DISC
2017
Electromagnetics Fundamentals and Applications

http://disc2017.geosci.xyz/perth

SOCIETY OF EXPLORATION GEOPHYSICISTS

Thanks to…

Kathlene Oliver   Emma Brand

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
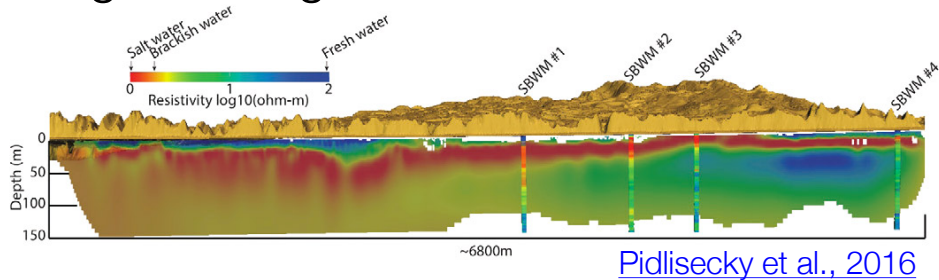- 3D FDEM, TDEM (with lots of sources) → 15
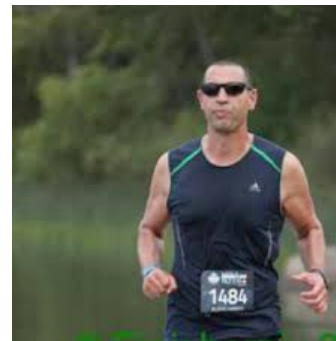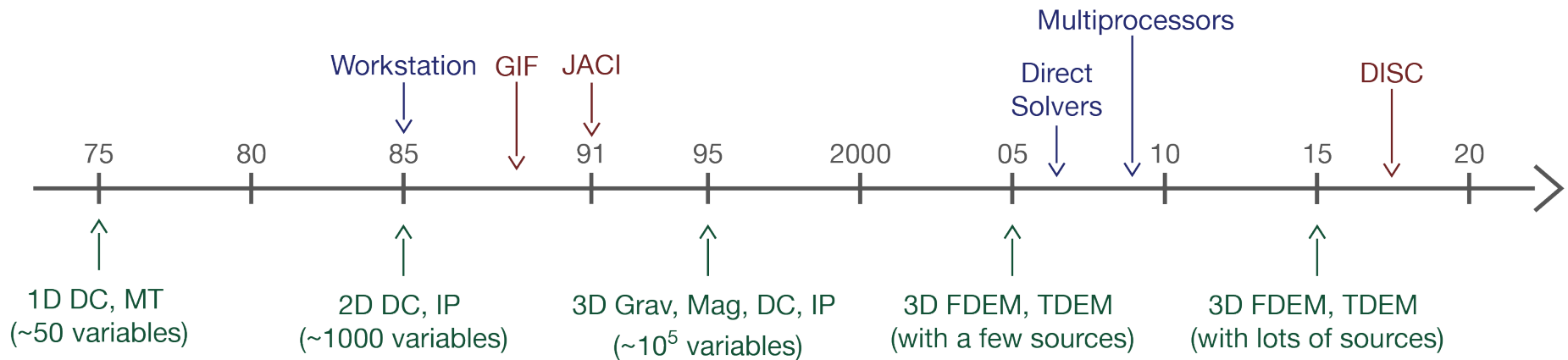
Result: Computing power + advances in inversion methodology → we can now solve most EM geophysics problems
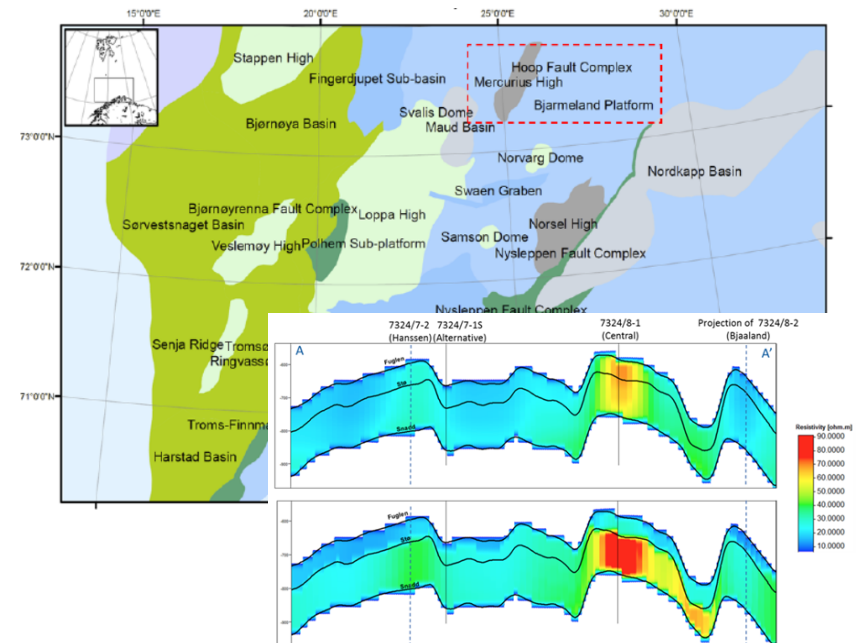
Instrumentation and Data

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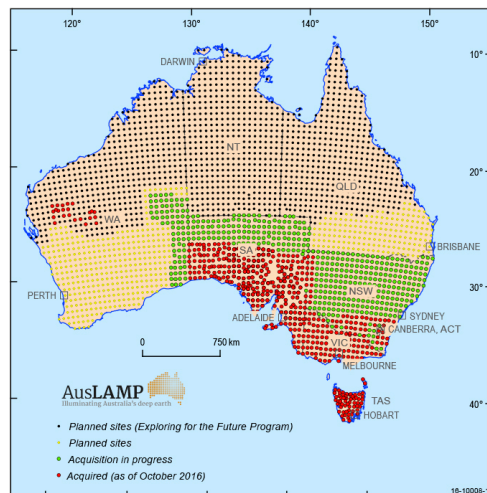
- Data with unprecedented data quality and quantity.

