



DISC

2017

Electromagnetics  
Fundamentals and Applications

<http://disc2017.geosci.xyz/denver>



SOCIETY OF EXPLORATION  
— GEOPHYSICISTS —

# Thanks to...



Yaoguo Li + Volunteers



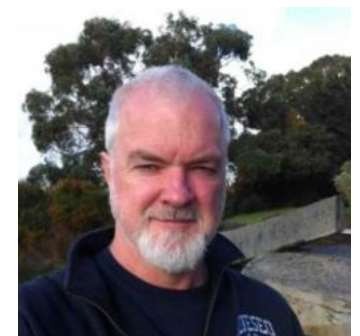
Andrei Swidinsky



Karen Christopherson



Misac Nabighian



Jeff Love

Thanks to...



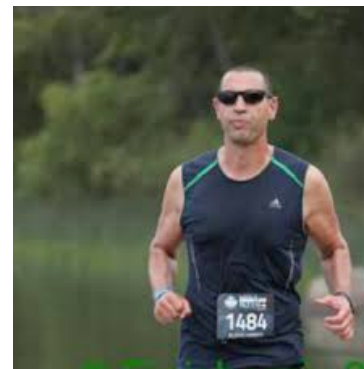
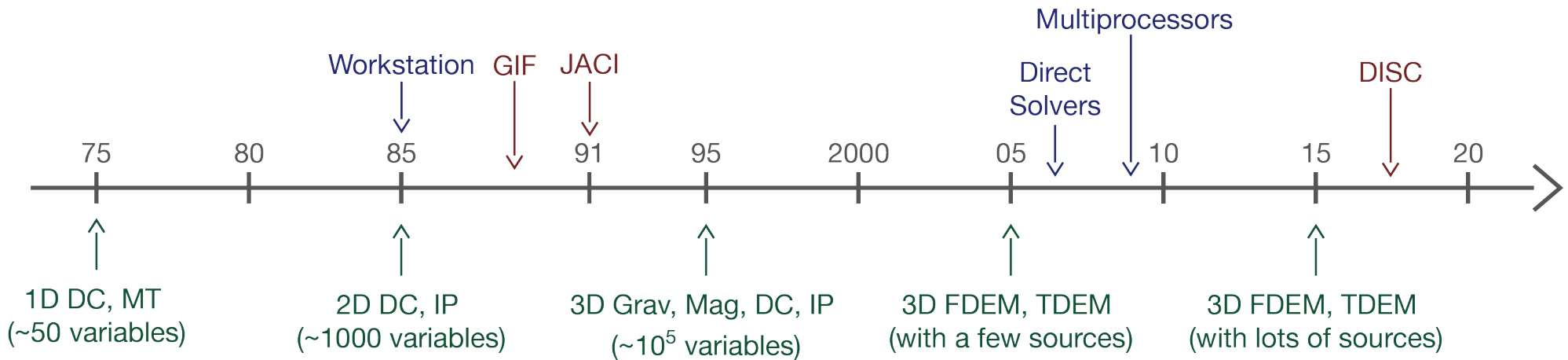
Student sponsorship



DISC Lab & support

# Some Background

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

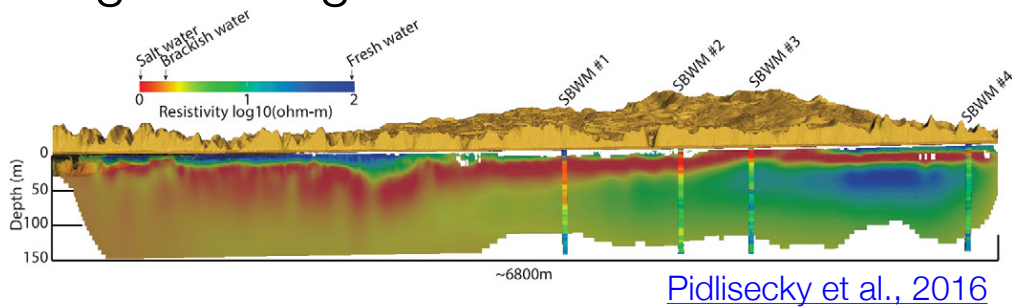


Result: Computing power + advances in inversion methodology  
→ we can now solve most EM geophysics problems

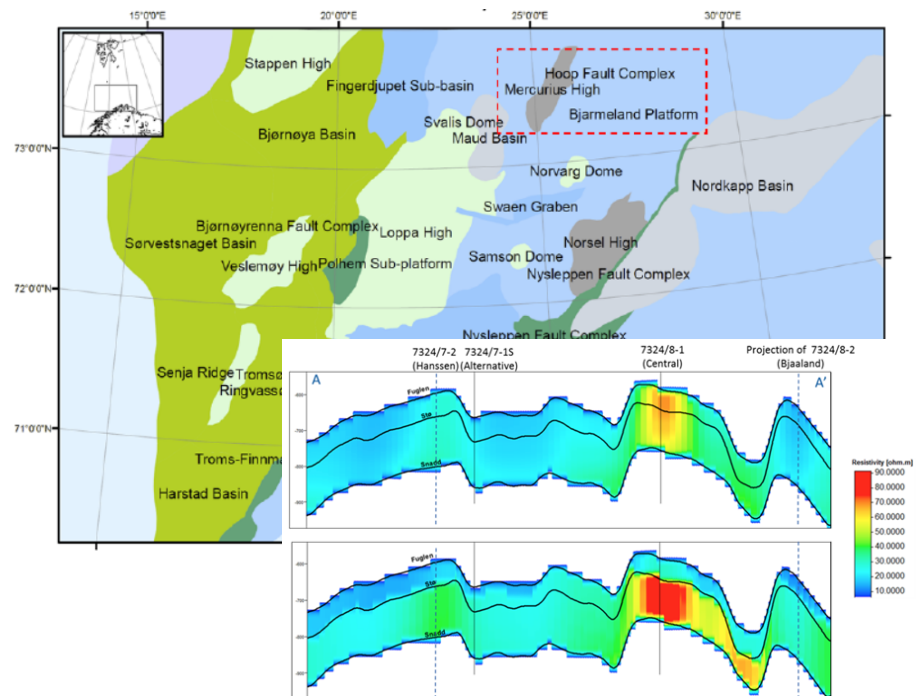
# Instrumentation and Data

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

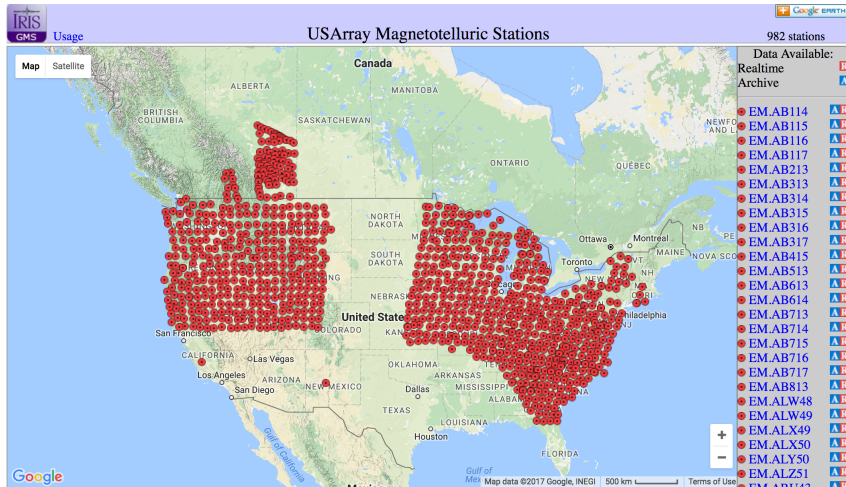
## Large-scale ground water studies: California



## Offshore: Hydrocarbon De-risking



## Earth scope: Continental Scale MT



[Earth Scope](#)

