



# DISC

## 2017

Electromagnetics  
Fundamentals and Applications

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



SOCIETY OF EXPLORATION  
— GEOPHYSICISTS —

Thanks to...

How-Wei Chen

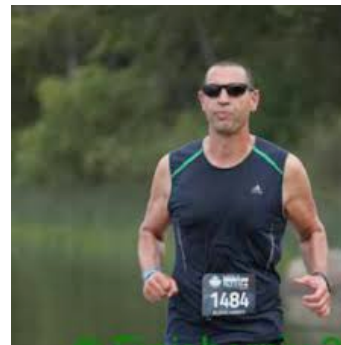
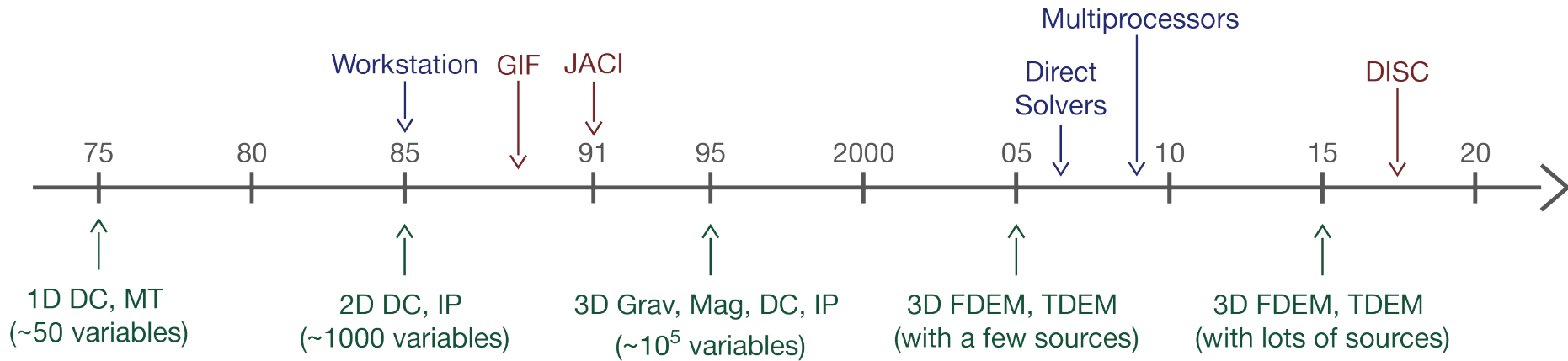


NCU



# Some Background

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

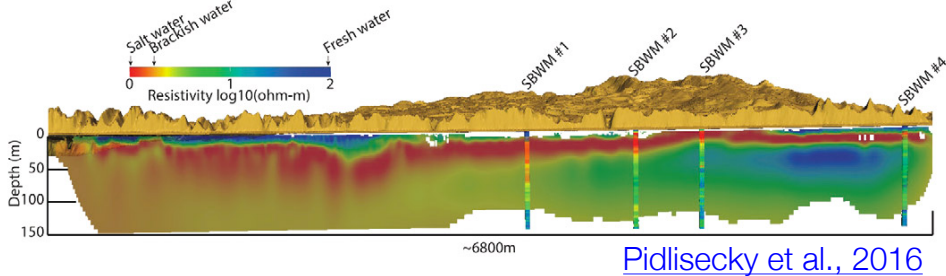


Result: Computing power + advances in inversion methodology  
→ we can now solve most EM geophysics problems

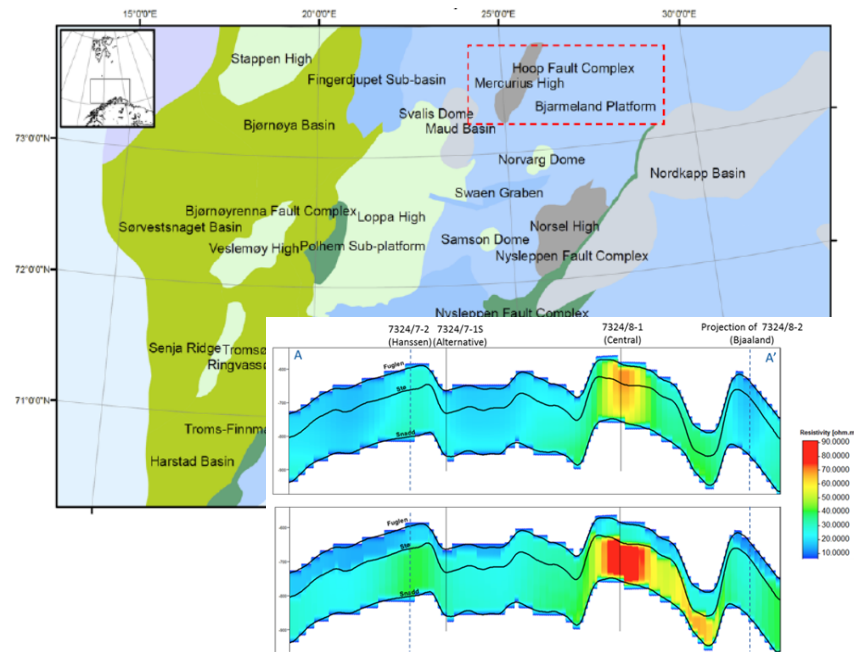
# Instrumentation and Data

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

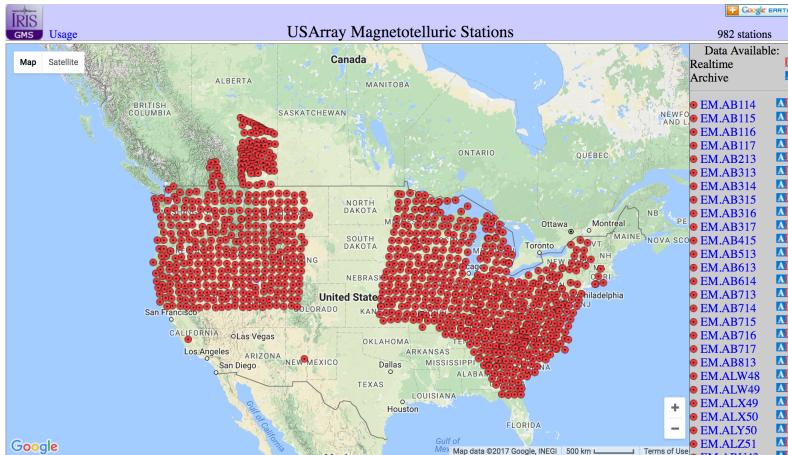
## Large-scale ground water studies: California



