

# Seogi Kang

Research Scientist in  
Stanford Environmental Geophysics Research Group

Computational geophysicist using various types of sensors  
(borehole, surface-based, airborne, satellite).

Passionate for adopting open-science practices to  
education.

Advance environmental geophysics to solve challenging  
geoscience problems

# Assumptions:

- This course is for 3<sup>rd</sup>/4<sup>th</sup> year students in geoscience.
- Strong background of math, physics, and computation are not required.
- Apps developed by Jupyter Labs, Python and SimPEG are used, but strong software background is not required.



A screenshot of a Jupyter Notebook titled "Sounding Curves over a 3 Layered Earth". The notebook interface includes a top bar with tabs, a toolbar with various icons, and a main content area. The content area contains text, figures, and code cells. The text describes the use of widgets to learn about sounding curves for a 3-layered Earth model. It includes a "Background: Sounding Curves" section with a detailed description of what sounding curves are and how they are used. Two figures are shown: a 2D plot of electrode locations (Wenner array) and a plot of sounding curves (apparent resistivity vs. electrode spacing) for both Wenner and Schlumberger arrays. A code cell at the bottom shows the import statements for the packages used in the notebook.

# Environmental Geophysics - Fundamentals & applications

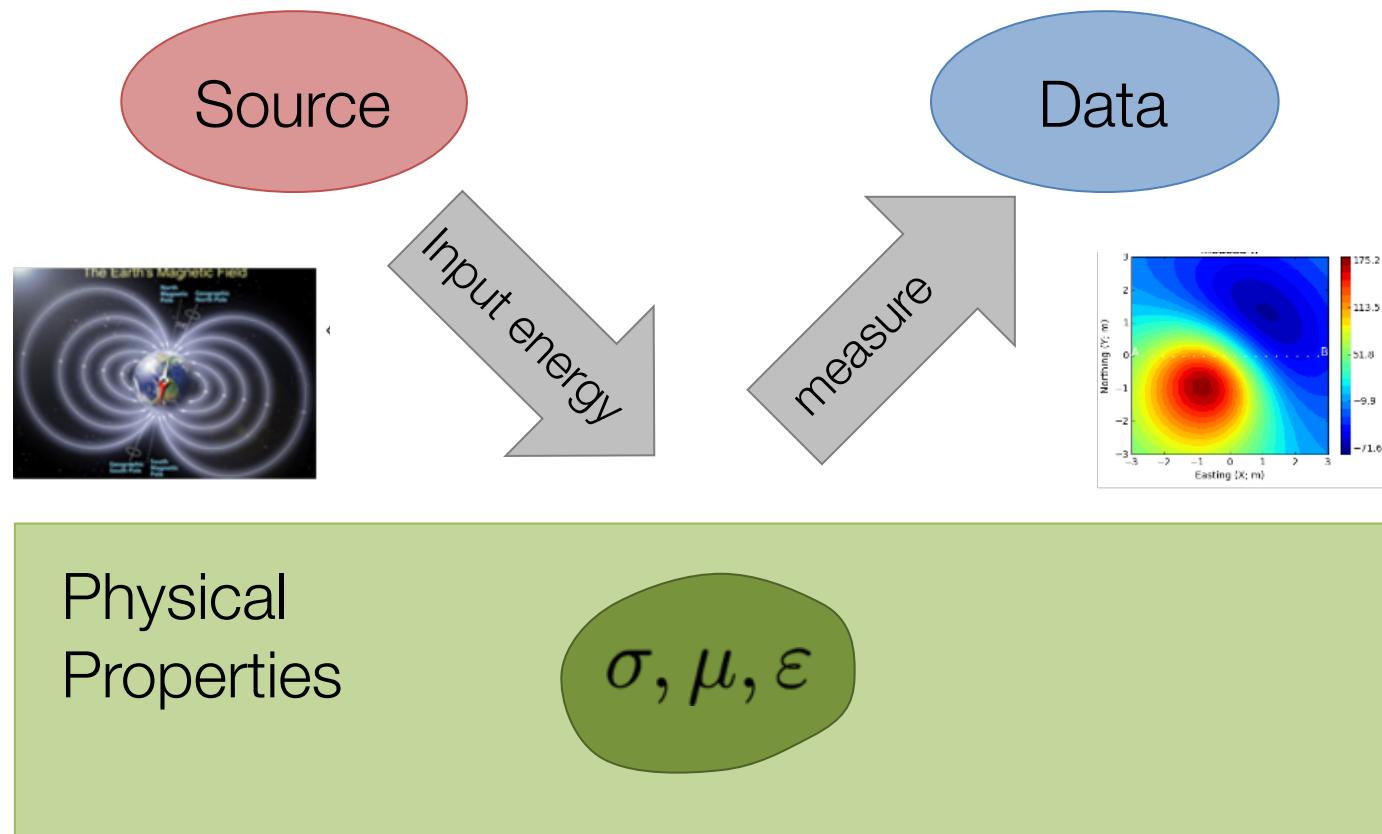
Seogi Kang

# What is Environmental Geophysics?

“Environmental Geophysics is the use of geophysical methods to image and understand the properties and processes in the top hundreds of meters of the earth (or more).”

# Generic geophysical experiment?

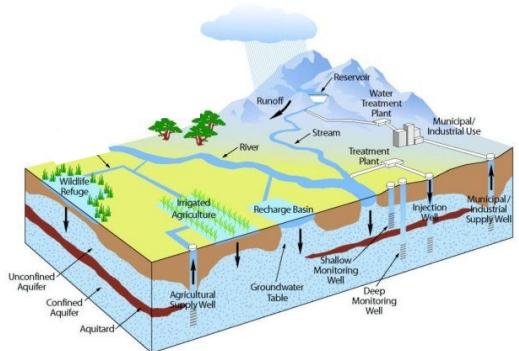
All require ways to see into the earth without direct sampling



# Climate change & Energy transition

Example problems where environmental geophysical can contribute to the solution

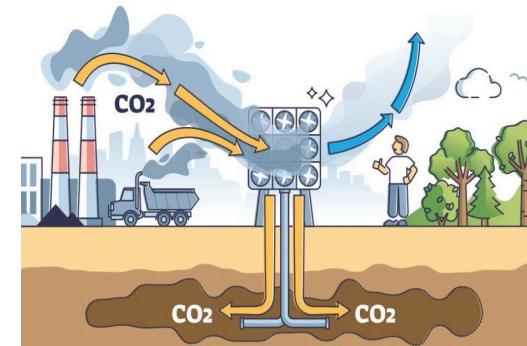
Groundwater



Critical minerals

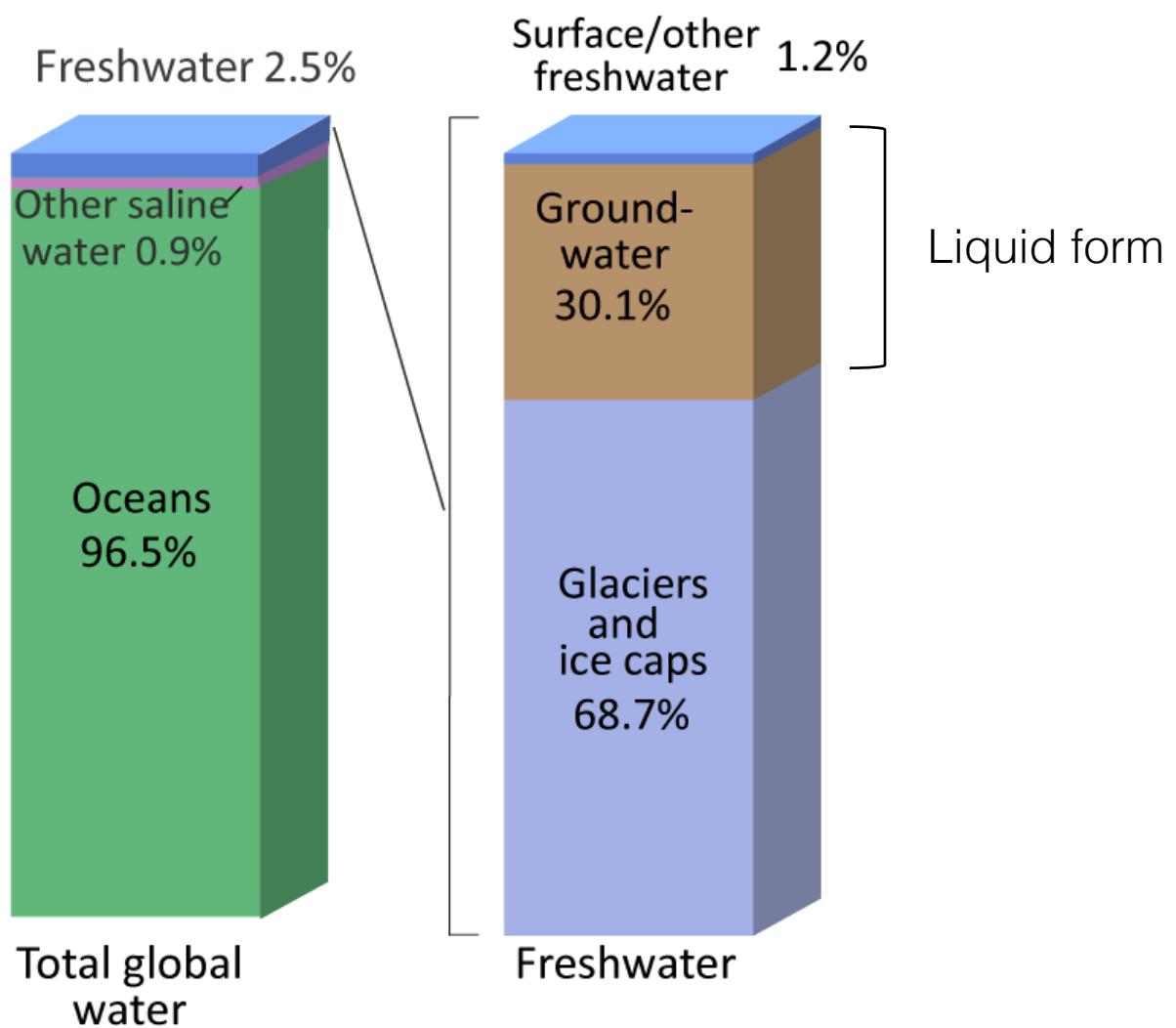


Geologic storage of CO<sub>2</sub>



Cryosphere  
(e.g., permafrost)





## Groundwater

97% of all liquid freshwater  
50% of all drinking water  
40% of the water used in irrigation

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Population growth &  
Climate change

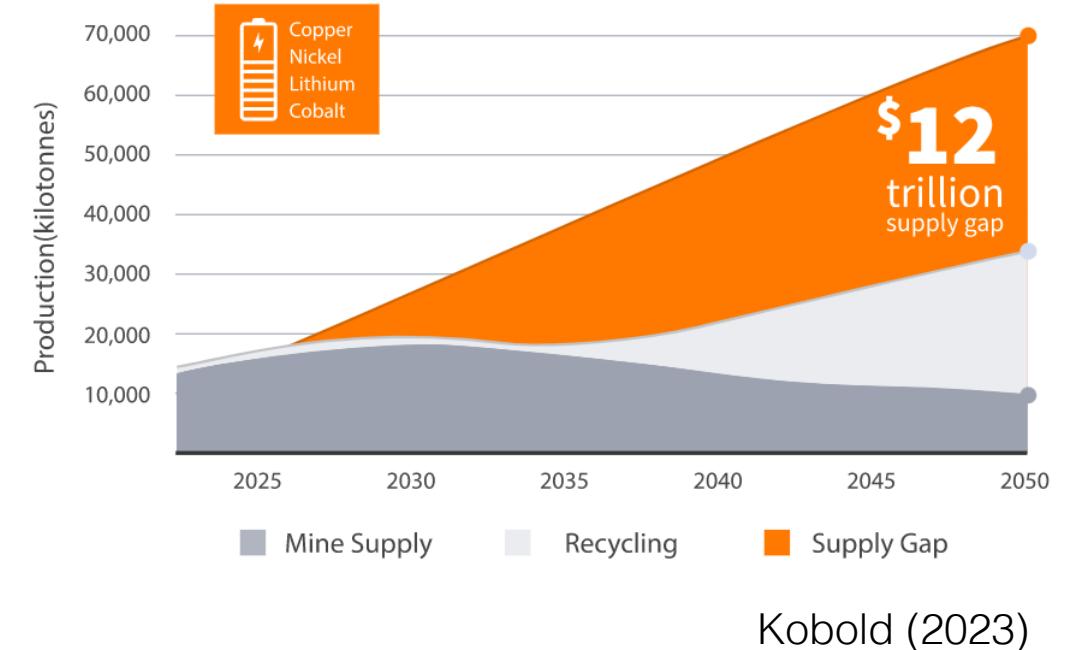
Increasing concerns about  
groundwater sustainability

Source: Igor Shiklomanov's chapter "World fresh water resources" in Peter H. Gleick (editor), 1993, Water in Crisis: A Guide to the World's Fresh Water Resources. (Numbers are rounded).

# Critical minerals



Need to secure supply of critical minerals for energy transition



E.g.  
Nickel (Ni)  
Copper (Cu)  
Lithium (Li)  
Cobalt (Co)

Easy targets on the surface have already been found.

Need to minimize undesirable hazards.  
(e.g., groundwater contamination)

# Geologic storage of CO<sub>2</sub>



Image from CAMI site, Alberta

Characterize the storage sites  
(e.g., depleted reservoirs, saline aquifers)

Monitor the leakage to the surface or  
shallow aquifers

# Cryosphere

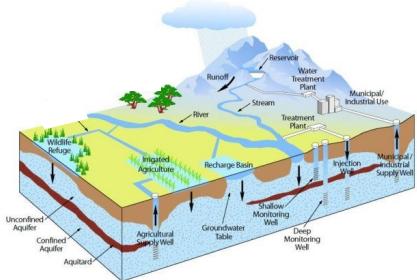
E.g., Permafrost



Melting ice in the Antarctic  
→ sea level rise

Melting permafrost in the Arctic  
→ loss of storage for green house gases  
→ geotechnical issues

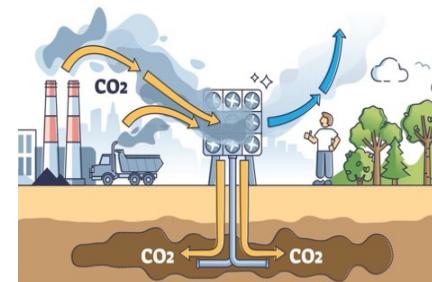
Groundwater



Critical minerals



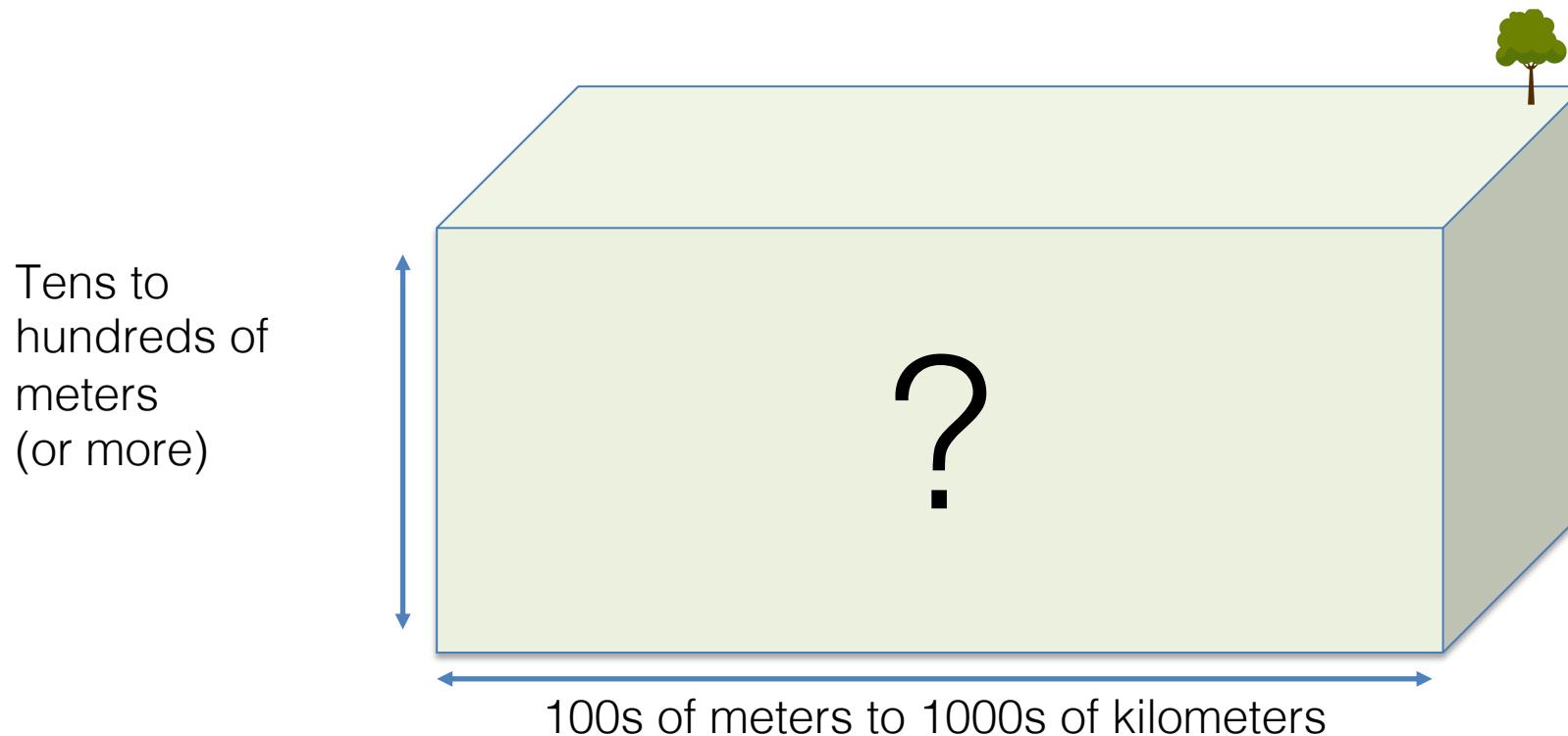
Geologic storage of CO<sub>2</sub>



Cryosphere  
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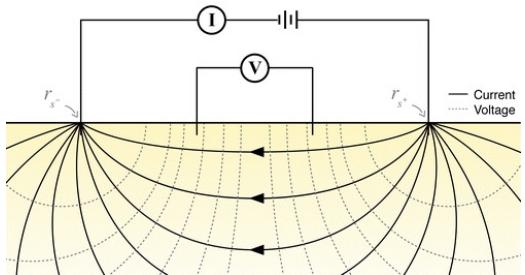