Large-scale ground water studies: California

Pidlisecky et al., 2016

Offshore: Hydrocarbon De-risking

AusLamp: Continental Scale MT
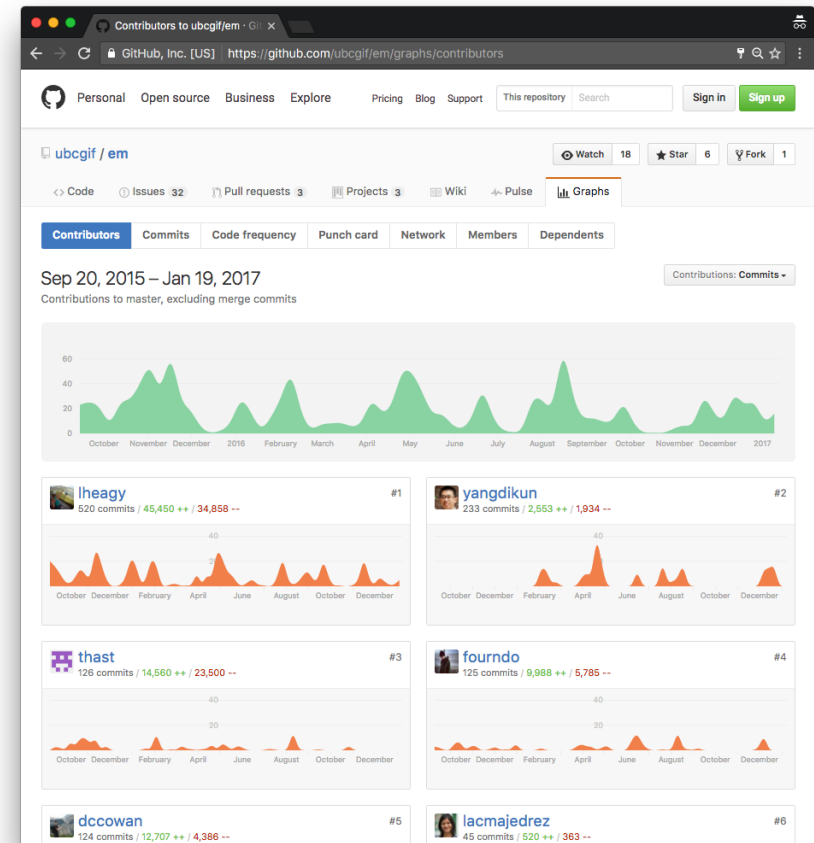

Alvarez et al, EM.GeoSci

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

5

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
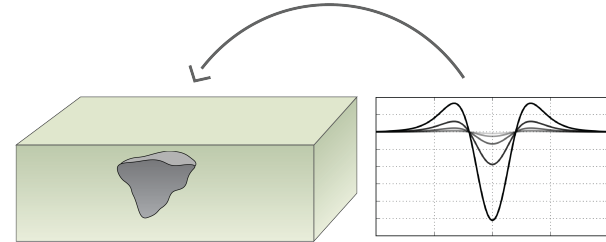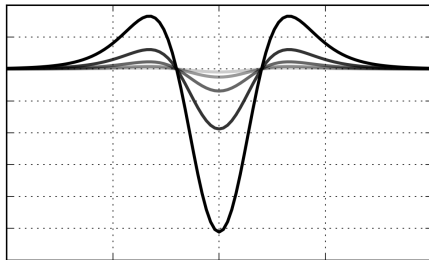
High quality data

Web tools to communicate

DISC can take advantage of a Perfect Storm

Problems

Inversion capabilities
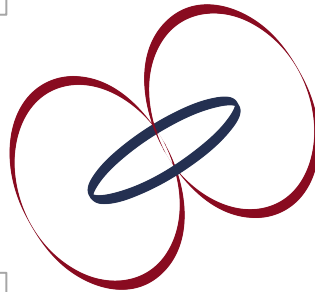
High quality data

Web tools to communicate
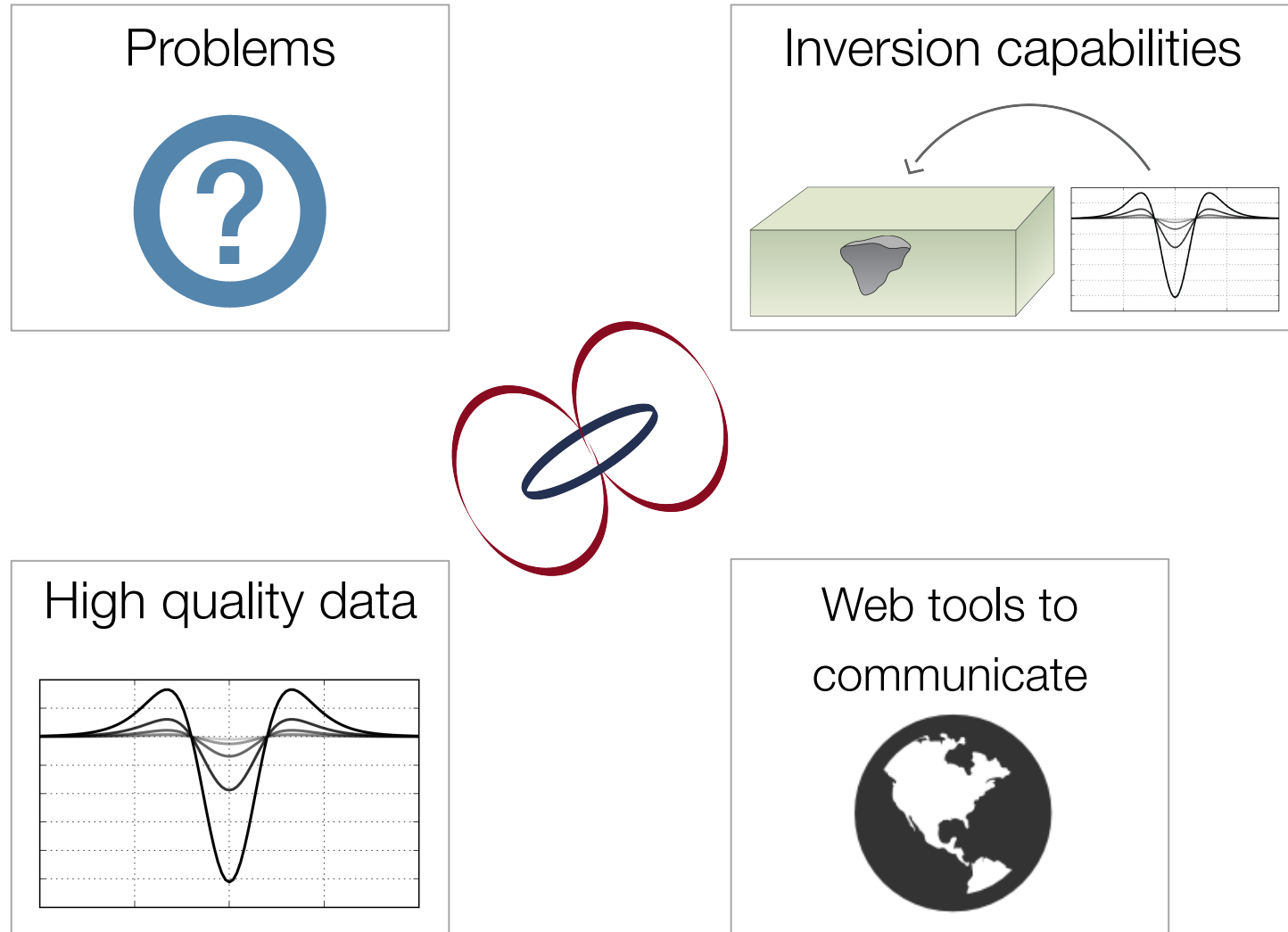
A good idea but missing an important ingredient …
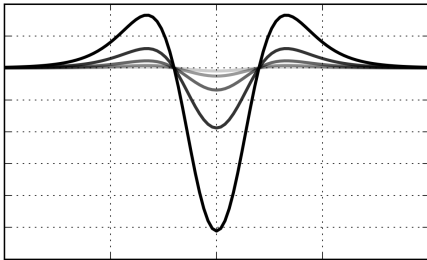
Talented Young Geoscientists

