Lecture 4

DC Resistivity: Surveys

GEOL 4397: Electromagnetic Methods for Exploration
GEOL 6398: Special Problems

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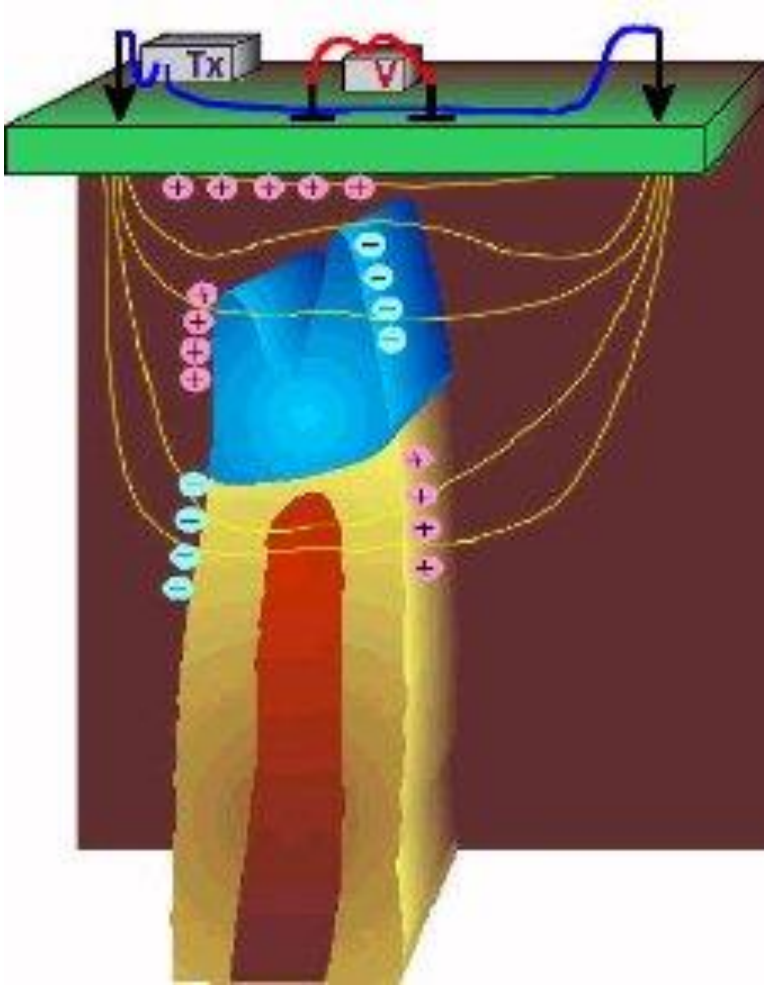
UNIVERSITY of HOUSTON
YOU ARE THE PRIDE
EARTH AND ATMOSPHERIC SCIENCES

Agenda

- Recap
- Sounding
- Profiling
- Different survey geometries
- Data
- Case Study

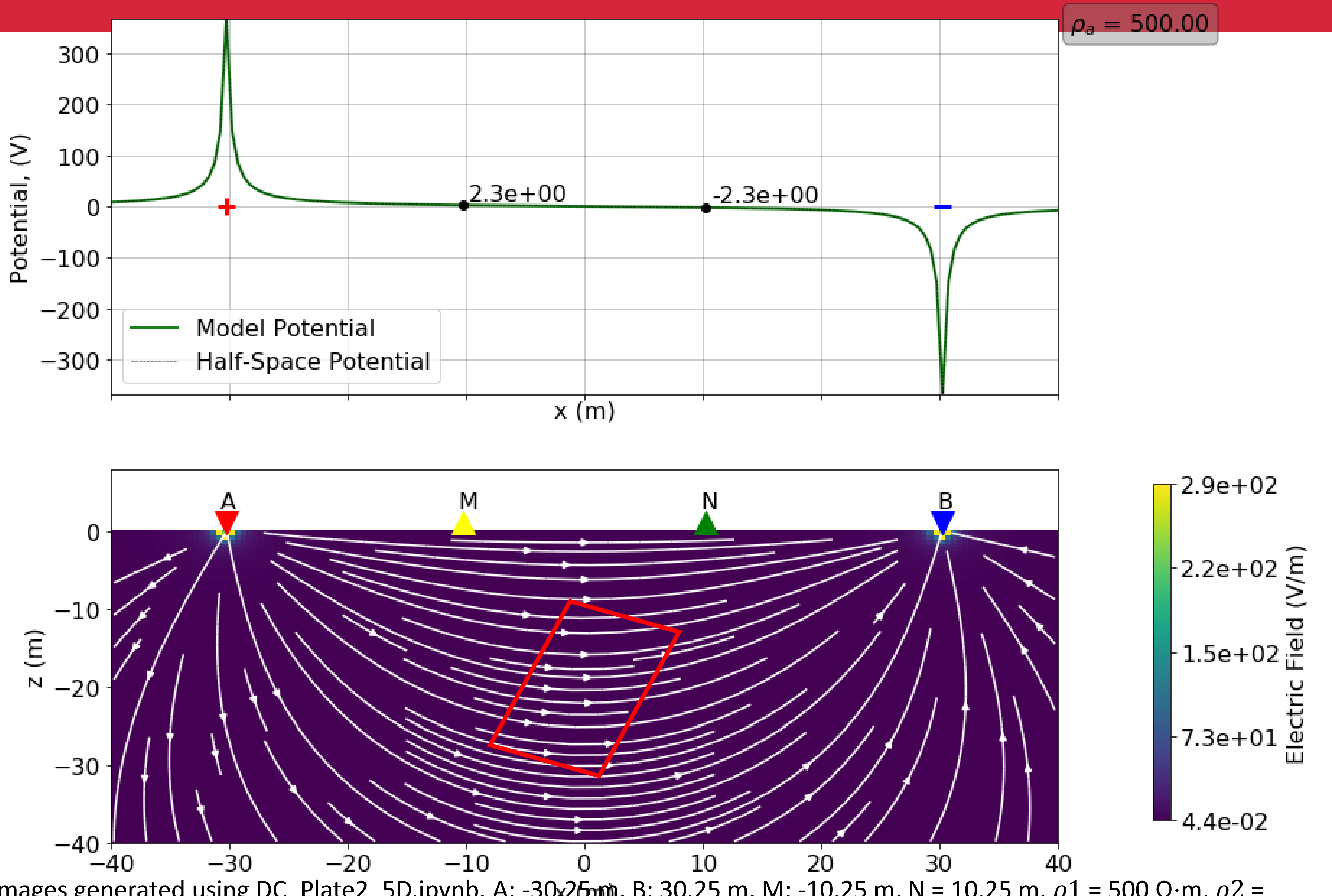
Understanding the charges



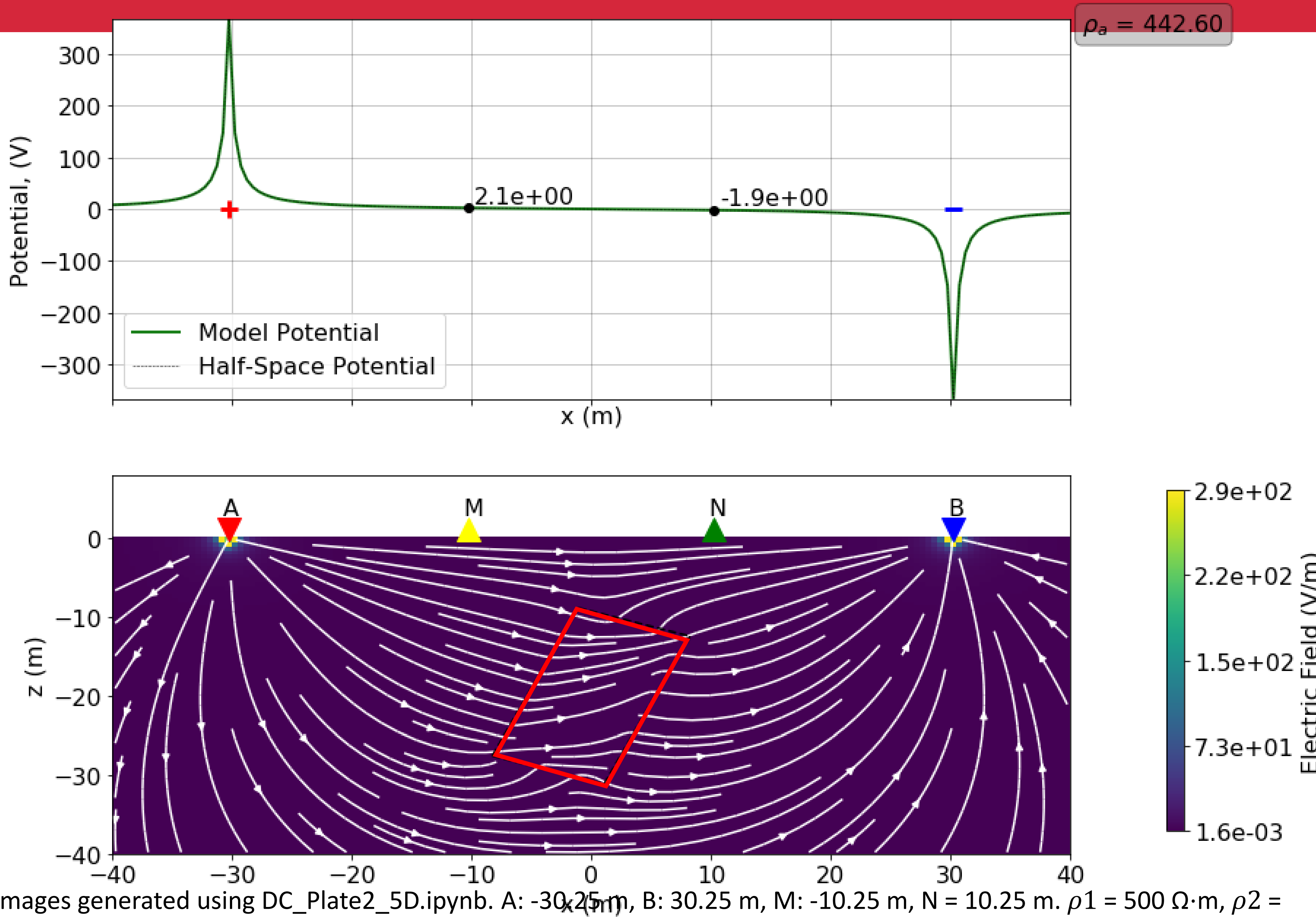
Elura Orebody Electrical resistivities

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

Credit: Doug Oldenburg, Seogi Kang and Linsey Heagy from UBC-GIF



Images generated using DC_Plate2_5D.ipynb. A: -30.25 m, B: 30.25 m, M: -10.25 m, N = 10.25 m. $\rho 1$ = 500 Ω·m, $\rho 2$ = 500 Ω·m. dx = 10, dz=20, xc = 0, zc = -20, theta = 21.



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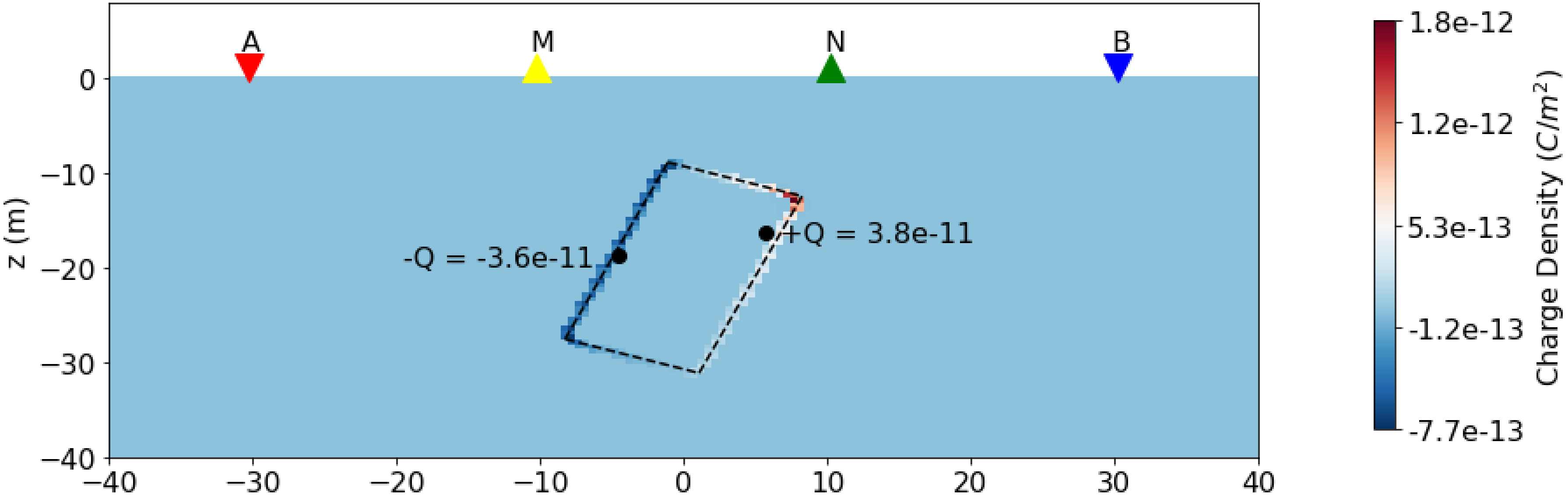
- What could have happened?

- The electric field becomes discontinuous across the boundary.

- What is the easiest way to make the electric field discontinuous?

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



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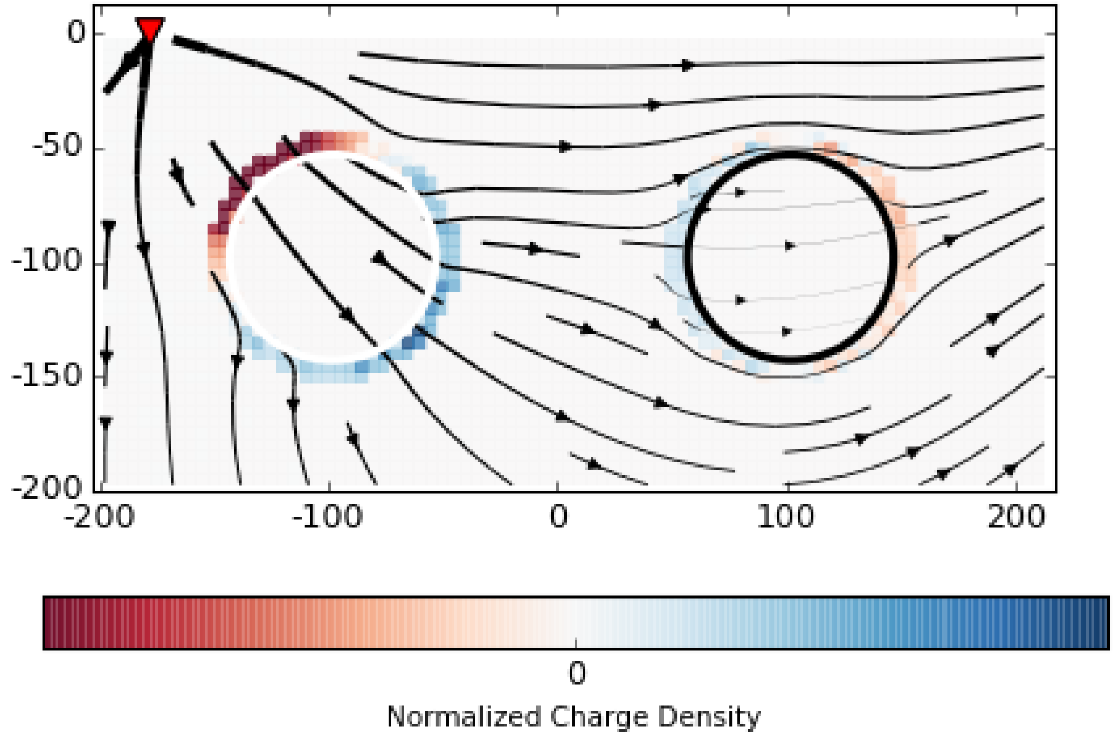
Test

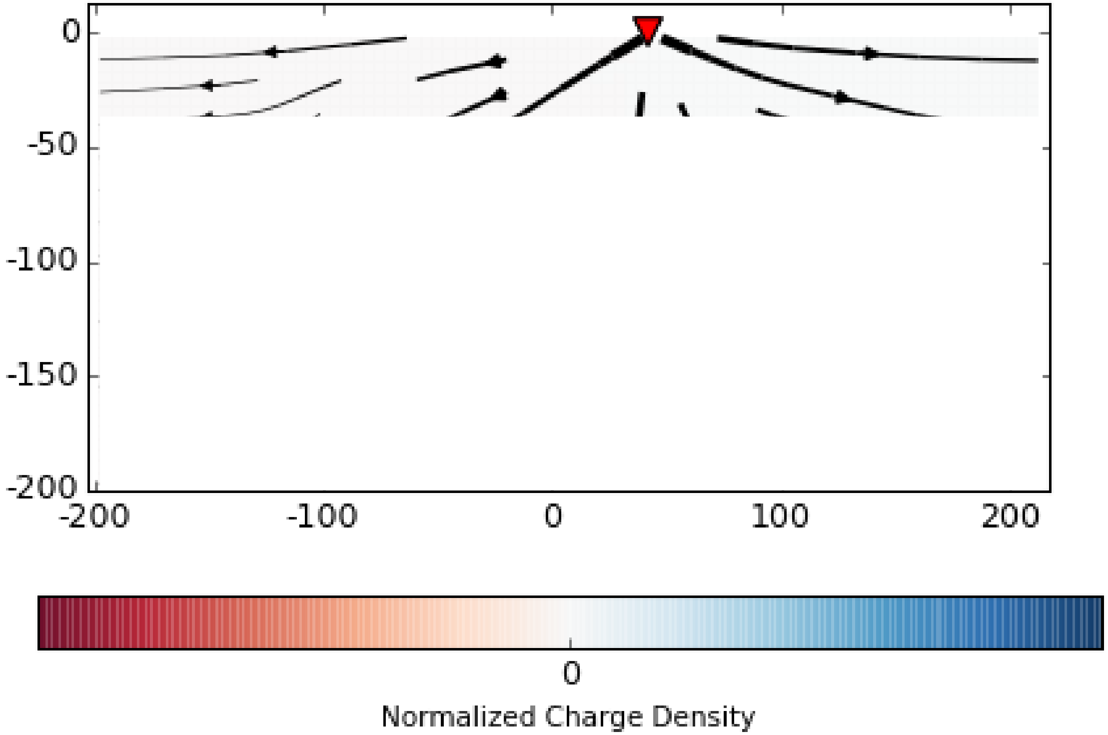
Can you tell which one is conductive and which one is resistive?



https://gpg.geosci.xyz/content/DC_resistivity/DC_basic_principles_heterogeneous_earth.html

Test

Now that you have figured out which one is conductive and which is resistive. What do you think the charges will look like for the following scenario?



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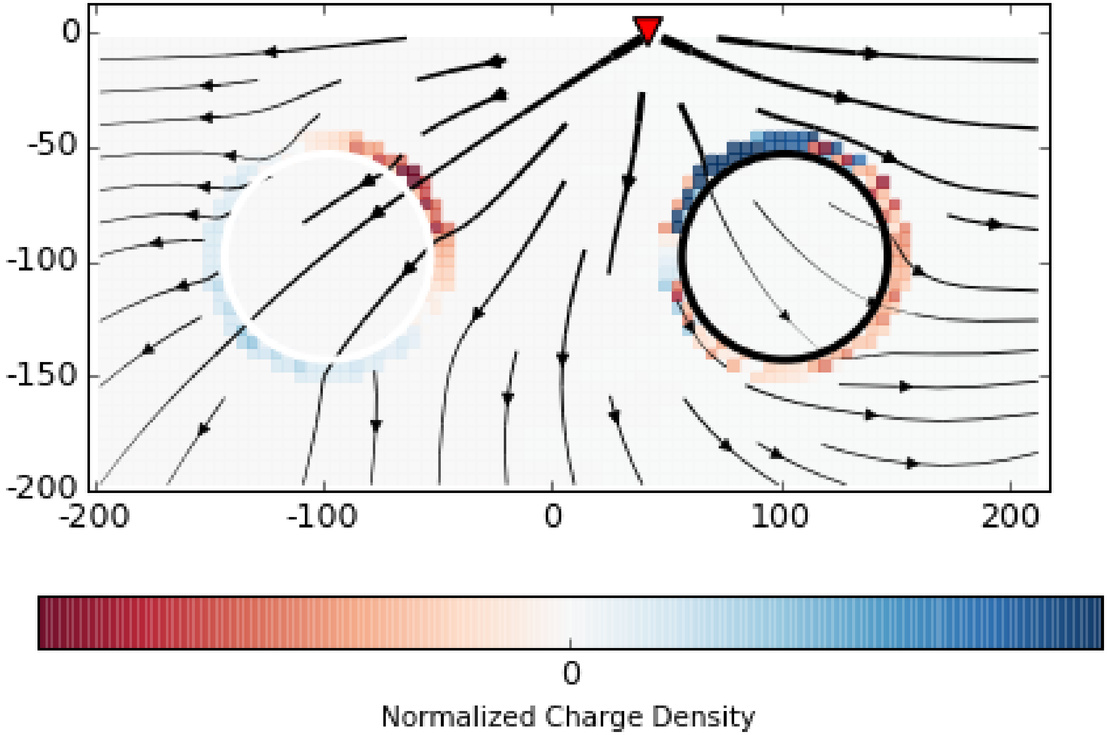

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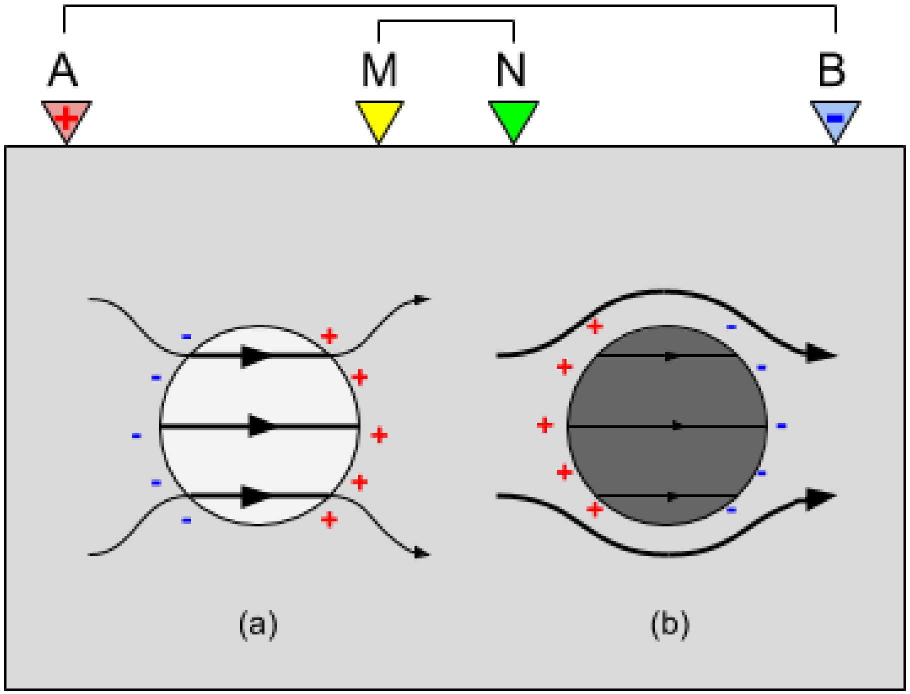
Charges on a resistor and conductor



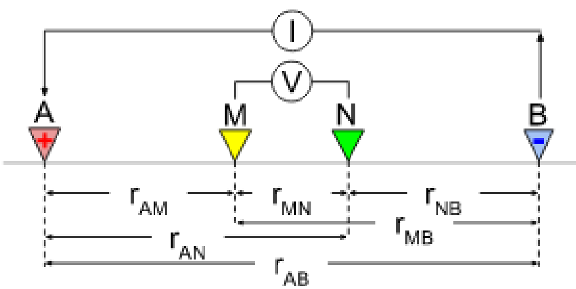
Direct Current Resisitivity (DCR) experiment showing current path and charge built up near a (a) conductive and (b) resistive anomaly. Image Courtesy: https://em.geosci.xyz/content/geophysical_surveys/dcr/index.html

What if no charge would be built up?