Need to image the subsurface (at multiple scales)

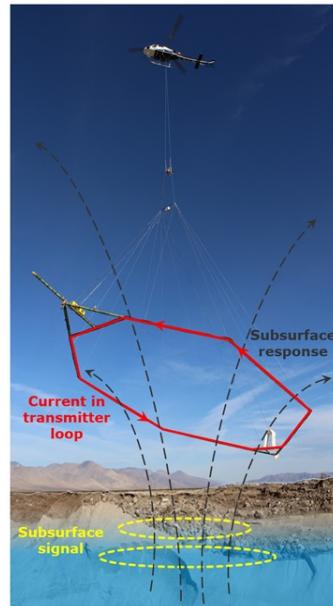


# Environmental geophysics can an important role

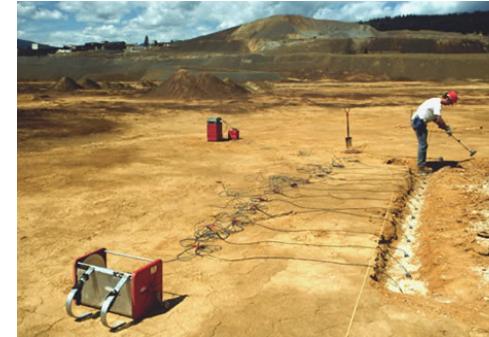
## Electrical methods



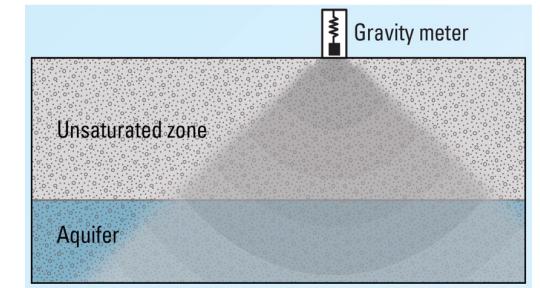
## Electromagnetic methods



## Seismic methods



## Potential fields (e.g., gravity)

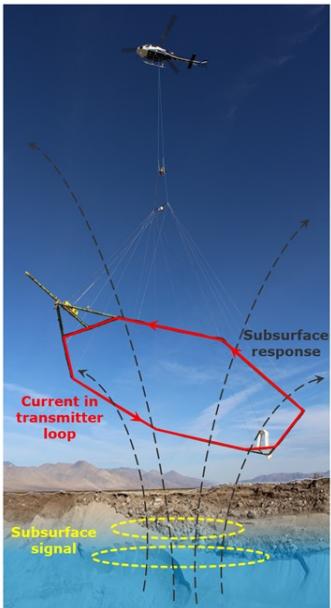


Provides a cost-effective way to image the subsurface

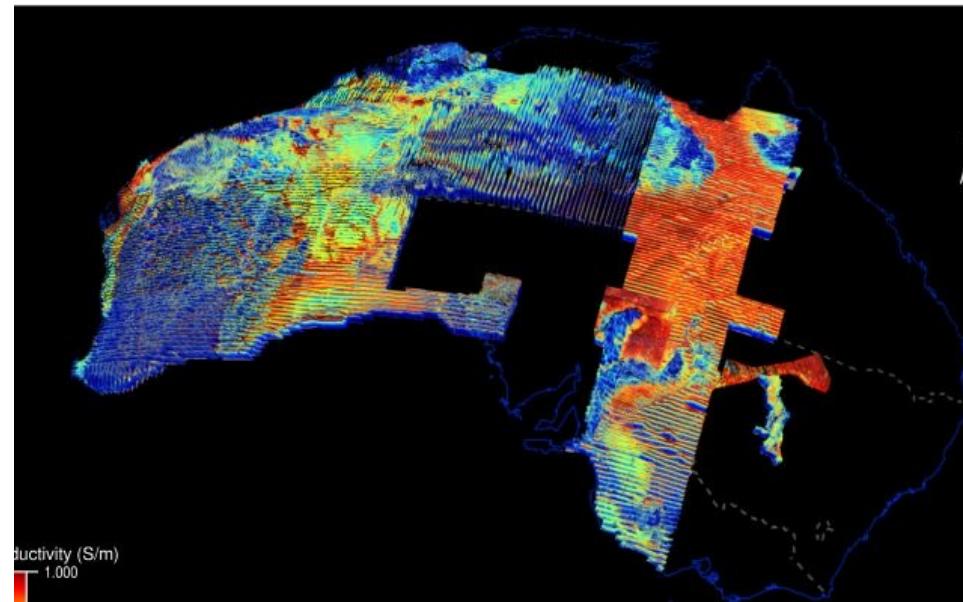
# Increasing volume & complexity of geophysical data

example: airborne EM (AEM)

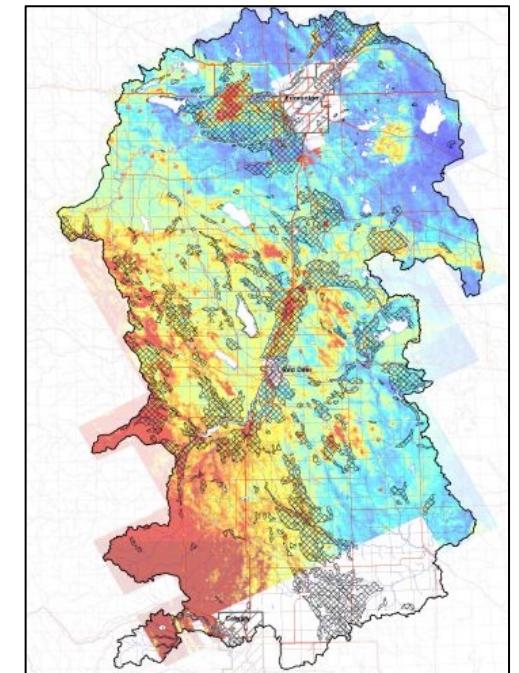
Airborne EM



AEM data covering Australia  
(continent-wide)



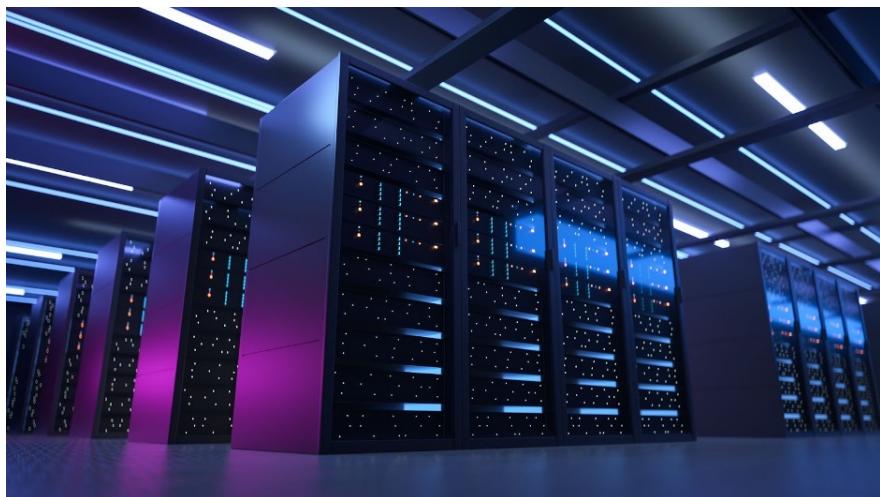
AEM data covering  
Edmonton-to-Calgary corridor  
(province-wide)



Geophysical data are publicly available

# Enhancement in computational power & sophisticated algorithms

High performance computing (HPC) &  
Graphical Processing Unit (GPU)



Open-source software packages



Easy access with a cloud platform



Google colab

My main overarching goals are

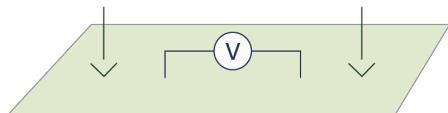
To engage students with concepts of geophysics – “fundamentals”

Promote active learning to equip students to be effective users of geophysical techniques in their work – “interactive learning with open data & open-source tools”

Encourage multidisciplinary thinking to empower them to collaborate on diverse problems. – “applications with case histories”

# Direct Current Resistivity Method

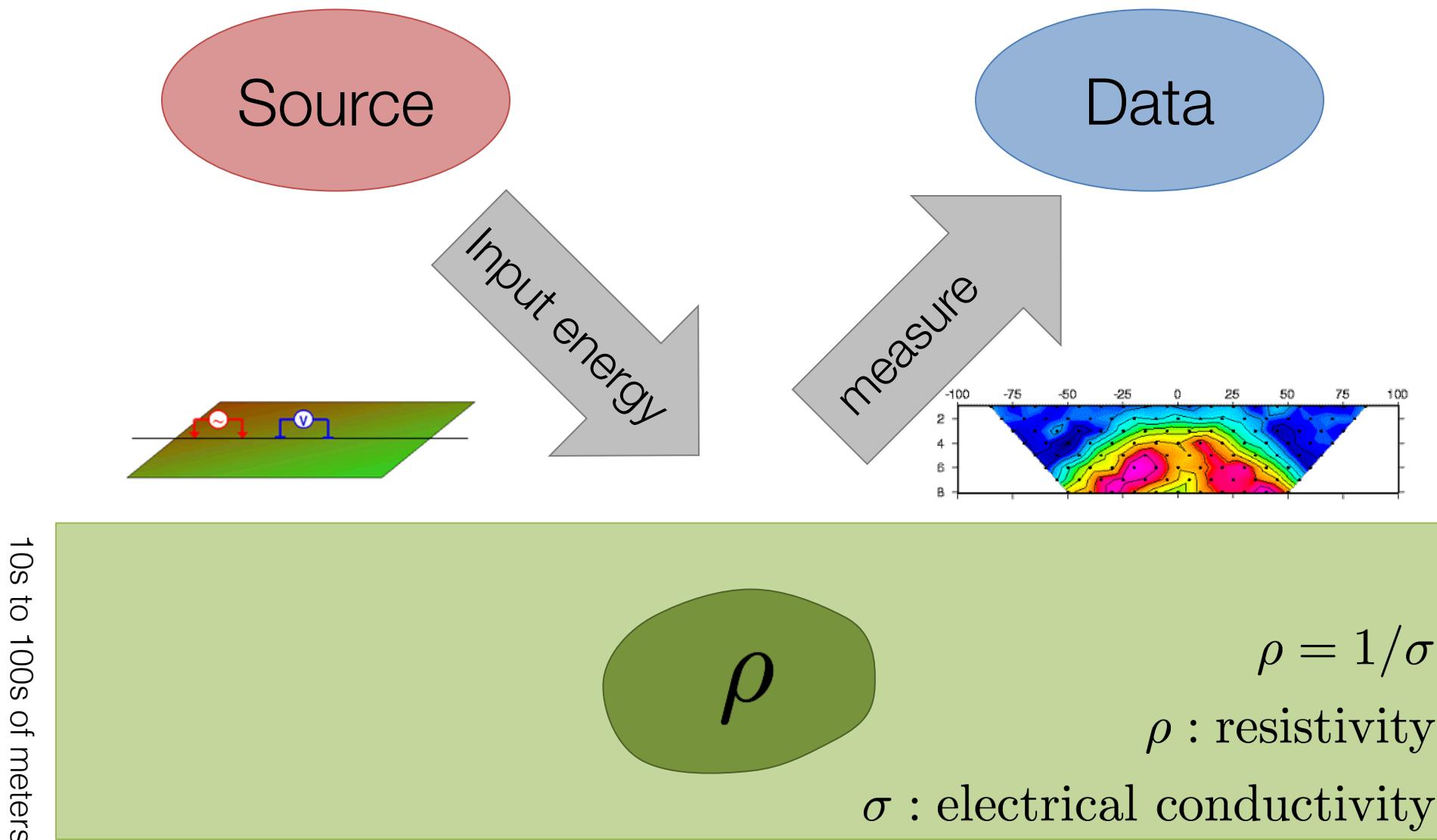
Seogi Kang



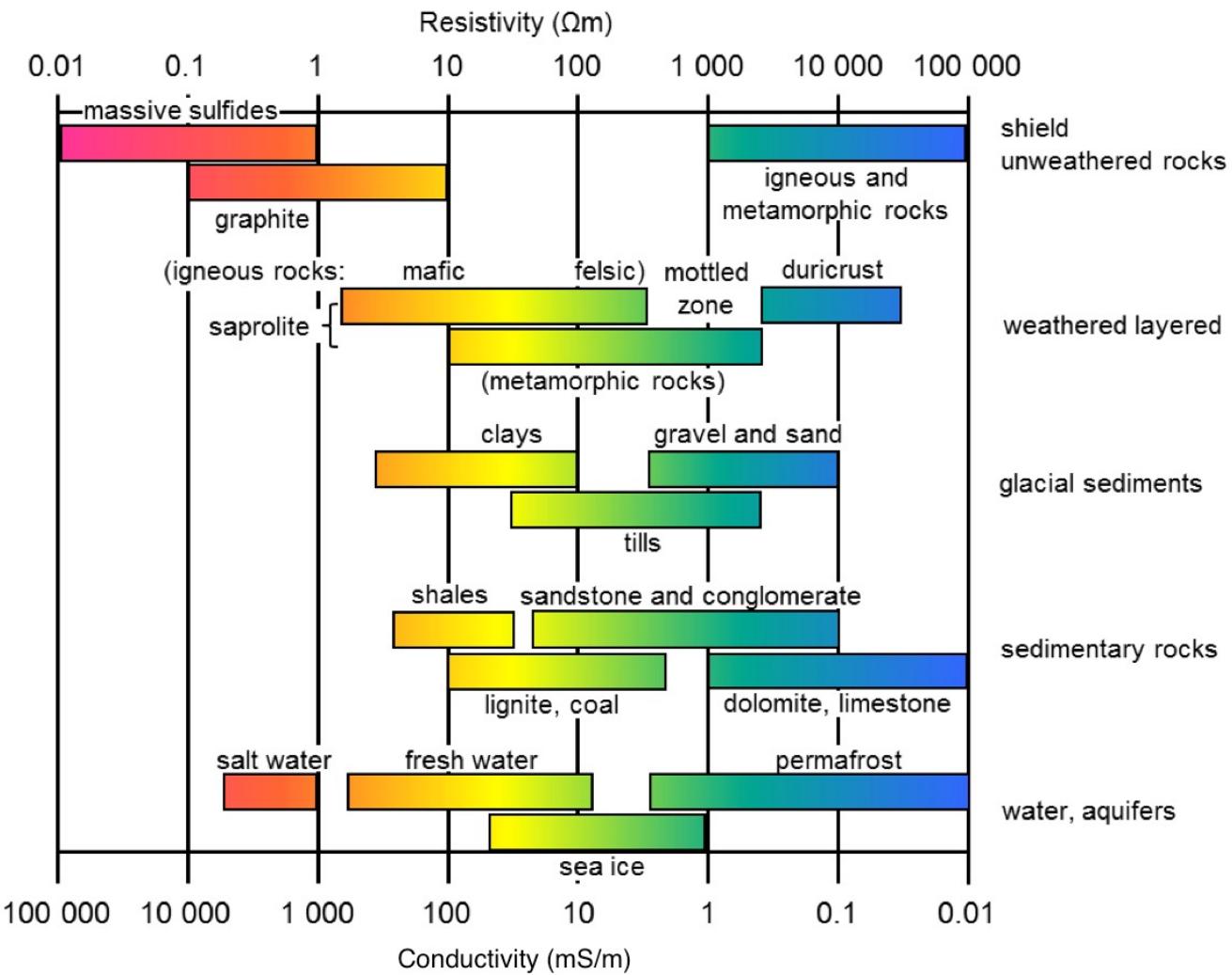
# Learning goals of the lecture

- Understand electrical resistivity and its linkage to geologic units.
- Understand a basic setup of direct current (DC) experiment.
  - Concept of an apparent resistivity
  - Concept of a sounding
- Understand fundamental physics of the DC related to electric currents.
- Understand the limitation of the method.

