



# DISC

## 2017

Electromagnetics  
Fundamentals and Applications

<https://disc2017.geosci.xyz/santiago>



SOCIETY OF EXPLORATION  
— GEOPHYSICISTS —

# Thanks to...

Daniel Díaz Alvarado

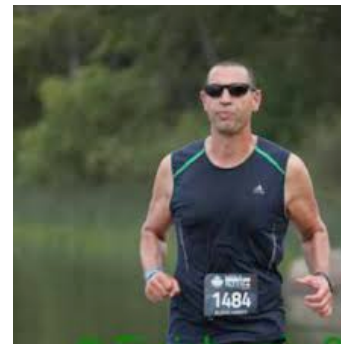
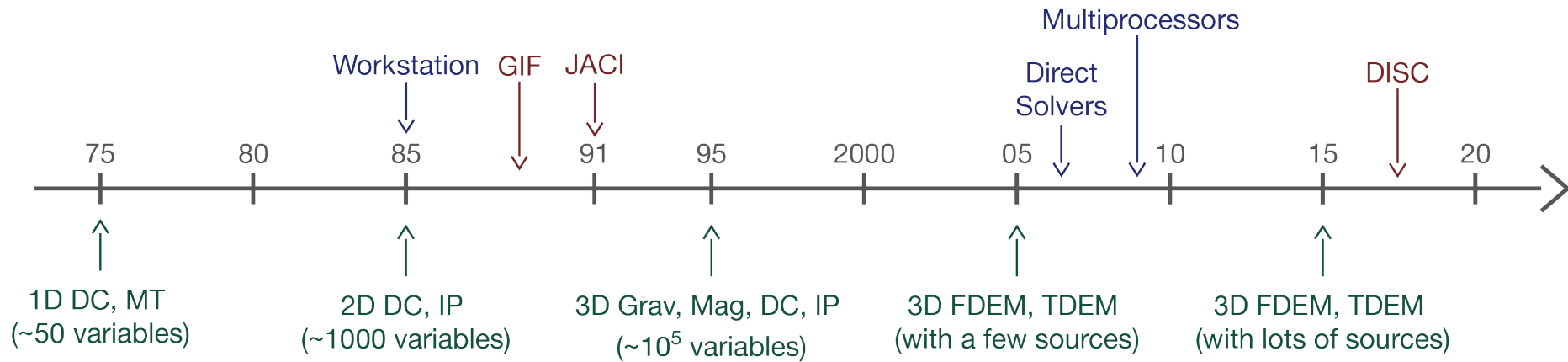


Diana Comte



# Some Background

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

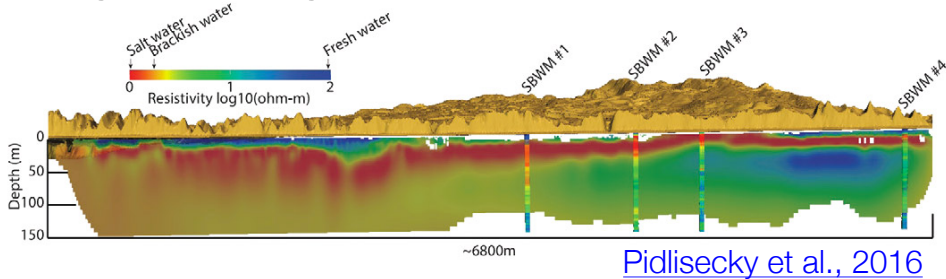


Result: Computing power + advances in inversion methodology  
→ we can now solve most EM geophysics problems

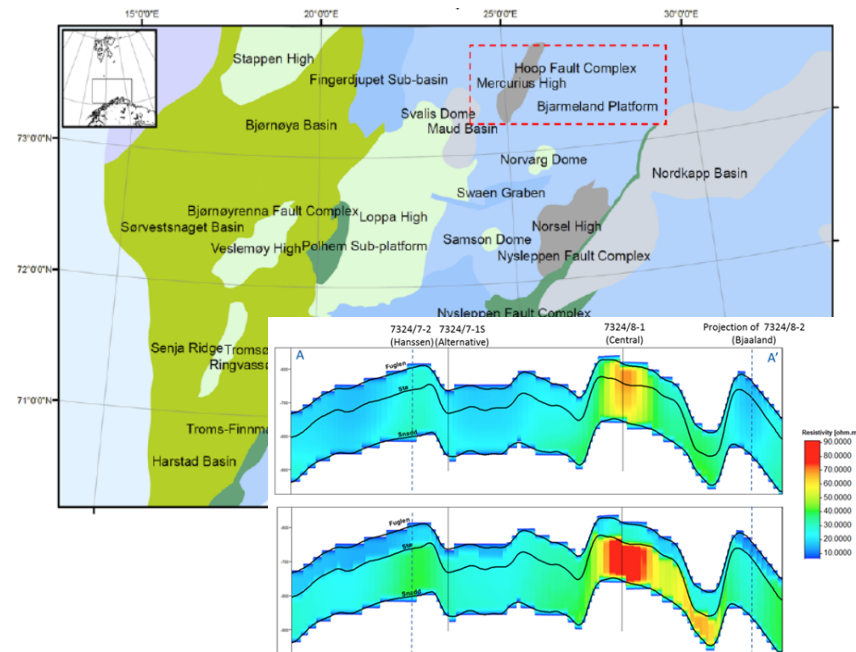
# Instrumentation and Data

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

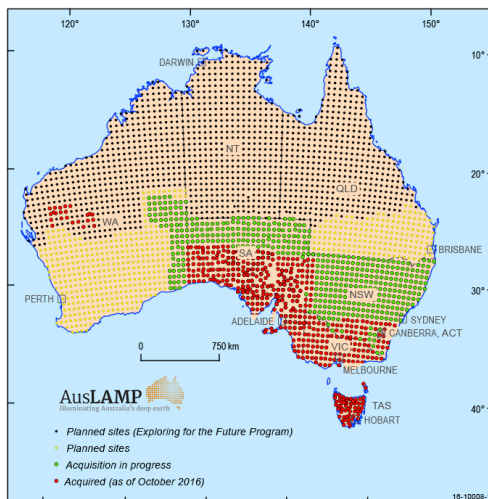
## Large-scale ground water studies: California



