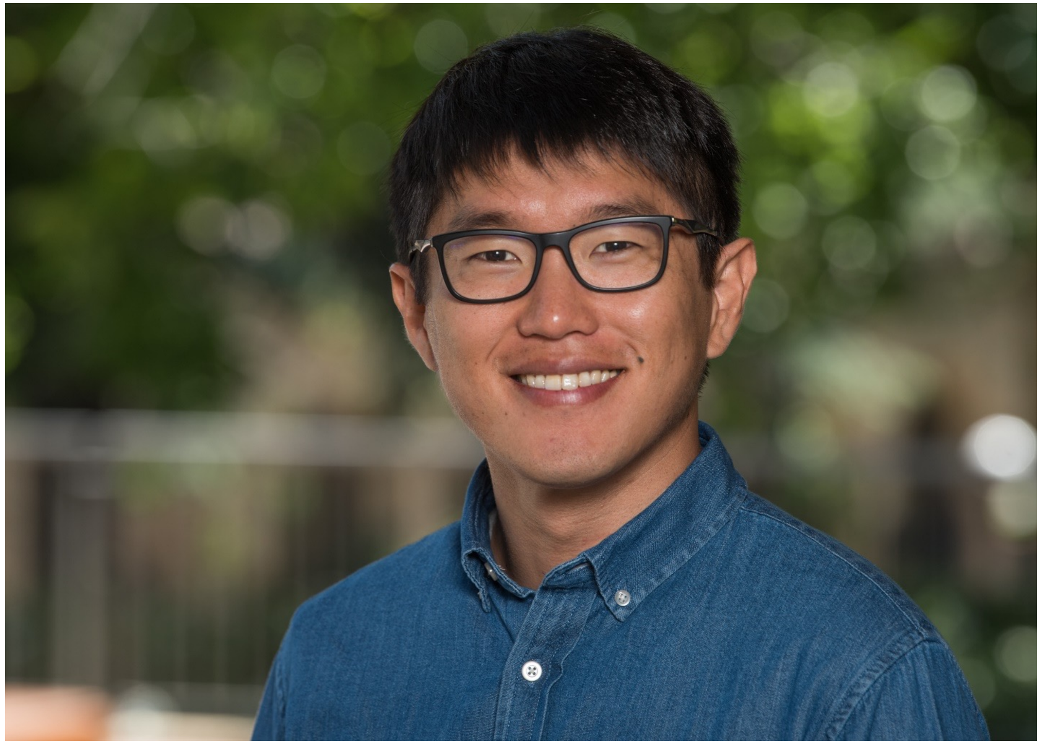


Seogi Kang

Research Scientist in
Stanford Environmental Geophysics Research Group

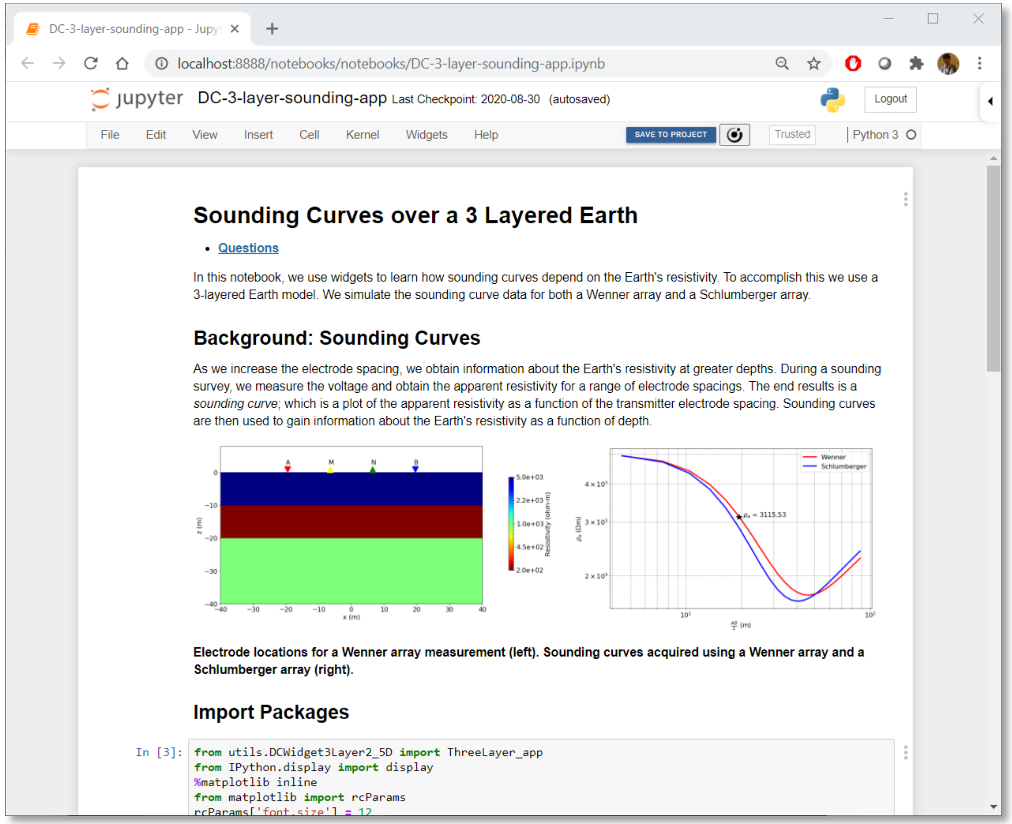
Computational geophysicist using various types of sensors (borehole, surface-based, airborne, satellite).

Passionate for adopting open-science practices to education.

Advance environmental geophysics to solve challenging geoscience problems

Assumptions:

- This course is for 3rd/4th 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.



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?

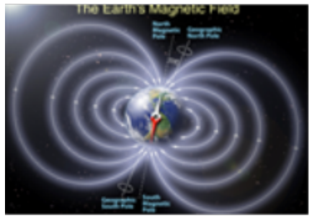
All require ways to see into the earth without direct sampling

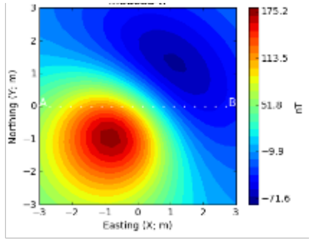
Source

Input energy

measure

Data





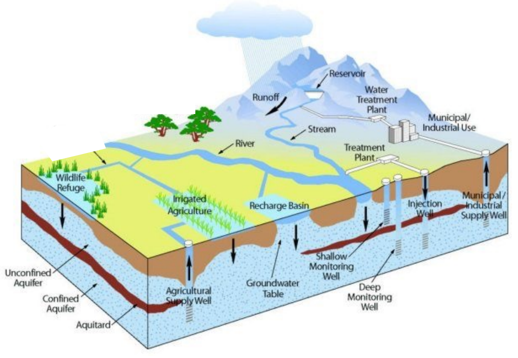
Physical Properties

σ, μ, ε

Climate change & Energy transition

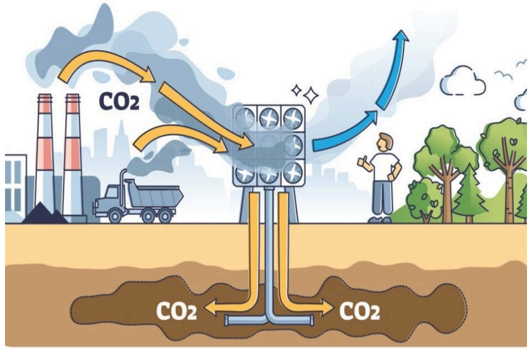
Example problems where environmental geophysical can contribute to the solution

Groundwater

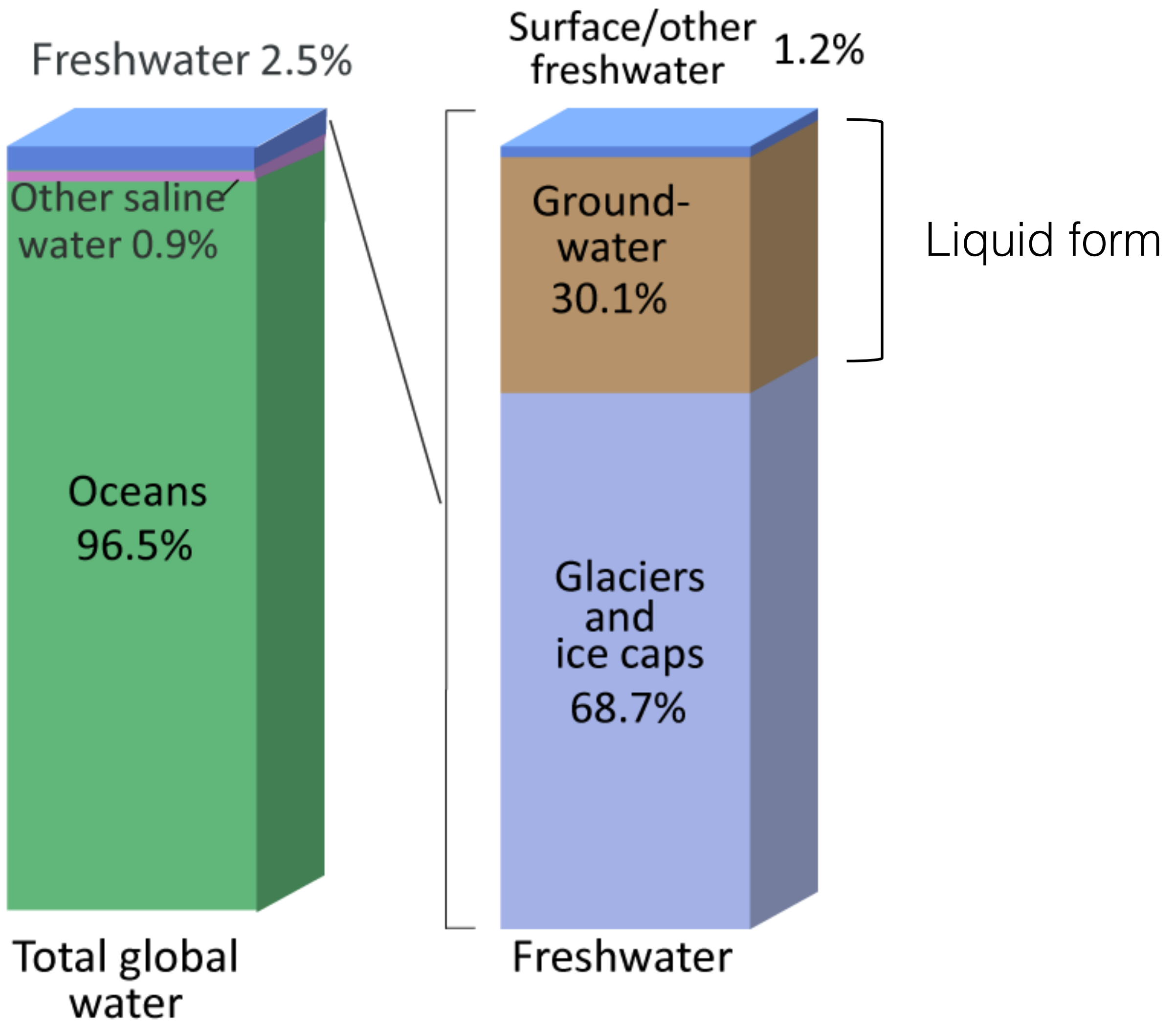


Critical minerals

Geologic storage of CO2



Cryosphere
(e.g., permafrost)



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).

Groundwater

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

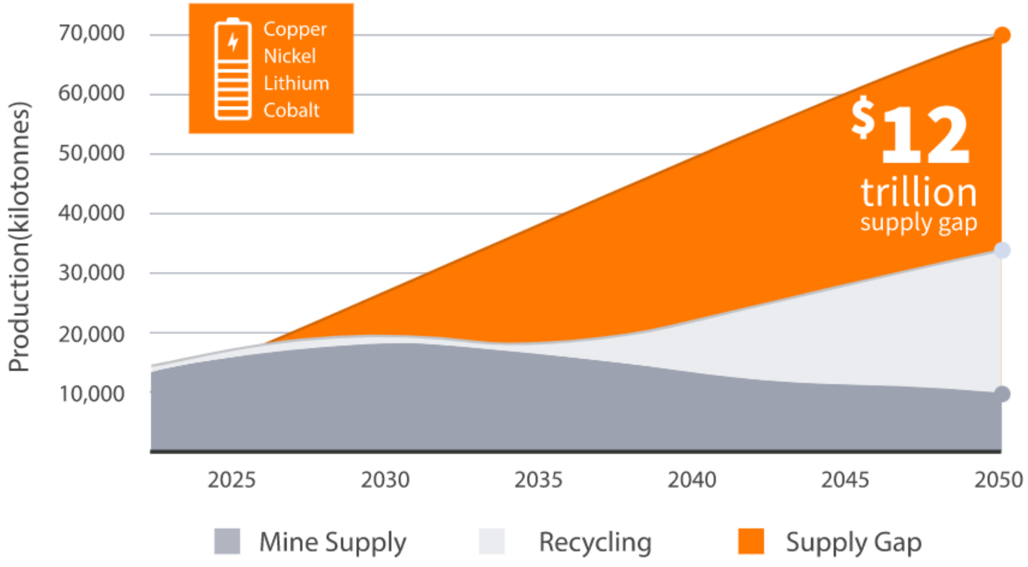
Population growth &
Climate change

Increasing concerns about
groundwater sustainability

Critical minerals

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

Need to secure supply of critical minerals for energy transition



Kobold (2023)

Easy targets on the surface have already been found.

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

Geologic storage of CO_2

Image from CAMI site, Alberta

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

Monitor the leakage to the surface or
shallow aquifers

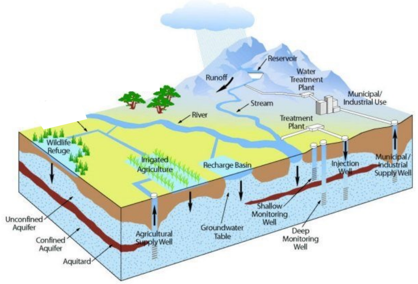
Cryosphere

E.g., Permafrost

Melting ice in the Antarctic
→ sea level rise

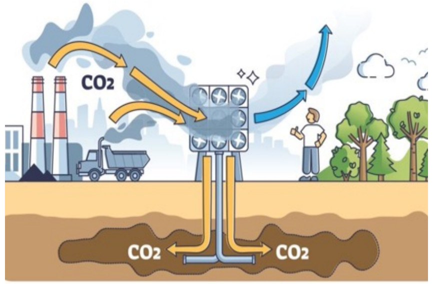
Melting permafrost in the Arctic
→ loss of storage for green house gases
→ geotechnical issues

Groundwater



Critical minerals

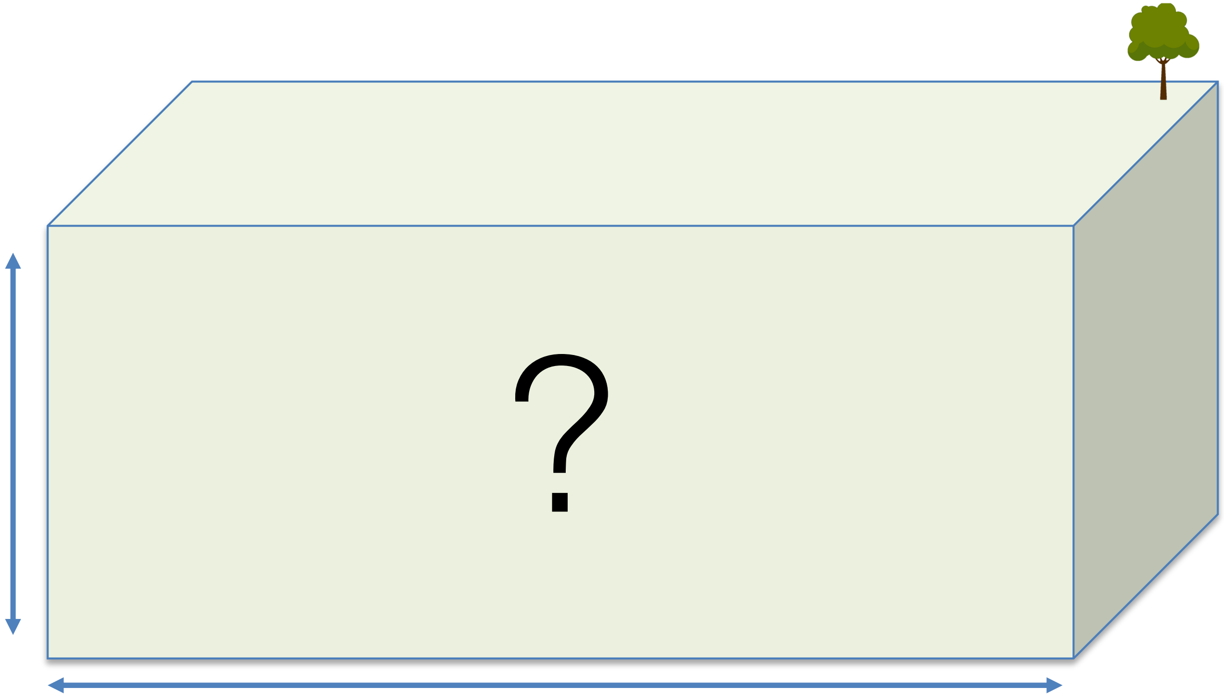
Geologic storage of CO2



Cryosphere
(e.g., permafrost)

