DISC

2017

Electromagnetics
Fundamentals and Applications

http://disc2017.geosci.xyz/denver

SEG SM SOCIETY OF EXPLORATION GEOPHYSICISTS

Thanks to…

Yaoguo Li + Volunteers

Andrei Swidinsky

Karen Christopherson

Misac Nabighian

Jeff Love

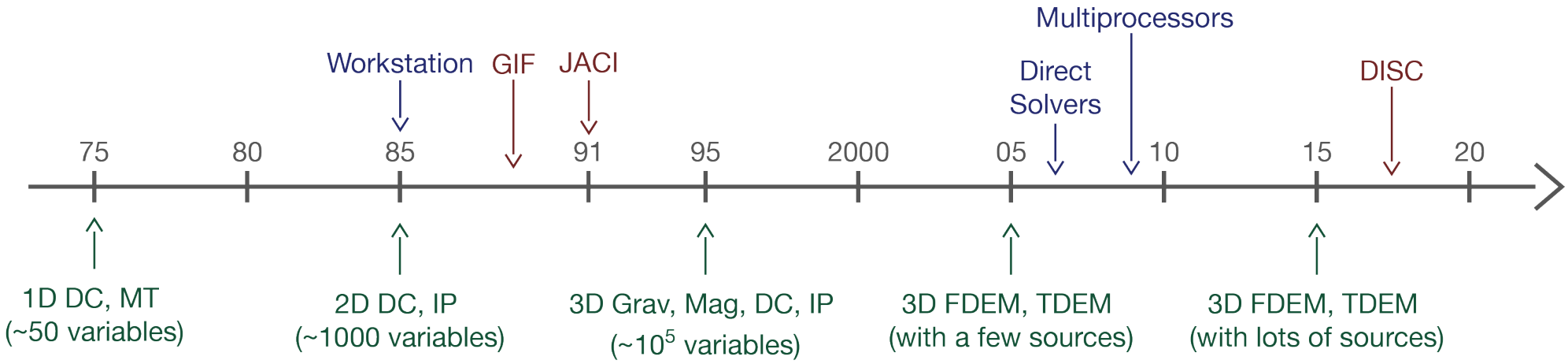
Thanks to…

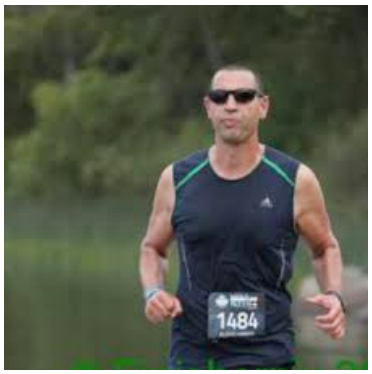
Student sponsorship

DISC Lab & support

Some Background

- Doug inspired by Bob Parker, Freeman Gilbert and George Backus: The Geophysical Inverse Problem



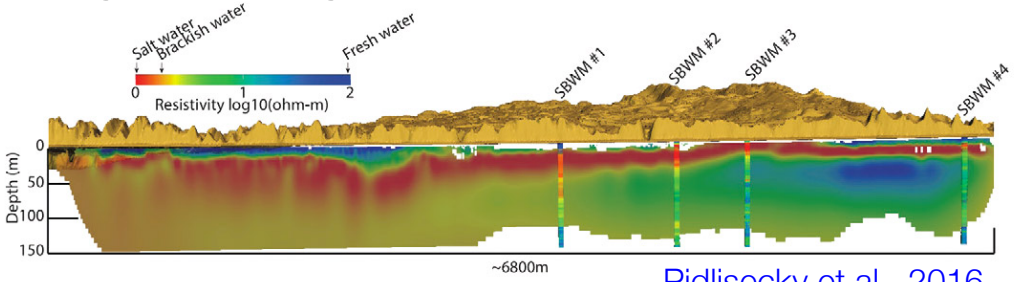


Result: Computing power + advances in inversion methodology
→ we can now solve most EM geophysics problems

Instrumentation and Data

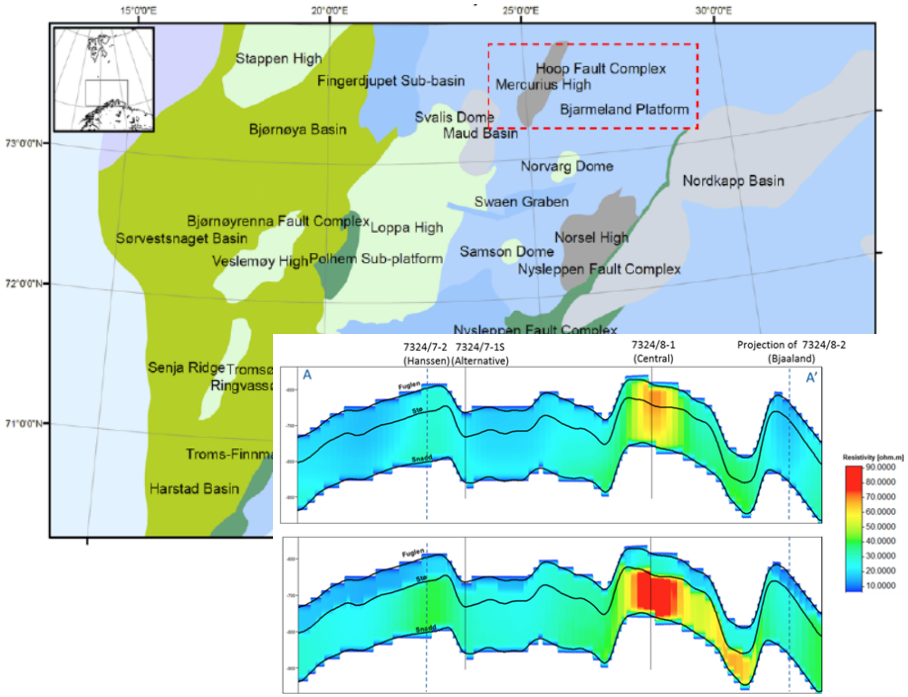
- The second major advance is in data acquisition
- Data with unprecedented data quality and quantity.

Large-scale ground water studies: California



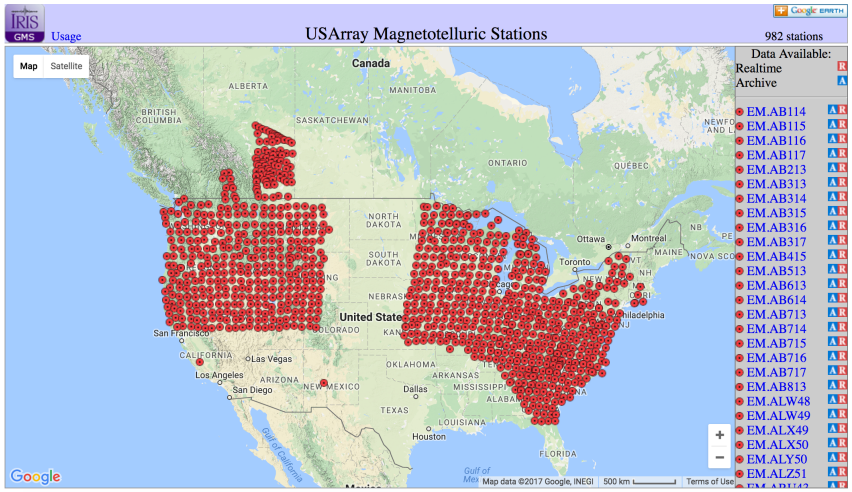
Pidlisecky et al., 2016

Offshore: Hydrocarbon De-risking



Alvarez et al, EM.GeoSci

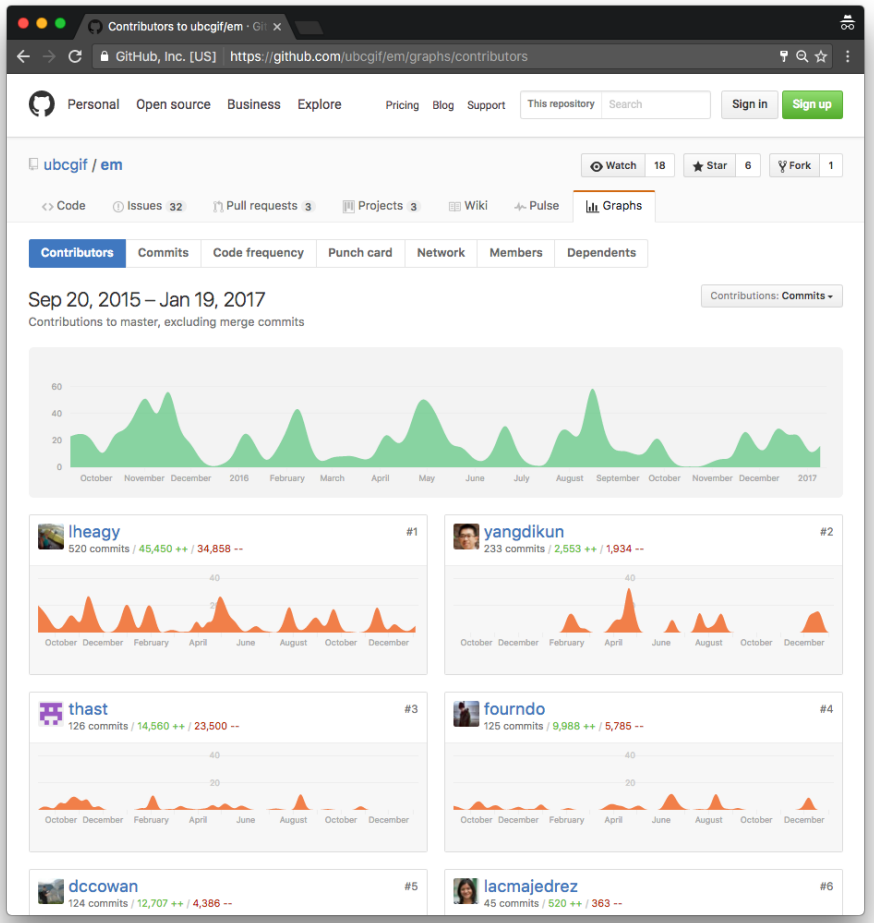
Earth scope: Continental Scale MT



Earth Scope

Web and Open Source Resources

- Open source development: Software and resources
  - Collaborate
  - Share
  - Test changes
  - Interactive computing



simpeg

Simulation and Parameter Estimation in Geophysics
http://simpeg.xyz

Github
versioning, collaborating

Travis CI
testing, deploy

Jupyter
interactive computing

Creative Commons
licensing, reuse

Python
computation

Many applications

Electromagnetics can be used for …


minerals


contaminants


water


geothermal


geotechnical


slope stability


hydrocarbons


unexploded ordnance

We have the basic ingredients

- Application problems
- High quality data
- Ability to invert EM data sets
- Web tools to communicate

What are the roadblocks?

