



DISC

2017

Electromagnetics
Fundamentals and Applications

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



SOCIETY OF EXPLORATION
— GEOPHYSICISTS —

Thanks to...

Esben Auken

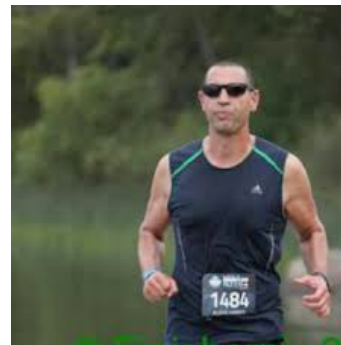
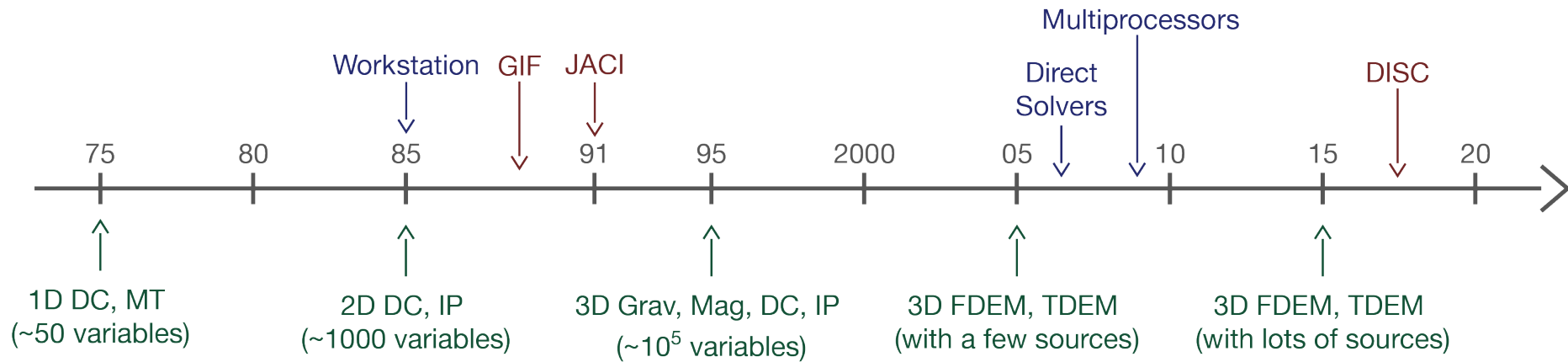


Anders Vest Christiansen



Some Background

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

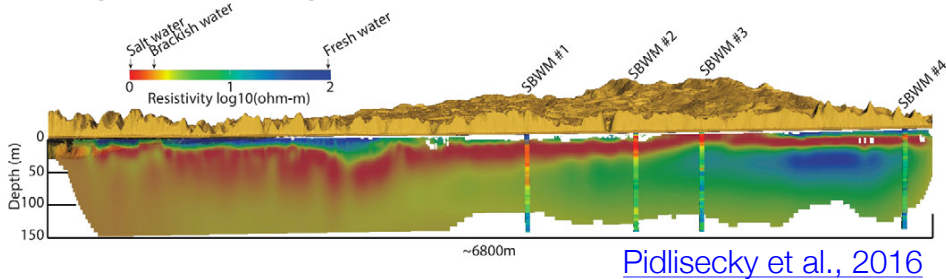


Result: Computing power + advances in inversion methodology
→ we can now solve most EM geophysics problems