## Offshore: Hydrocarbon De-risking



## AusLamp: Continental Scale MT



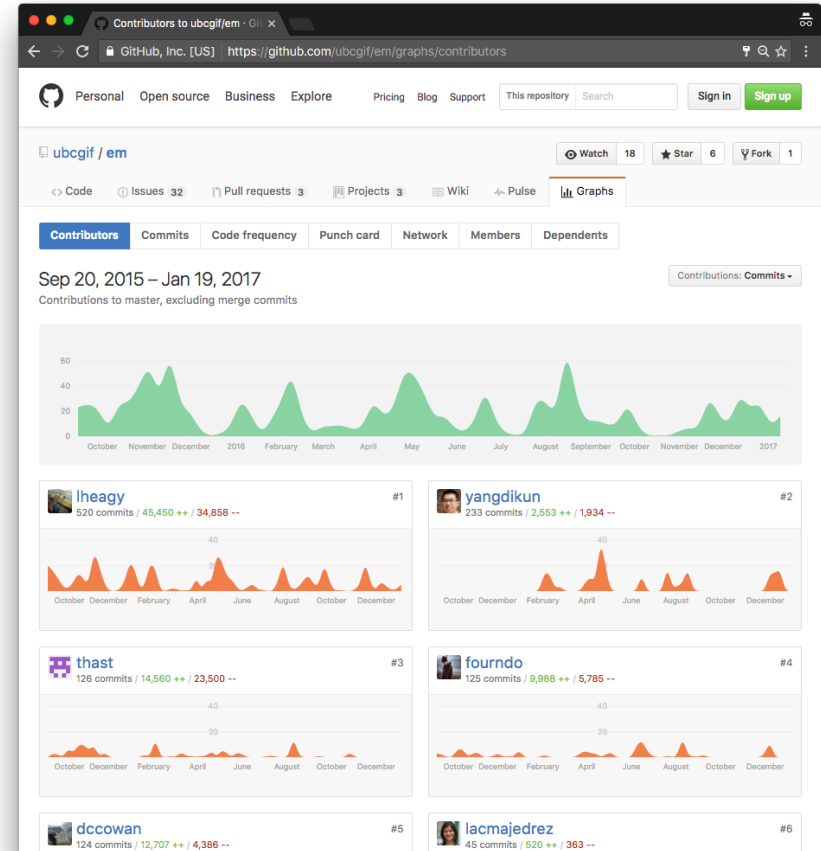
# Web and Open Source Resources

- 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
  - Confusing terminology
  - Seems complicated and unintuitive

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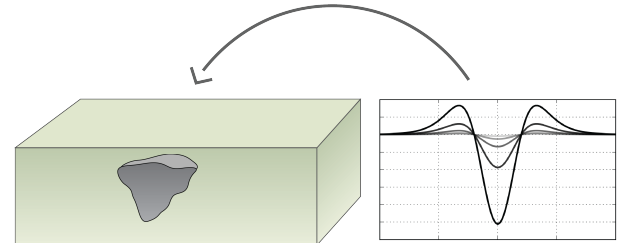
Are there situations, similar to mine, in which EM has been applied?

# DISC can take advantage of a Perfect Storm

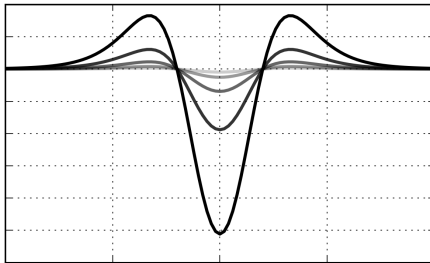
Problems



Inversion capabilities



High quality data



Web tools to  
communicate

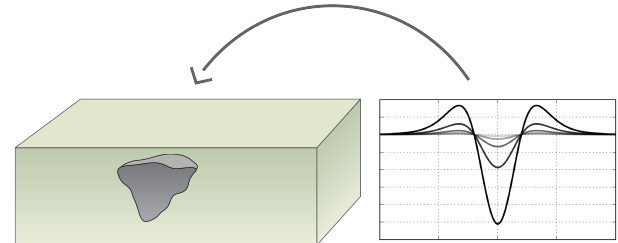


# DISC can take advantage of a Perfect Storm

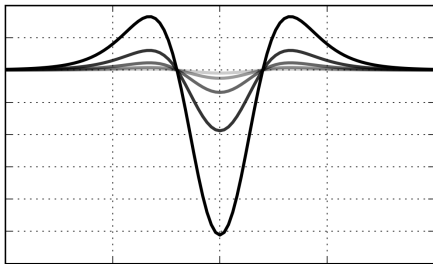
Problems



Inversion capabilities



High quality data



Web tools to  
communicate



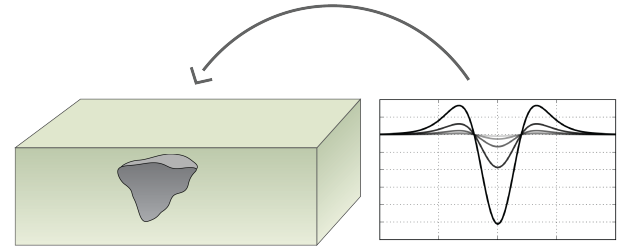
A good idea but missing an important ingredient ...

# Talented Young Geoscientists

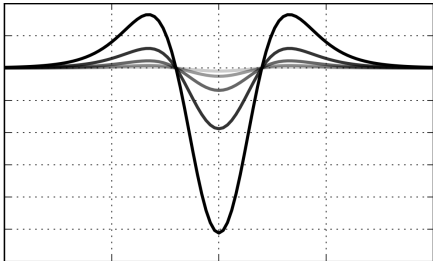
Problems



Inversion capabilities



High quality data



Web tools to  
communicate



Seogi

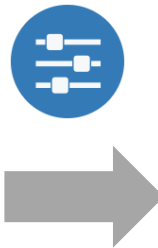
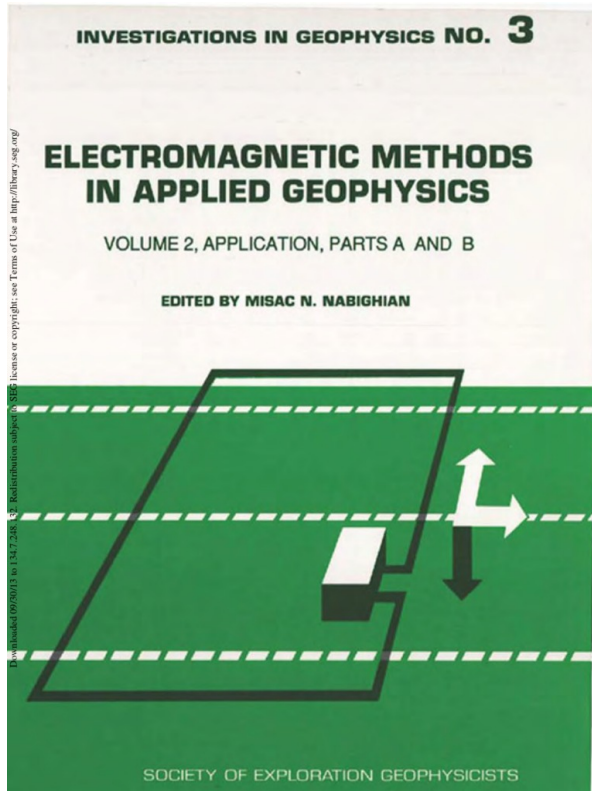