Roadblocks

In general, geoscientists…

- Don't realize that EM can play a role in solving the problem
- Don't understand the technique
  - Confusing terminology
  - Seems complicated and unintuitive

What is the connection between my problem and the physical properties?

So many types of surveys, how to choose?

- DC, frequency, time?
- Surveys in air on ground, downhole?
- What to expect for resolution?

Are there situations, similar to mine, in which EM has been applied?

Goal of DISC: Remove Roadblocks

In general, geoscientists…

- Don't realize that EM can play a role in solving the problem
- Don't understand the technique
  - Confusing terminology
  - Seems complicated and unintuitive

What is the connection between my problem and the physical properties?

So many types of surveys, how to choose?

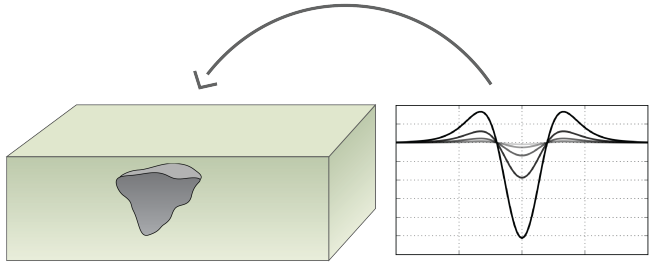
- DC, frequency, time?
- Surveys in air on ground, downhole?
- What to expect for resolution?

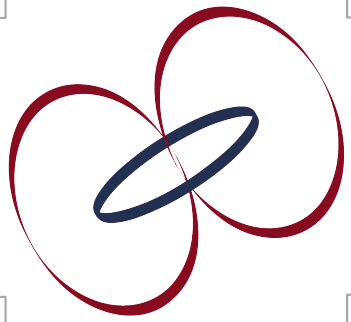
Are there situations, similar to mine, in which EM has been applied?