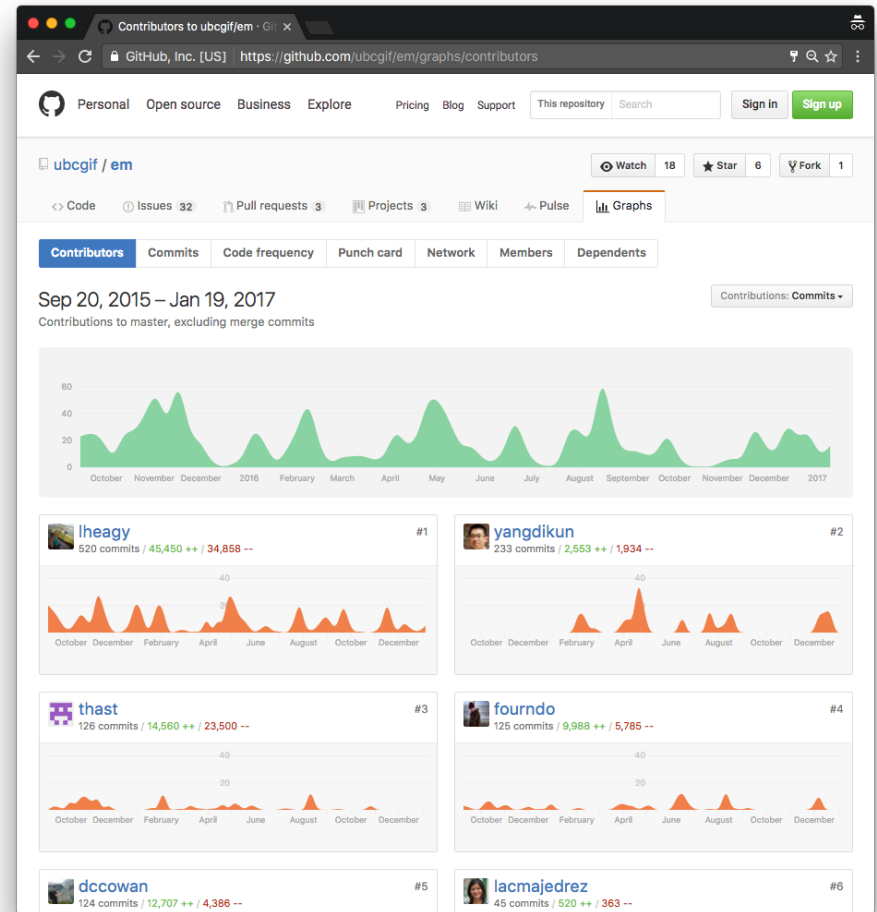
# Web and Open Source Resources

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



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



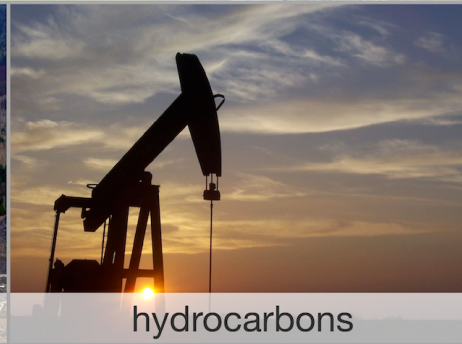
geothermal



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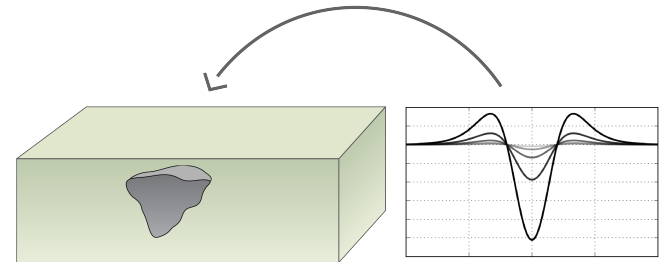
Are there situations, similar to mine, in which EM has been applied?

# DISC can take advantage of a Perfect Storm

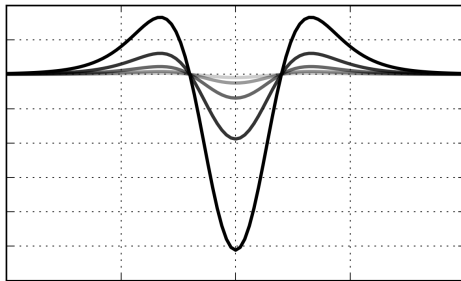
Problems



Inversion capabilities



High quality data



Web tools to  
communicate

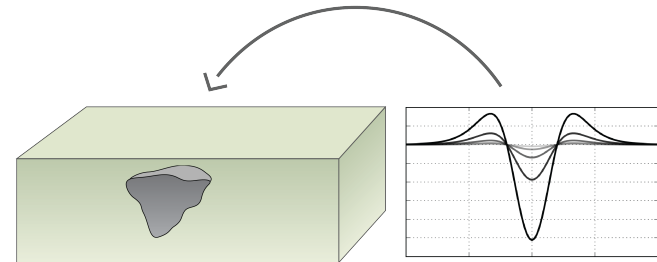


# DISC can take advantage of a Perfect Storm

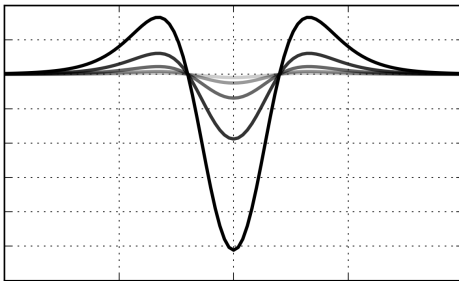
Problems



Inversion capabilities



High quality data



Web tools to  
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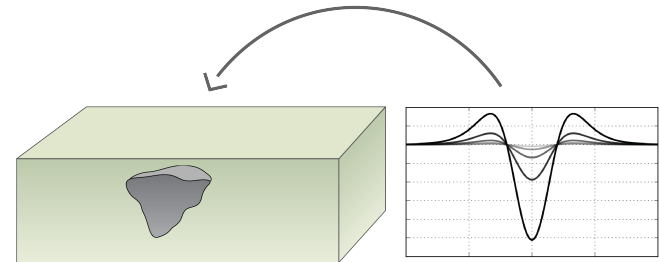
A good idea but missing an important ingredient ...

# Talented Young Geoscientists

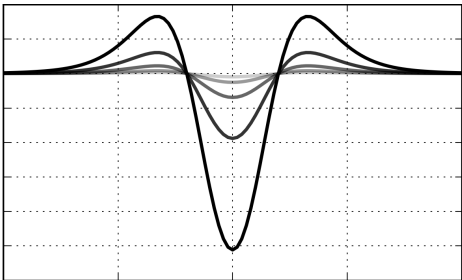
Problems



Inversion capabilities



High quality data



Web tools to  
communicate



Seogi

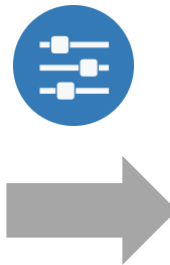
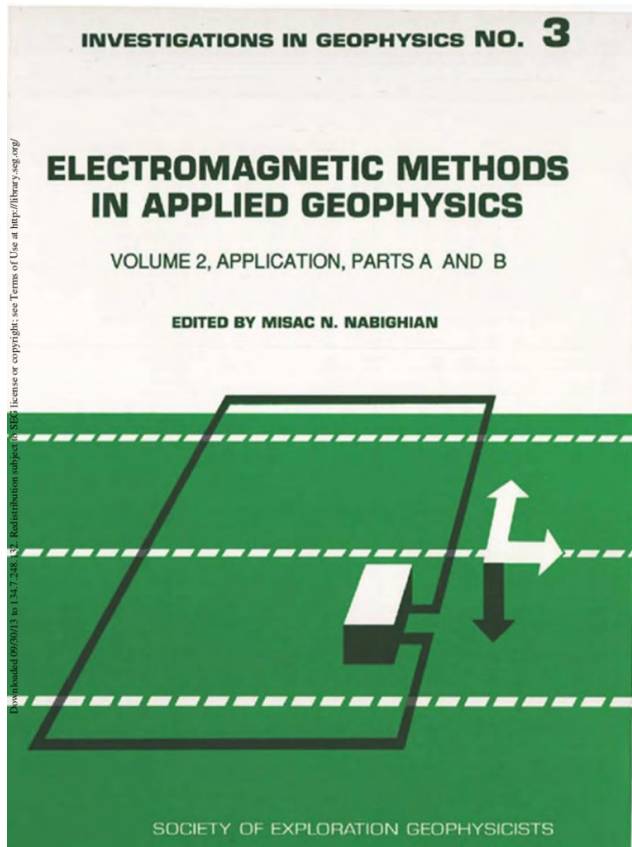