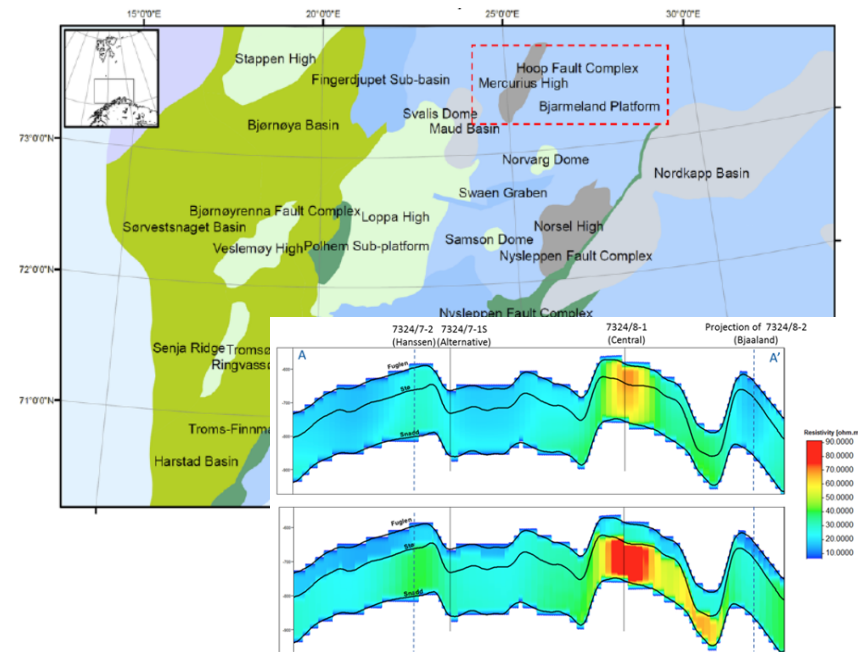
Instrumentation and Data

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

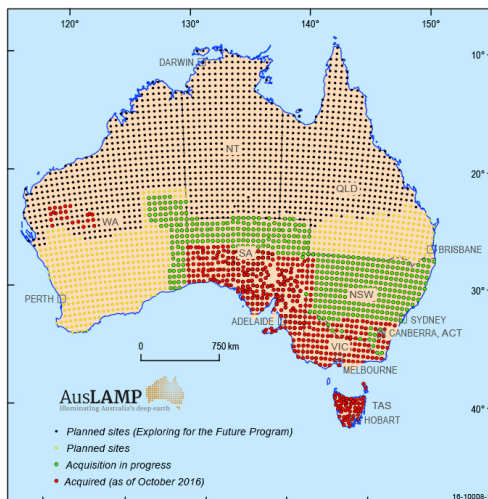
Large-scale ground water studies: California



Offshore: Hydrocarbon De-risking



AusLamp: Continental Scale MT



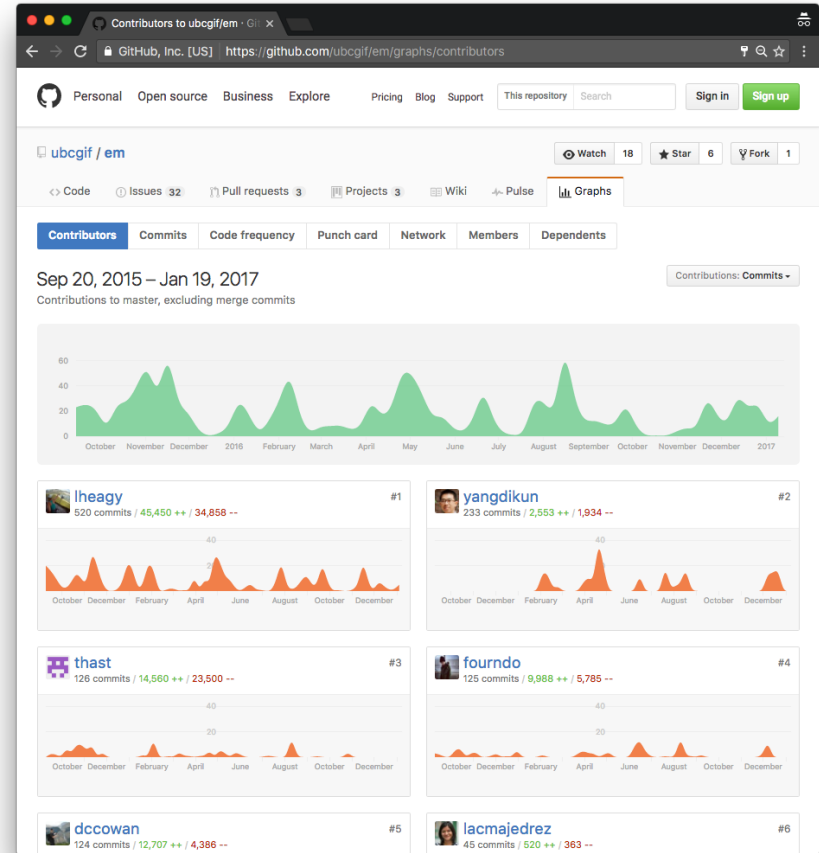
Web and Open Source Resources

- 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

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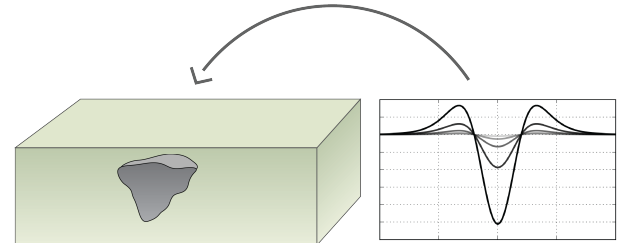
Are there situations, similar to mine, in which EM has been applied?