DISC can take advantage of a Perfect Storm

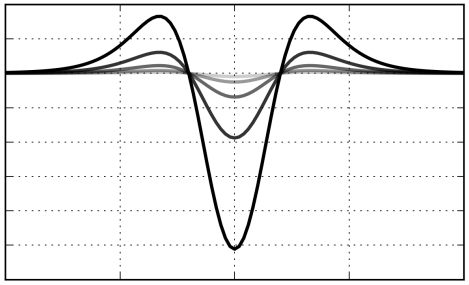
Problems

Inversion capabilities





High quality data

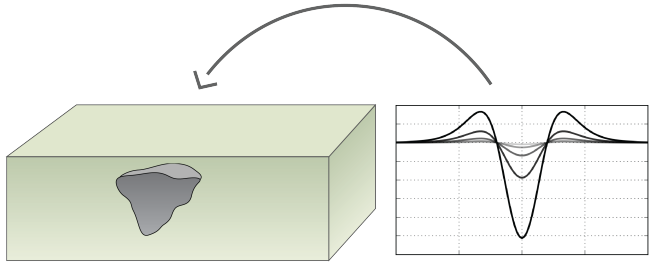


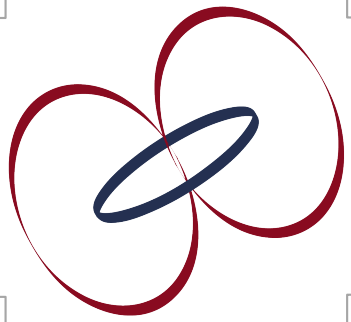
Web tools to communicate

DISC can take advantage of a Perfect Storm

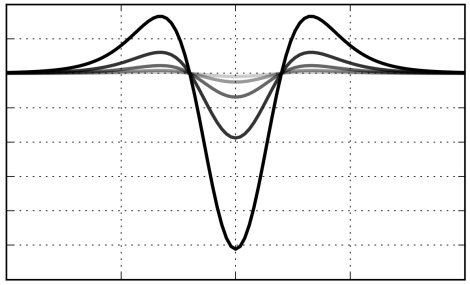
Problems

Inversion capabilities





High quality data



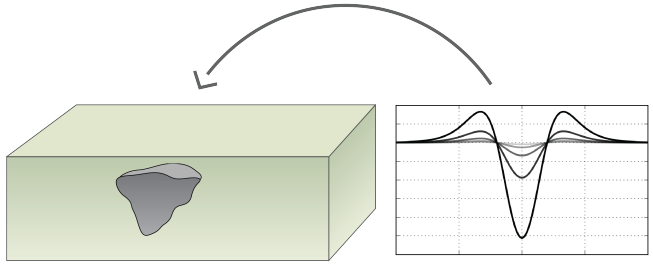
Web tools to communicate

A good idea but missing an important ingredient …

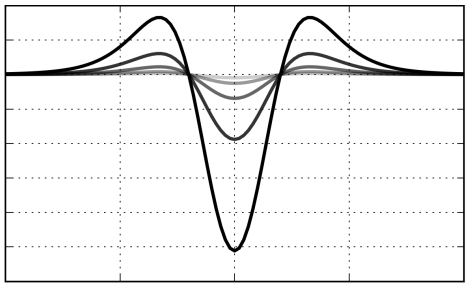
Talented Young Geoscientists

Problems

Inversion capabilities



High quality data



Web tools to communicate

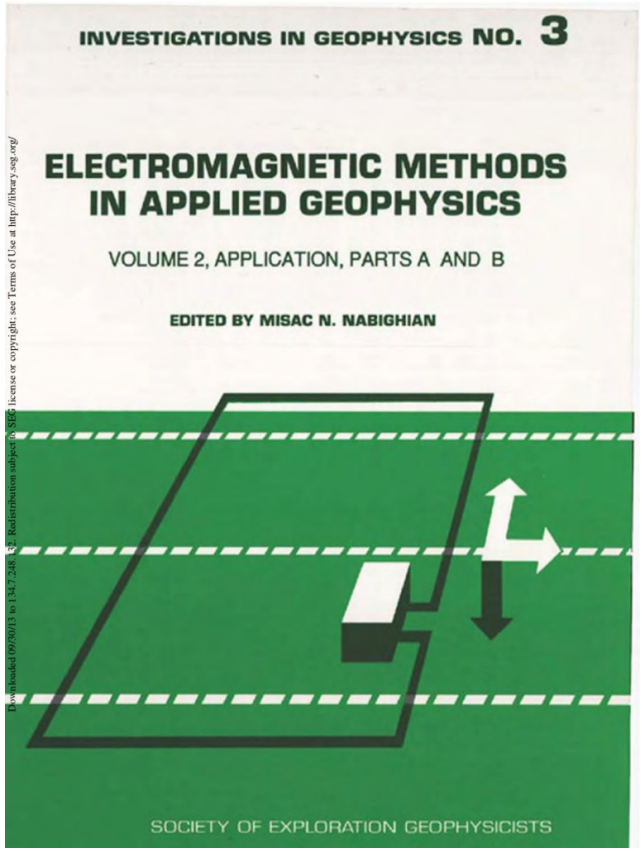
Seogi

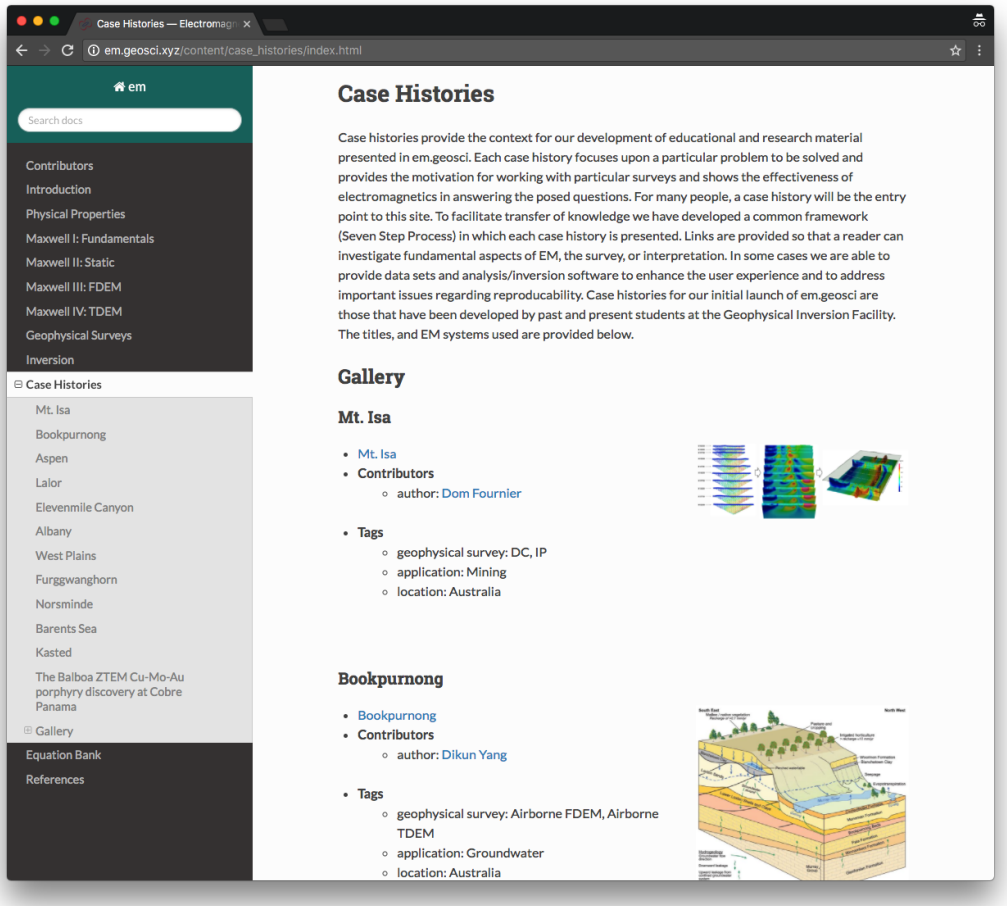
Lindsey

Goals for the DISC

- Inspire
  - See the variety of potential applications
  - Illustrate effectiveness using case histories
- Build a foundation
  - Basic principles of EM
  - Exploration and visualization with interactive apps
  - Open source resource: http://em.geosci.xyz
- Set realistic expectations
- Promote development of an EM community
  - Open source software
  - Capturing case histories world-wide