Lindsey

# 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

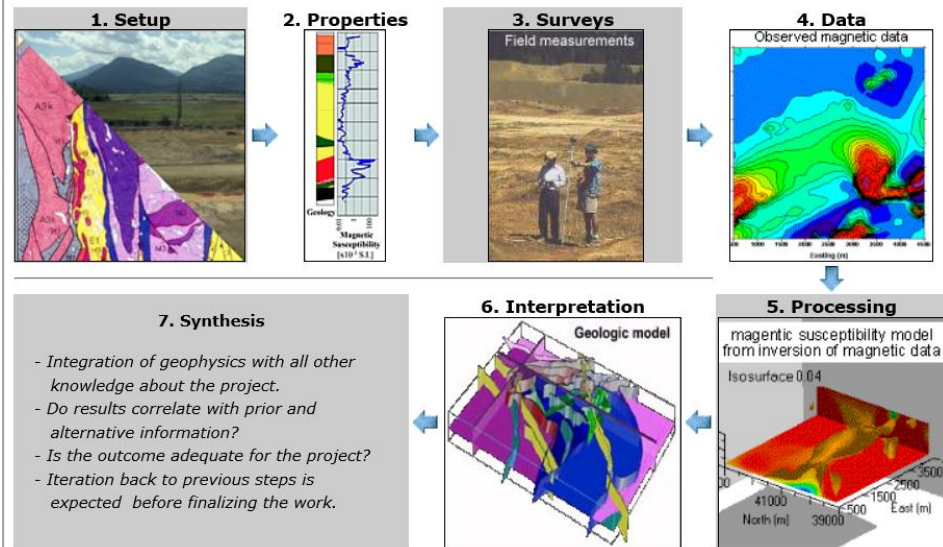


The screenshot shows the website "em.geosci" with the "Case Histories" section. The page has a dark green header with the "em" logo and a search bar. A sidebar on the left lists navigation options: Contributors, Introduction, Physical Properties, Maxwell I: Fundamentals, Maxwell II: Static, Maxwell III: FDEM, Maxwell IV: TDEM, Geophysical Surveys, Inversion, Case Histories (expanded), Mt. Isa, Bookpurnong, Aspen, Lalor, Elevenmile Canyon, Albany, West Plains, Furggwanghorn, Norsminde, Barents Sea, Kasted, The Balboa ZTEM Cu-Mo-Au porphyry discovery at Cobre Panama, Gallery, Equation Bank, and References. The main content area is titled "Case Histories" and contains a paragraph explaining the purpose of case histories. Below this is a "Gallery" section with two entries: "Mt. Isa" and "Bookpurnong". Each entry lists contributors and tags. The "Mt. Isa" entry lists the author as Dom Fournier and tags include geophysical survey: DC, IP; application: Mining; and location: Australia. The "Bookpurnong" entry lists the author as Dikun Yang and tags include geophysical survey: Airborne FDEM, Airborne TDEM; application: Groundwater; and location: Australia. Two small images are shown: a 3D plot of magnetic field components for Mt. Isa and a geological cross-section for Bookpurnong.

<http://em.geosci.xyz>

# Resources: EM.geosci

## 7 step framework for Case Histories



Case Histories — Electromagn...

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

em

Search docs

Contributors

Introduction

Physical Properties

Maxwell I: Fundamentals

Maxwell II: Static

Maxwell III: FDEM

Maxwell IV: TDEM

Geophysical Surveys

Inversion

Case Histories

- Mt. Isa
- Bookpurnong
- Aspen
- Lalor
- Elevenmile Canyon
- Albany
- West Plains
- Furggwanhorn
- Norsminde
- Barents Sea
- Kasted
- The Balboa ZTEM Cu-Mo-Au porphyry discovery at Cobre Panama

Equation Bank

References

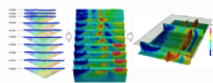
### Case Histories

Case histories provide the context for our development of educational and research material presented in em.geosci. Each case history focuses upon a particular problem to be solved and provides the motivation for working with particular surveys and shows the effectiveness of electromagnetics in answering the posed questions. For many people, a case history will be the entry point to this site. To facilitate transfer of knowledge we have developed a common framework (Seven Step Process) in which each case history is presented. Links are provided so that a reader can investigate fundamental aspects of EM, the survey, or interpretation. In some cases we are able to provide data sets and analysis/inversion software to enhance the user experience and to address important issues regarding reproducibility. Case histories for our initial launch of em.geosci are those that have been developed by past and present students at the Geophysical Inversion Facility. The titles, and EM systems used are provided below.

### Gallery

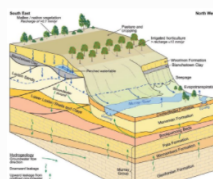
#### Mt. Isa

- **Contributors**
  - author: Dom Fournier
- **Tags**
  - geophysical survey: DC, IP
  - application: Mining
  - location: Australia



#### Bookpurnong

- **Contributors**
  - author: Dikun Yang
- **Tags**
  - geophysical survey: Airborne FDEM, Airborne TDEM
  - application: Groundwater
  - location: Australia

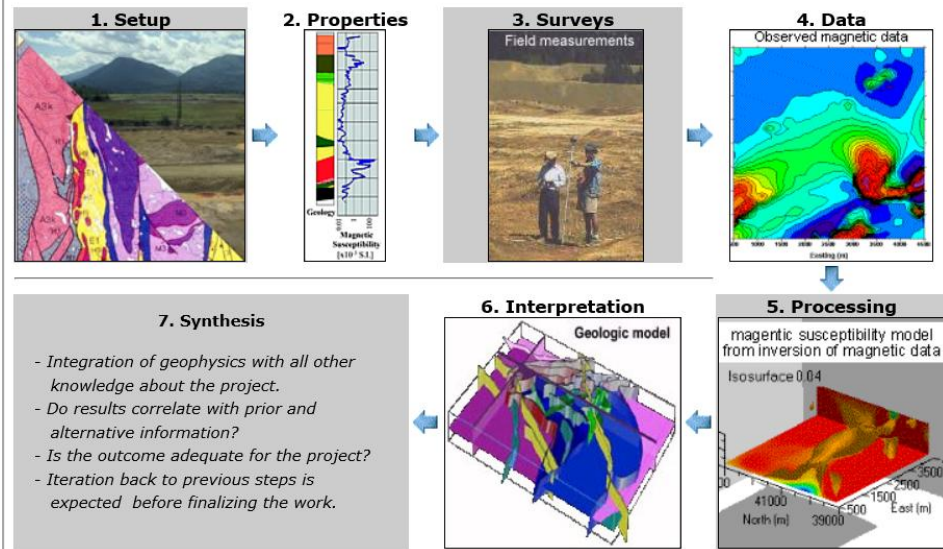


<http://em.geosci.xyz>



# Resources: EM.geosci

## 7 step framework for Case Histories



**Case Histories**

Contributors

Introduction

Physical Properties

Maxwell I: Fundamentals

Maxwell II: Static

Maxwell III: FDEM

Maxwell IV: TDEM

Geophysical Surveys

Inversion

Case Histories

- Mt. Isa
- Bookpurnong
- Aspen
- Lalor
- Elevenmile Canyon
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- West Plains
- Furggawanghorn
- Norsminde
- Barents Sea
- Kasted
- The Balboa ZTEM Cu-Mo-Au porphyry discovery at Cobre Panama

Equation Bank

References

**Gallery**

**Mt. Isa**

- **Contributors**
  - author: Dom Fournier
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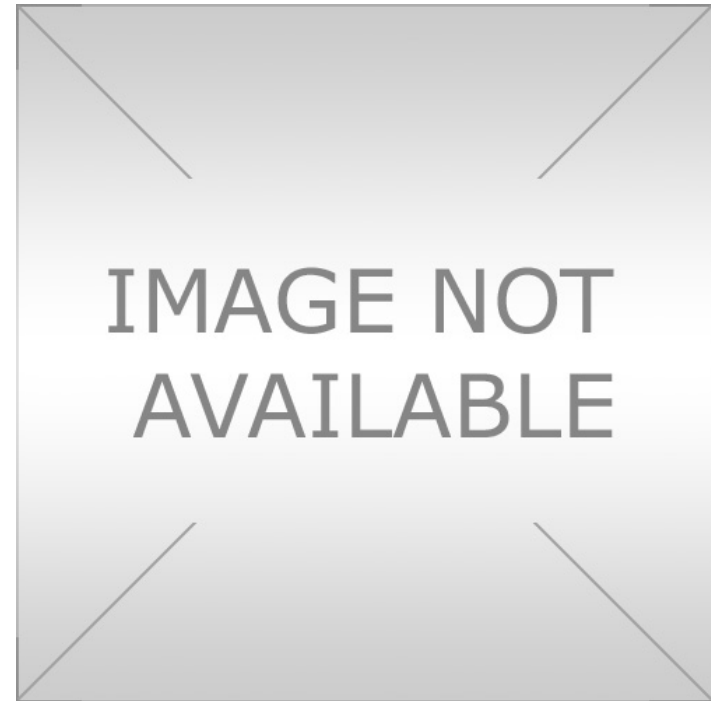
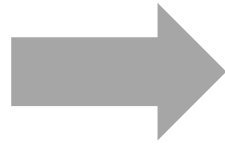
**Bookpurnong**