- The electric field would not be distorted
- It would be the same as the electric field from a homogeneous Earth

- DC resistivity would become totally useless!!

Currents and Apparent Resistivity

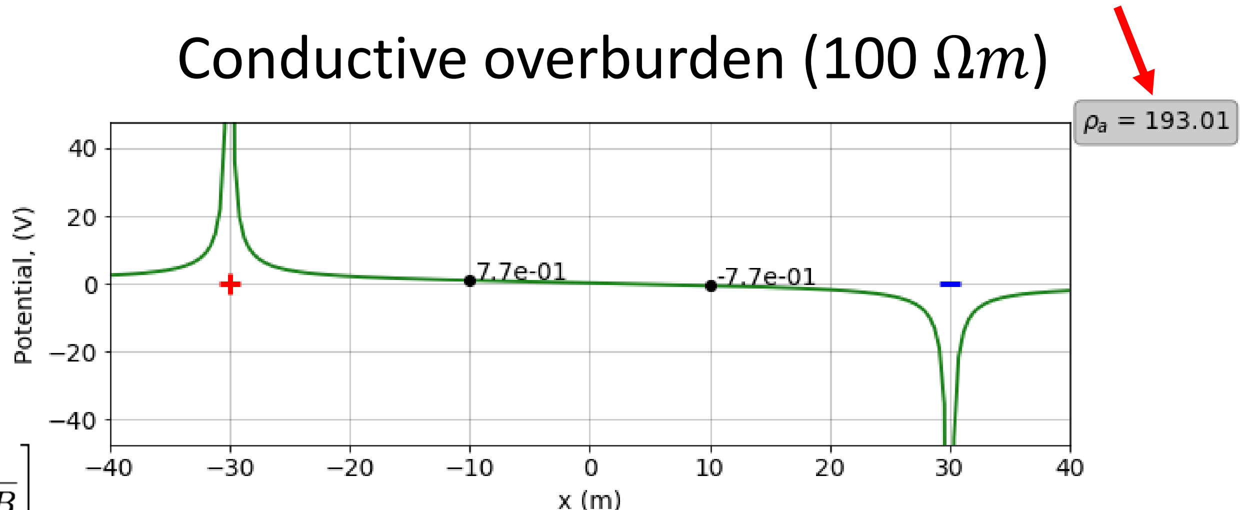


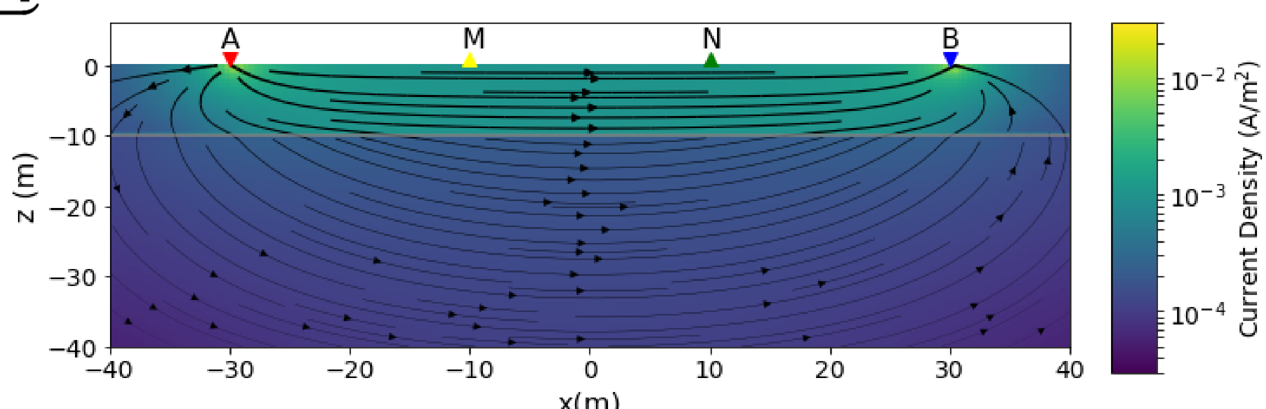
$$\Delta V_{MN} = \rho I \underbrace{\frac{1}{2\pi}\left[\frac{1}{AM} - \frac{1}{MB} - \frac{1}{AN} + \frac{1}{NB}\right]}_{G}$$

Apparent resistivity

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

Conductive overburden (100 Ωm)





Images generated using DC_Layered Earth.ipynb. A: -30 m, B: 30 m, M: -10 m, N = 10 m. $\rho 1$ = 100 Ω·m, $\rho 2$ = 500 Ω·m. h = 10 m.

Credit: Doug Oldenburg, Seogi Kang and Linsey Heagy from UBC-GIF

Apparent resistivity

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

- If the Earth is homogeneous, the apparent resistivity is equal to the true resistivity of the Earth.
- For inhomogeneous Earth, the apparent resistivity is some complicated averaging of the resistivities of all materials encountered by the currents.

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

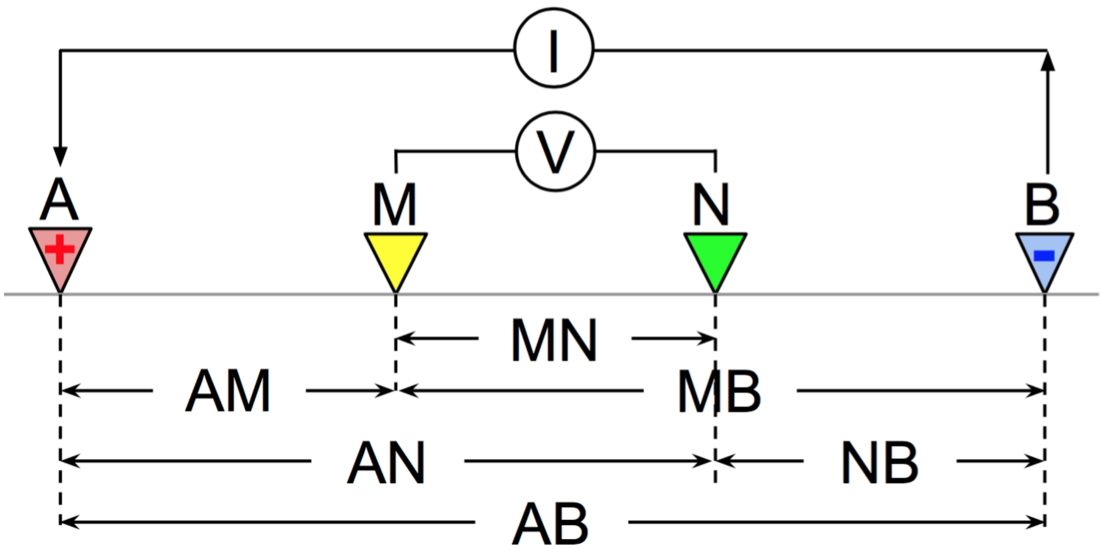
- If the Earth is homogeneous, the apparent resistivity is equal to the true resistivity of the Earth.
- For inhomogeneous Earth, the apparent resistivity is some complicated averaging of the resistivities of all materials encountered by the currents.
- It can be interpreted as the resistivity that would have been measured if the Earth were homogeneous.

Agenda

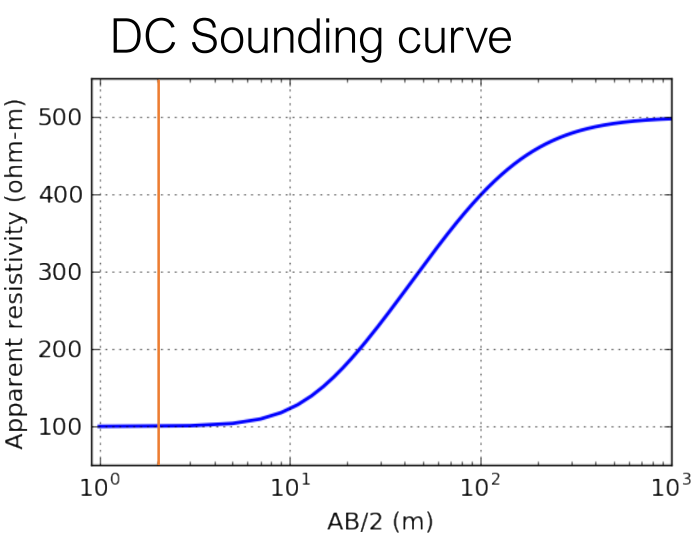
- Recap
- Sounding
- Profiling
- Different survey geometries
- Data
- Case Study

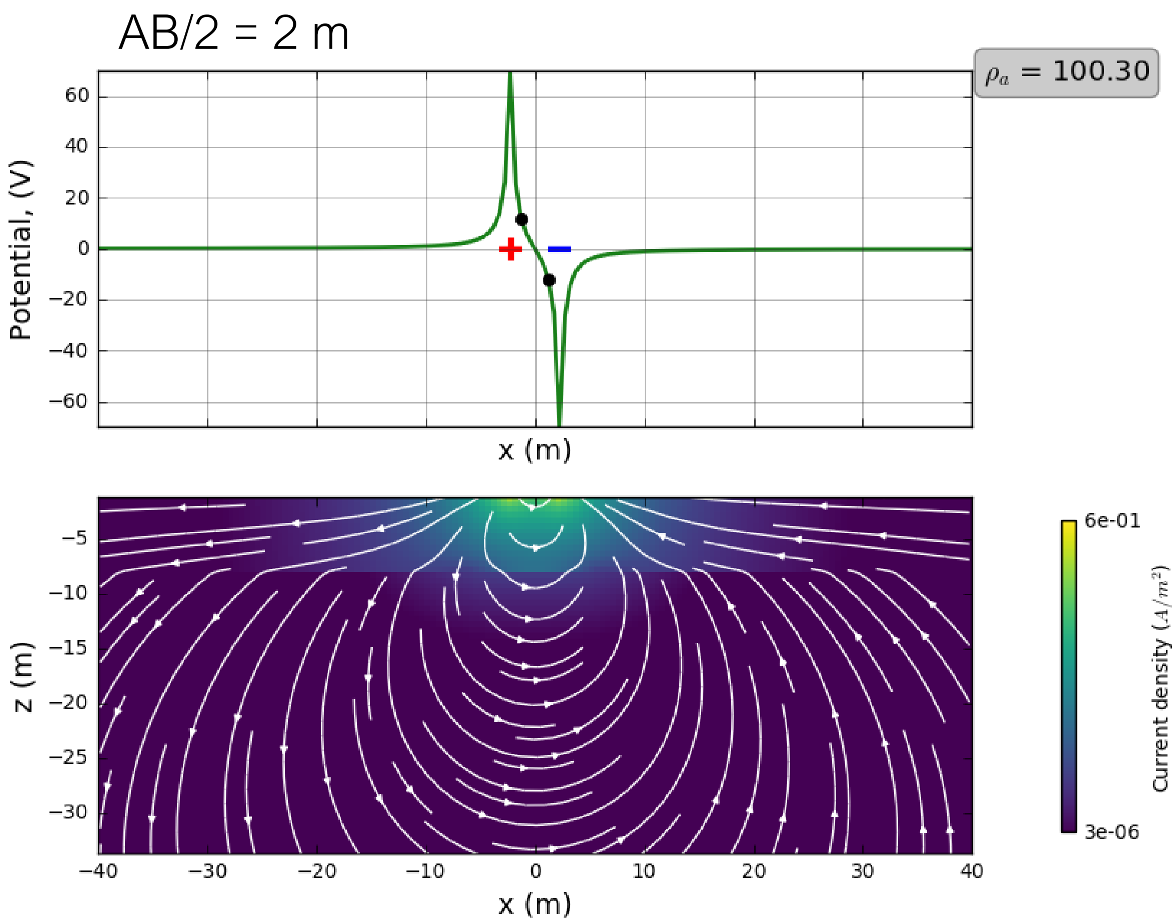
Sounding

- Keep the distance between M and N fixed
- Expand A and B



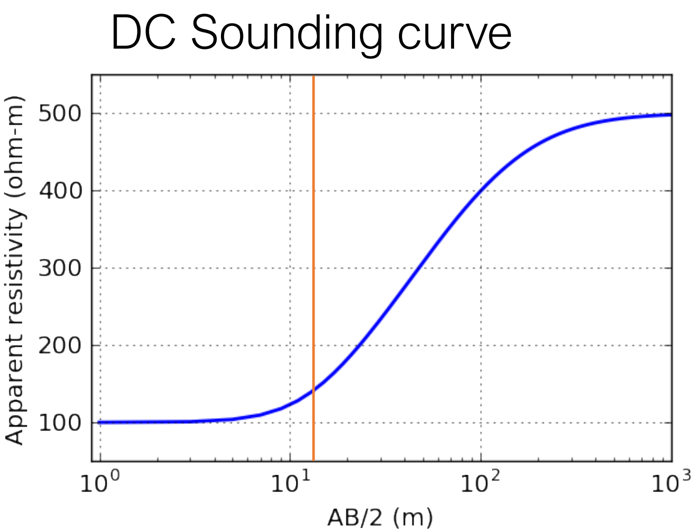
Sounding

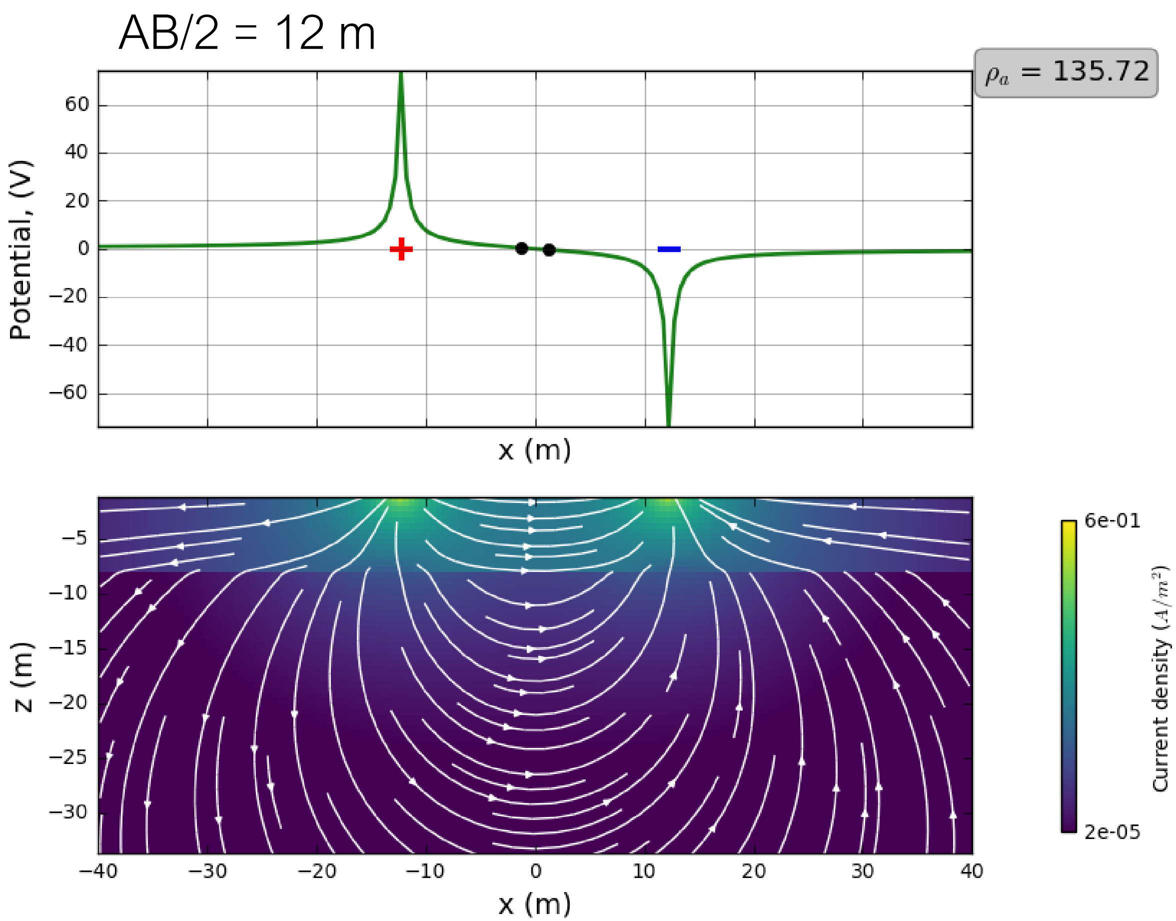




Credit: Doug Oldenburg, Seogi Kang and Linsey Heagy from UBC-GIF

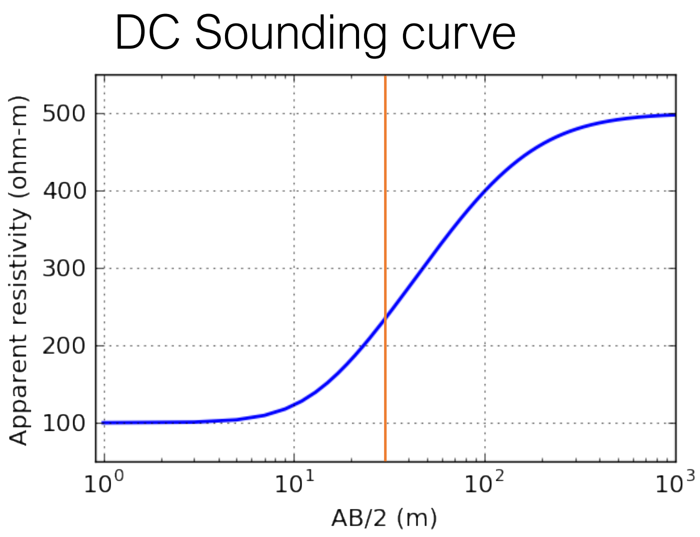
Sounding

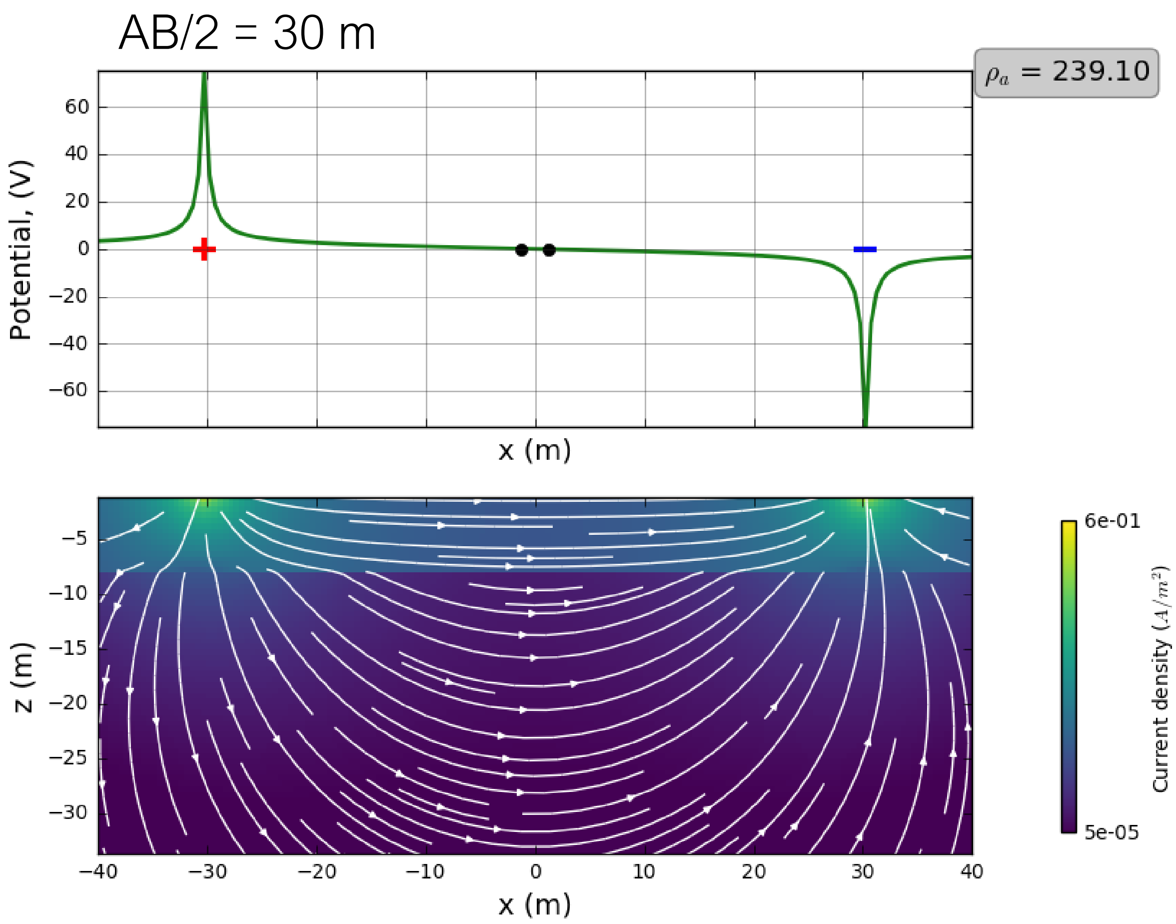




Credit: Doug Oldenburg, Seogi Kang and Linsey Heagy from UBC-GIF

Sounding





Credit: Doug Oldenburg, Seogi Kang and Linsey Heagy from UBC-GIF

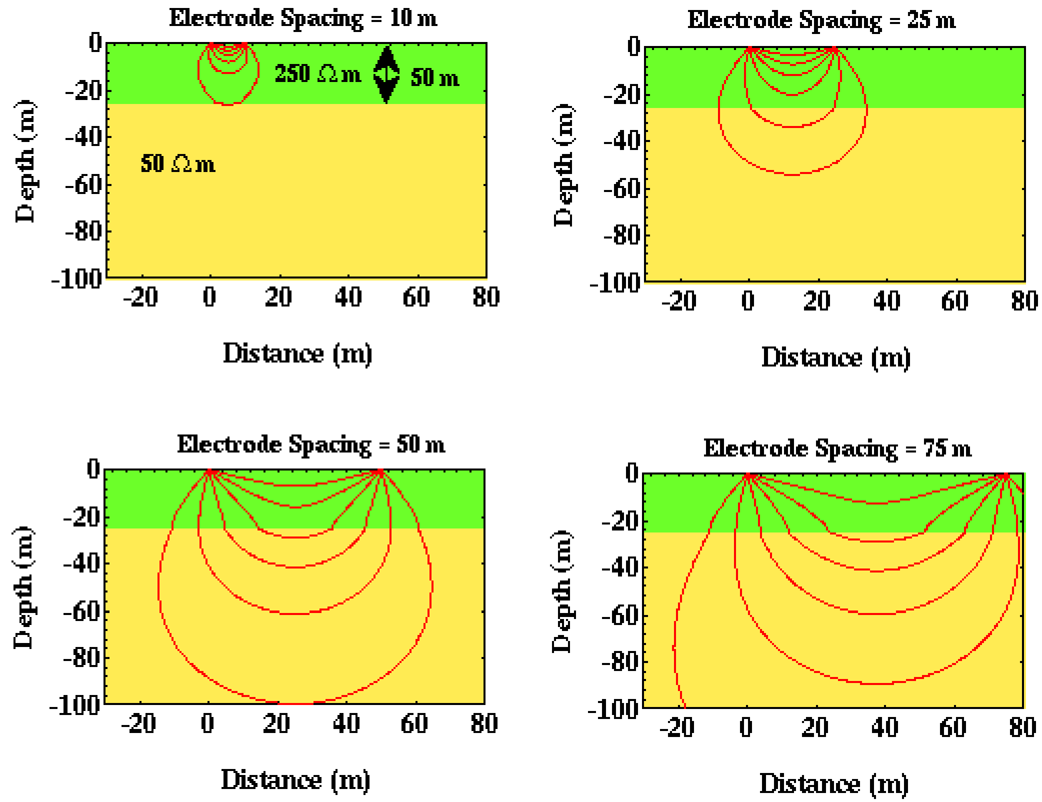
Observations:

- At small electrode spacings current flows only in near-surface regions. Apparent resistivities look similar to the true resistivity of overburden.
- As current flows deeper, apparent resistivities are influenced by the true resistivities of deeper materials.
- The sounding curve begins to indicate that there are at least 2 layers under this location.
- At very large electrode spacings most of the information reflects deeper ground because that is where most of the current is flowing.

https://em.geosci.xyz/content/geophysical_surveys/dcr/data.html

Observations

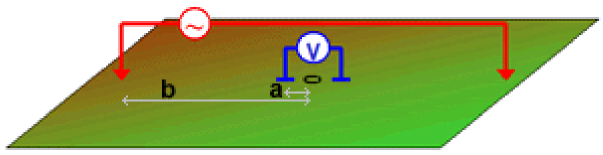
- The larger the distance between A and B, the deeper we can see.
- Because more currents are able to flow to deeper part of the Earth.