# Direct Current (DC) Resistivity Survey



# Electrical resistivity (or conductivity)

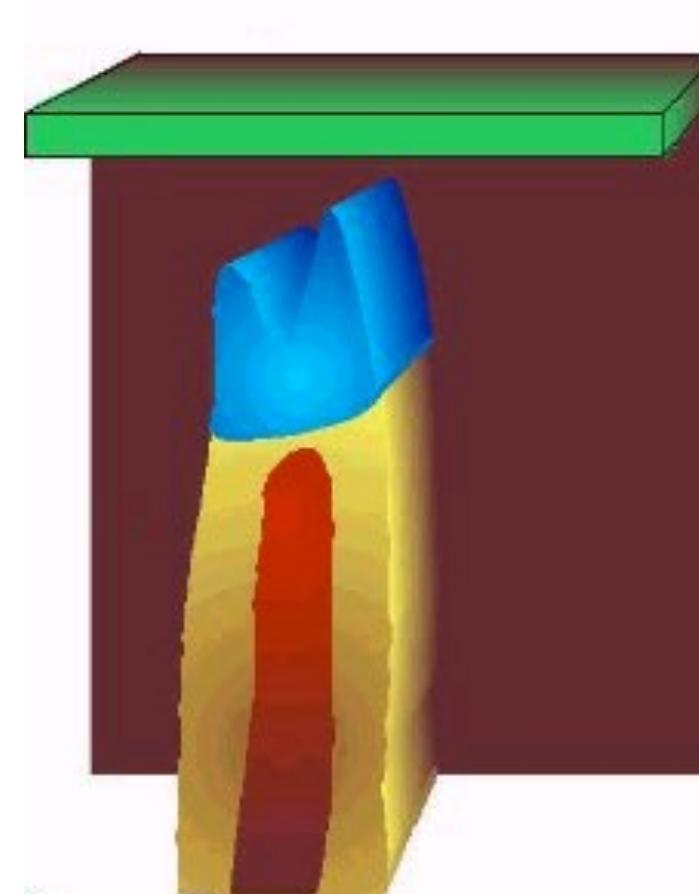


- DC resistivity is sensitive to:
  - $\sigma$ : Conductivity [ $\text{S/m}$ ]
  - $\rho$ : Resistivity [ $\Omega\text{m}$ ]
  - $\sigma = 1/\rho$
- Varies over many orders of magnitude
- Depends on many factors:
  - Rock type
  - Porosity
  - Connectivity of pores
  - Nature of the fluid
  - Metallic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

# Basic Experiment

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

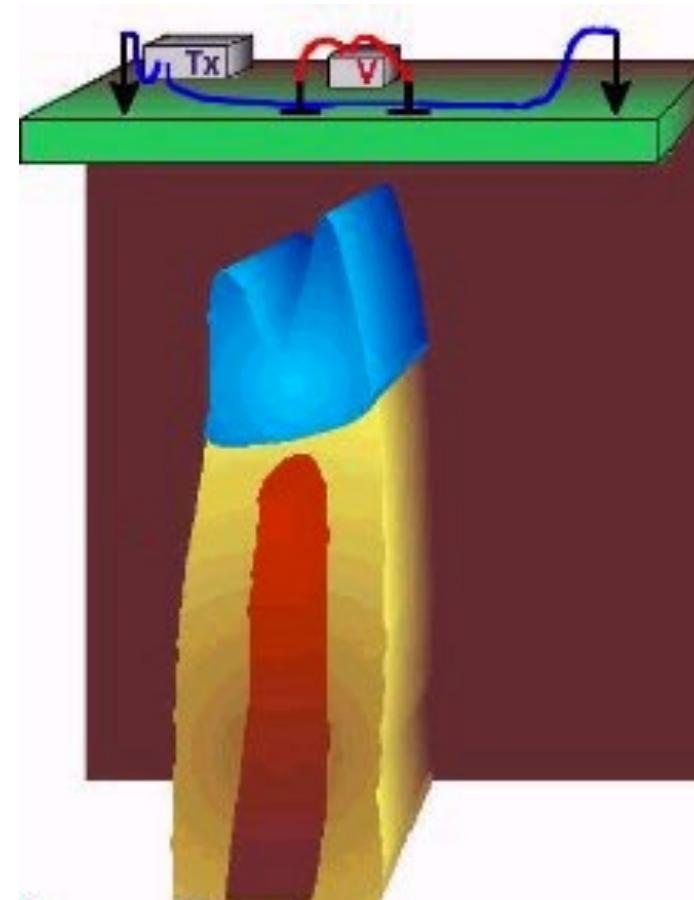
Elura Orebody Electrical resistivities	
<i>Rock Type</i>	<i>Ohm-m</i>
Overburden	12
Host rocks	200
Gossan	420
Mineralization (pyritic)	0.6
Mineralization (pyrrhotite)	0.6



# Basic Experiment

- Target:
  - Ore body. Mineralized regions less resistive than host
- Setup:
  - Tx: Current electrodes
  - Rx: Potential electrodes

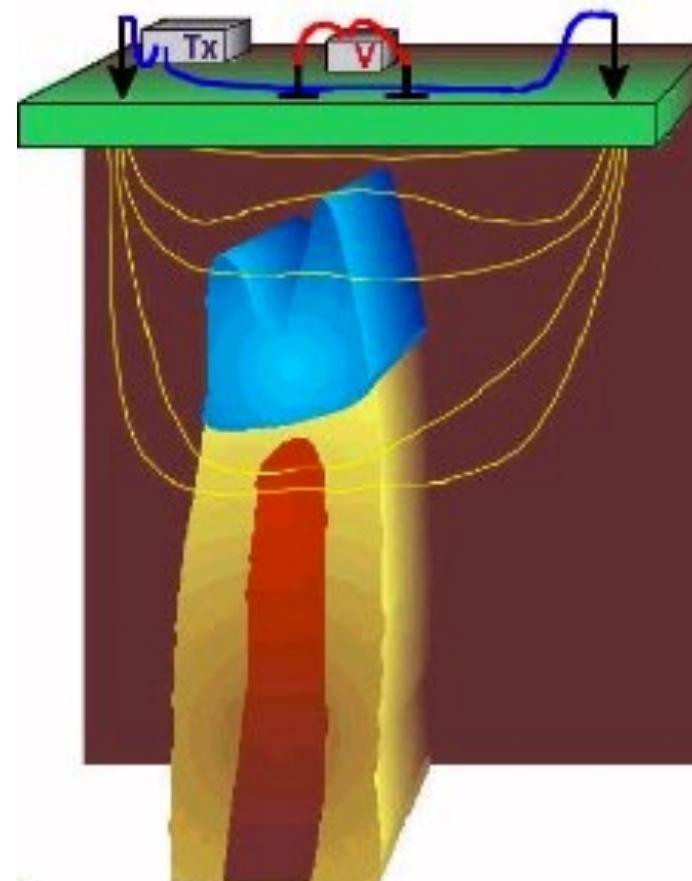
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# Basic Experiment

- **Target:**
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  - Rx: Potential electrodes
- **Currents:**
  - Preferentially flow through conductors

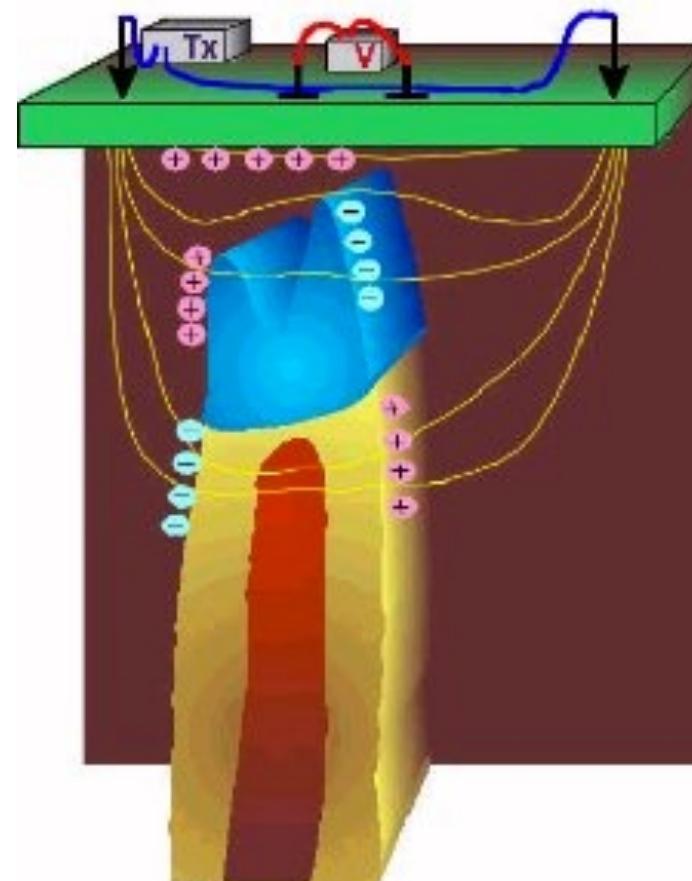
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# Basic Experiment

- **Target:**
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- **Setup:**
  - Tx: Current electrodes
  - Rx: Potential electrodes
- **Currents:**
  - Preferentially flow through conductors
- **Charges:**
  - Build up at interfaces

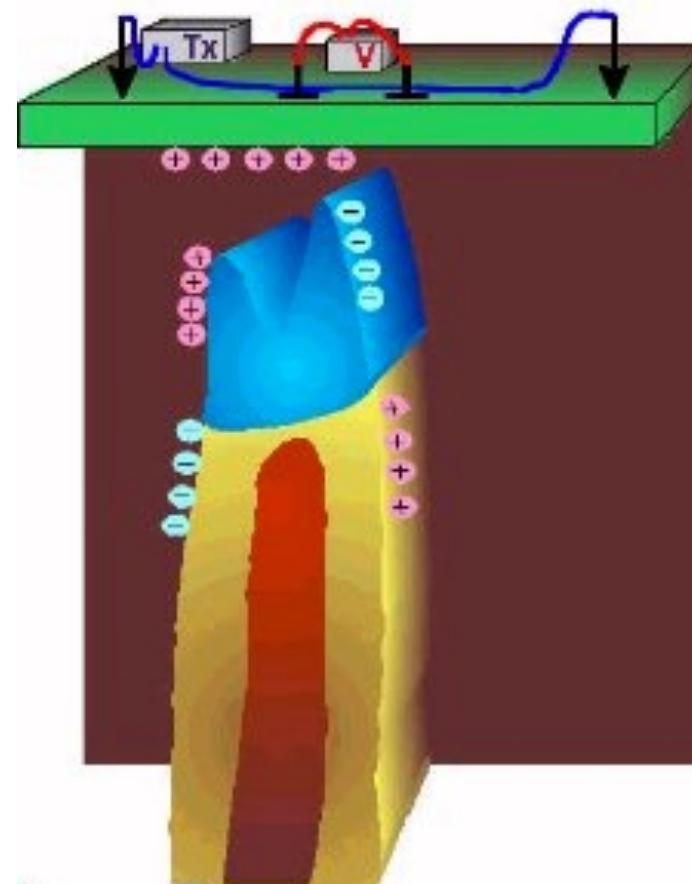
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# Basic Experiment

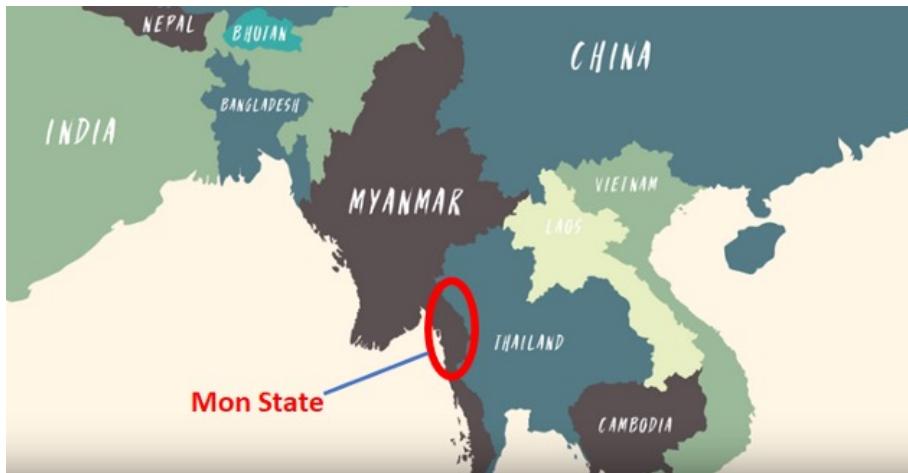
- **Target:**
  - Ore body. Mineralized regions less resistive than host
- **Setup:**
  - Tx: Current electrodes
  - Rx: Potential electrodes
- **Currents:**
  - Preferentially flow through conductors
- **Charges:**
  - Build up at interfaces
- **Potentials:**
  - Associated with the charges are measured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

