# DISC

## 2017

## Electromagnetics
## Fundamentals and Applications
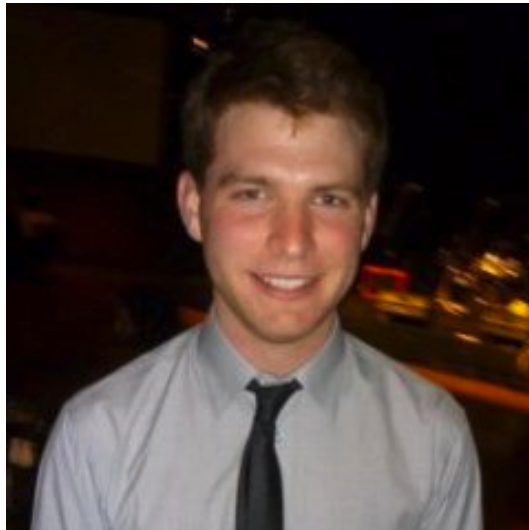
http://disc2017.geosci.xyz/adelaide

SEG SOCIETY OF EXPLORATION GEOPHYSICISTS

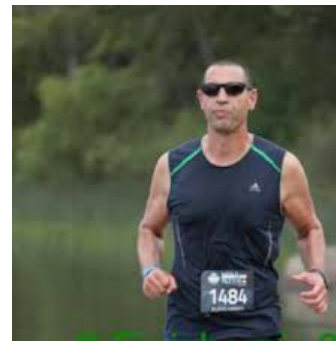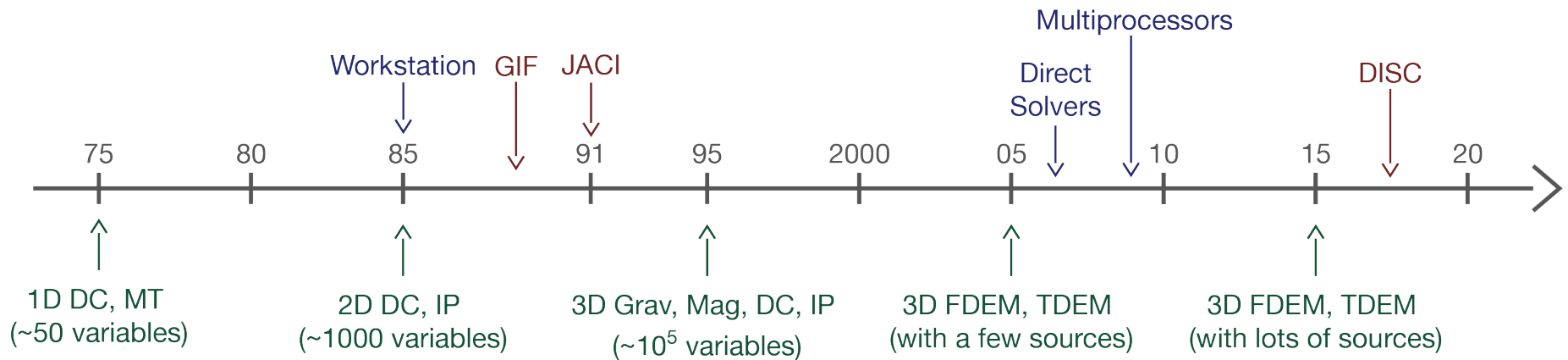# Thanks to…

Josh Sage          Emma Brand

Australian Society of Exploration Geophysicists

GIF

# Some Background

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



Timeline:

Above the line:
- Workstation → 85
- GIF → (between 85 and 91)
- JACI → 91
- Direct Solvers → 05
- Multiprocessors → 10
- DISC → (between 15 and 20)

Timeline marks: 75, 80, 85, 91, 95, 2000, 05, 10, 15, 20

Below the line:
- 1D DC, MT (~50 variables) → 75
- 2D DC, IP (~1000 variables) → 85
- 3D Grav, Mag, DC, IP (~$10^5$ variables) → 91
- 3D FDEM, TDEM (with a few sources) → 05
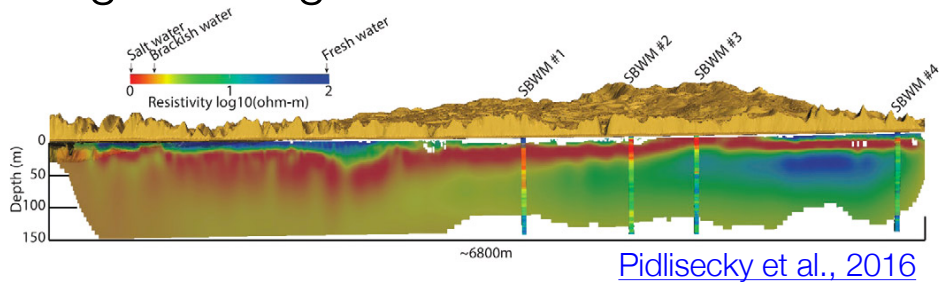- 3D FDEM, TDEM (with lots of sources) → 15