- **Bookpurnong**
- **Contributors**
  - author: Dikun Yang
- **Tags**
  - geophysical survey: Airborne FDEM, Airborne TDEM
  - application: Groundwater
  - location: Australia

# Why Apps

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

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

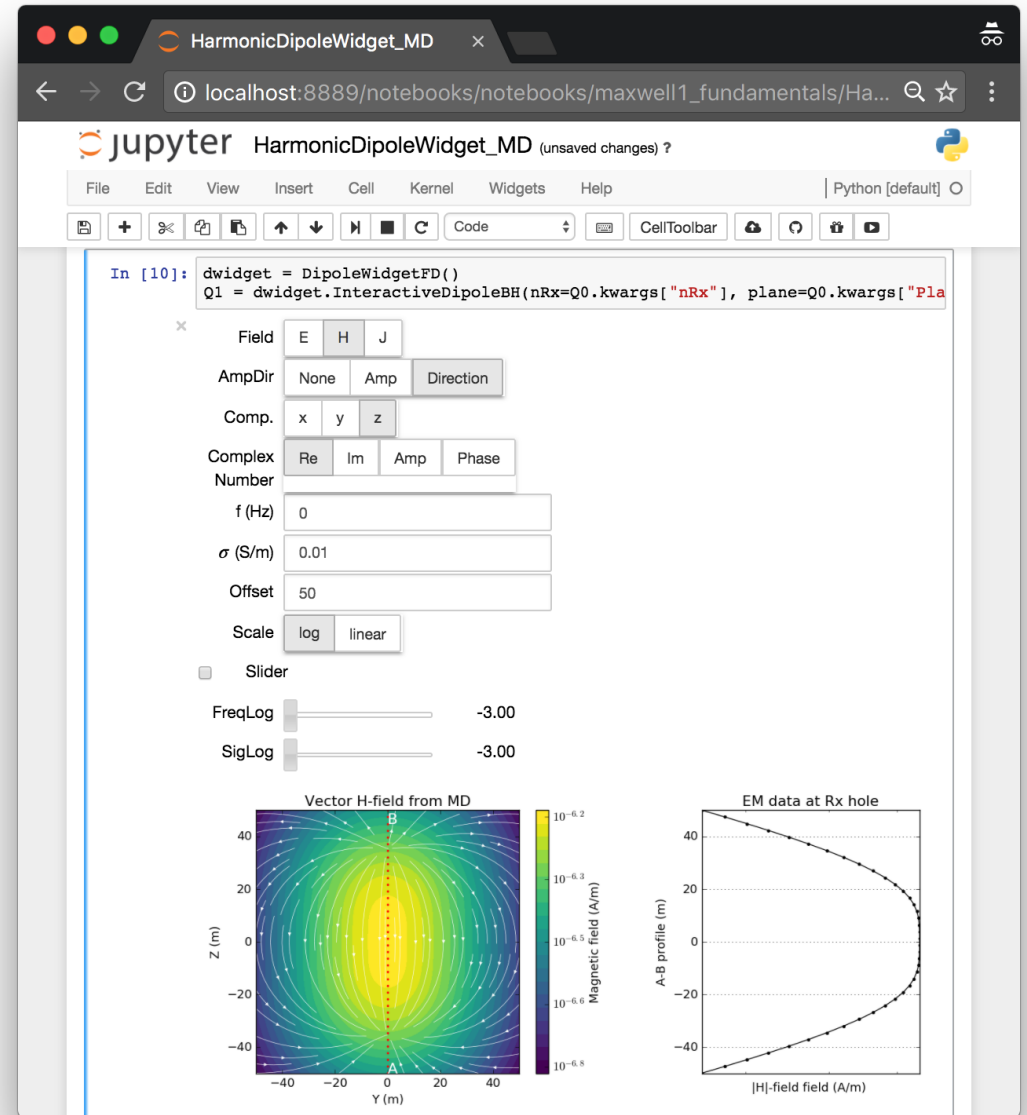


<http://em.geosci.xyz/apps.html>

# 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

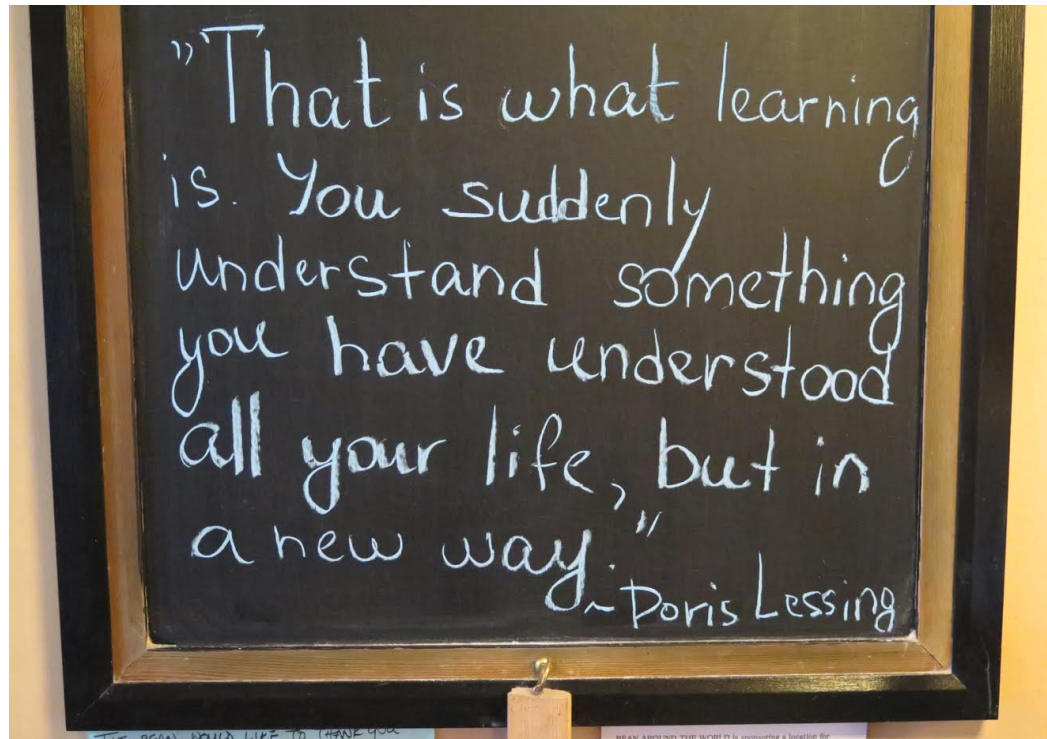
# Agenda for today

- 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...



