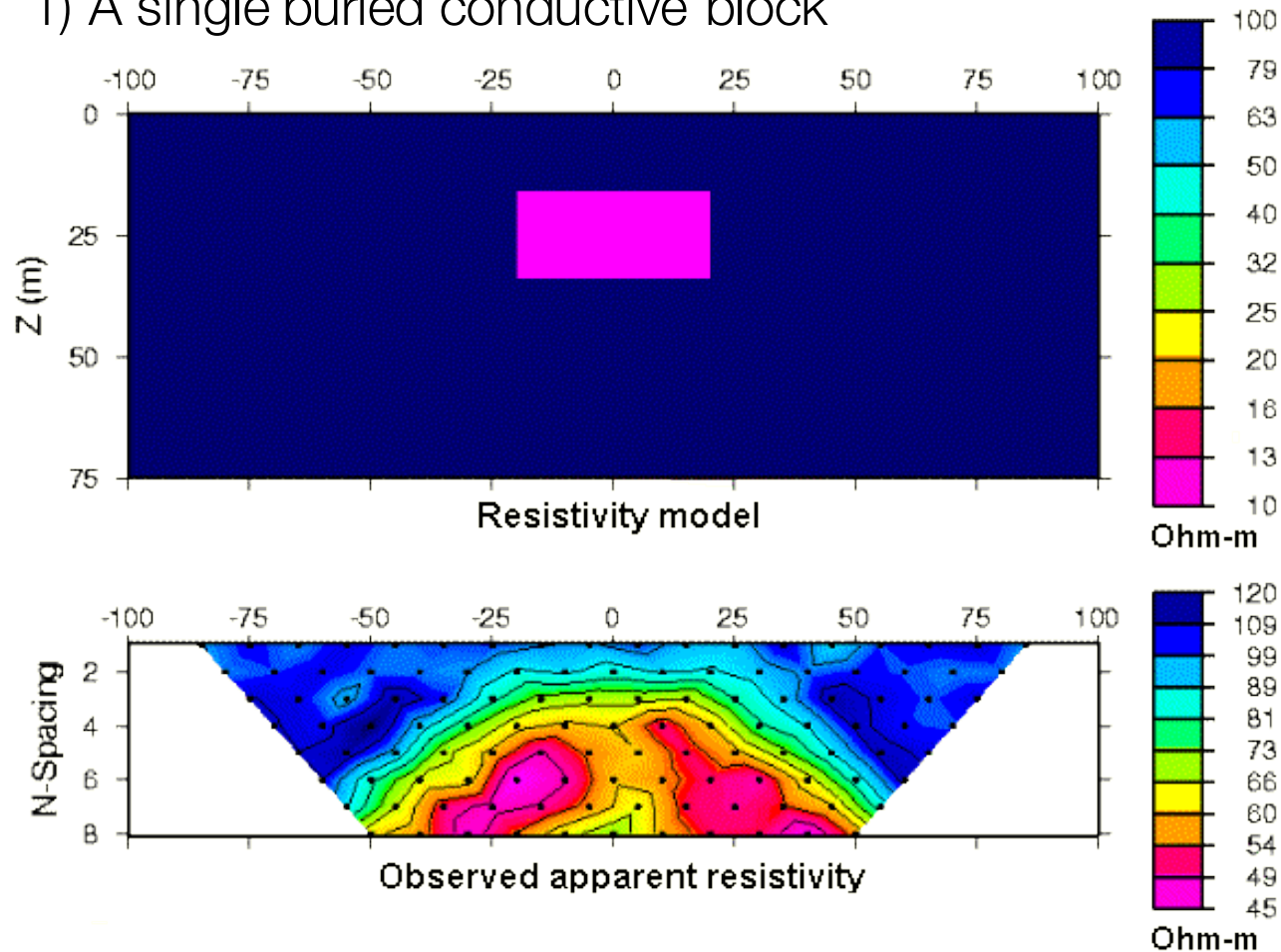
Pole-Dipole

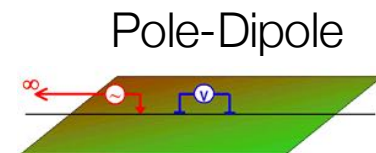• Pole-dipole; n=1,8; a=10m; N=316
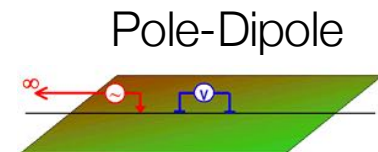
Example pseudosections

2) The conductive block with geologic noise.

Resistivity model

Observed apparent resistivity

Pole-Dipole

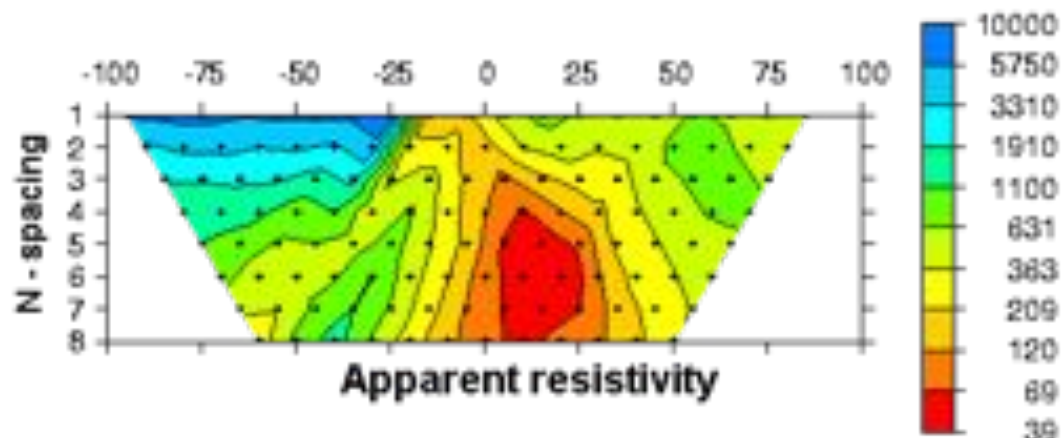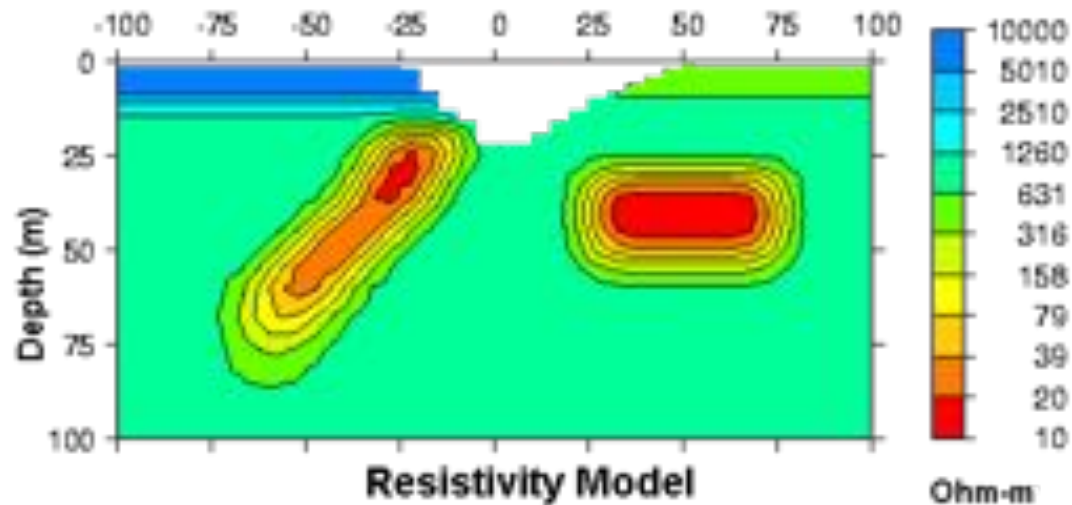• Pole-dipole; n=1,8; a=10m; N=316

Example pseudosections

3) The "UBC-GIF model"

Resistivity Model — Ohm·m

Apparent resistivity

Pole-Dipole

Inversion

Measurements over the Earth are data.

Data

Observed apparent resistivity
Dipole dipole, a=10m, n=1, ..., 8, 5% noise added.

Inversion processing

?

Model

Inversion estimates Earth models based upon data and prior knowledge.