## Offshore: Hydrocarbon De-risking



## Earth scope: Continental Scale MT



Earth Scope

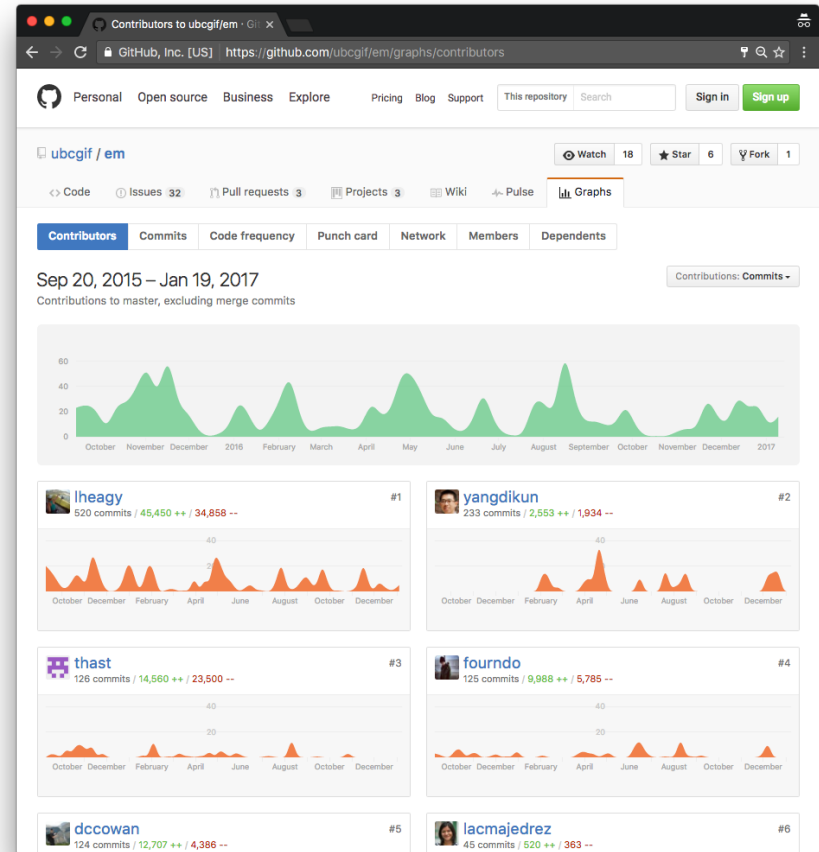
# Web and Open Source Resources

- 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



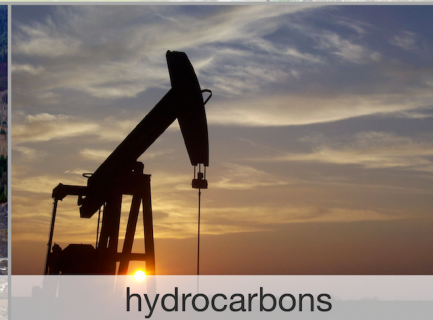
geothermal



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
  - Confusing terminology
  - Seems complicated and unintuitive

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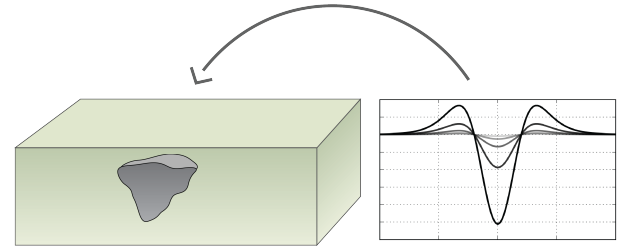
Are there situations, similar to mine, in which EM has been applied?

# DISC can take advantage of a Perfect Storm

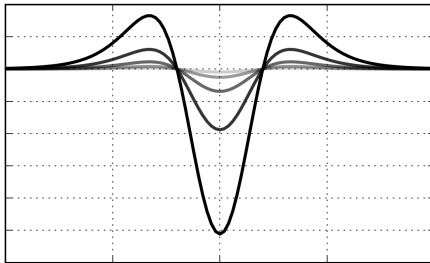
Problems



Inversion capabilities



High quality data



Web tools to communicate

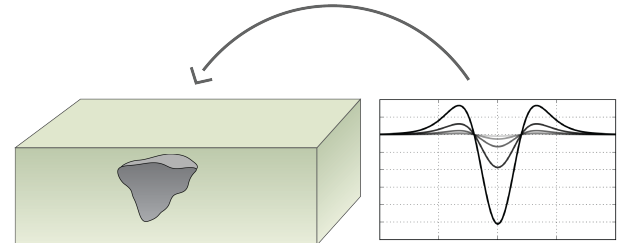


# DISC can take advantage of a Perfect Storm

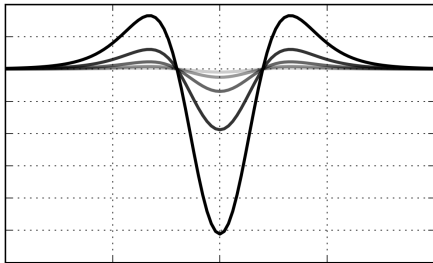
Problems



Inversion capabilities



High quality data



Web tools to  
communicate



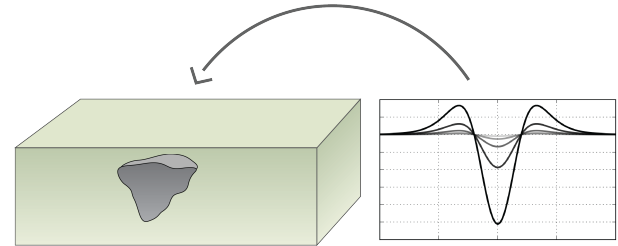
A good idea but missing an important ingredient ...