Lindsey

# 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



Case Histories — Electromag... x  
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  
Furggawanghorn  
Norsminde  
Barents Sea  
Kasted  
The Balboa ZTEM Cu-Mo-Au porphyry discovery at Cobre Panama

Gallery  
Equation Bank  
References

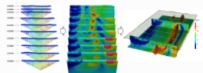
## Case Histories

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

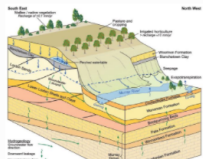
### Mt. Isa

- [Mt. Isa](#)
- **Contributors**
  - author: [Dom Fournier](#)
- **Tags**
  - geophysical survey: DC, IP
  - application: Mining
  - location: Australia



### Bookpurnong

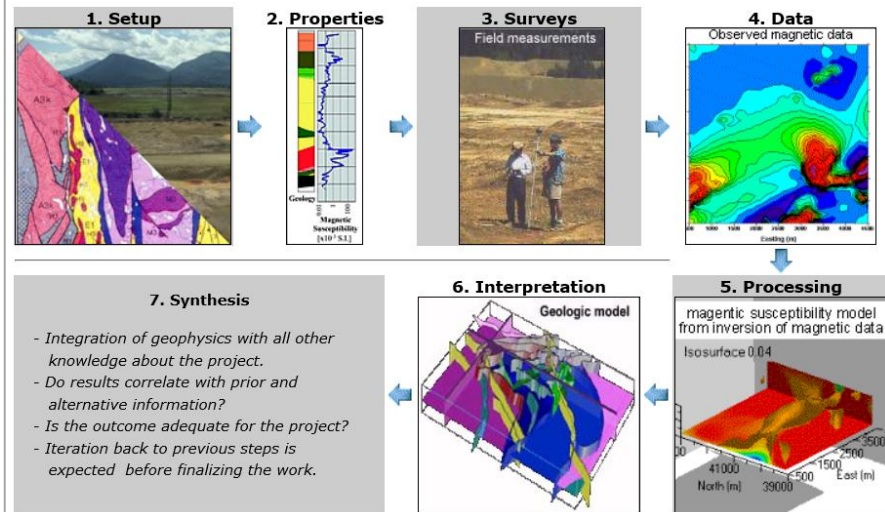
- [Bookpurnong](#)
- **Contributors**
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- **Tags**
  - geophysical survey: Airborne FDEM, Airborne TDEM
  - application: Groundwater
  - location: Australia



<http://em.geosci.xyz>

# Resources: EM.geosci

## 7 step framework for Case Histories



Case Histories — Electromag...  
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

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Case Histories

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The Balboa ZTEM Cu-Mo-Au porphyry discovery at Cobre Panama

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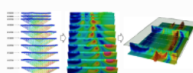
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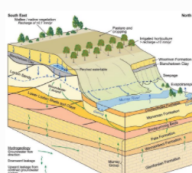
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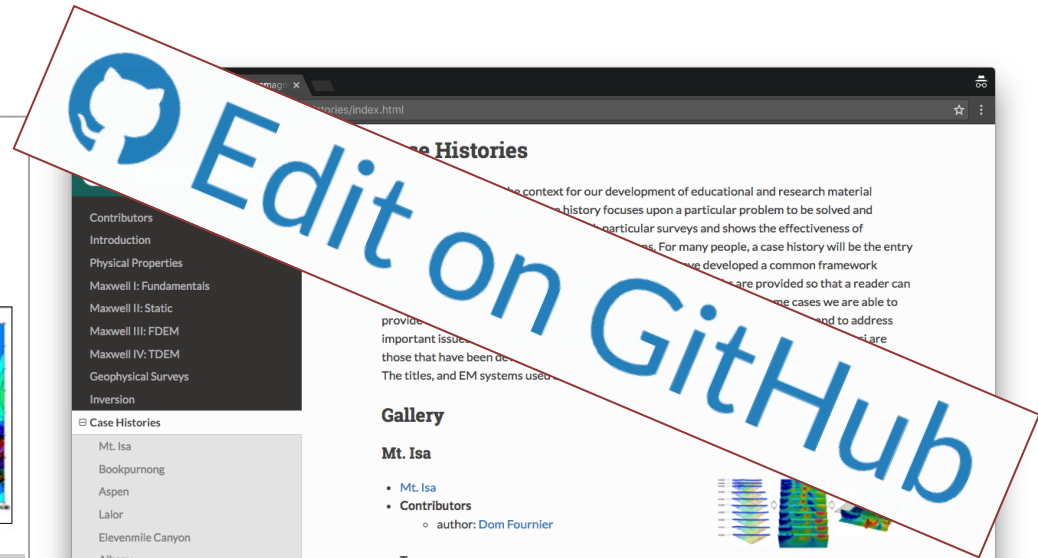
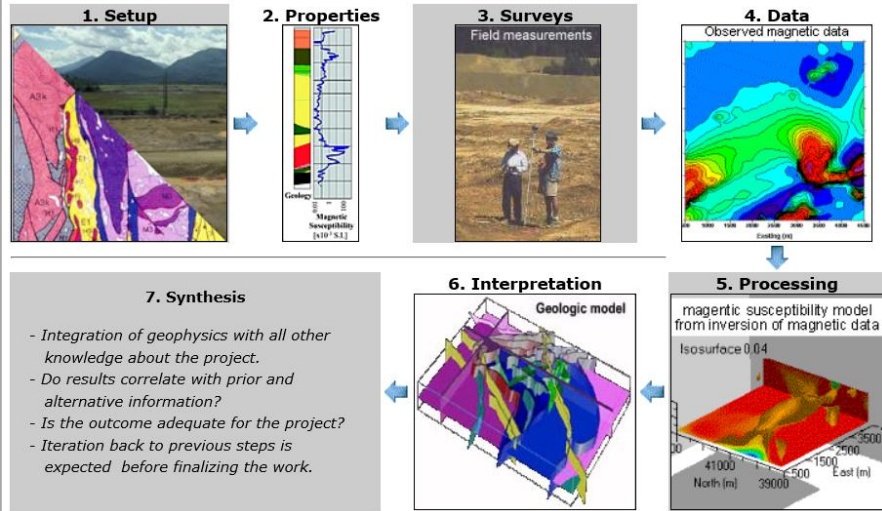
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- **Tags**
  - geophysical survey: Airborne FDEM, Airborne TDEM
  - application: Groundwater
  - location: Australia