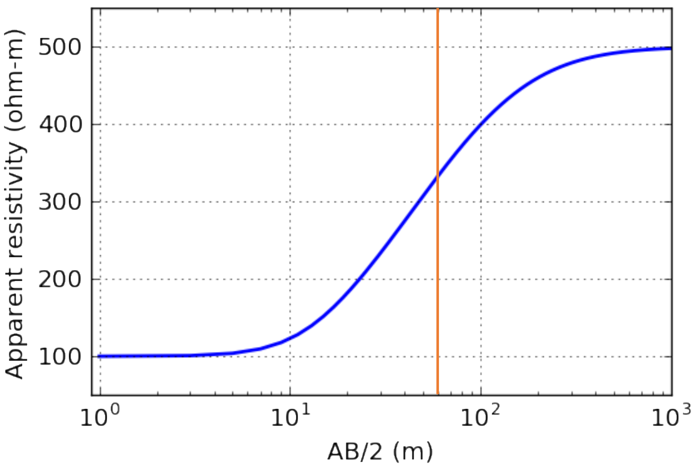
https://pburnley.faculty.unlv.edu/GEOL442_642/RES/NOTES/ResistivityNotes015Layered_02.html

Summary: soundings

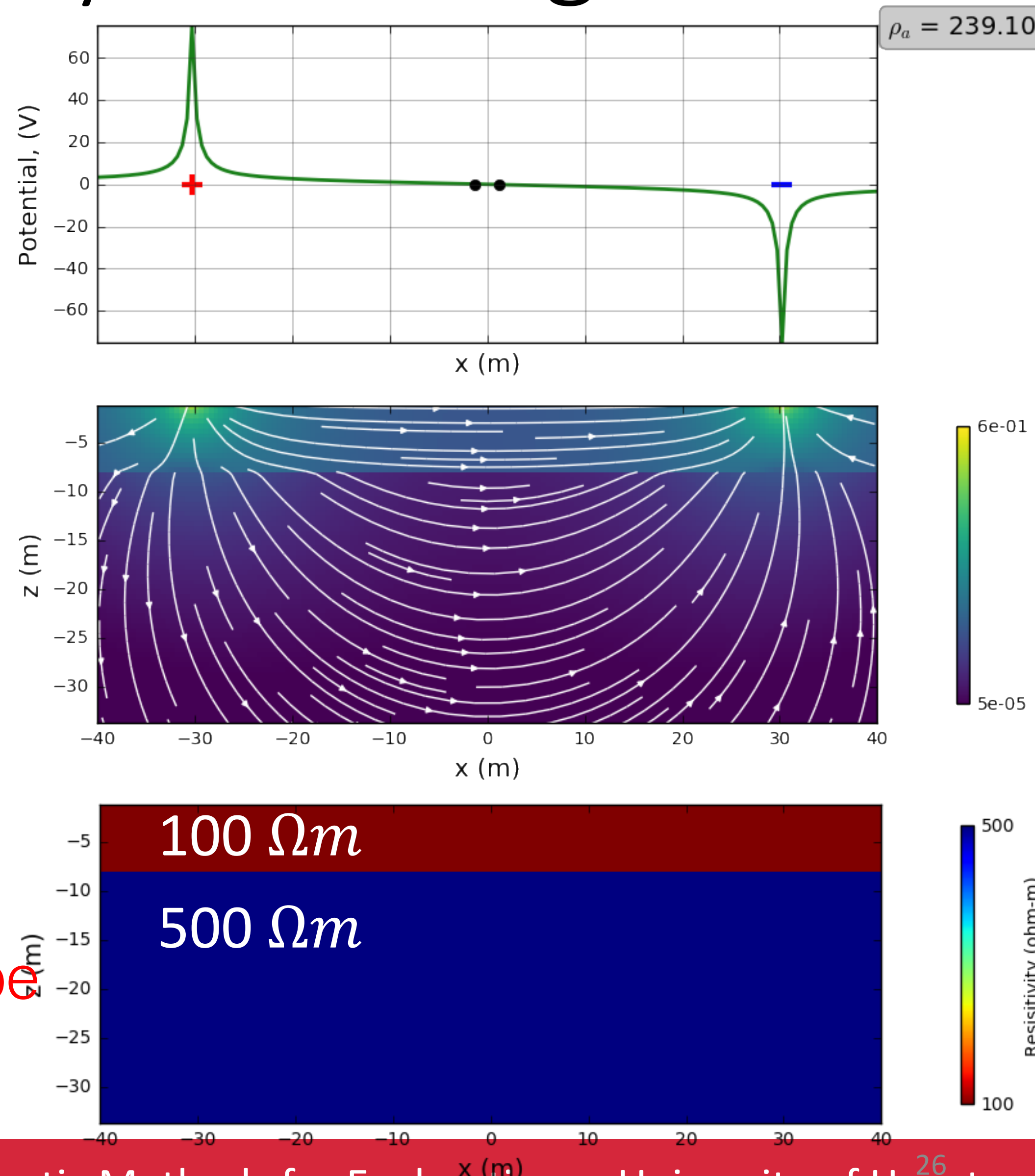
Schlumberger array



DC Sounding curve

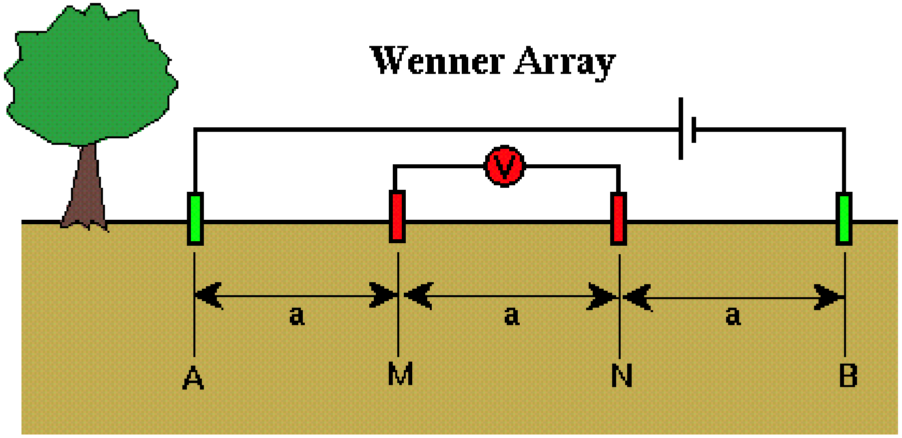


Scale length of array must be large to see deep



Wenner Array

- To generate a sounding curve, from which we could interpret the resistivity variation with depth, we would have to compute apparent resistivity for a variety of electrode spacings, ***a***.
- Therefore, after making a measurement we would have to move all four electrodes to new positions.

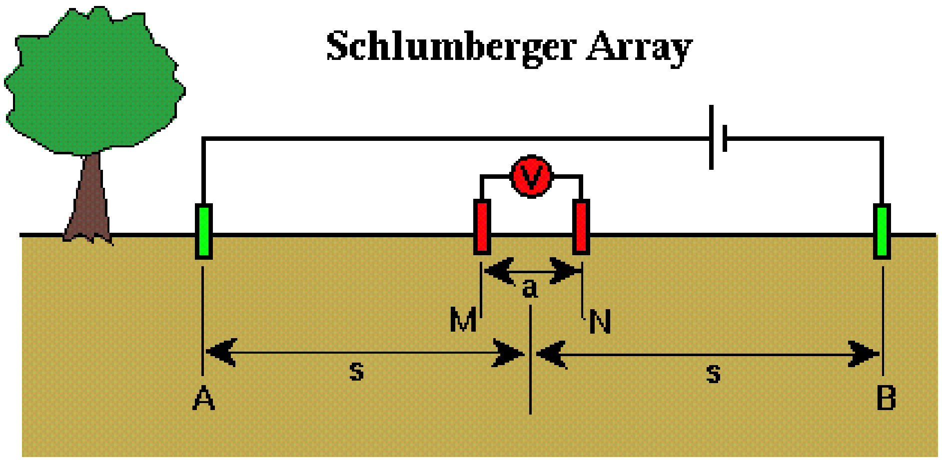


$$\rho_a = 2\pi a \frac{\Delta V}{i}$$

https://pburnley.faculty.unlv.edu/GEOL442_642/RES/NOTES/ResistivityNotes19Sounding.html

Schlumberger Array

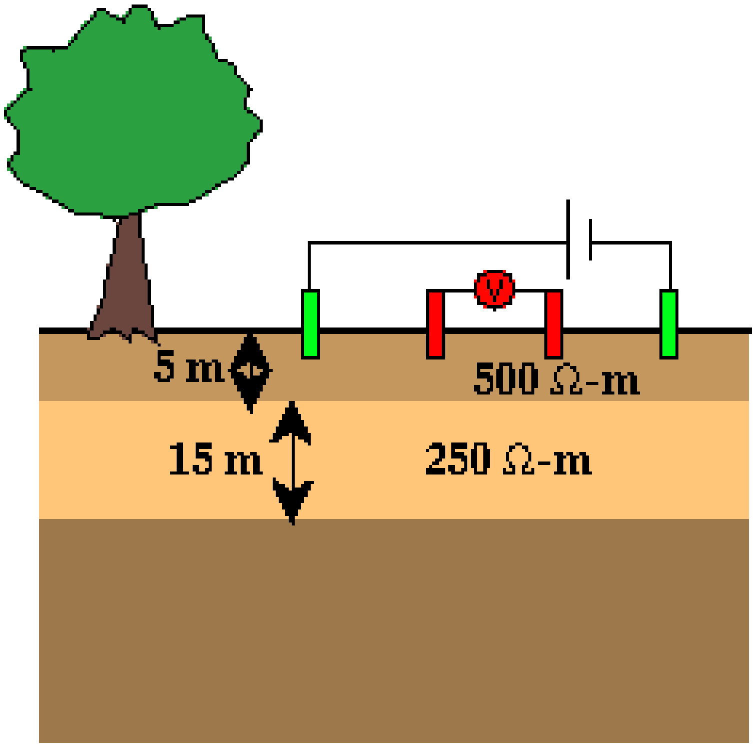
- a << s
- To make a sounding curve, we can simply increase the distance between the current electrodes A and B.
- In principle, we do not need to move potential electrodes, M and N.
- In practice, as the current electrodes are moved outward, the potential difference between M and N gets smaller. Eventually, smaller than our voltmeter is capable of reading. Therefore, we will need to increase ***a*** to increase the potential difference we are attempting to measure.

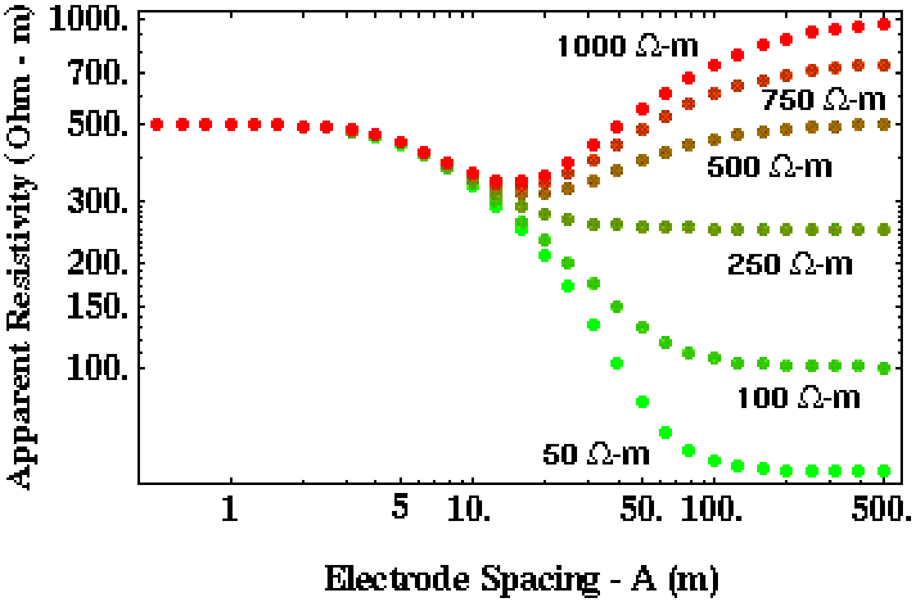


$$\rho_a = \frac{\pi(s^2 - a^2/4)}{a}\frac{\Delta V}{i}$$

https://pburnley.faculty.unlv.edu/GEOL442_642/RES/NOTES/ResistivityNotes19Sounding.html

A three-layer model



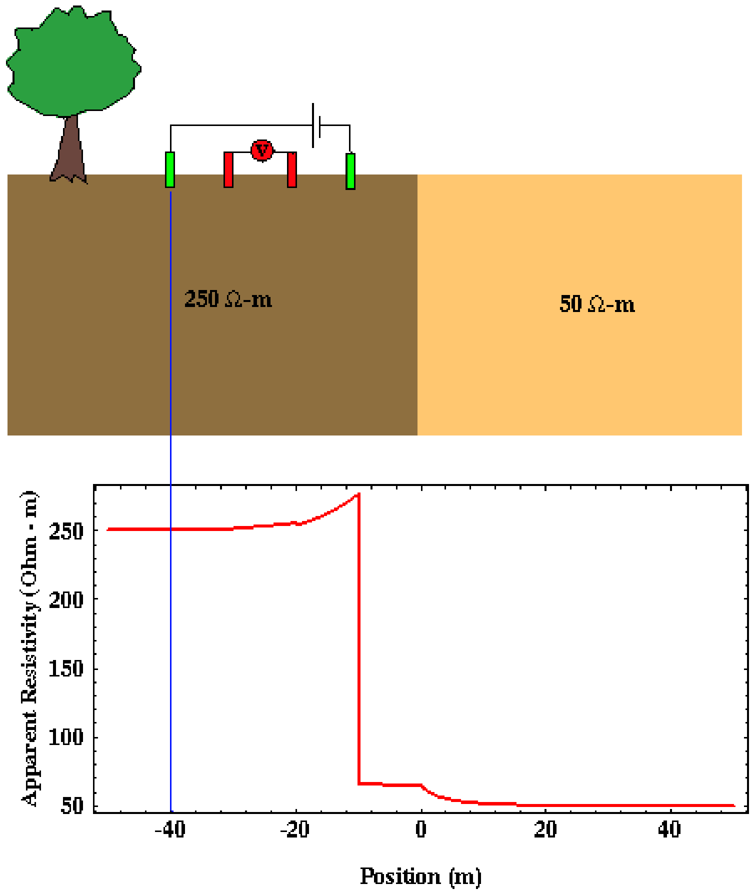


For mode discussions on the sounding curves:

https://pburnley.faculty.unlv.edu/GEOL442_642/RES/NOTES/ResistivityNotes25MLayer1.html

Profiling

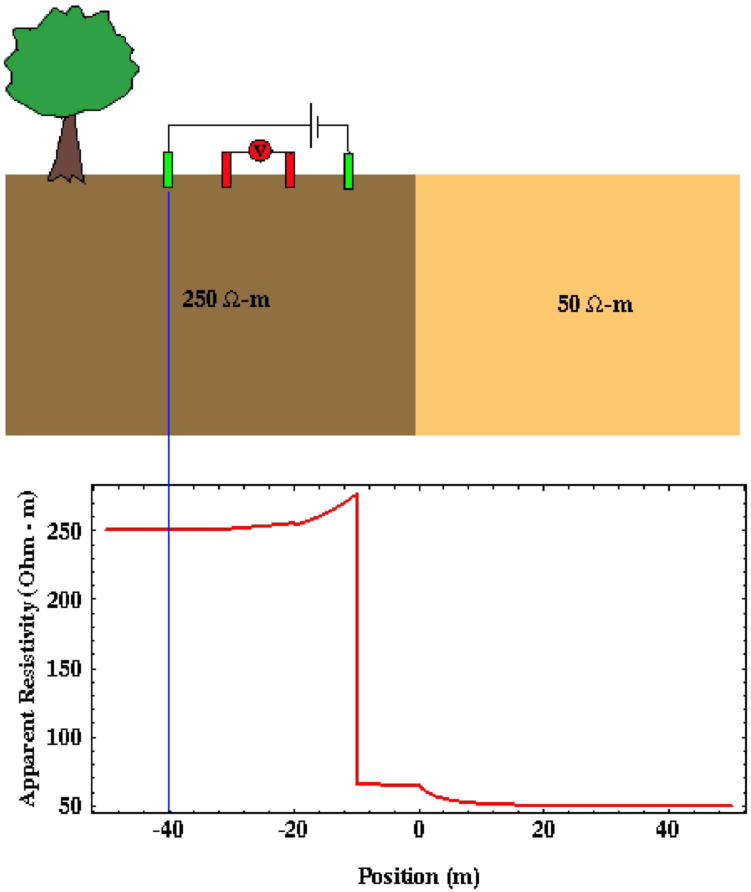
- In this example, Wenner array is used.
- the entire electrode spread is moved from left to right.



https://pburnley.faculty.unlv.edu/GEOL442_642/RES/NOTES/ResistivityNotes22Profile.html

Profiling

- If the electrode array is far removed from the vertical fault, the measured apparent resistivity is equal to the resistivity of the underlying rock.
- As the array approaches the fault, the resistivity varies in a discontinuous fashion
- The discontinuities in the resistivity profile correspond to array locations where electrodes move across the fault.