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

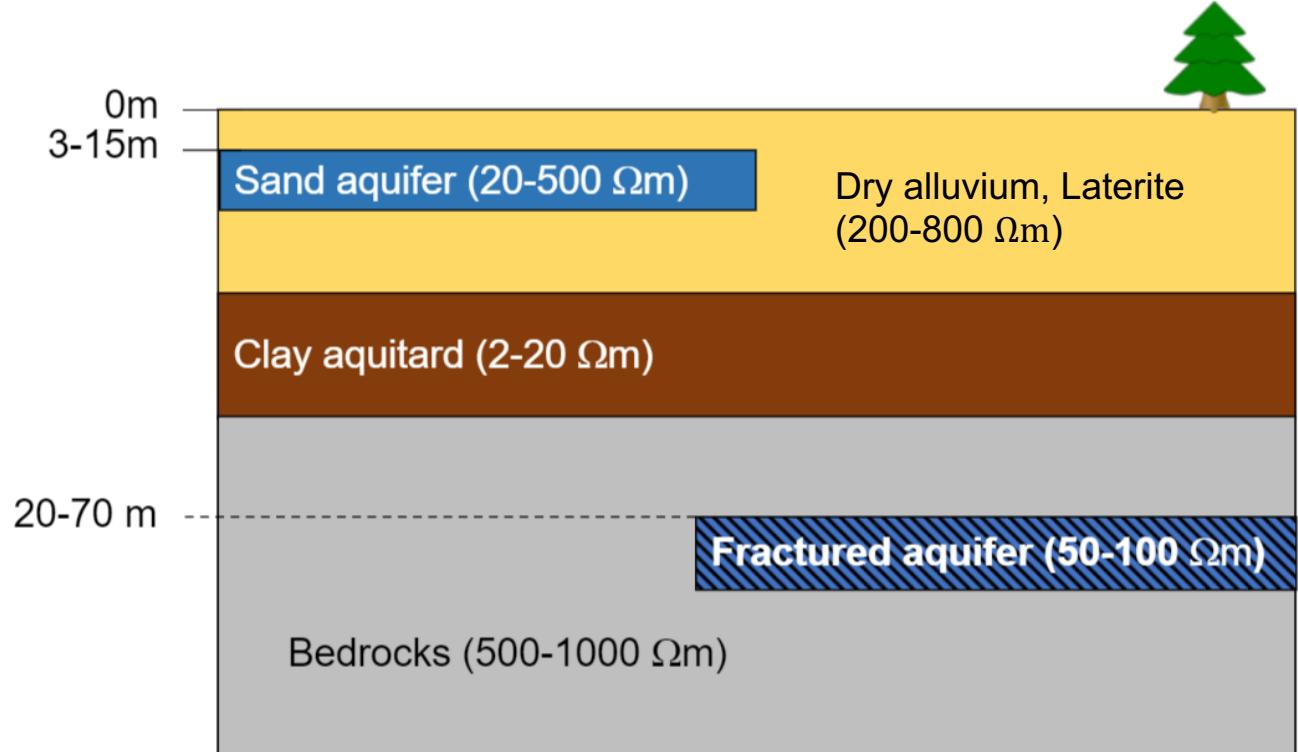


# Motivating example: Mon State, Myanmar

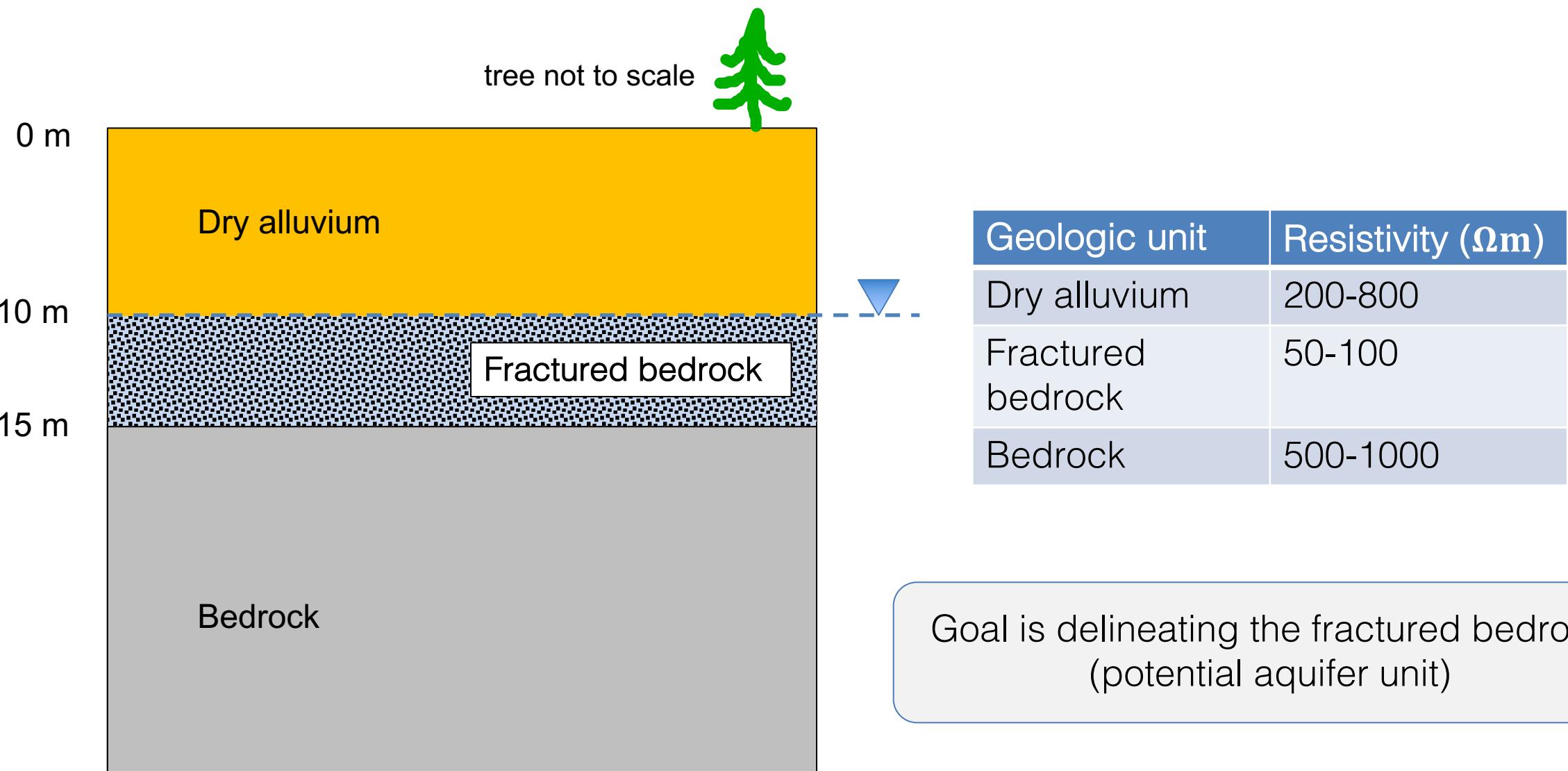
A local water stressed region



A general hydrogeology



# An example layered-model for groundwater application



How do we obtain resistivity?

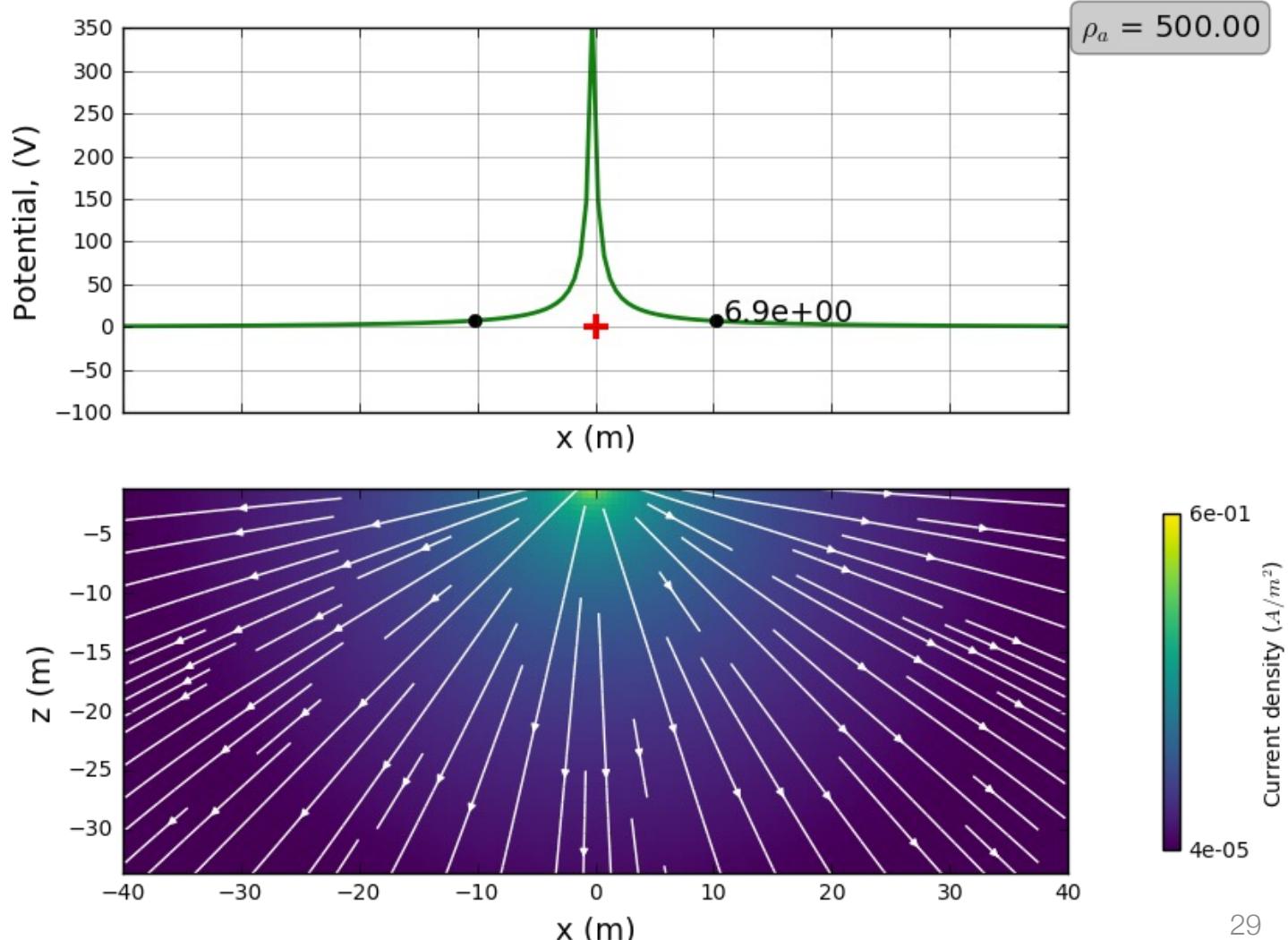
# Steady-state Maxwell's equations

	Full	Steady State
Faraday	$\nabla \times \vec{e} = -\frac{\partial \vec{b}}{\partial t}$	$\nabla \times \vec{e} = 0 \quad \vec{e} = -\nabla V$
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		$V = \frac{I}{2\pi\sigma} \frac{1}{r} \quad V = \frac{\rho I}{2\pi r}$

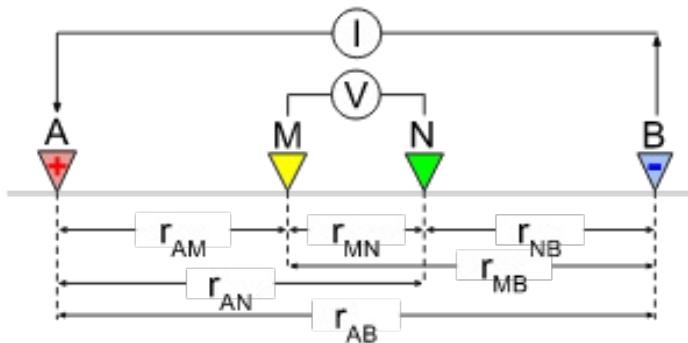
# Currents and potentials: halfspace

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

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



# Currents and potentials: 4-electrode array

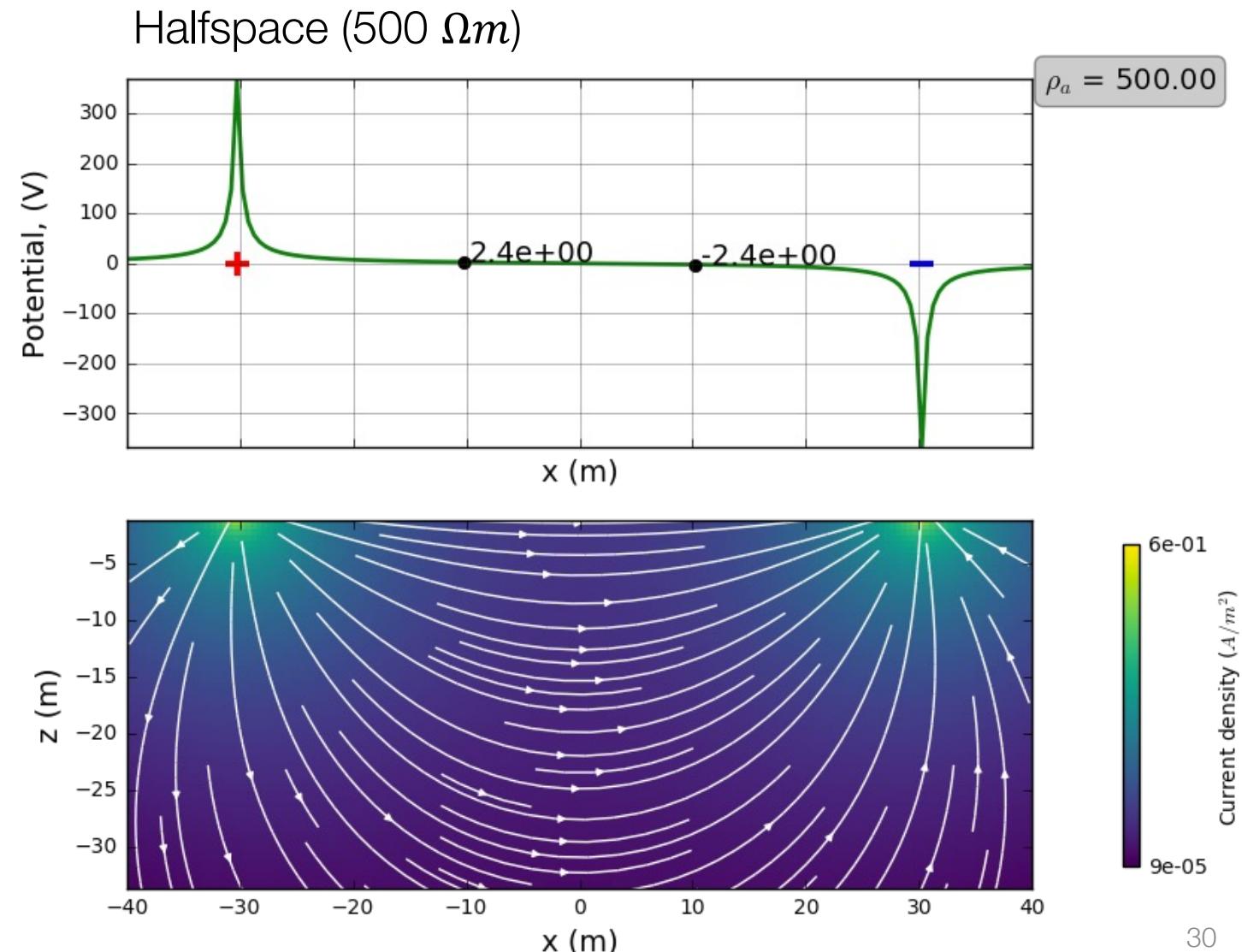


$$\Delta V_{MN} = \rho I \frac{1}{2\pi} \underbrace{\left[ \frac{1}{AM} - \frac{1}{MB} - \frac{1}{AN} + \frac{1}{NB} \right]}_G$$

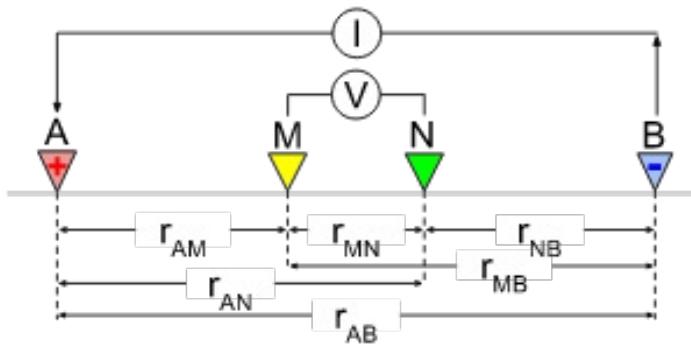
Resistivity

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

G: geometric factor



# Currents and Apparent Resistivity



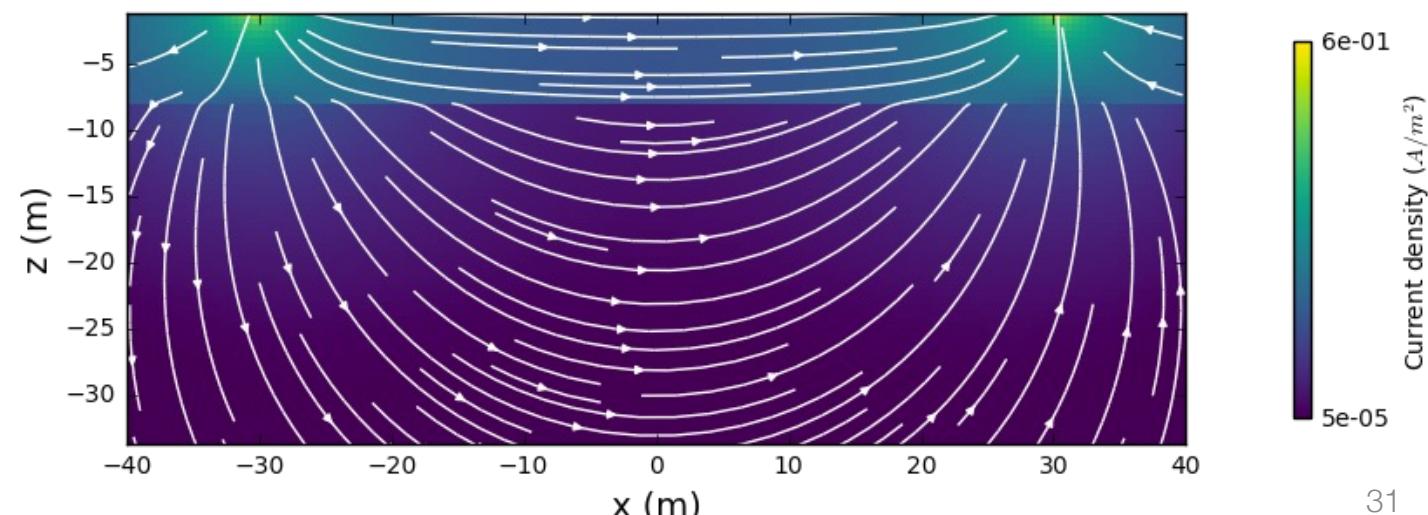
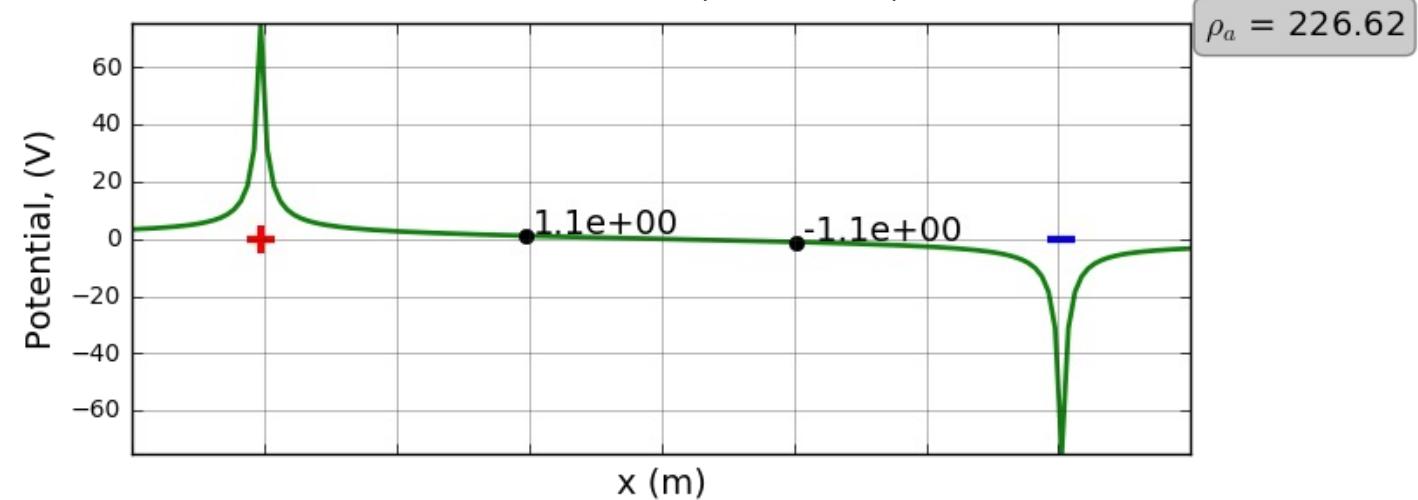
$$\Delta V_{MN} = \rho I \frac{1}{2\pi} \underbrace{\left[ \frac{1}{AM} - \frac{1}{MB} - \frac{1}{AN} + \frac{1}{NB} \right]}_G$$