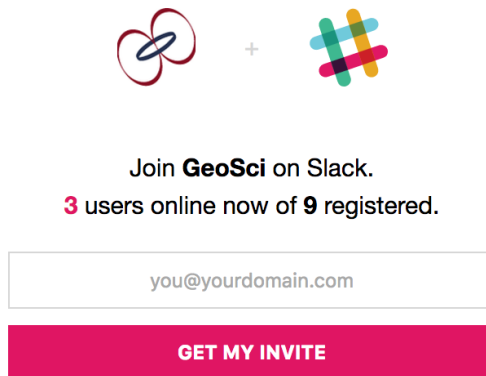
# DISC is a 2-day event

- 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

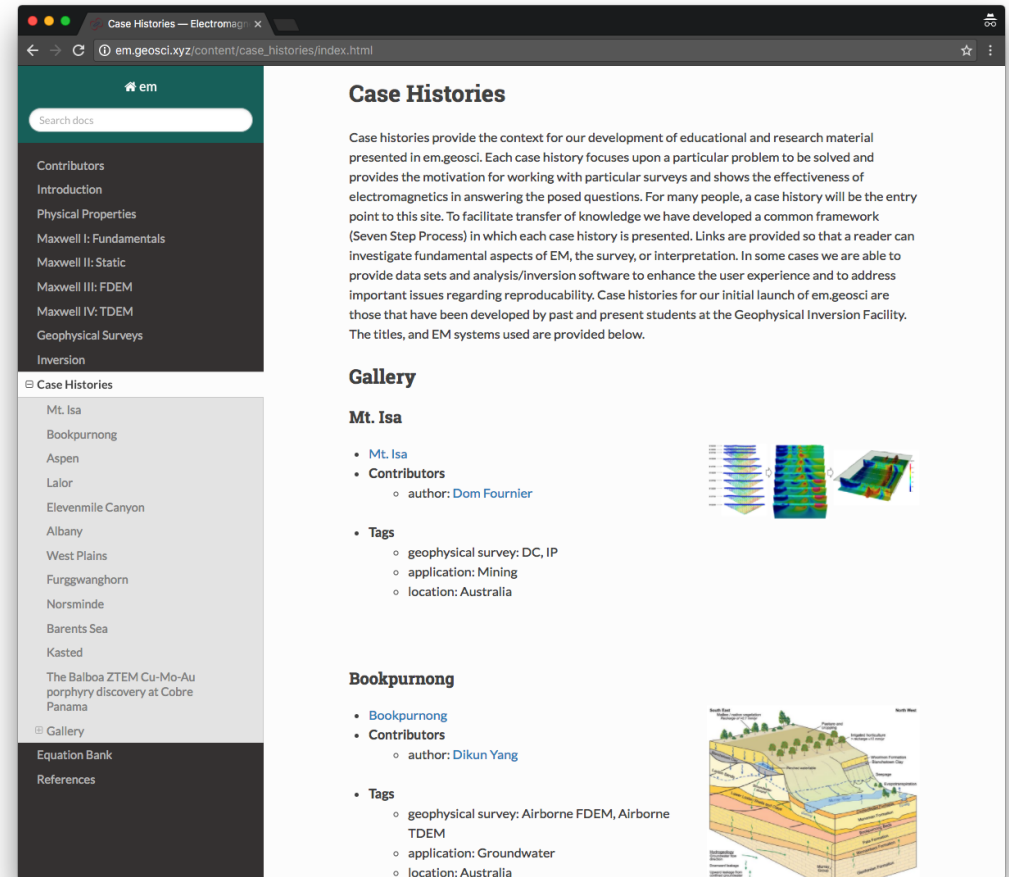
- Today: Slack
  - <http://slack.geosci.xyz/>



Join **GeoSci** on Slack.  
3 users online now of 9 registered.

**GET MY INVITE**

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



The screenshot shows a web browser displaying the 'Case Histories' page on the em.geosci.xyz website. The page has a dark green header with the 'em' logo and a search bar. A left sidebar contains a navigation menu with categories like 'Contributors', 'Introduction', 'Physical Properties', and 'Case Histories'. The main content area features a 'Case Histories' section with an introductory paragraph, followed by a 'Gallery' section. The gallery includes two entries: 'Mt. Isa' with a 3D visualization of a geological cross-section and associated data, and 'Bookpurnong' with a 2D geological cross-section diagram. Each entry lists contributors and tags such as 'geophysical survey', 'application', and 'location'.