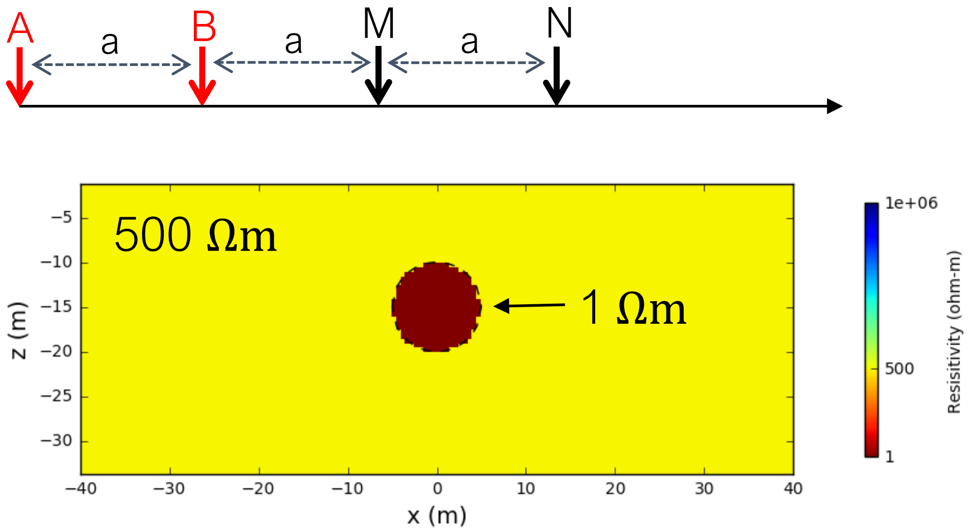


https://pburnley.faculty.unlv.edu/GEOL442_642/RES/NOTES/ResistivityNotes22Profile.html

Profiling

Fixed geometry: Move laterally

Long offset, a=20m



Credit: Doug Oldenburg, Seogi Kang and Linsey Heagy from UBC-GIF

Profiling

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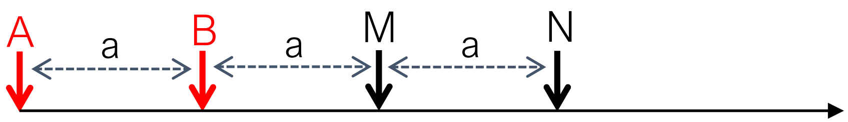

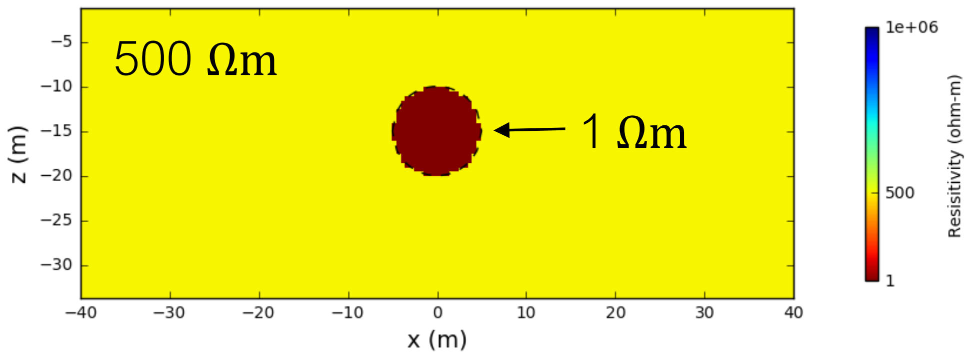

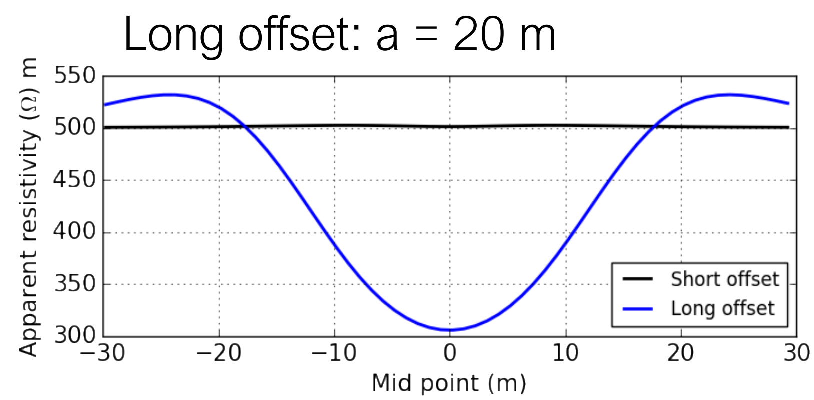

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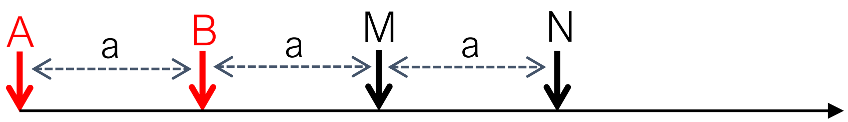
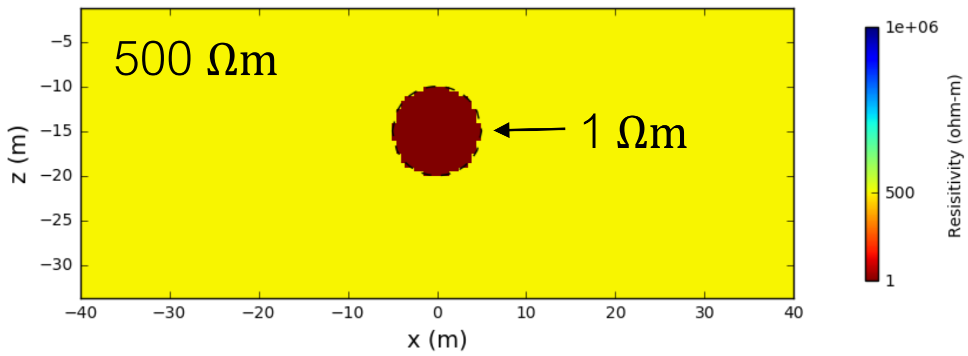
Profiling

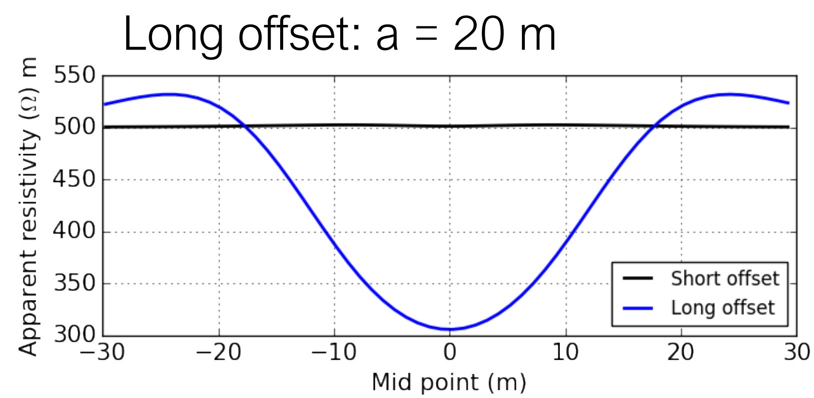
Fixed geometry: Move laterally

Short offset, a=4m

Long offset, a=20m







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Profiling

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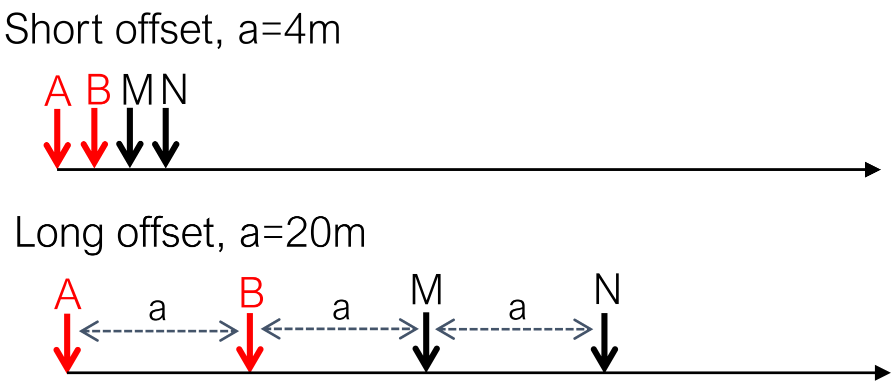

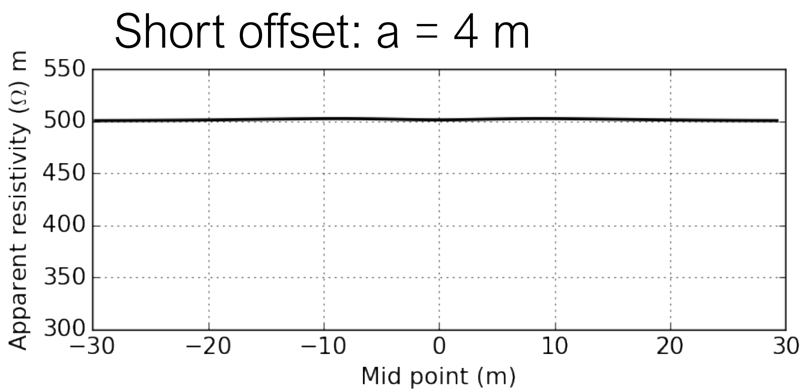

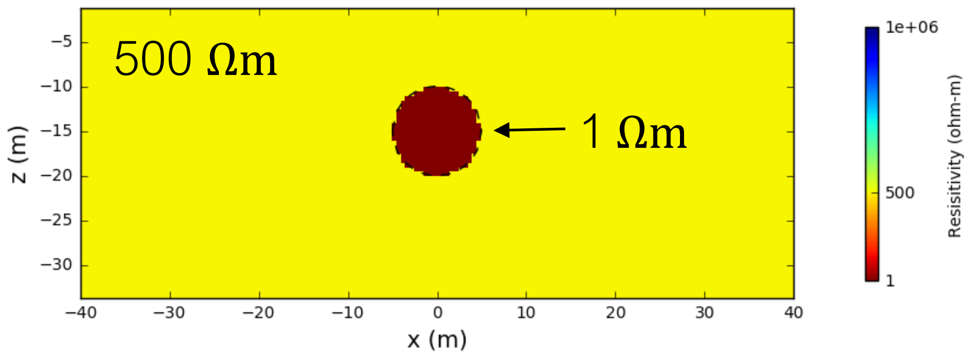

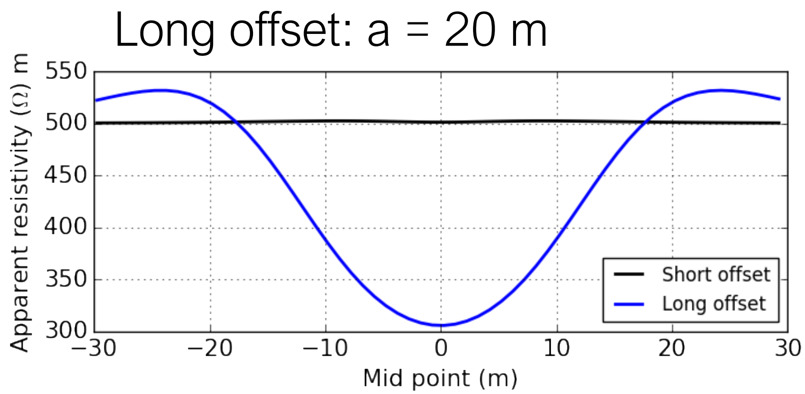

Depth of investigation depends upon offset or array length

Credit: Doug Oldenburg, Seogi Kang and Linsey Heagy from UBC-GIF

Summary: Profiling

- An array with fixed geometry (or, configuration) is moved along a line

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- The data provide information about lateral variations of the Earth's resistivity

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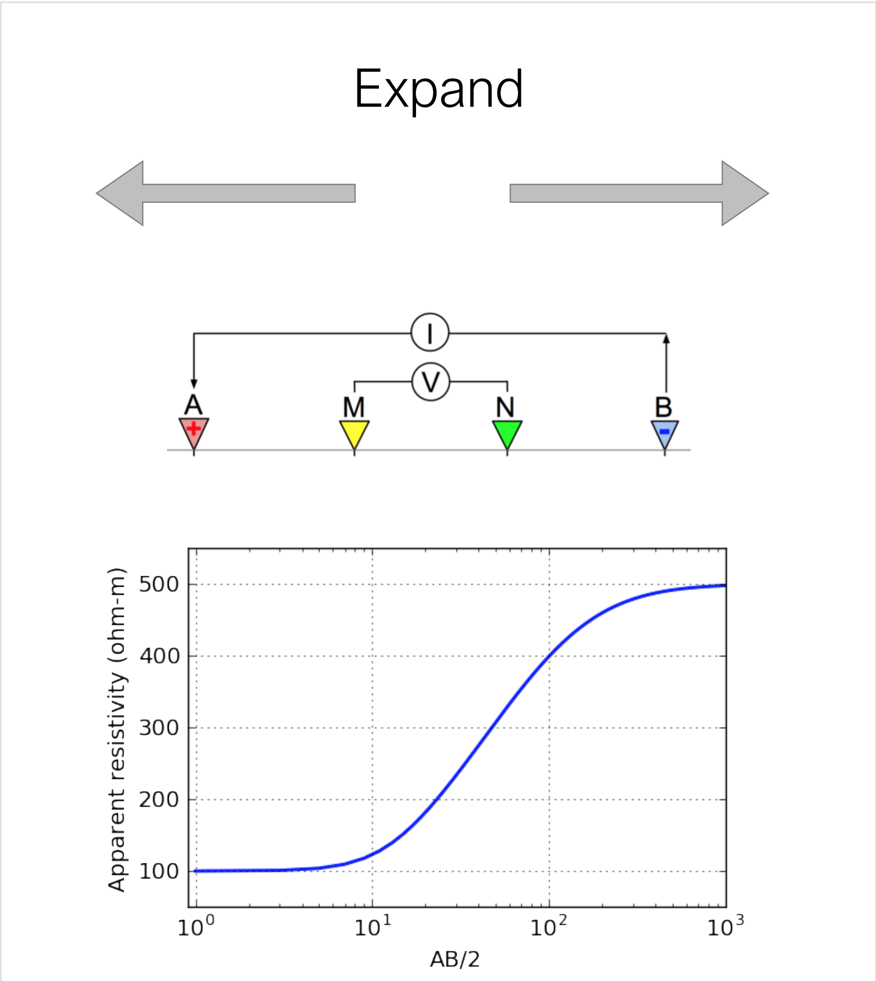
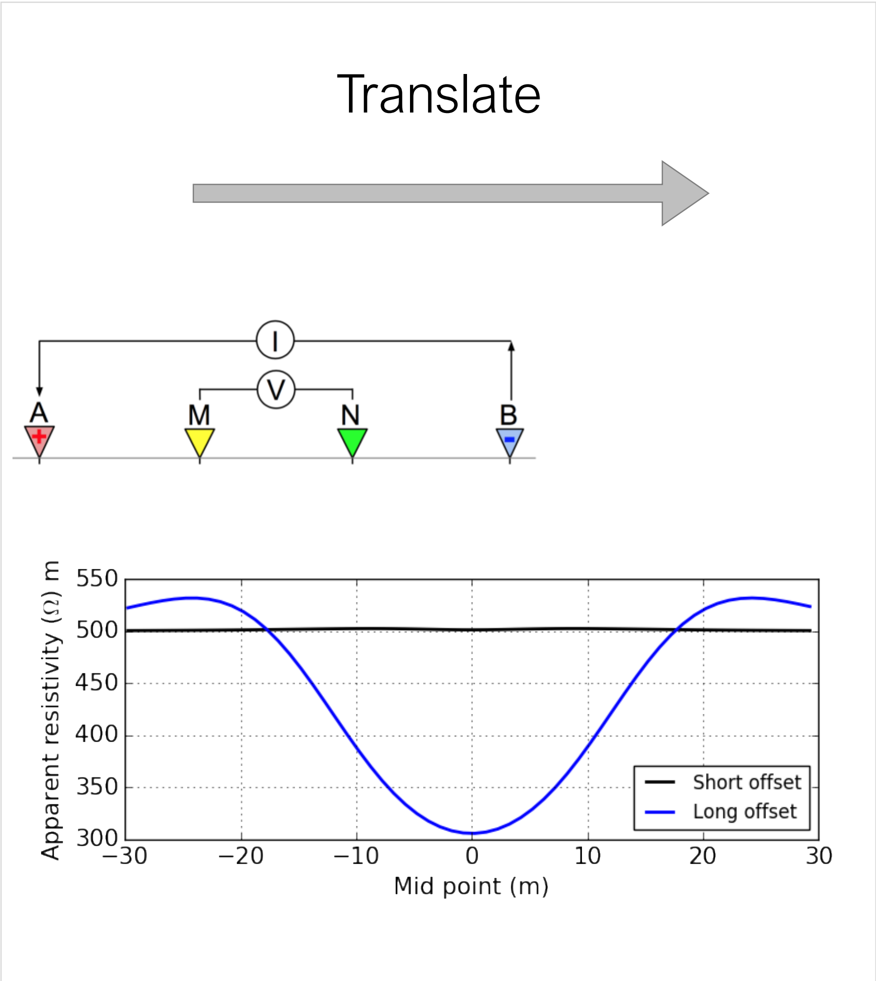
- An array with fixed geometry (or, configuration) is moved along a line
- The data provide information about lateral variations of the Earth's resistivity up to a depth that is determined by the length of the array

Summary: Soundings and Profiles

Sounding



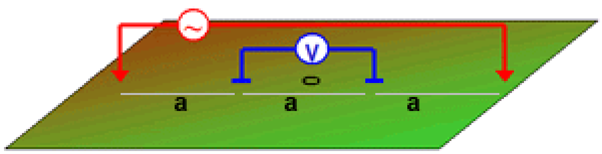
Profiling



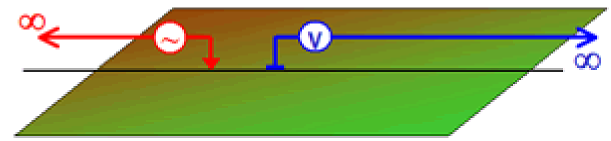
Credit: Doug Oldenburg, Seogi Kang and Linsey Heagy from UBC-GIF

Basic Survey Setups

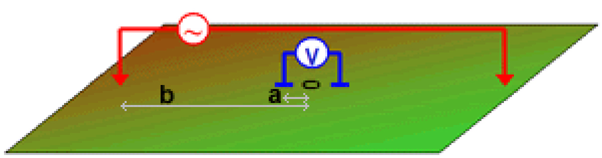
Wenner



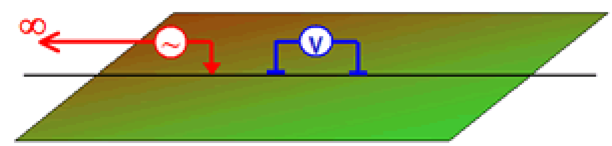
Pole-Pole



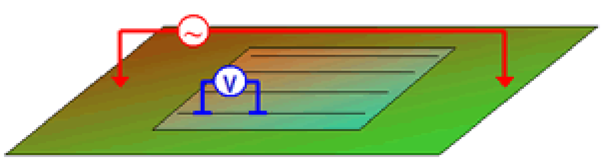
Schulmberger



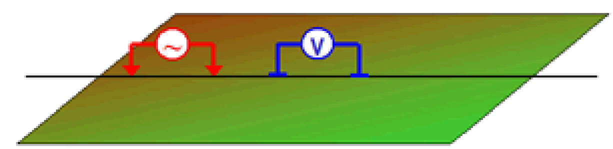
Pole-Dipole



Gradient



Dipole-Dipole



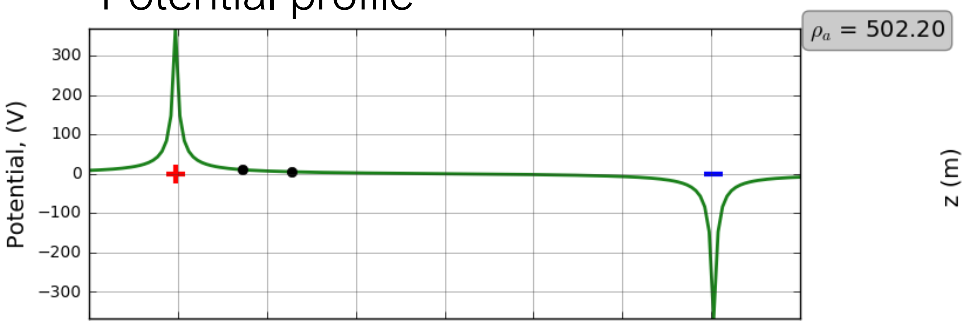
Credit: Doug Oldenburg, Seogi Kang and Linsey Heagy from UBC-GIF

Gradient array

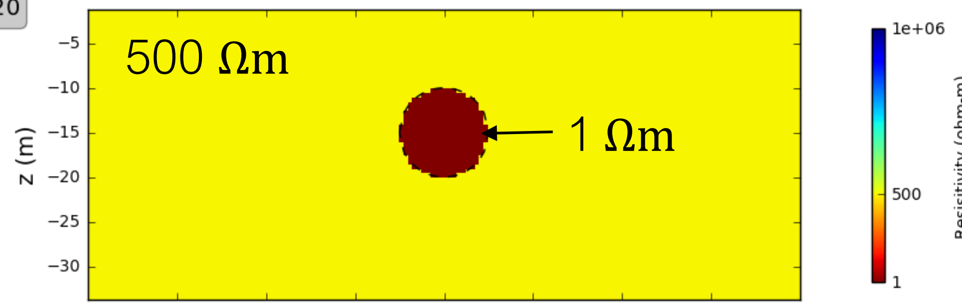
- Fixed locations for the A and B electrodes which are far apart.
- Voltage measurements are taken at various locations between A and B.