Apparent resistivity

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

G: geometric factor

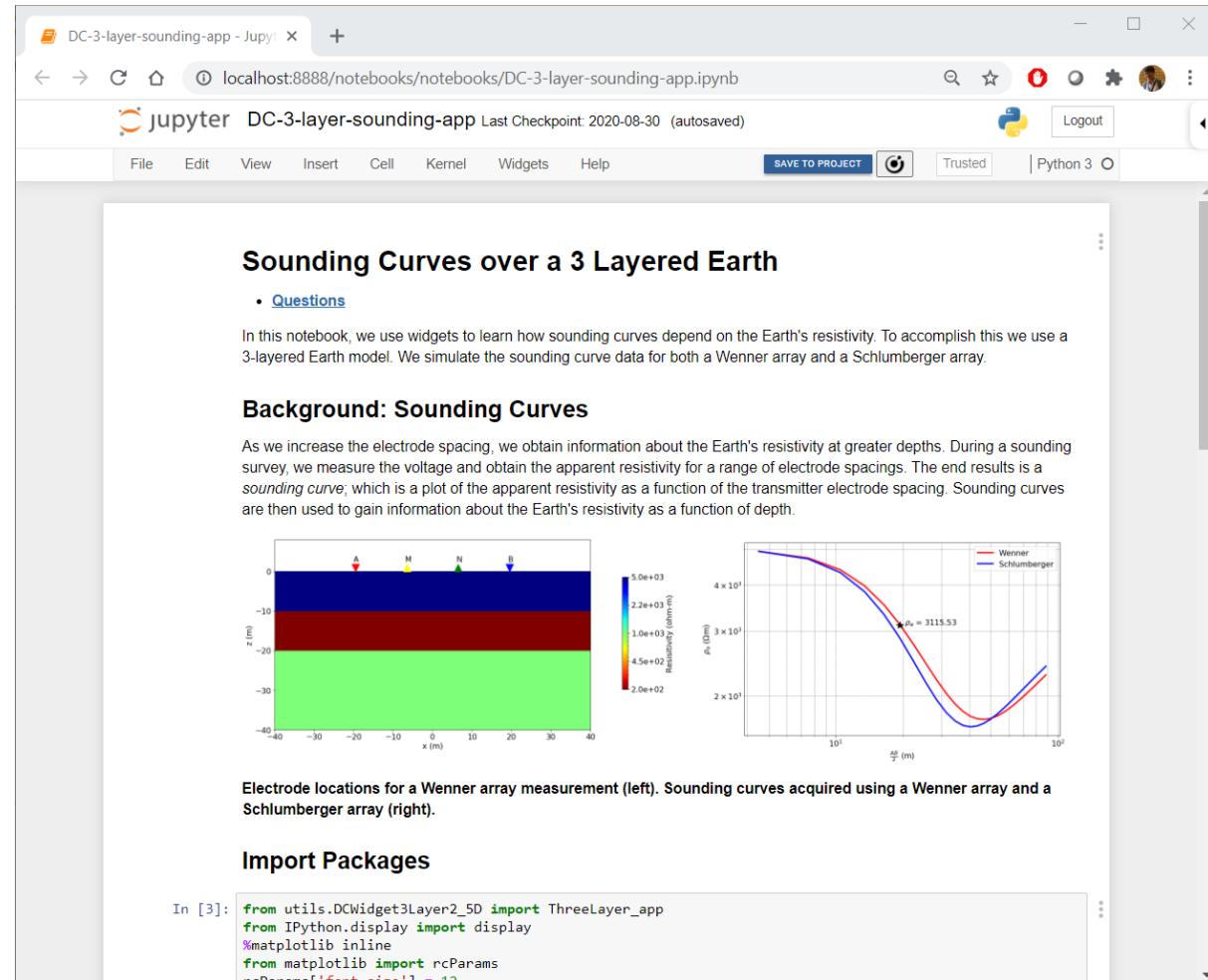
Conductive overburden ( $100 \Omega m$ )



# Demo: DC-3-layer-sounding-app

## Why interactive apps?

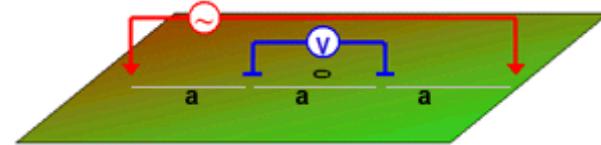
- Visualization aids understanding
- Learn through interaction
  - ask questions and investigate
- Open source:
  - Free to use
  - Welcome contributions!



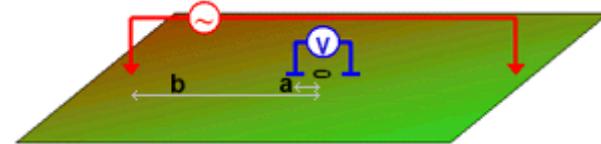
# Sounding and Arrays

Geometry

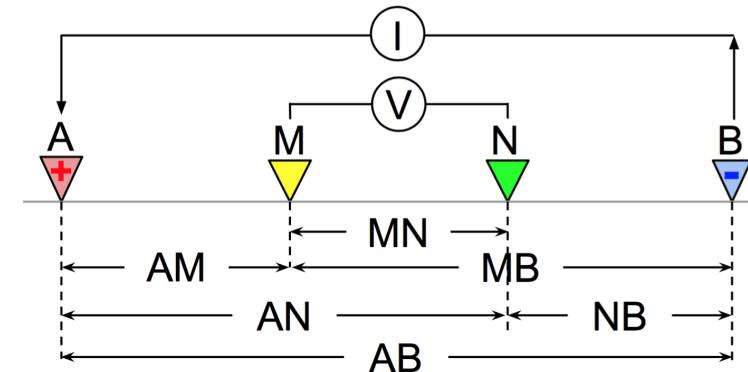
Wenner



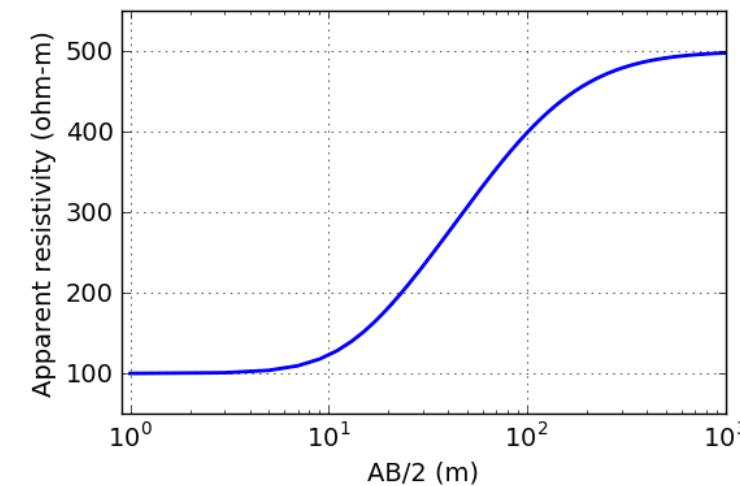
Schlumberger



4 electrode Array

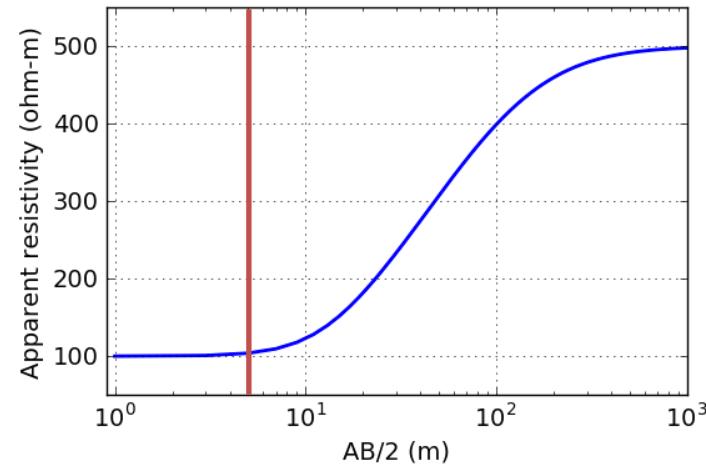


Sounding



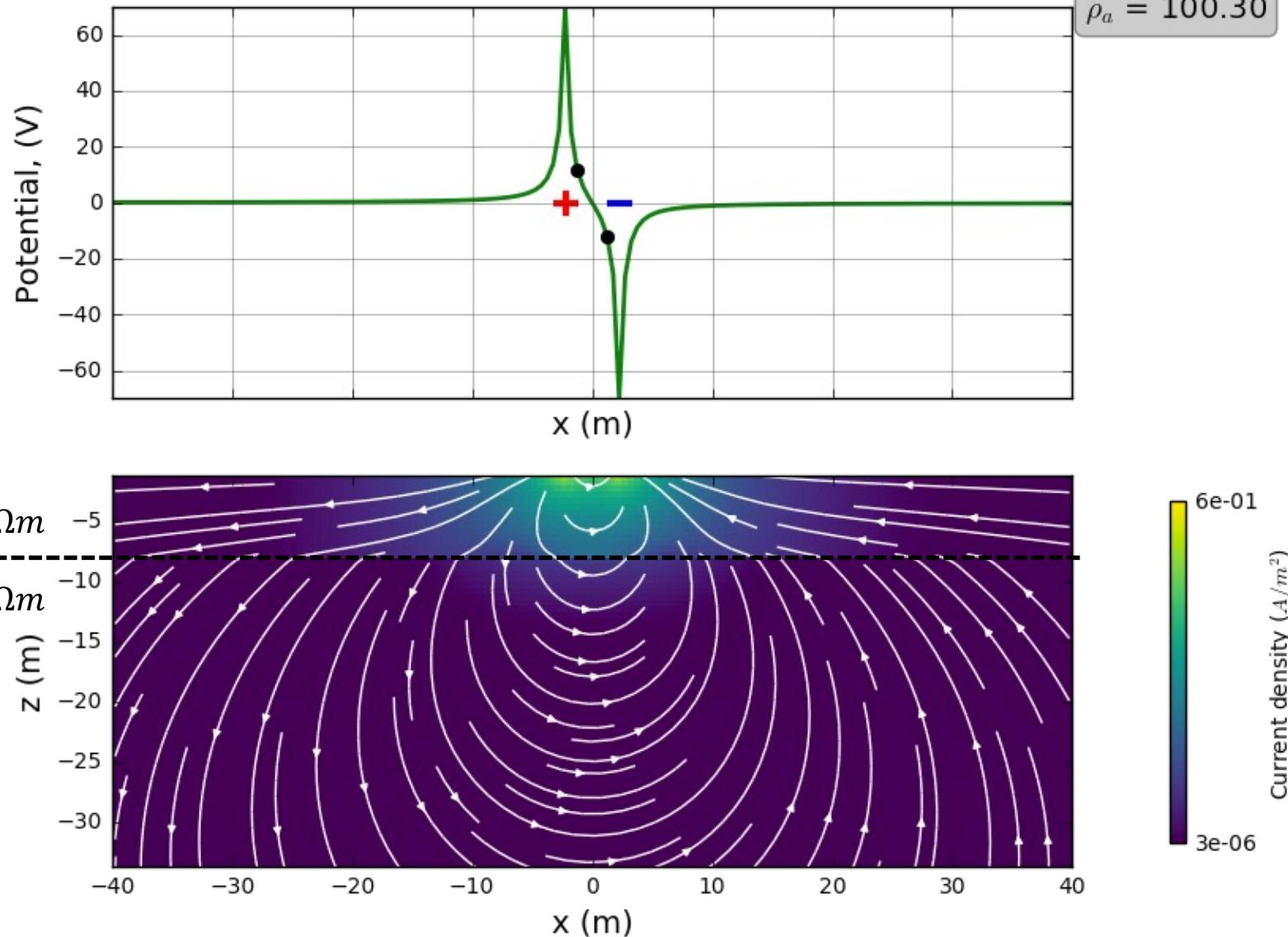
# Soundings

DC Sounding curve



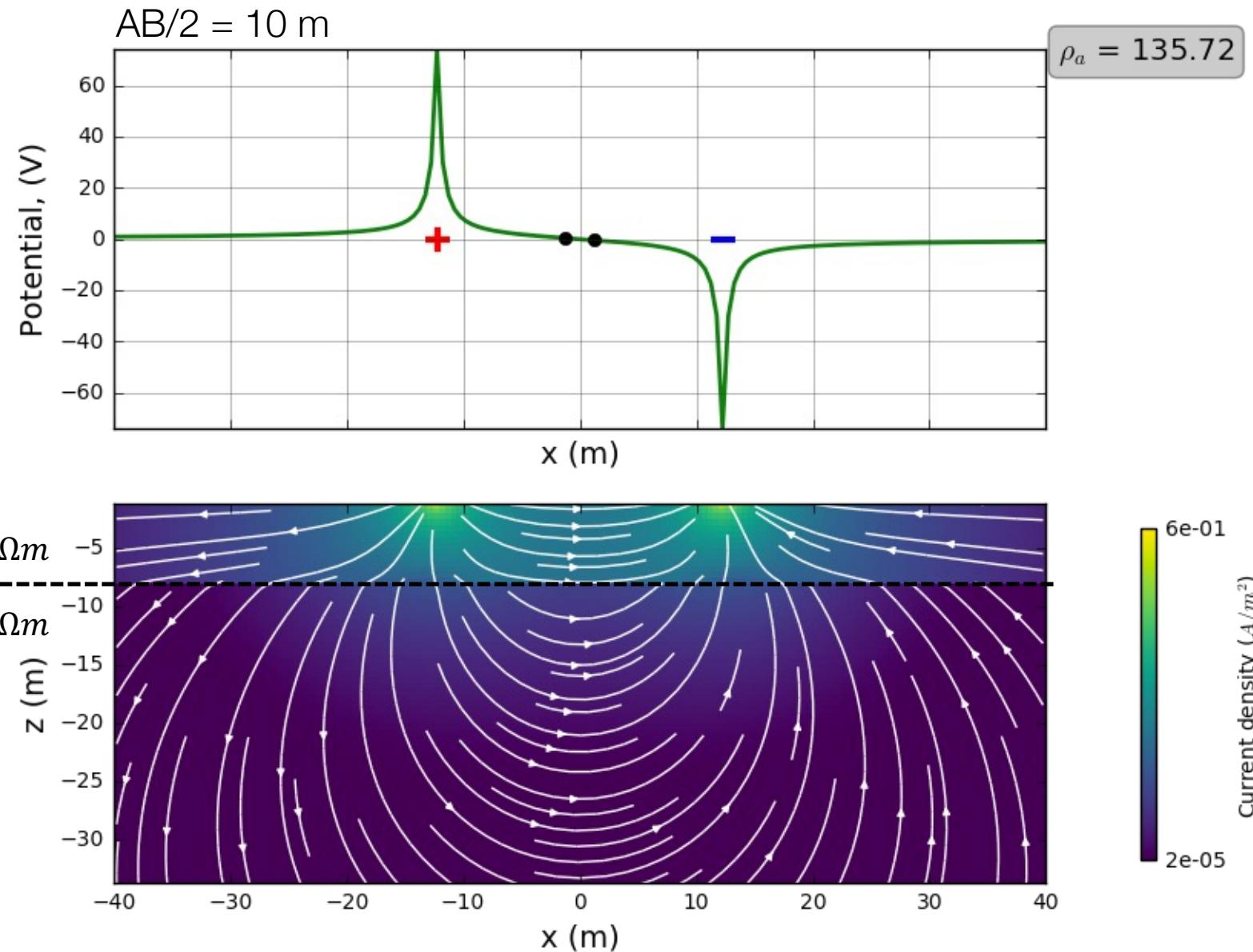
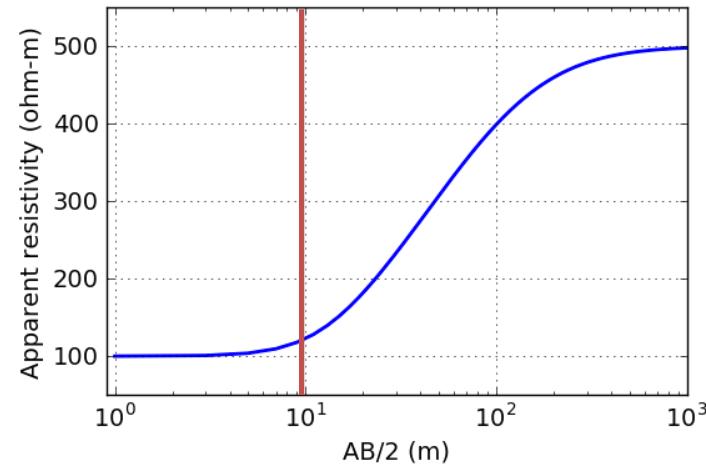
AB/2 = 5 m