Example 1: buried prism

Resistivity model — Ohm-m

Recovered resistivity — Ohm-m

Data with 5% Gaussian noise

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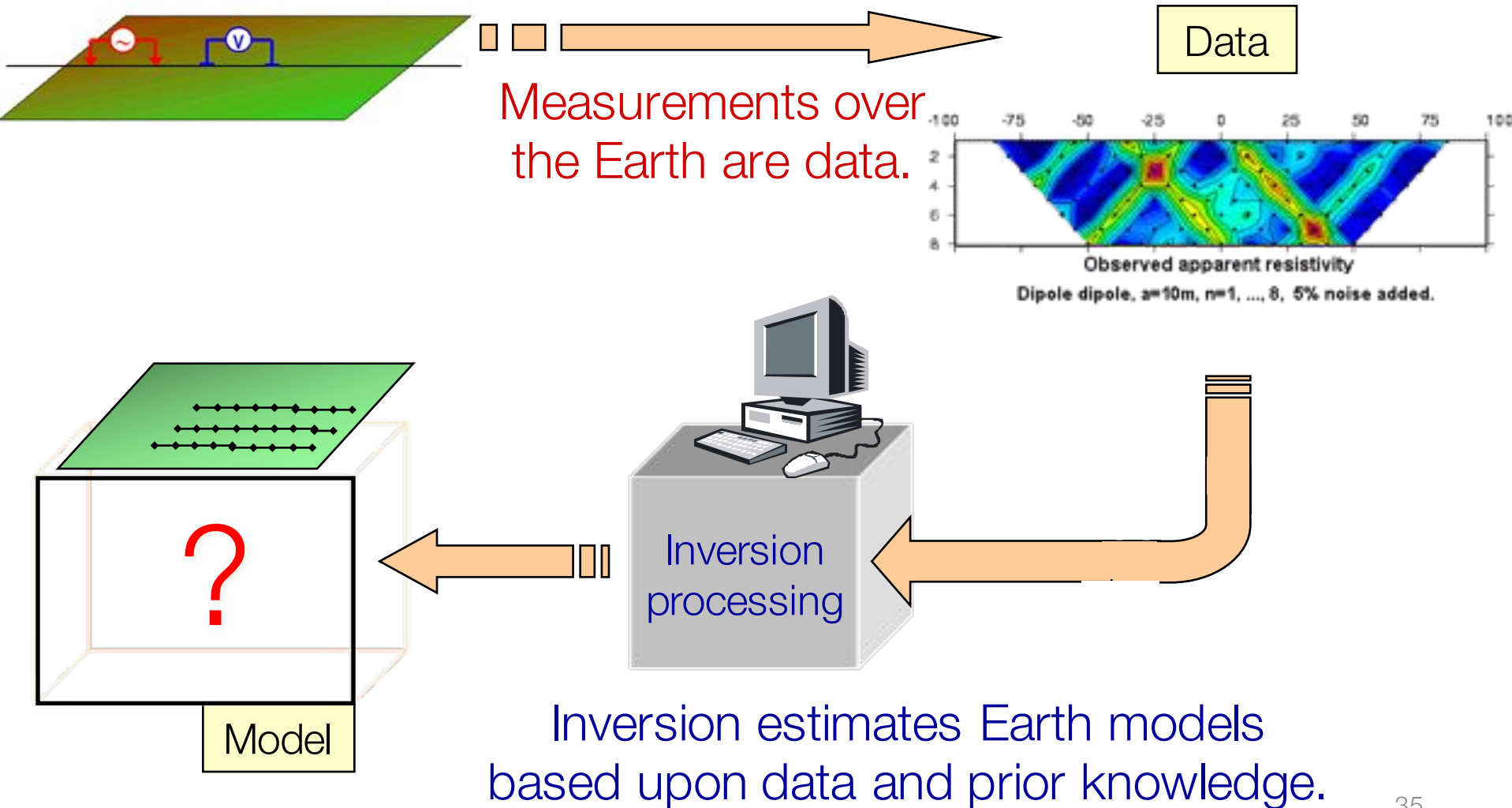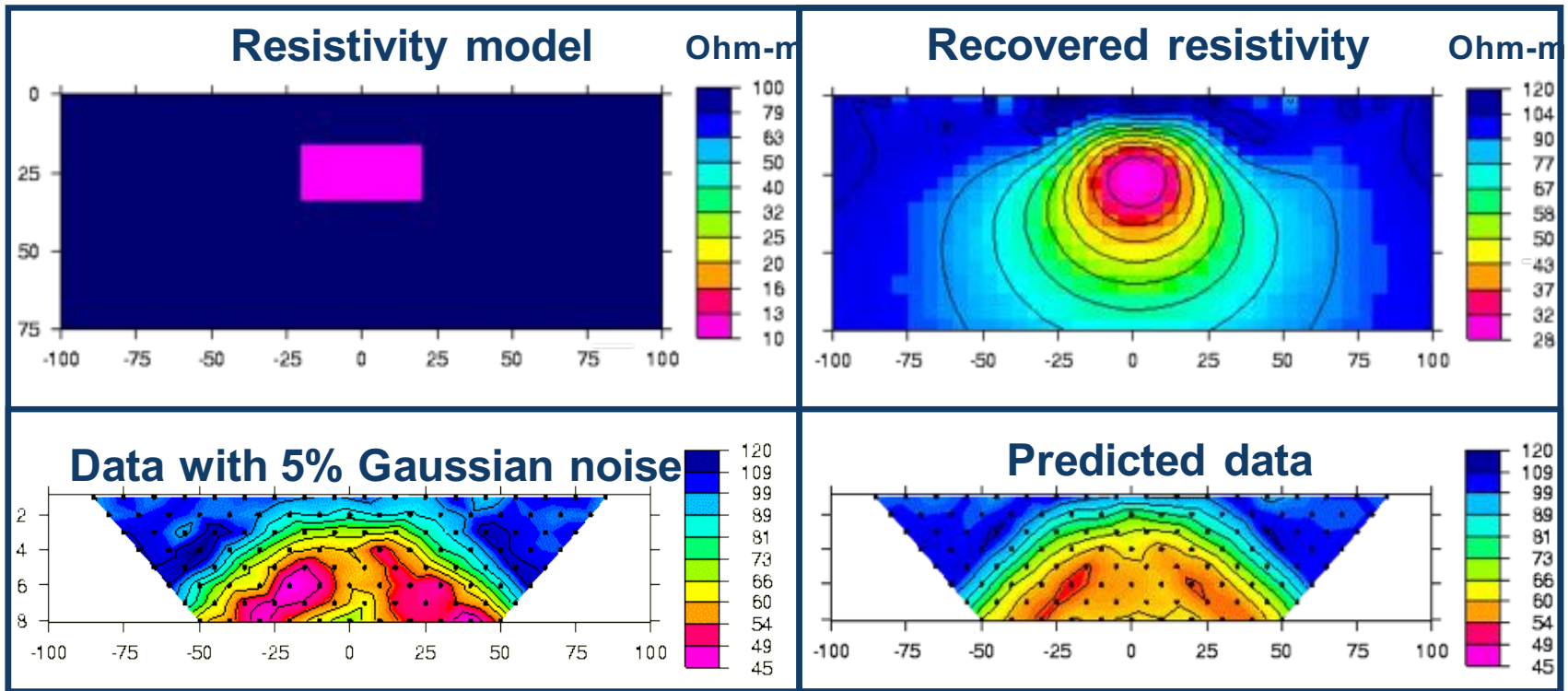
- Pole-dipole; n=1,8; a=10m; N=316; $(\alpha_s, \alpha_x, \alpha_z)$=(.001, 1.0, 1.0)

Example 2: prism with geologic noise
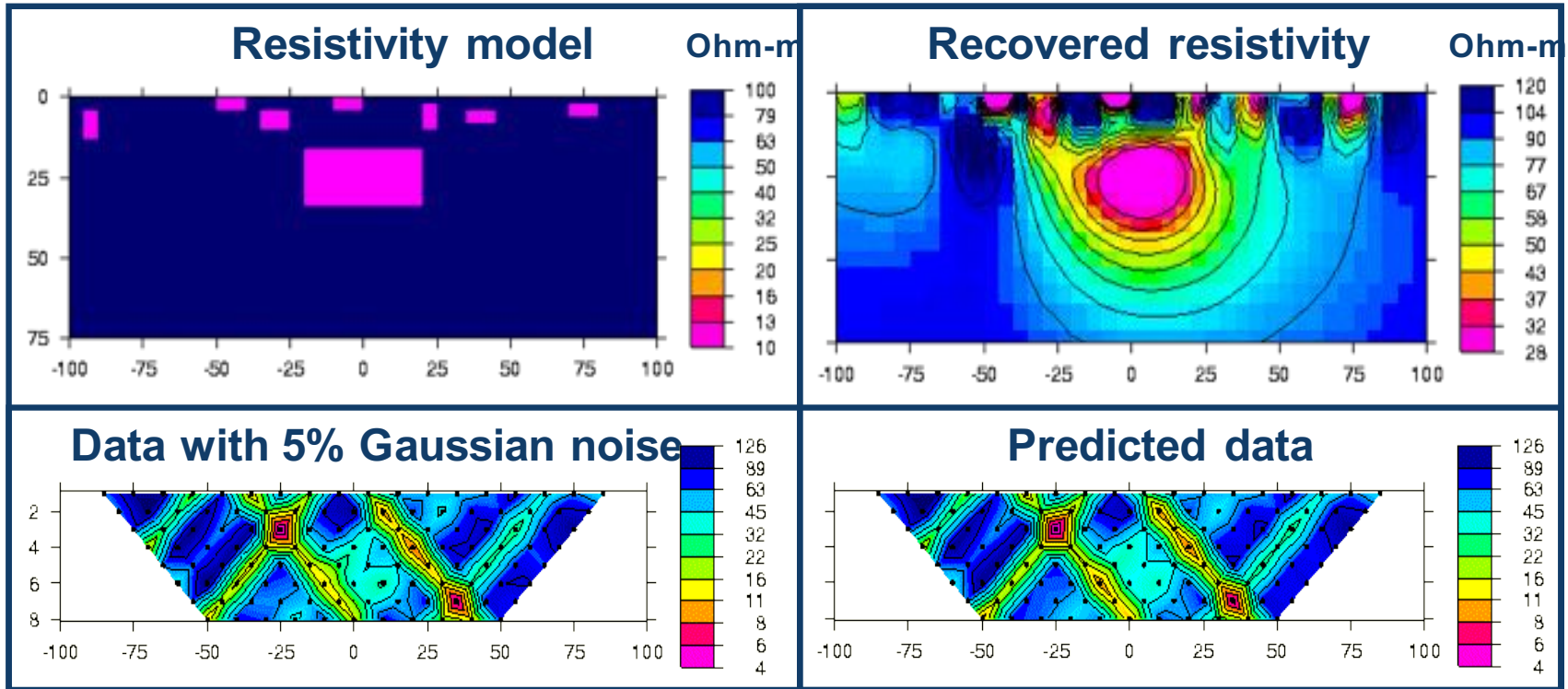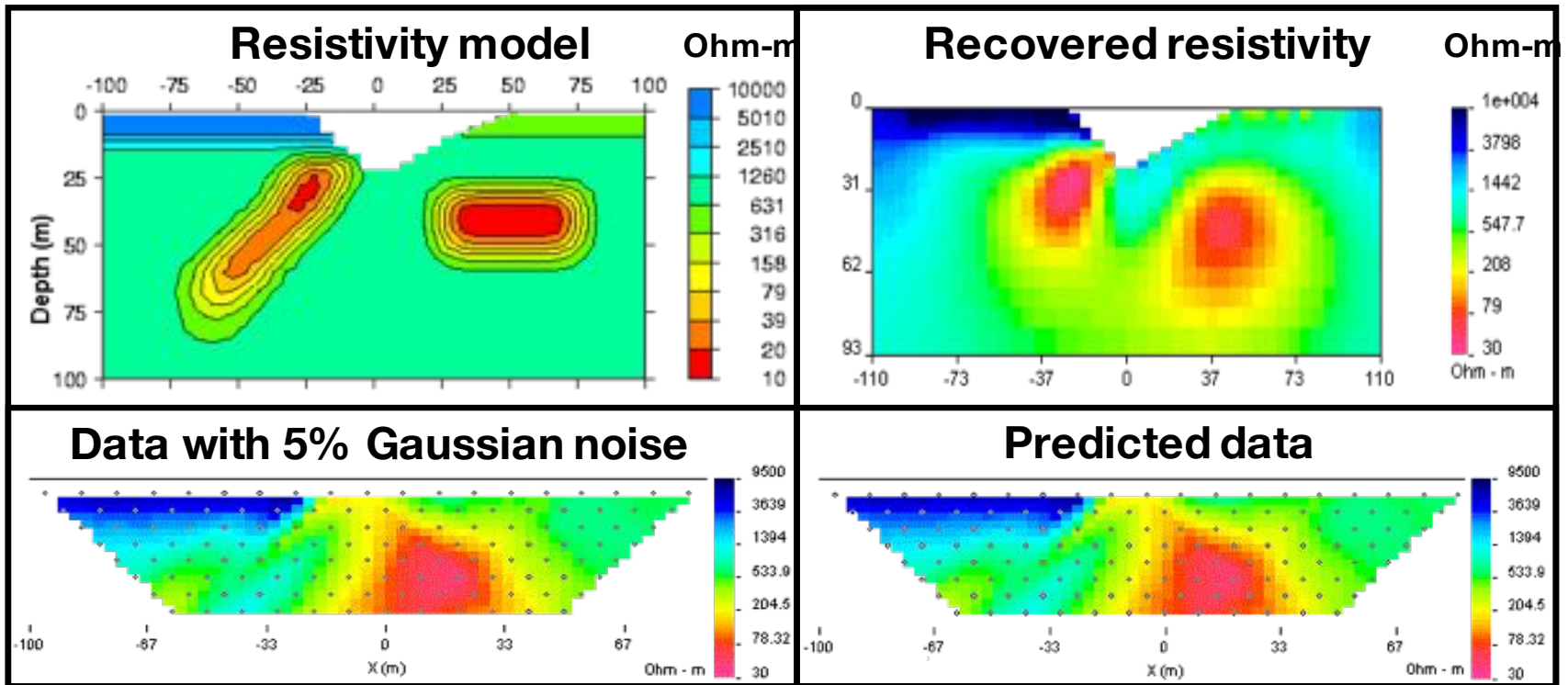