Measurements of DC data: gradient array

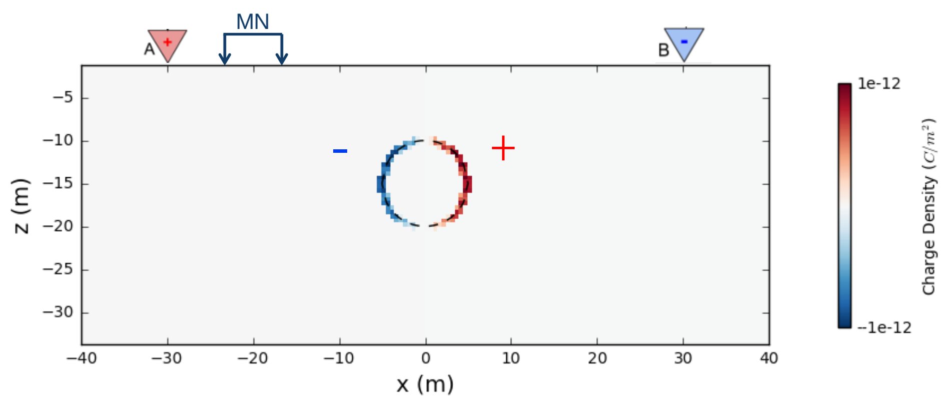
Potential profile



Resistivity model

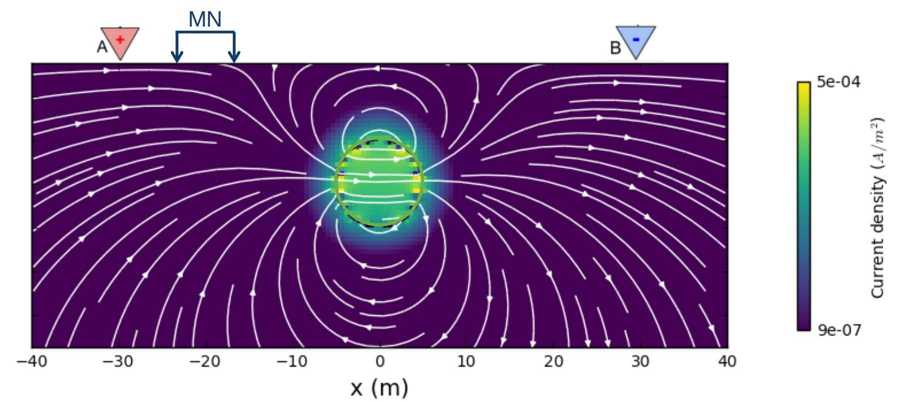


ρ_a = 502



Secondary charges: Q_s

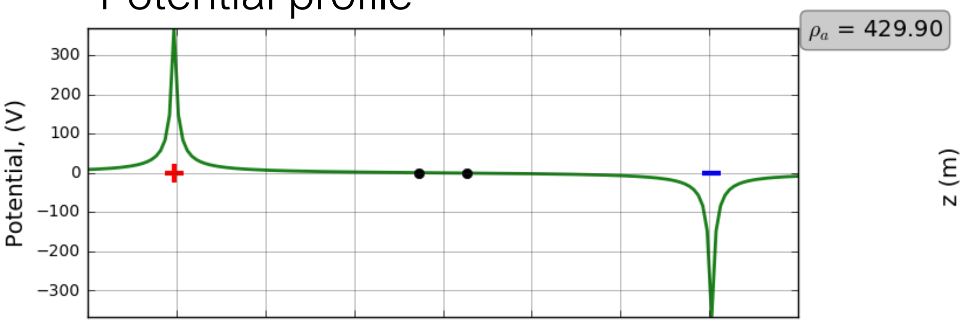
ρ_a = 502



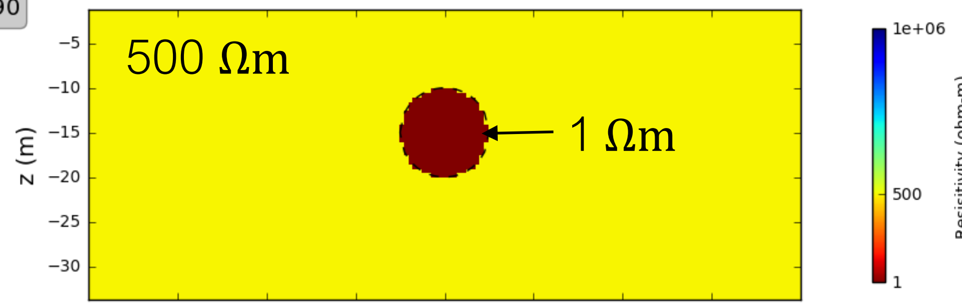
Secondary currents: J_s

Measurements of DC data: gradient array

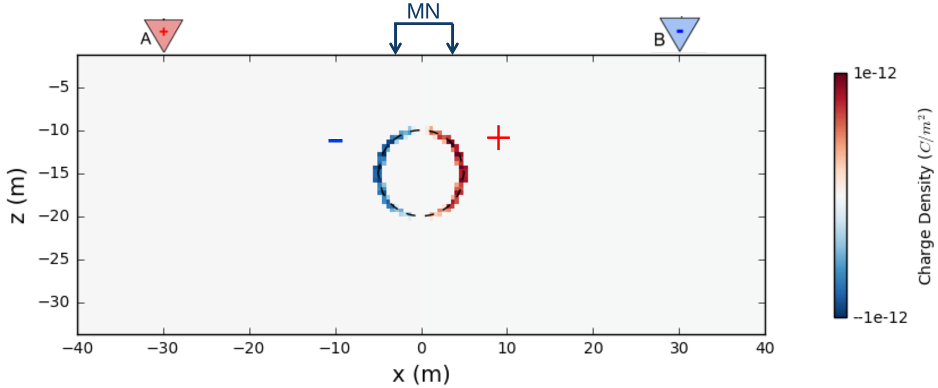
Potential profile



Resistivity model

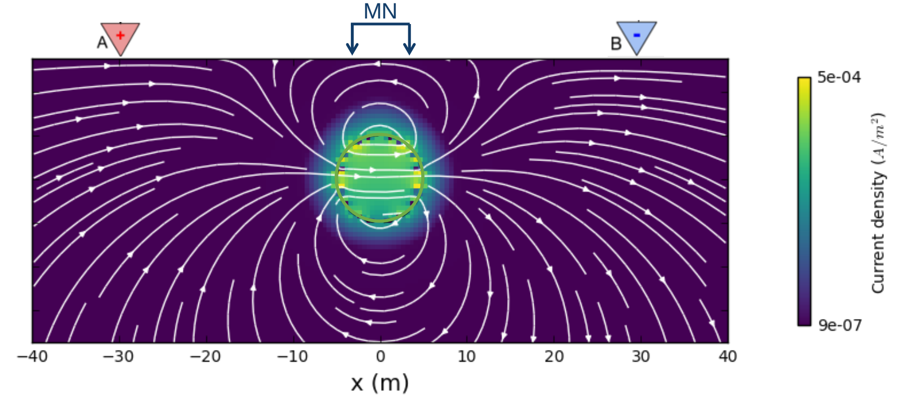


ρ_a = 430



Secondary charges: Q_s

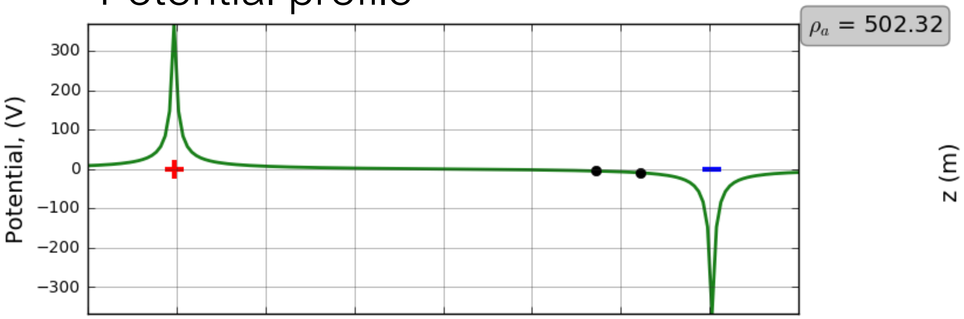
ρ_a = 430



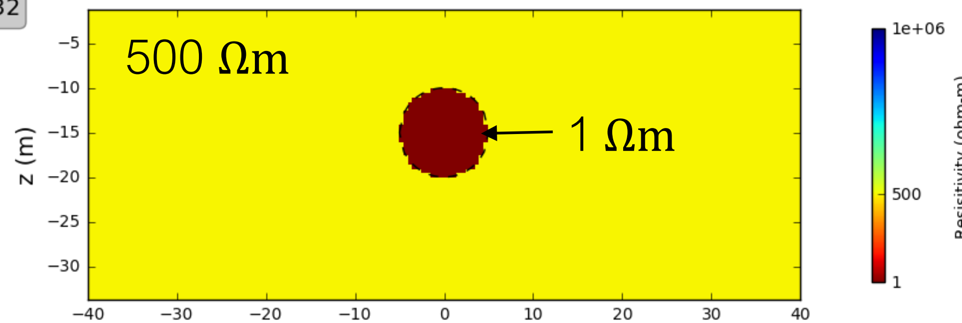
Secondary currents: J_s

Measurements of DC data: gradient array

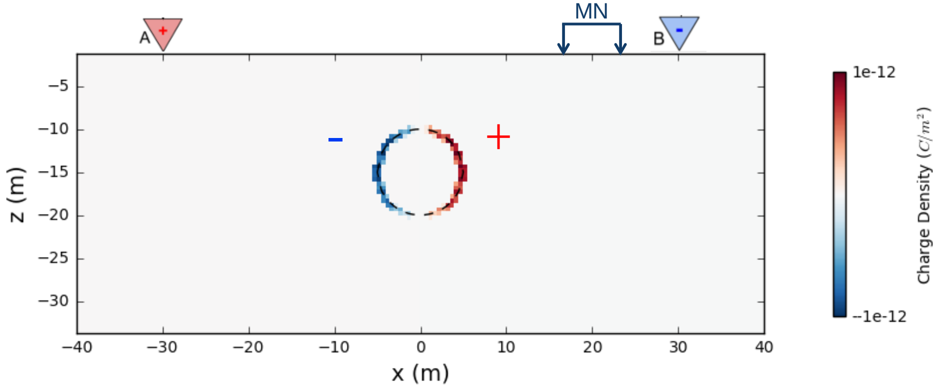
Potential profile



Resistivity model

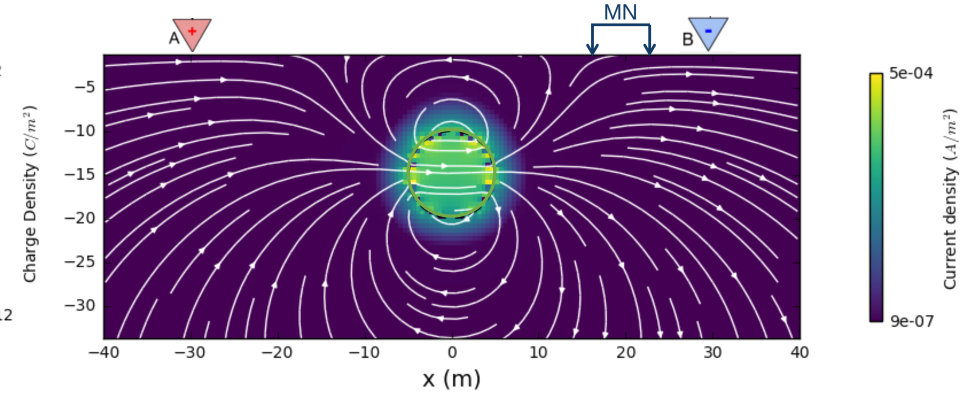


ρ_a = 502



Secondary charges: Q_s

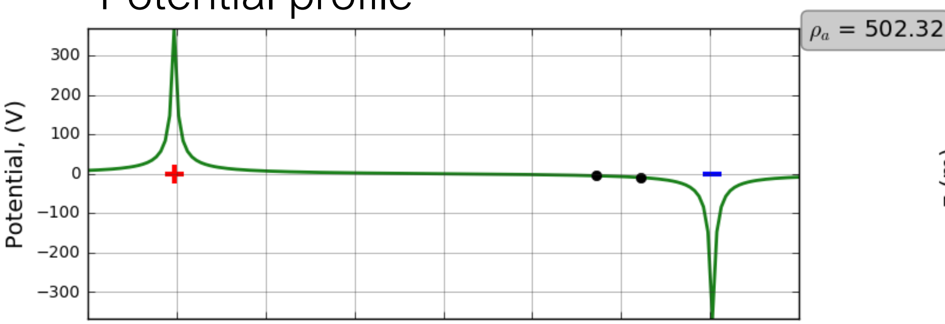
ρ_a = 502



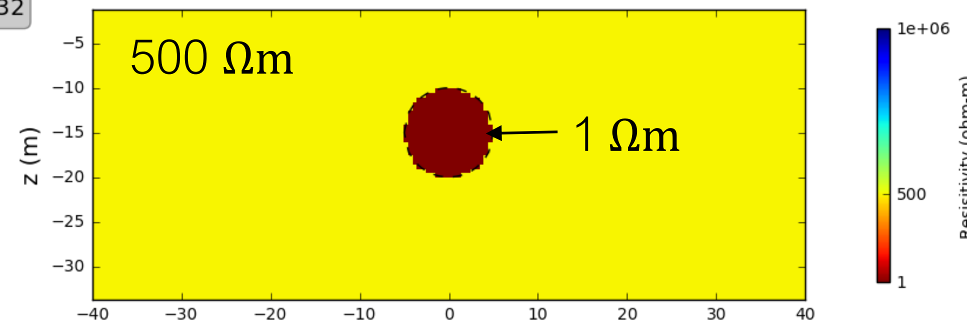
Secondary currents: J_s

Measurements of DC data: gradient array

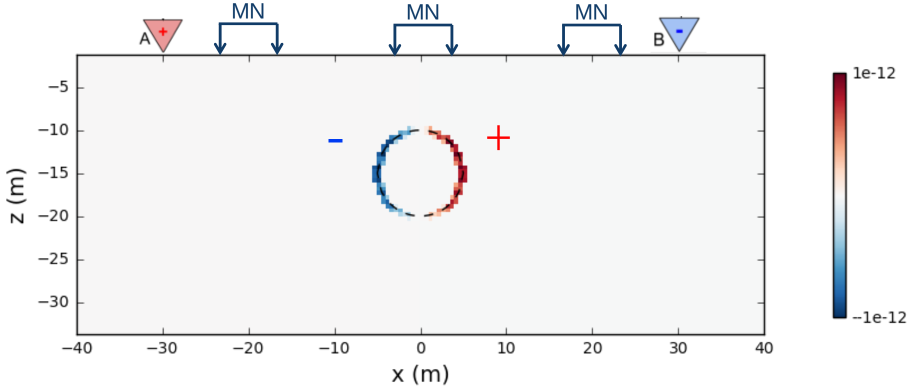
Potential profile



Resistivity model

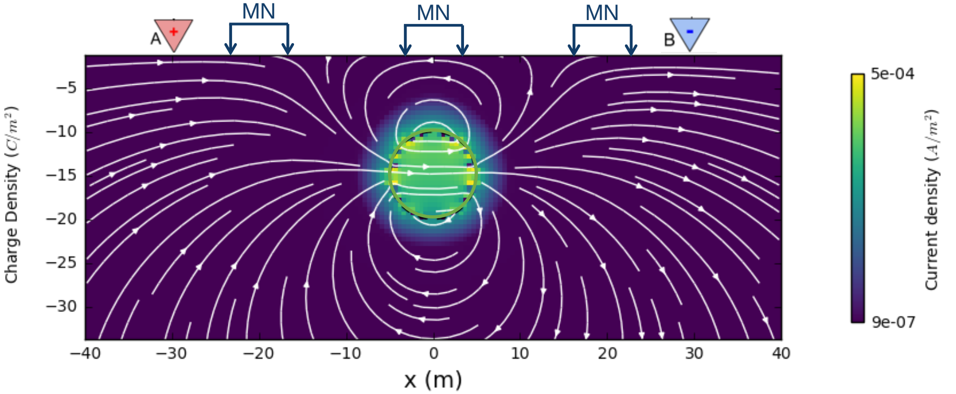


ρ_a = 502 ρ_a = 430 ρ_a = 502



Secondary charges: Q_s

ρ_a = 502 ρ_a = 430 ρ_a = 502



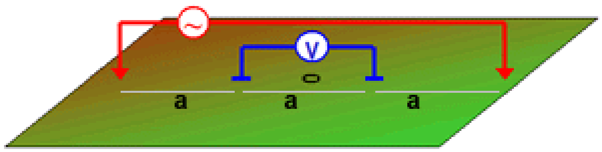
Secondary currents: J_s

Optional reading materials

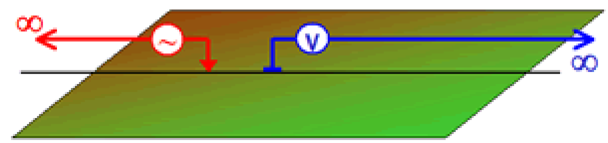
- https://em.geosci.xyz/content/geophysical_surveys/dcr/survey.html
- https://gpg.geosci.xyz/content/DC_resistivity/DC_surveys.html#survey-configurations
- https://pburnley.faculty.unlv.edu/GEOL442_642/RES/NOTES/ResistivityNotes18FieldOverview.html
- https://pburnley.faculty.unlv.edu/GEOL442_642/RES/NOTES/ResistivityNotes21ASounding.html

Basic Survey Setups

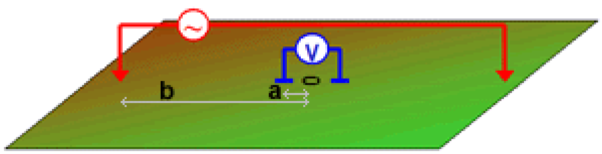
Wenner



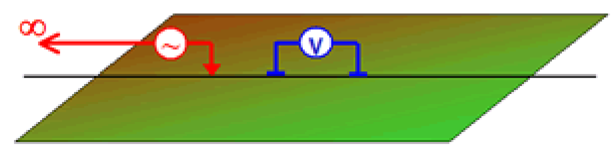
Pole-Pole



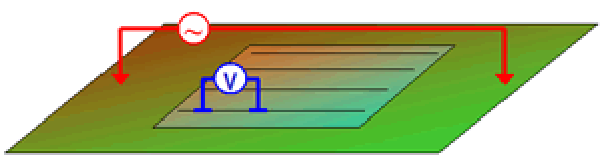
Schulmberger



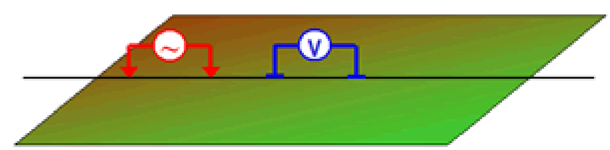
Pole-Dipole



Gradient



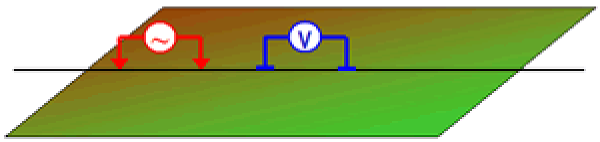
Dipole-Dipole



Credit: Doug Oldenburg, Seogi Kang and Linsey Heagy from UBC-GIF

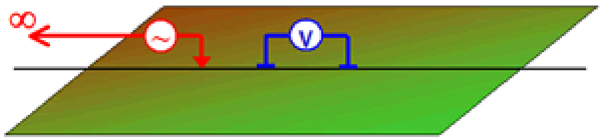
What is pole-pole?

Dipole-Dipole



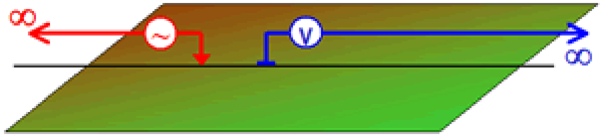
Variants of dipole-dipole

Pole-Dipole



- If we put one of the current electrodes very far away from our survey area, it is called pole-dipole.

Pole-Pole



- If we put one of the current electrodes and one of the potential electrodes very far, it is called pole-pole.

Well-logging

- Same physical principles, different geometry

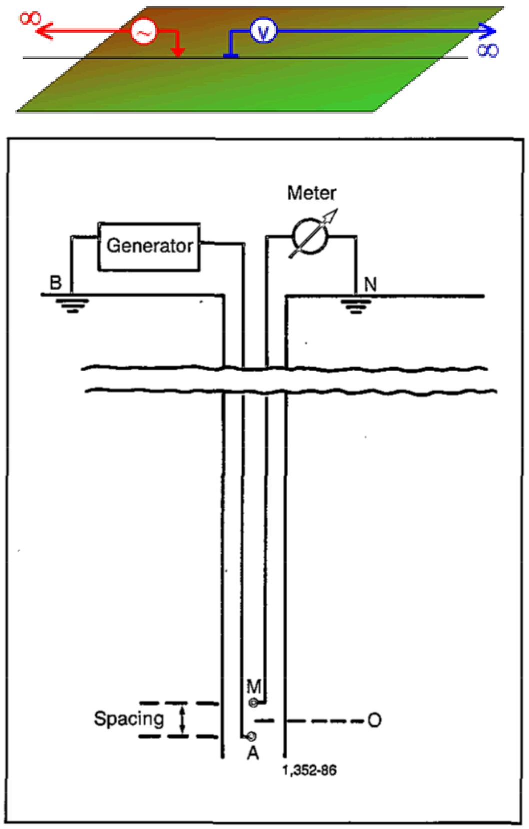


Fig. 7-1—Normal device—basic arrangement.

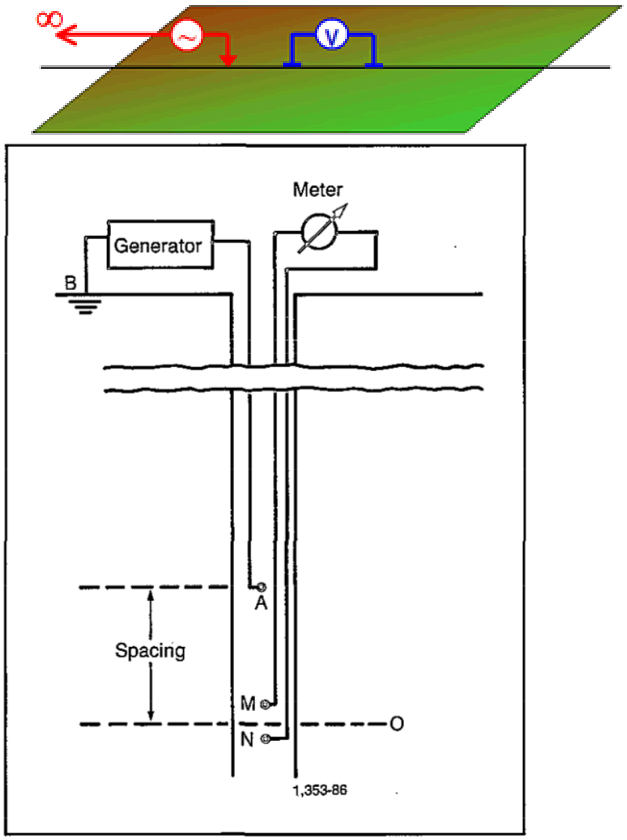
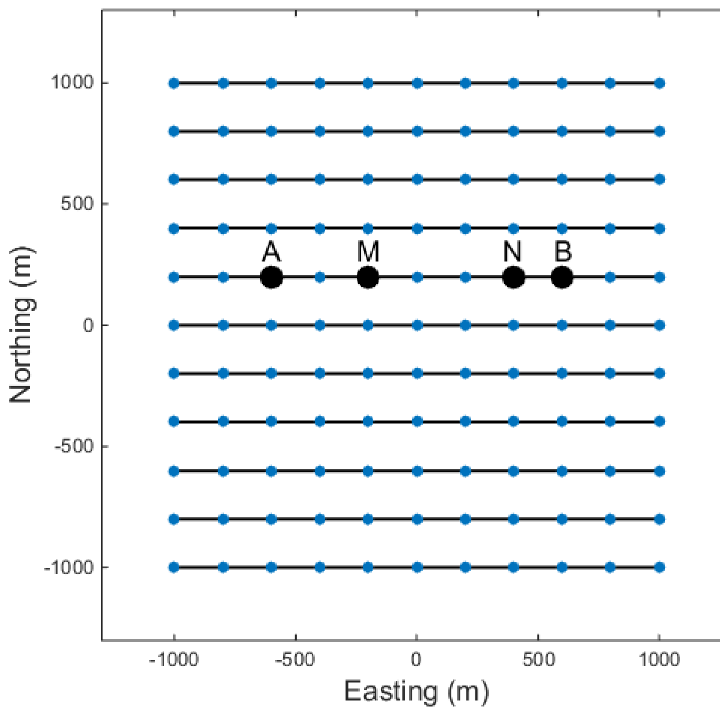


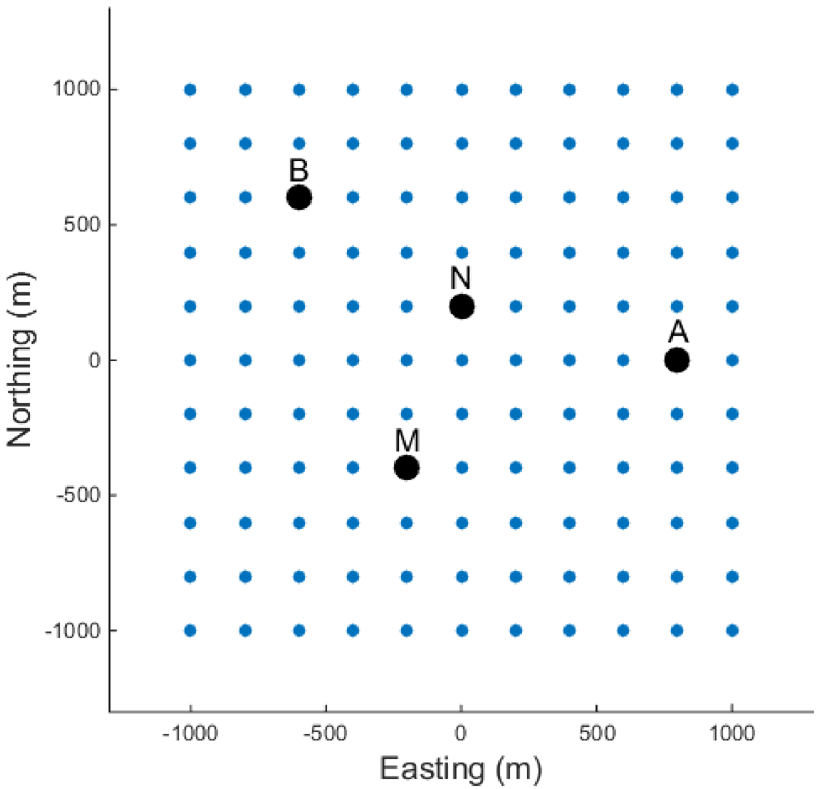
Fig. 7-2—Lateral device—basic arrangement.