Problems

Inversion capabilities
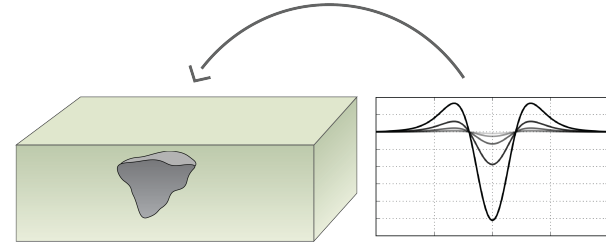
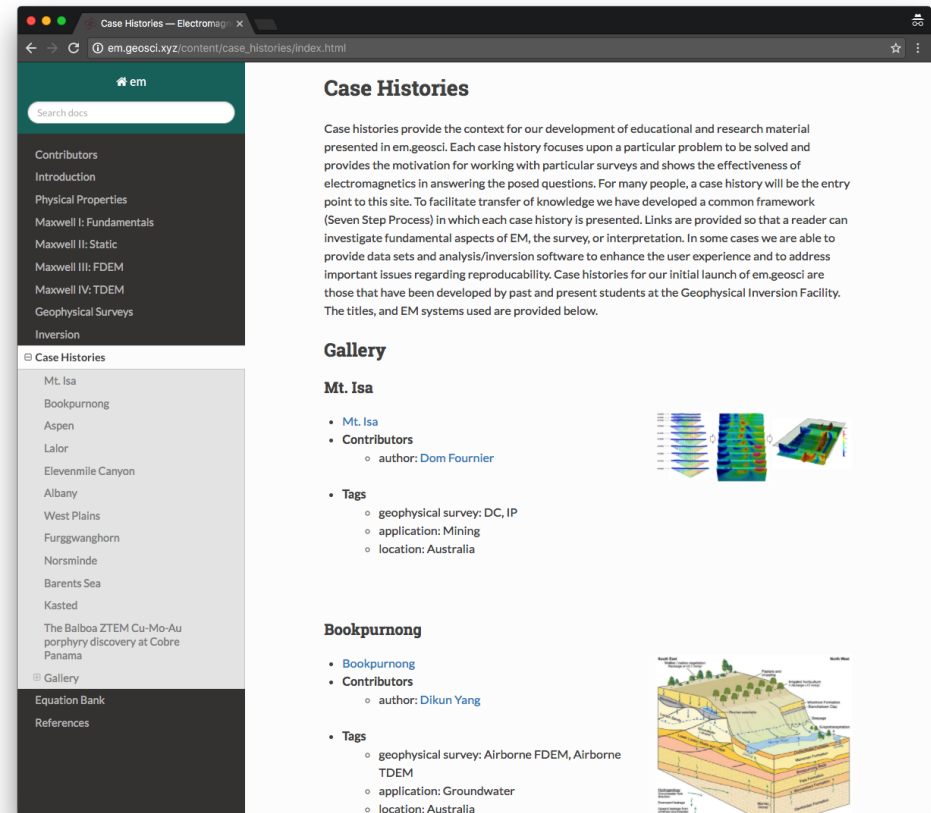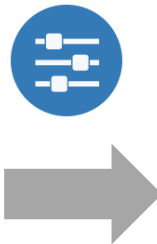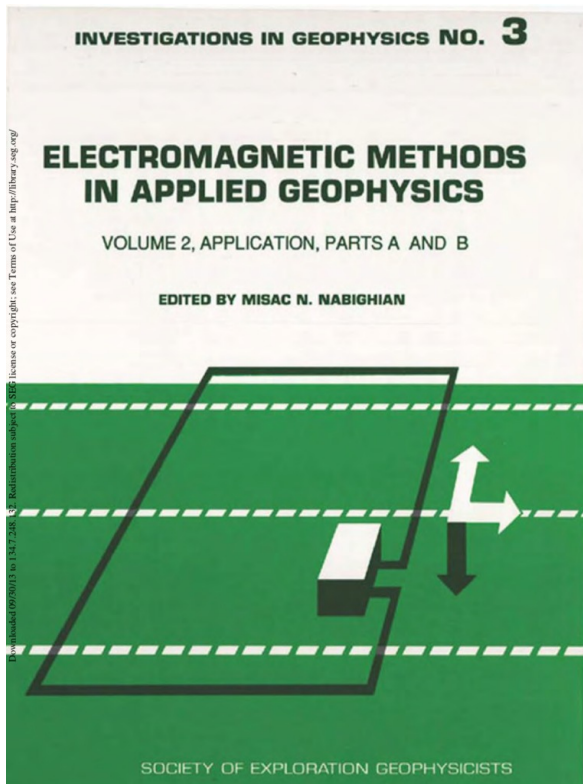High quality data
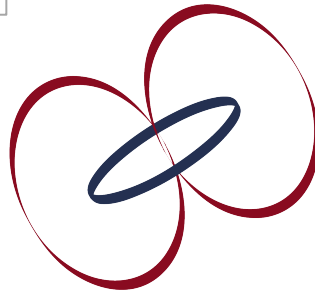
Web tools to communicate