Need to image the subsurface (at multiple scales)

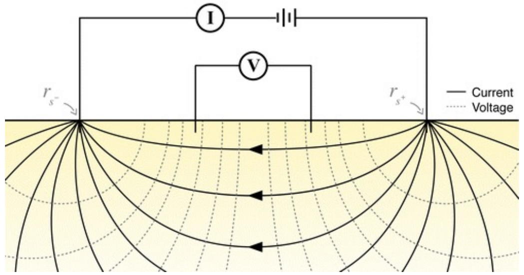
Tens to
hundreds of
meters
(or more)



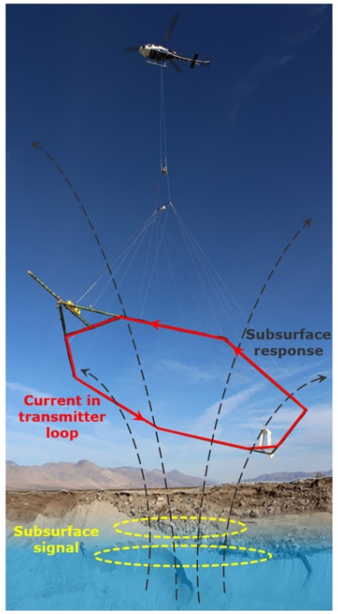
100s of meters to 1000s of kilometers

Environmental geophysics can an important role

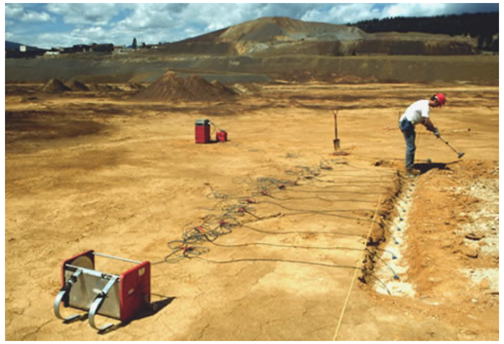
Electrical methods



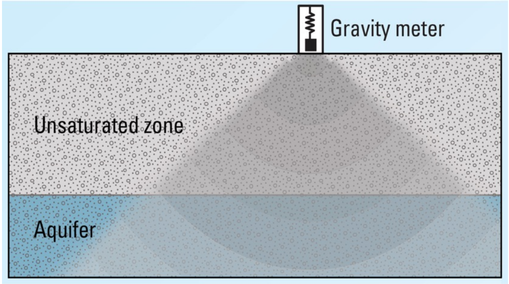
Electromagnetic methods



Seismic methods



Potential fields (e.g., gravity)

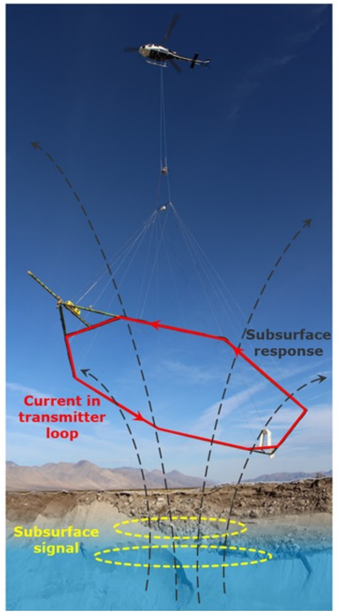


Provides a cost-effective way to image the subsurface

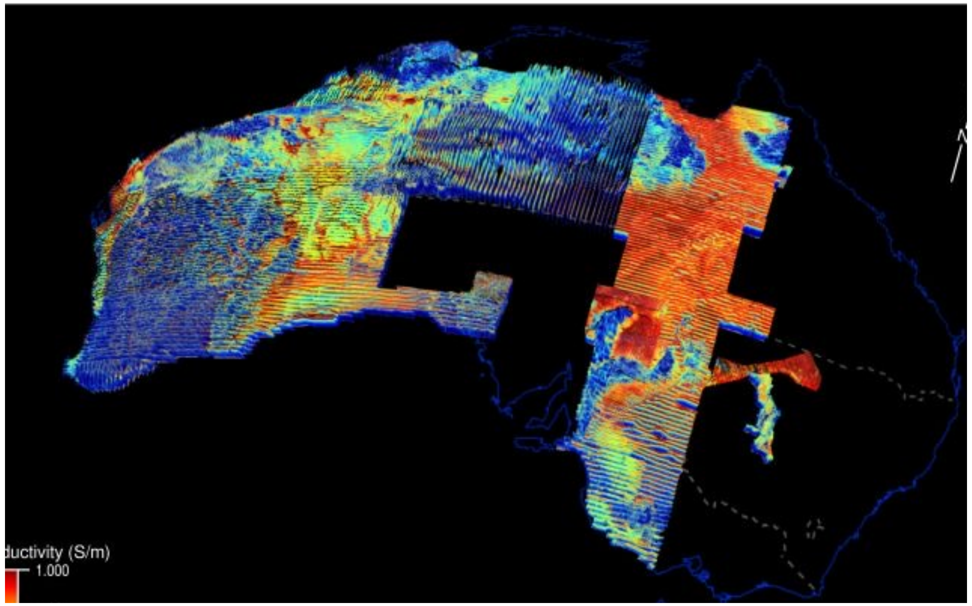
Increasing volume & complexity of geophysical data

example: airborne EM (AEM)

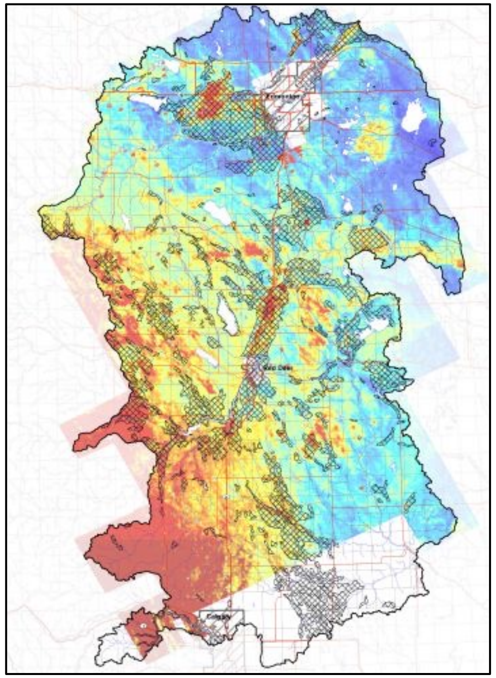
Airborne EM



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

My main overarching goals are

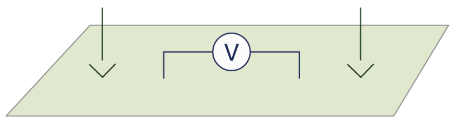
To engage students with concepts of geophysics – <u>“fundamentals”</u>

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

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

Direct Current Resistivity Method

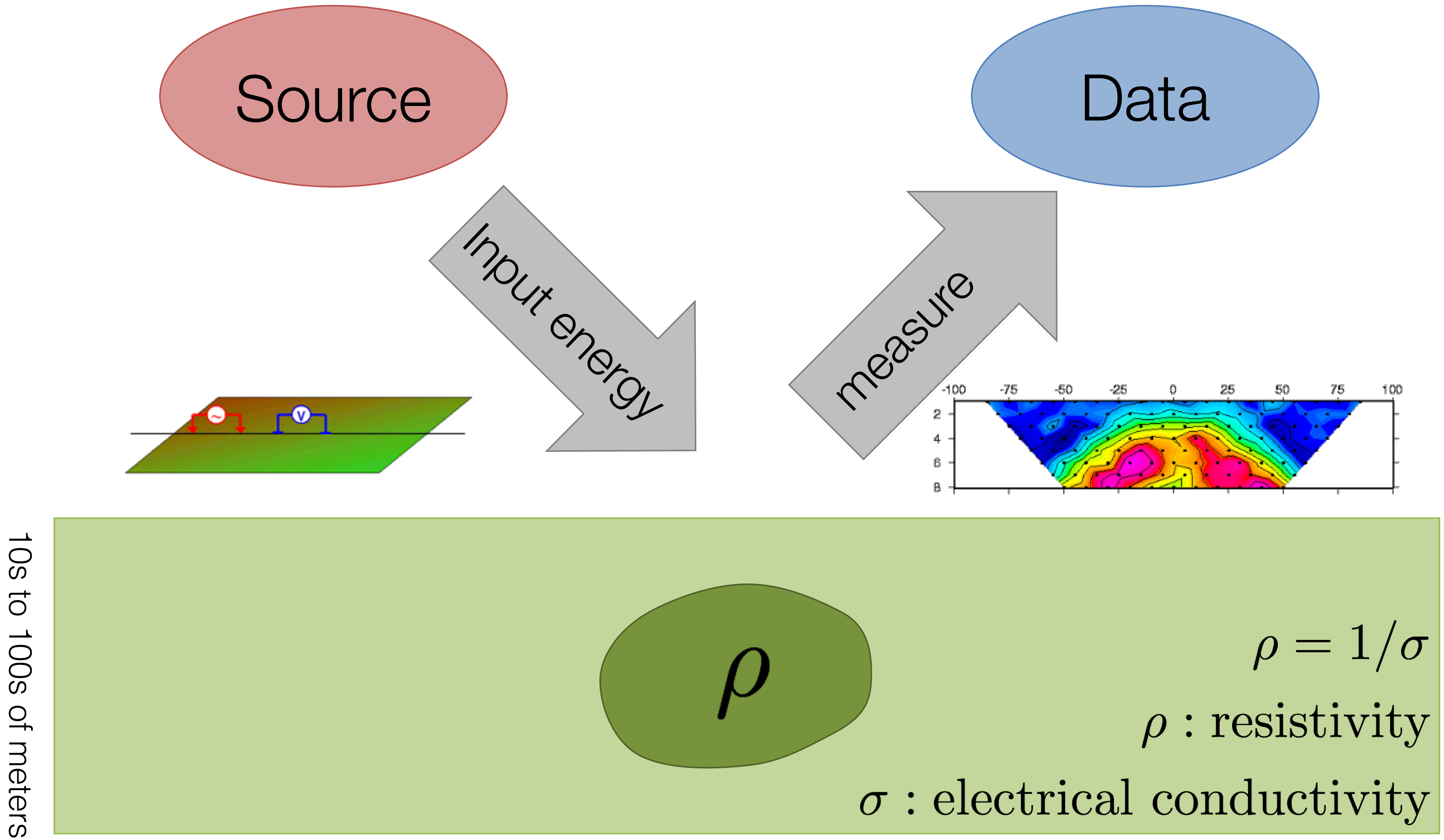
Seogi Kang



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

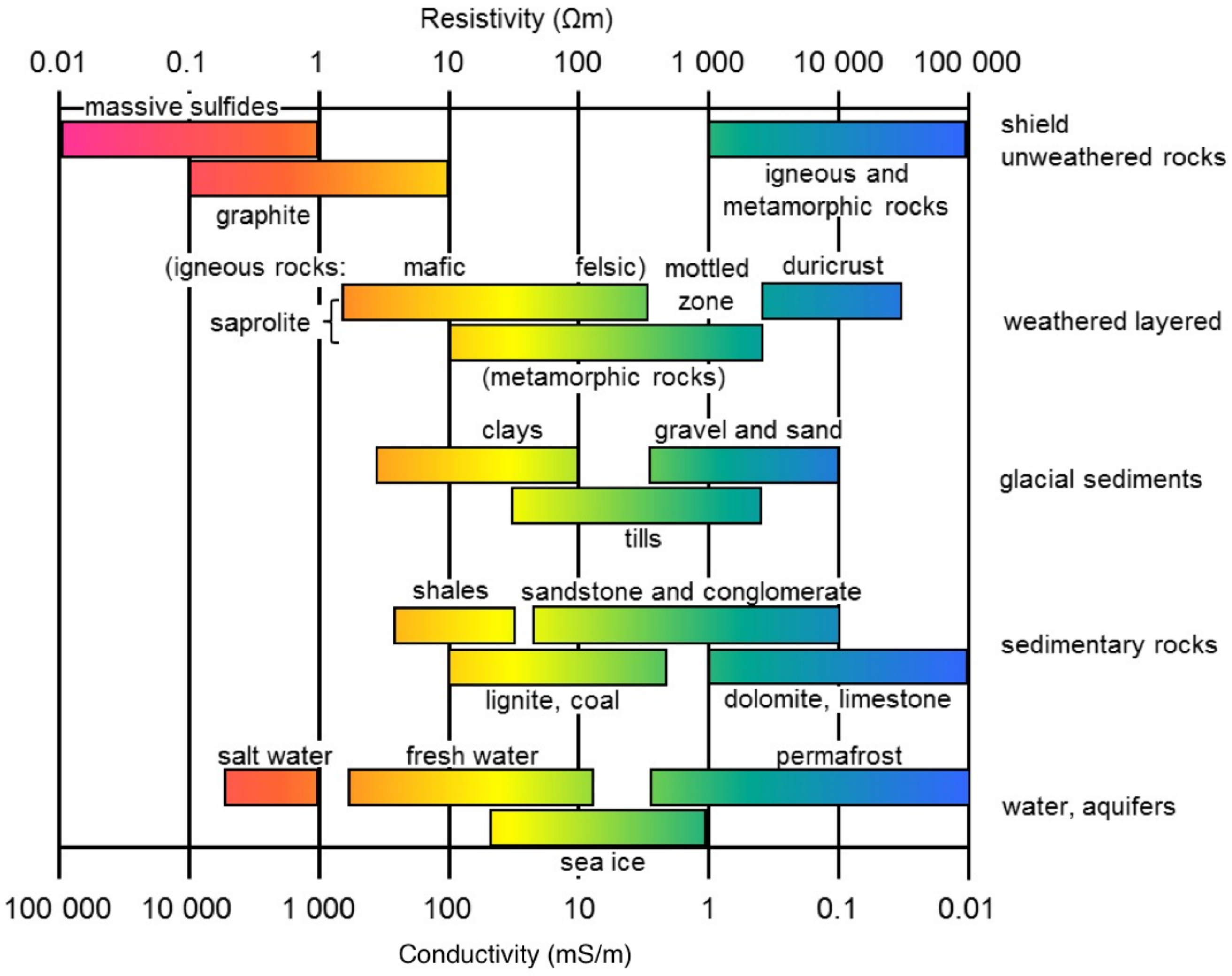


$$\rho = 1/\sigma$$

ρ : resistivity

σ : electrical conductivity

Electrical resistivity (or conductivity)



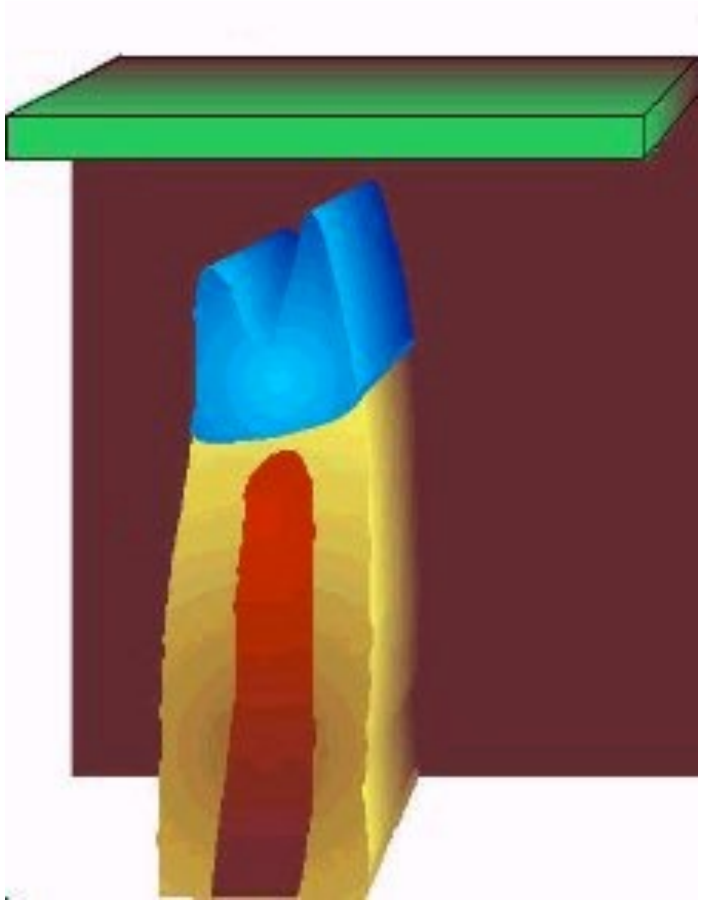
- DC resistivity is sensitive to:
  - σ: Conductivity [S/m]
  - ρ: Resistivity [Ωm]
  - $\sigma = 1/\rho$
- Varies over many orders of magnitude
- Depends on many factors:
  - Rock type
  - Porosity
  - Connectivity of pores
  - Nature of the fluid
  - Metallic content of the solid matrix