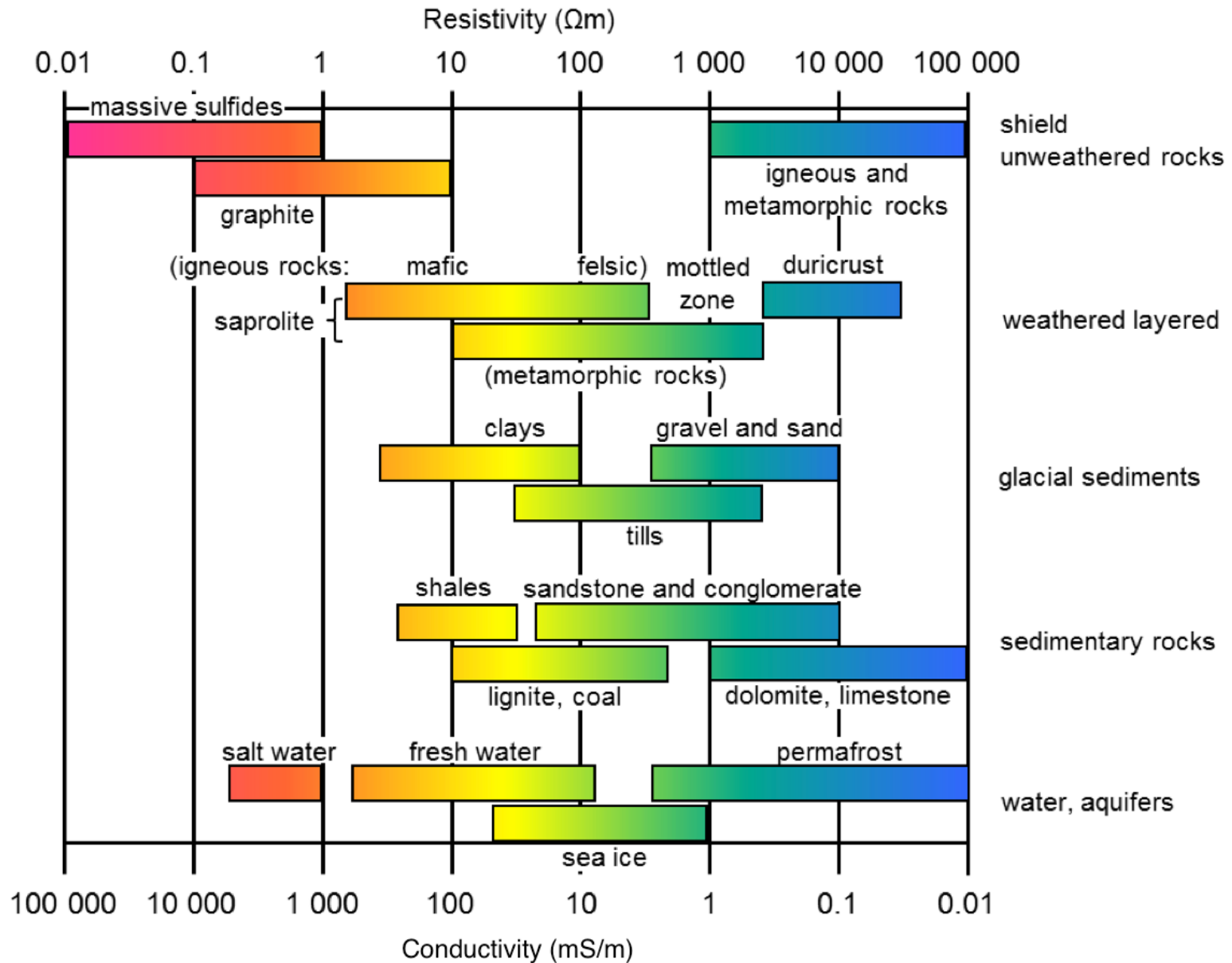
# Introduction to EM



# Three problems



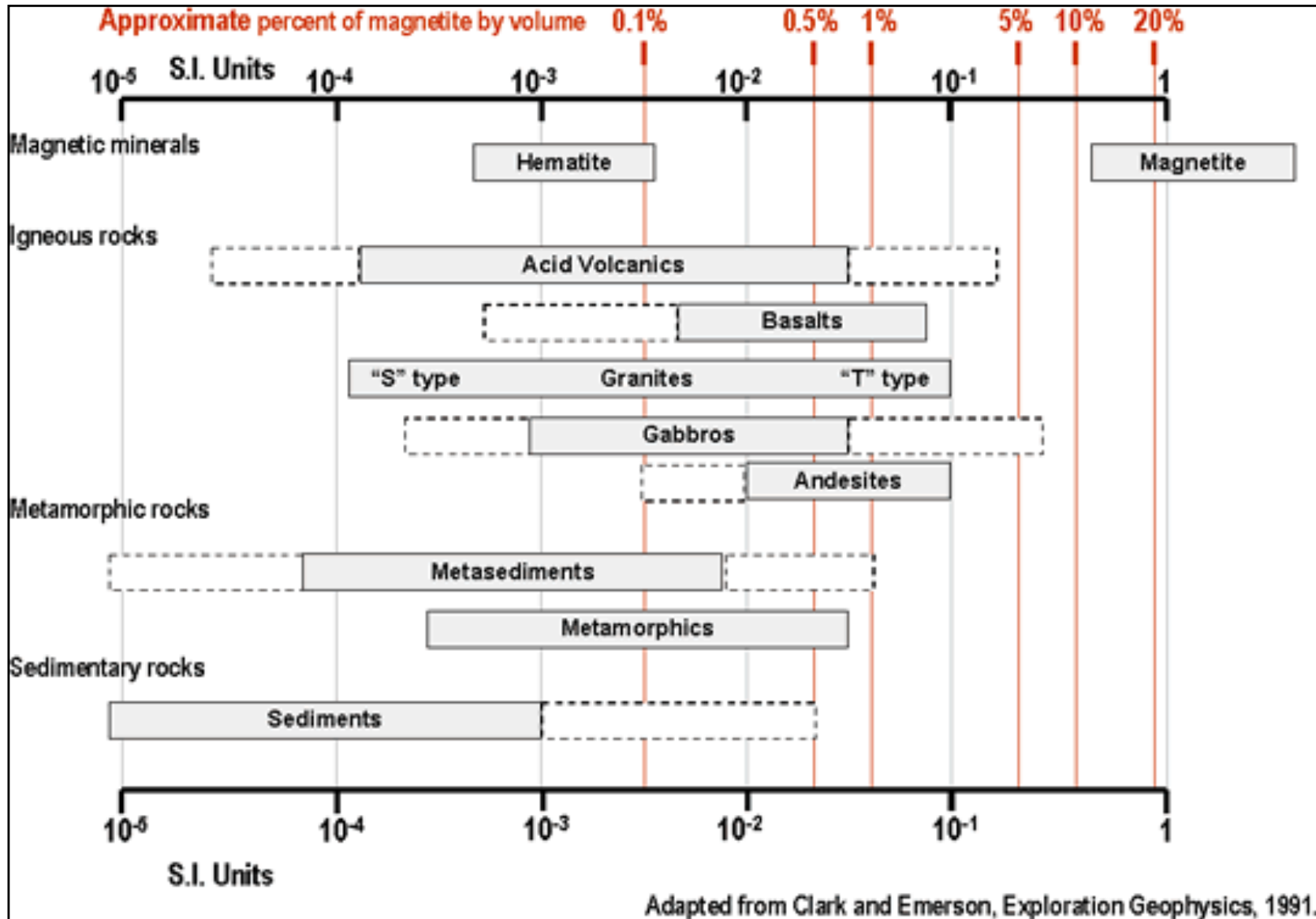
# Electrical Resistivity / Conductivity



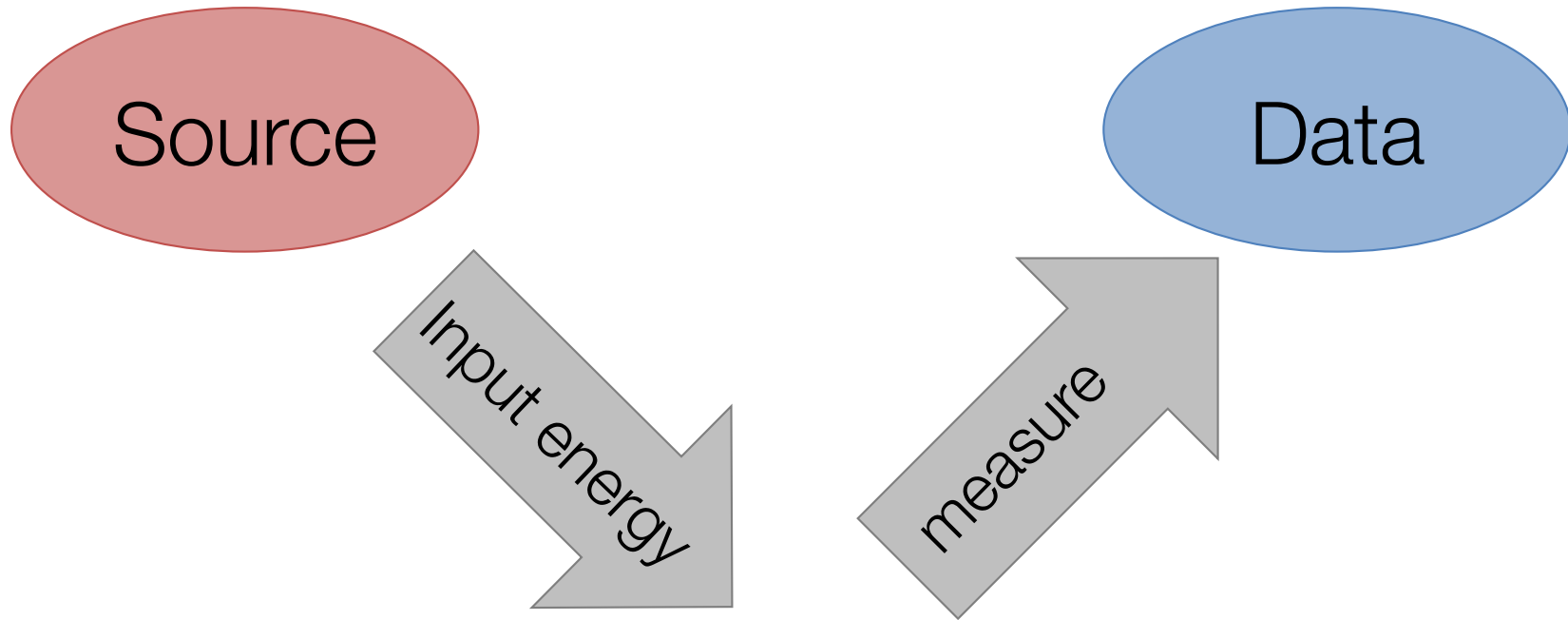
# Dielectric constant

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



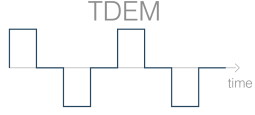
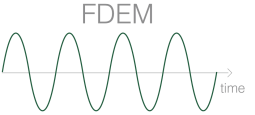
# EM Survey & Physical Properties



Physical  
Properties

$\sigma, \mu, \epsilon$

# Basic Equations

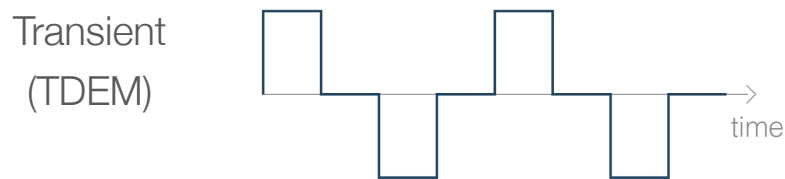
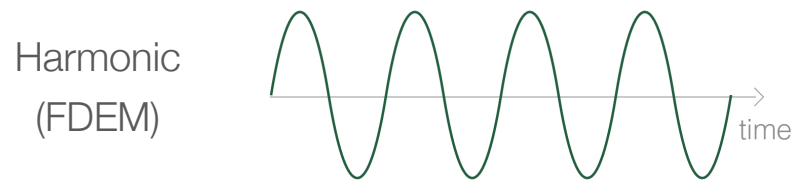
	Time 	Frequency 
Faraday's Law	$\nabla \times \mathbf{e} = - \frac{\partial \mathbf{b}}{\partial t}$	$\nabla \times \mathbf{E} = - i\omega \mathbf{B}$
Ampere's Law	$\nabla \times \mathbf{h} = \mathbf{j} + \frac{\partial \mathbf{d}}{\partial t}$	$\nabla \times \mathbf{H} = \mathbf{J} + i\omega \mathbf{D}$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