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

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

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

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

IMAGE NOT AVAILABLE

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

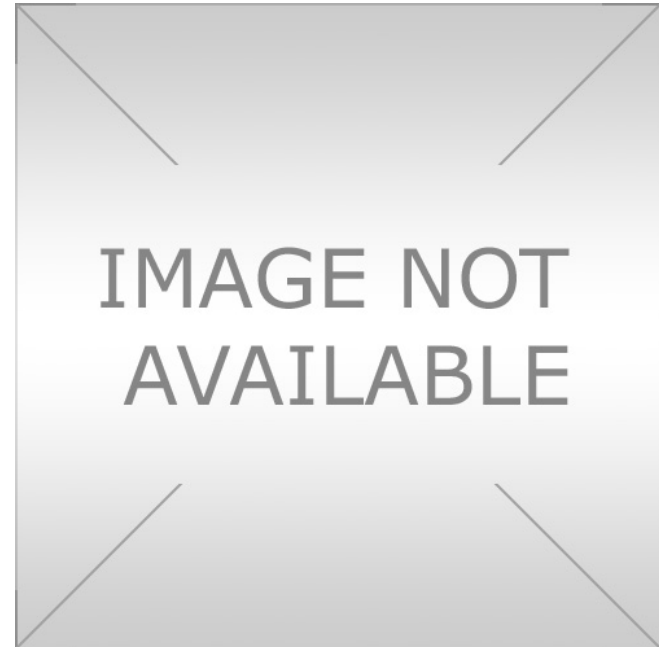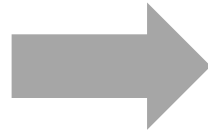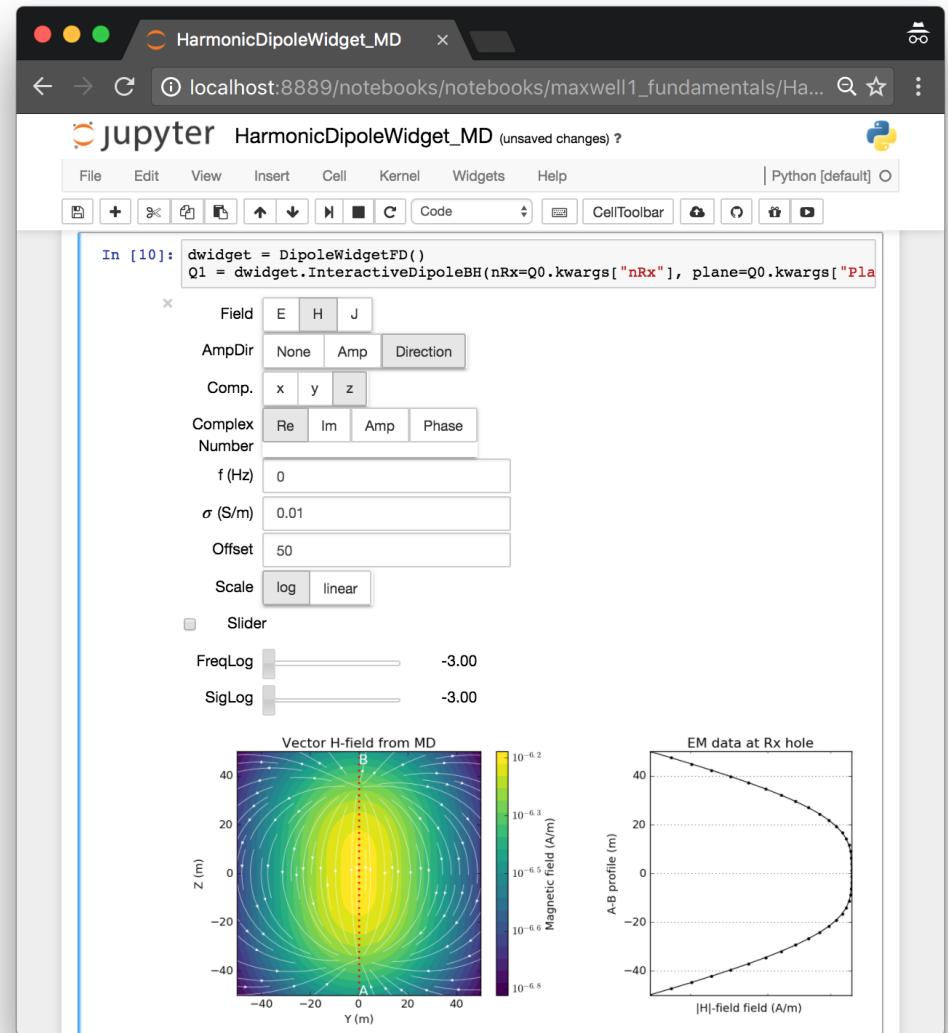# Why Apps

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

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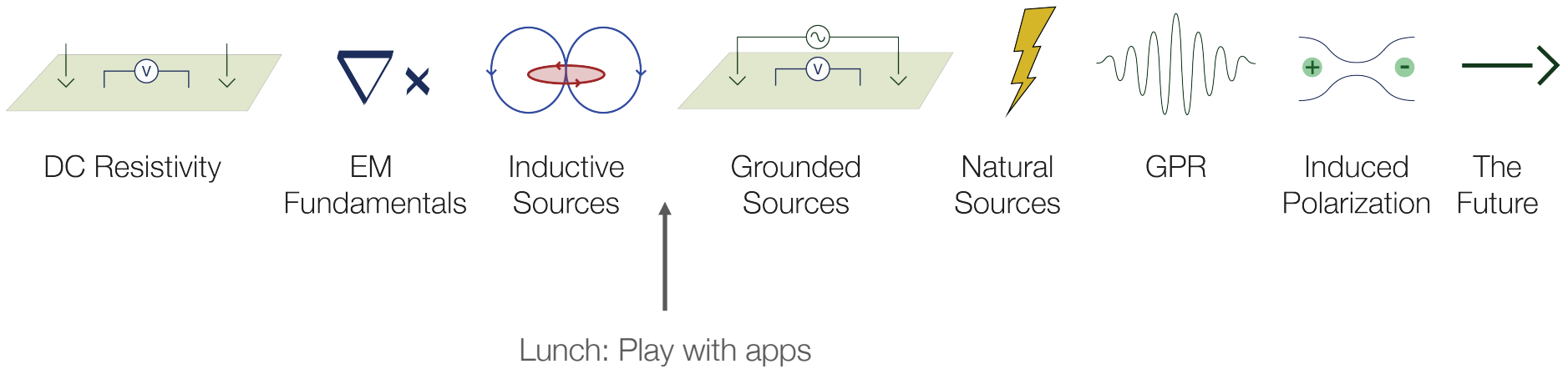