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

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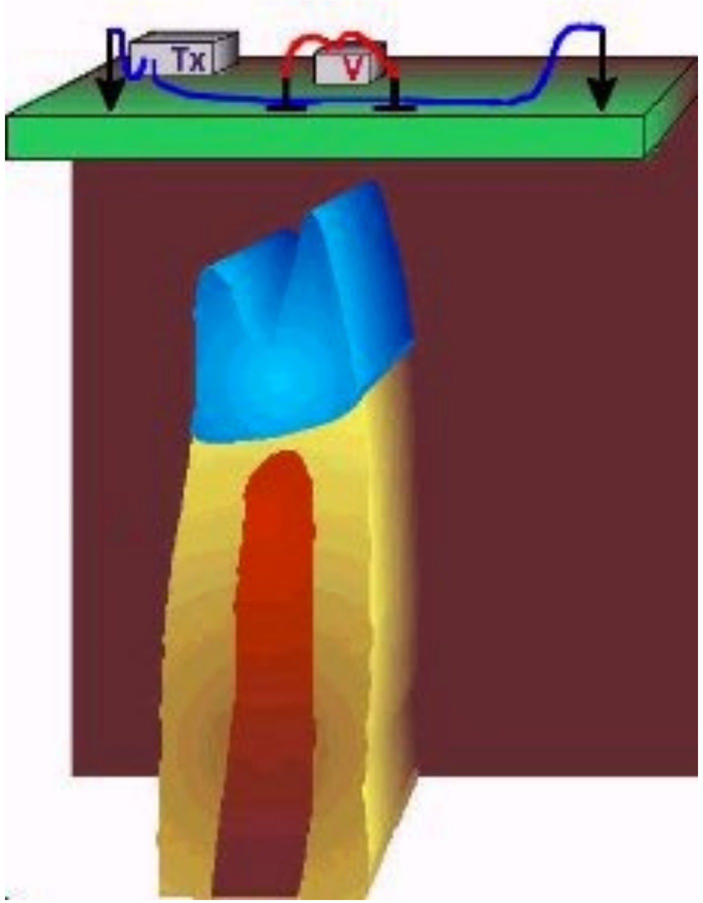

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- Target:
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- Currents:
  - Preferentially flow through conductors

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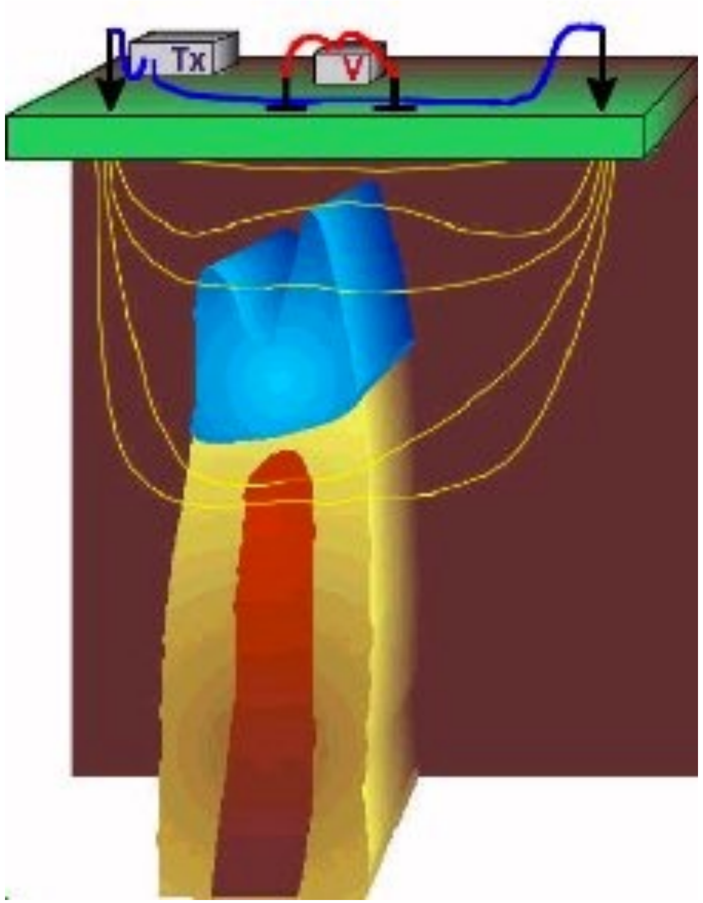

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- Target:
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- Charges:
  - Build up at interfaces

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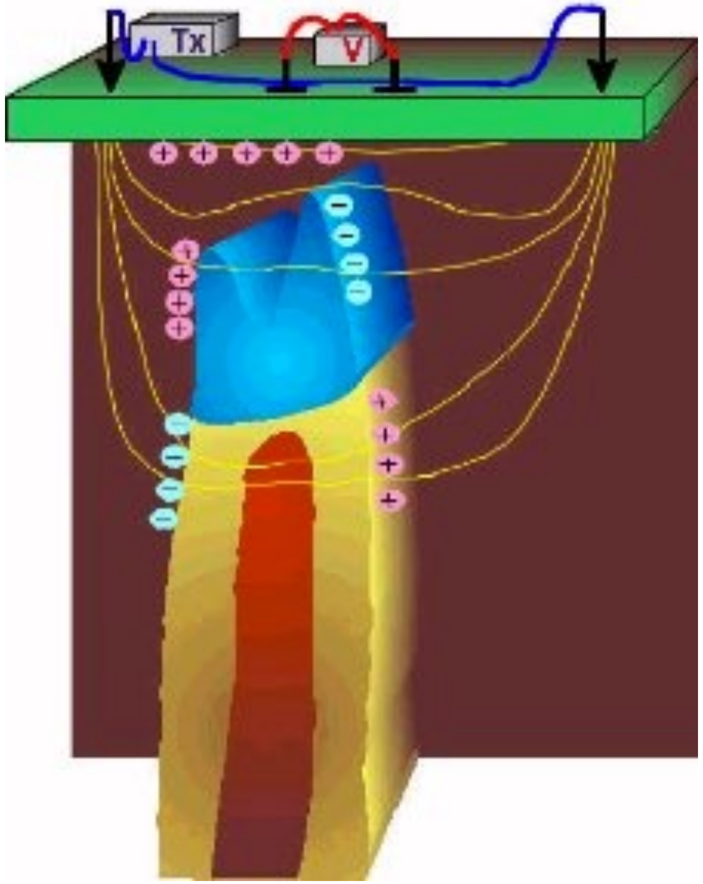

Basic Experiment

- 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*
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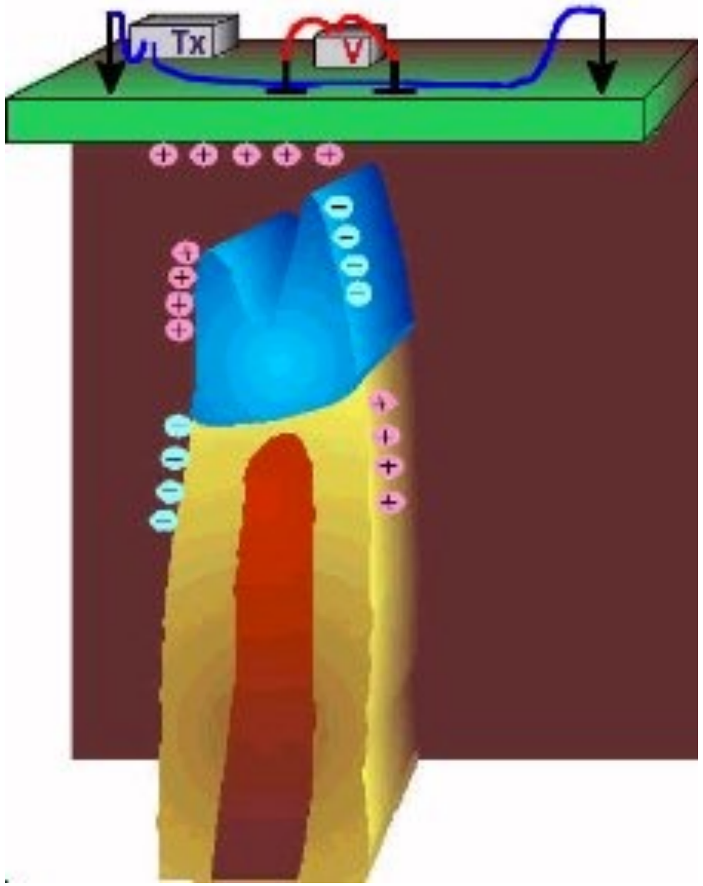
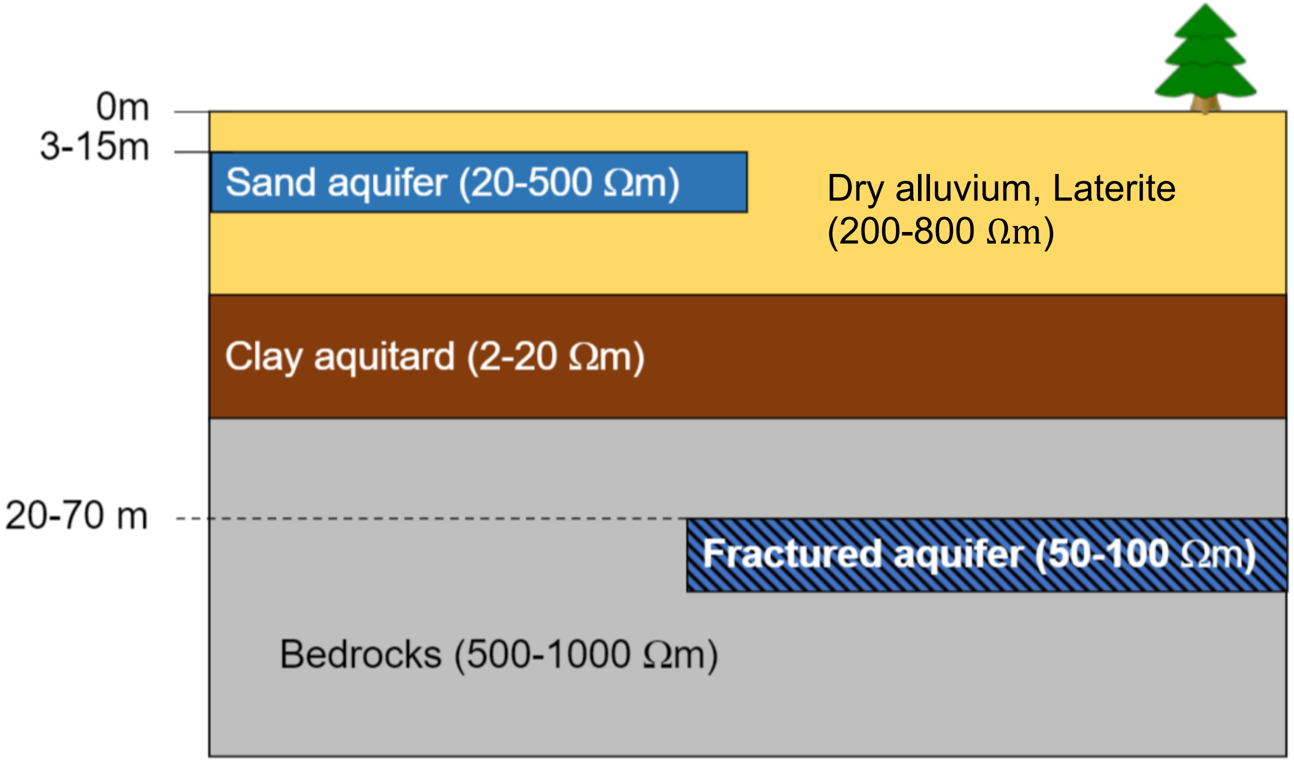


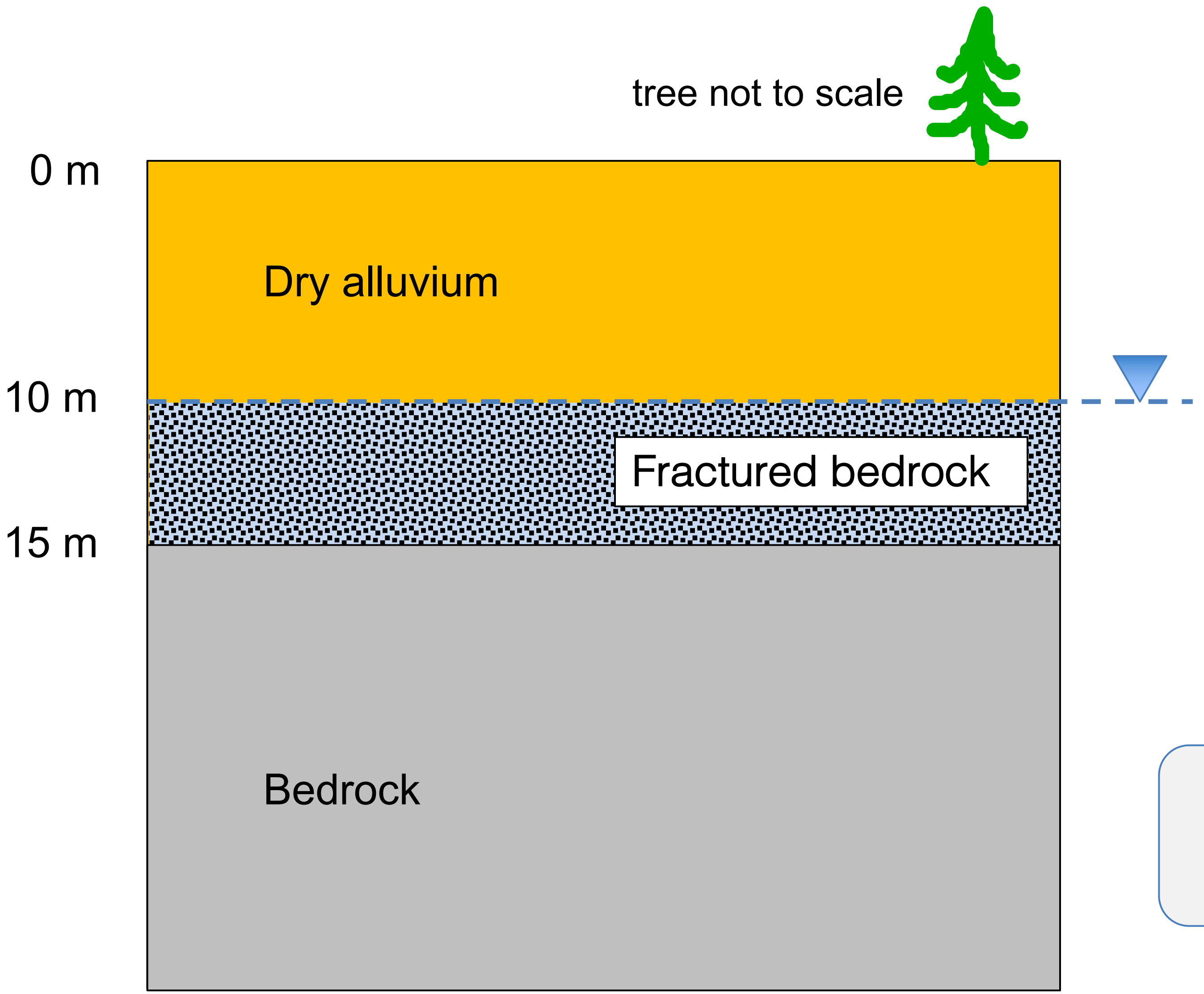
Motivating example: Mon State, Myanmar

A local water stressed region

A general hydrogeology



An example layered-model for groundwater application



Geologic unit	Resistivity (Ωm)
Dry alluvium	200-800
Fractured bedrock	50-100
Bedrock	500-1000

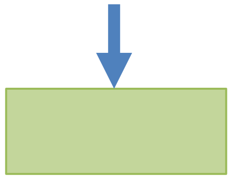
Goal is delineating the fractured bedrock (potential aquifer unit)

How do we obtain resistivity?