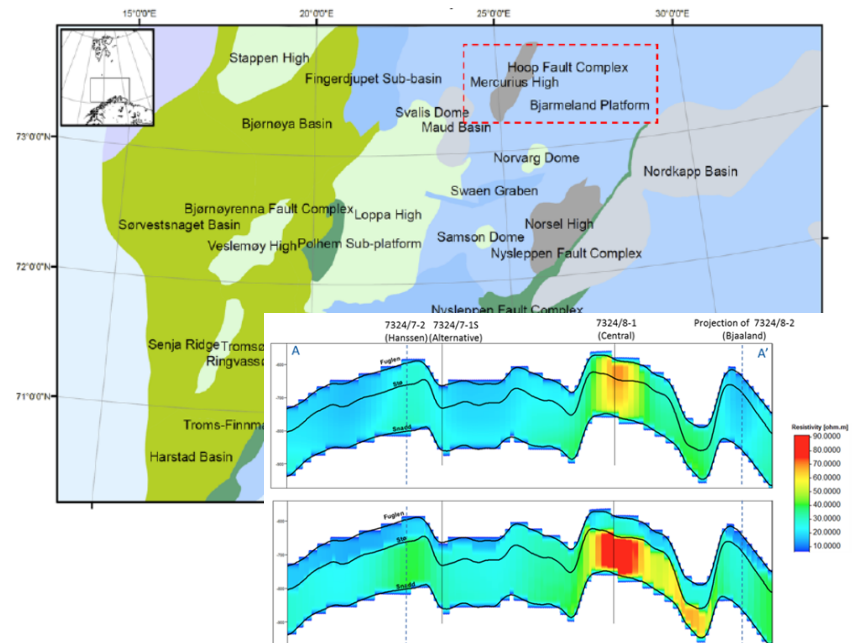Result: Computing power + advances in inversion methodology → we can now solve most EM geophysics problems

3

# Instrumentation and Data

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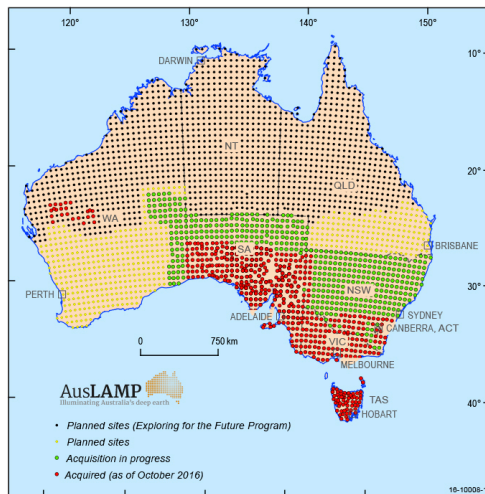- Data with unprecedented data quality and quantity.

Large-scale ground water studies: California



Pidlisecky et al., 2016

Offshore: Hydrocarbon De-risking



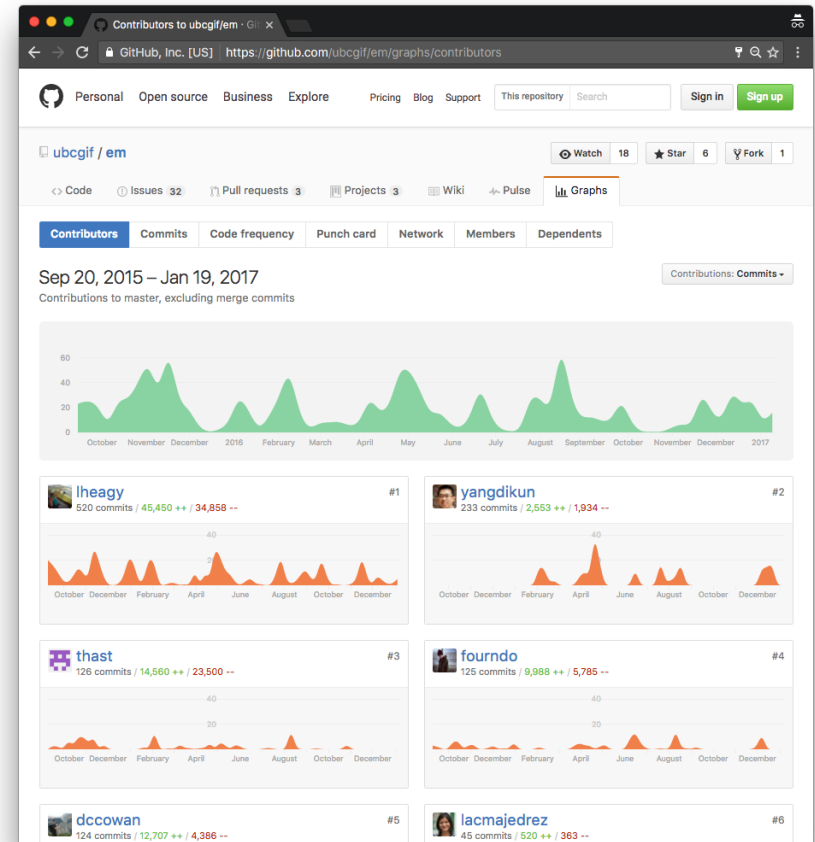Alvarez et al, EM.GeoSci

AusLamp: Continental Scale MT

# 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

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# DISC can take advantage of a Perfect Storm



Problems

Inversion capabilities
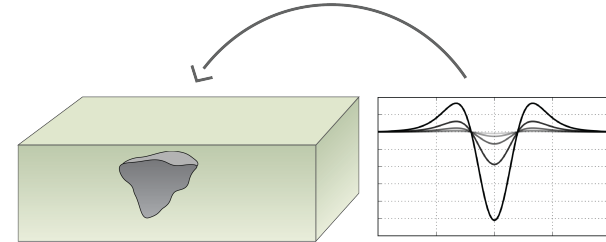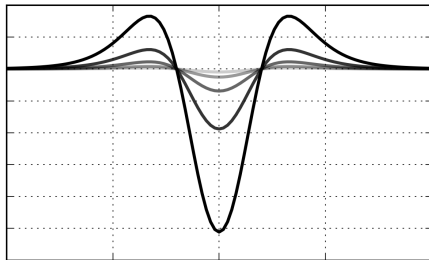
High quality data

Web tools to communicate
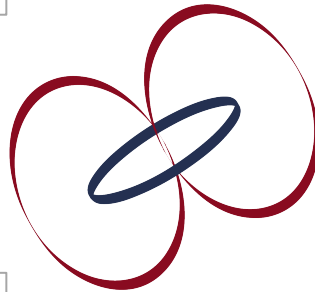
# DISC can take advantage of a Perfect Storm