\* Solve with sources and boundary conditions

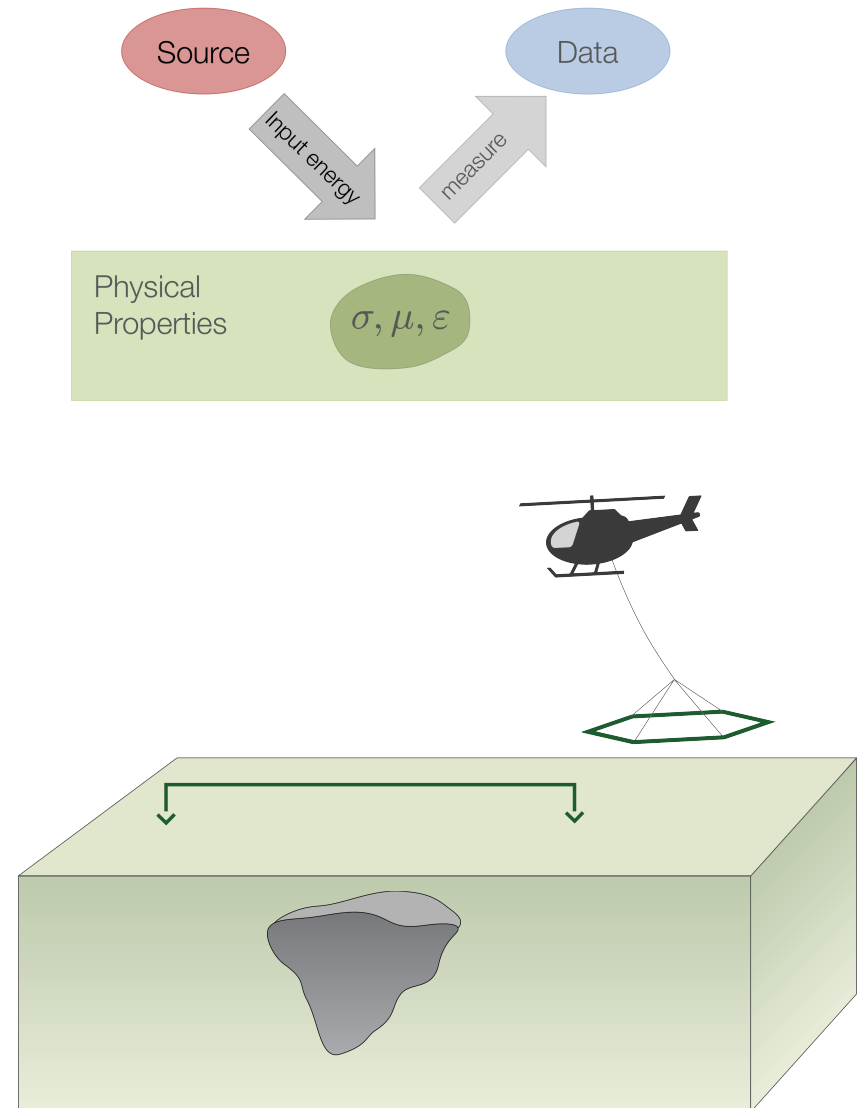
# Electromagnetic Survey: Sources

- Type
  - Inductive
  - Grounded

- Waveform



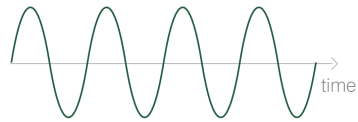
- Location
  - Airborne
  - Ground
  - Borehole



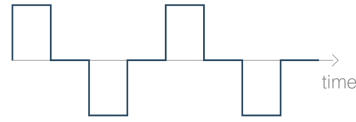


# Electromagnetic Survey: Data

- Which field?



**E, B**

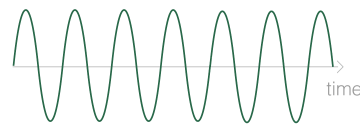


**e, b,  $\frac{db}{dt}$**

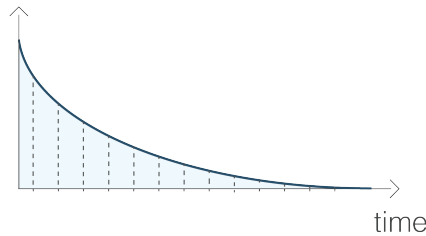
- Which frequencies?



or



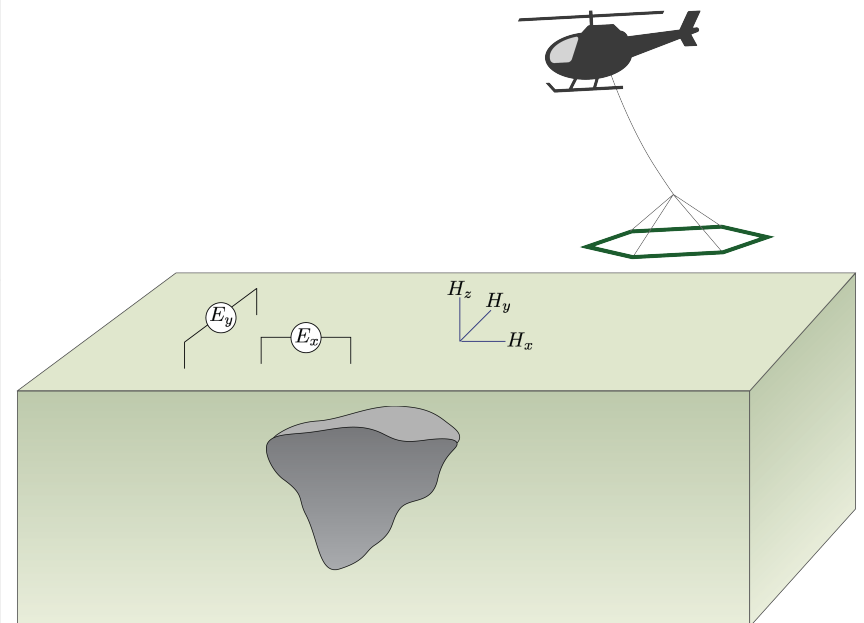
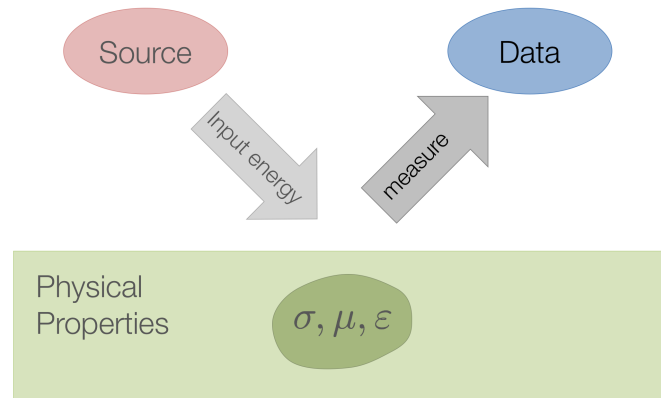
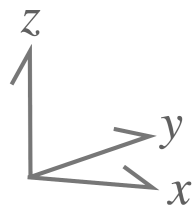
- times?



- Components?

- Location?