# Talented Young Geoscientists

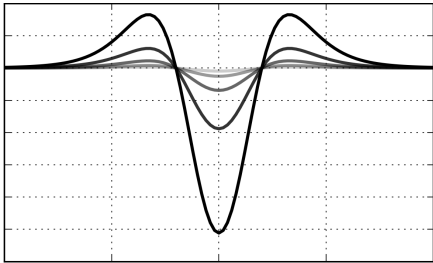
Problems



Inversion capabilities



High quality data



Web tools to  
communicate



Seogi

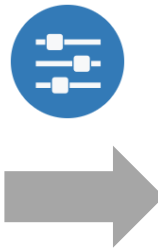
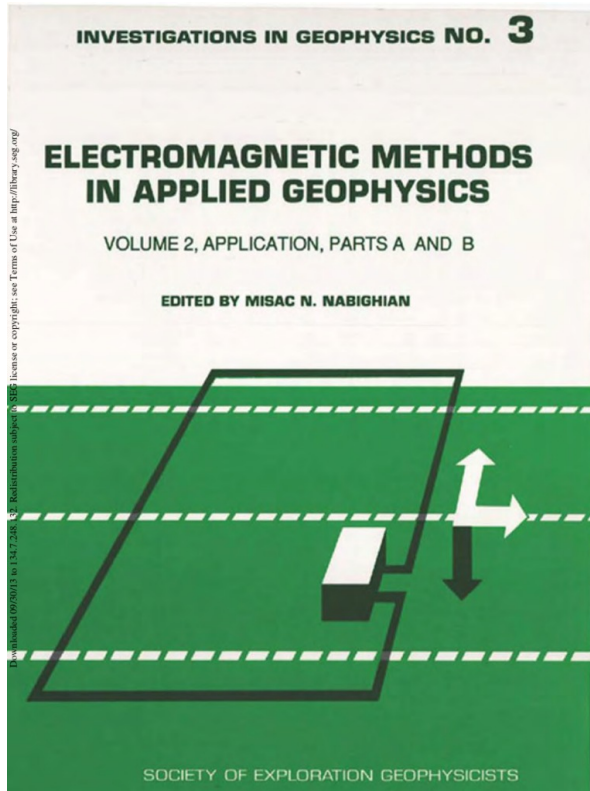


Lindsey

# 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



The screenshot shows a web browser window with the URL [em.geosci.xyz/content/case\\_histories/index.html](http://em.geosci.xyz/content/case_histories/index.html). The page has a dark green header with the text 'em'. Below the header is a search bar and a navigation menu. The main content area is titled 'Case Histories' and contains a paragraph of text, a 'Gallery' section, and two case study entries: 'Mt. Isa' and 'Bookpurnong'. Each entry includes a list of contributors and tags. The 'Mt. Isa' entry has a contributor 'Dom Fournier' and tags 'geophysical survey: DC, IP', 'application: Mining', and 'location: Australia'. The 'Bookpurnong' entry has a contributor 'Dikun Yang' and tags 'geophysical survey: Airborne FDEM, Airborne TDEM', 'application: Groundwater', and 'location: Australia'. There are also small images of geophysical data plots and a 3D model of a geological structure.

## 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

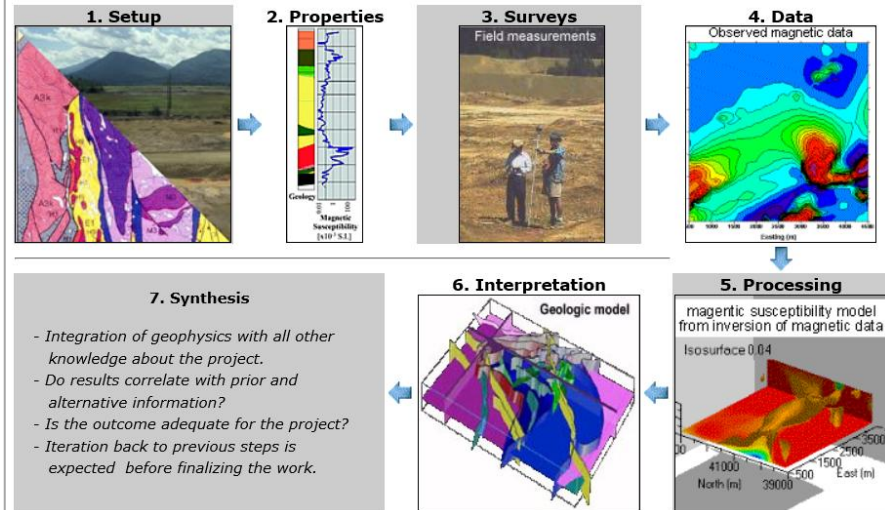
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- [Contributors](#)
  - author: [Dikun Yang](#)
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  - geophysical survey: Airborne FDEM, Airborne TDEM
  - application: Groundwater
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<http://em.geosci.xyz>

# 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

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

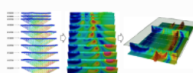
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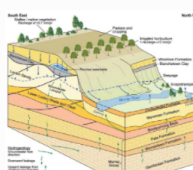
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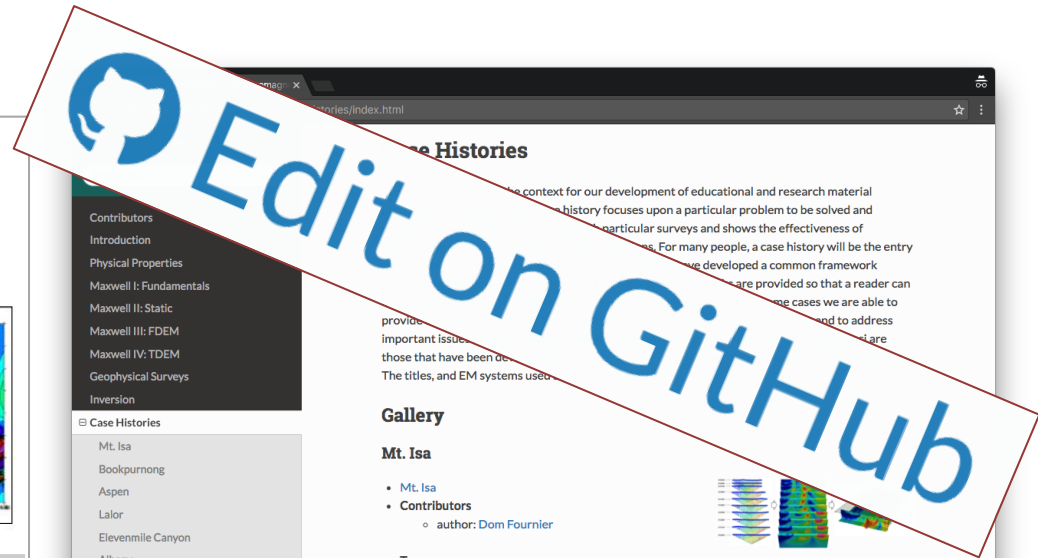
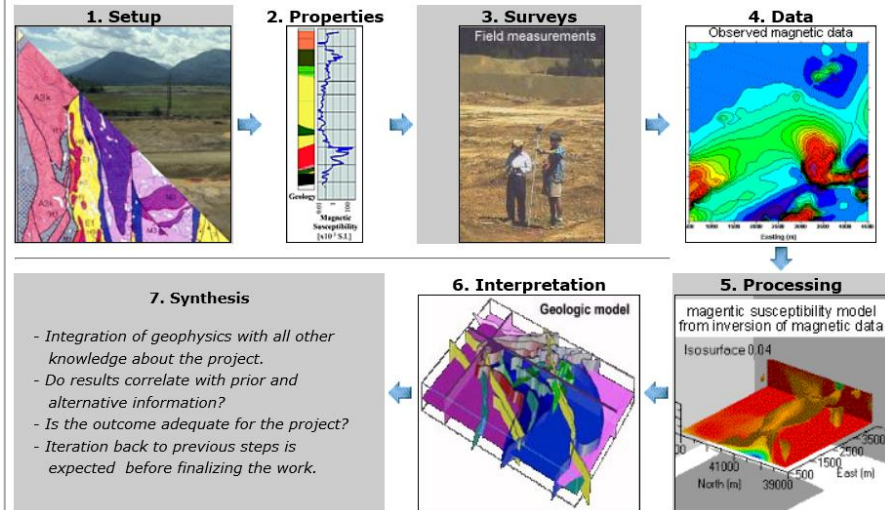
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  - location: Australia