From Chapter 7 of the Schlumberger Log Interpretation Principles/Applications Textbook

Survey configurations

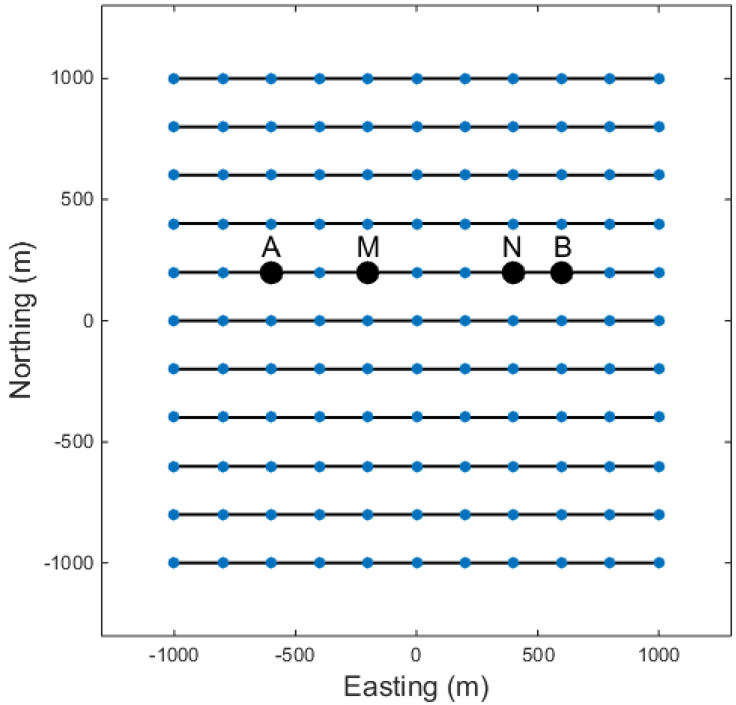


An example of a co-linear survey with multiple lines.

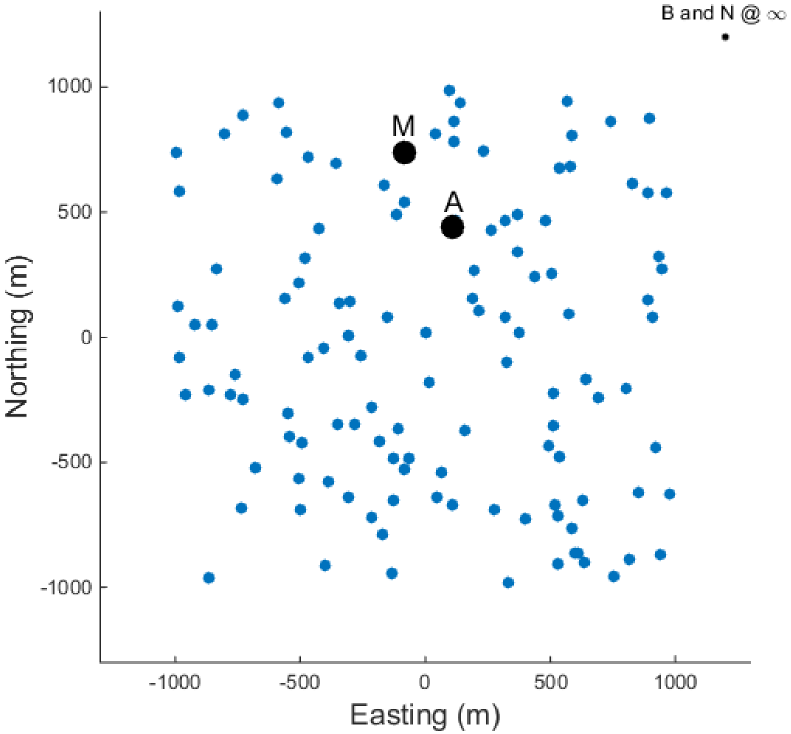


An example of a 3D DC survey

Survey configurations

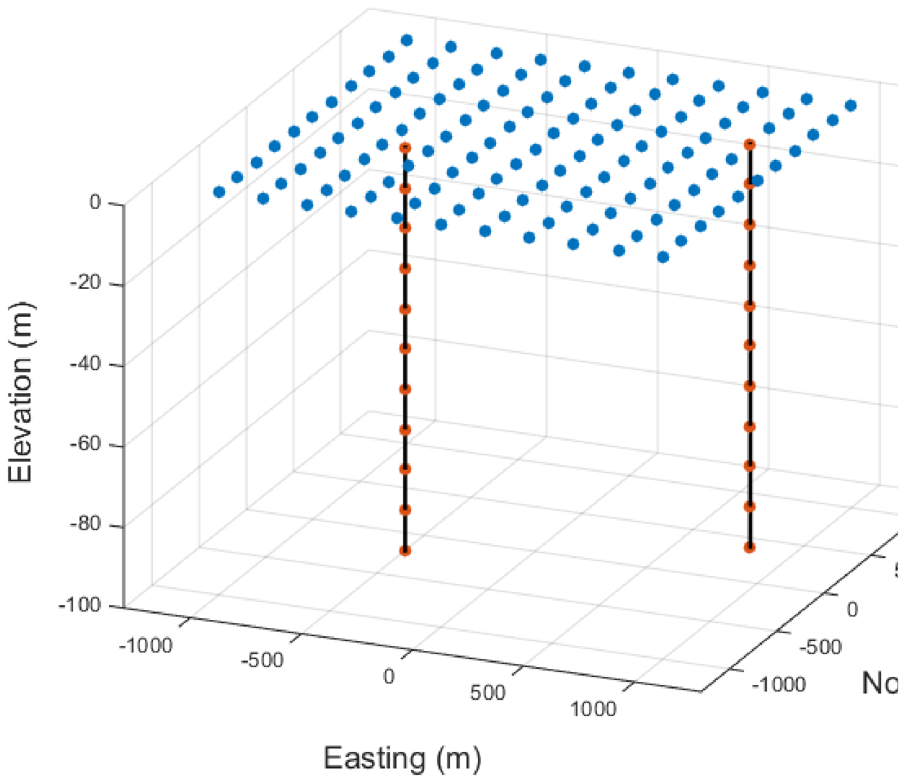


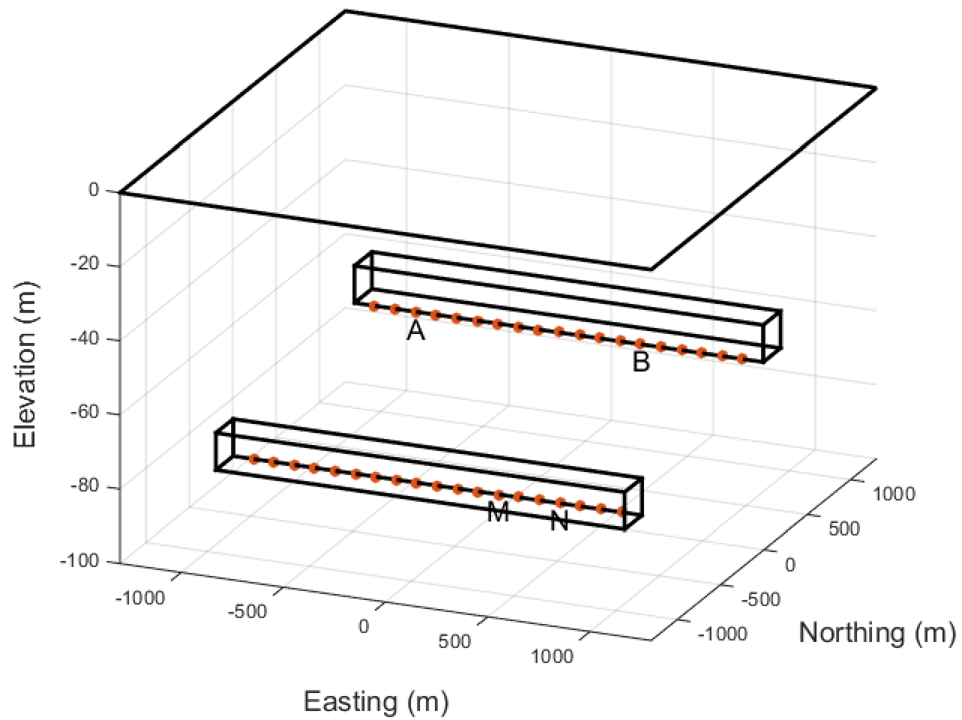
An example of a co-linear survey with multiple lines.



An example of an E-Scan survey, which uses a pole-pole configuration in a non-grid format.

Survey configurations





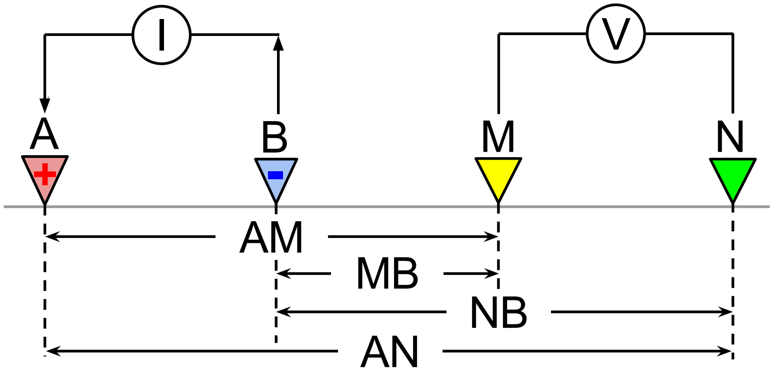
Electrodes can be placed at the surface or along boreholes.

DC resistivity surveys in a tunnel environment. The tunnel restricts where the electrodes can be placed

Agenda

- Recap
- Sounding
- Profiling
- Different survey geometries
- Data
- Case Study

Measured voltages



- The flow of currents in the ground causes charges to be built up on interfaces between regions of differing conductivity. These charges contribute to the measured potential difference (or, voltage).

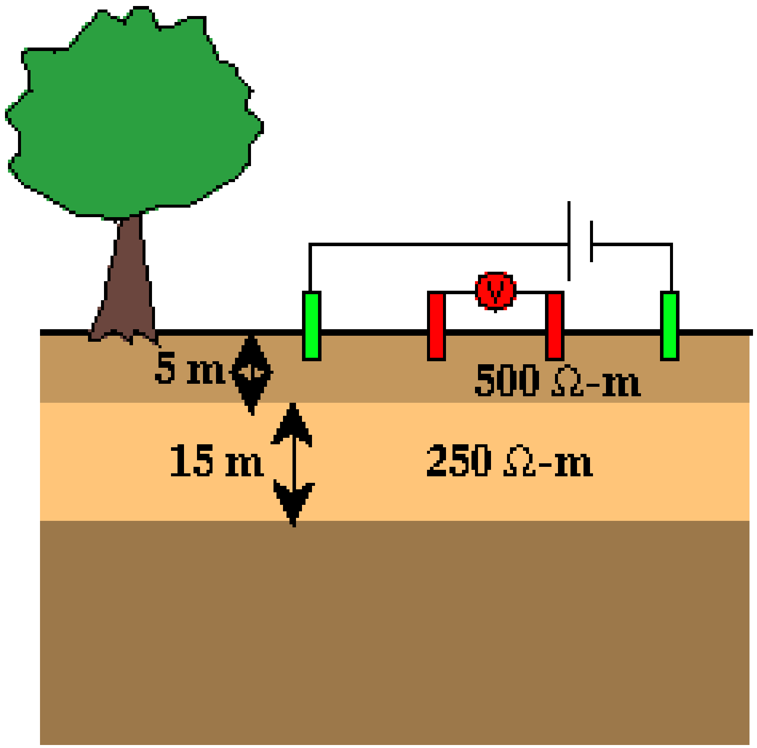
$$\Delta V_{MN} = V_M - V_N = \rho I \frac{1}{2\pi}\left(\frac{1}{r_{AM}} - \frac{1}{r_{BM}} - \frac{1}{r_{AN}} + \frac{1}{r_{BN}}\right)$$

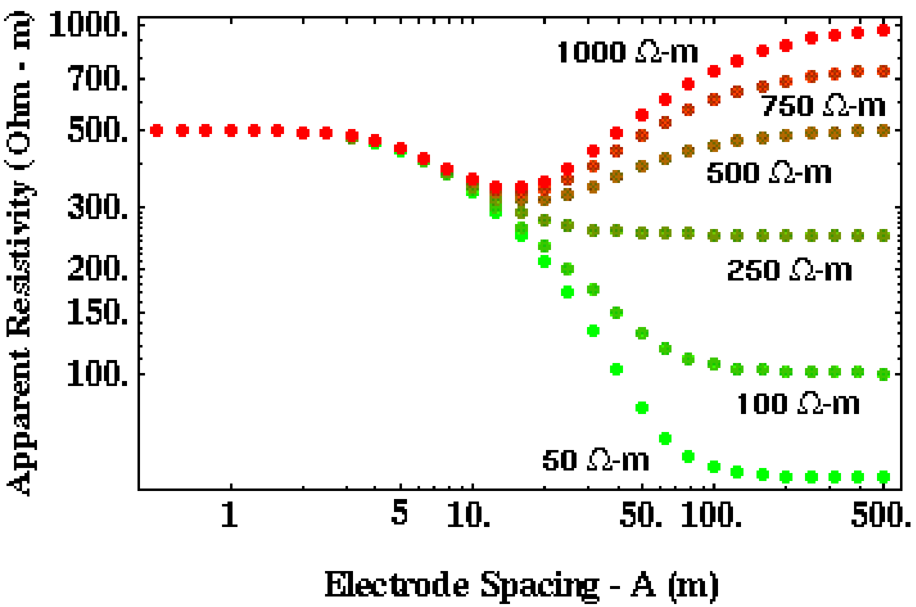
Calculating apparent resistivity

- Converting voltage measurements to apparent resistivity is extremely valuable for plotting data and making first assessments about the subsurface.

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

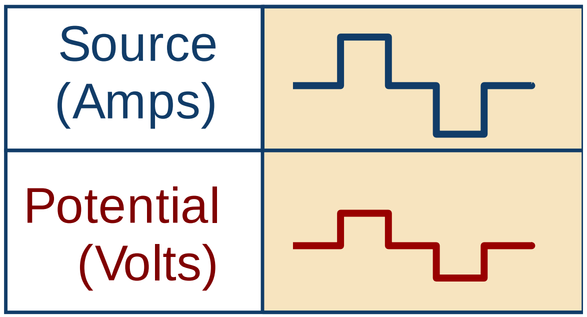
Visualizing data: Sounding Curve

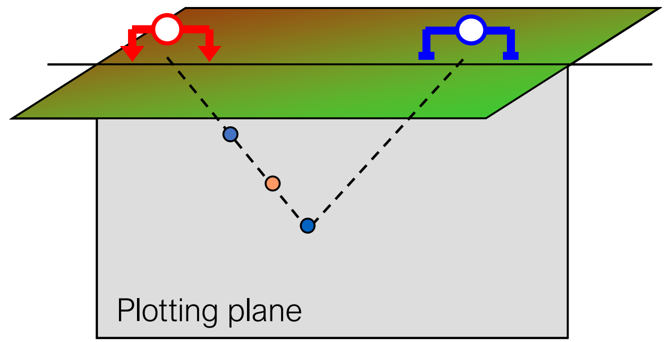




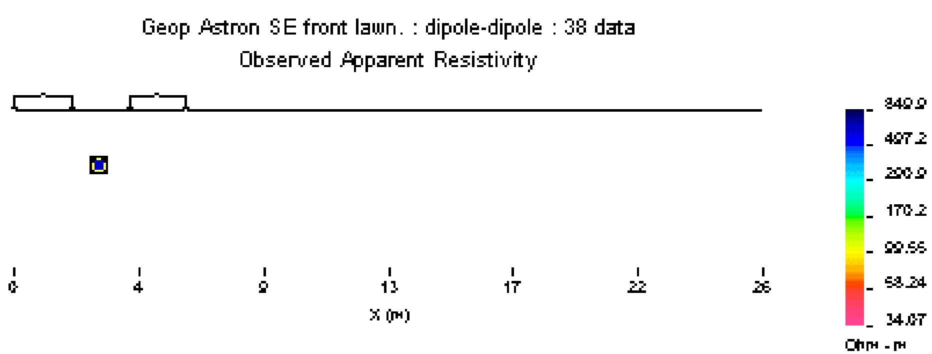
https://pburnley.faculty.unlv.edu/GEOL442_642/RES/NOTES/ResistivityNotes25MLayer1.html

Visualizing data: Pseudosection





Each data point is an apparent resistivity: $$\rho_a = \frac{2\pi \Delta V}{IG}$$

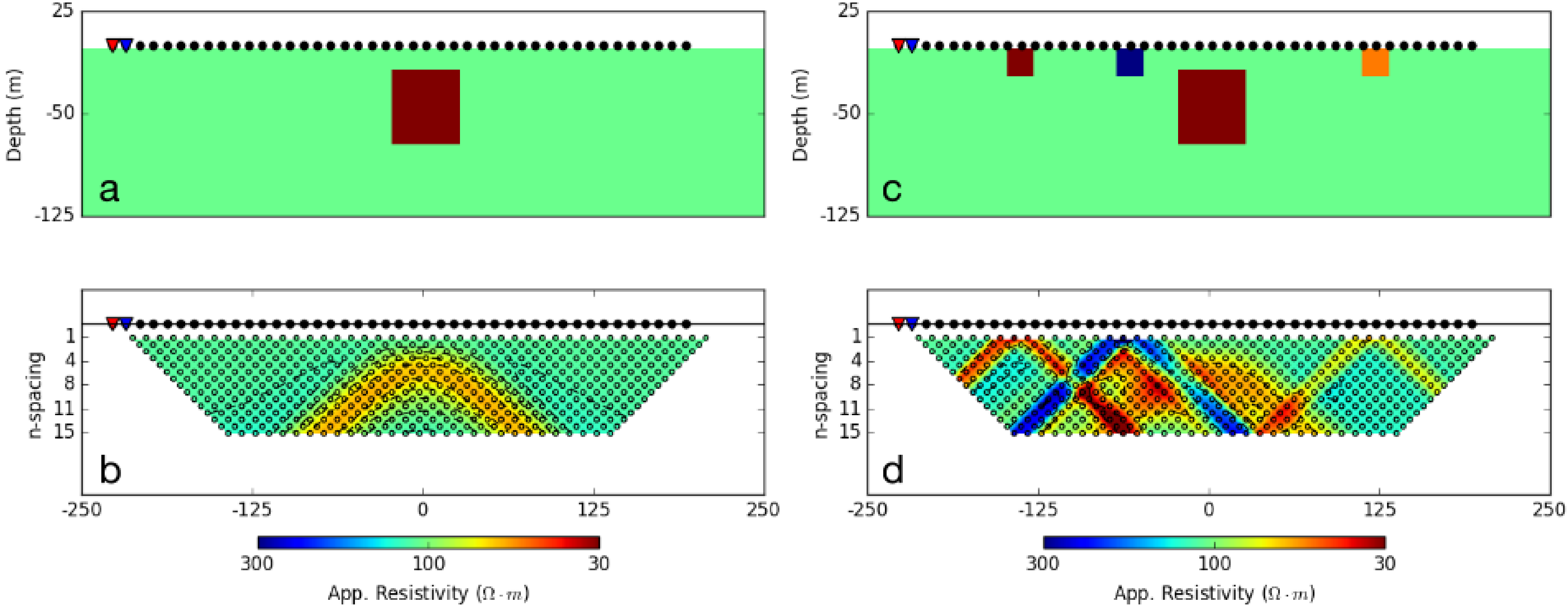


Credit: Doug Oldenburg, Seogi Kang and Linsey Heagy from UBC-GIF

Visualizing data: Pseudosection

- lines at 45^{o} degree angles, are drawn from the mid-points of the current and potential electrode pairs and the datum (i.e., apparent resistivity) is plotted at the intersection of these lines.
- In cases where a pole transmitter or receiver is used, the 45^{o} lines are drawn directly from the electrode location.