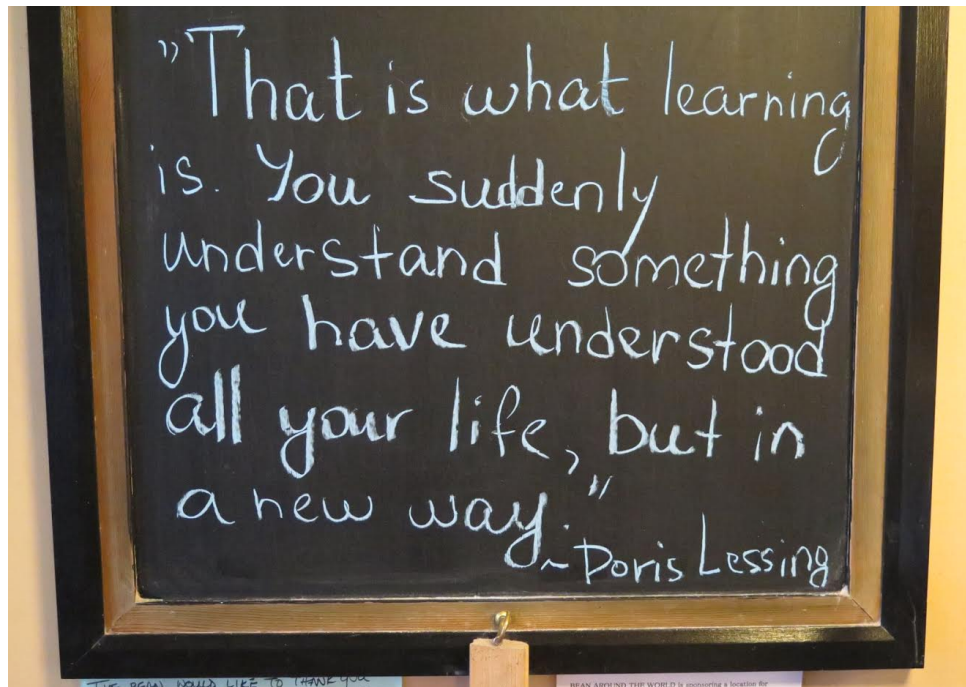http://em.geosci.xyz/apps.html

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

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

  – Sign up at http://disc2017.geosci.xyz/schedule#tokyo

- The tour:

  – 30 locations

  – Capture geoscience problems around the world

  – Connect geoscientists worldwide, build a community
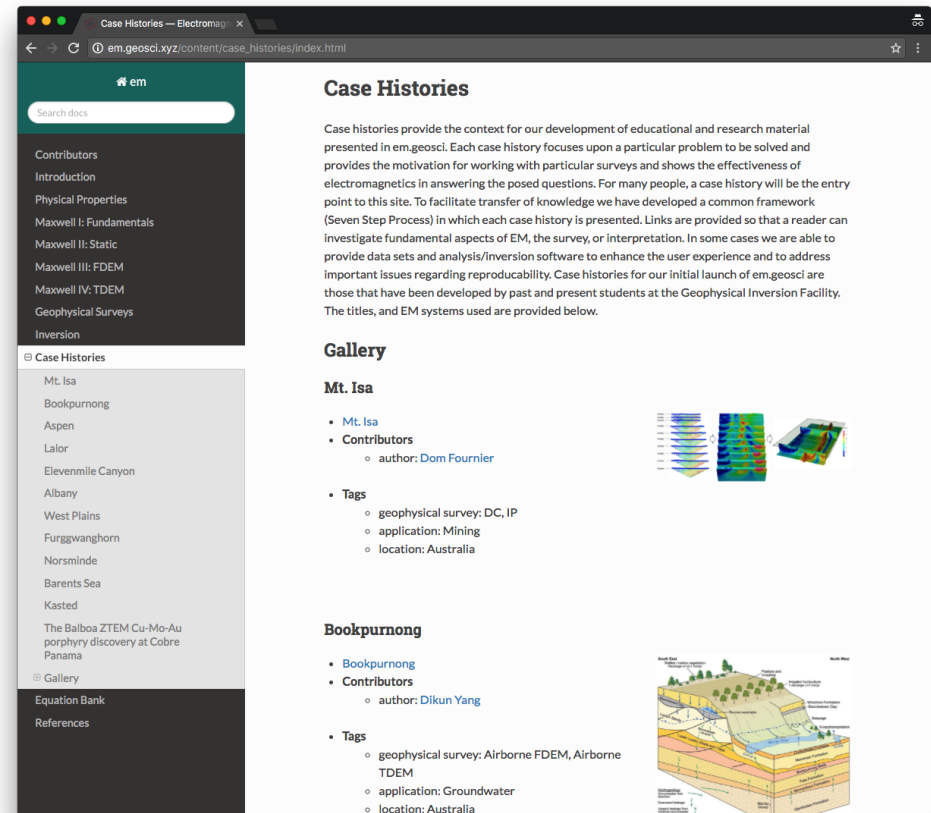
Connecting & Contributing

- Today: Slack

  – http://slack.geosci.xyz/

- Contributing:

  – EM GeoSci

    - Case histories

    - Content

  – SimPEG

    - Software

Introduction to EM

Three problems

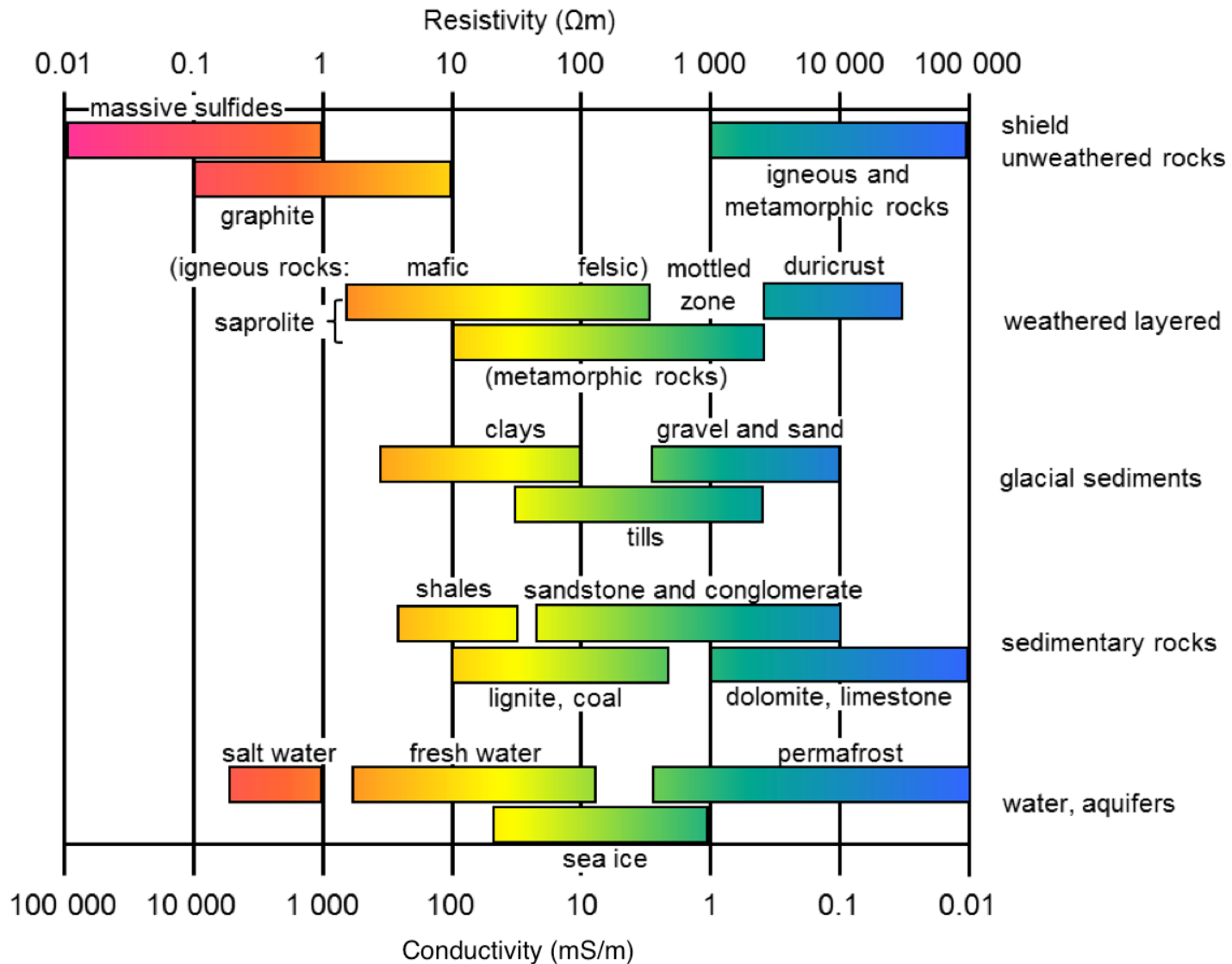How do we locate and characterize …

minerals

unexploded ordnance
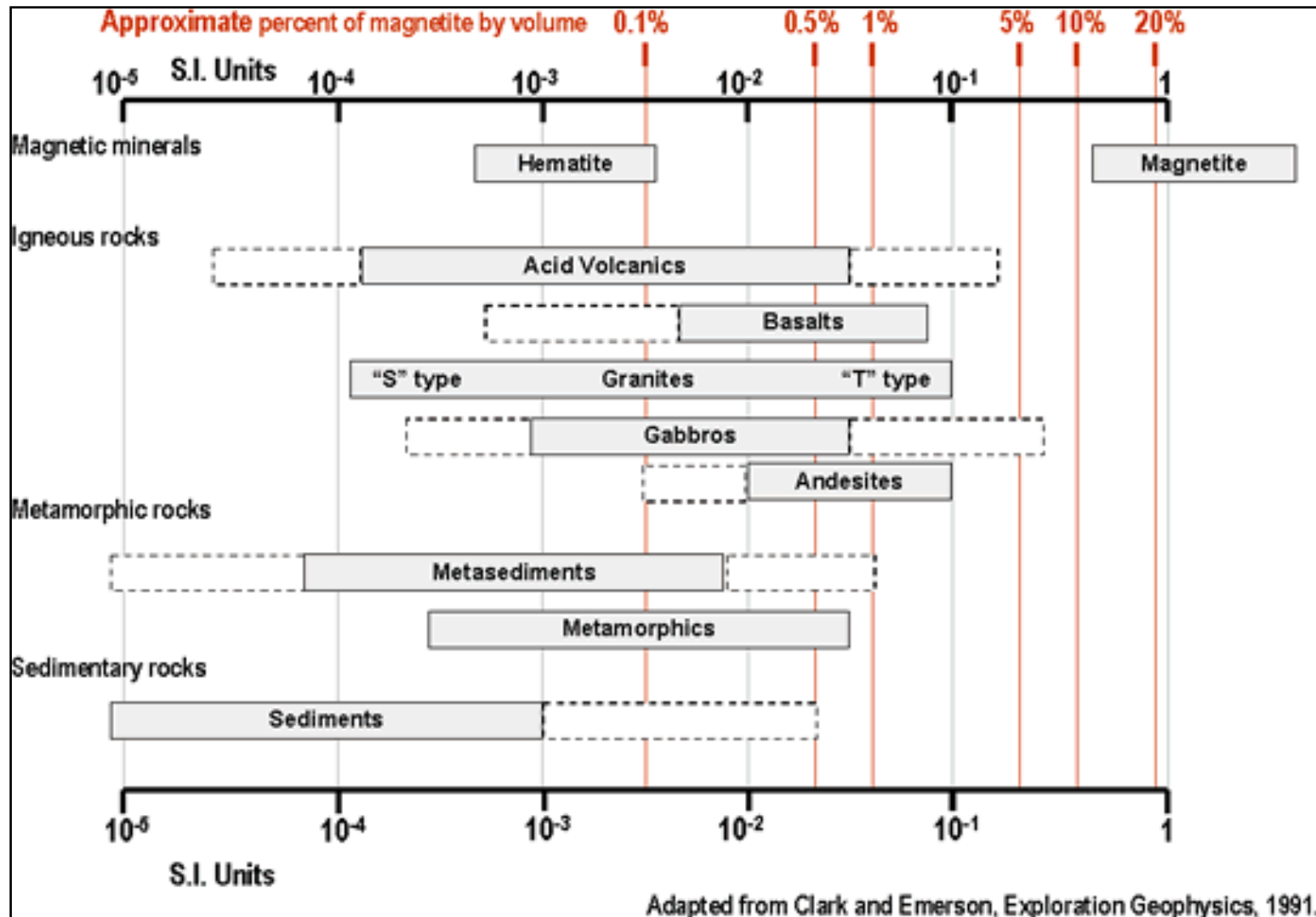

water

Electrical Resistivity / Conductivity
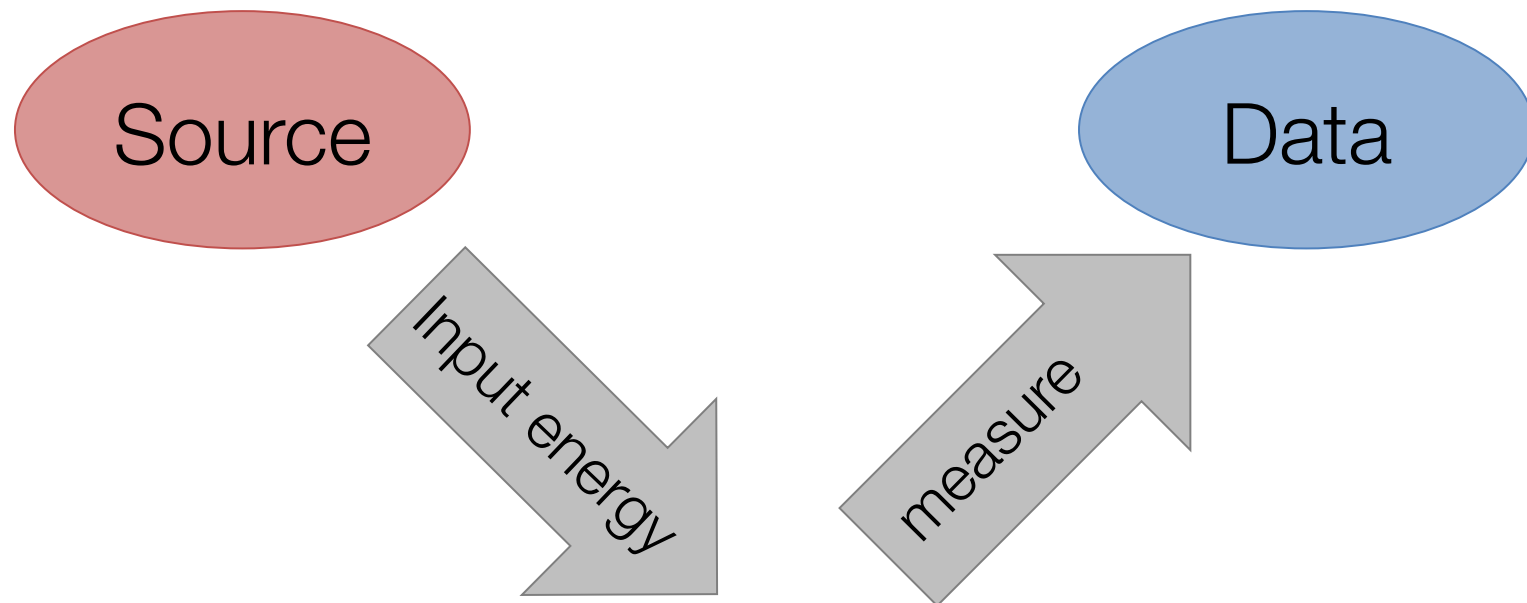
Dielectric constant

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
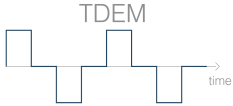
Magnetic Susceptibility

Adapted from Clark and Emerson, Exploration Geophysics, 1991.

EM Survey & Physical Properties

Source

Data

Input energy