# Resources: EM.geosci

## 7 step framework for Case Histories

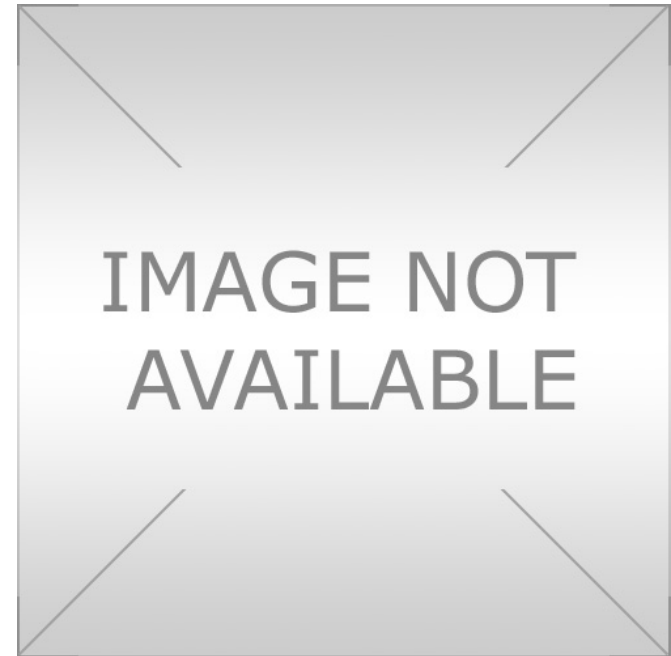




# Why Apps

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

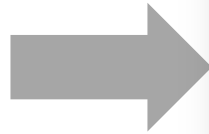
$$\nabla \times \mathbf{h} = \mathbf{j} + \frac{\partial \mathbf{d}}{\partial t}$$



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

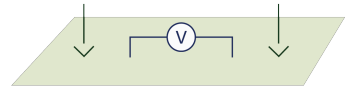
Two plots are displayed:

- 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 (m) versus the |H|-field (A/m). The A-B profile ranges from -40 to 40 m, and the |H|-field ranges from  $10^{-6.5}$  to  $10^{-6.2}$  A/m. The plot shows a smooth, bell-shaped curve.

# 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

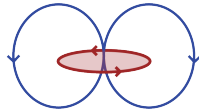
# Agenda for today



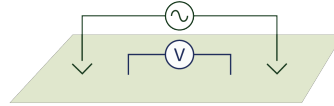
DC Resistivity



EM  
Fundamentals



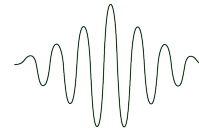
Inductive  
Sources



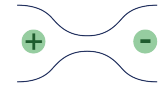
Grounded  
Sources



Natural  
Sources



GPR



Induced  
Polarization

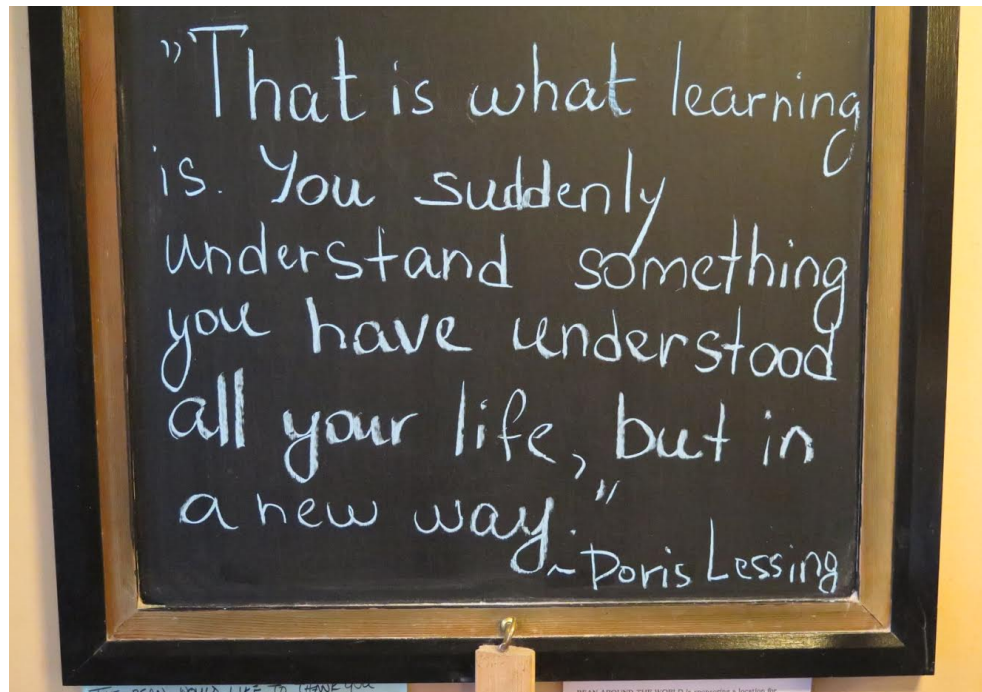


The  
Future

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
  - Sign up at <http://disc2017.geosci.xyz/schedule#taiwan>
- 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 image is a screenshot of a web browser displaying the 'Case Histories' page on the 'em.geosci.xyz' website. The browser's address bar shows the URL '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 navigation menu with categories like 'Contributors', 'Introduction', 'Physical Properties', and 'Case Histories'. The 'Case Histories' section is expanded, showing a list of case studies including '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'. 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' and 'Bookpurnong'. Each entry lists contributors and tags. The 'Mt. Isa' entry lists 'Dom Fournier' as the author and tags include 'geophysical survey: DC, IP', 'application: Mining', and 'location: Australia'. The 'Bookpurnong' entry lists 'Dikun Yang' as the author and tags include 'geophysical survey: Airborne FDEM, Airborne TDEM', 'application: Groundwater', and 'location: Australia'. Both entries are accompanied by small images showing geophysical data visualizations.