Example Pseudosections

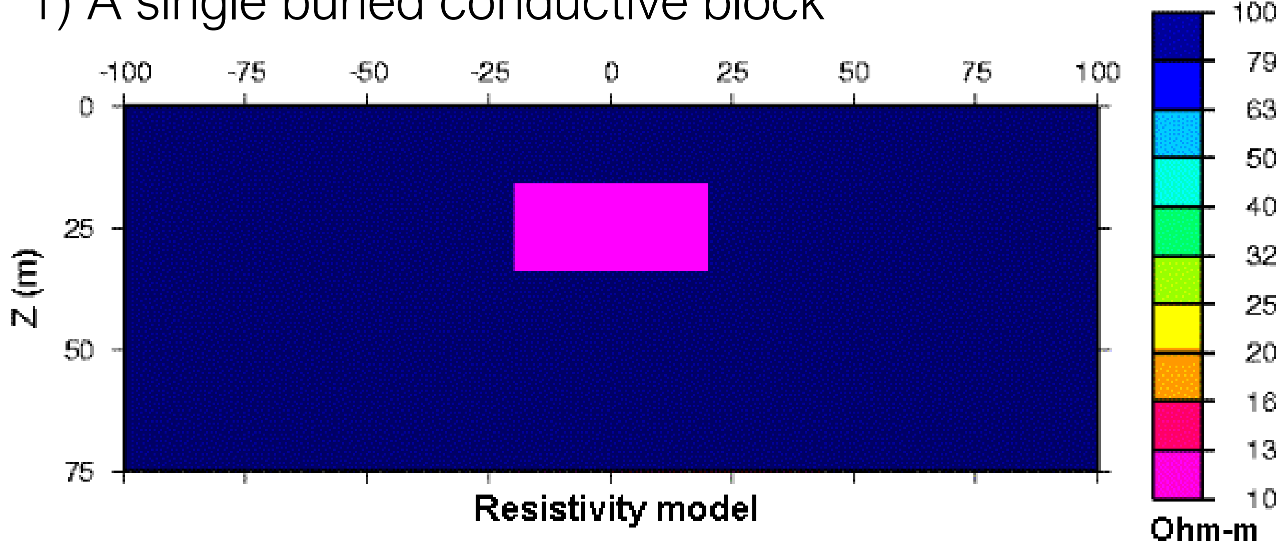


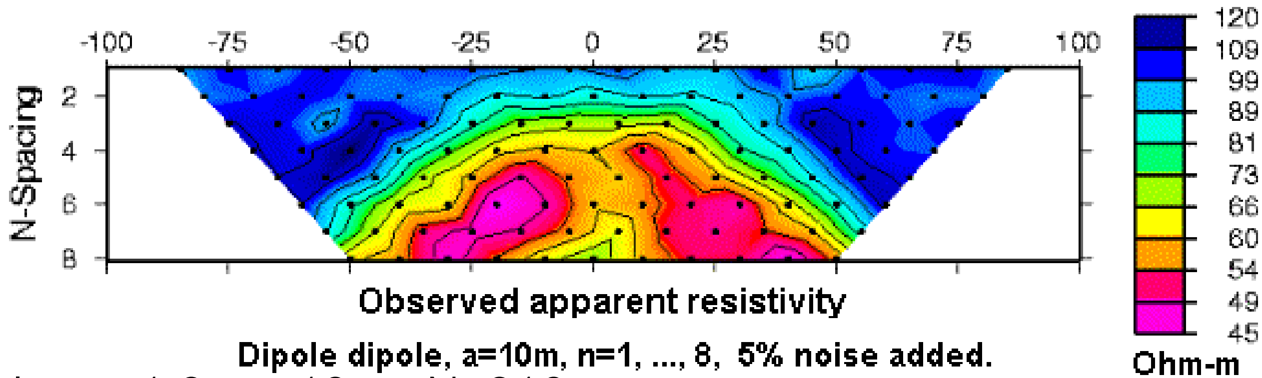
Dipole-dipole survey

https://em.geosci.xyz/content/geophysical_surveys/dcr/interpretation.html#dcr-synthetics

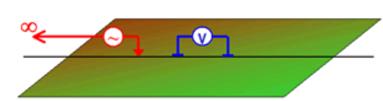
Example pseudosections

1) A single buried conductive block





Pole-Dipole

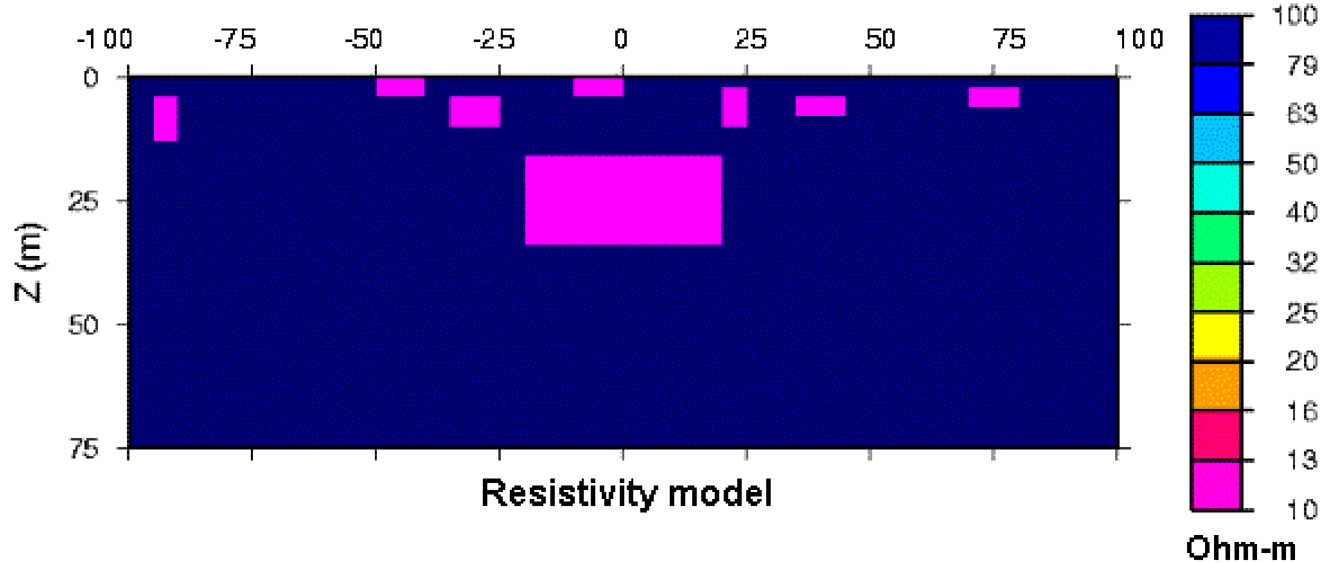


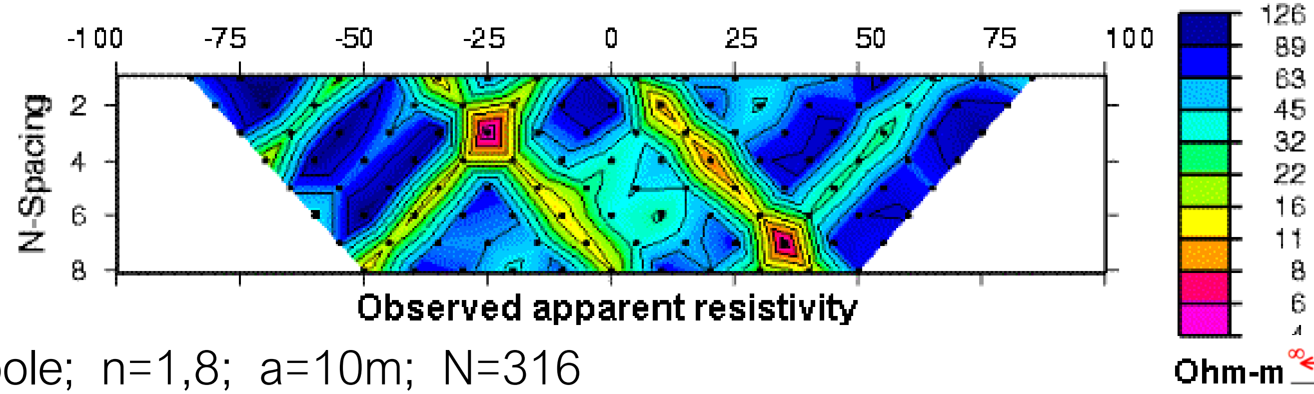
- Pole-dipole; n=1,8; a=10m; N=316

Credit: Doug Oldenburg, Seogi Kang and Linsey Heagy from UBC-GIF

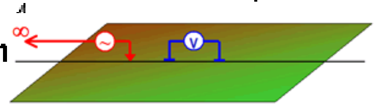
Example pseudosections

2) The conductive block with geologic noise.





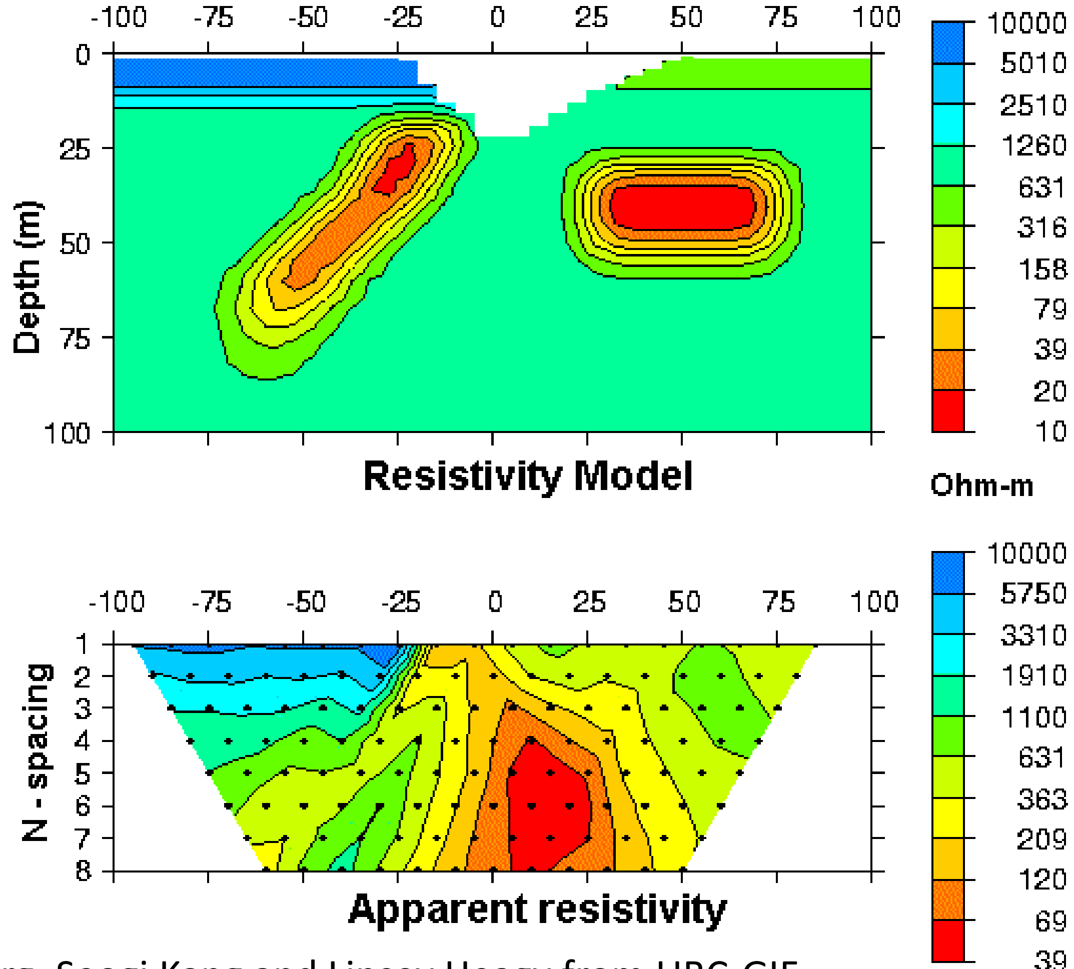
- Pole-dipole; n=1,8; a=10m; N=316



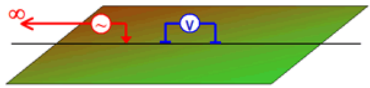
Credit: Doug Oldenburg, Seogi Kang and Linsey Heagy from UBC-GIF

Example pseudosections

3) The "UBC-GIF model"

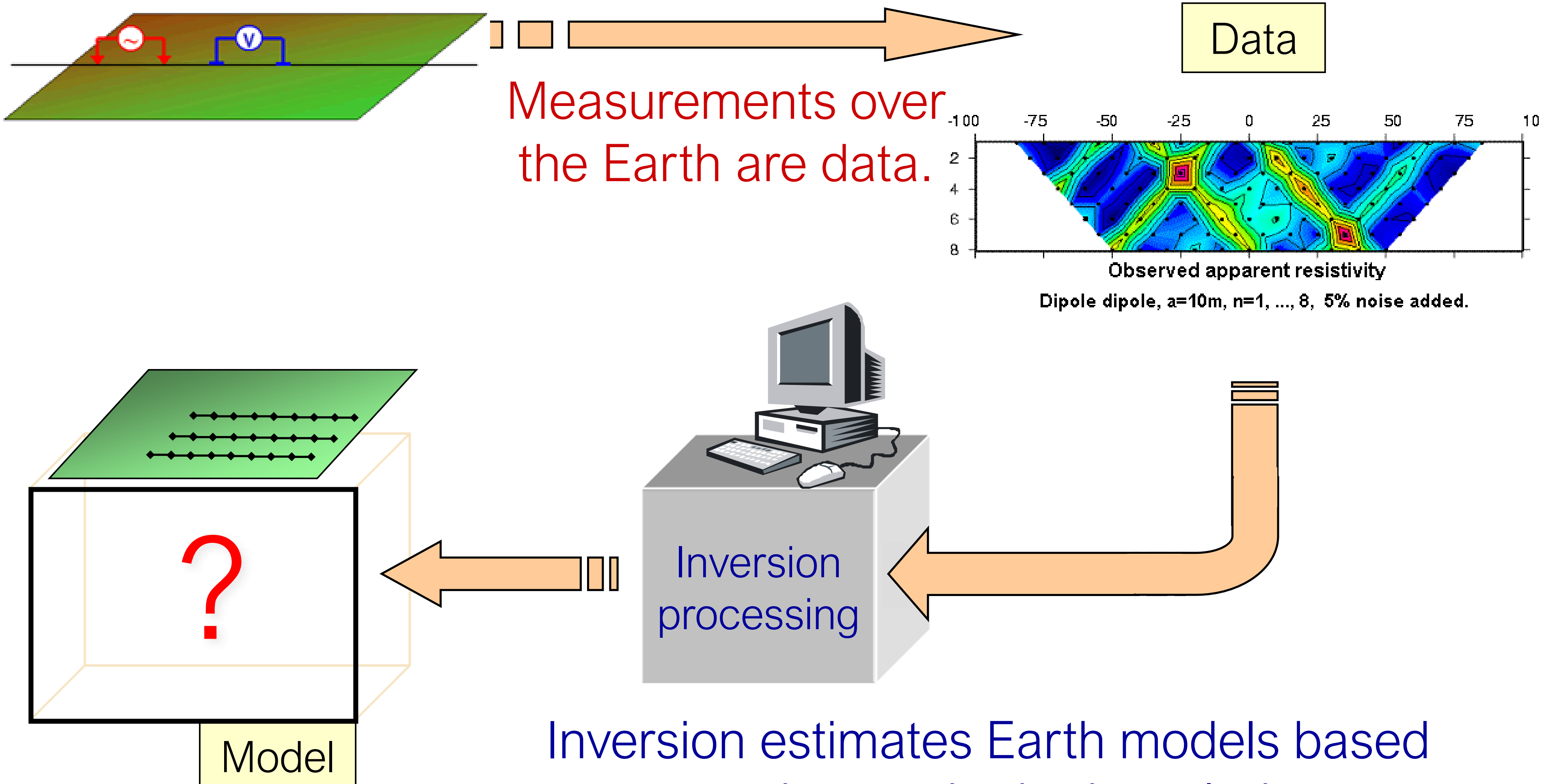


Pole-Dipole



Credit: Doug Oldenburg, Seogi Kang and Linsey Heagy from UBC-GIF

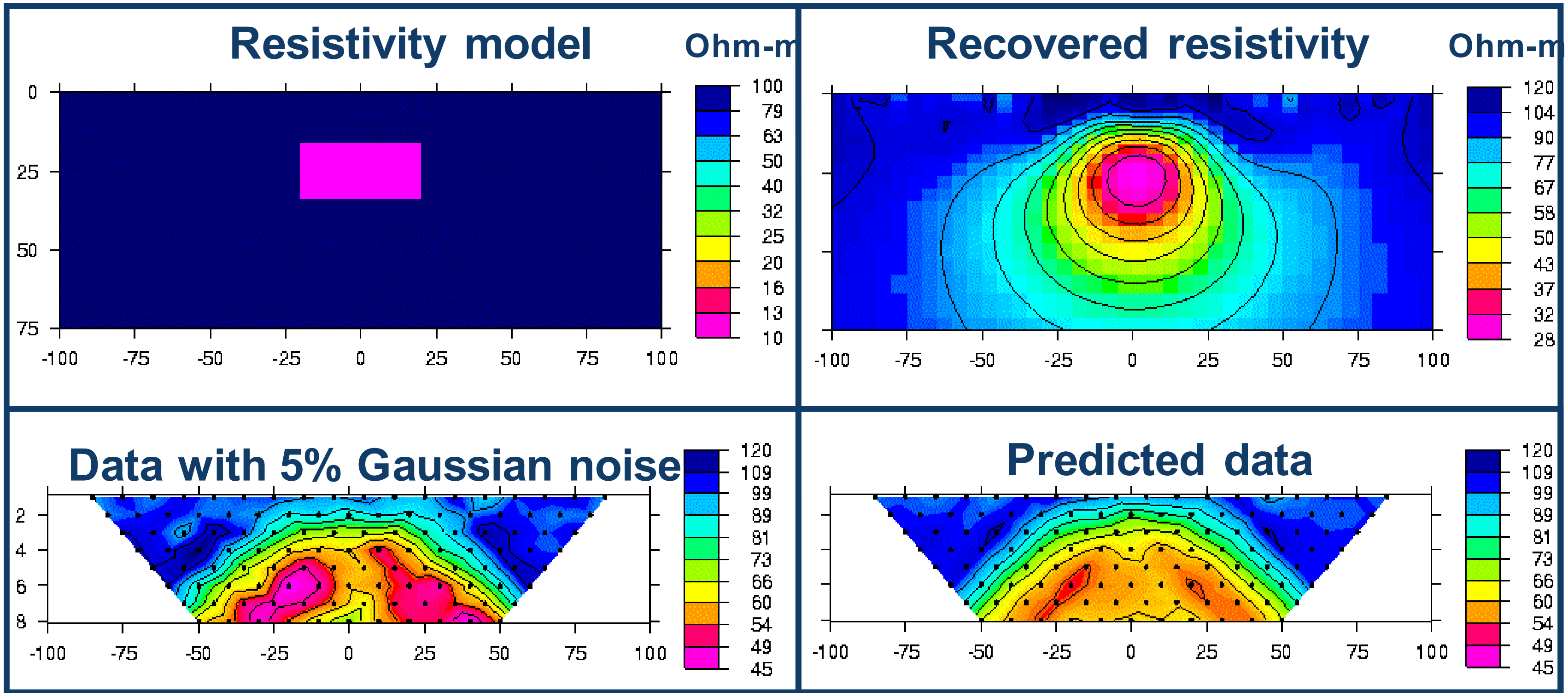
Inversion



Inversion estimates Earth models based upon data and prior knowledge.