- Pole-dipole; n=1,8; a=10m; N=316; $(\alpha_s, \alpha_x, \alpha_z) = (.001, 1.0, 1.0)$

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
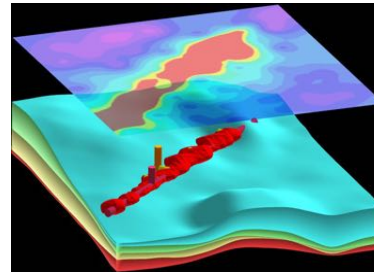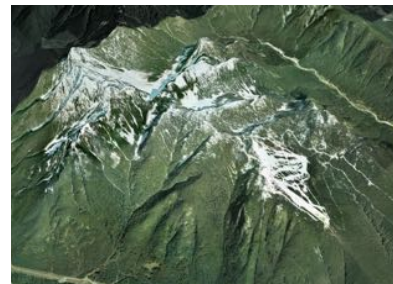
- Crucial element is the **sensitivity**
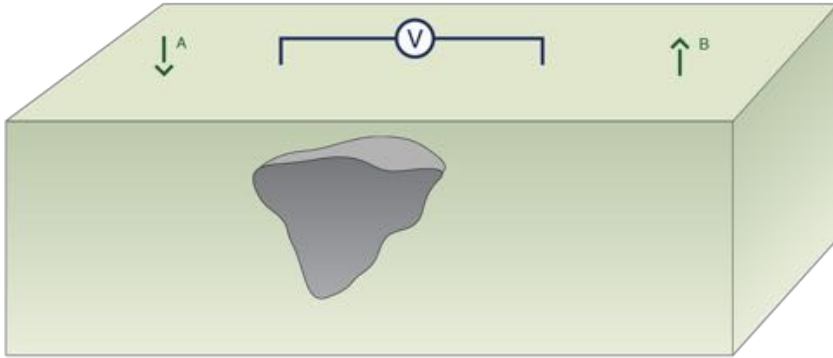
Host

Water underground

Ore body

Topography

Sensitivity

Sensitivity Function

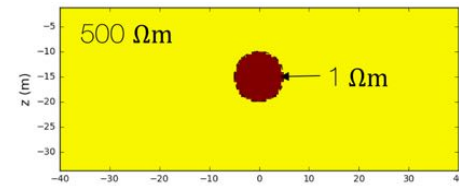Is the measured potential *sensitive* to the target?

Quantified by the sensitivity

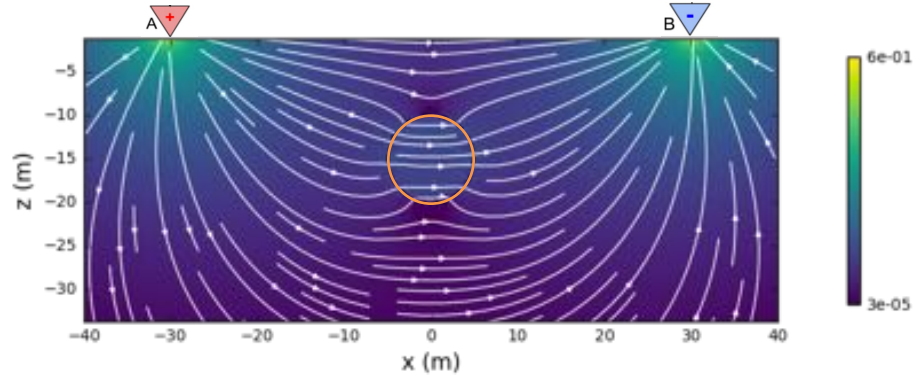$$G = \frac{\Delta d}{\Delta p} = \frac{\text{change in data}}{\text{change in model}}$$

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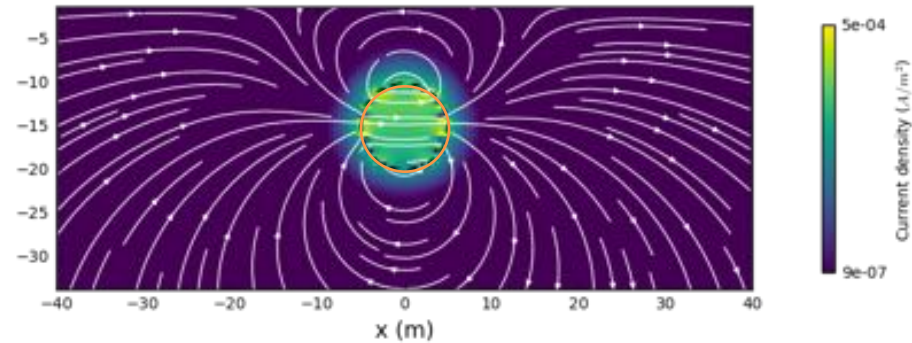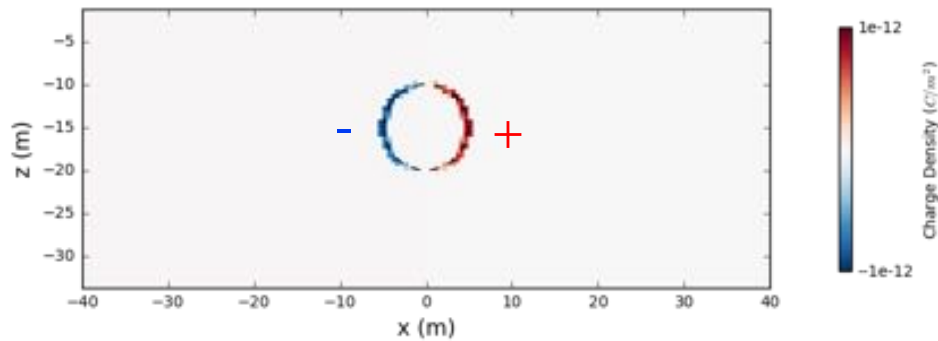
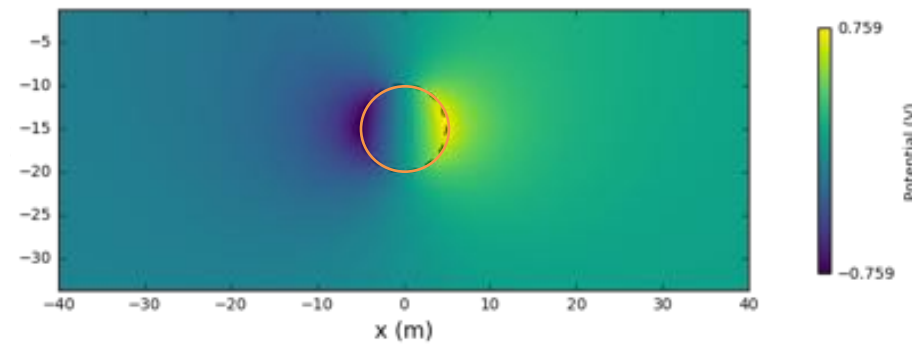# Exciting the target