DISC can take advantage of a Perfect Storm

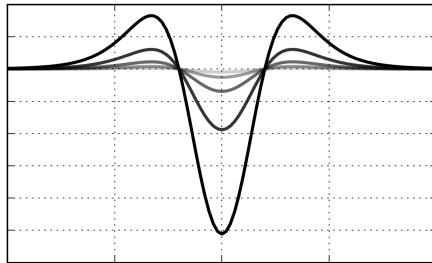
Problems



Inversion capabilities



High quality data



Web tools to communicate

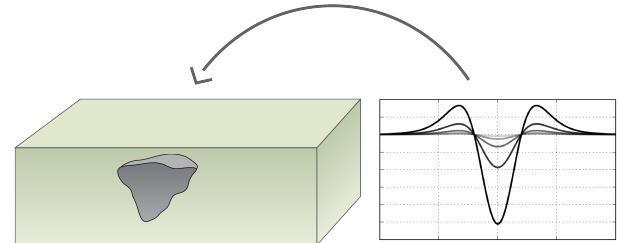


DISC can take advantage of a Perfect Storm

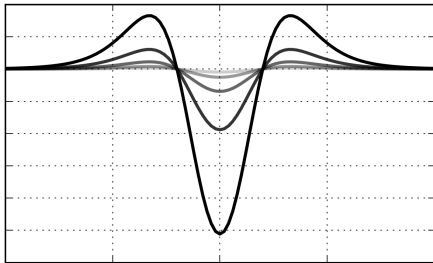
Problems



Inversion capabilities



High quality data



Web tools to
communicate



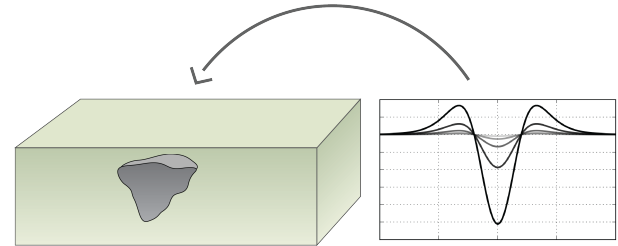
A good idea but missing an important ingredient ...

Talented Young Geoscientists

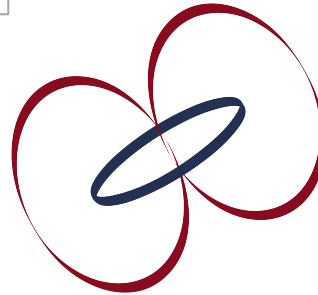
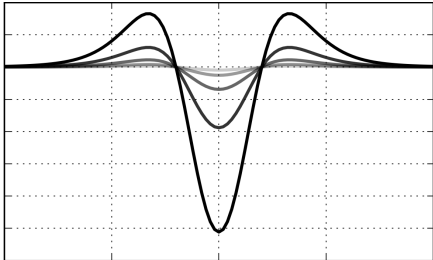
Problems



Inversion capabilities



High quality data



Web tools to
communicate



Seogi

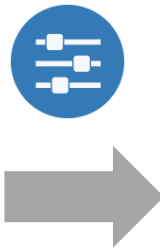
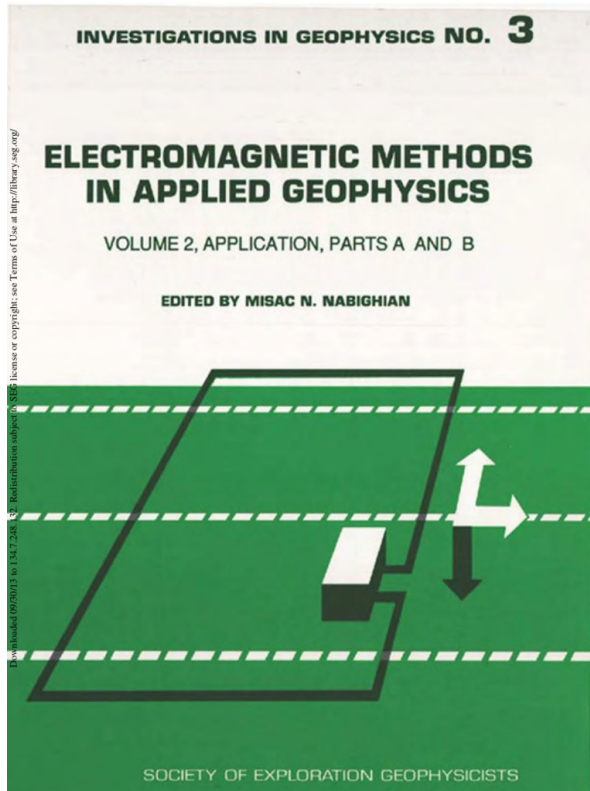