# Introduction to EM





# Three problems

How do we locate and characterize ...



minerals

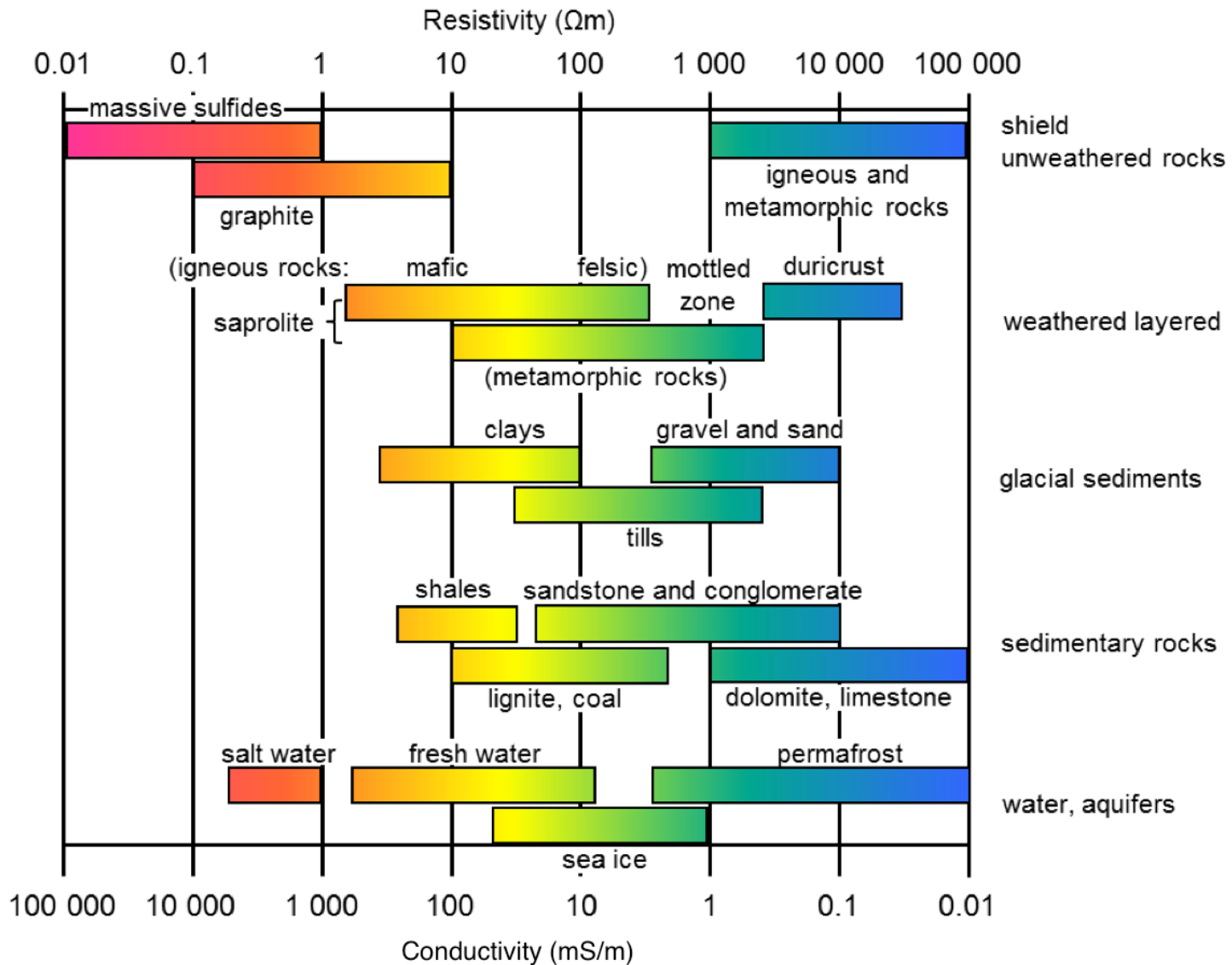


unexploded ordnance



water

# Electrical Resistivity / Conductivity

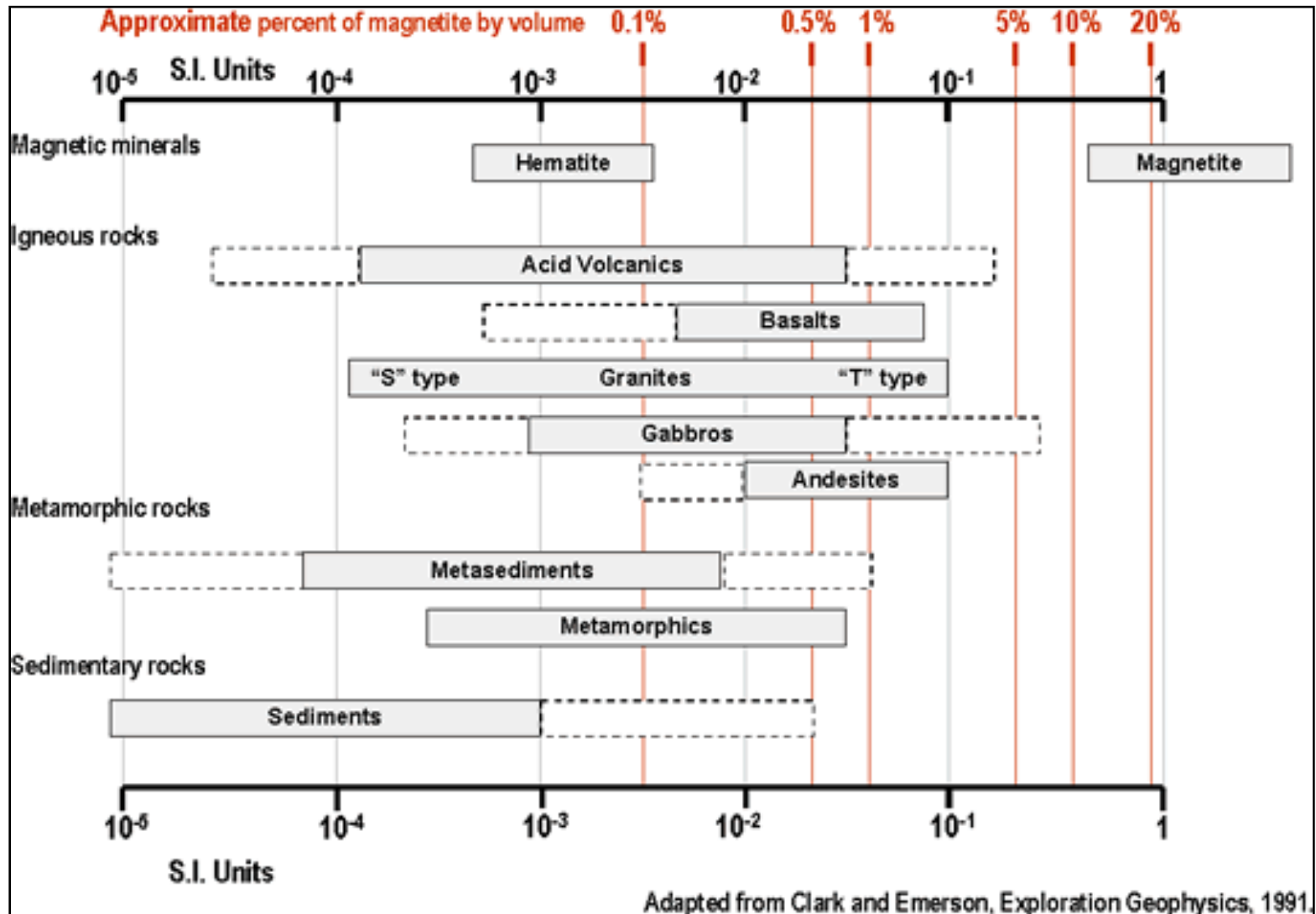


# Dielectric constant

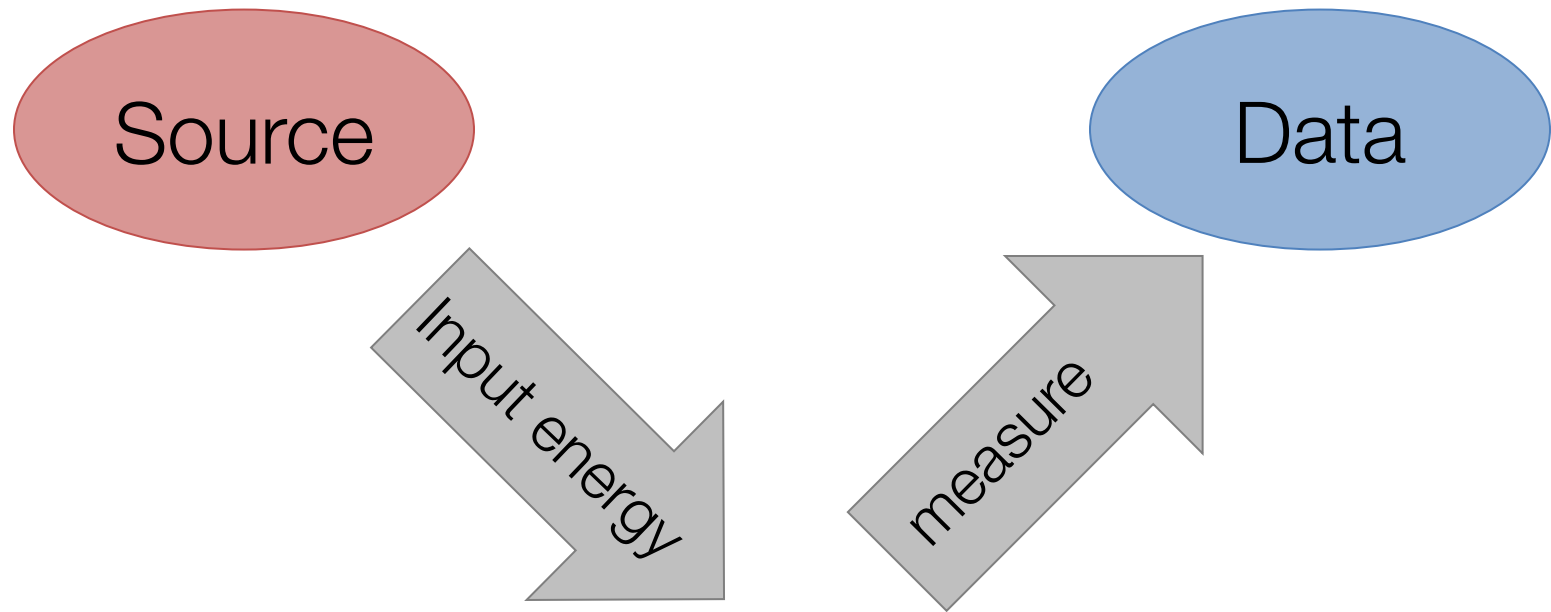
Material	Relative Permittivity	Conductivity (mS/m)
Air	1	0
Fresh Water	80	0.5
Sea Water	80	3000
Ice	3-4	0.01
Dry Sand	3-5	0.01
Saturated Sand	20-30	0.1-1
Limestone	4-8	0.5-2
Shales	5-15	1-100
Silts	5-30	1-100
Clays	5-40	2-1000
Granite	4-6	0.01-1
Anhydrites	3-4	0.01-1



# Magnetic Susceptibility



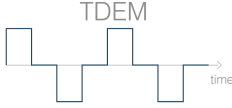
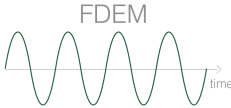
# EM Survey & Physical Properties