## Problems

## Inversion capabilities
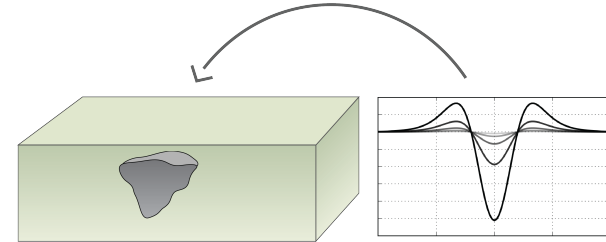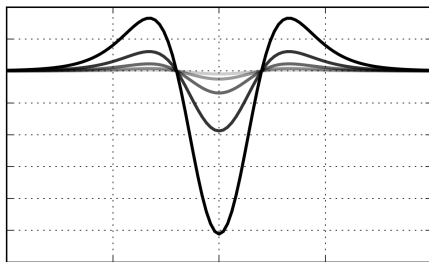
## High quality data

## Web tools to communicate

A good idea but missing an important ingredient …

# Talented Young Geoscientists

Problems

Inversion capabilities
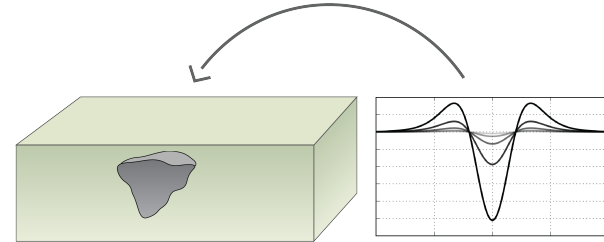
High quality data
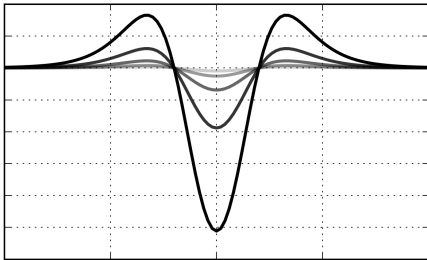
Web tools to communicate

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

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7 step framework
for Case Histories



http://em.geosci.xyz

# Resources: EM.geosci



7 step framework
for Case Histories

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

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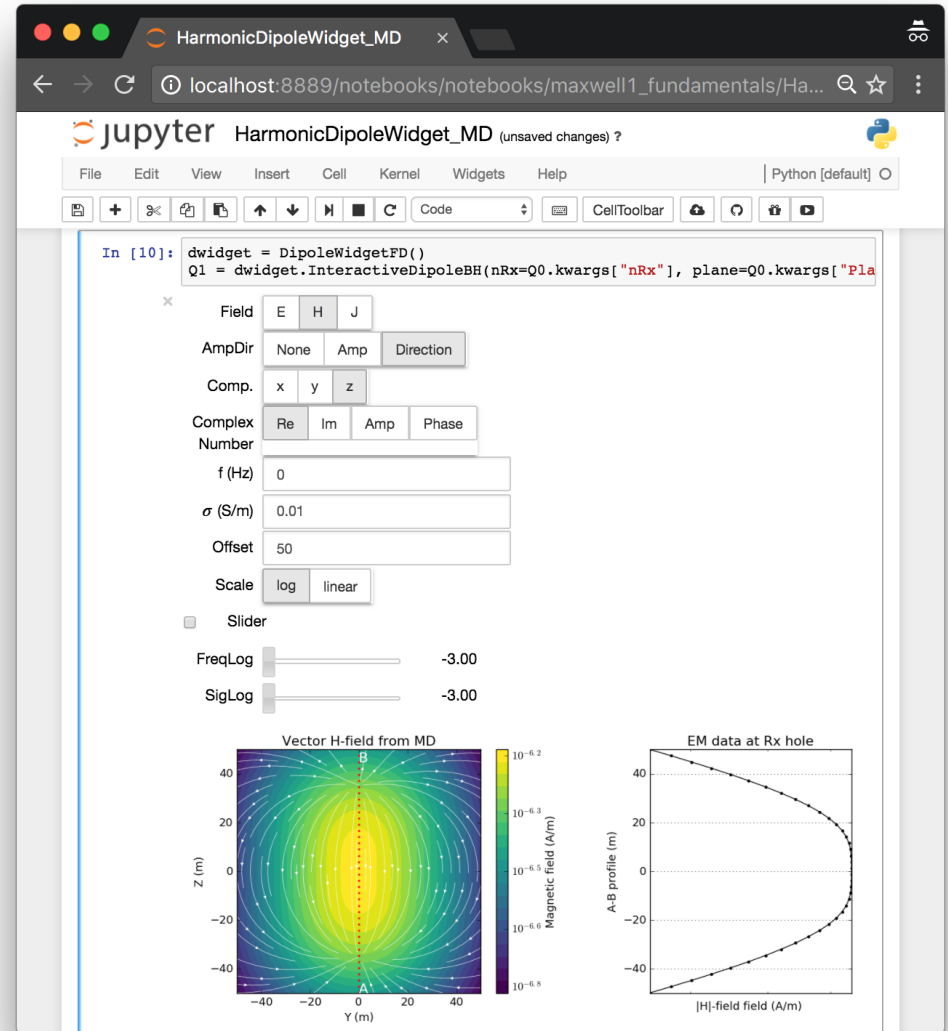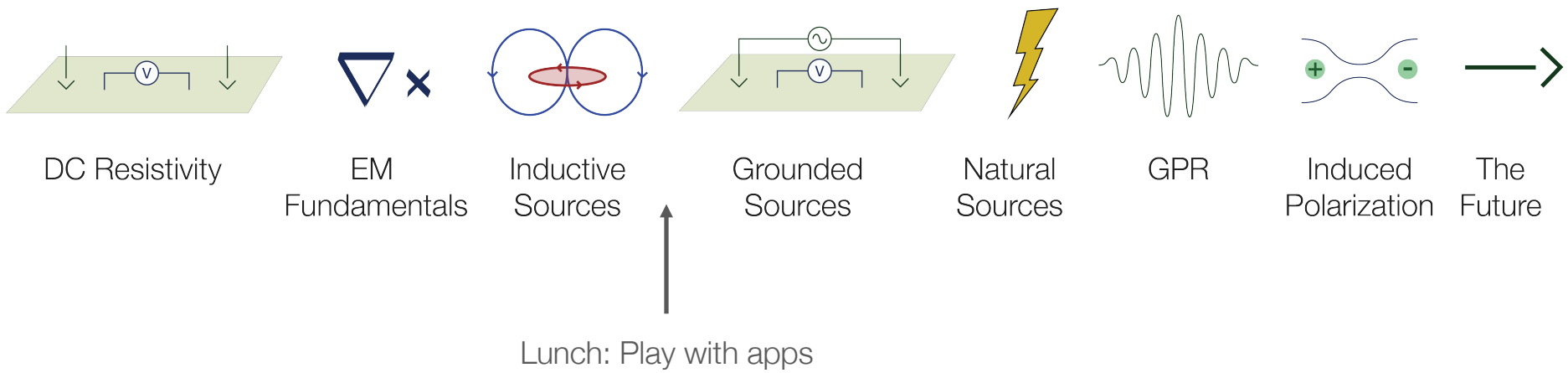