Lindsey

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

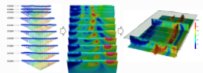
Case Histories

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

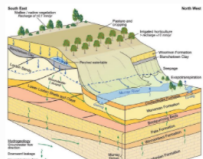
Mt. Isa

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



Bookpurnong

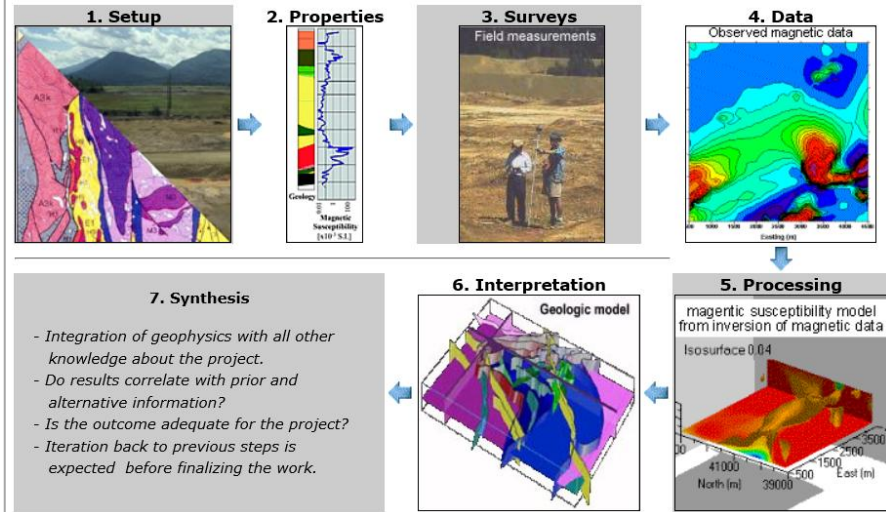
- [Bookpurnong](#)
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- **Tags**
 - geophysical survey: Airborne FDEM, Airborne TDEM
 - application: Groundwater
 - location: Australia