Resistivity model

Total currents: **J**

Secondary currents: **J**$_s$

Secondary charges: Q$_s$

Secondary potential: ϕ_s

Measurements

500 Ωm   1 Ωm
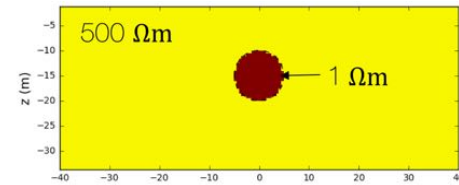
Secondary charges: Q_s

Potential profile

$\rho_a = 502.32$
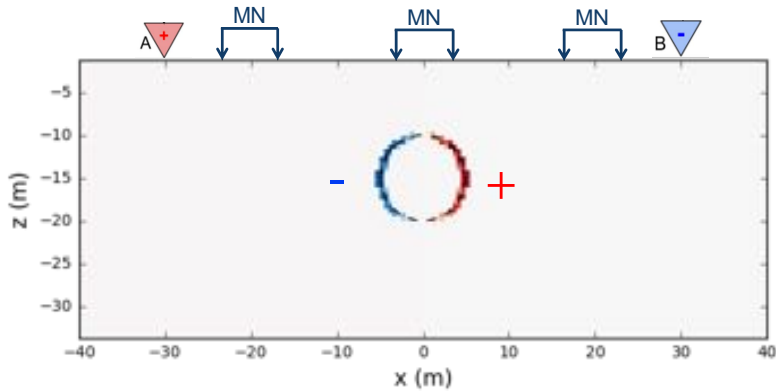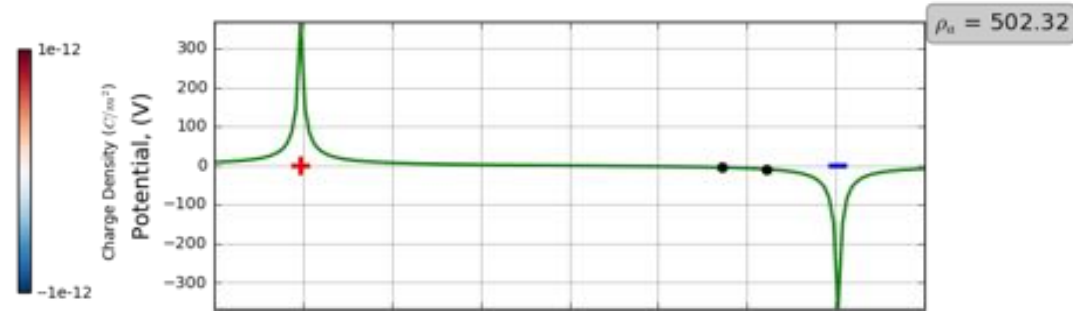
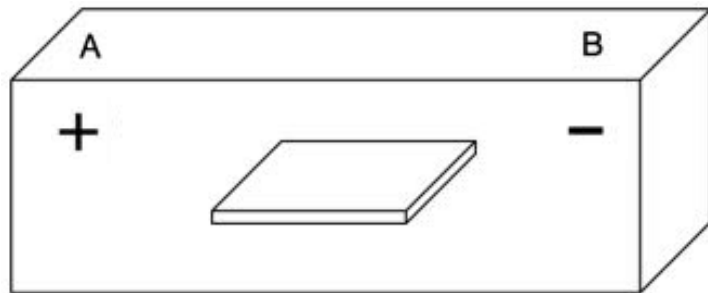### Secondary potential: ϕ_s
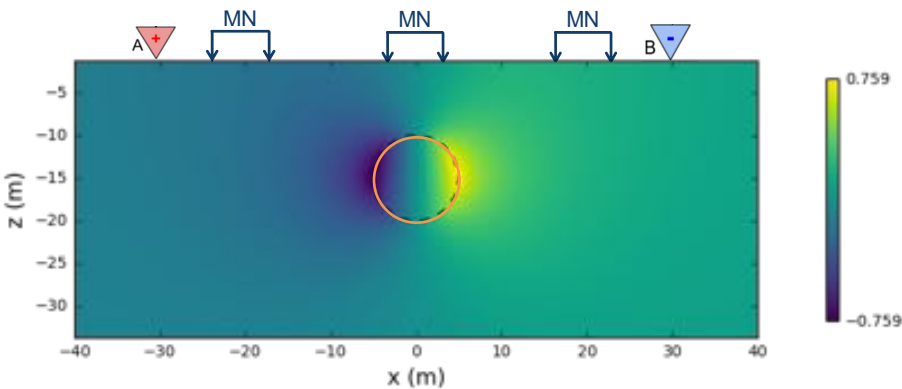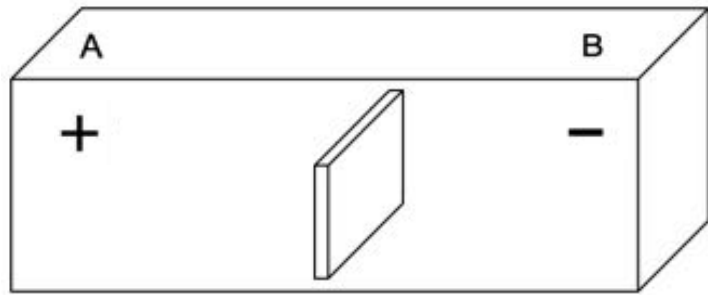

Total potential: ϕ
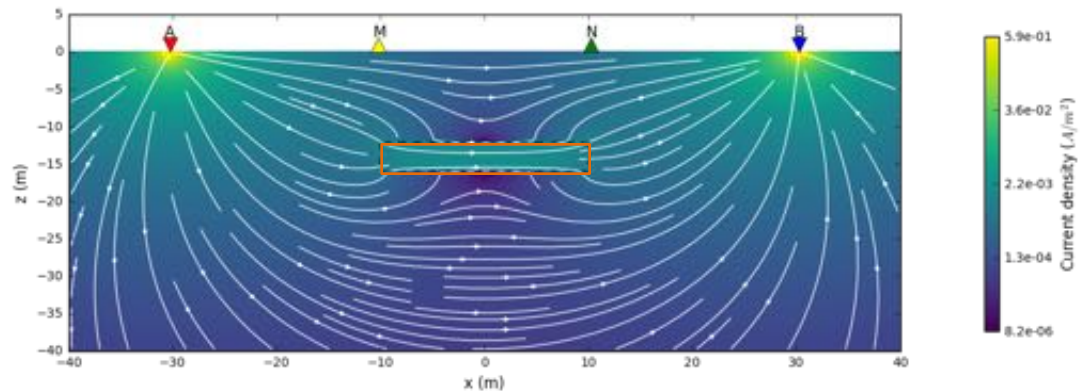
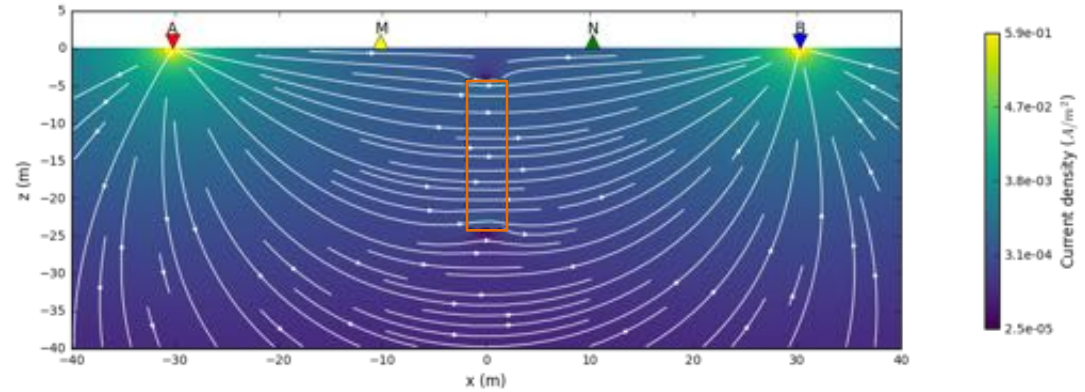$\rho_a = 502$ $\rho_a = 430$ $\rho_a = 502$
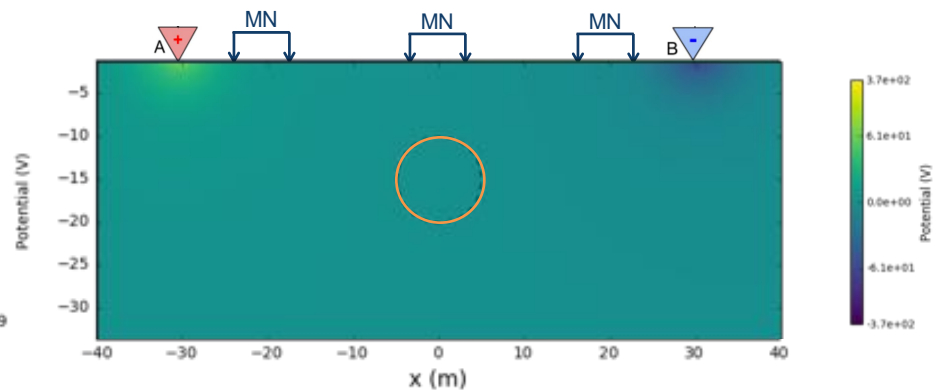
Coupling

- Thin plate – different orientations
  → different data

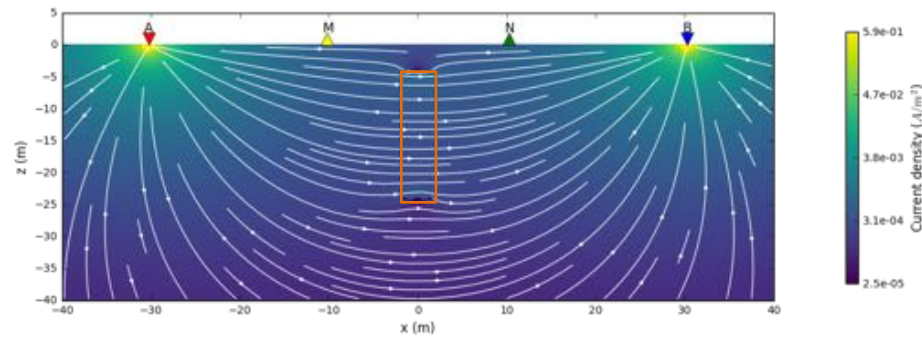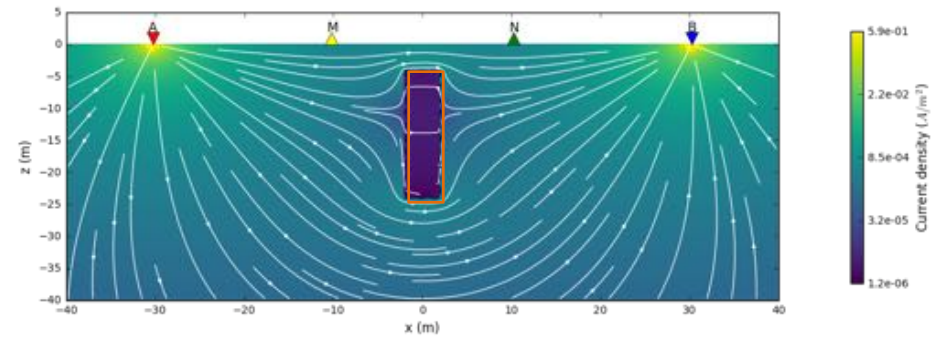Total currents: **J**