Physical  
Properties

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

# Basic Equations

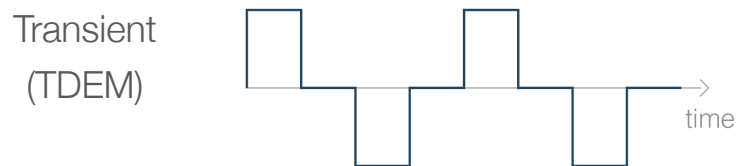
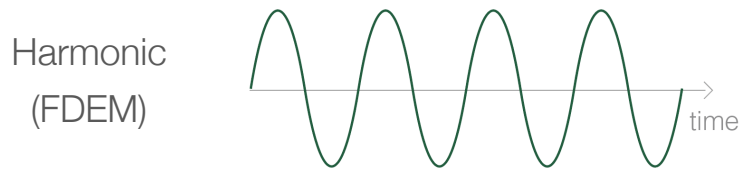
	Time 	Frequency 
Faraday's Law	$\nabla \times \mathbf{e} = - \frac{\partial \mathbf{b}}{\partial t}$	$\nabla \times \mathbf{E} = - i\omega \mathbf{B}$
Ampere's Law	$\nabla \times \mathbf{h} = \mathbf{j} + \frac{\partial \mathbf{d}}{\partial t}$	$\nabla \times \mathbf{H} = \mathbf{J} + i\omega \mathbf{D}$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

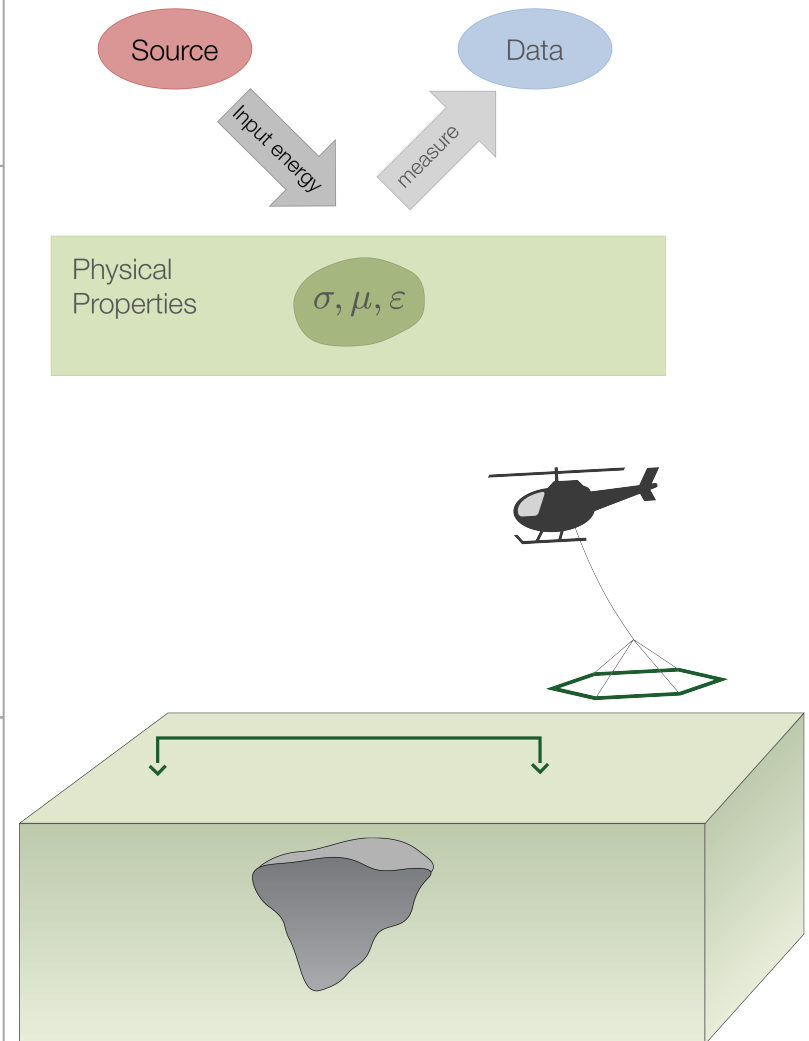
# Electromagnetic Survey: Sources

- Type
  - Inductive
  - Grounded

- Waveform

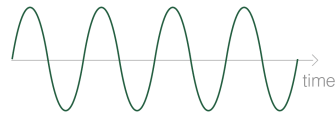


- Location
  - Airborne
  - Ground
  - Borehole

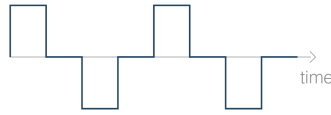


# Electromagnetic Survey: Data

- Which field?

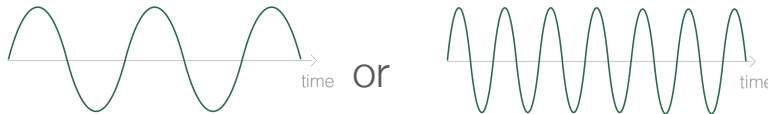


**E, B**

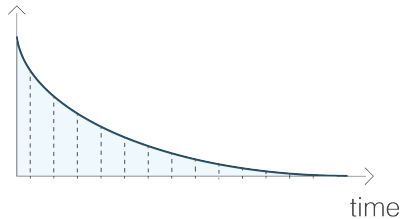


**e, b,  $\frac{db}{dt}$**

- Which frequencies?



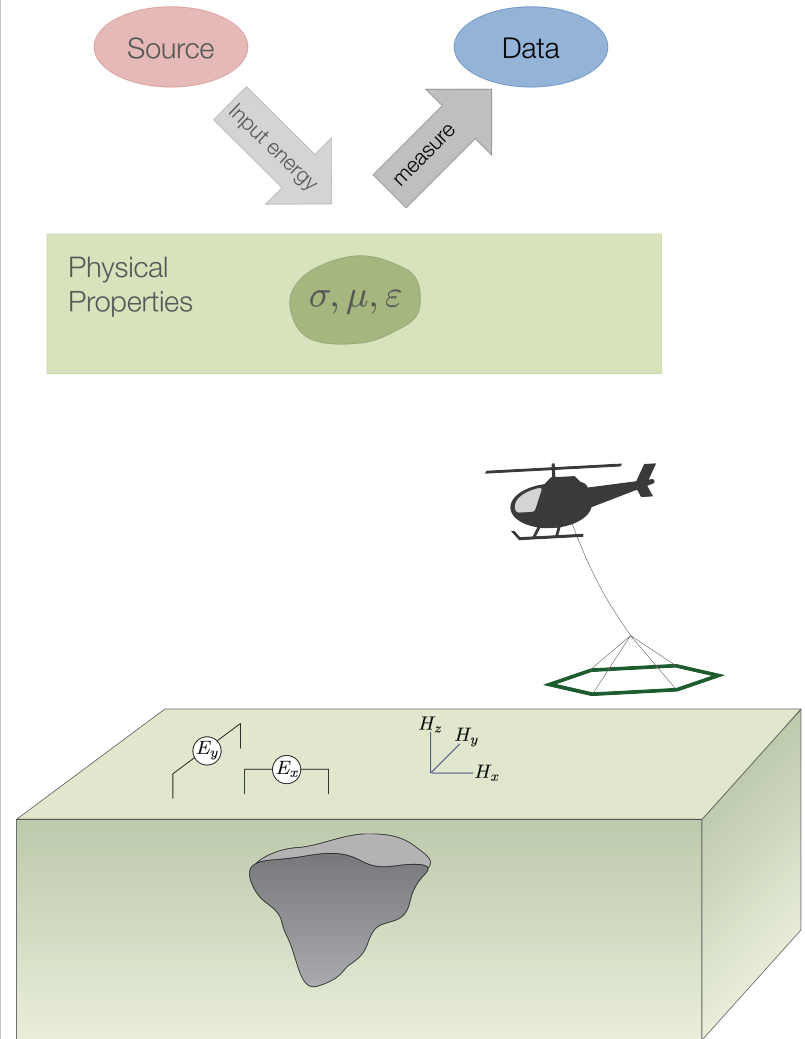
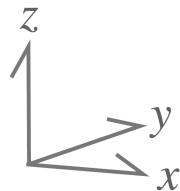
- times?