measure

Physical
Properties

σ, μ, ε

Basic Equations

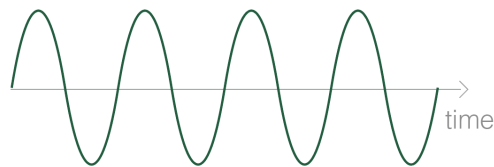|	Time TDEM	Frequency FDEM
Faraday's Law	$$\nabla \times \mathbf{e} = -\frac{\partial \mathbf{b}}{\partial t}$$	$$\nabla \times \mathbf{E} = -i\omega\mathbf{B}$$
Ampere's Law	$$\nabla \times \mathbf{h} = \mathbf{j} + \frac{\partial \mathbf{d}}{\partial t}$$	$$\nabla \times \mathbf{H} = \mathbf{J} + i\omega\mathbf{D}$$
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
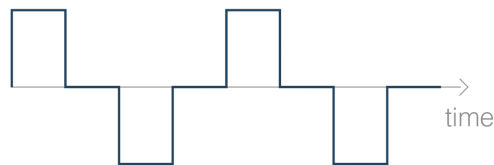
Electromagnetic Survey: Sources
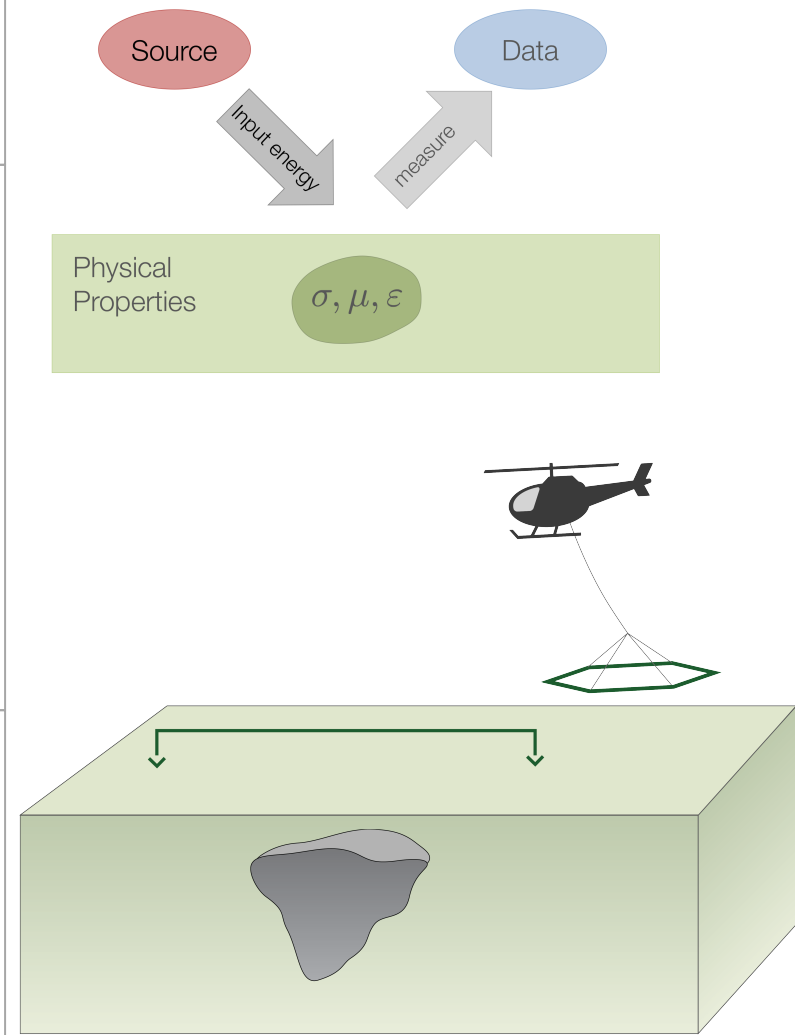
- Type
  - Inductive
  - Grounded