- Airborne
- Ground
- Borehole



# Three problems

Electrical conductivity is diagnostic for all three



minerals



unexploded ordnance



water

# Finding resources

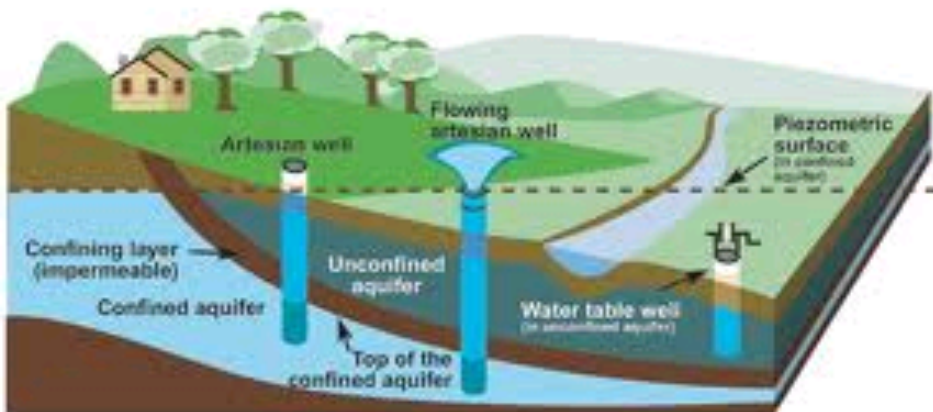
## Hydrocarbons



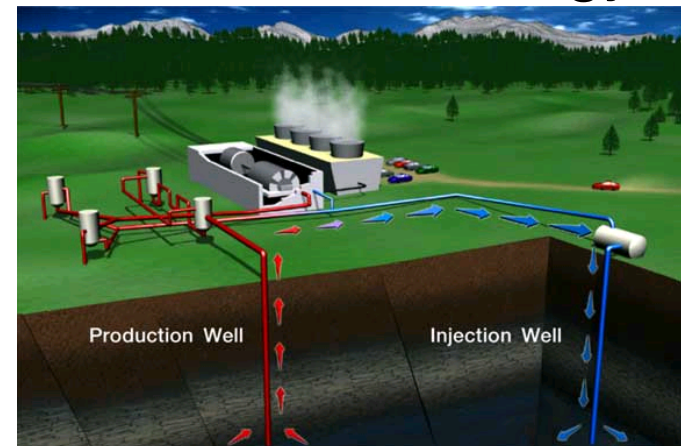
## Minerals



## Ground Water



## Geothermal Energy



# Natural Hazards

Volcano



Landslide



Tsunami



Earthquake



# Geotechnical engineering

Tunnels and highways



In-mine safety



Slope stability



Subsurface voids

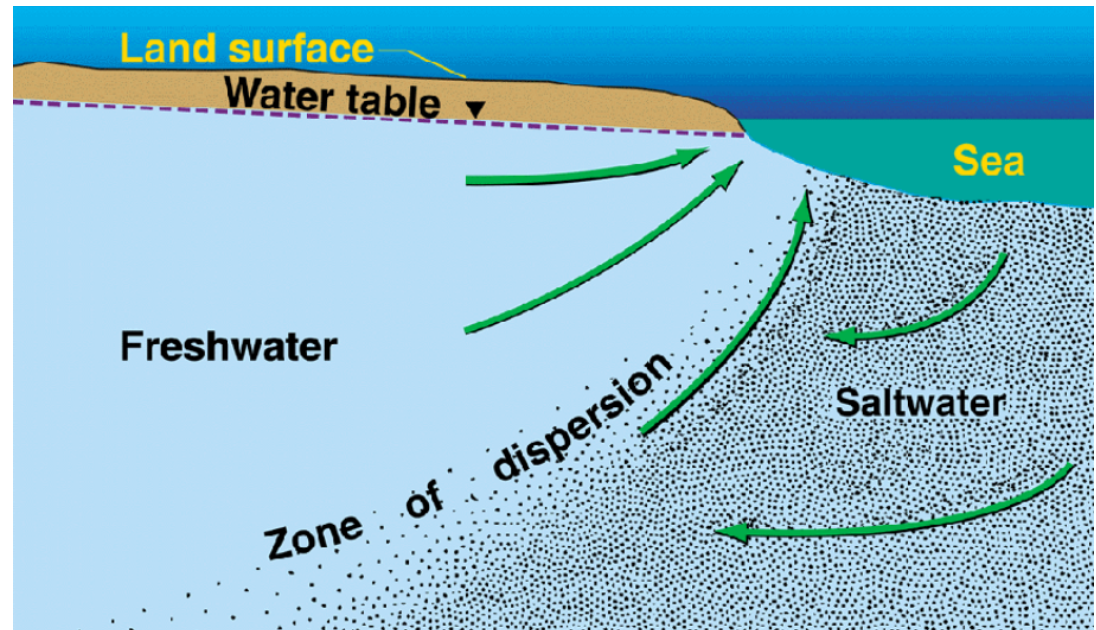


# Environmental

Water contamination



Saline water intrusion

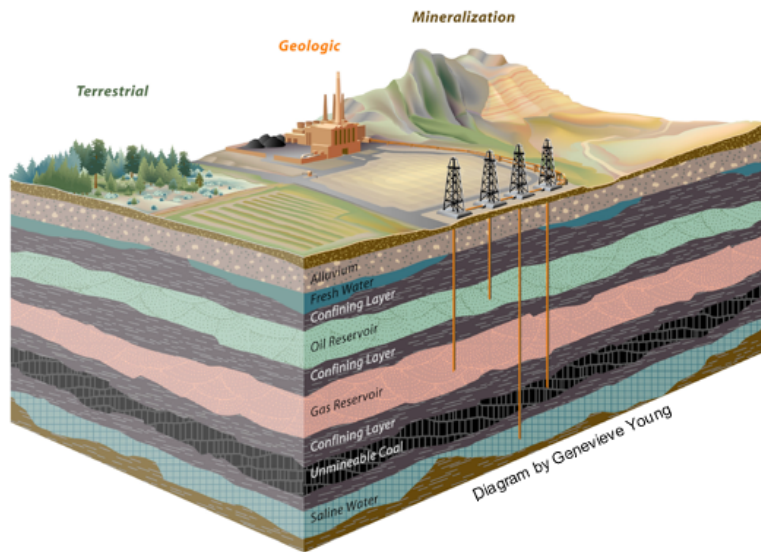


UXO detection

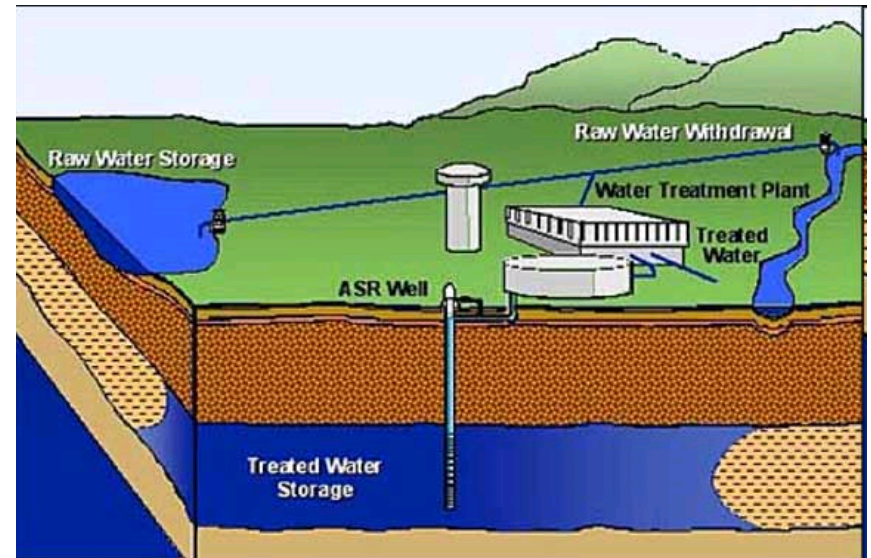


# Surface or Underground Storage

CO<sub>2</sub> sequestration



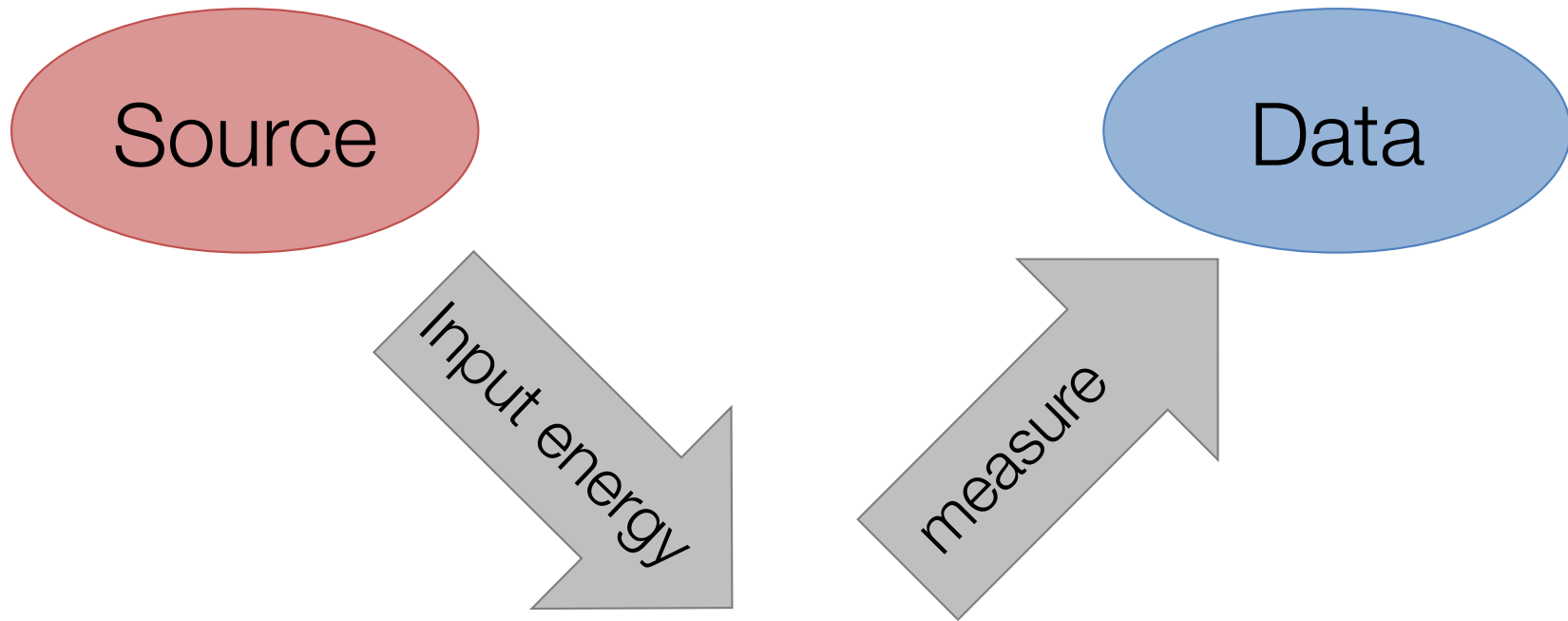
Aquifer storage and recovery



Industrial and radioactive waste



# EM Survey & Physical Properties



Physical  
Properties

$\sigma, \mu, \epsilon$



# 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