# Resources: EM.geosci

## 7 step framework for Case Histories

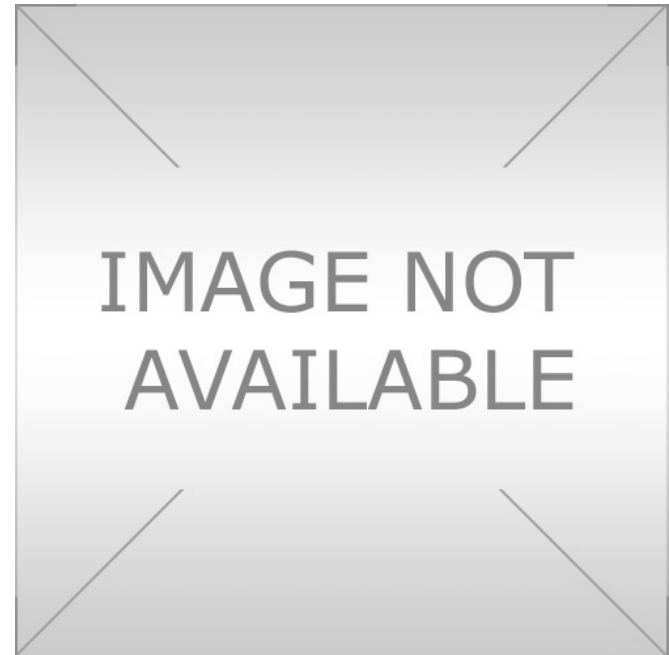
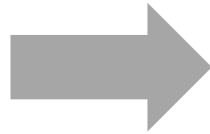




# Why Apps

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

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



# Why Apps

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

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



The screenshot shows a Jupyter notebook titled "HarmonicDipoleWidget\_MD" running on localhost:8889. The code cell contains the following Python code:

```
In [10]: dwidget = DipoleWidgetFD()
Q1 = dwidget.InteractiveDipoleBH(nRx=Q0.kwarg["nRx"], plane=Q0.kwarg["Pl
```

The control panel includes the following settings:

- Field: E, H, J (selected)
- AmpDir: None, Amp, Direction (selected)
- Comp.: x, y, z (selected)
- Complex Number: Re, Im, Amp, Phase (selected)
- f (Hz): 0
- $\sigma$  (S/m): 0.01
- Offset: 50
- Scale: log, linear (selected)
- Slider:
- FreqLog: -3.00
- SigLog: -3.00

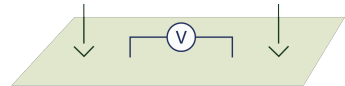
Two plots are displayed:

- Vector H-field from MD:** A 2D vector field plot showing magnetic field lines in the Y-Z plane. The Y-axis ranges from -40 to 40 m, and the Z-axis ranges from -40 to 40 m. The field is centered at the origin and shows a dipole-like pattern. A color bar on the right indicates the magnitude of the magnetic field in A/m, ranging from  $10^{-6.5}$  to  $10^{-6.2}$ .
- EM data at Rx hole:** A line plot showing the A-B profile of the magnetic field. The Y-axis is labeled "A-B profile (m)" and ranges from -40 to 40. The X-axis is labeled "[H]-field (A/m)" and ranges from  $10^{-6.5}$  to  $10^{-6.2}$ . The plot shows a smooth, bell-shaped curve peaking at the center.

# 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

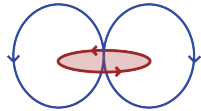
# Agenda for today



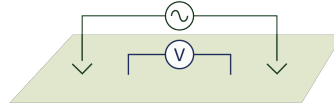
DC Resistivity



EM  
Fundamentals



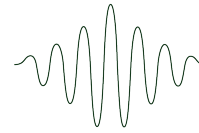
Inductive  
Sources



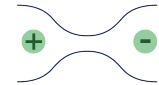
Grounded  
Sources



Natural  
Sources



GPR



Induced  
Polarization

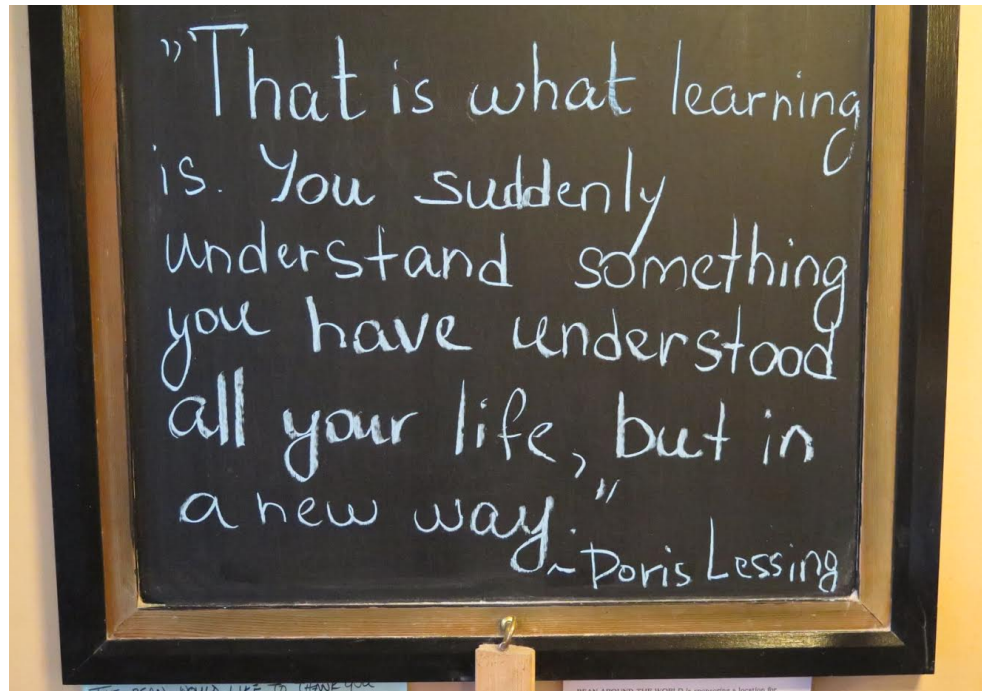


The  
Future

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...