Steady-state Maxwell's equations

	Full	Steady State
Faraday	$\nabla \times \vec{e} = -\frac{\partial \vec{b}}{\partial t}$	$\nabla \times \vec{e} = 0 \qquad \vec{e} = -\nabla V$
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

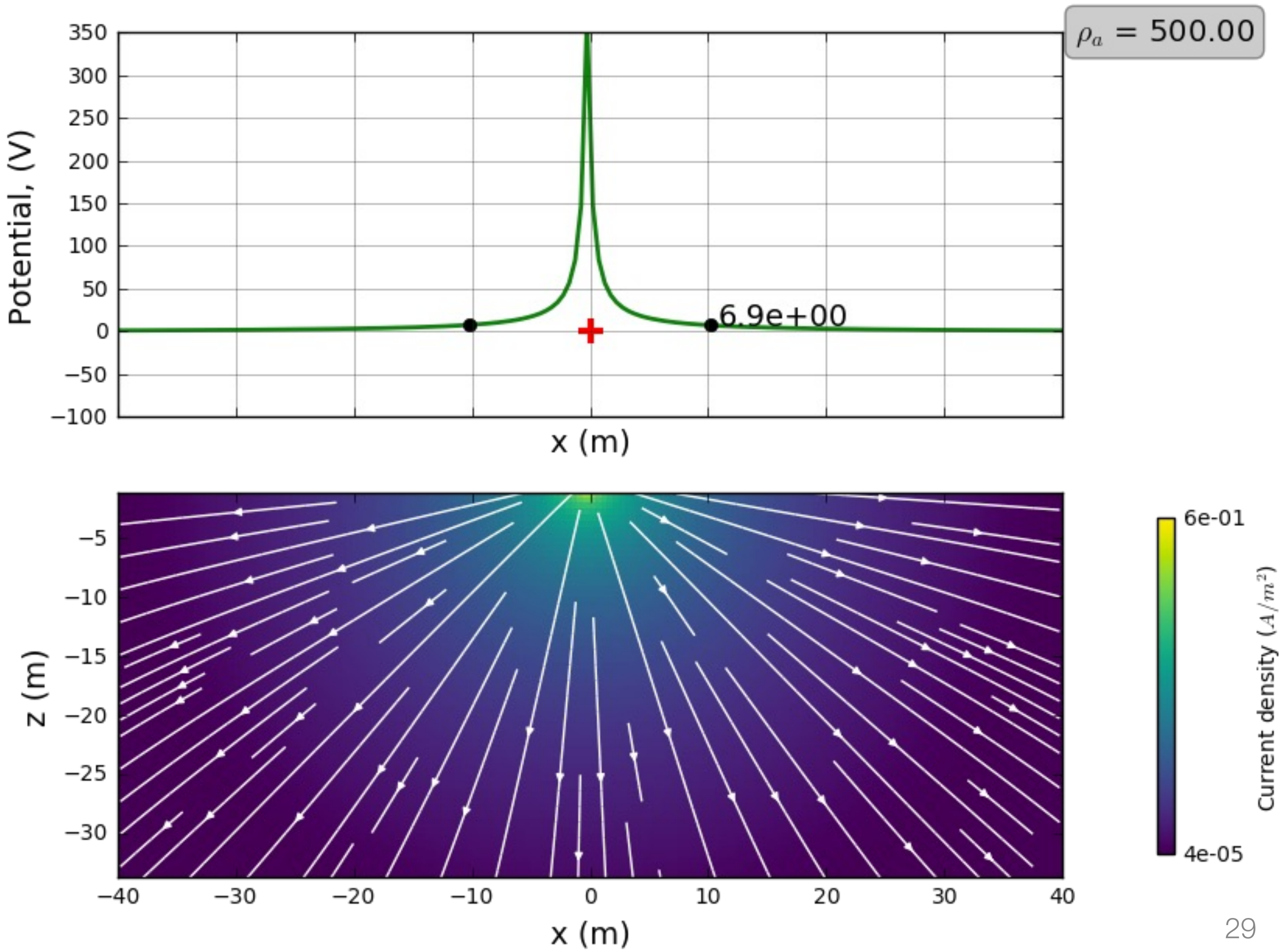


$$V = \frac{I}{2\pi\sigma}\frac{1}{r} \qquad V = \frac{\rho I}{2\pi r}$$

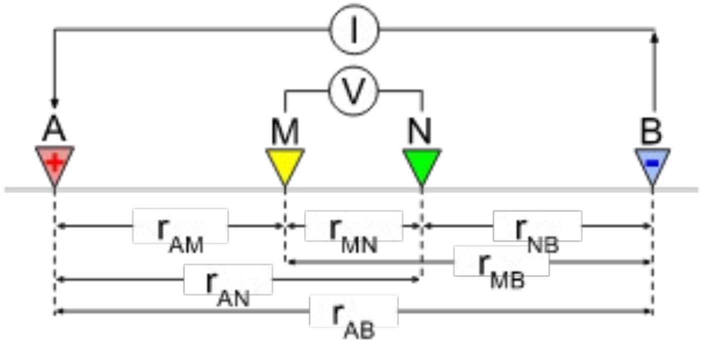
Currents and potentials: halfspace

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

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



Currents and potentials: 4-electrode array



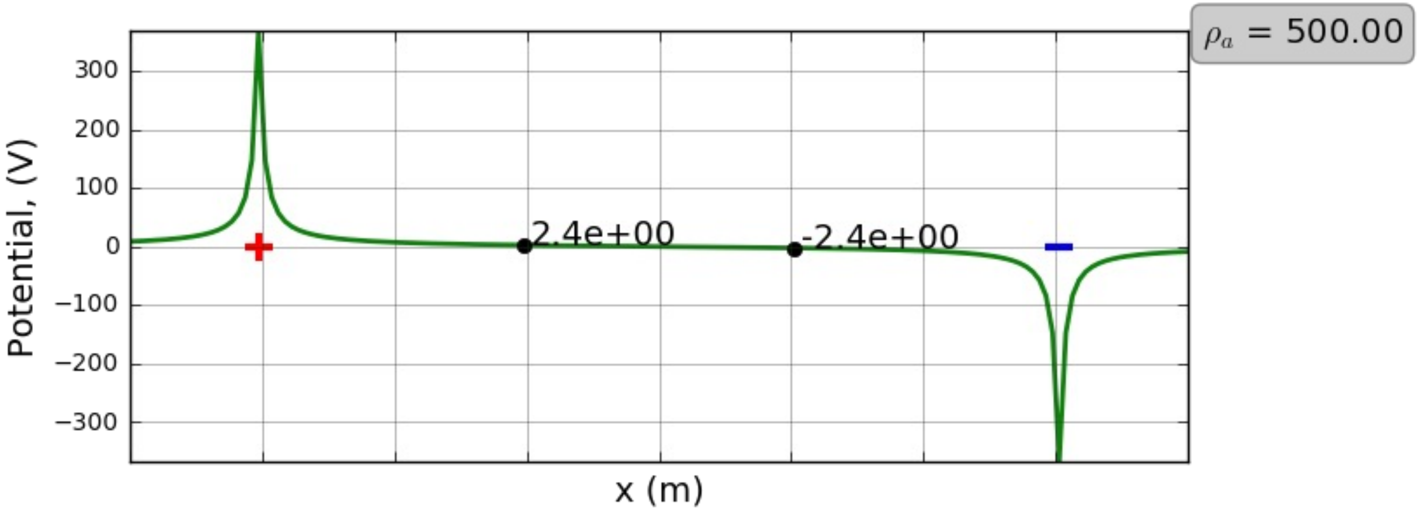
$$\Delta V_{MN} = \rho I \underbrace{\frac{1}{2\pi}\left[\frac{1}{AM} - \frac{1}{MB} - \frac{1}{AN} + \frac{1}{NB}\right]}_{G}$$

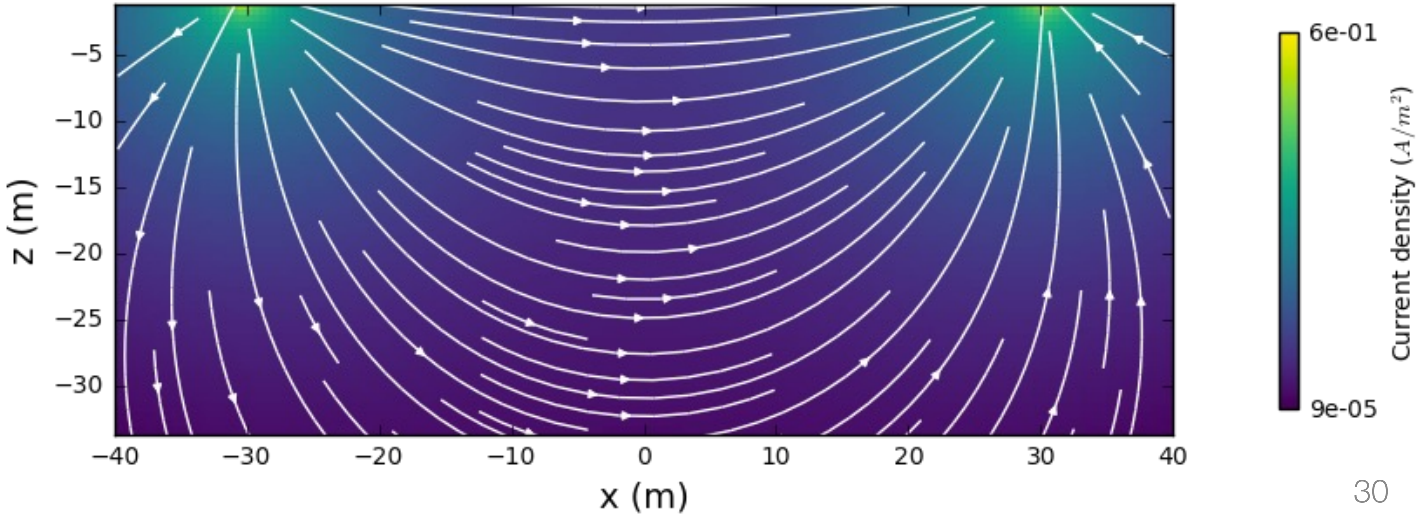
Resistivity

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

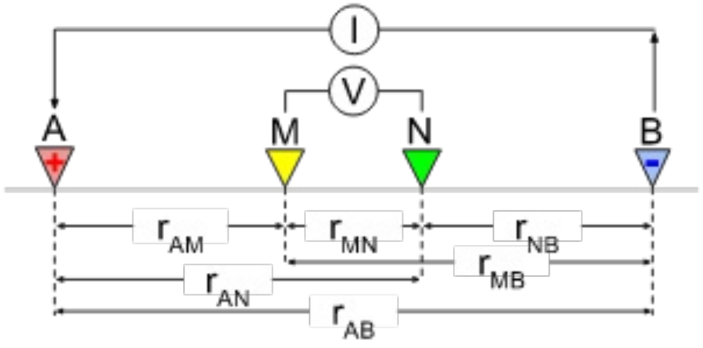
G: geometric factor

Halfspace (500 Ωm)





Currents and Apparent Resistivity



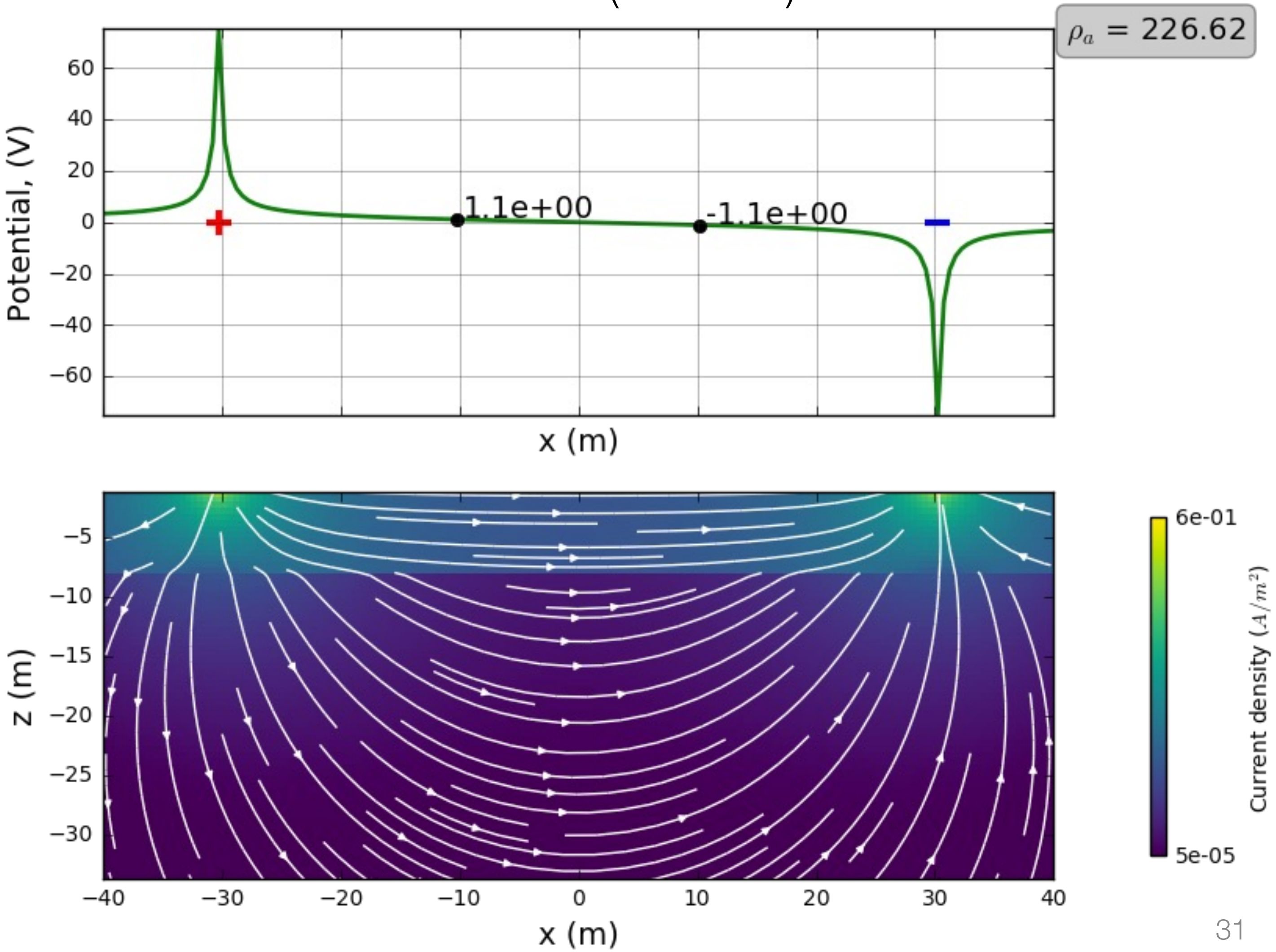
$$\Delta V_{MN} = \rho I \underbrace{\frac{1}{2\pi}\left[\frac{1}{AM} - \frac{1}{MB} - \frac{1}{AN} + \frac{1}{NB}\right]}_{G}$$

Apparent resistivity

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

G: geometric factor

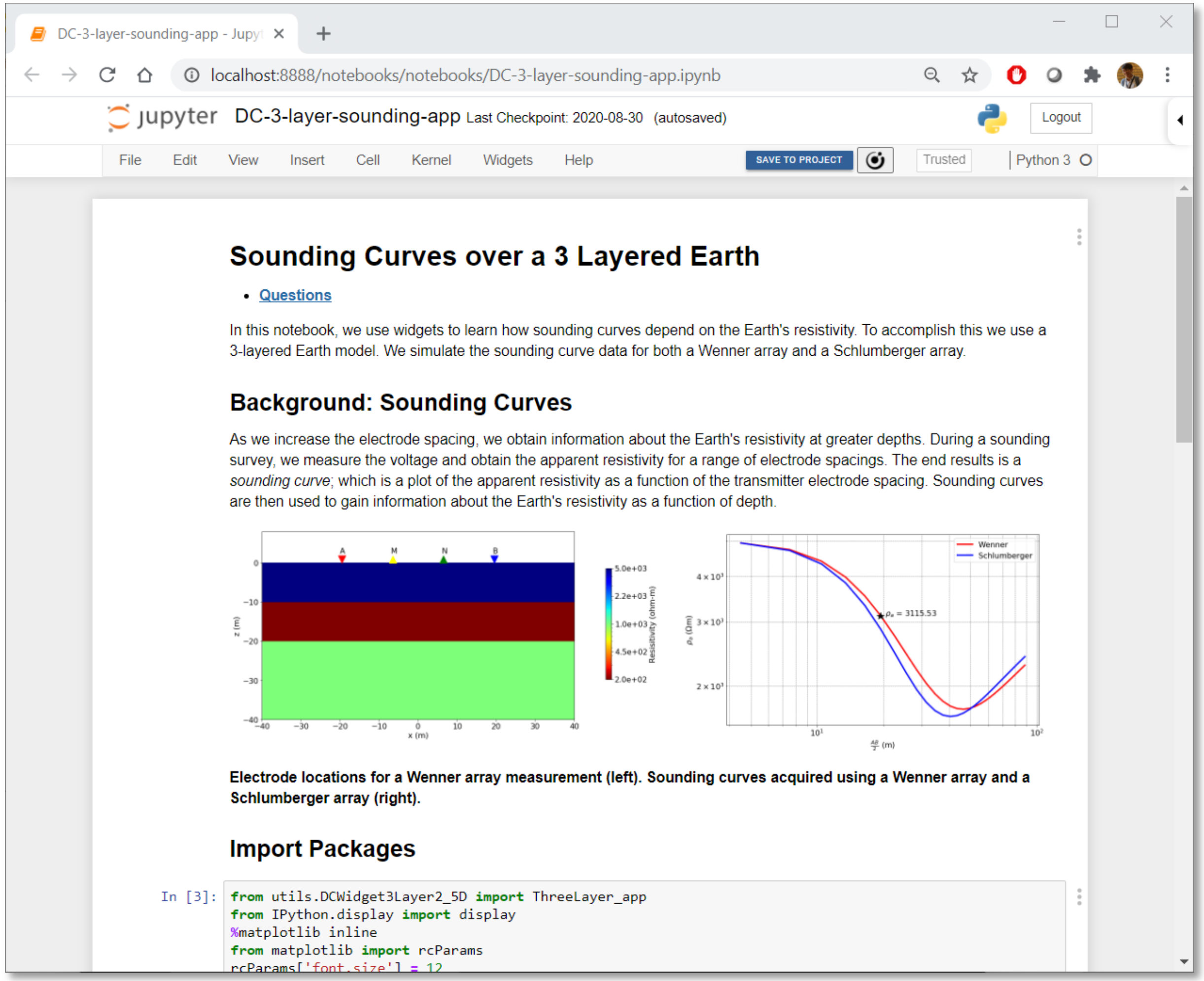
Conductive overburden (100 Ωm)



Demo: DC-3-layer-sounding-app

Why interactive apps?