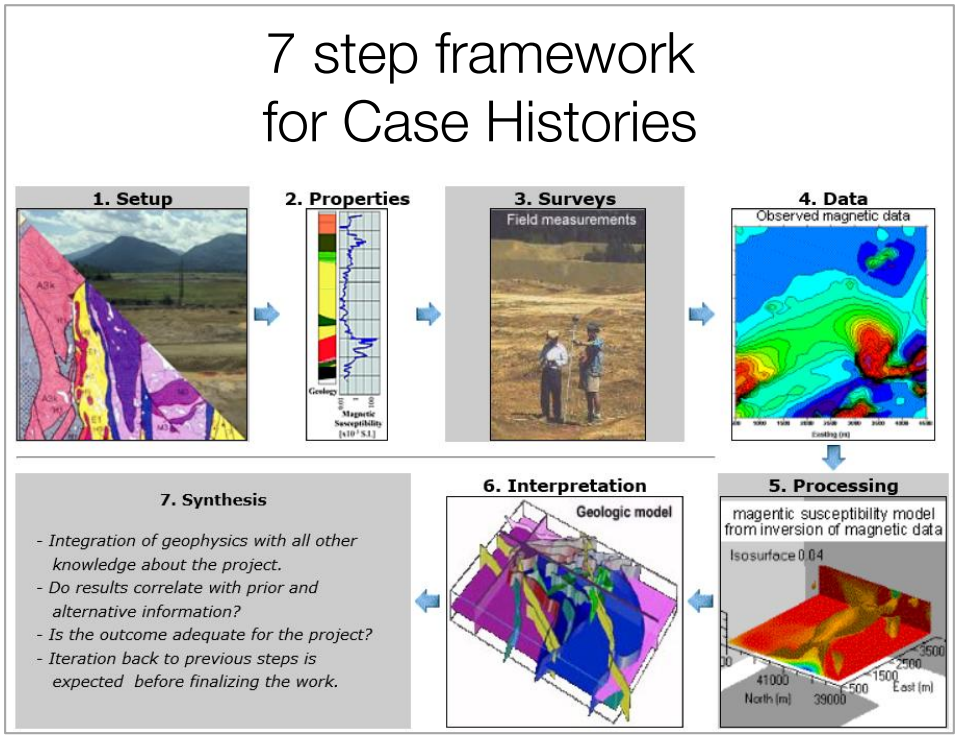
Resources: EM.geosci

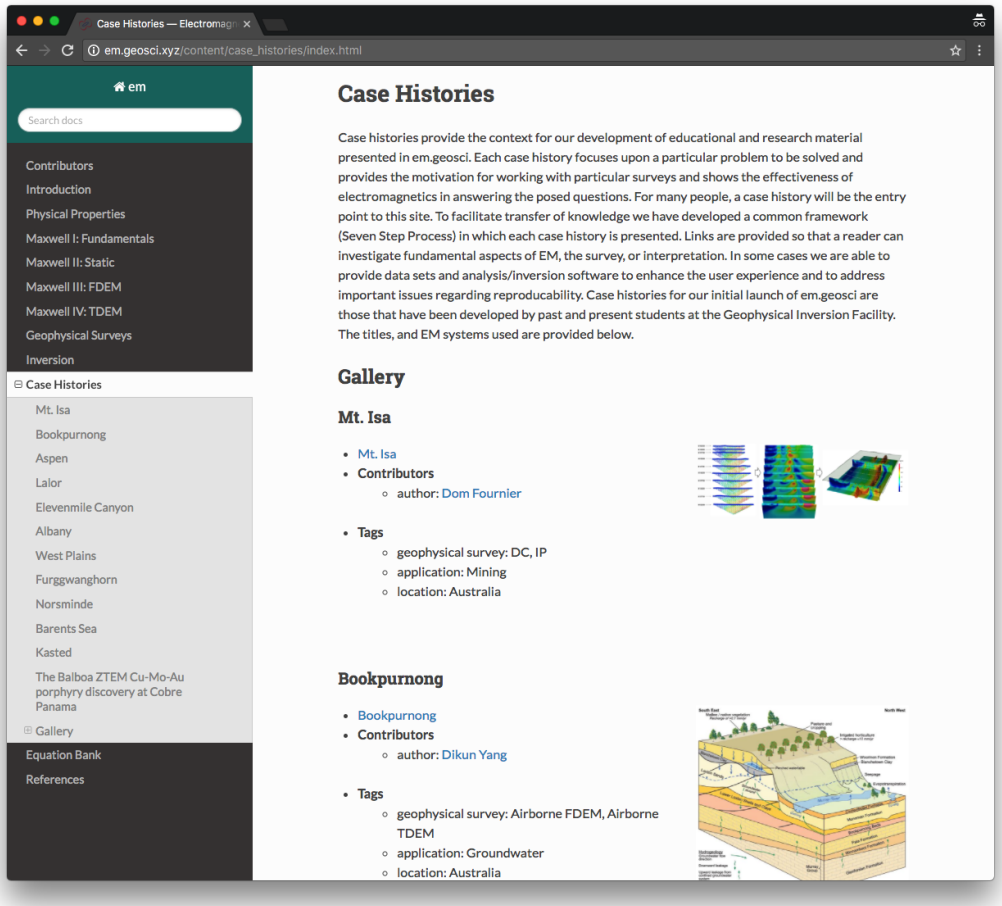




http://em.geosci.xyz

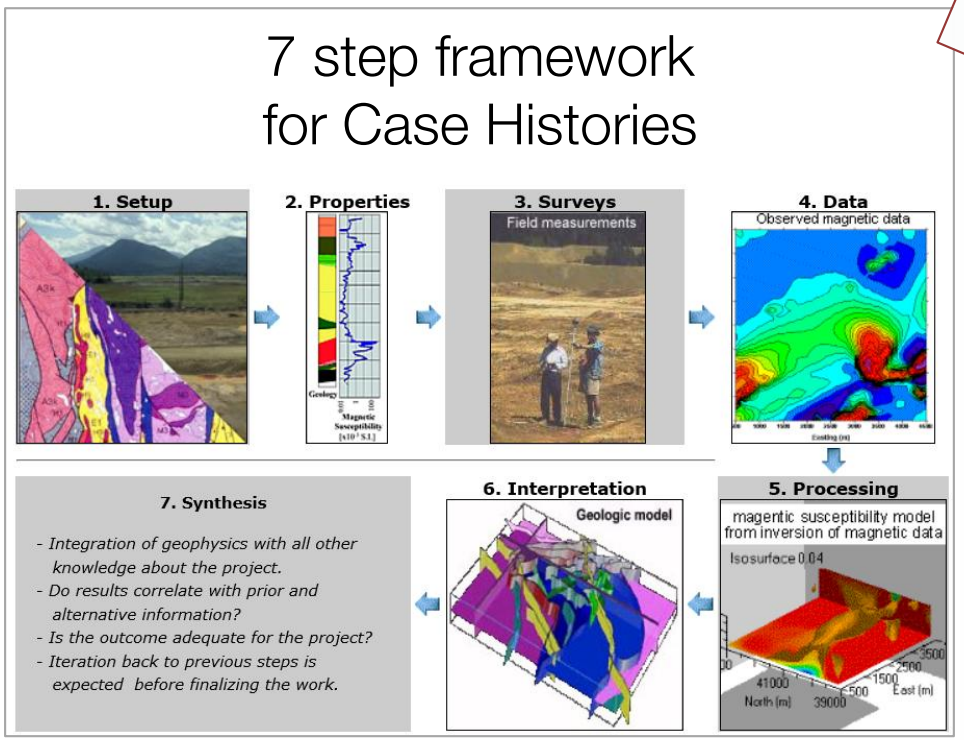
Resources: EM.geosci





http://em.geosci.xyz

Resources: EM.geosci

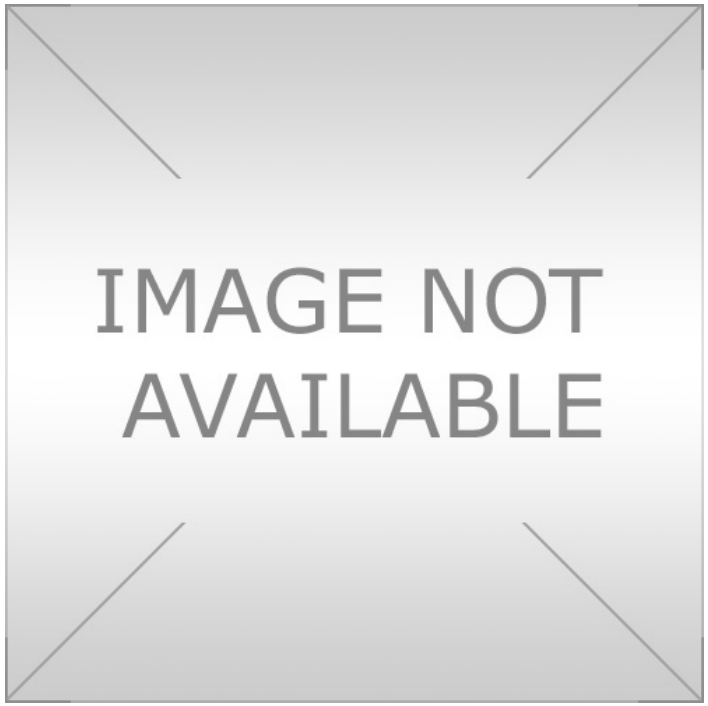


http://em.geosci.xyz

Why Apps

$$\nabla \times \mathbf{e} = -\frac{\partial \mathbf{b}}{\partial t}$$

$$\nabla \times \mathbf{h} = \mathbf{j} + \frac{\partial \mathbf{d}}{\partial t}$$

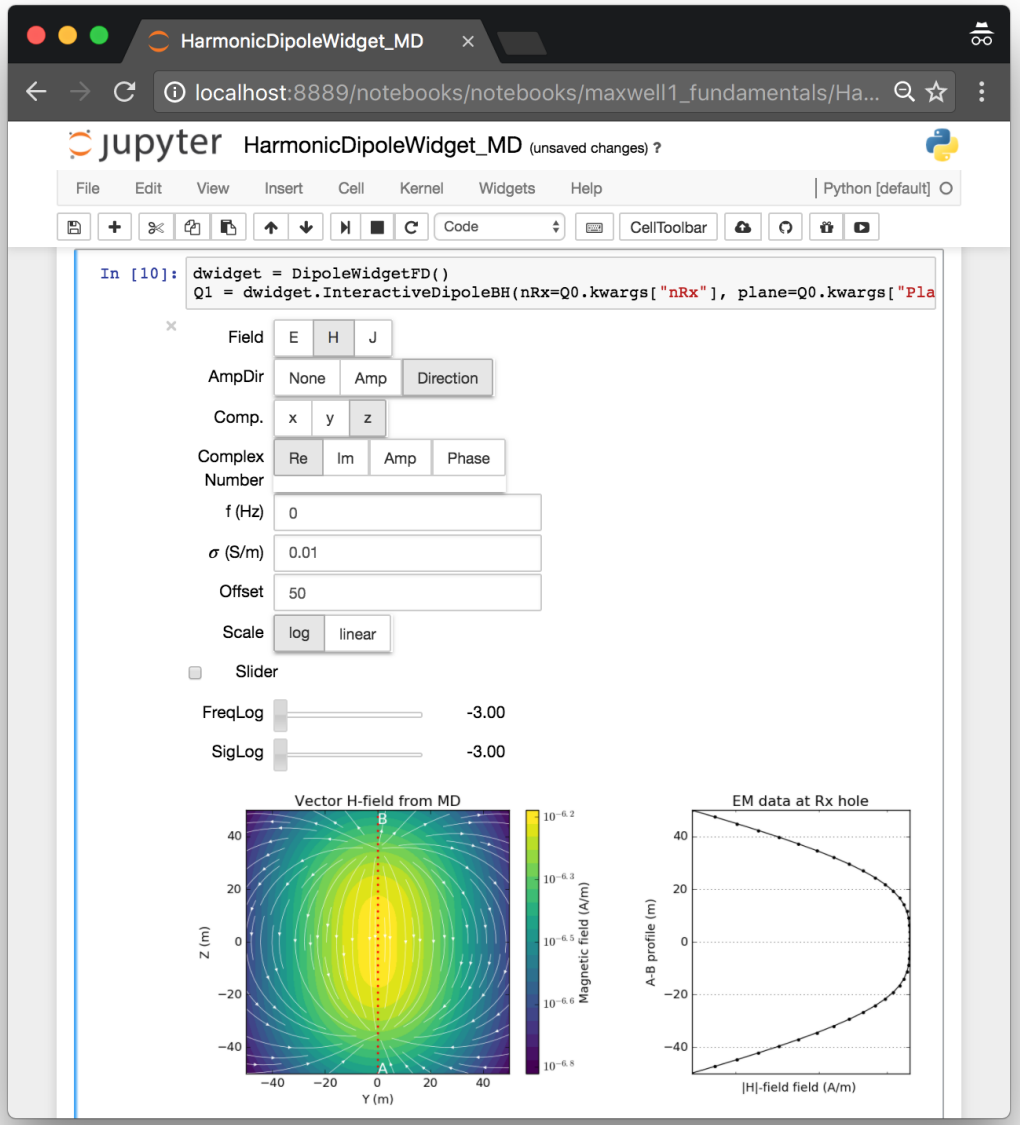


http://em.geosci.xyz/apps.html

Why Apps

$$\nabla \times \mathbf{e} = -\frac{\partial \mathbf{b}}{\partial t}$$

$$\nabla \times \mathbf{h} = \mathbf{j} + \frac{\partial \mathbf{d}}{\partial t}$$



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

How do we achieve our goals

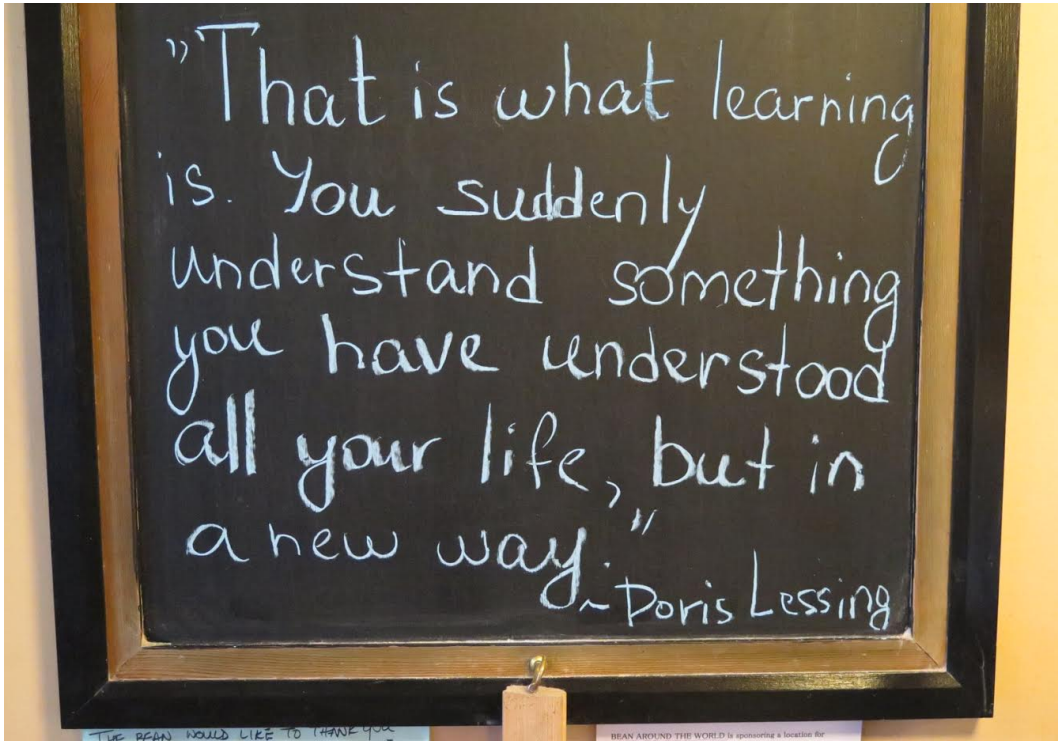
- Connect to relevant applications
- Select a type of survey
- Use apps to explore and ask questions
- Show success in a case history

Agenda for today

- Introduction to EM
- DCR
- EM Fundamentals
- Inductive sources
  - Lunch: Play with apps
- Grounded sources
- Natural sources
- GPR
- Induced polarization
- The Future

A touch of realism

- Ambitious schedule
- Wide variety of backgrounds but hope there is something for everybody
- Not really targeting the experts but even them…



DISC is a 2-day event

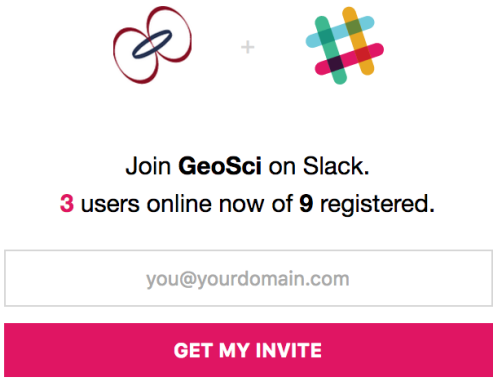
- SEG DISC Course (today)
  - Sponsored by SEG

- DISC Lab (tomorrow) (sponsored by GIF)
  - Capture “local” applications
  - Discuss and put them in a 7-step procedure
  - Share on the web
  - Sign up at http://disc2017.geosci.xyz/schedule#denver