Conductive vs. Resistive Target

Conductive Target

Total currents: **J**
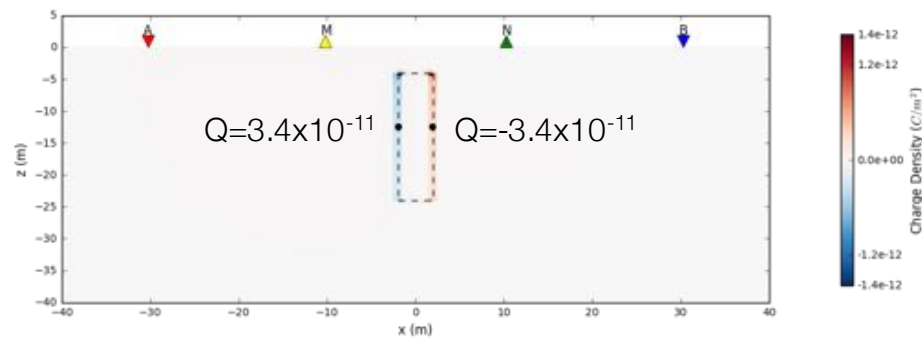

Resistive Target

Total currents: **J**

Secondary charges: Q_S

$Q=3.4 \times 10^{-11}$ $Q=-3.4 \times 10^{-11}$

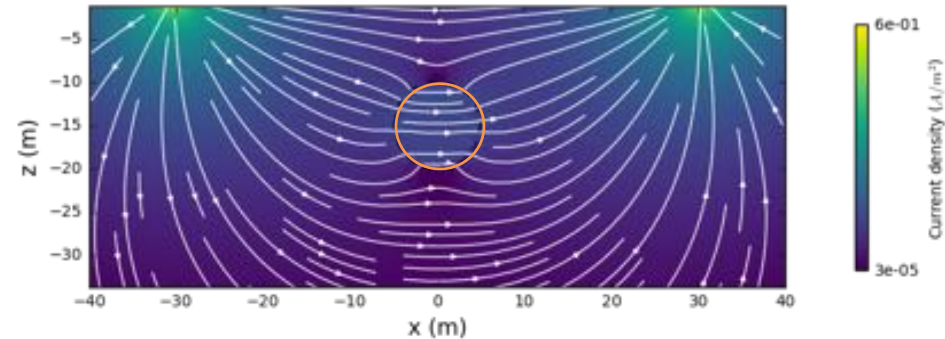Secondary charges: Q_S

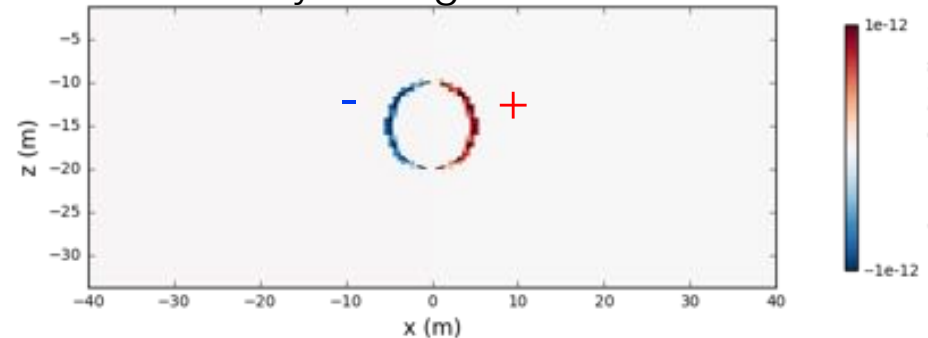$Q=1.6 \times 10^{-10}$ $Q=-1.6 \times 10^{-10}$
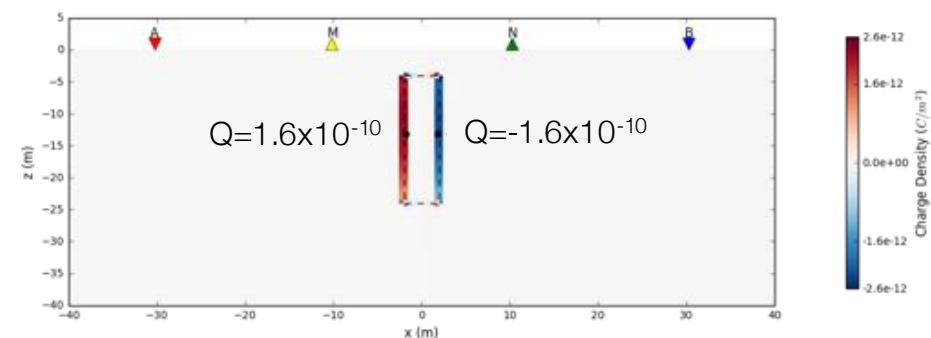
Summary: Sensitivity

- "Excite" the target
  - Drive currents to target
  - Need good coupling with target

- Measuring a datum
  - Proximity to target
  - Electrode orientation and separation
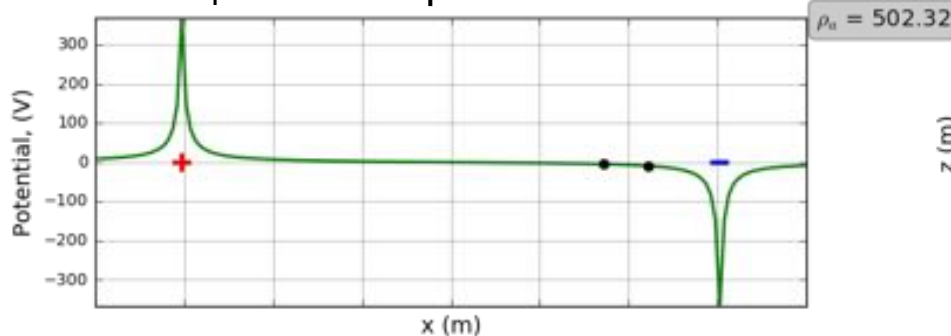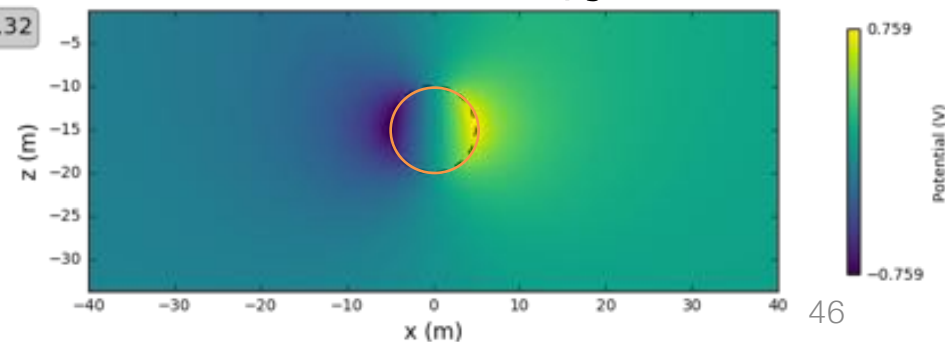
- Background resistivity is important

Total currents: **J**

Secondary Charges: Q

Total potential: ϕ
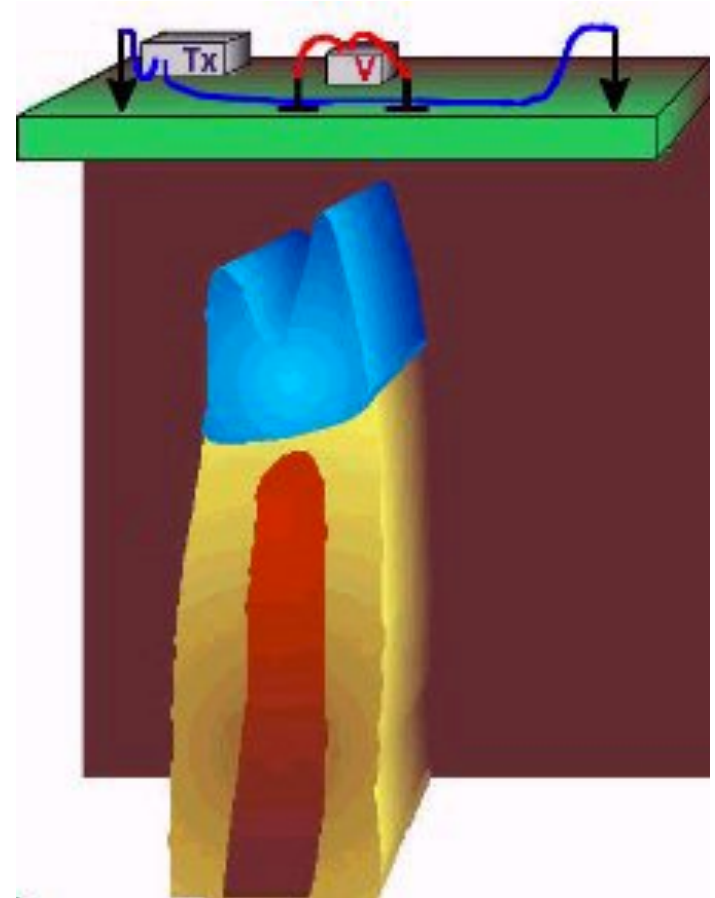

$\rho_a = 502.32$

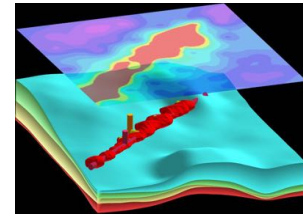Secondary potential: ϕ_s

46

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
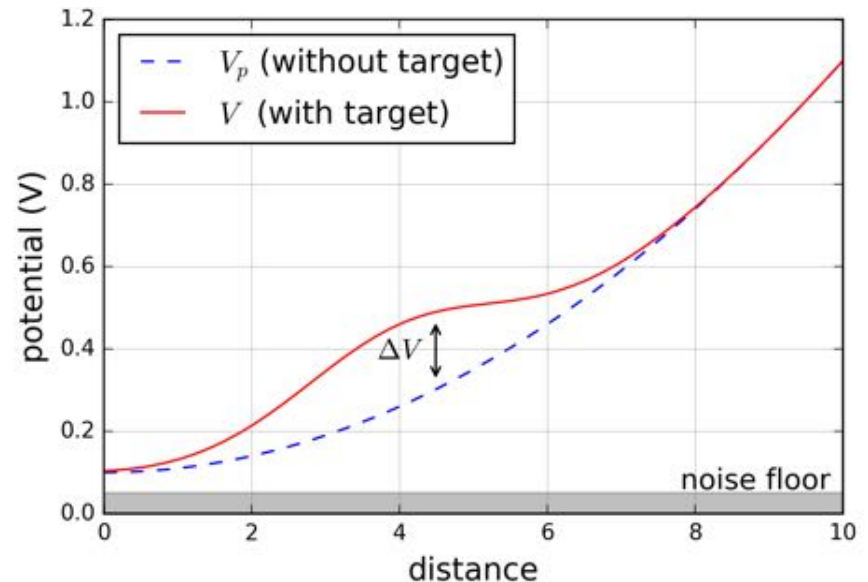
Signal from target
$$\Delta V = V - V_p$$