Credit: Doug Oldenburg, Seogi Kang and Linsey Heagy from UBC-GIF

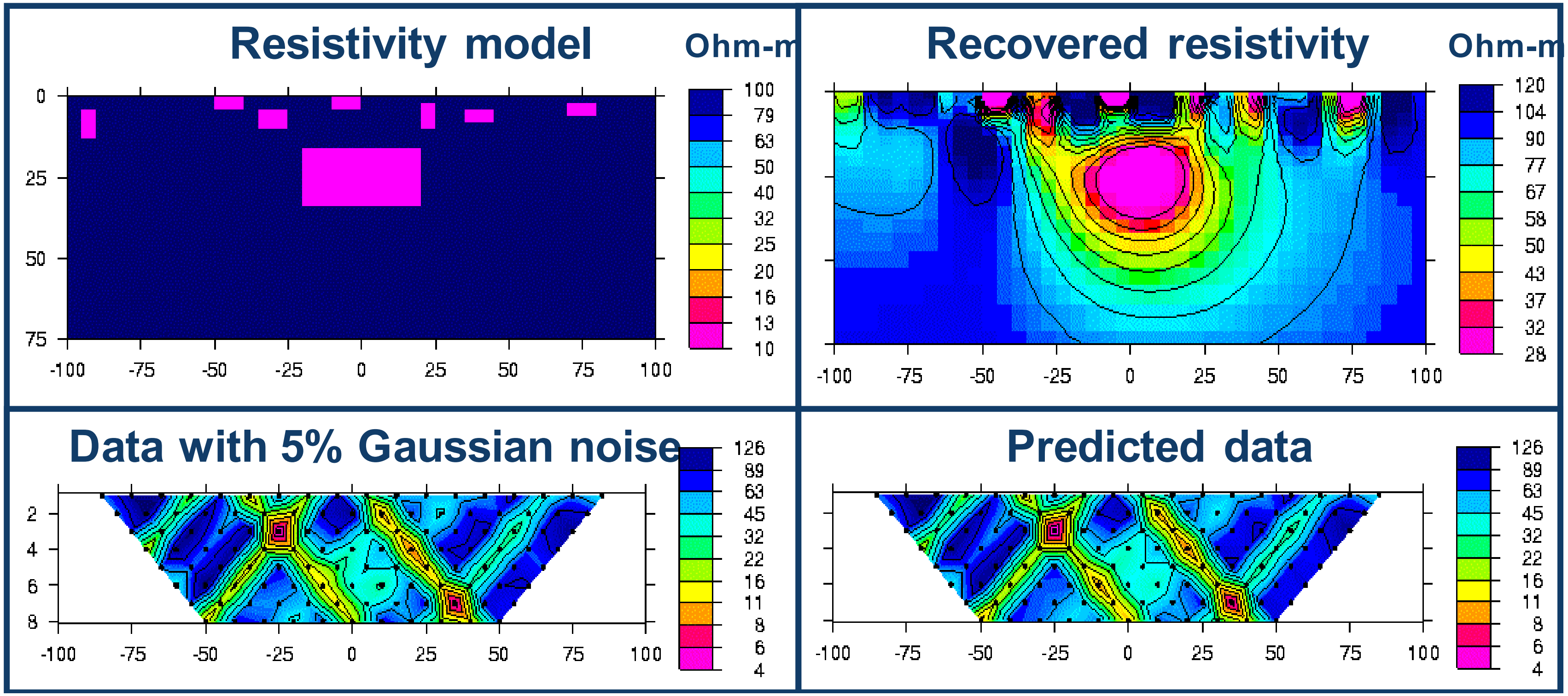
Example 1: buried prism



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

Credit: Doug Oldenburg, Seogi Kang and Linsey Heagy from UBC-GIF

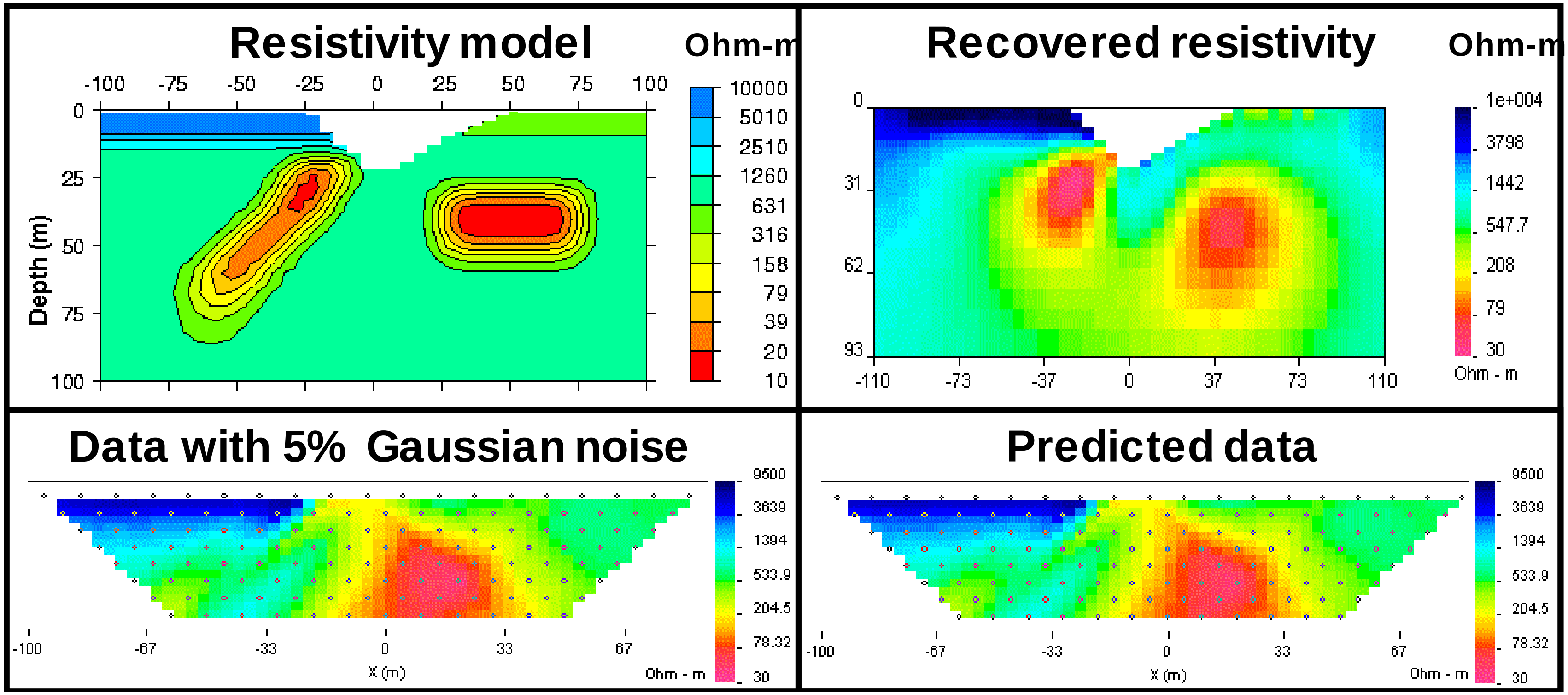
Example 2: prism with geologic noise



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

Credit: Doug Oldenburg, Seogi Kang and Linsey Heagy from UBC-GIF

Example 3: UBC-GIF model

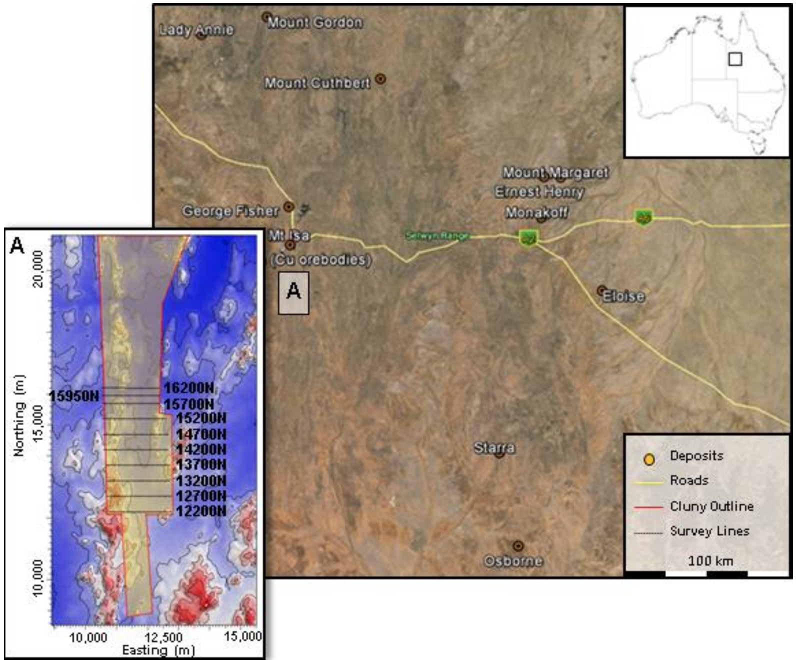


- Pole-dipole; n=1,8; a=10m

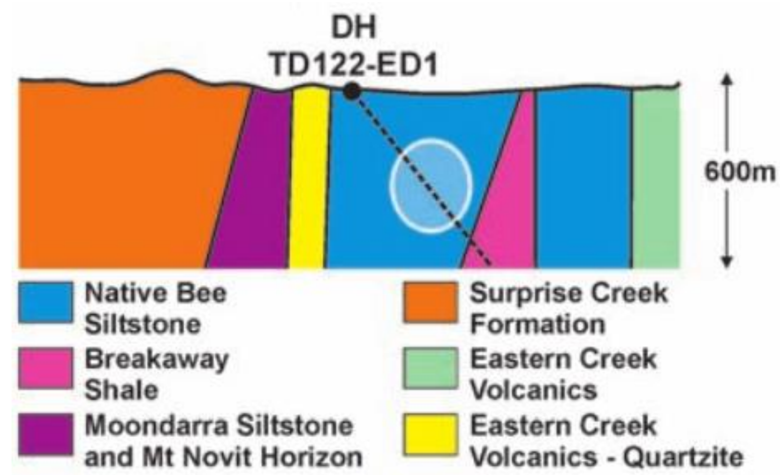
Credit: Doug Oldenburg, Seogi Kang and Linsey Heagy from UBC-GIF

Cast History at Mt. Isa

Setup



Geologic model



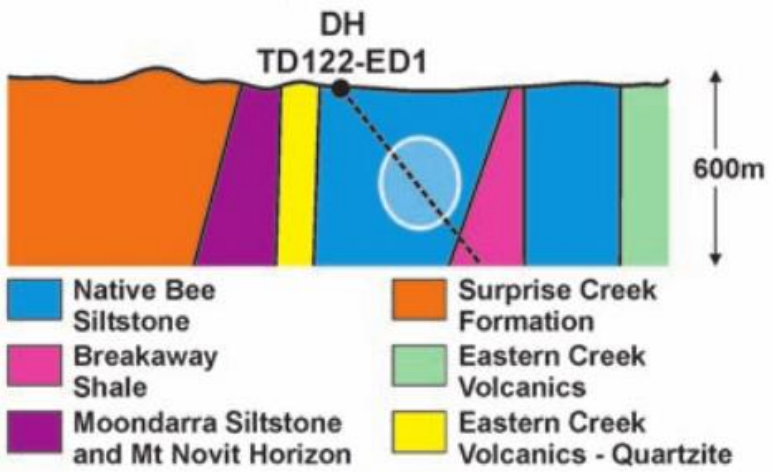
Question

- Can DC data delineate the various units shown in the geologic cross section?
- Can conductive units, which would be potential targets within the siltstones, be identified with DC data?

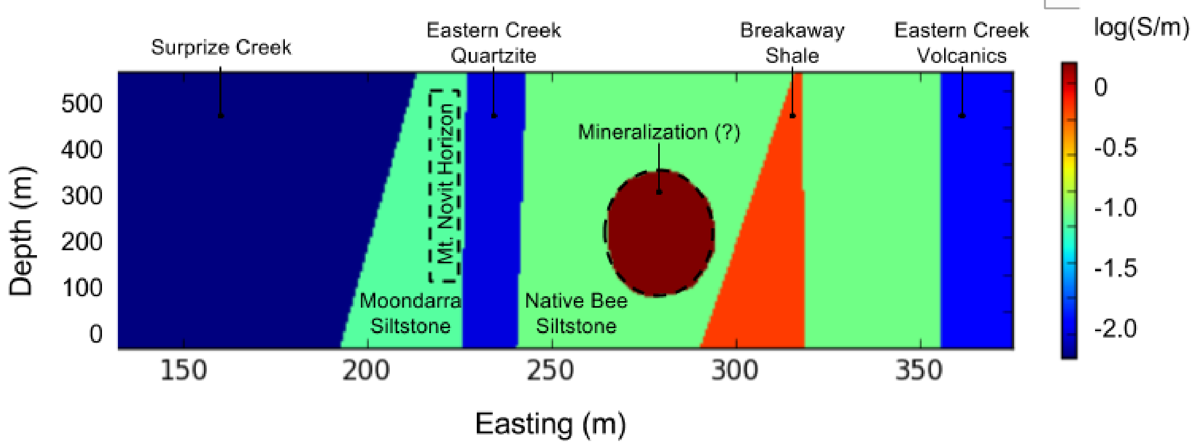
Credit: Doug Oldenburg, Seogi Kang and Linsey Heagy from UBC-GIF

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

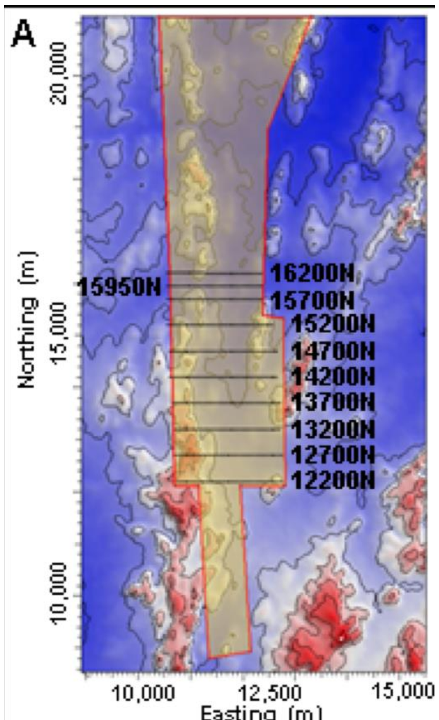


Credit: Doug Oldenburg, Seogi Kang and Linsey Heagy from UBC-GIF

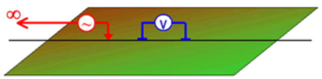
Survey and Data

- 10 survey lines
- Two survey configurations.

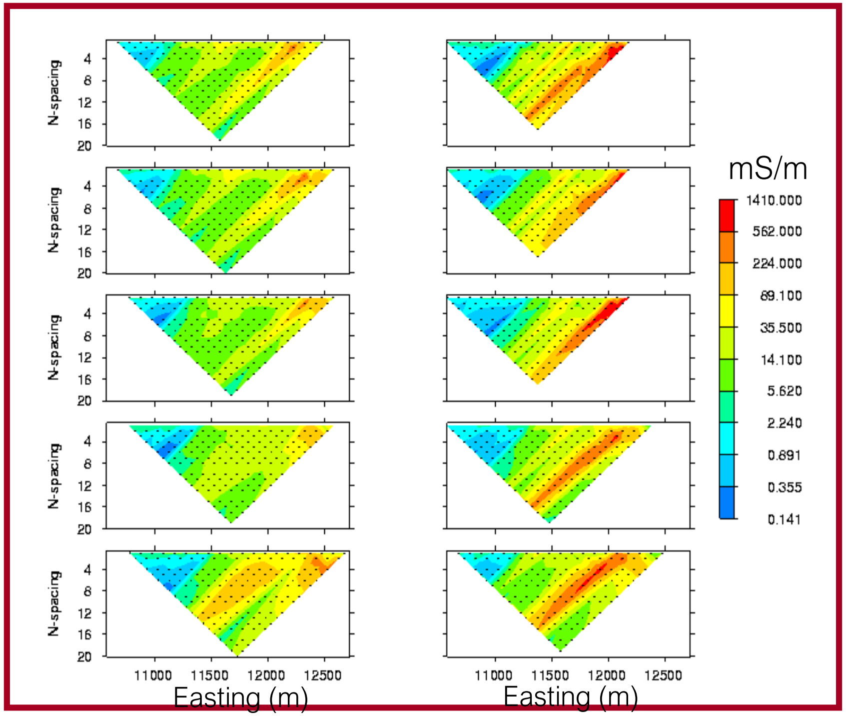
Surface topography



Data set #1:



Apparent resistivity, pole - dipole.

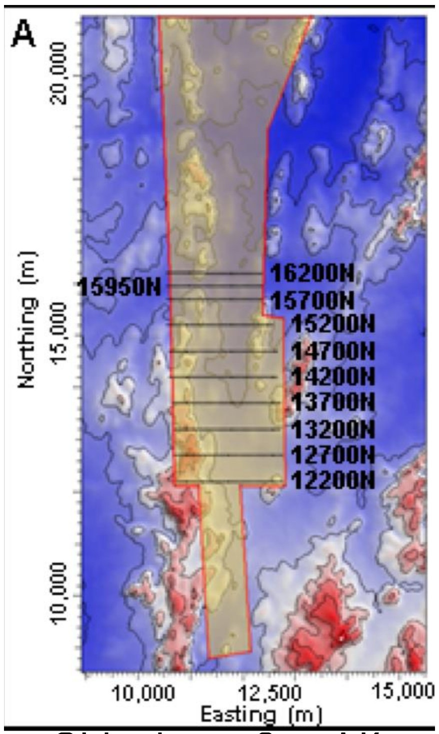


Credit: Doug Oldenburg, Seogi Kang and Linsey Heagy from UBC-GIF

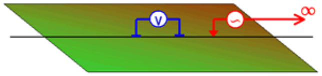
Survey and Data

- 10 survey lines
- Two survey configurations.

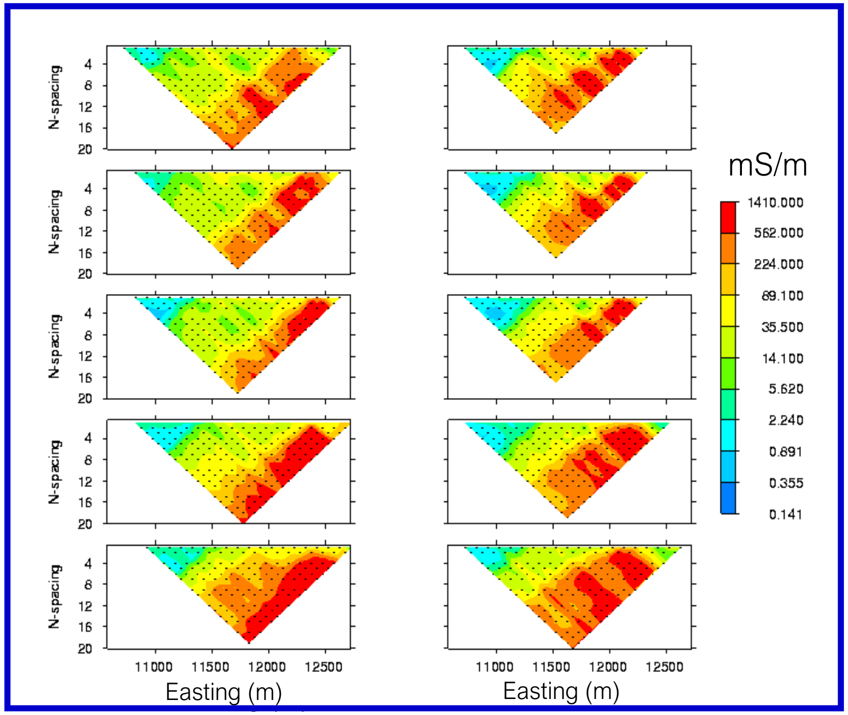
Surface topography



Data set #2:



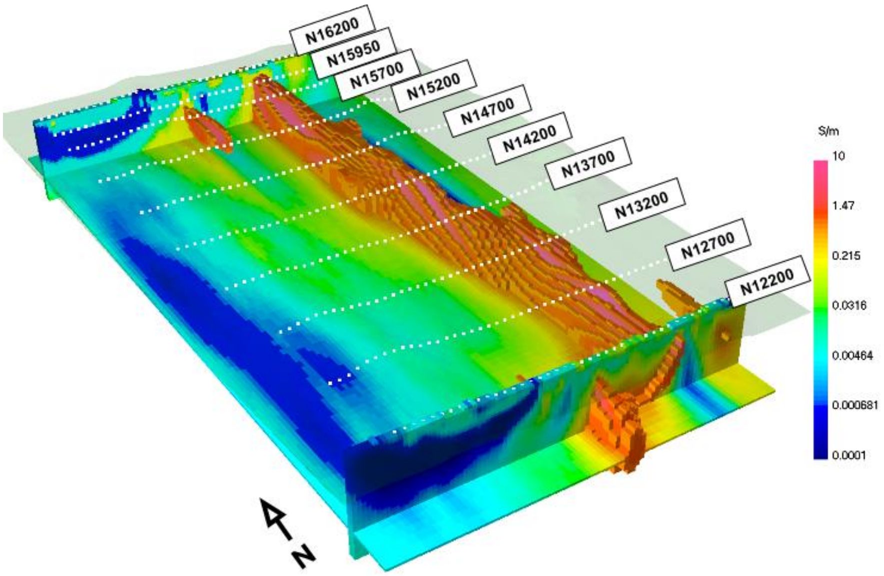
Apparent resistivity, dipole - pole



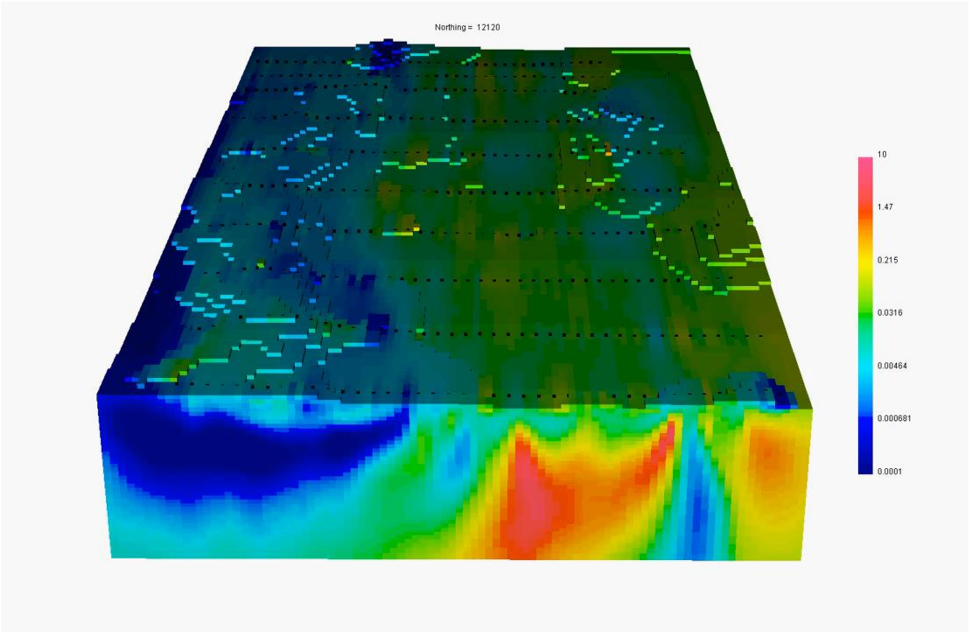
Credit: Doug Oldenburg, Seogi Kang and Linsey Heagy from UBC-GIF

Processing and interpretation

3D resistivity model



Animation

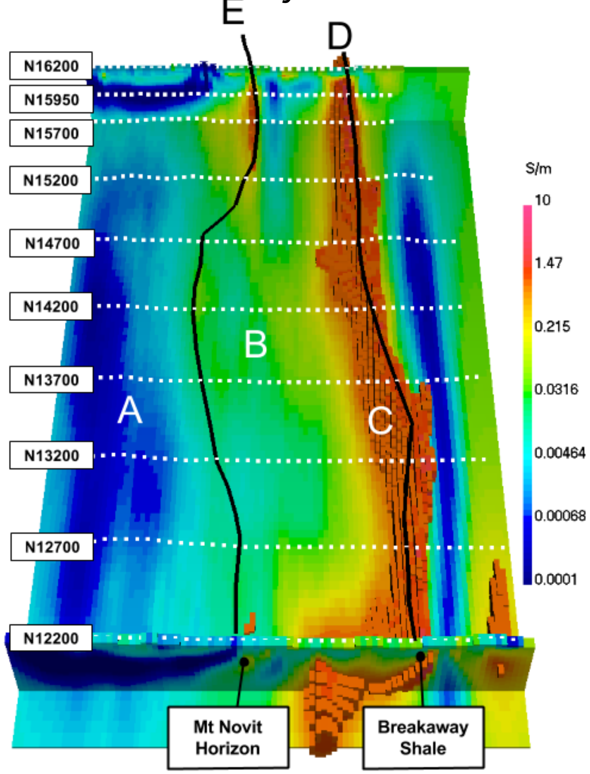


Credit: Doug Oldenburg, Seogi Kang and Linsey Heagy from UBC-GIF

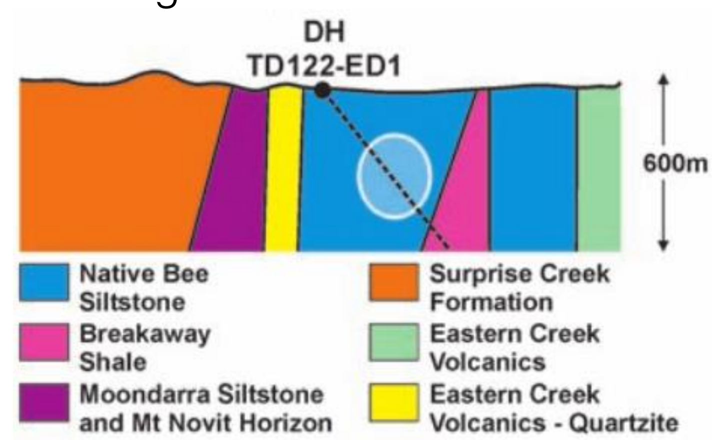
Synthesis

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

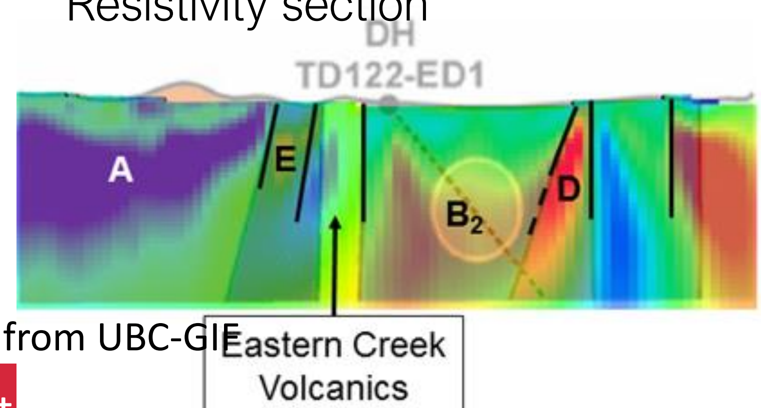
3D resistivity model



Geologic section



Resistivity section



Credit: Doug Oldenburg, Seogi Kang and Linsey Heagy from UBC-GIF

Optional reading materials

- https://em.geosci.xyz/content/case_histories/mt_isa/index.html