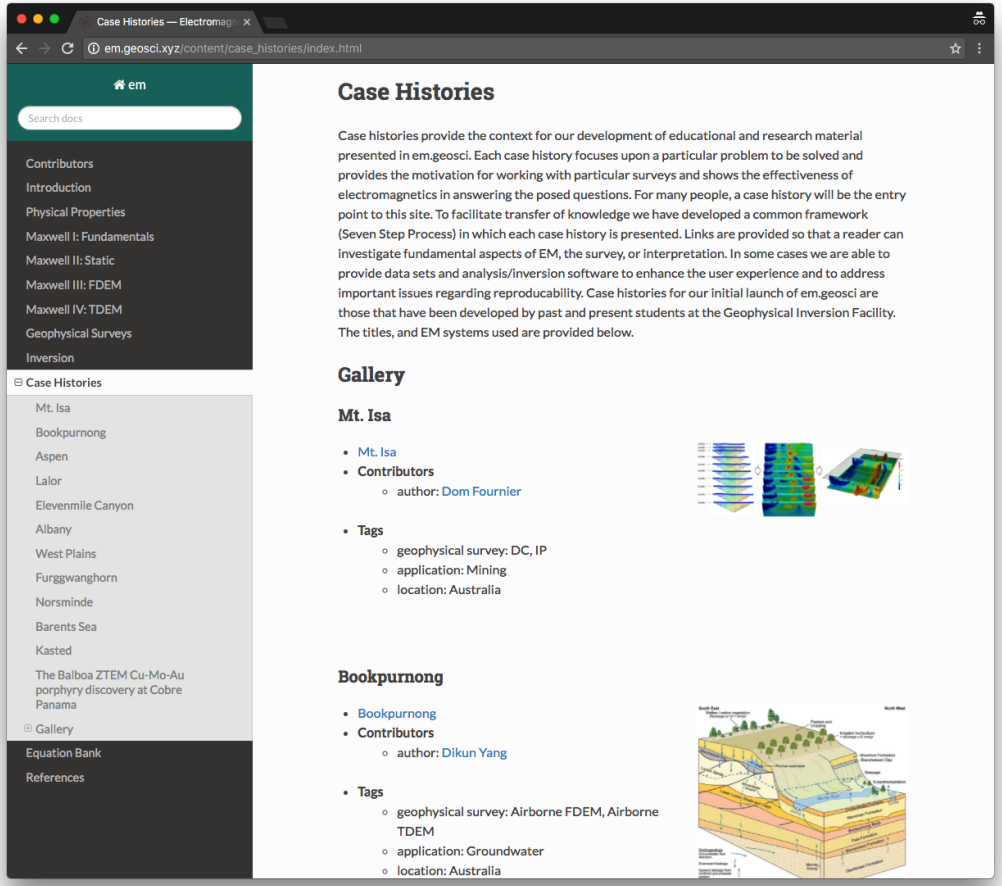
- The tour:
  - 30 locations
  - Capture geoscience problems around the world
  - Connect geoscientists worldwide, build a community

Connecting & Contributing

- Today: Slack
  - http://slack.geosci.xyz/



- Contributing:
  - EM GeoSci
    - Case histories
    - Content
  - SimPEG
    - Software