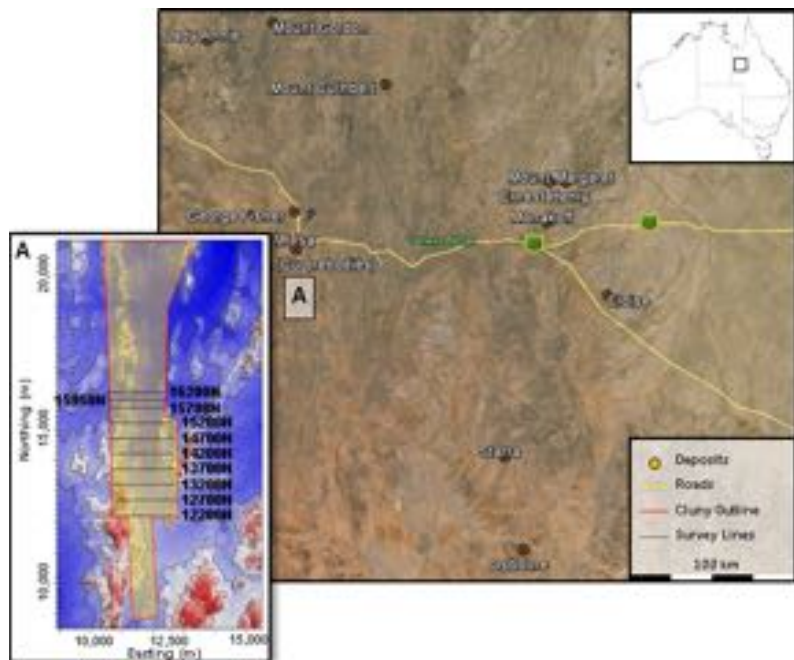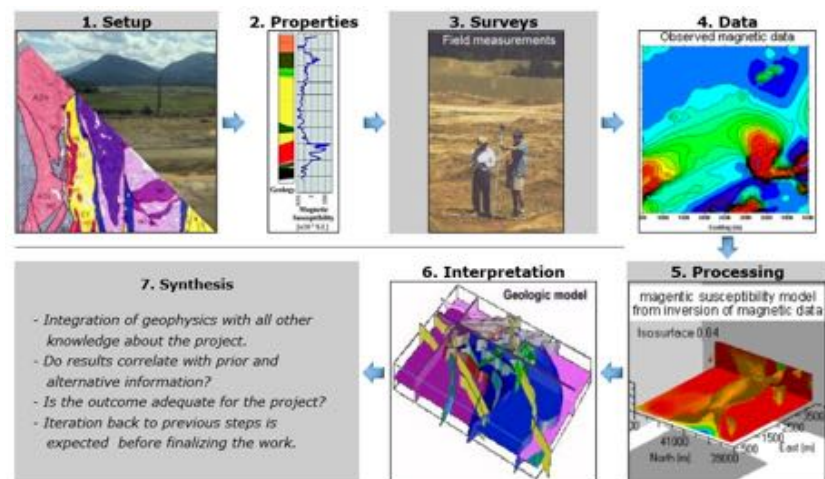| Need |
| --- |
| $$\Delta V > floor$$ |
| $$\frac{\Delta V}{V_p} > \%|V|$$ |

Outline

- Basic experiment
- Currents, charges, potentials and apparent resistivities
- Soundings, profiles and arrays
- Data, pseudosections and inversion
- Sensitivity
- Survey Design

- Questions

- Case History – Mt Isa
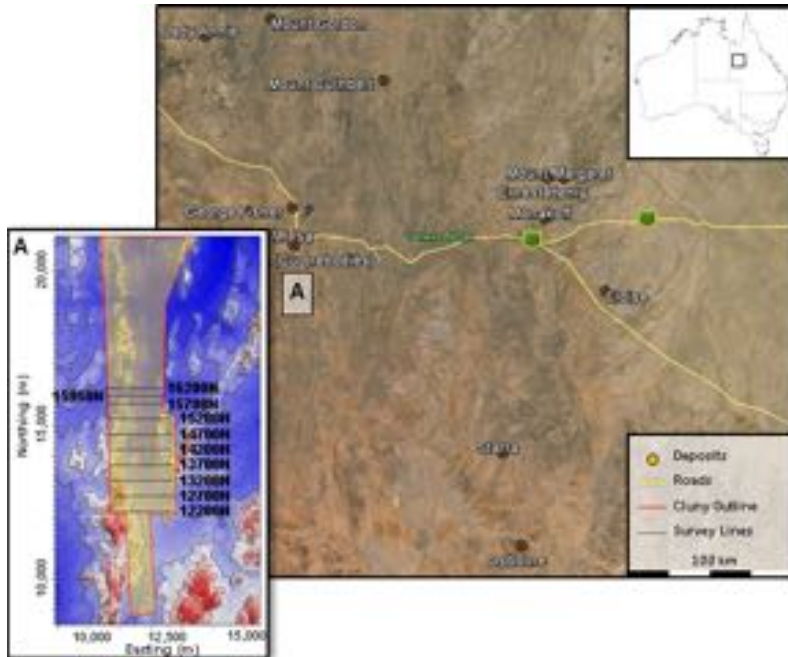- Effects of background resistivity
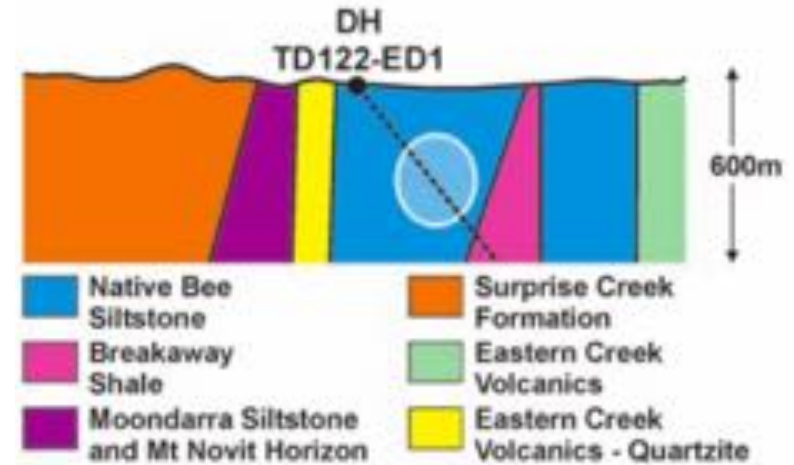
Mt. Isa

Mt. Isa (Cluny prospect)

Seven Steps

Setup

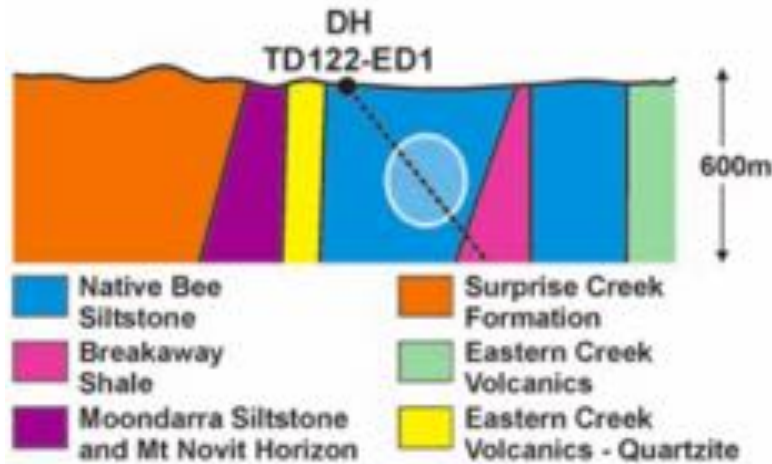## Mt. Isa (Cluny prospect)

Geologic model

Question

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

Properties

Geologic model

DH TD122-ED1

600m

- Native Bee Siltstone
- Breakaway Shale
- Moondarra Siltstone and Mt Novit Horizon
- Surprise Creek Formation
- Eastern Creek Volcanics
- Eastern Creek Volcanics - Quartzite

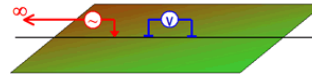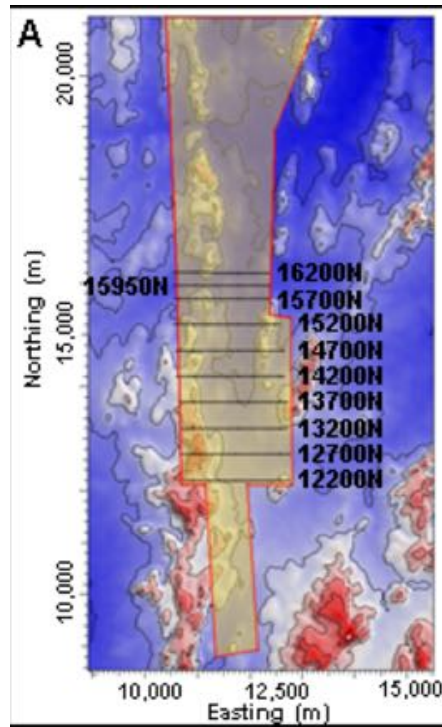| Rock Unit	Conductivity
Native Bee Siltstone	Moderate
Moondarra Siltstone	Moderate
Breakaway Shale	Very High
Mt Novit Horizon	High
Surprise Creek Formation	Low
Eastern Creek Volcanics	Low