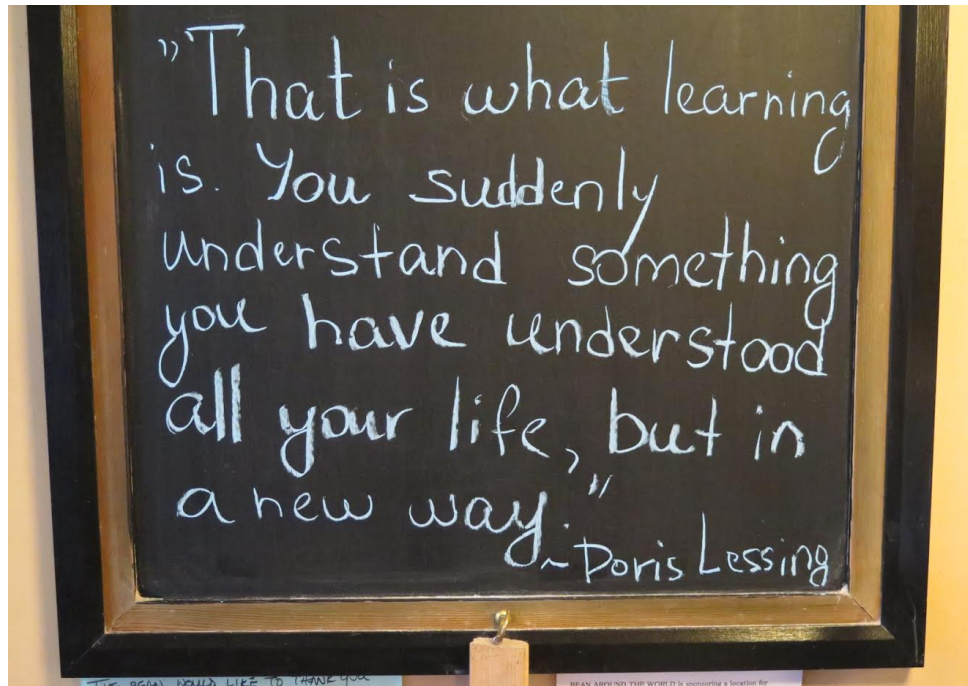http://em.geosci.xyz/apps.html

# 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



| DC Resistivity | EM Fundamentals | Inductive Sources | Grounded Sources | Natural Sources | GPR | Induced Polarization | The Future |

Lunch: Play with apps

# 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…



"That is what learning is. You suddenly understand something you have understood all your life, but in a new way." ~Doris Lessing
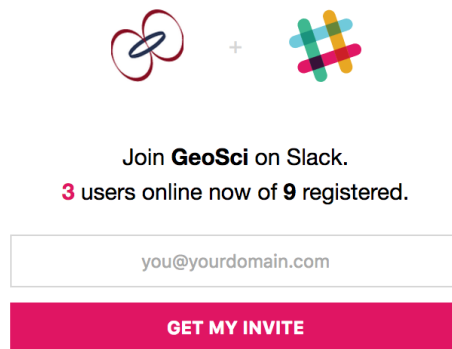
# DISC is a 2-day event

- SEG DISC Course (today)
  - Sponsored by SEG

- DISC Lab (tomorrow) (sponsored by GIF)
  - Capture "local" applications
  - Share on the web