Introduction to EM

DISC

2017

Electromagnetics
Fundamentals and Applications

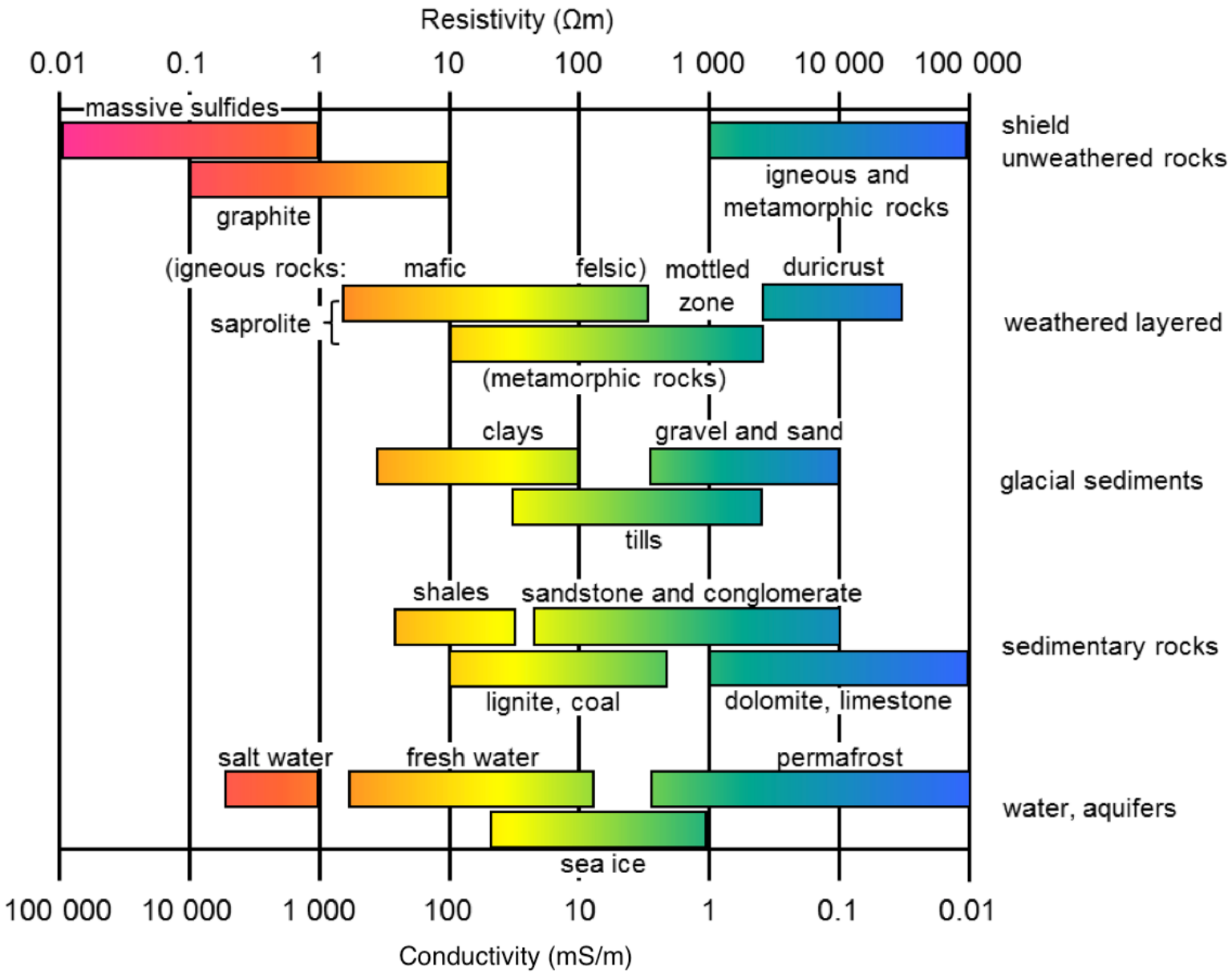
Three problems

minerals

unexploded ordnance

water

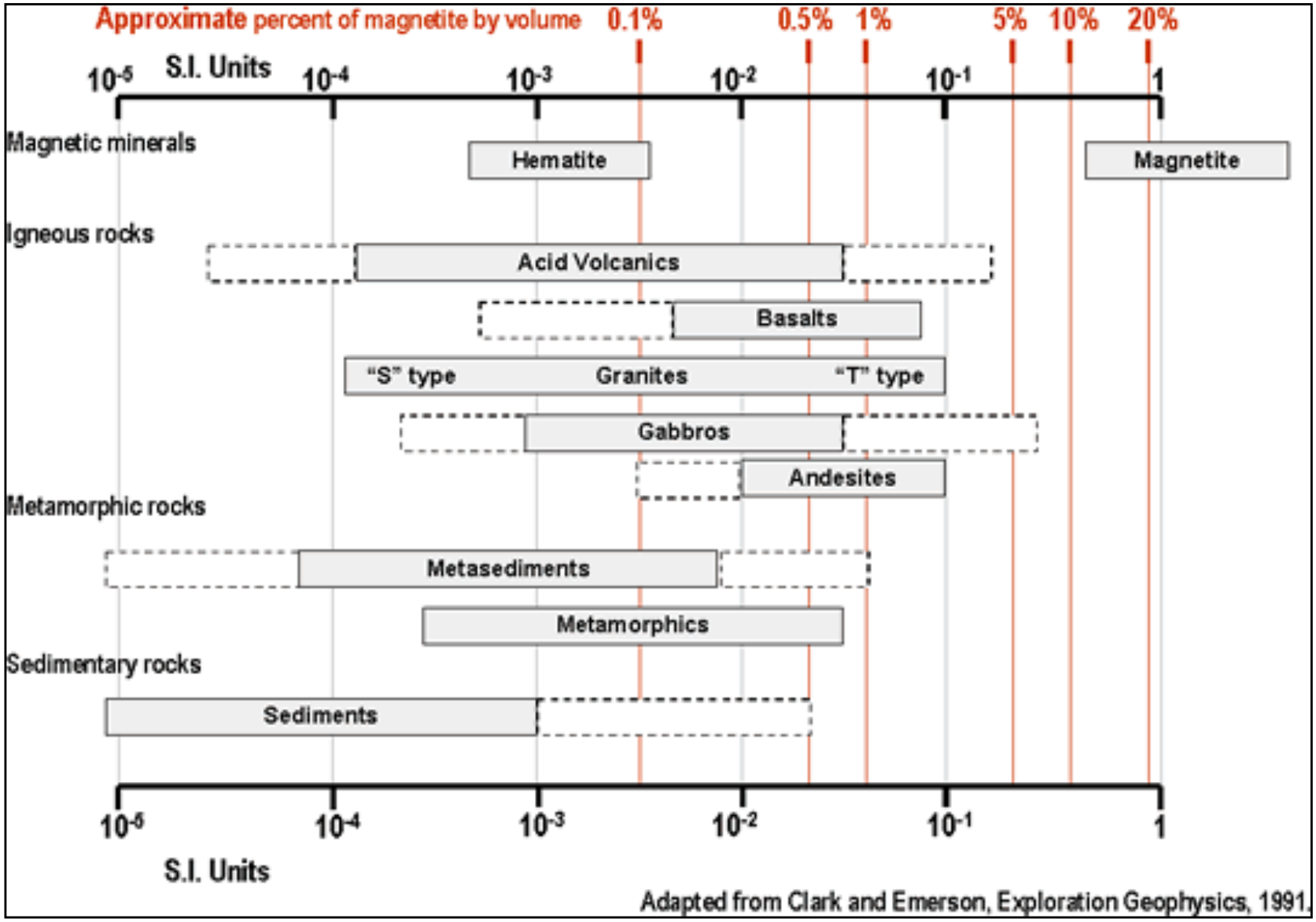
Electrical Resistivity / Conductivity



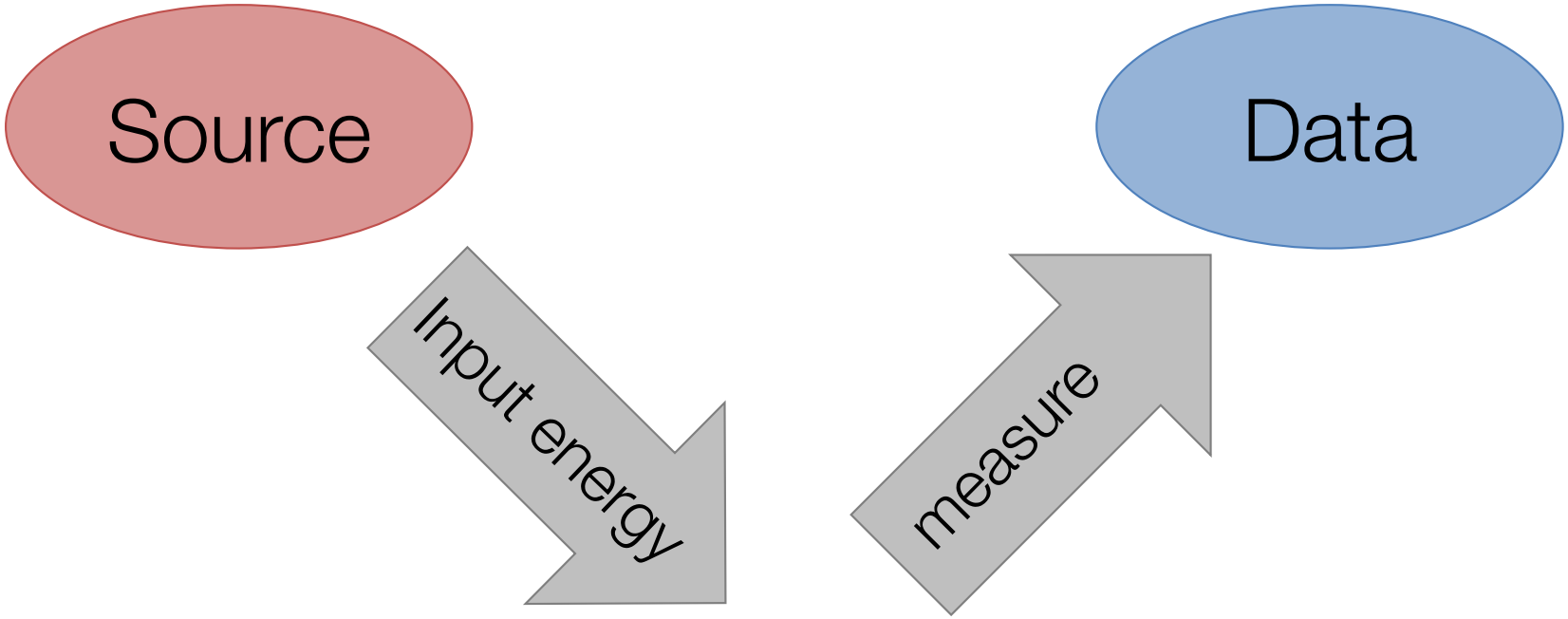
Dielectric constant

Material	Relative Permittivity	Conductivity (mS/m)	Average Velocity (m/ns)
Air	1	0	3
Fresh Water	80	0.5	0.033
Sea Water	80	3000	0.01
Ice	3-4	0.01	0.16
Dry Sand	3-5	0.01	0.15
Saturated Sand	20-30	0.1-1	0.06
Limestone	4-8	0.5-2	0.12
Shales	5-15	1-100	0.09
Silts	5-30	1-100	0.07
Clays	5-40	2-1000	0.06
Granite	4-6	0.01-1	0.13
Anhydrites	3-4	0.01-1	0.13

Magnetic Susceptibility



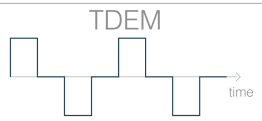
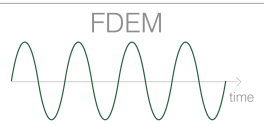
EM Survey & Physical Properties



Physical Properties

σ, μ, ε

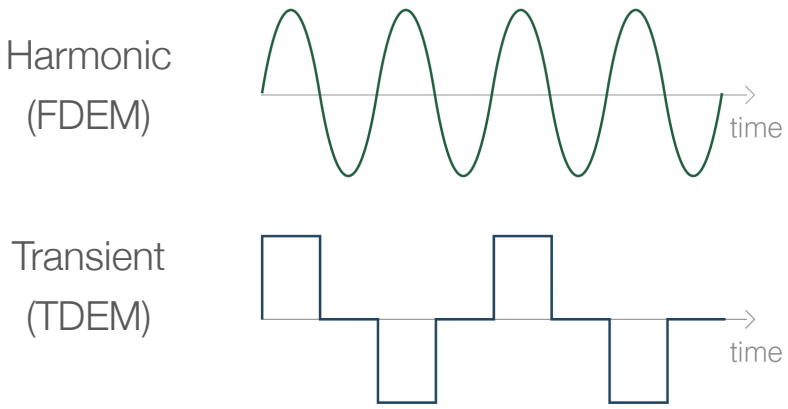
Basic Equations

	Time 	Frequency 
Faraday's Law	$\nabla \times \mathbf{e} = -\frac{\partial \mathbf{b}}{\partial t}$	$\nabla \times \mathbf{E} = -i\omega\mathbf{B}$
Ampere's Law	$\nabla \times \mathbf{h} = \mathbf{j} + \frac{\partial \mathbf{d}}{\partial t}$	$\nabla \times \mathbf{H} = \mathbf{J} + i\omega\mathbf{D}$
No Magnetic Monopoles	$\nabla \cdot \mathbf{b} = 0$	$\nabla \cdot \mathbf{B} = 0$
Constitutive Relationships (non-dispersive)	$\mathbf{j} = \sigma\mathbf{e}$ $\mathbf{b} = \mu\mathbf{h}$ $\mathbf{d} = \varepsilon\mathbf{e}$	$\mathbf{J} = \sigma\mathbf{E}$ $\mathbf{B} = \mu\mathbf{H}$ $\mathbf{D} = \varepsilon\mathbf{E}$

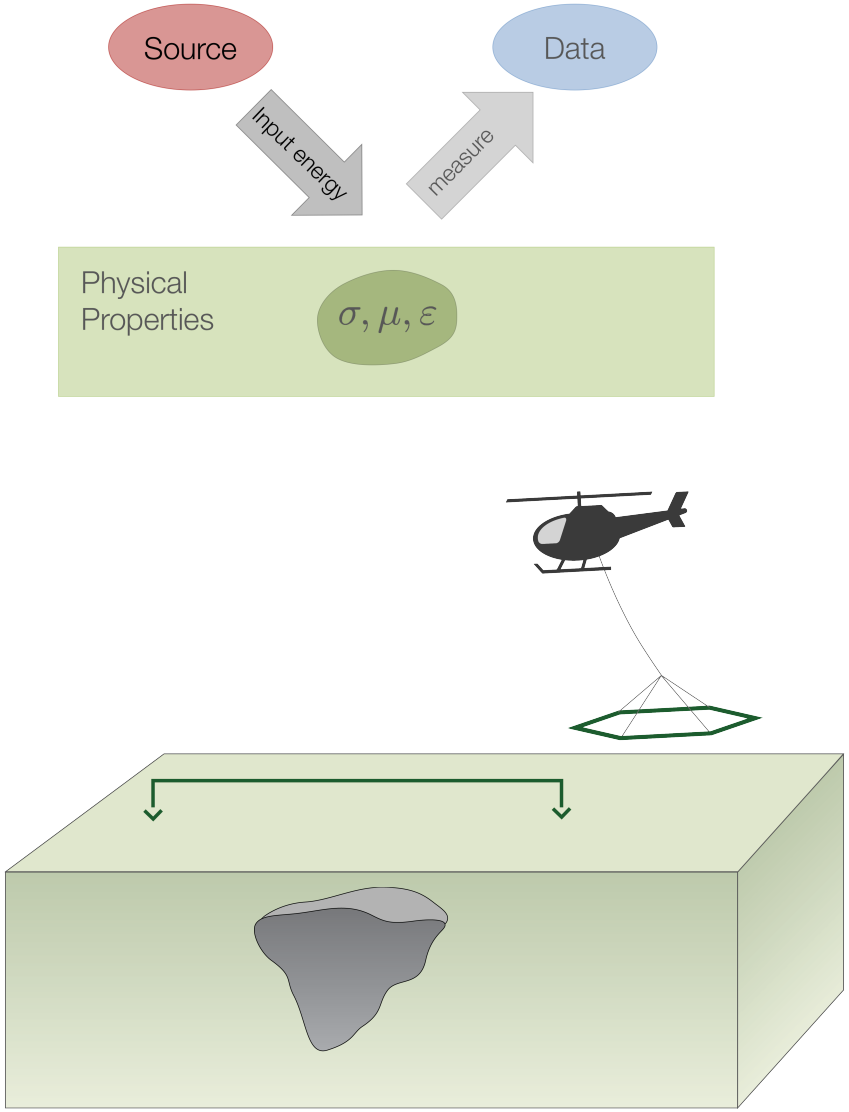
* Solve with sources and boundary conditions