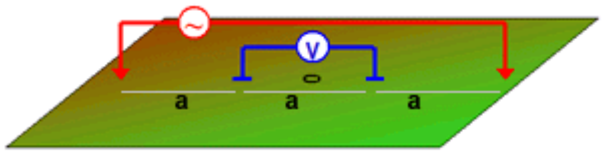
- Visualization aids understanding
- Learn through interaction
  - ask questions and investigate
- Open source:
  - Free to use
  - Welcome contributions!



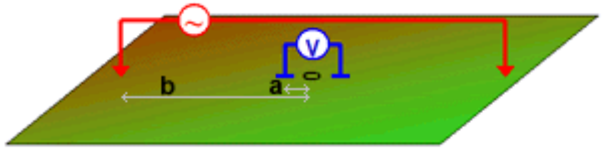
Sounding and Arrays

Geometry

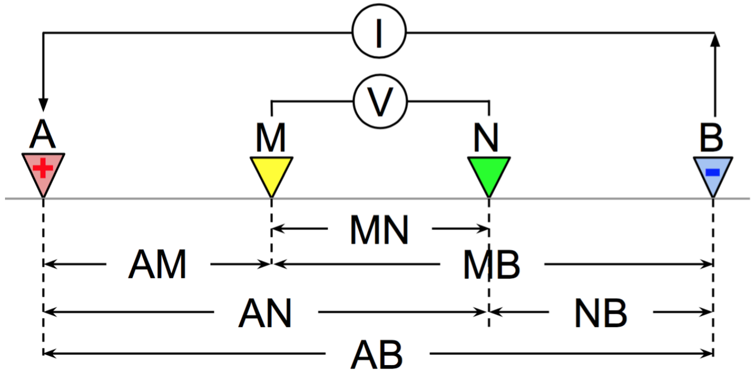
Wenner



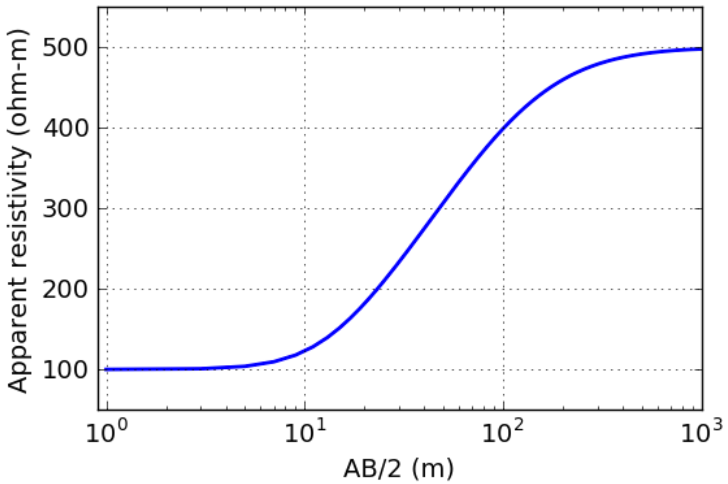
Schlumberger



4 electrode Array

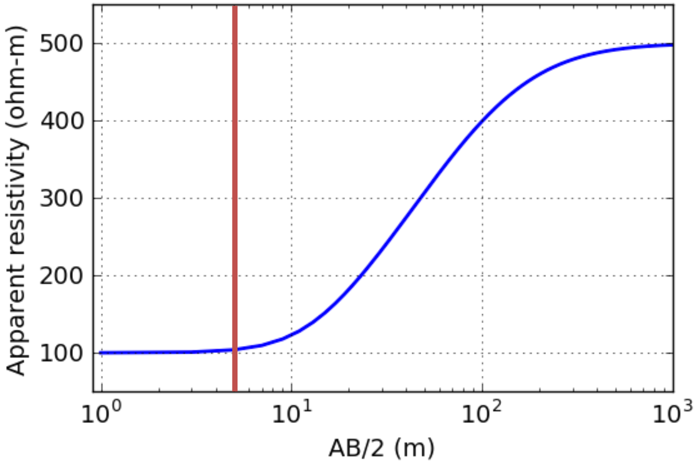


Sounding

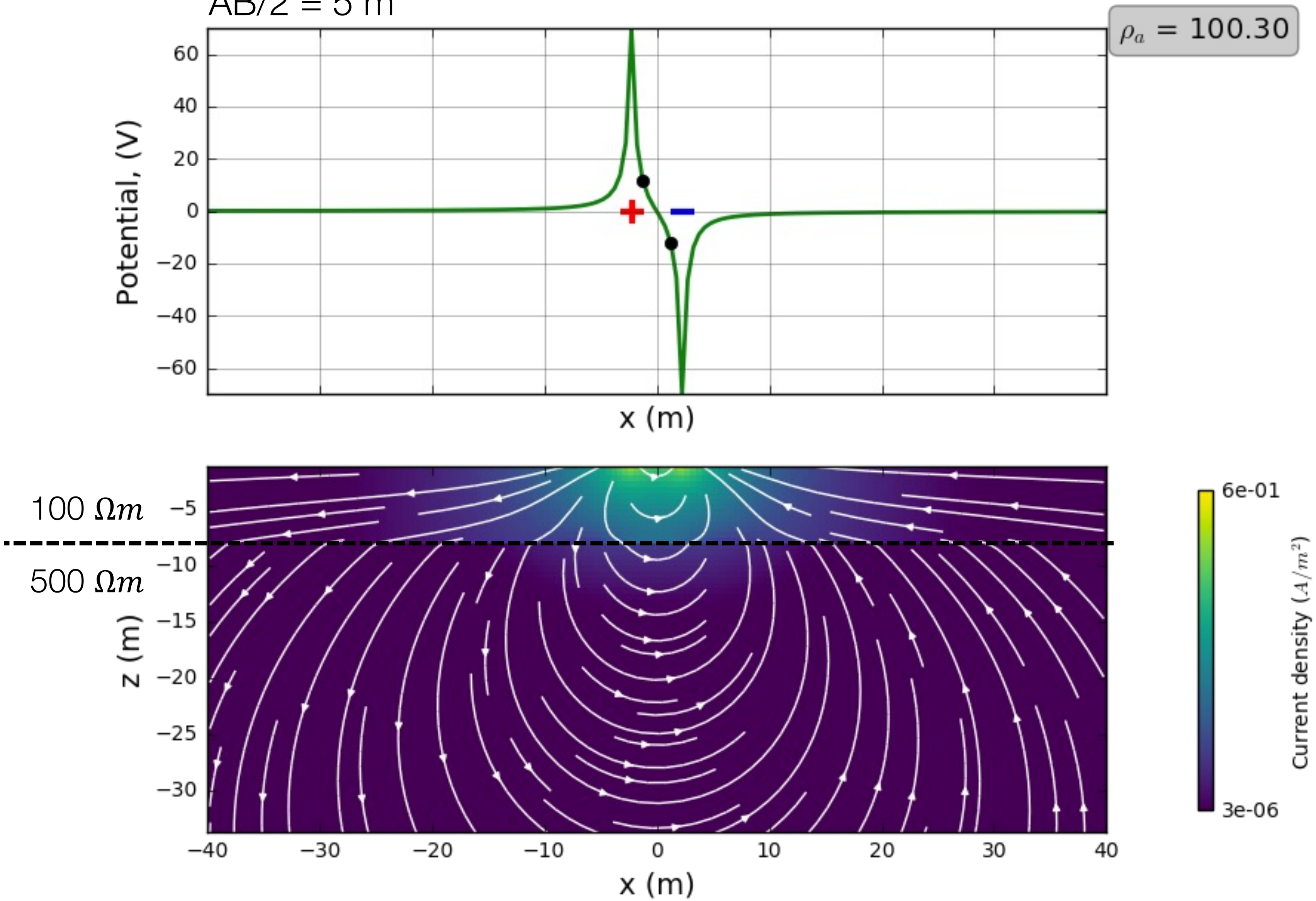


Soundings

DC Sounding curve



AB/2 = 5 m



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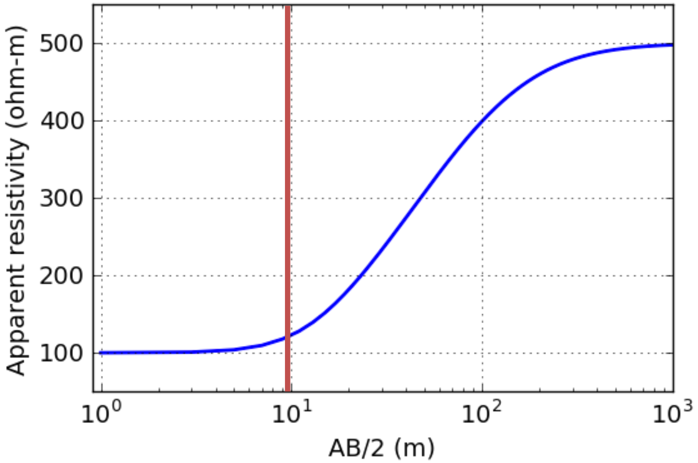
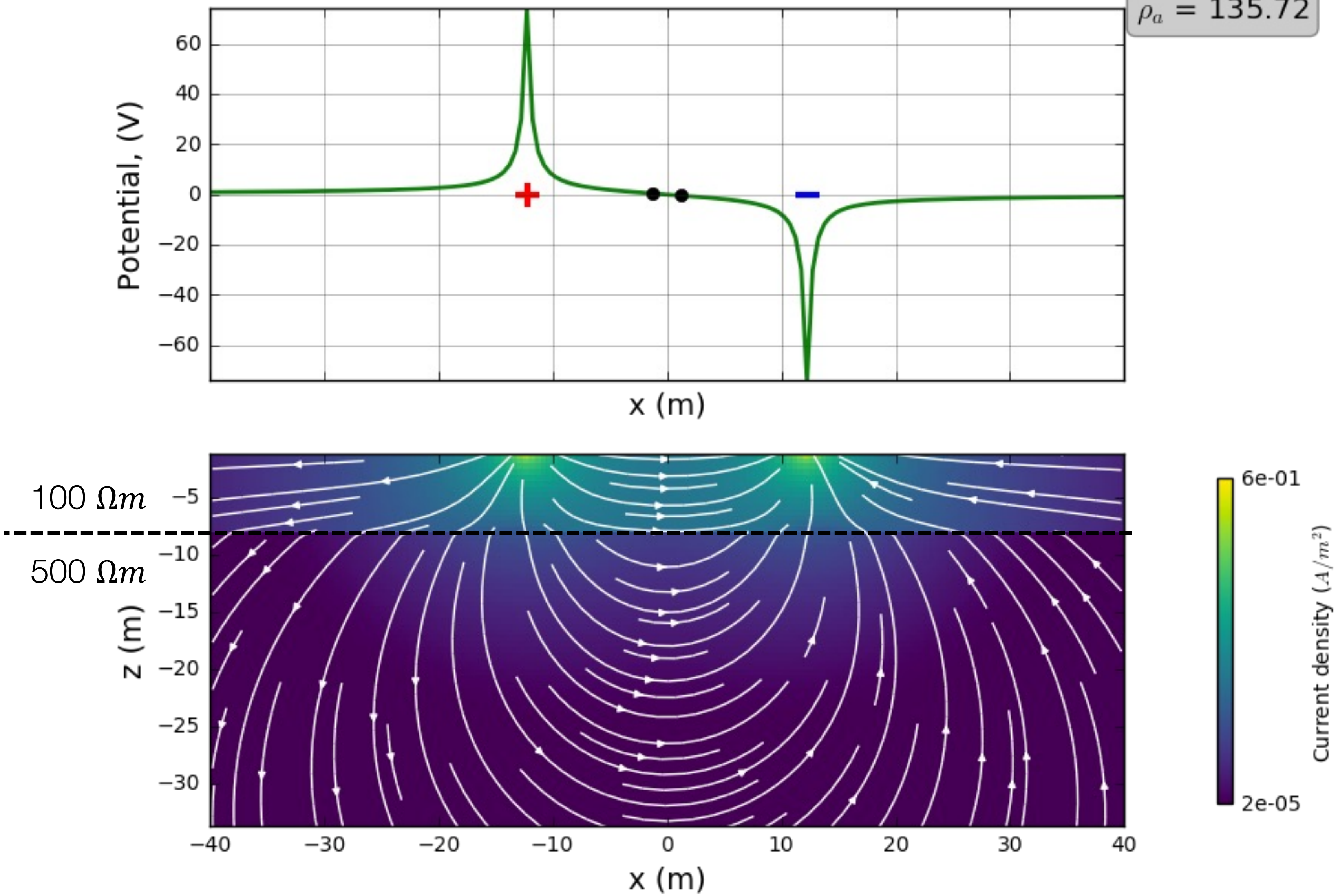