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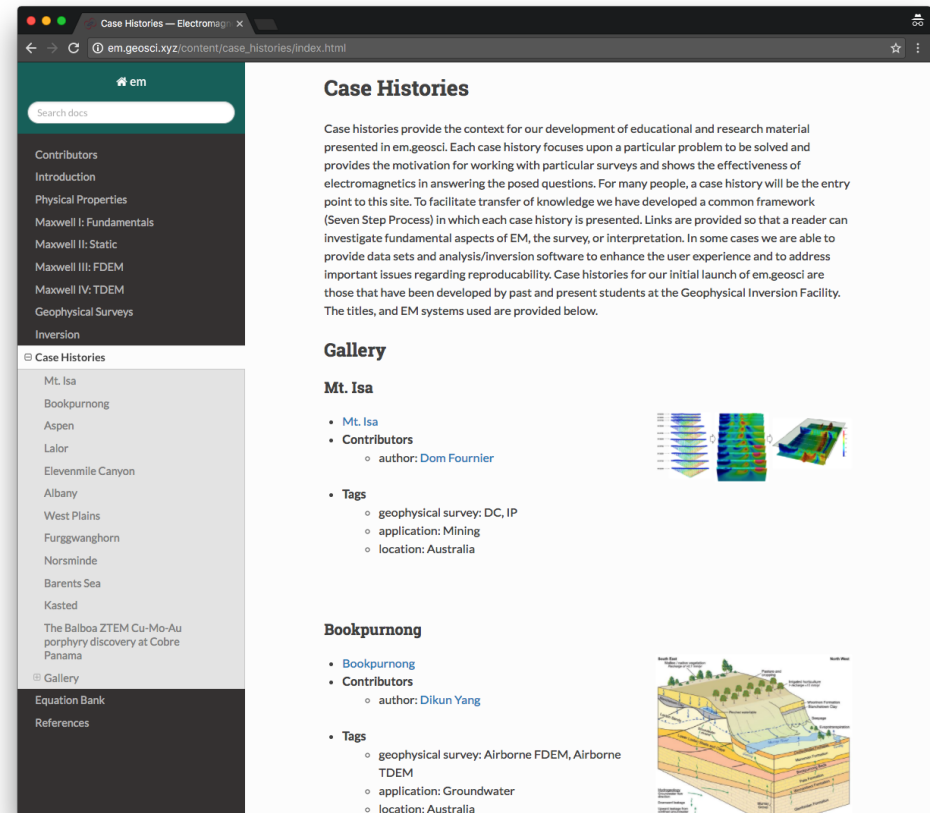
# Connecting & Contributing

- Today: Slack

    - http://slack.geosci.xyz/



- Contributing:

    - EM GeoSci

        - Case histories

        - Content

    - SimPEG

        - Software

# Introduction to EM

# Three problems

How do we locate and characterize …


minerals


unexploded ordnance


water

# Electrical Resistivity / Conductivity
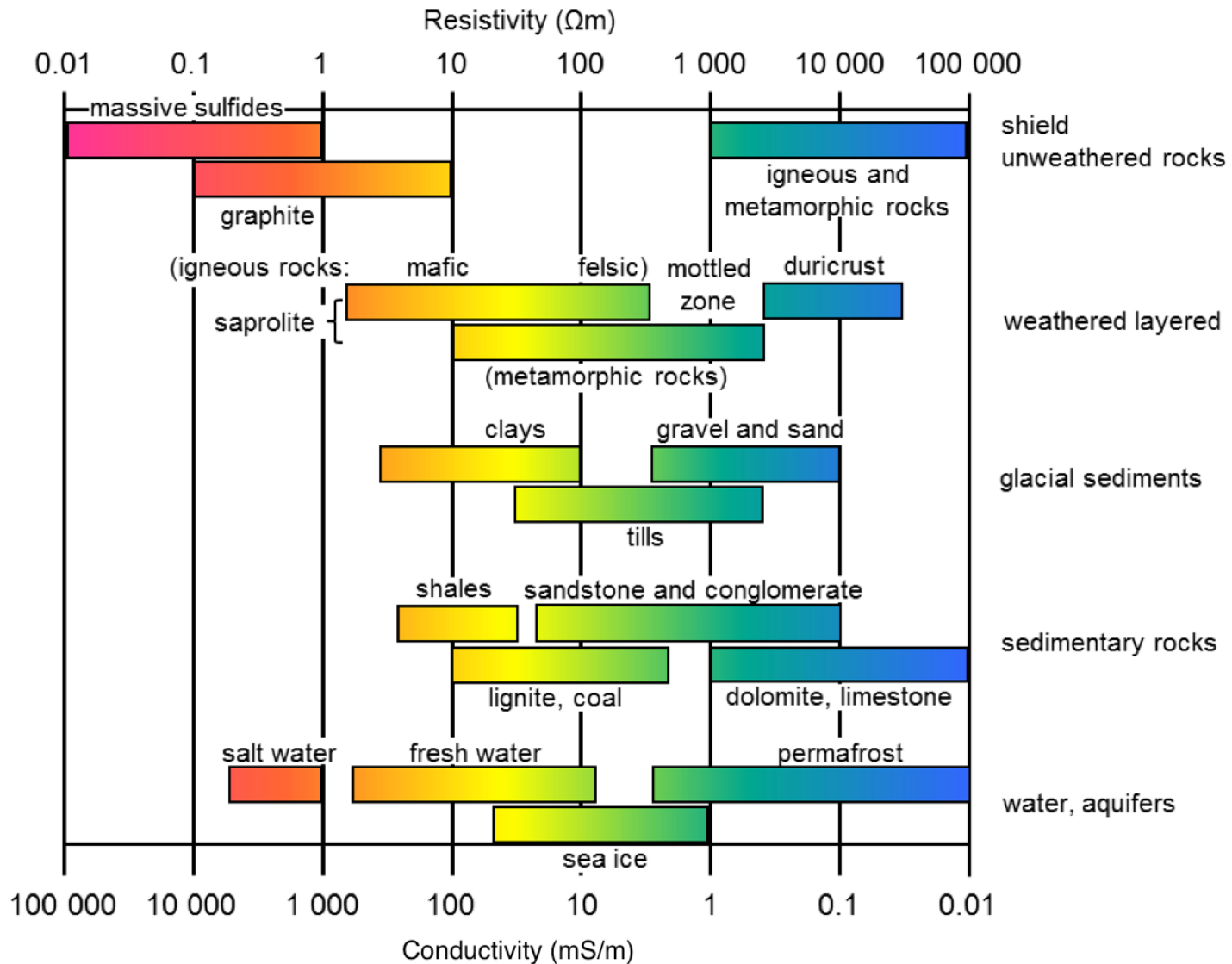
# Dielectric constant

| Material | Relative Permittivity | Conductivity (mS/m) |
| --- | --- | --- |
| Air | 1 | 0 |
| Fresh Water | 80 | 0.5 |
| Sea Water | 80 | 3000 |
| Ice | 3-4 | 0.01 |
| Dry Sand | 3-5 | 0.01 |
| Saturated Sand | 20-30 | 0.1-1 |
| Limestone | 4-8 | 0.5-2 |
| Shales | 5-15 | 1-100 |
| Silts | 5-30 | 1-100 |
| Clays | 5-40 | 2-1000 |
| Granite | 4-6 | 0.01-1 |
| Anhydrites | 3-4 | 0.01-1 |