Electromagnetic Survey: Sources

- Type
  - Inductive
  - Grounded
- Waveform

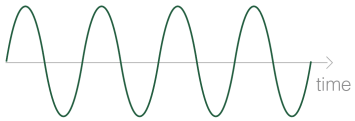


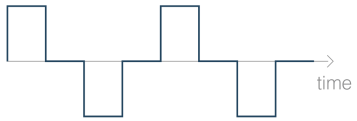
- Location
  - Airborne
  - Ground
  - Borehole



Electromagnetic Survey: Data

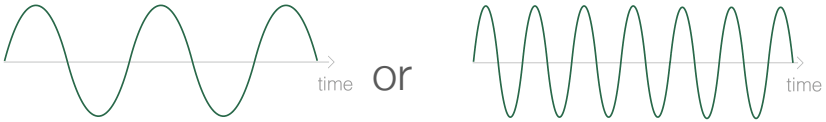
- Which field?



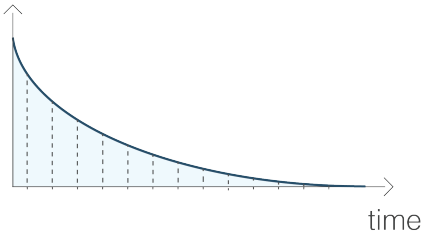


$\mathbf{E}, \mathbf{B}$ $\quad \mathbf{e}, \mathbf{b}, \frac{d\mathbf{b}}{dt}$

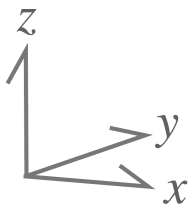
- Which frequencies?

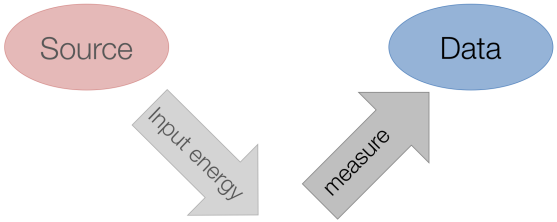


- times?