$\rho_a = 100.30$



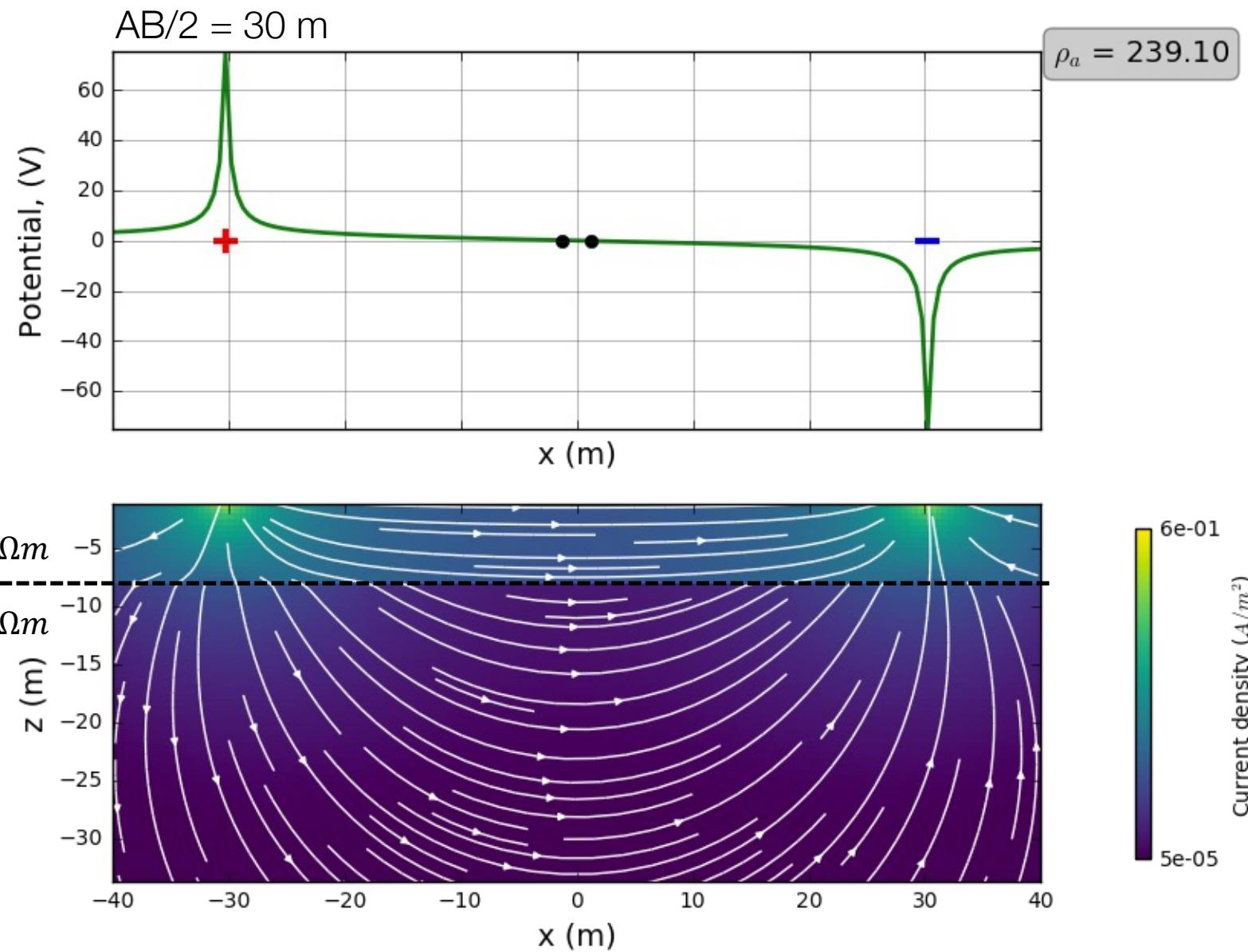
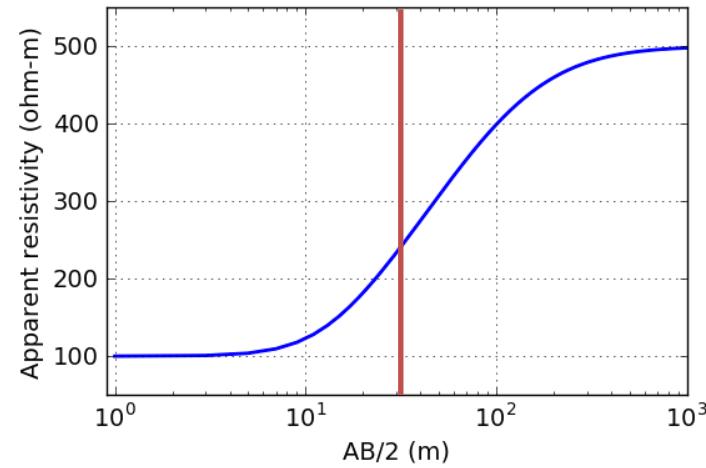
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DC Sounding curve



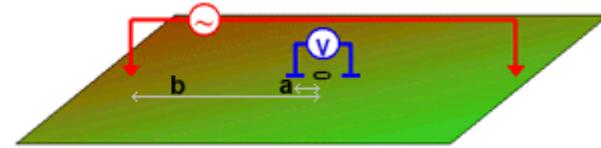
# Soundings

DC Sounding curve

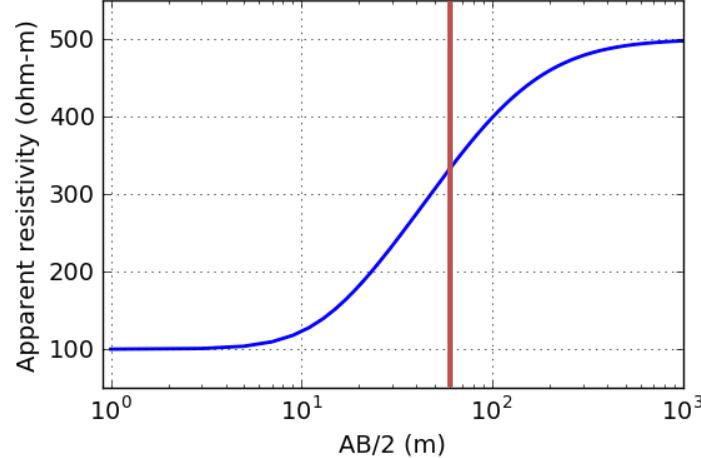


# Summary: soundings

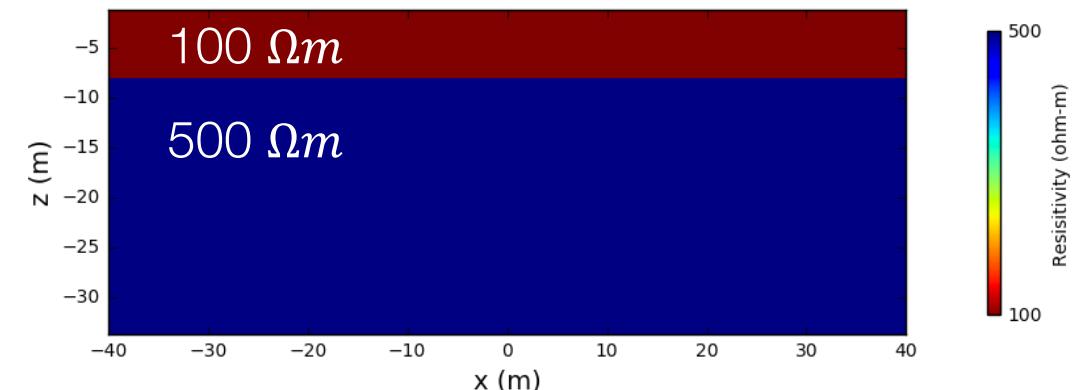
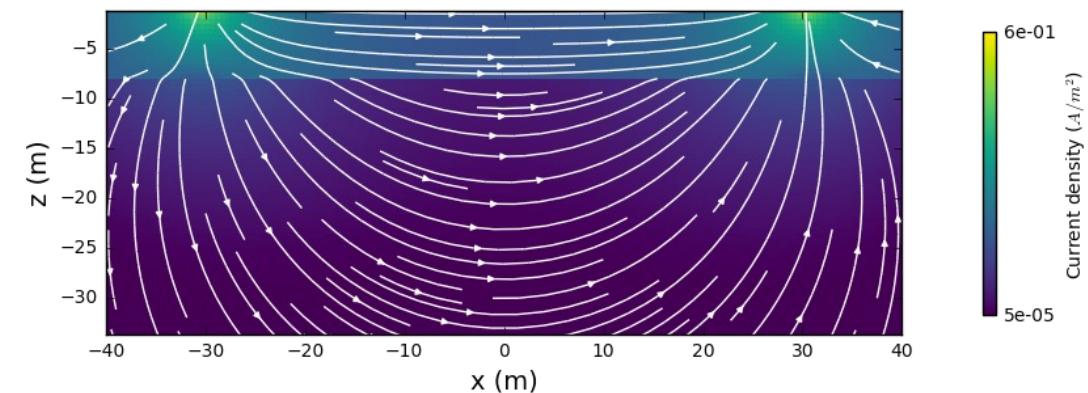
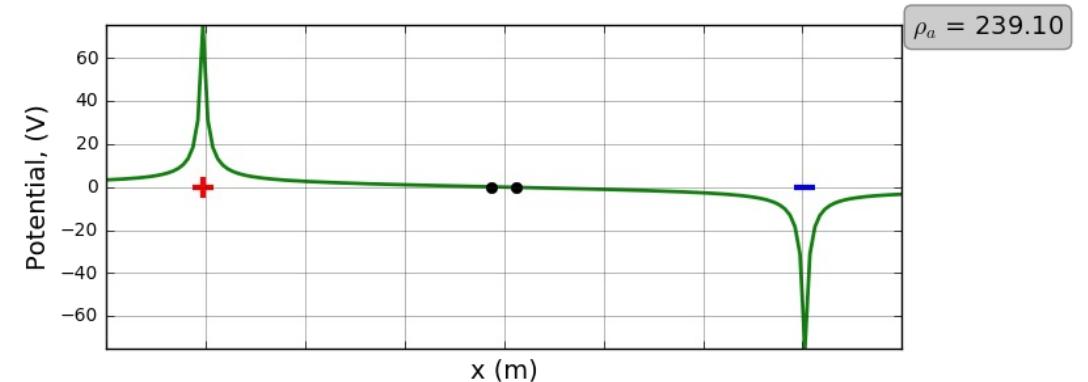
Schlumberger array



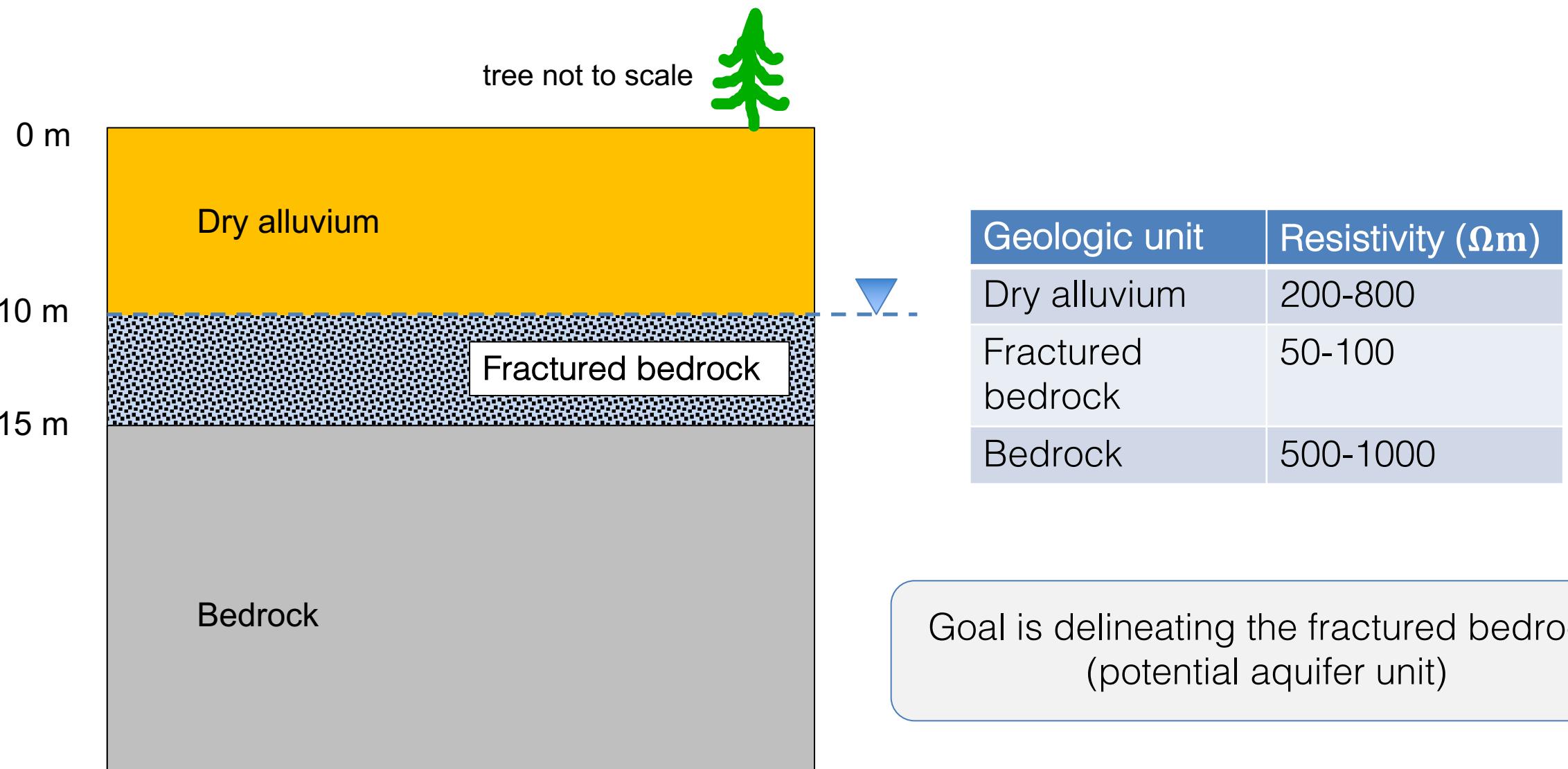
DC sounding curve



Scale length of array must be large to see deep



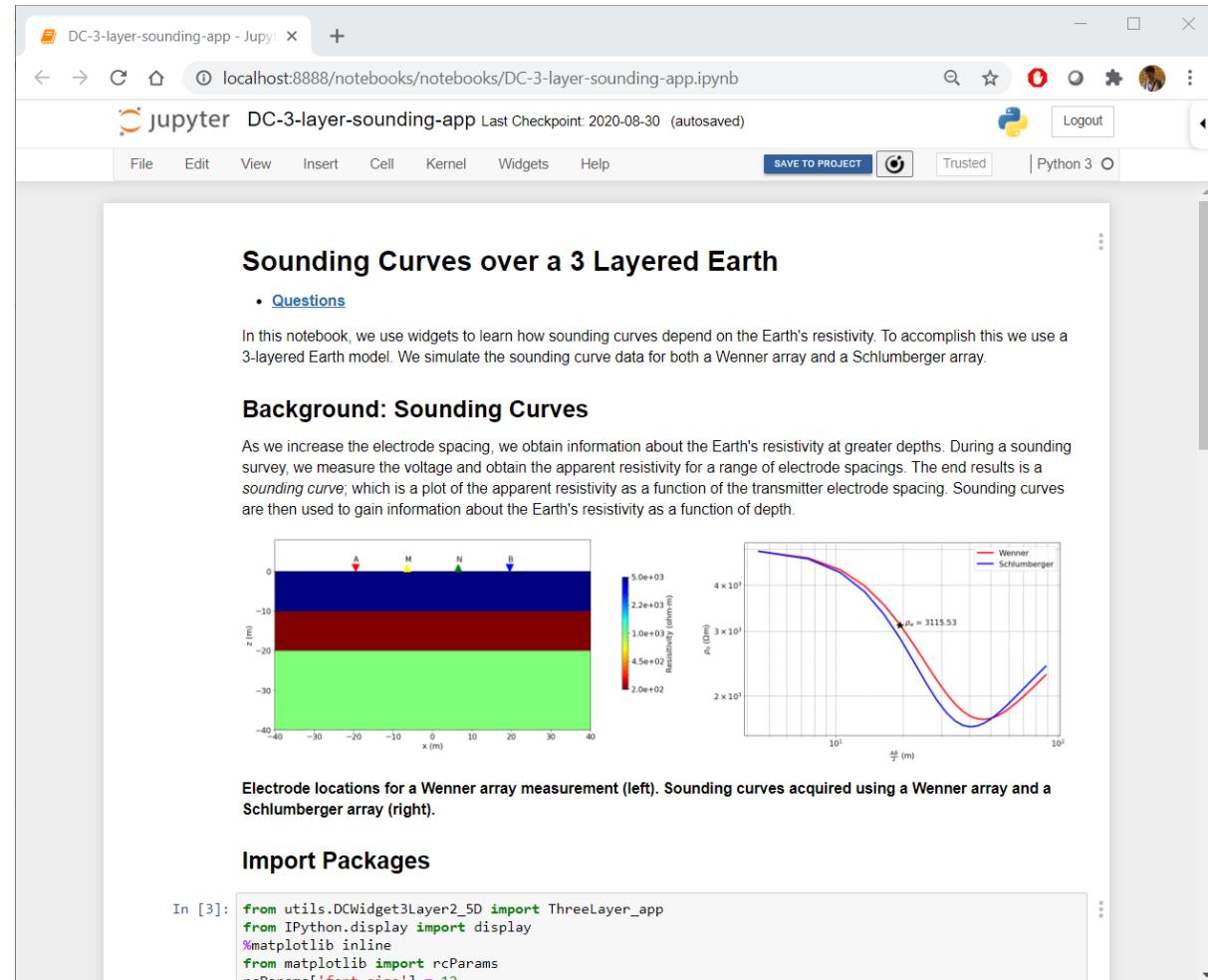
# An example layered-model for groundwater application