# 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/>



Join **GeoSci** on Slack.

**3** users online now of **9** registered.

you@yourdomain.com

**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 browser's address bar shows 'em.geosci.xyz/content/case\_histories/index.html'. The page has a dark green header with the 'em' logo and a search bar. A sidebar on the left contains a menu with categories like 'Contributors', 'Introduction', 'Physical Properties', 'Maxwell I: Fundamentals', 'Maxwell II: Static', 'Maxwell III: FDEM', 'Maxwell IV: TDEM', 'Geophysical Surveys', and 'Inversion'. Under 'Case Histories', it lists various locations: Mt. Isa, Bookpurnong, Aspen, Lalor, Elevenmile Canyon, Albany, West Plains, Furggawanghorn, Norsminde, Barents Sea, Kasted, and 'The Balboa ZTEM Cu-Mo-Au porphyry discovery at Cobre Panama'. There are also links for 'Gallery', 'Equation Bank', and 'References'. The main content area is titled 'Case Histories' and contains an introductory paragraph. Below this is a 'Gallery' section with two entries: 'Mt. Isa' and 'Bookpurnong'. Each entry includes a list of 'Contributors' and 'Tags' (geophysical survey, application, location). The 'Mt. Isa' entry lists 'Dom Fournier' as the author and 'DC, IP', 'Mining', and 'Australia' as tags. The 'Bookpurnong' entry lists 'Dikun Yang' as the author and 'Airborne FDEM, Airborne TDEM', 'Groundwater', and 'Australia' as tags. To the right of the text are two 3D geological diagrams: one showing a cross-section of a subsurface with various layers and a well, and another showing a similar cross-section with different layering and a well.

# Introduction to EM





# Three problems

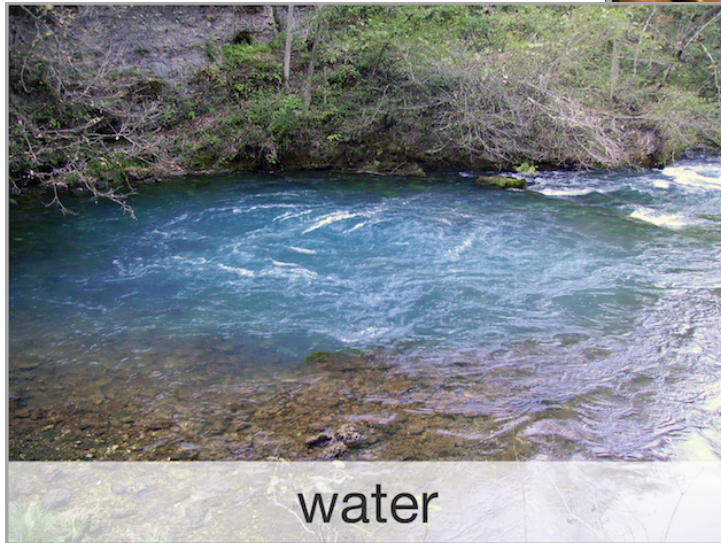
How do we locate and characterize ...