Surface topography
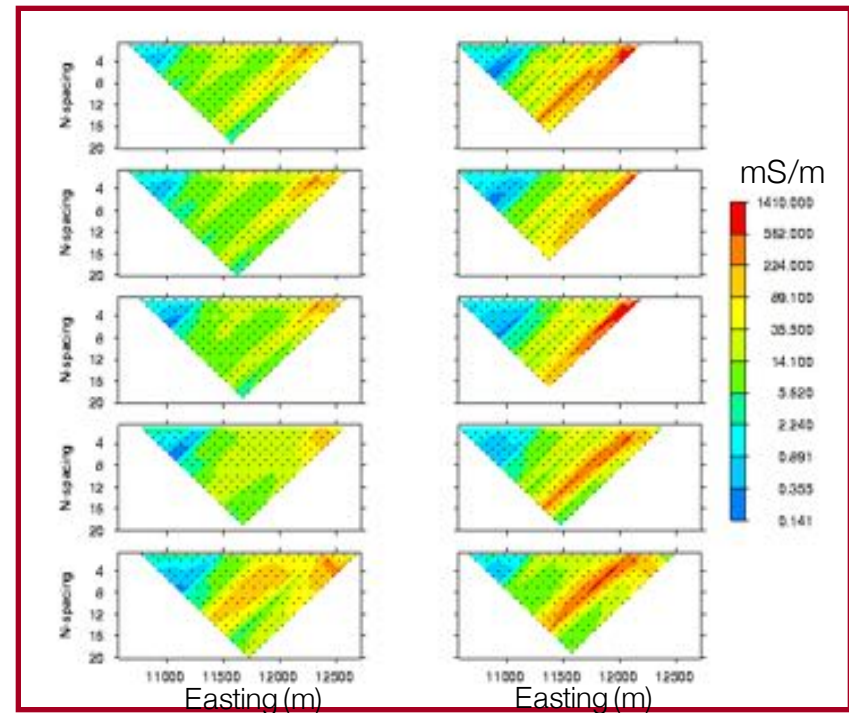

52
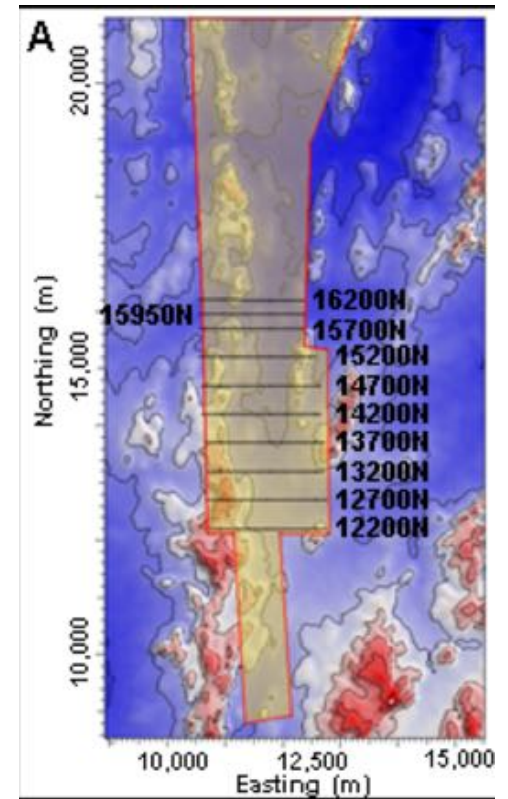
Survey and Data

- Eight survey lines
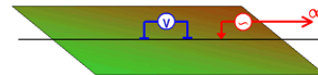
- Two survey configurations.

Surface topography

Data set #1:
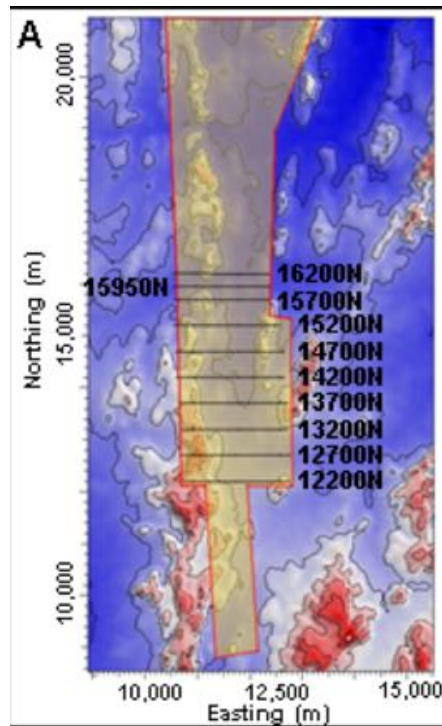
Apparent resistivity, pole - dipole.

Survey and Data

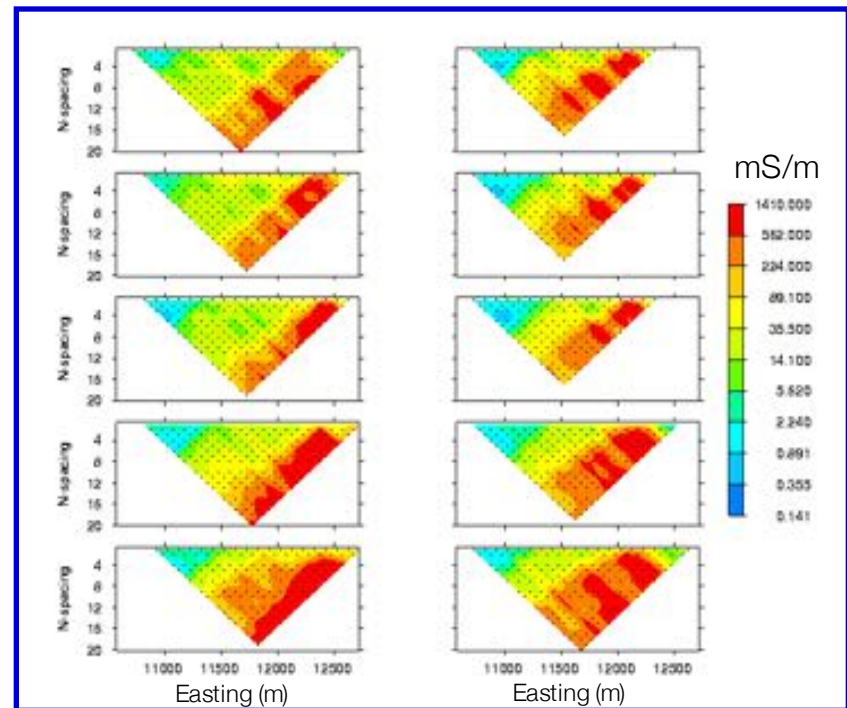- Eight survey lines
- Two survey configurations.

Data set #2:

Apparent resistivity, dipole - pole
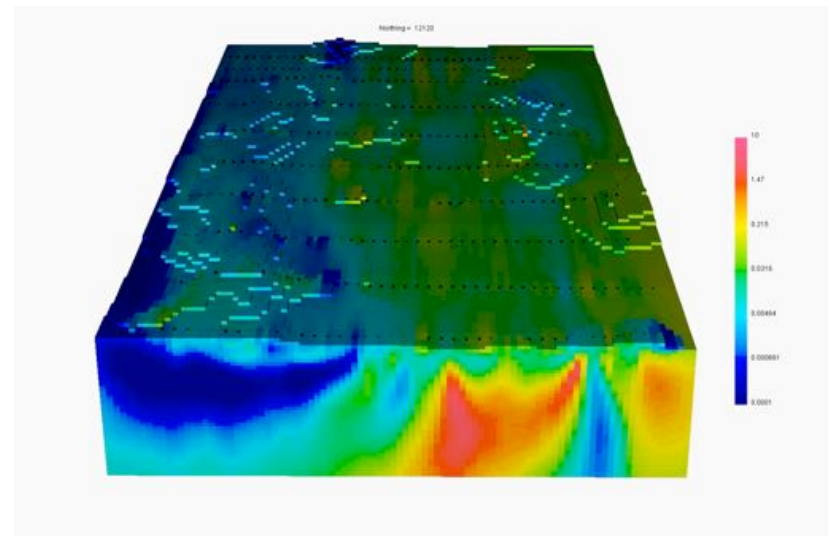
Surface topography