# Demo: DC-3-layer-sounding-app

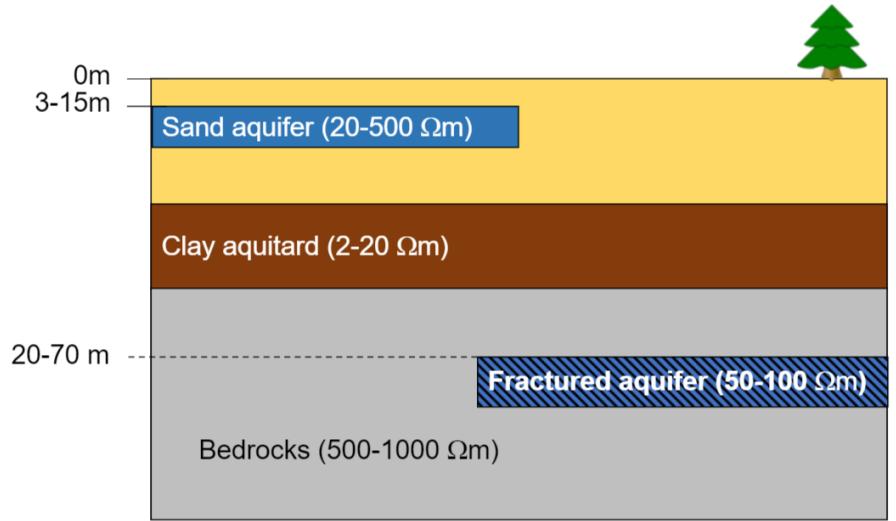
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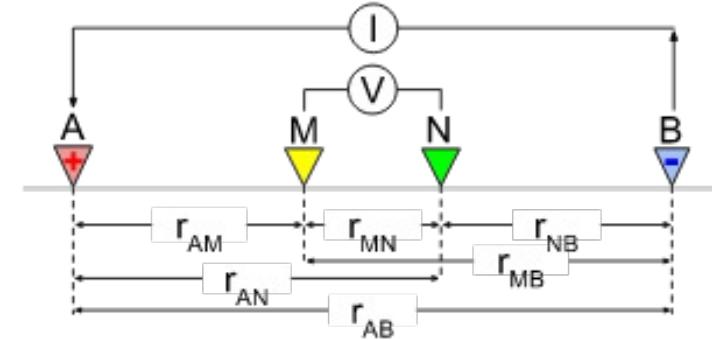
# Learning goals of the lecture

- Understand electrical resistivity and its linkage to geologic units.



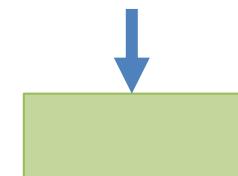
# Learning goals of the lecture

- Understand electrical resistivity and its linkage to geologic units.
- Understand a basic setup of direct current (DC) resistivity experiment.
  - Concept of an 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

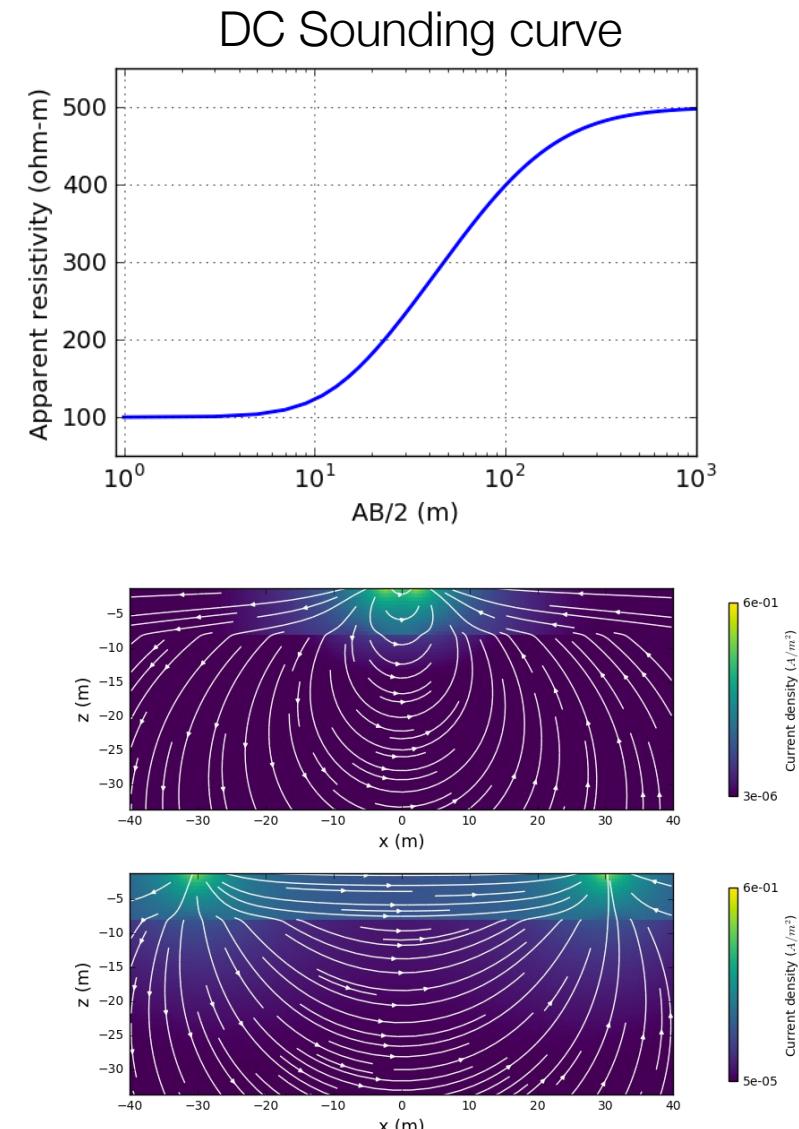


$$\rho_a = \frac{\Delta V_{MN}}{IG}$$

G: geometric factor

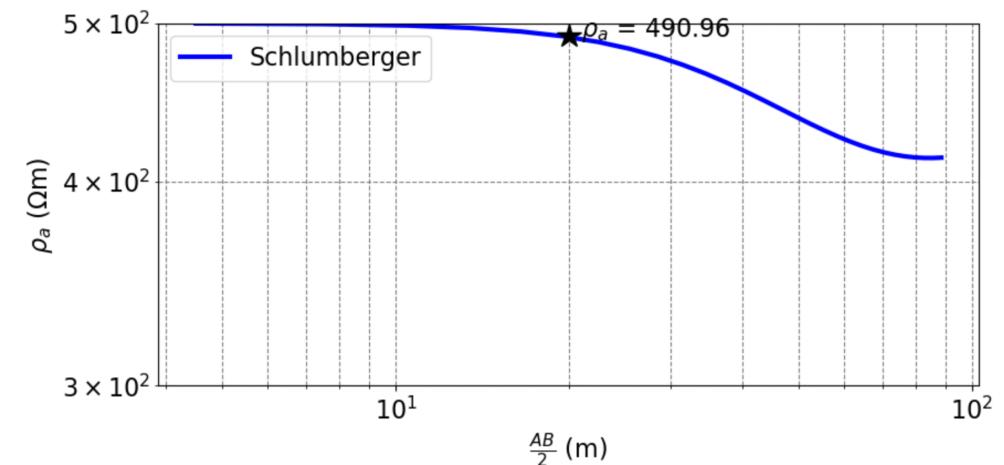
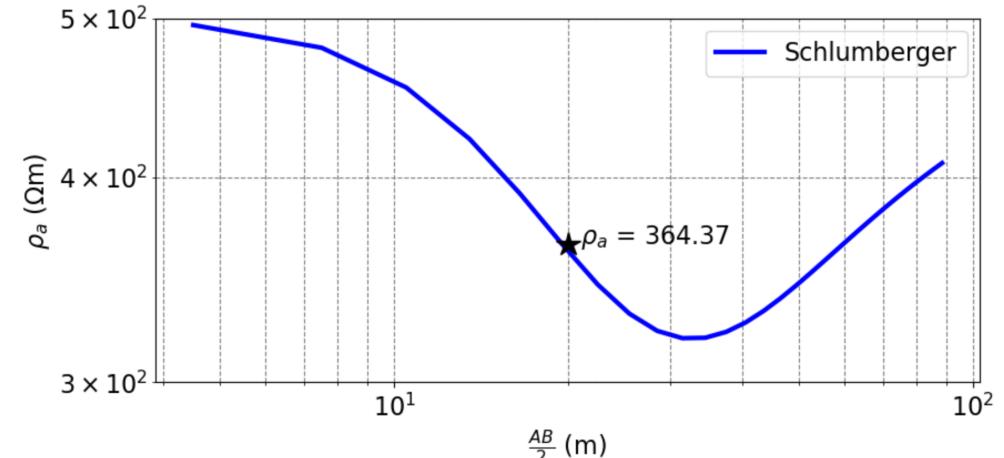
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- Understand electrical resistivity and its linkage to geologic units.
- Understand a basic setup of direct current (DC) resistivity experiment.
  - Concept of an apparent resistivity
  - Concept of a sounding
- Understand fundamental physics of the DC method related to electric currents.



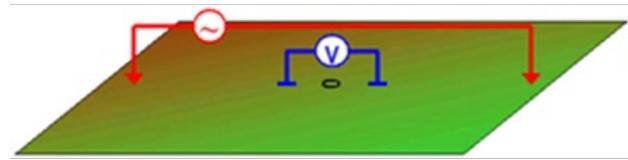
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- Understand a basic setup of direct current (DC) resistivity experiment.
  - Concept of an apparent resistivity
  - Concept of a sounding
- Understand fundamental physics of the DC method related to electric currents.
- Understand the limitation of the method, and necessity of careful survey design.

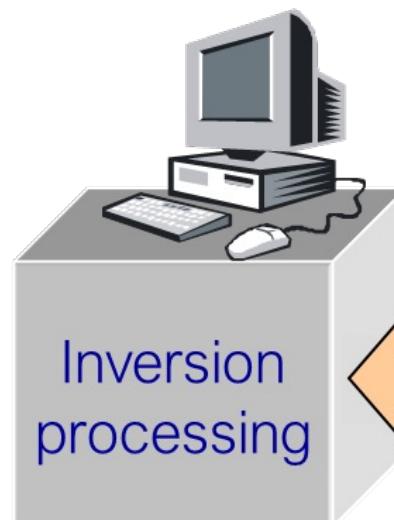
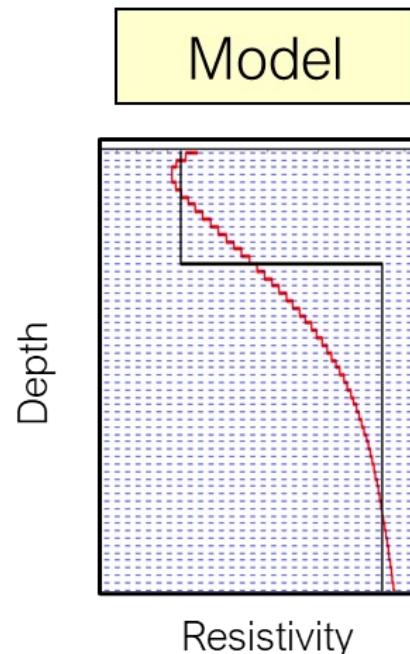
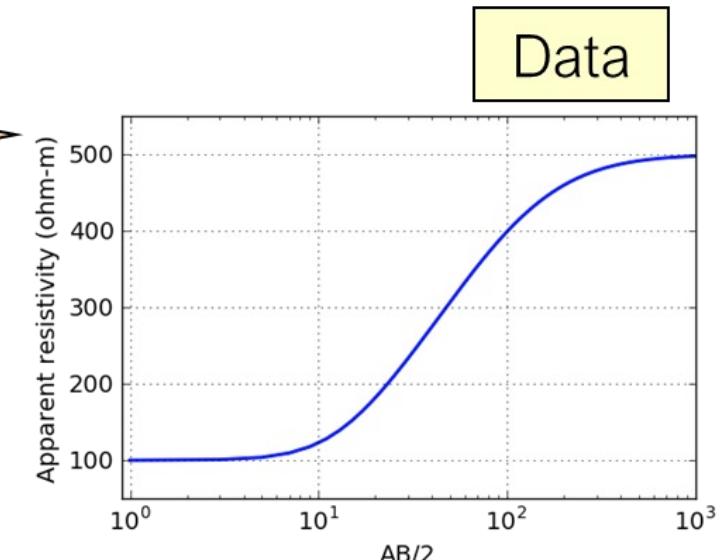


In the next lecture...

# Inversion



Measurements over  
the Earth are data.

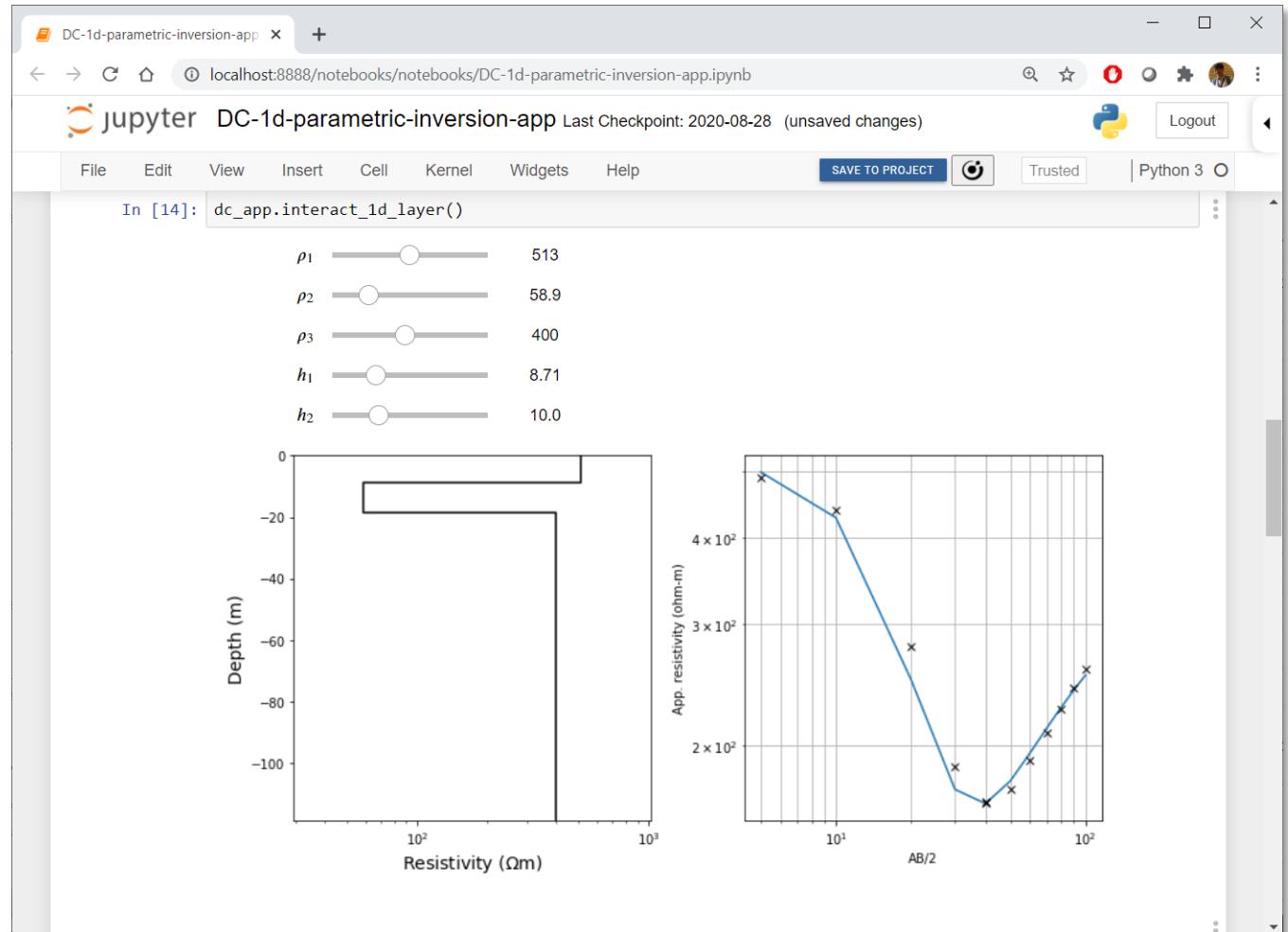


Inversion estimates Earth models  
based upon data and prior knowledge.