minerals

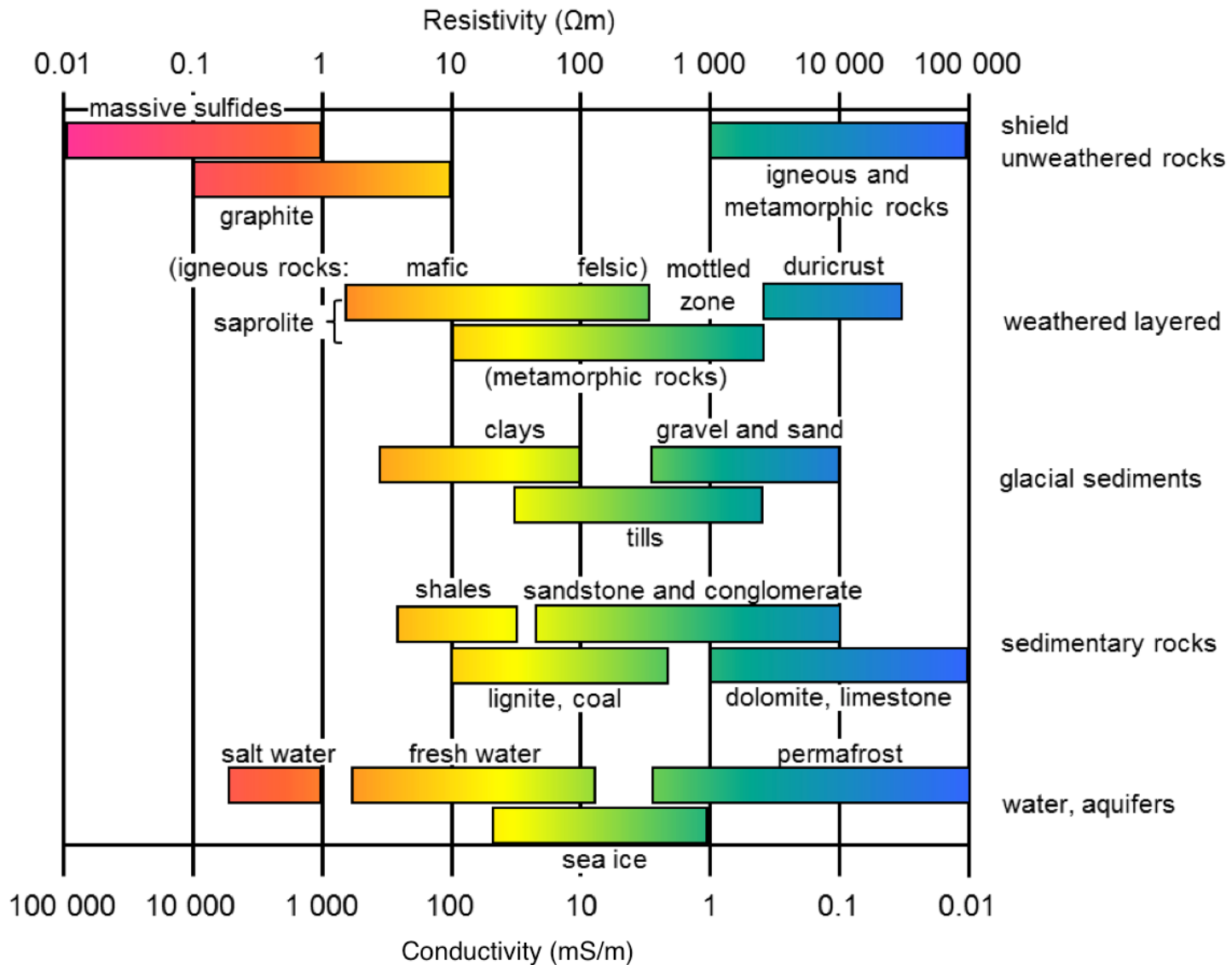


unexploded ordnance



water

# Electrical Resistivity / Conductivity

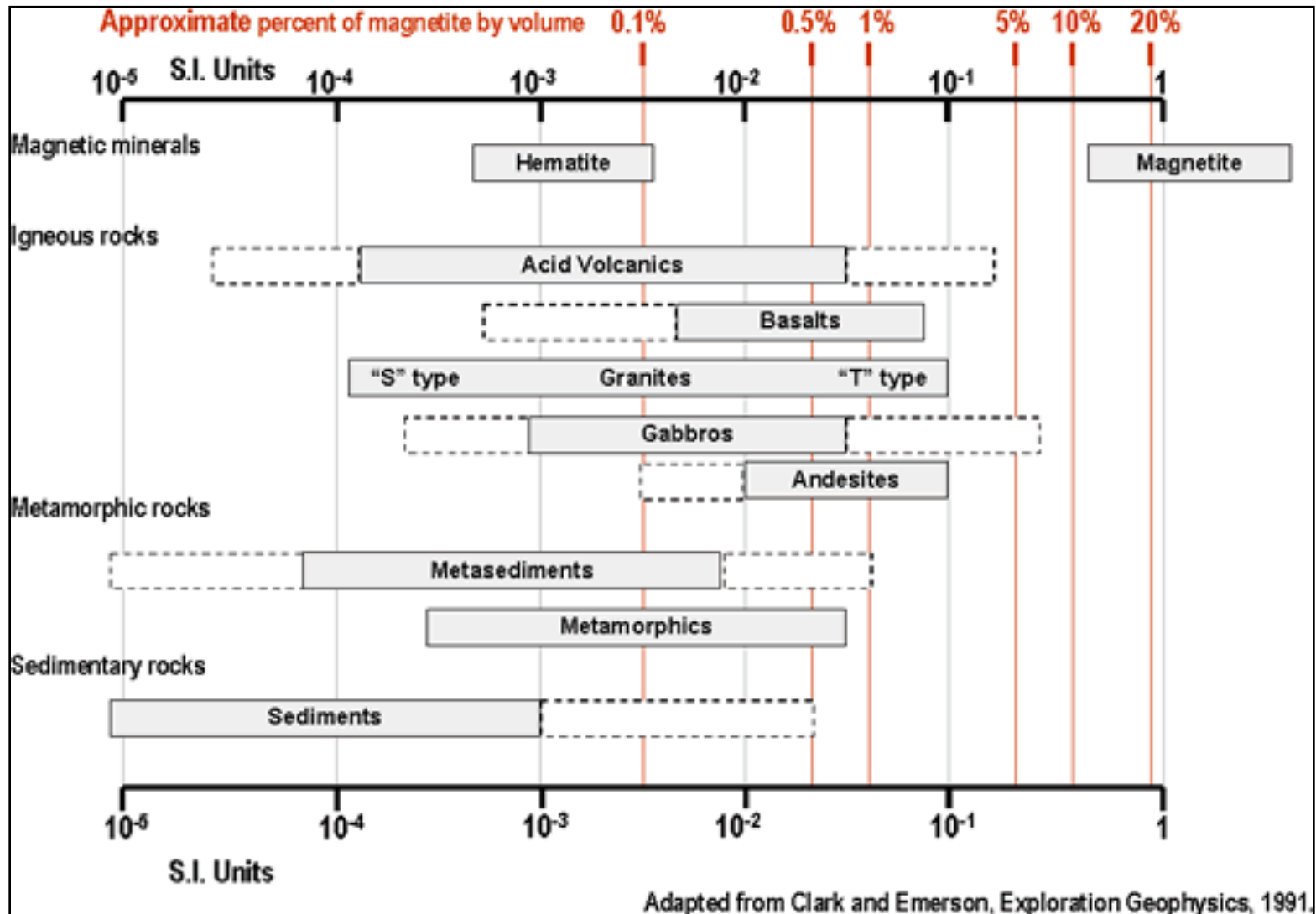


# Dielectric constant

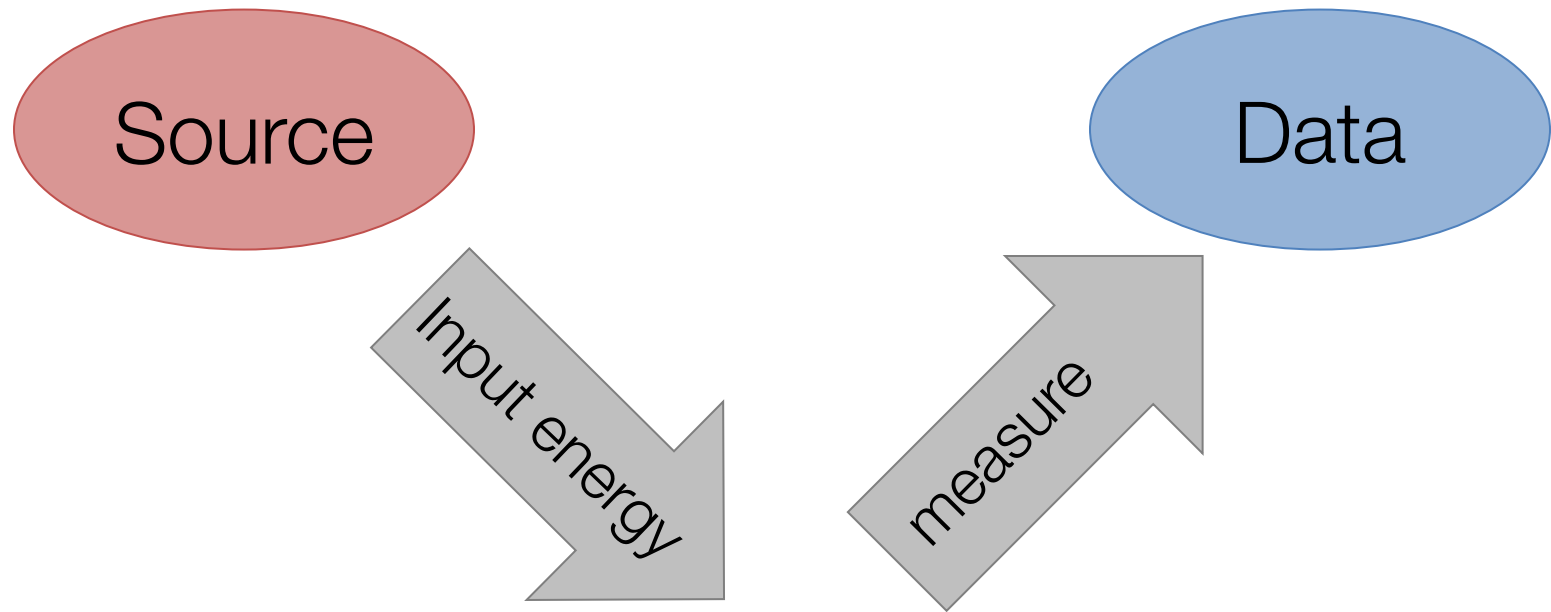
Material	Relative Permittivity	Conductivity (mS/m)
Air	1	0
Fresh Water	80	0.5
Sea Water	80	3000
Ice	3-4	0.01
Dry Sand	3-5	0.01
Saturated Sand	20-30	0.1-1
Limestone	4-8	0.5-2
Shales	5-15	1-100
Silts	5-30	1-100
Clays	5-40	2-1000
Granite	4-6	0.01-1
Anhydrites	3-4	0.01-1