- Components?

- Location?

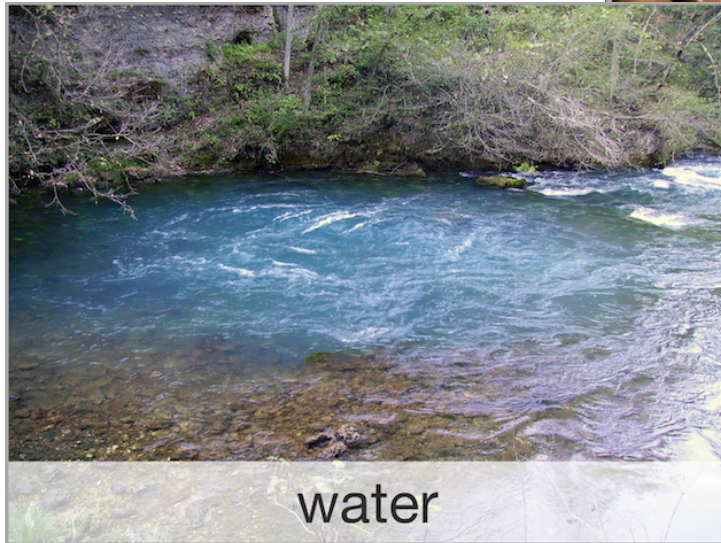
- Airborne
- Ground
- Borehole



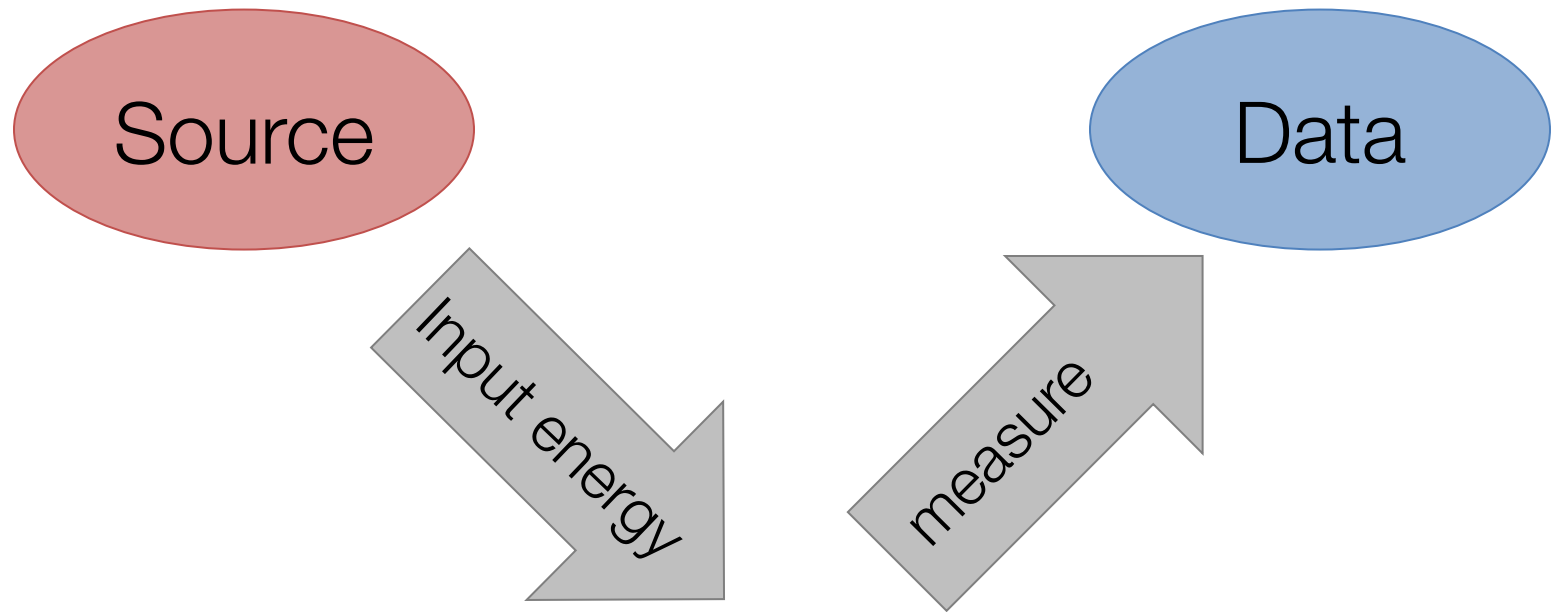


# Three problems

Electrical conductivity is diagnostic for all three



# EM Survey & Physical Properties

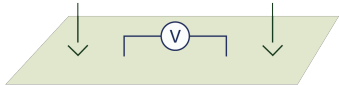


Physical  
Properties

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

# End of Introduction

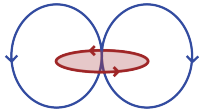
Next up



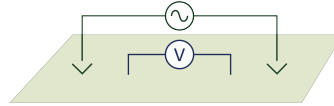
DC Resistivity



EM  
Fundamentals



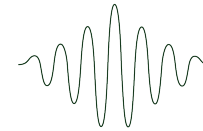
Inductive  
Sources



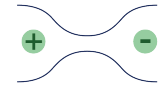
Grounded  
Sources



Natural  
Sources



GPR



Induced  
Polarization



The  
Future

Lunch: Play with apps