AB/2 = 10 m



Soundings

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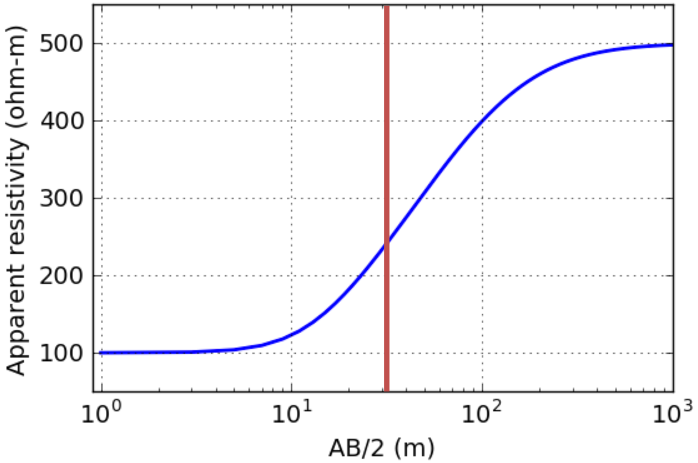
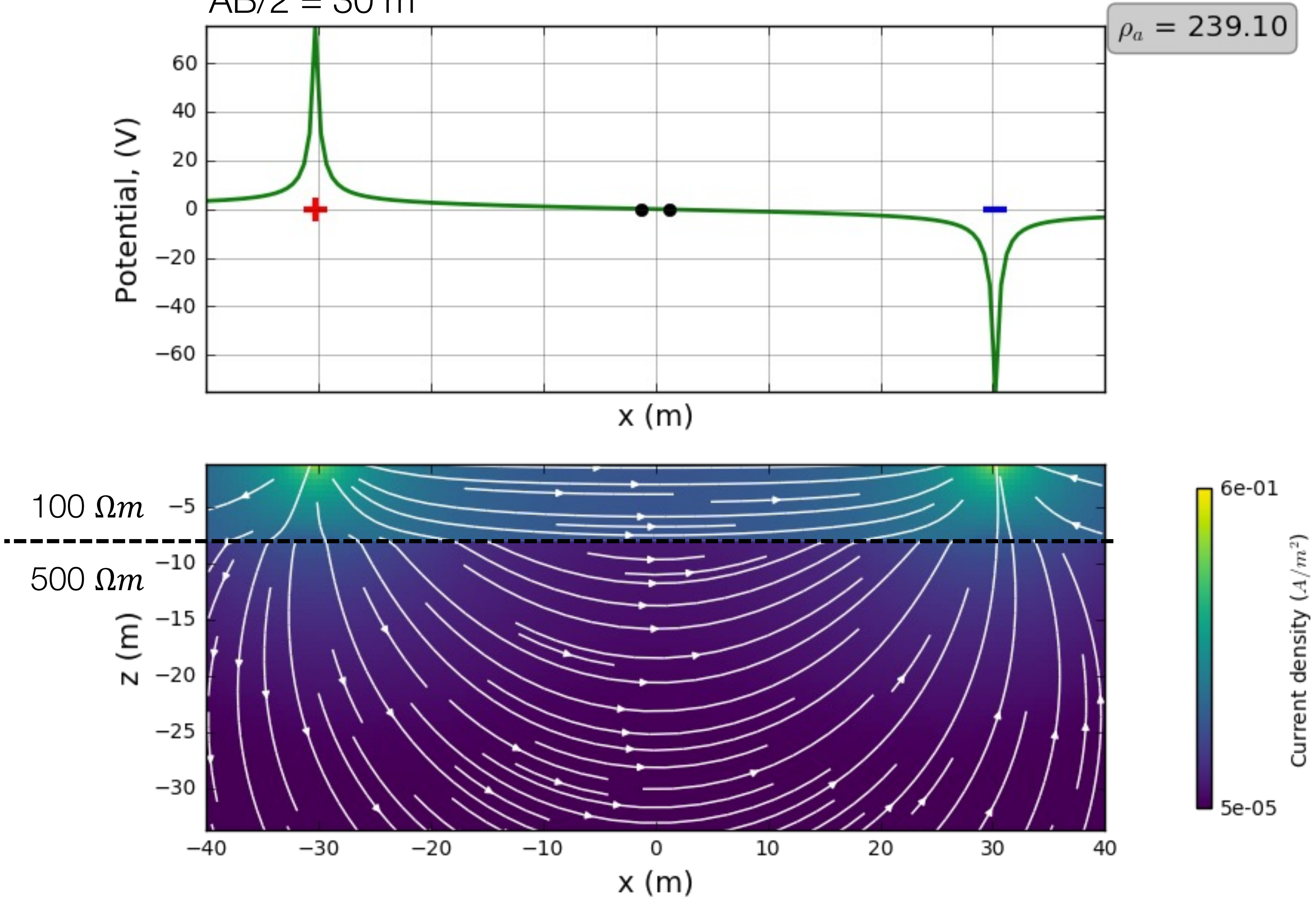
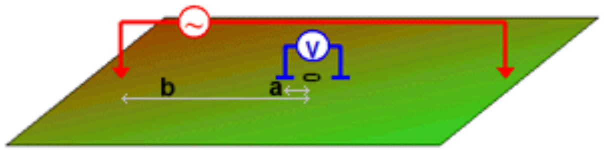


AB/2 = 30 m

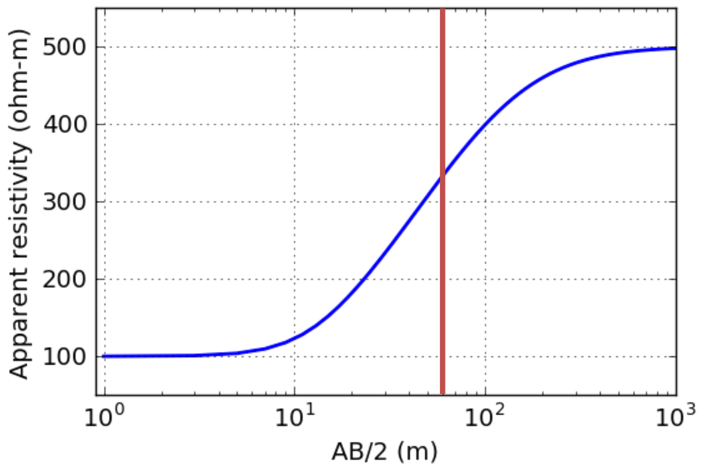


Summary: soundings

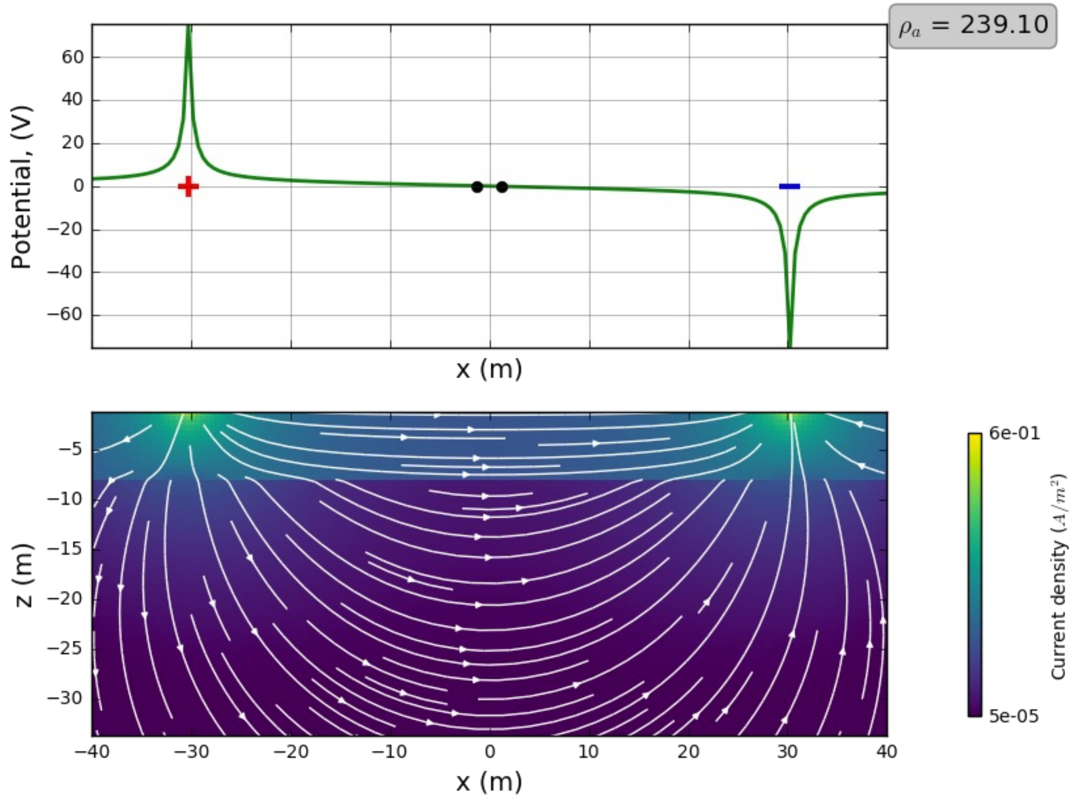
Schlumberger array

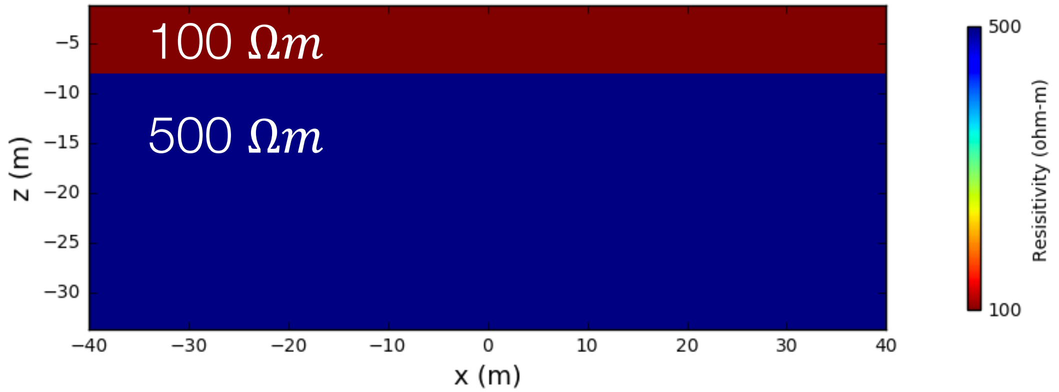


DC sounding curve

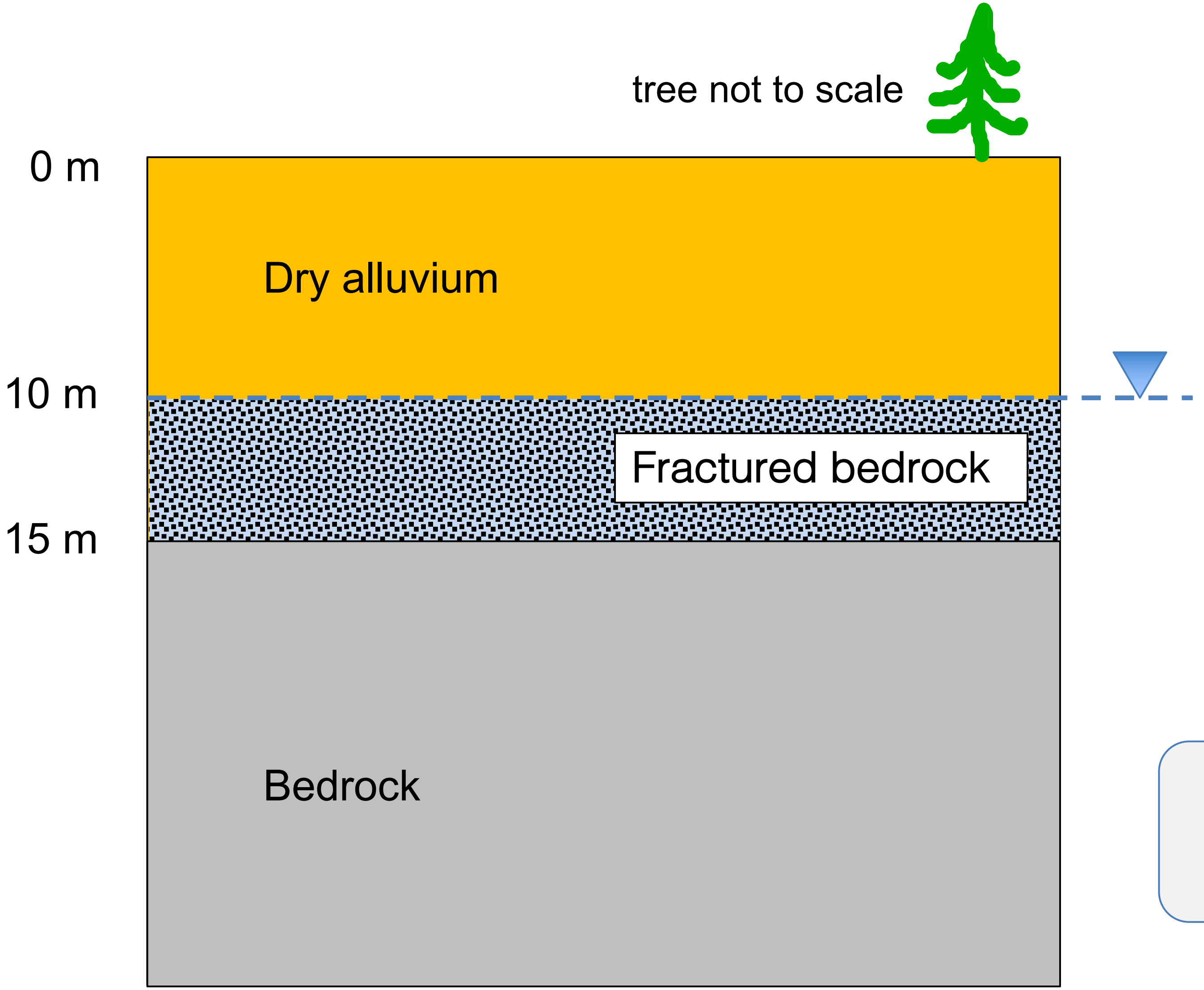


Scale length of array must be large to see deep





An example layered-model for groundwater application



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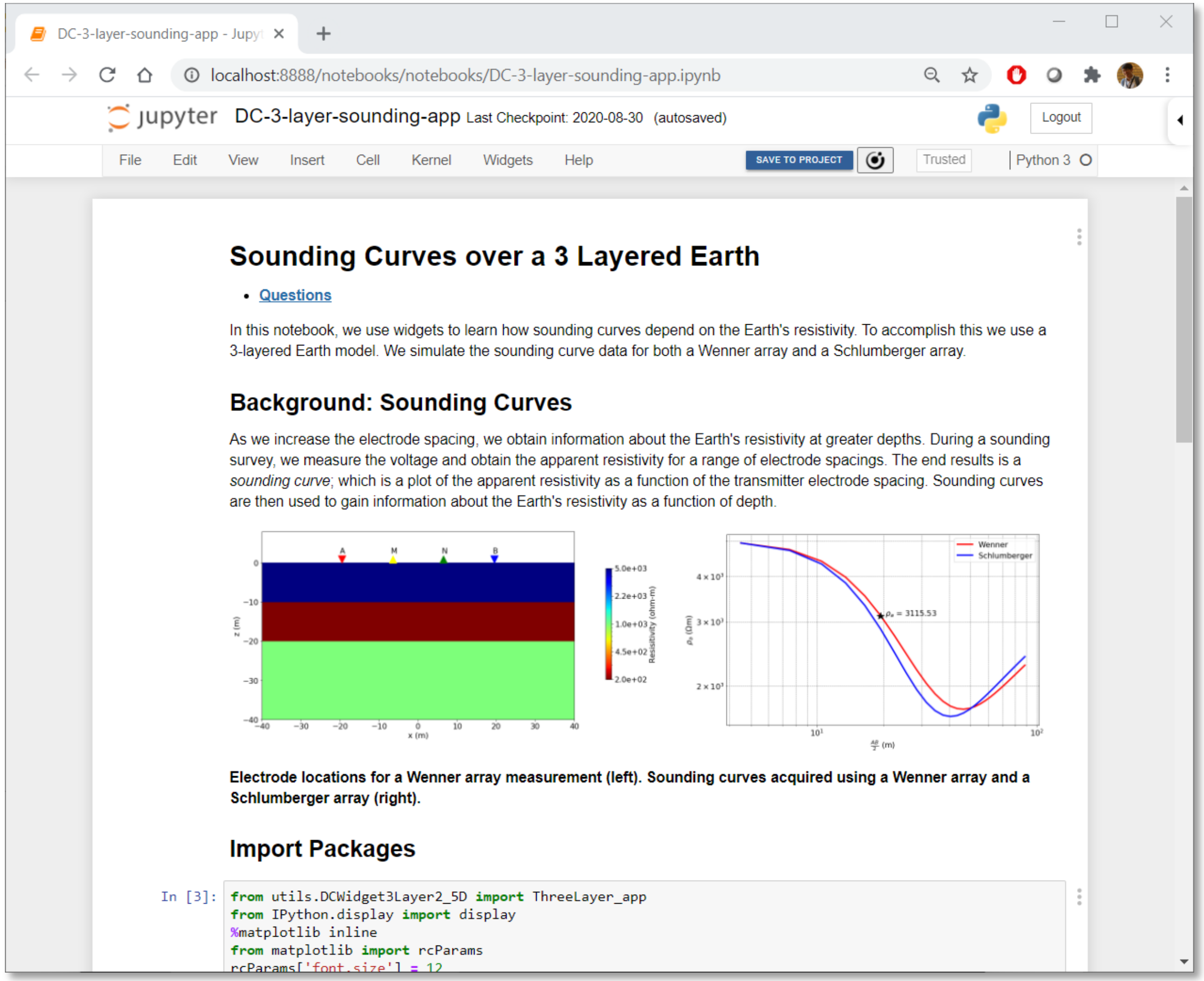
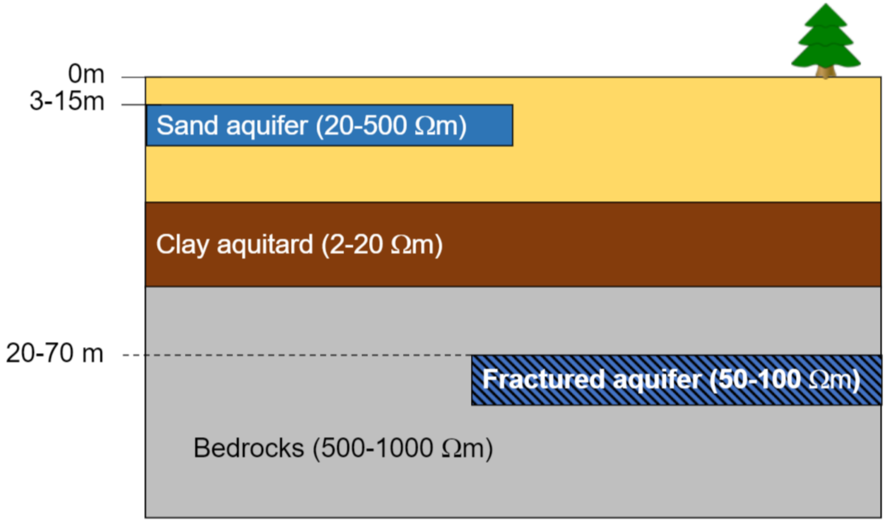


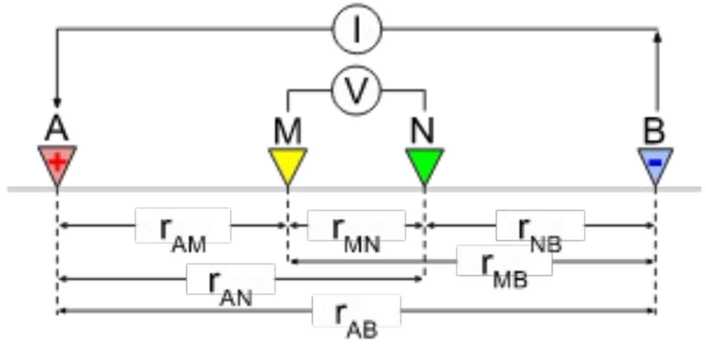
Learning goals of the lecture

- Understand electrical resistivity and its linkage to geologic units.