# Magnetic Susceptibility



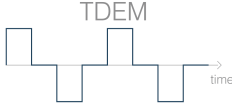
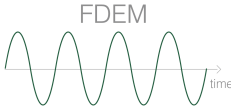
# EM Survey & Physical Properties



Physical  
Properties

$$\sigma, \mu, \epsilon$$

# Basic Equations

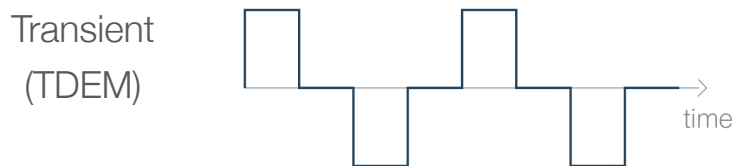
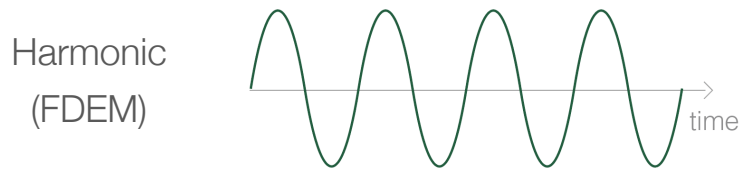
	Time 	Frequency 
Faraday's Law	$\nabla \times \mathbf{e} = - \frac{\partial \mathbf{b}}{\partial t}$	$\nabla \times \mathbf{E} = - i\omega \mathbf{B}$
Ampere's Law	$\nabla \times \mathbf{h} = \mathbf{j} + \frac{\partial \mathbf{d}}{\partial t}$	$\nabla \times \mathbf{H} = \mathbf{J} + i\omega \mathbf{D}$
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

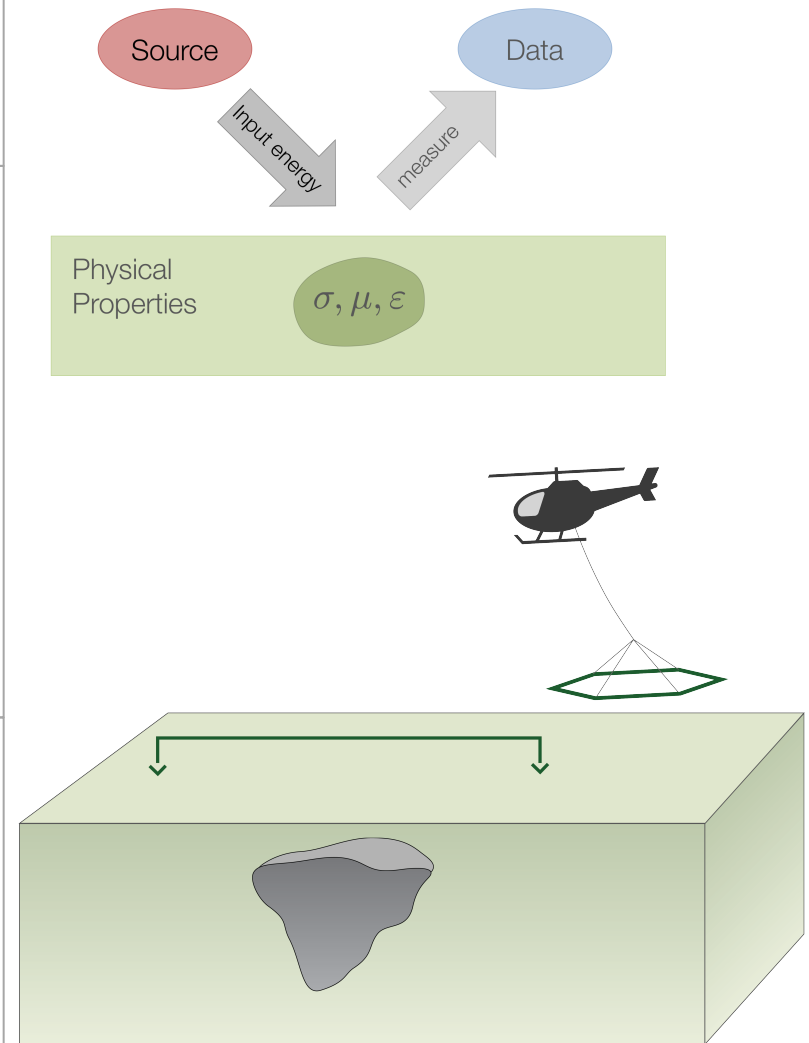
# Electromagnetic Survey: Sources

- Type
  - Inductive
  - Grounded

- Waveform

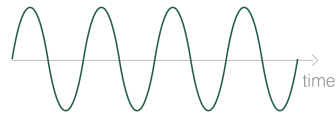


- Location
  - Airborne
  - Ground
  - Borehole

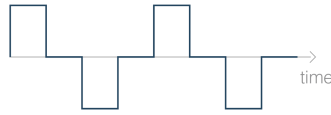


# Electromagnetic Survey: Data

- Which field?