# Magnetic Susceptibility



Adapted from Clark and Emerson, Exploration Geophysics, 1991.
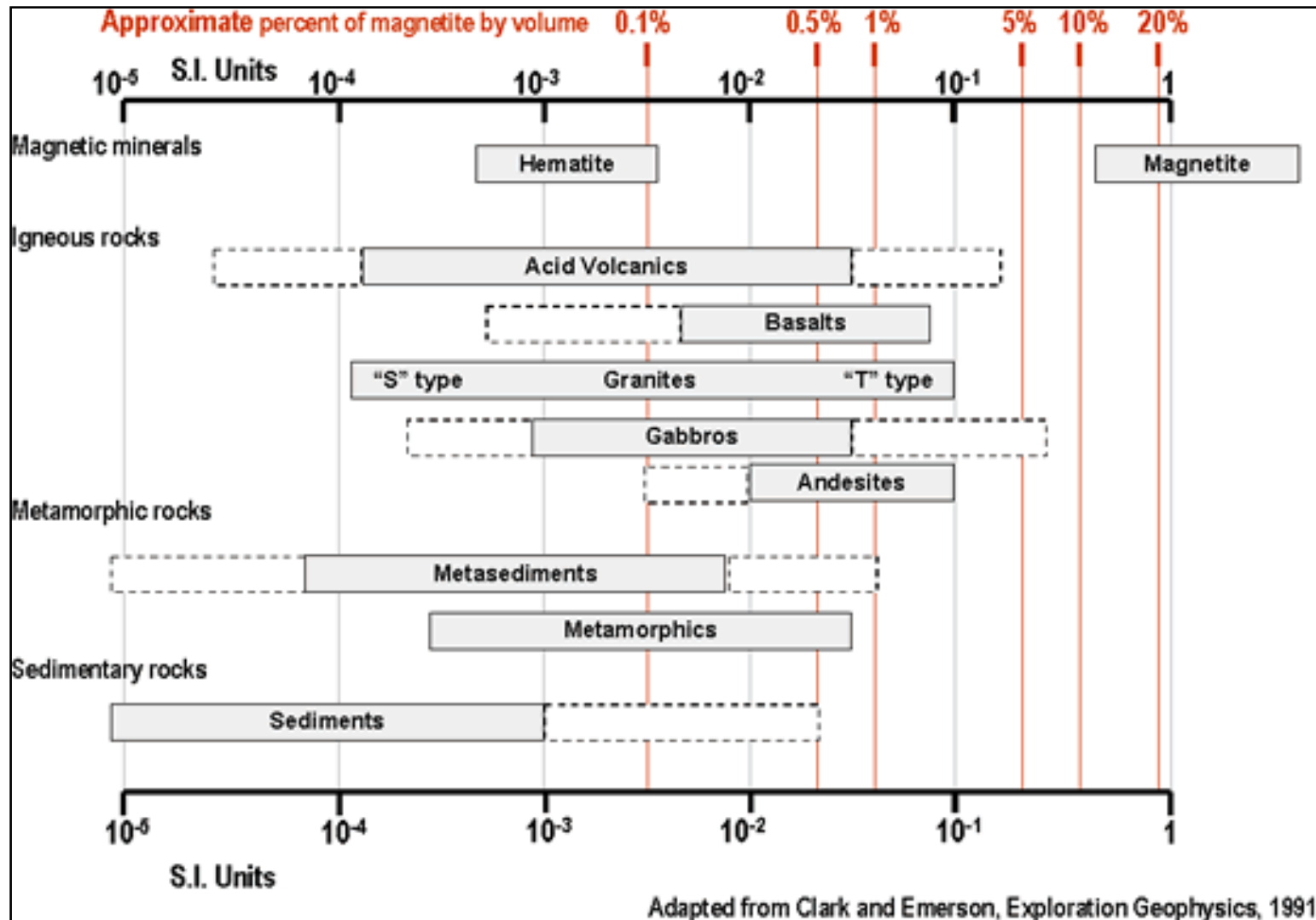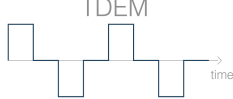
# EM Survey & Physical Properties