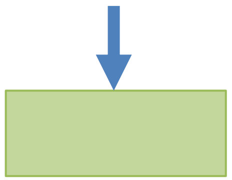
Learning goals of the lecture

- 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



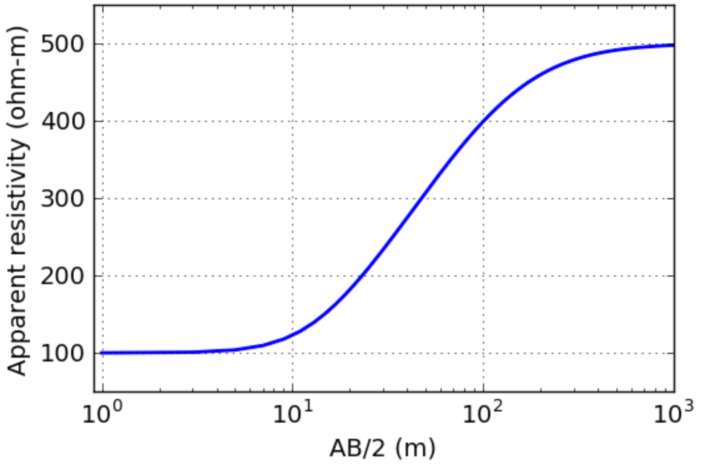
$$\rho_a = \frac{\Delta V_{MN}}{IG}$$

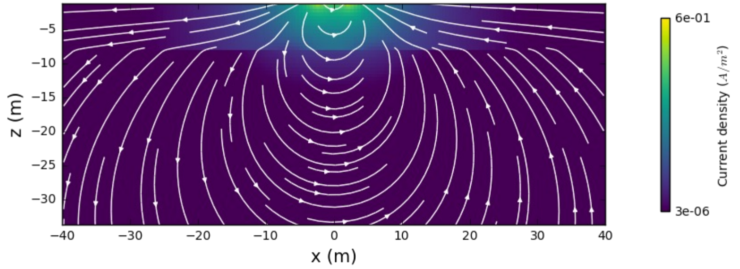
G: geometric factor

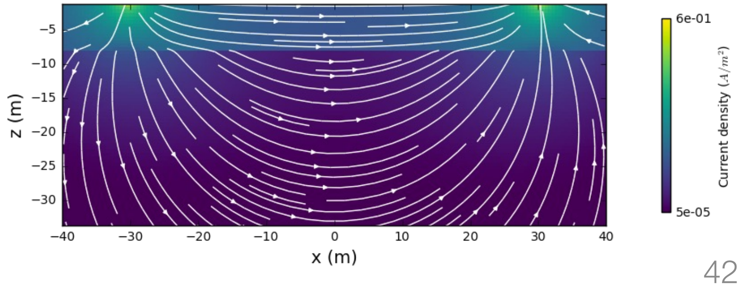
Learning goals of the lecture

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

DC Sounding curve

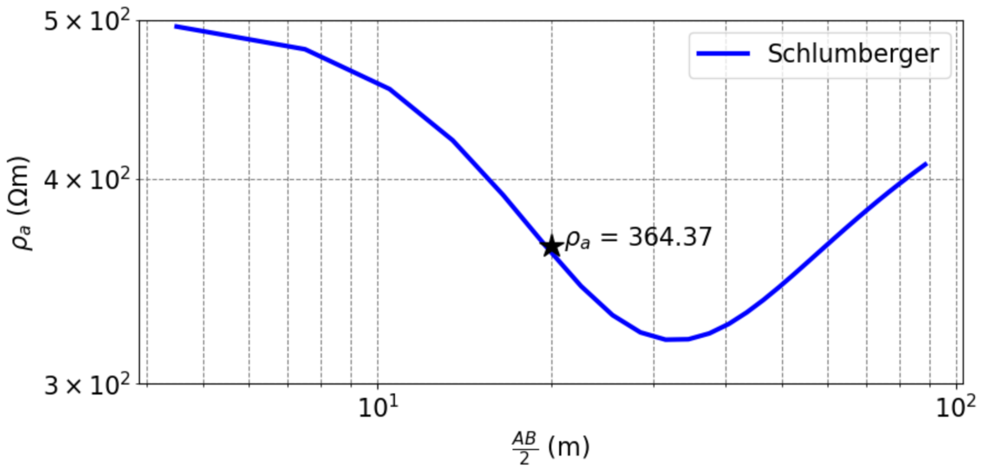


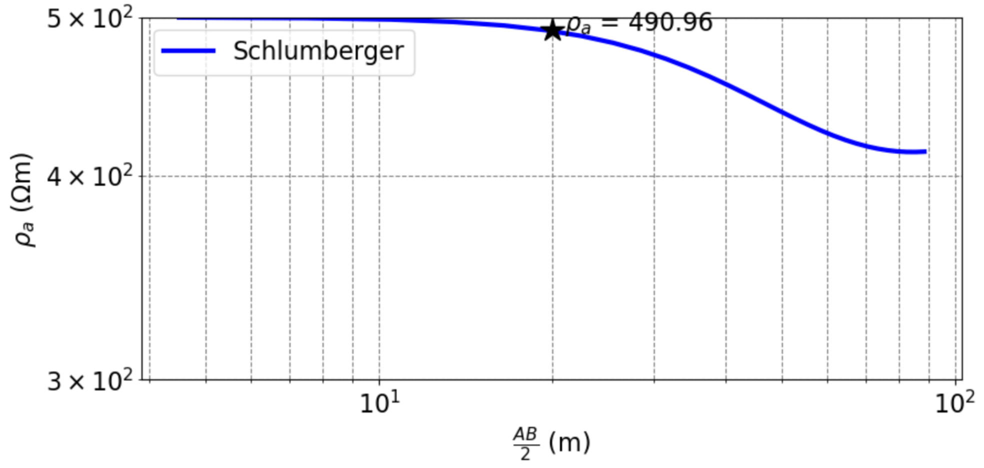




Learning goals of the lecture

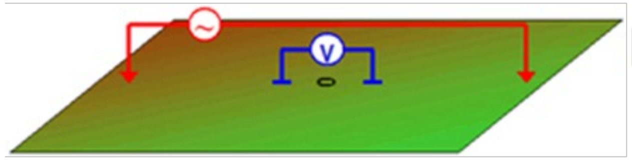
- Understand electrical resistivity and its linkage to geologic units.
- Understand a basic setup of direct current (DC) resistivity experiment.
  - Concept of an apparent resistivity
  - Concept of a sounding
- Understand fundamental physics of the DC method related to electric currents.
- Understand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





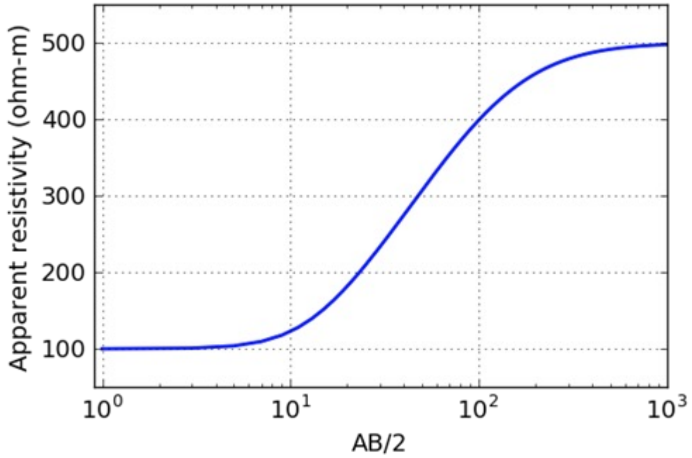
In the next lecture…

Inversion

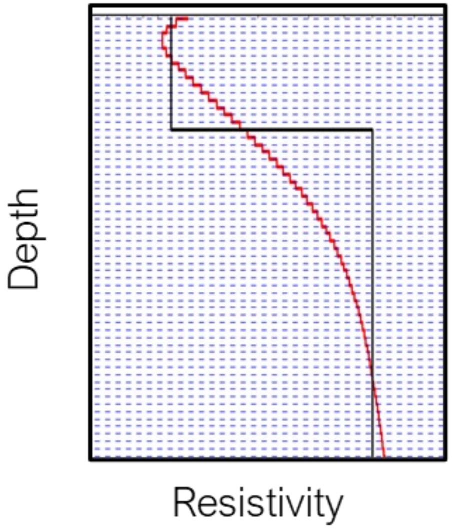


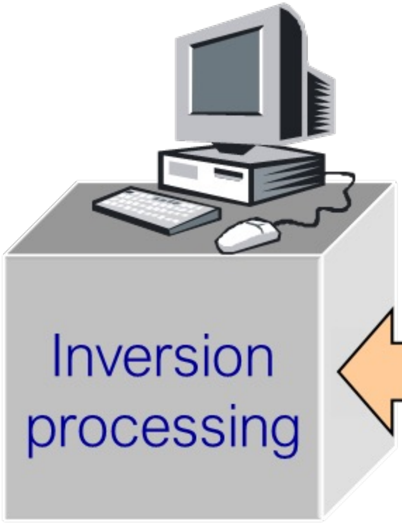
Measurements over the Earth are data.

Data



Model



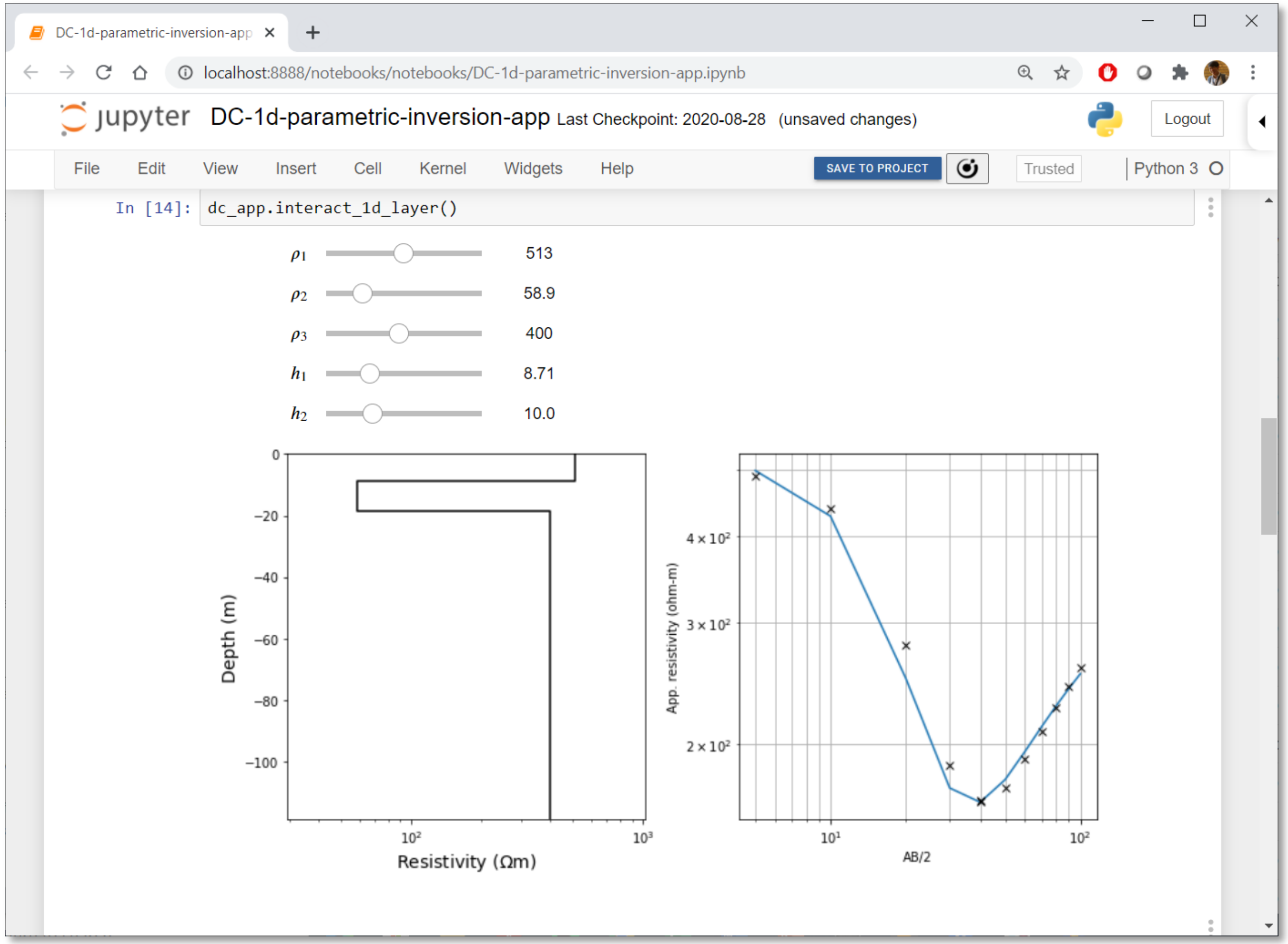


Inversion estimates Earth models based upon data and prior knowledge.