**E, B**

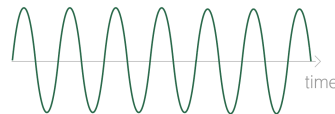


**e, b,  $\frac{db}{dt}$**

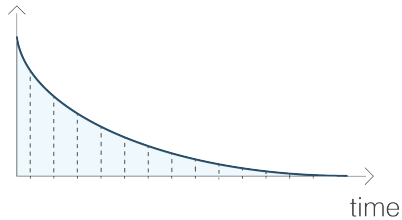
- Which frequencies?



or



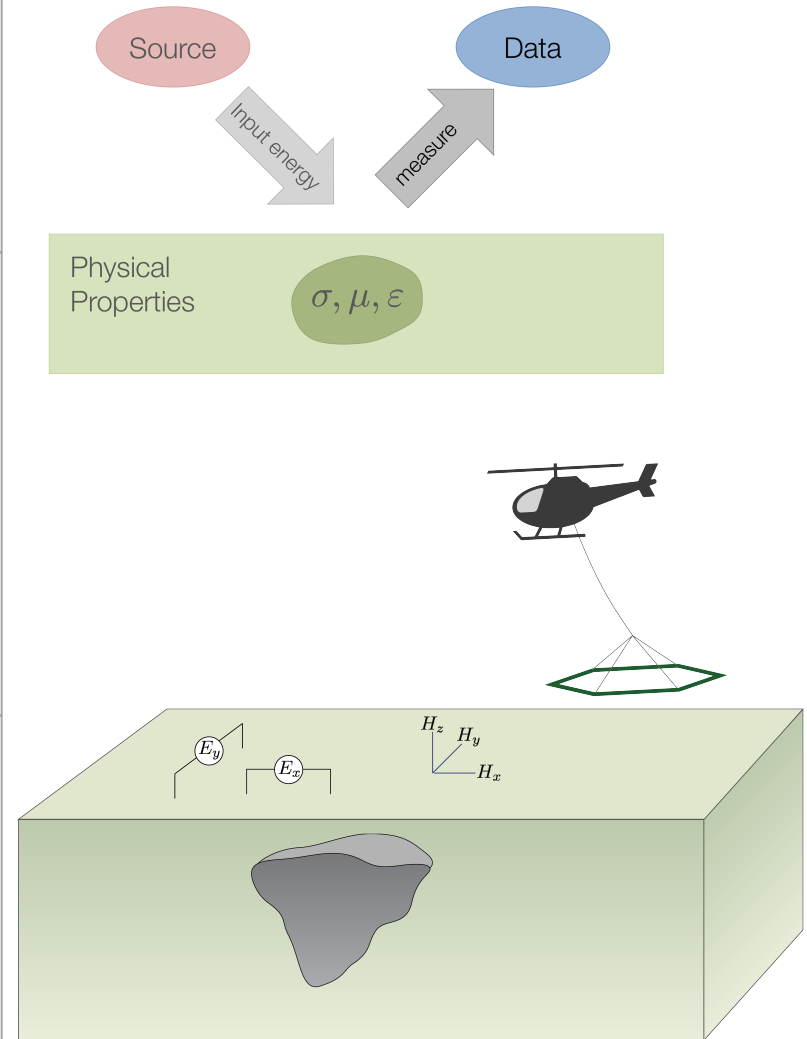
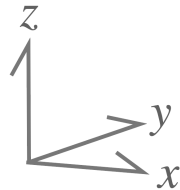
- times?



- Components?

- Location?

- Airborne
- Ground
- Borehole





# Three problems

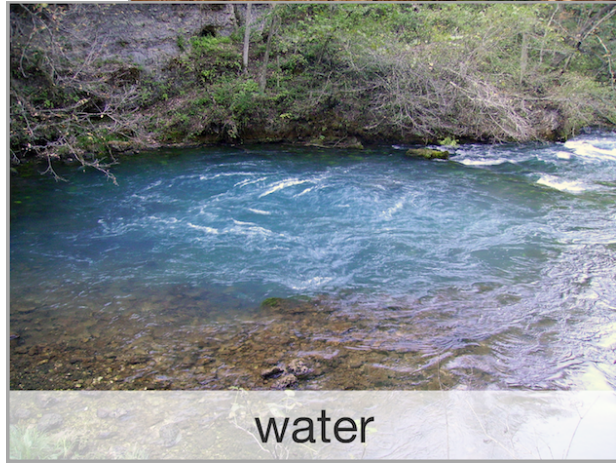
Electrical conductivity is diagnostic for all three



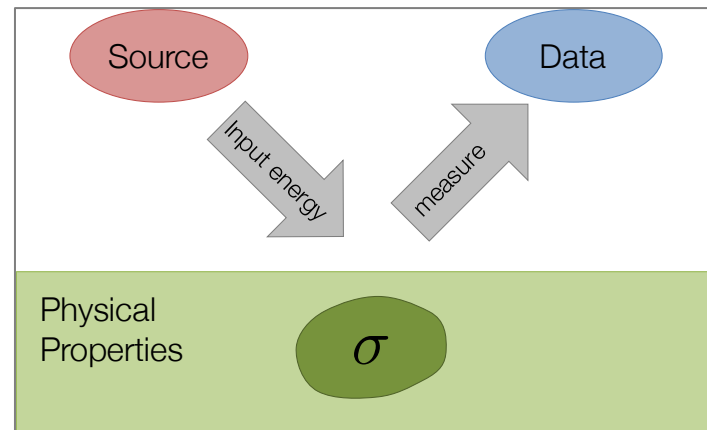
minerals



unexploded ordnance

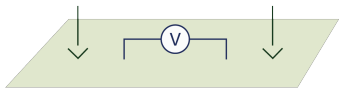


water



# End of Introduction

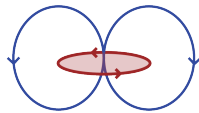
Next up



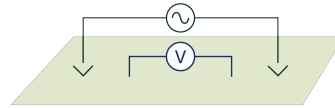
DC Resistivity



EM  
Fundamentals



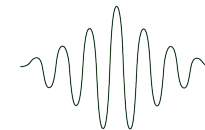
Inductive  
Sources



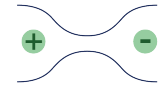
Grounded  
Sources



Natural  
Sources



GPR



Induced  
Polarization



The  
Future

Lunch: Play with apps