- Waveform
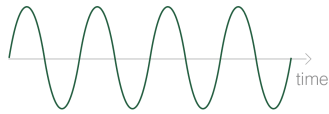
  Harmonic
  (FDEM)

  time

  Transient
  (TDEM)

  time

- Location
  - Airborne
  - Ground
  - Borehole

Source

Data

Input energy

measure

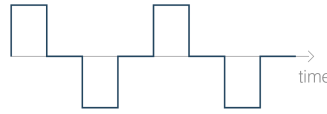Physical
Properties σ, μ, ε

Electromagnetic Survey: Data

- Which field?
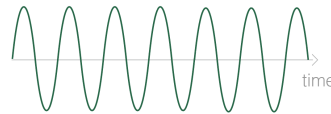
$$\mathbf{E}, \mathbf{B}$$

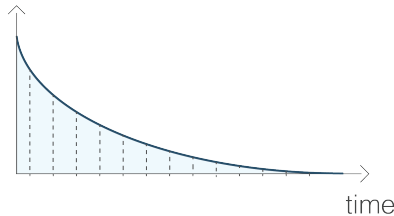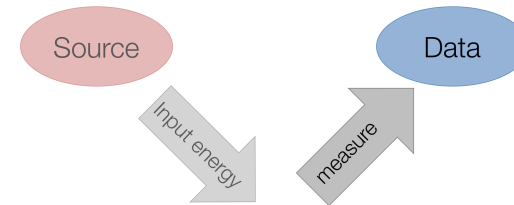$$\mathbf{e}, \mathbf{b}, \frac{d\mathbf{b}}{dt}$$
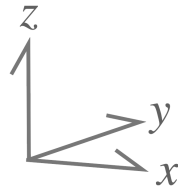
- Which frequencies?
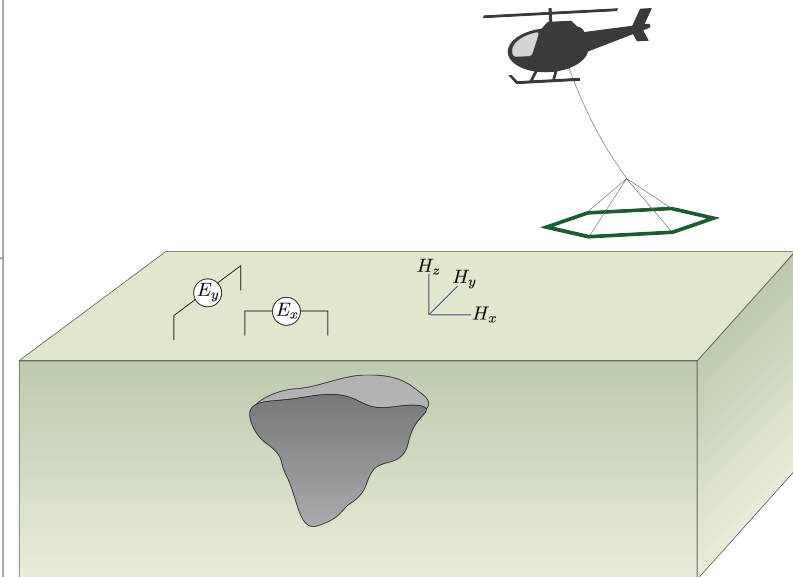
or

- times?

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

Source

Data

Input energy

measure

Physical Properties σ, μ, ε
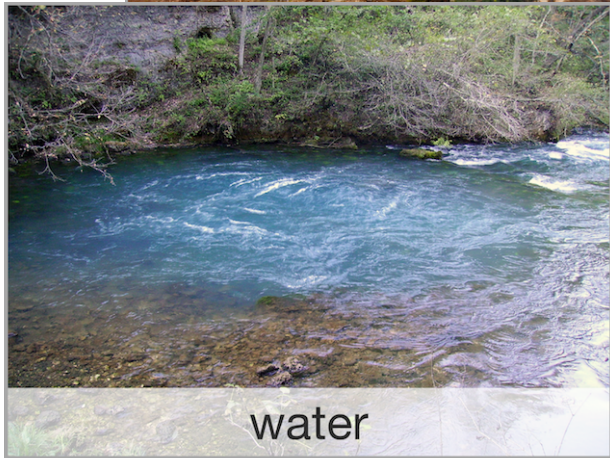
E_y E_x H_z H_y H_x

Three problems

Electrical conductivity is diagnostic for all three

minerals

unexploded ordnance

water

Source

Data

Input energy

measure

Physical Properties

σ

End of Introduction

Next up

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

Lunch: Play with apps