Source

Data

Input energy

measure
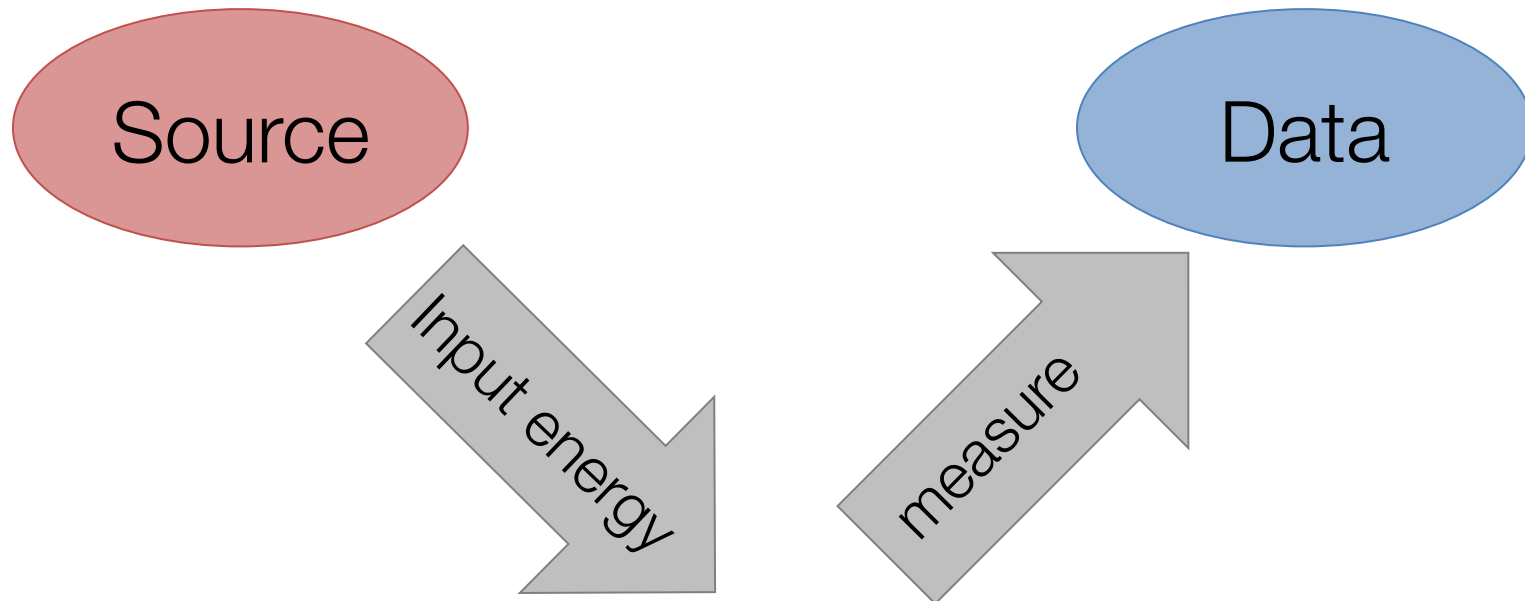
Physical Properties

$$\sigma, \mu, \varepsilon$$

# Basic Equations

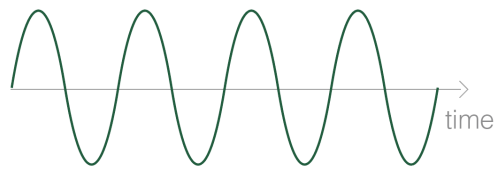| | Time TDEM | Frequency FDEM |
|---|---|---|
| Faraday's Law | $\nabla \times \mathbf{e} = -\dfrac{\partial \mathbf{b}}{\partial t}$ | $\nabla \times \mathbf{E} = -i\omega\mathbf{B}$ |
| Ampere's Law | $\nabla \times \mathbf{h} = \mathbf{j} + \dfrac{\partial \mathbf{d}}{\partial t}$ | $\nabla \times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

\* Solve with sources and boundary conditions
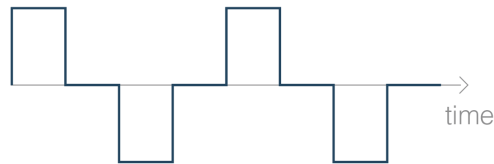
# Electromagnetic Survey: Sources
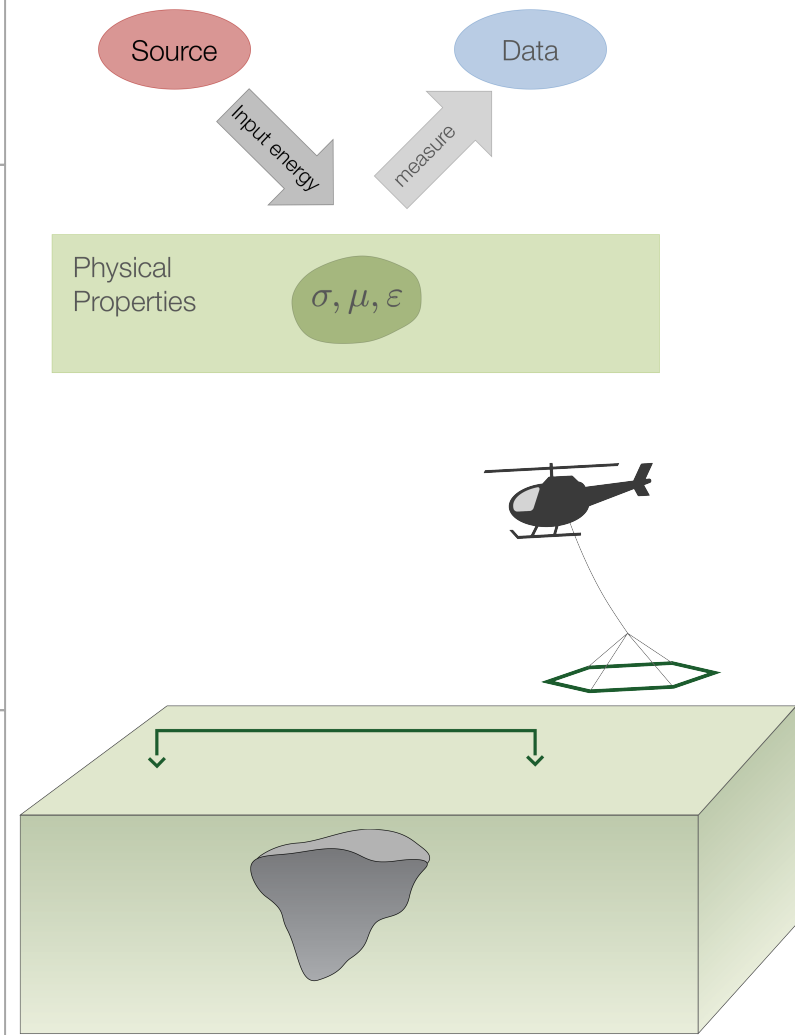
- **Type**
  - Inductive
  - Grounded

- **Waveform**

Harmonic
(FDEM)

time

Transient
(TDEM)

time

- **Location**
  - Airborne
  - Ground
  - Borehole

Source

Data
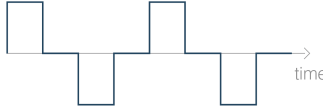
Input energy

measure

Physical
Properties   $\sigma, \mu, \varepsilon$

# Electromagnetic Survey: Data
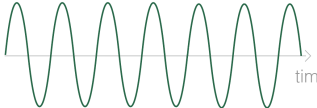
- Which field?

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

- Which frequencies?

or

- times?