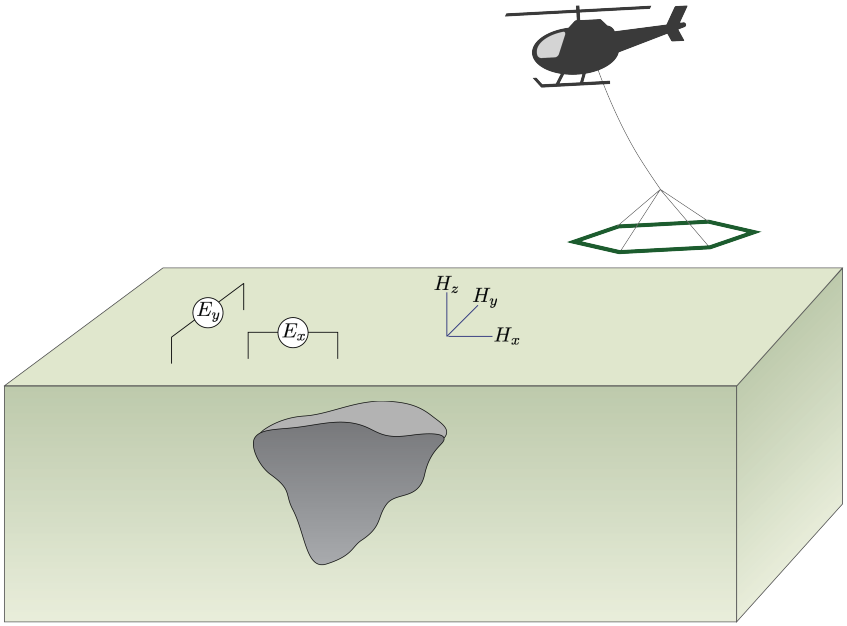


- Components?
- Location?
  - Airborne
  - Ground
  - Borehole





Physical Properties σ, μ, ε



Three problems

Electrical conductivity is diagnostic for all three

minerals

unexploded ordnance

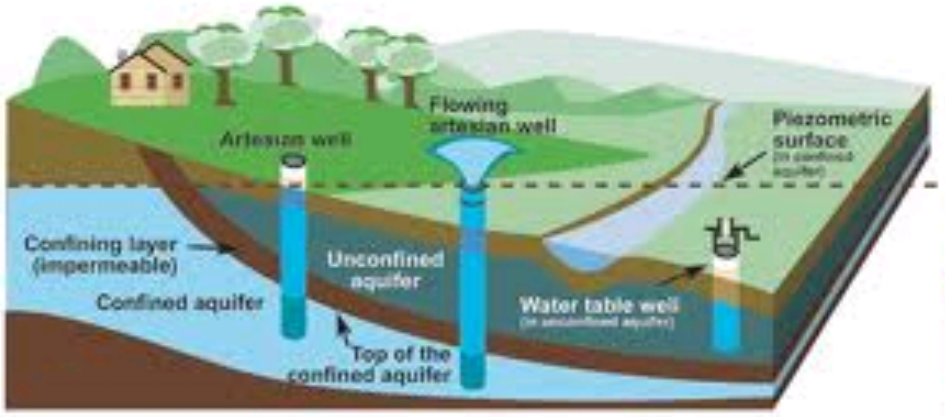
water

Finding resources

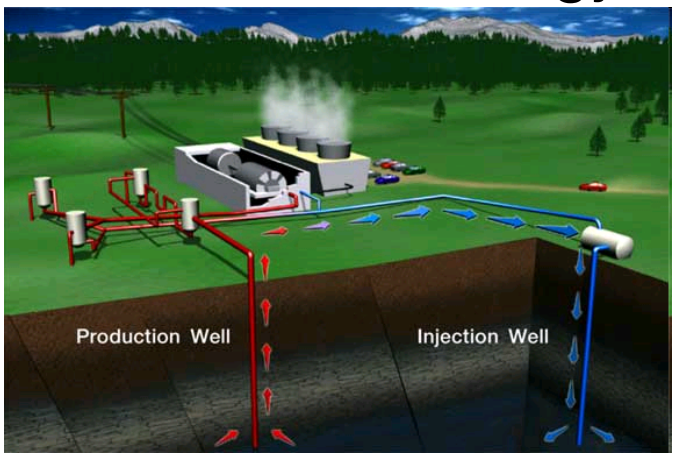
Hydrocarbons

Minerals

Ground Water



Geothermal Energy



Natural Hazards

Volcano

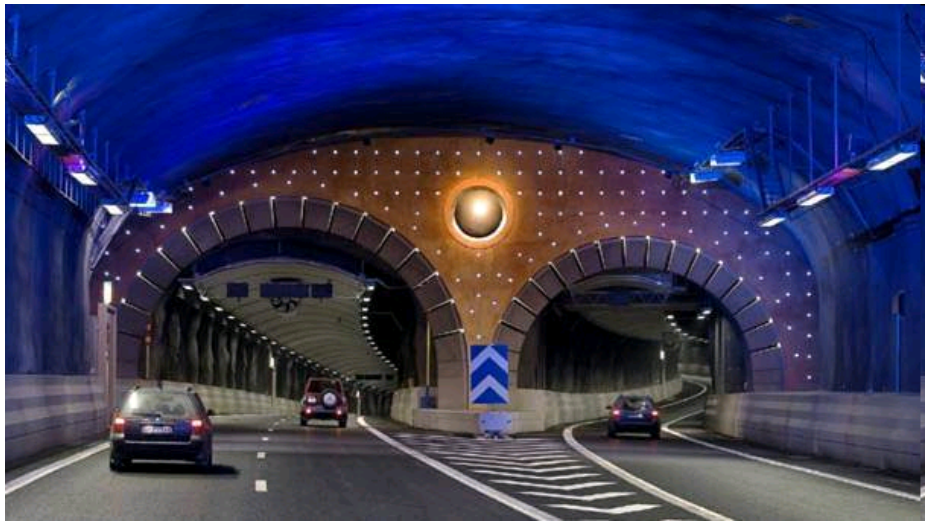
Landslide

Tsunami

Earthquake

Geotechnical engineering

Tunnels and highways



In-mine safety

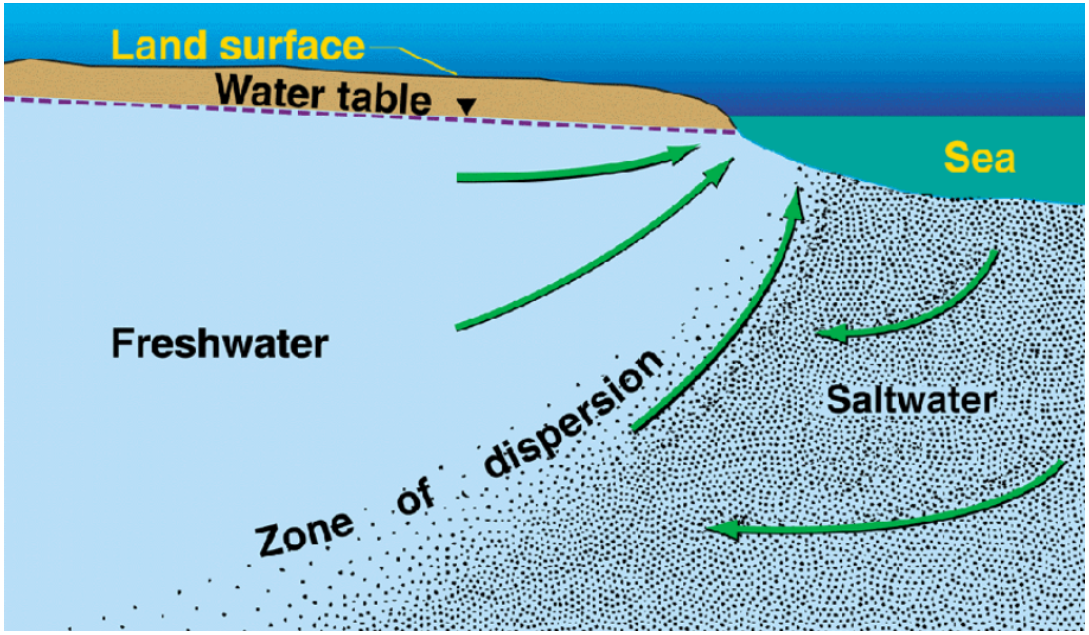
Slope stability

Subsurface voids

Environmental

Water contamination

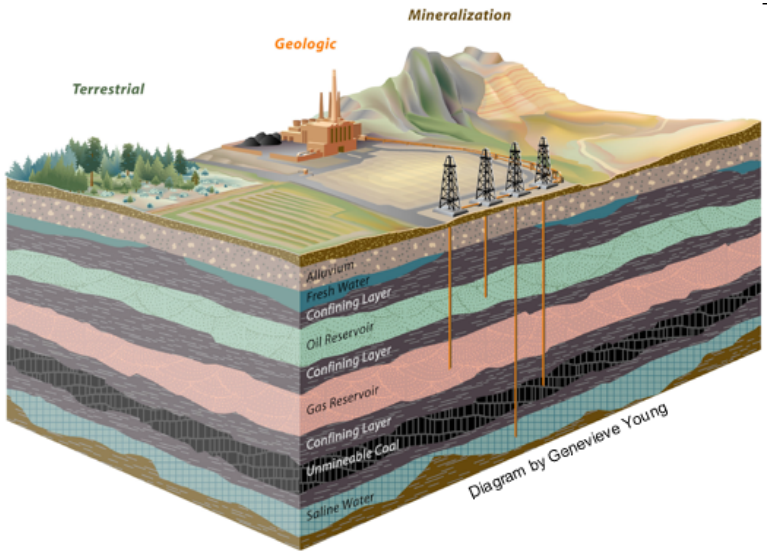
Saline water intrusion



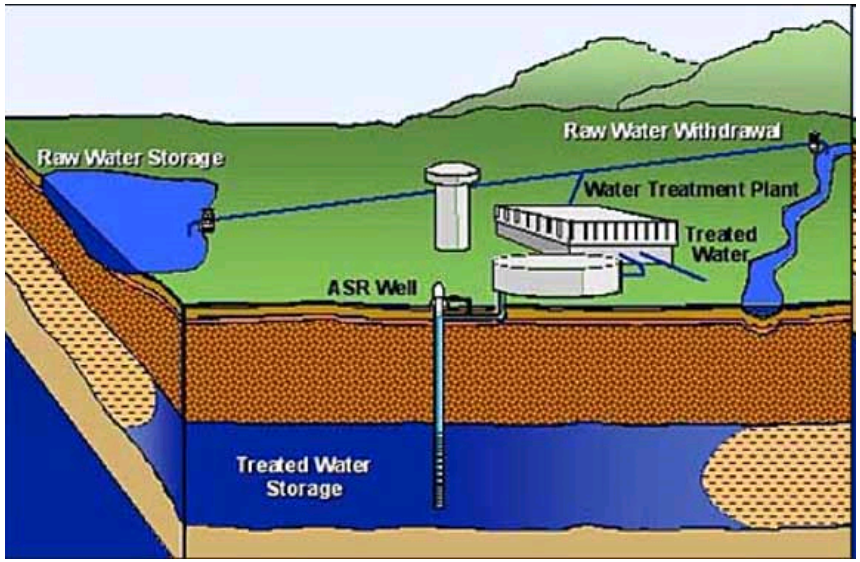
UXO detection

Surface or Underground Storage

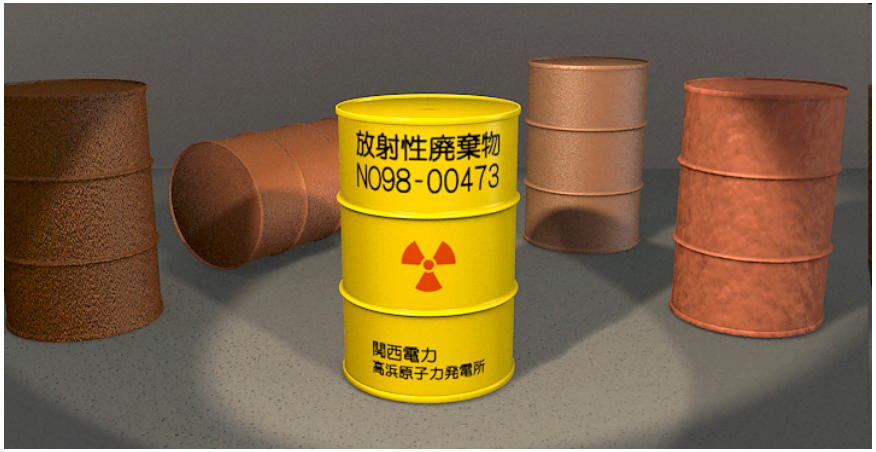
CO_2 sequestration



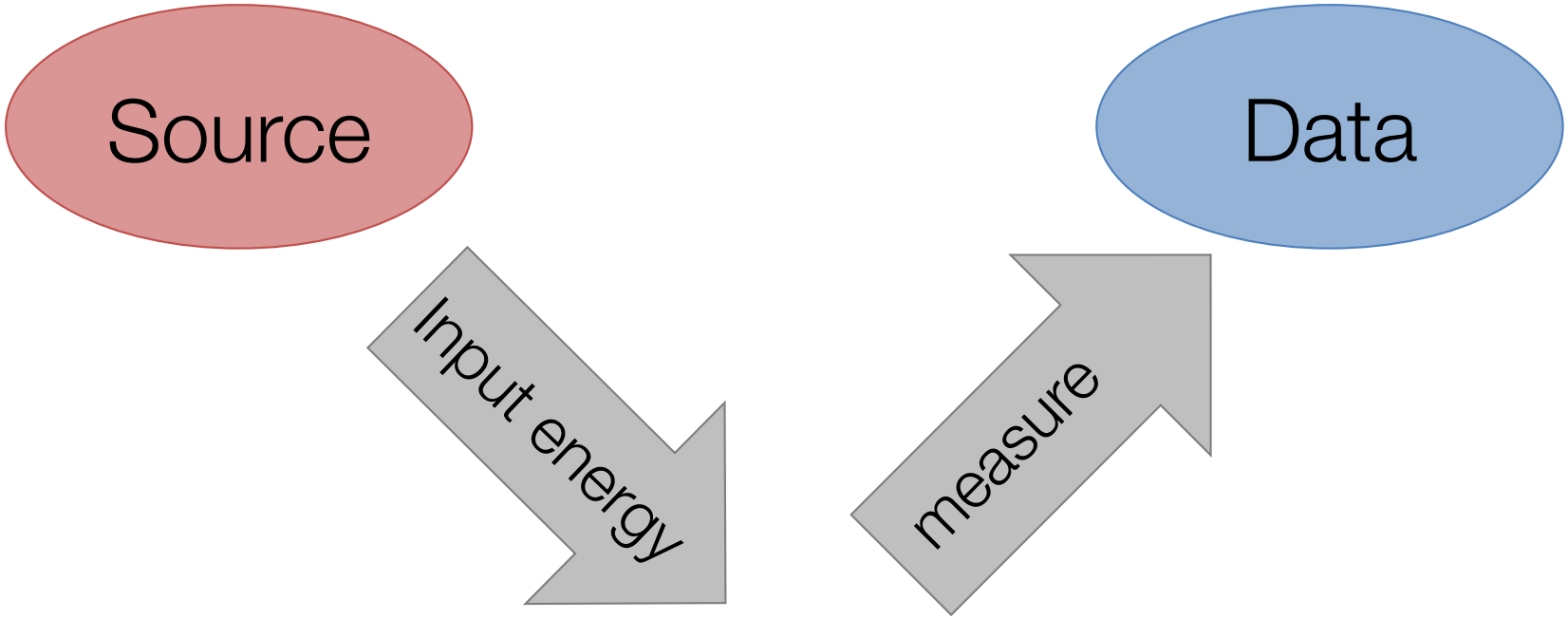
Aquifer storage and recovery



Industrial and radioactive waste



EM Survey & Physical Properties



Physical Properties

σ, μ, ε

End of Introduction

Next up →

- Introduction to EM
- DCR
- EM Fundamentals
- Inductive sources
  - Lunch: Play with apps
- Grounded sources
- Natural sources
- GPR
- Induced polarization
- The Future