Processing and interpretation
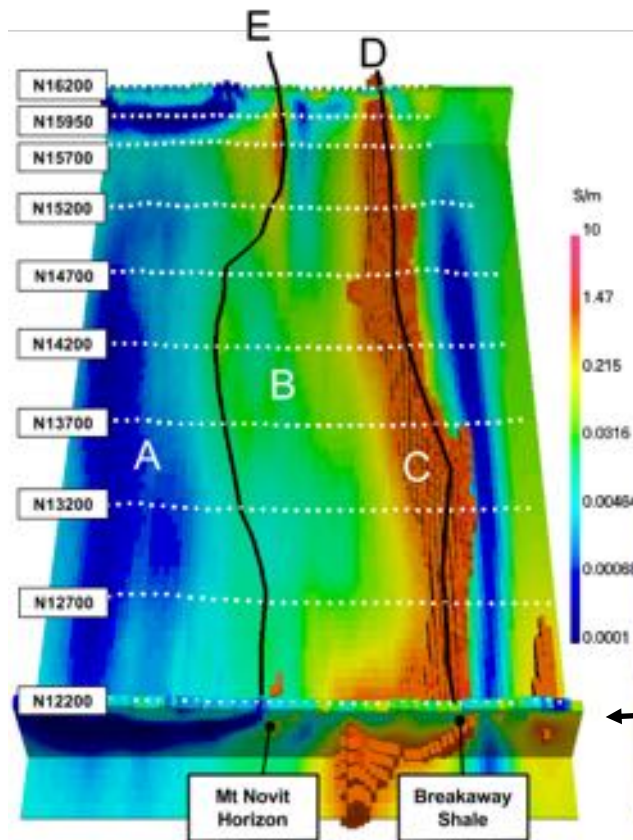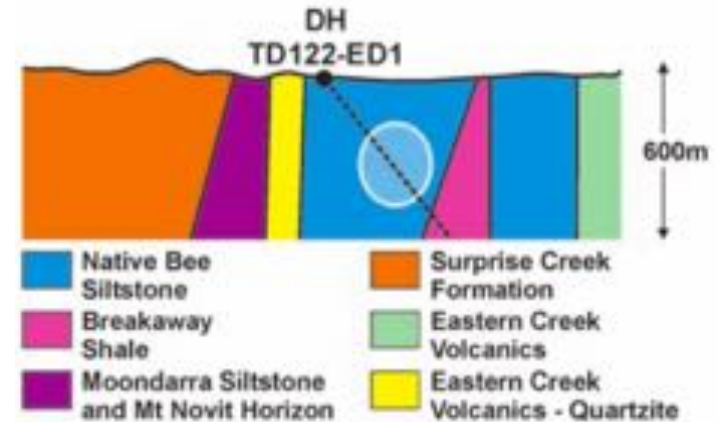
3D resistivity model
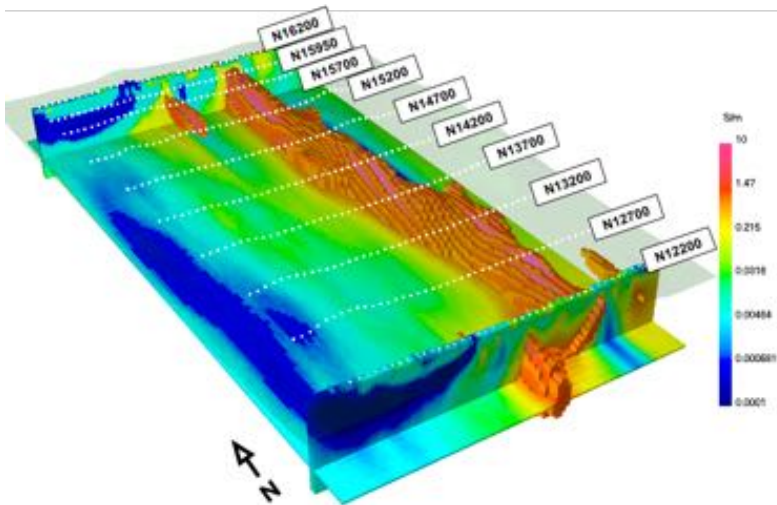
Animation

Synthesis

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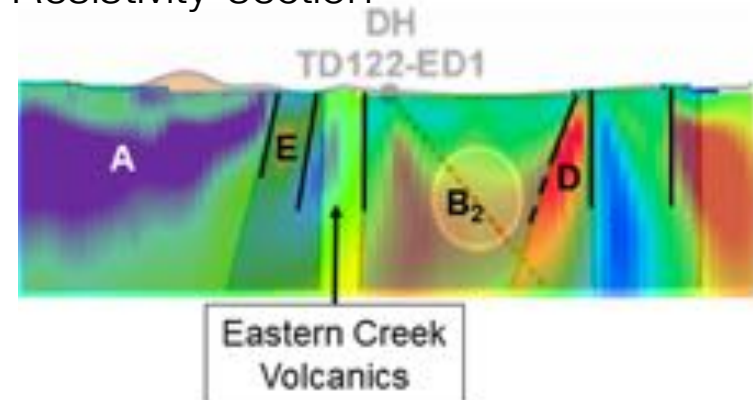- Some indication of a moderate conductor

3D resistivity model

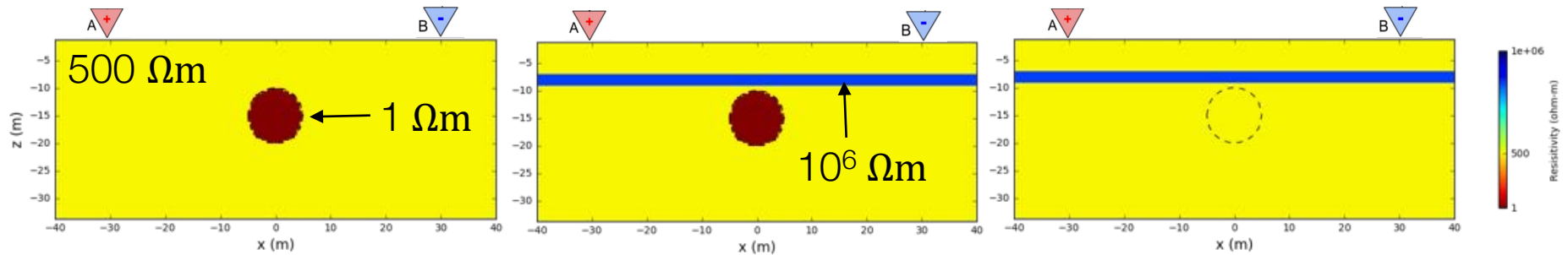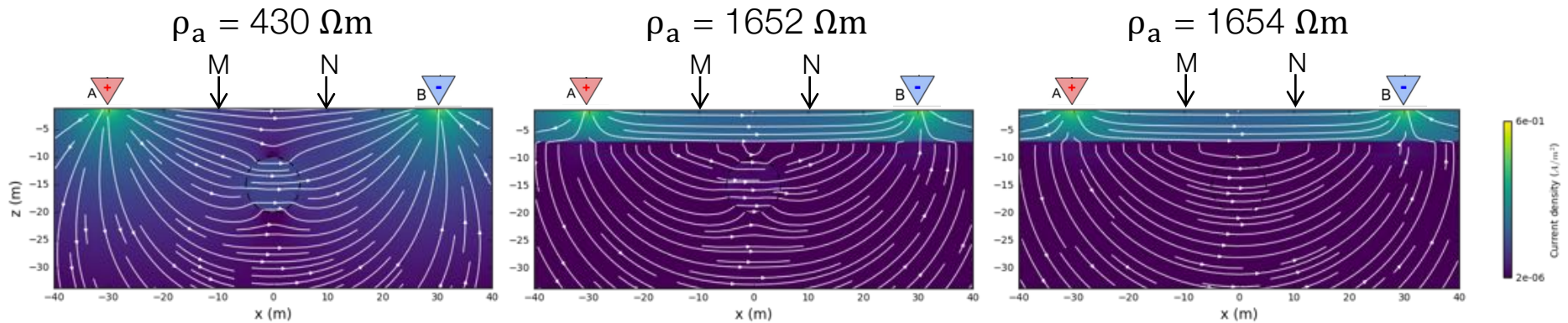Geologic section

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
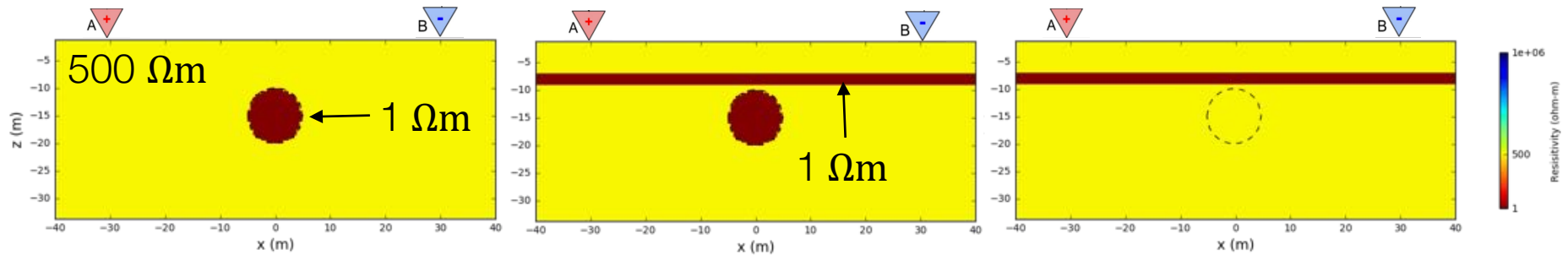
Resistivity models (thin resistive layer)

500 Ωm

← 1 Ωm

10^6 Ωm

Currents and measured data at MN
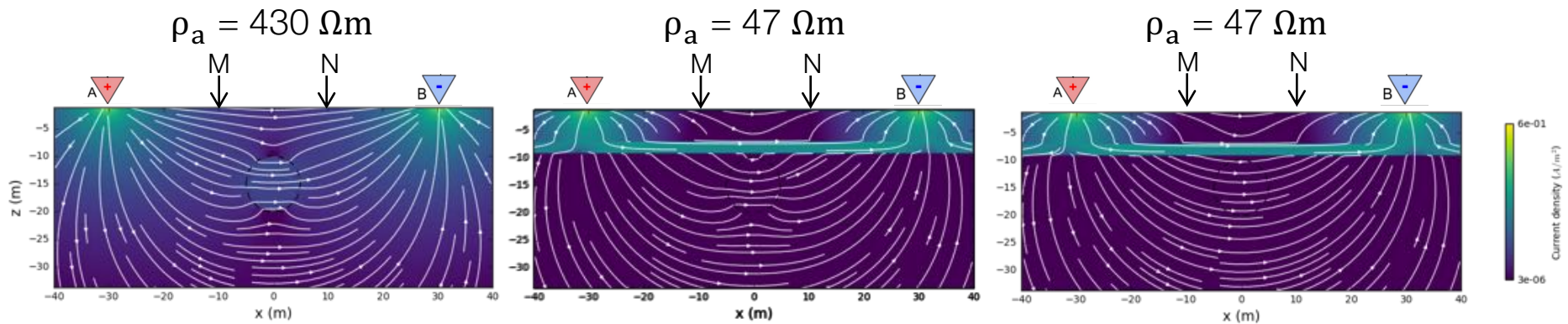

$\rho_a = 430$ Ωm

$\rho_a = 1652$ Ωm

$\rho_a = 1654$ Ωm

Effects of background resistivity

Resistivity models (thin conductive layer)

Currents and measured data at MN

End of DCR

Next up

Lunch: Play with apps
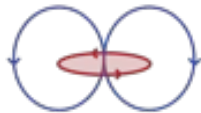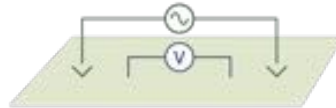
DC Resistivity

EM Fundamentals

Inductive Sources
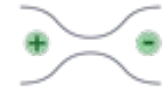
Grounded Sources

Natural Sources

GPR

Induced Polarization

The Future