# Demo: DC-1d-parametric-inversion-app

## Why interactive apps?

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



Course resources are available:

Github repository:

[https://github.com/sgkang/uofm\\_envgp](https://github.com/sgkang/uofm_envgp)

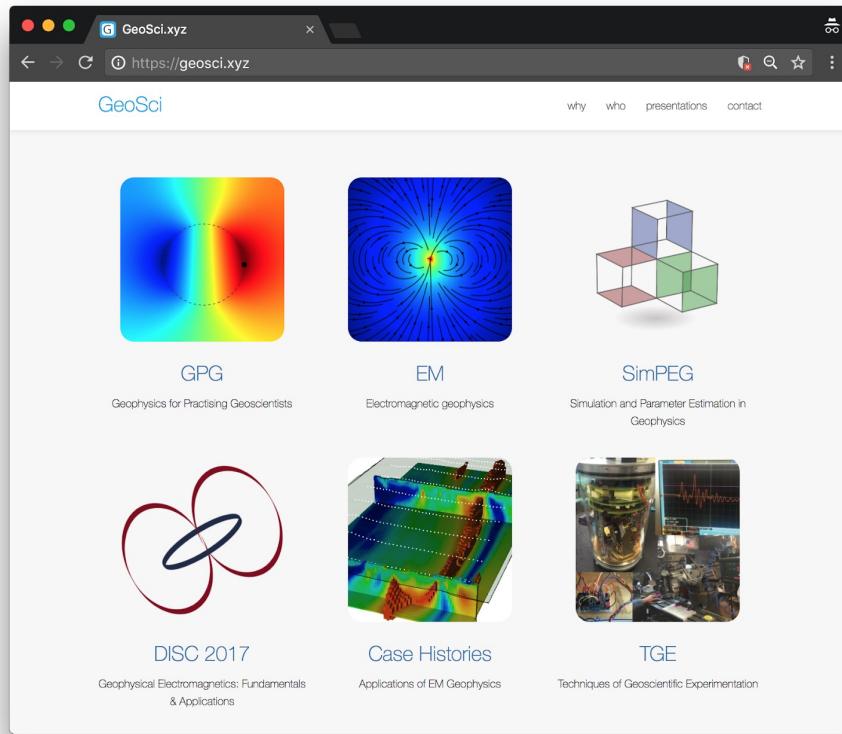
The Google Colab logo, featuring the word "Google" in its signature blue, red, and yellow colors, followed by "colab" in a yellow sans-serif font.

<https://bit.ly/DC-3-layer-sounding-app>

# Open resources for education

# GeoSci.xyz: Open-source Resources for Learning

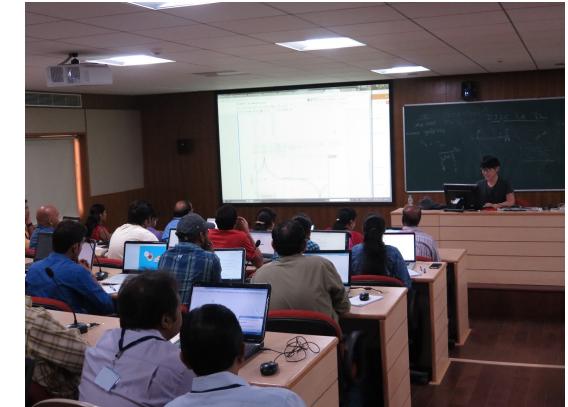
<https://www.geosci.xyz>



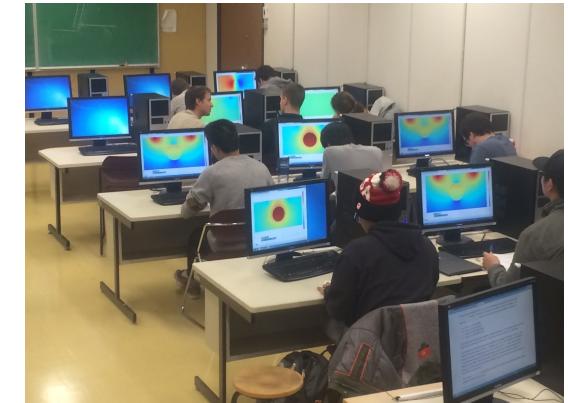
Content + Interactive computing

A screenshot showing the 'Geophysics for Practicing Geoscientists' (GPG) documentation on the left and a Jupyter notebook on the right. The GPG documentation page lists topics like Foundations, Physical Properties, Magnetics, Seismic, and DC Resistivity. The Jupyter notebook is titled 'jupyter DC-2d-inversion-app (unsaved changes)' and shows a 'Step 2: Plot observed data' section with a code cell and a resulting 2D resistivity pseudo-section plot.

EM course (DISC 2017)



Undergrad geophysics course



- Universities relying on GeoSci for courses

University of Houston

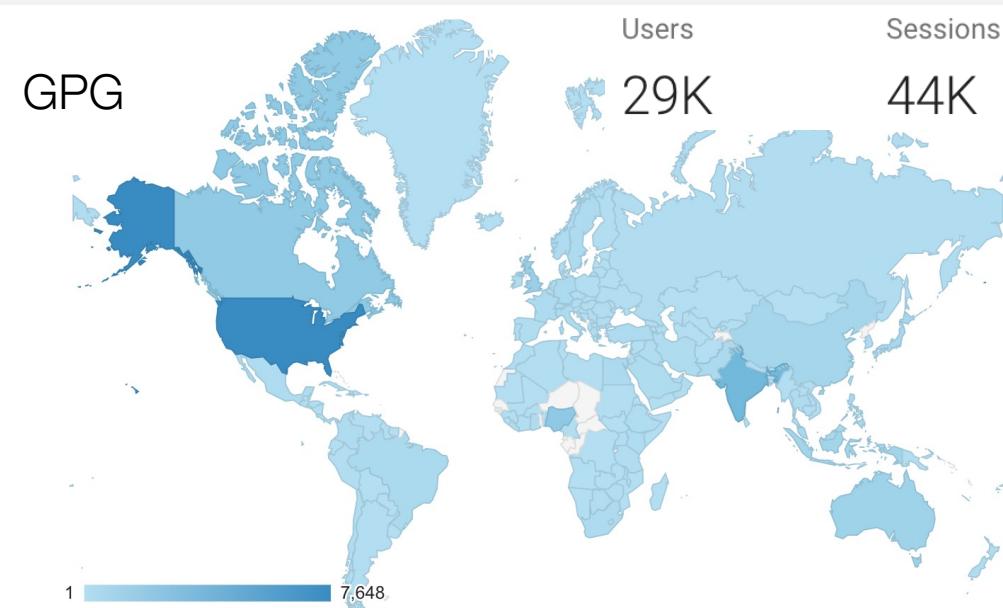
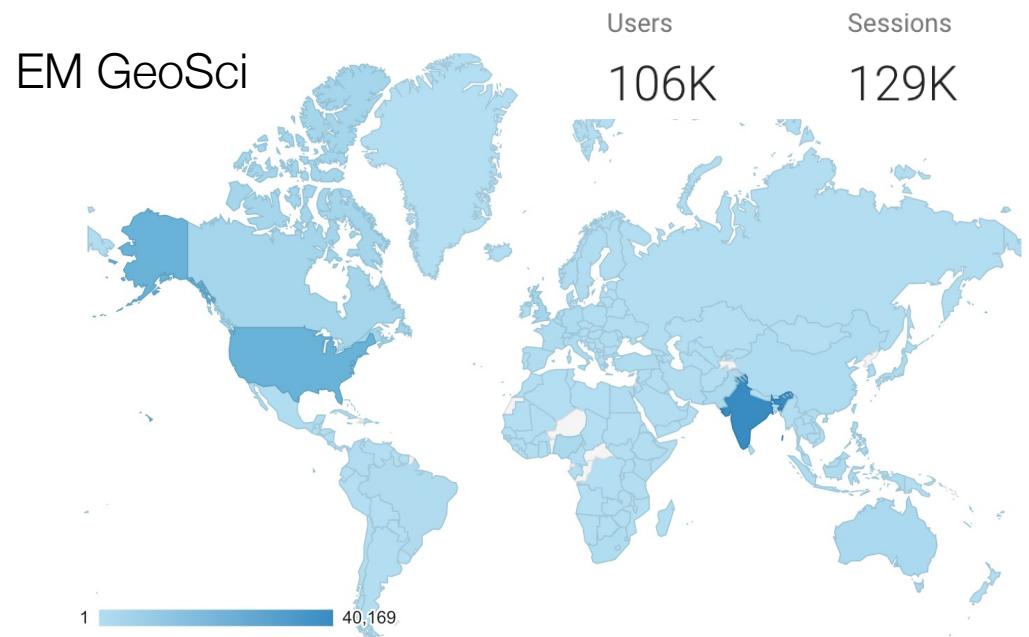
University of Alabama

UBC, Canada

Southern University of Science and Technology (China)

The Federal University of Minas Gerais (Brazil)

...



# Open-source software



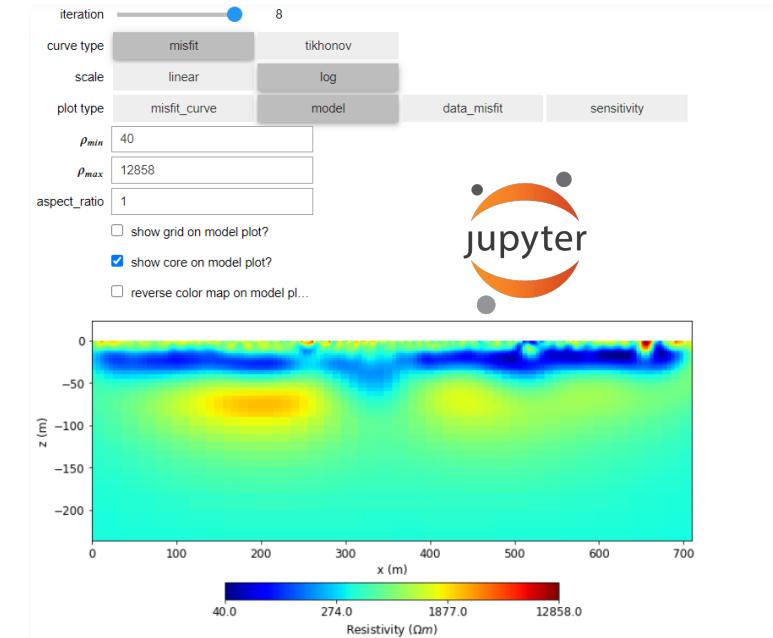
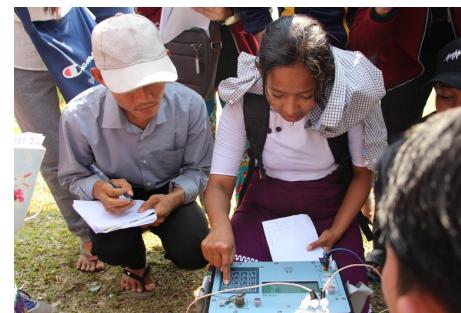
Expanding use of research  
software for educational purposes

<https://www.simpeg.xyz>

# Humanitarian geophysics



Build local capacity through training.  
Leave open-sources resources for sustainability.  
Local groundwater in stressed villages.



Doug Oldenburg



Kevin Fan



Michael (Max)  
Maxwell



Devin Cowan



Seogi Kang

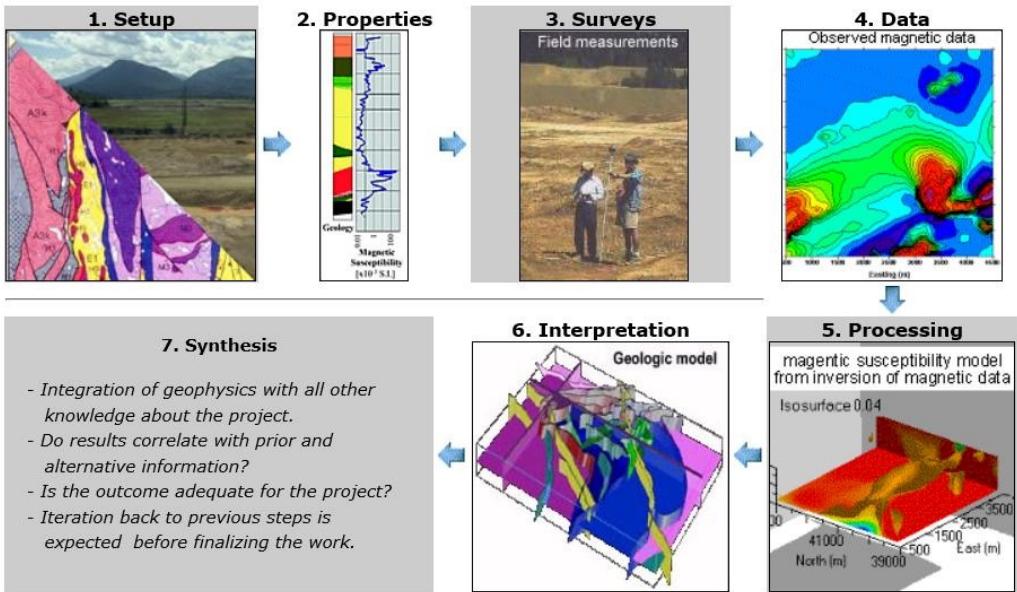


Lindsey Heagy

<https://medium.com/gwb-myanmar>

# Case histories

Structured, reproducible scientific narratives



Mt Isa — Electromagnetic Geo X

em.geosci.xyz/content/case\_histories/mt\_isa/index.html

Incognito (2)

Introduction

Physical Properties

Maxwell I: Fundamentals

Maxwell II: Static

Maxwell III: FDEM

Maxwell IV: TDEM

Geophysical Surveys

Inversion

**Mt. Isa**

- Authors: Dom Fournier, Dr. Kris Davis
- Editor: Douglas Oldenburg

Prelude

This case history follows the inversion of DC/IP data to delineate ore-bearing rock units at Mt. Isa, Queensland, Australia.

Special Thanks

Thanks to CSIRO publishing for permission to reproduce figures and adapt text from the source material. This Case History is based upon the paper: [2-D and 3-D IP/resistivity for the interpretation of Isa-style targets](#) by Rutley, Oldenburg and Shekhtman [ROS01].

Abstract

Here, we show one of the first examples of inverting DC/IP field data to recover 3D distributions of resistivity and chargeability. Prior to this, the inversion of field data was primarily carried out in 2D. We use this case history to provide an example for inverting DCR and IP data and to link different parts of the survey and processing to the fundamentals of EM as presented in [EM.geosci](#). We have re-inverted the data but have kept as many details as possible to be the same as in the original paper. This enables us to show how current technology has increased the ability to recover details about the subsurface.

- Setup
- Properties
- Survey
- Data
- Processing
- Interpretation
- Synthesis
- Lessons worth highlighting

Noranda

Norsminde

SAGD

Saurashtra

Wadi Sabha

Red Sea

West Plains

Gallery

References

NT1200  
NT1150  
NT1100  
NT1050  
NT1000  
NT14700  
NT14200  
NT13700  
NT13200  
NT12700  
NT12200

[https://em.geosci.xyz/content/case\\_histories](https://em.geosci.xyz/content/case_histories)