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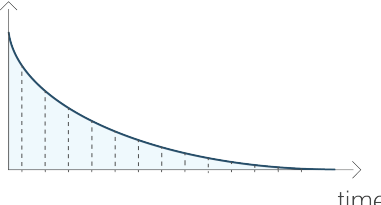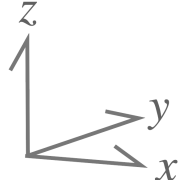- Location?
  – Airborne
  – Ground
  – Borehole

Source

Data

Input energy

measure

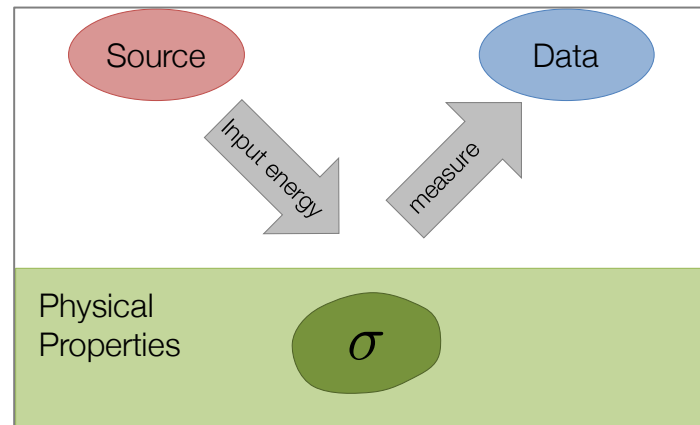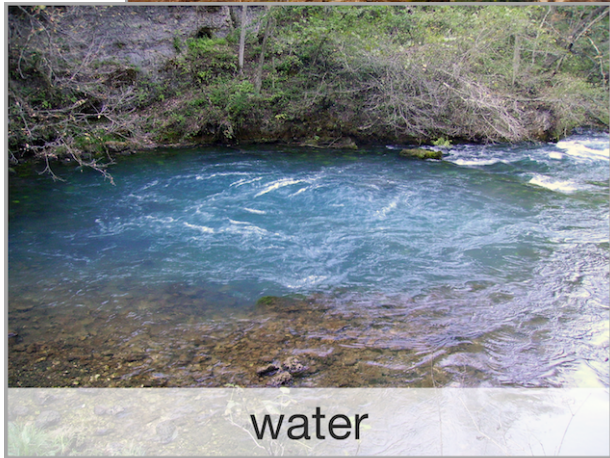Physical Properties $\quad \sigma, \mu, \varepsilon$

$H_z$ $H_y$

$E_y$ $E_x$ $H_x$
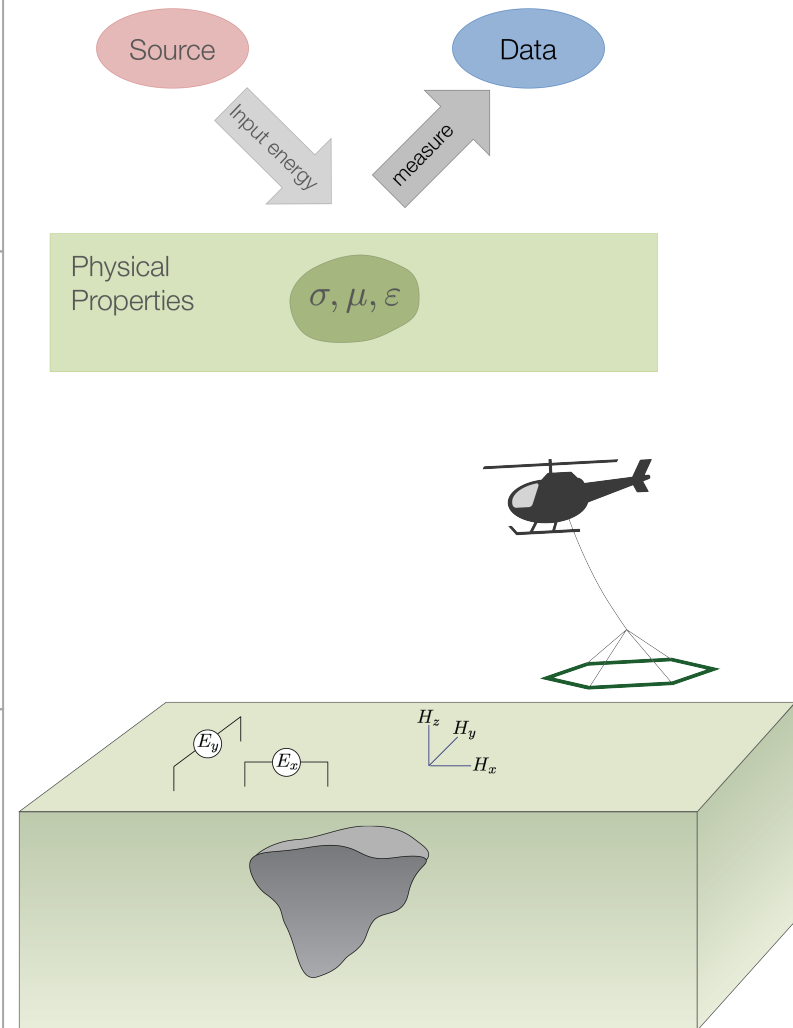
# Three problems

Electrical conductivity is diagnostic for all three



minerals

unexploded ordnance

water

Source

Data

Input energy

measure

Physical Properties

$\sigma$

# End of Introduction

Next up

DC Resistivity    EM
Fundamentals

Inductive
Sources

Grounded
Sources

Natural
Sources

GPR

Induced
Polarization

The
Future

Lunch: Play with apps