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

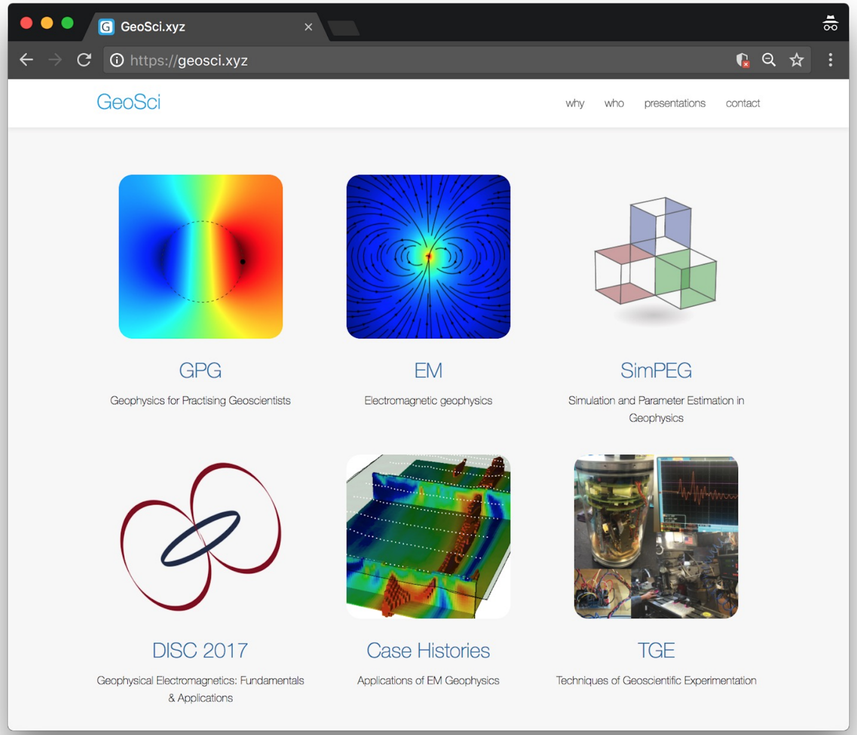
Google colab

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

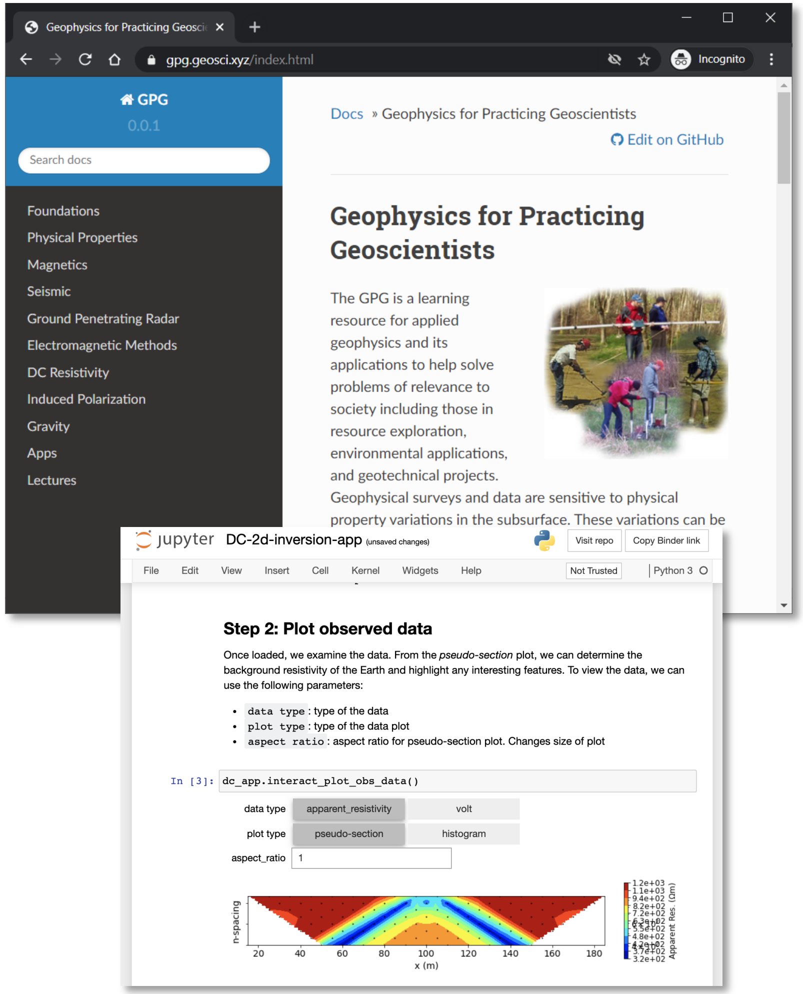
Open resources for education

GeoSci.xyz: Open-source Resources for Learning

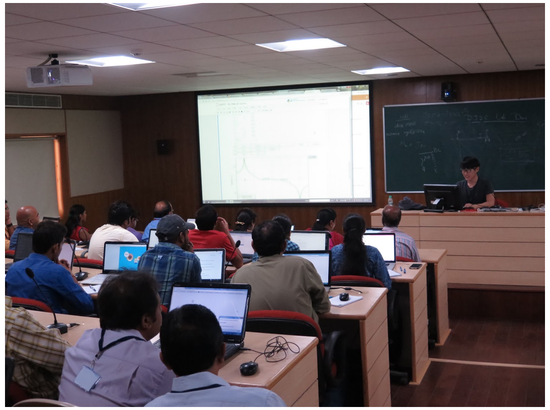
https://www.geosci.xyz



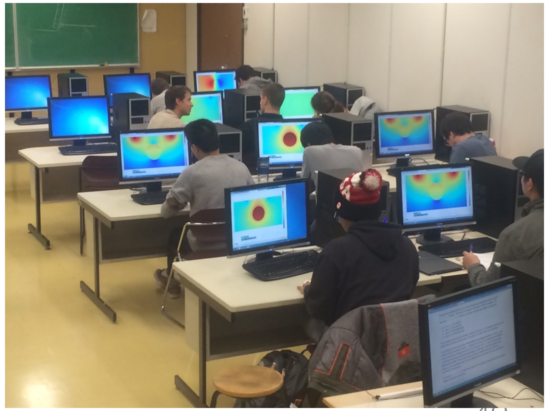
Content + Interactive computing



EM course (DISC 2017)



Undergrad geophysics course



GeoSci.xyz

- Universities relying on GeoSci for courses

  University of Houston

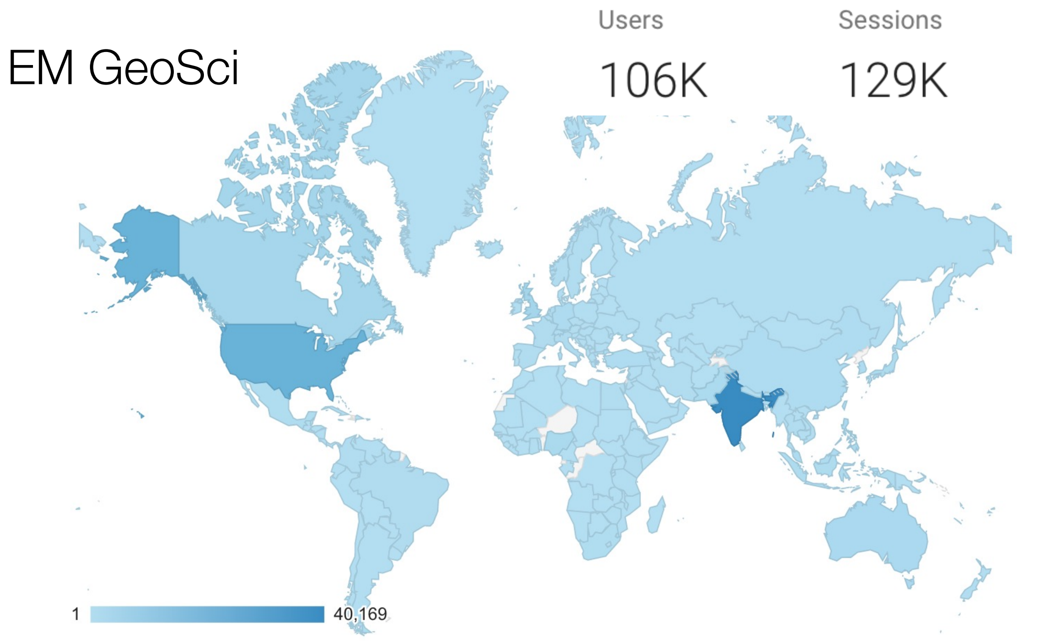
  University of Alabama

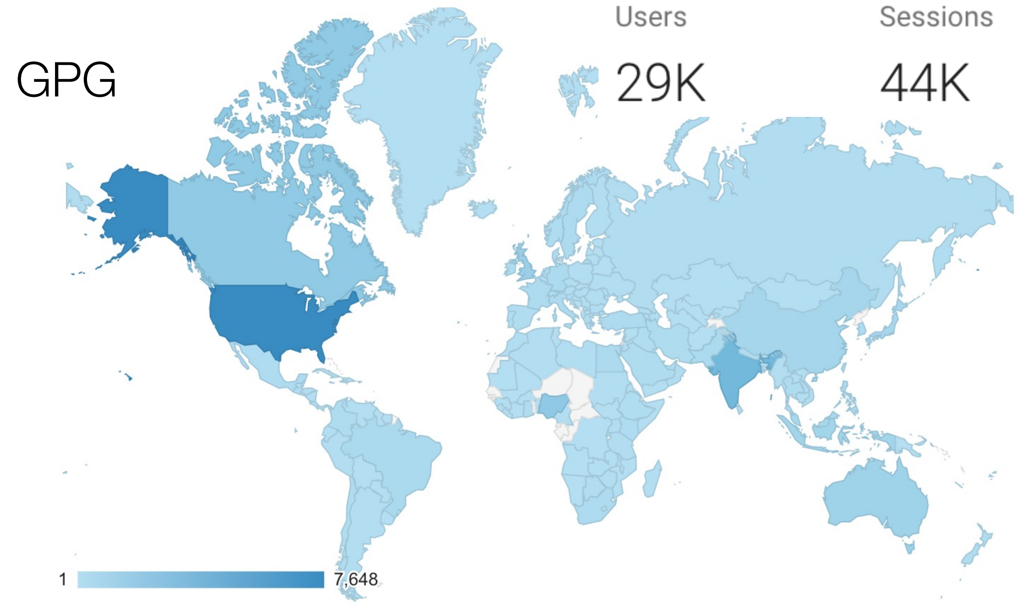
  UBC, Canada

  Southern University of Science and Technology (China)

  The Federal University of Minas Gerais (Brazil)

  …





Open-source software

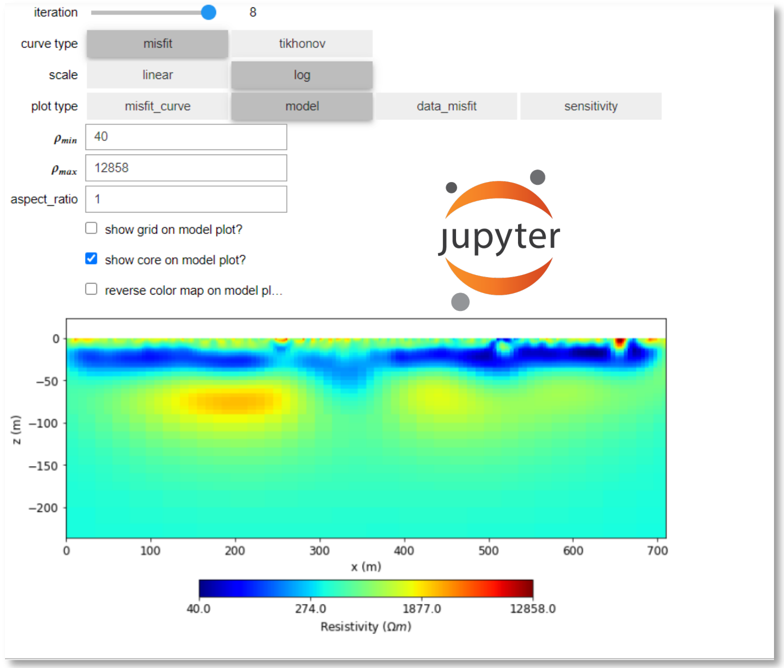
simpeg

https://www.simpeg.xyz

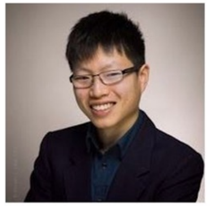
Expanding use of research software for educational purposes

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

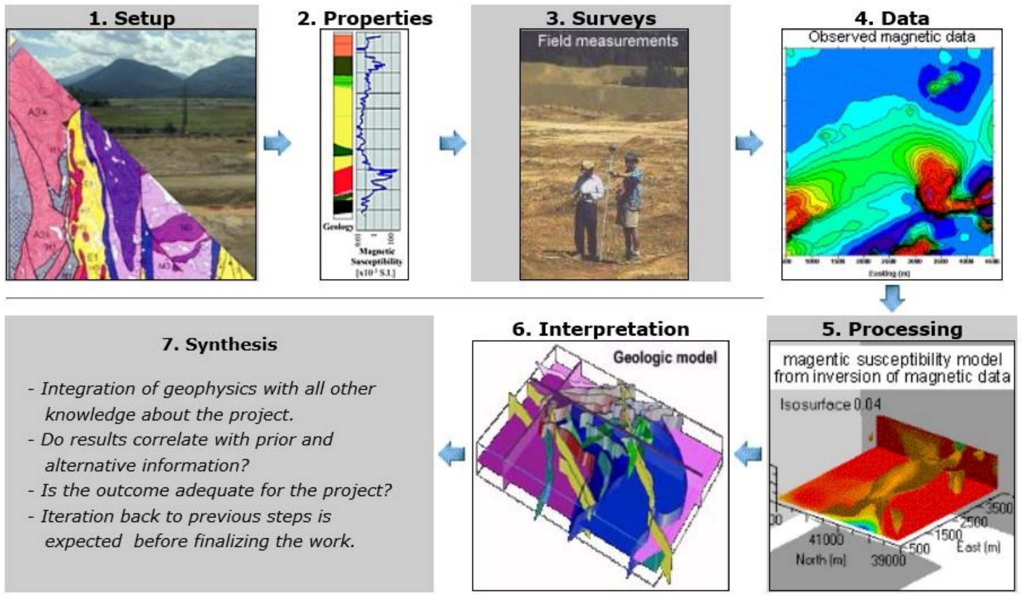
Seogi Kang

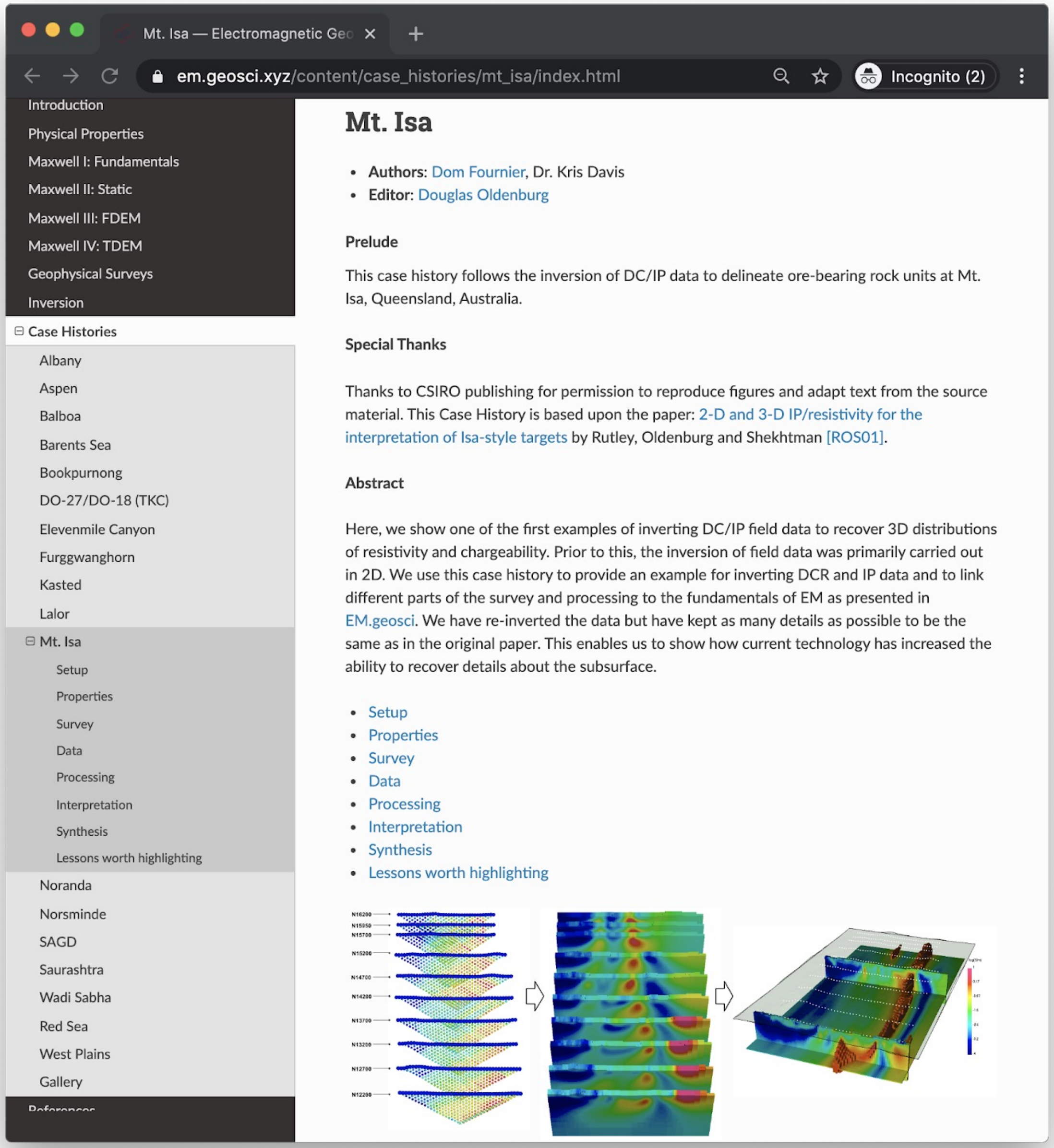
Lindsey Heagy

https://medium.com/gwb-myanmar

Case histories

Structured, reproducible scientific narratives





https://em.geosci.xyz/content/case_histories