<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

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Maxwell II: Static

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

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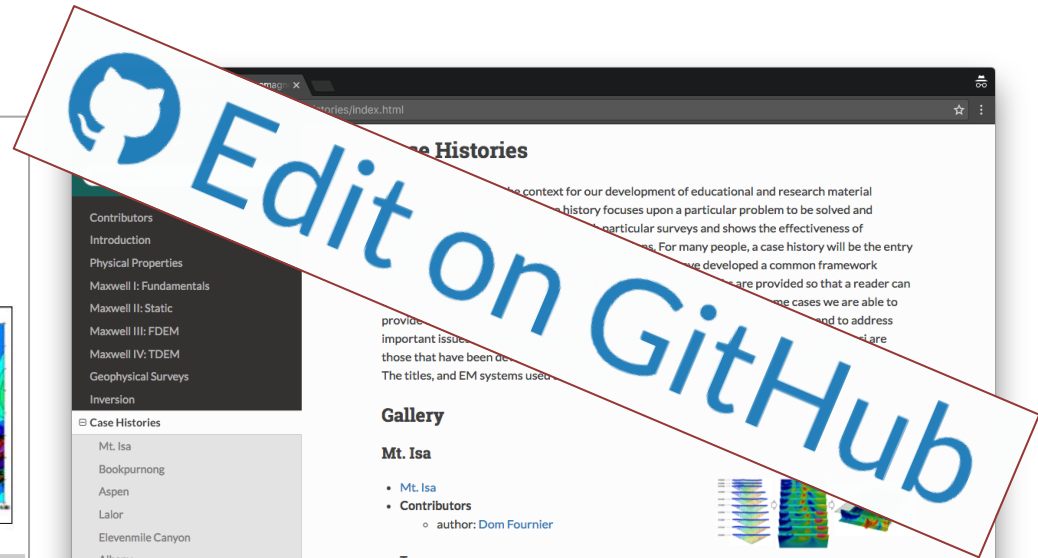
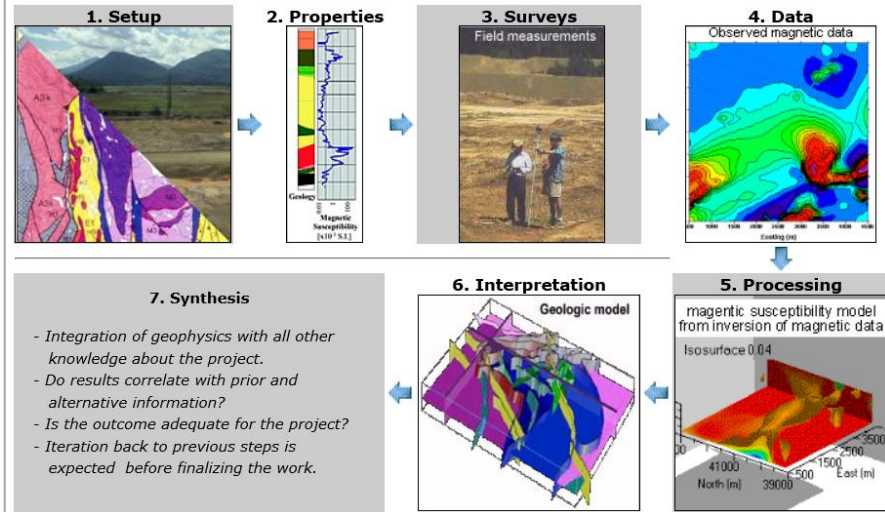
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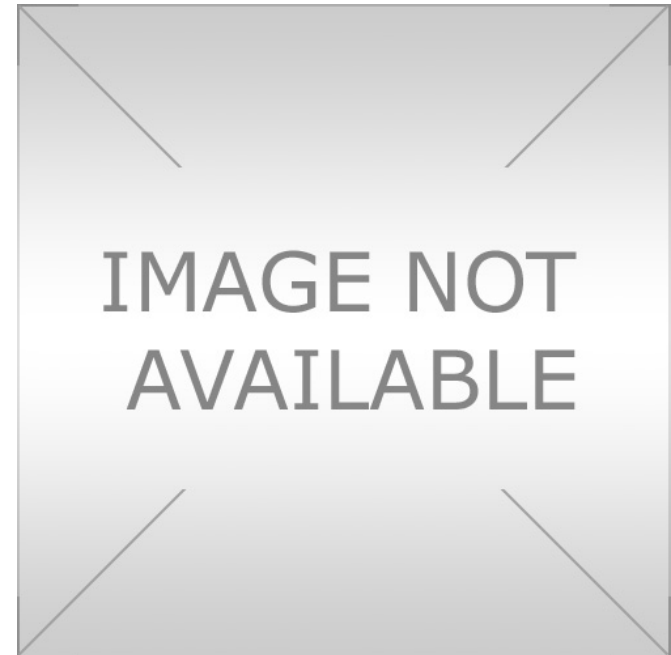
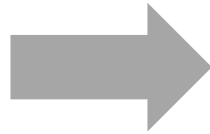
7 step framework for Case Histories



Why Apps

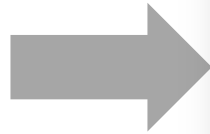
$$\nabla \times \mathbf{e} = -\frac{\partial \mathbf{b}}{\partial t}$$

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



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 in the notebook defines a widget and its interactive components. The control panel includes:

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

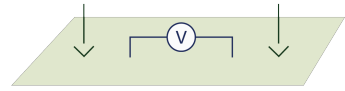
Two plots are displayed:

- 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. 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) on the y-axis (ranging from -40 to 40) versus the |H|-field (A/m) on the x-axis. The plot shows a parabolic-like 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

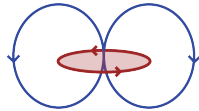
Agenda for today



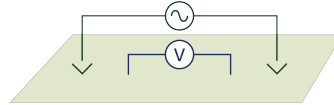
DC Resistivity



EM
Fundamentals



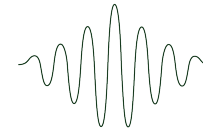
Inductive
Sources



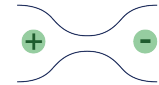
Grounded
Sources



Natural
Sources



GPR



Induced
Polarization

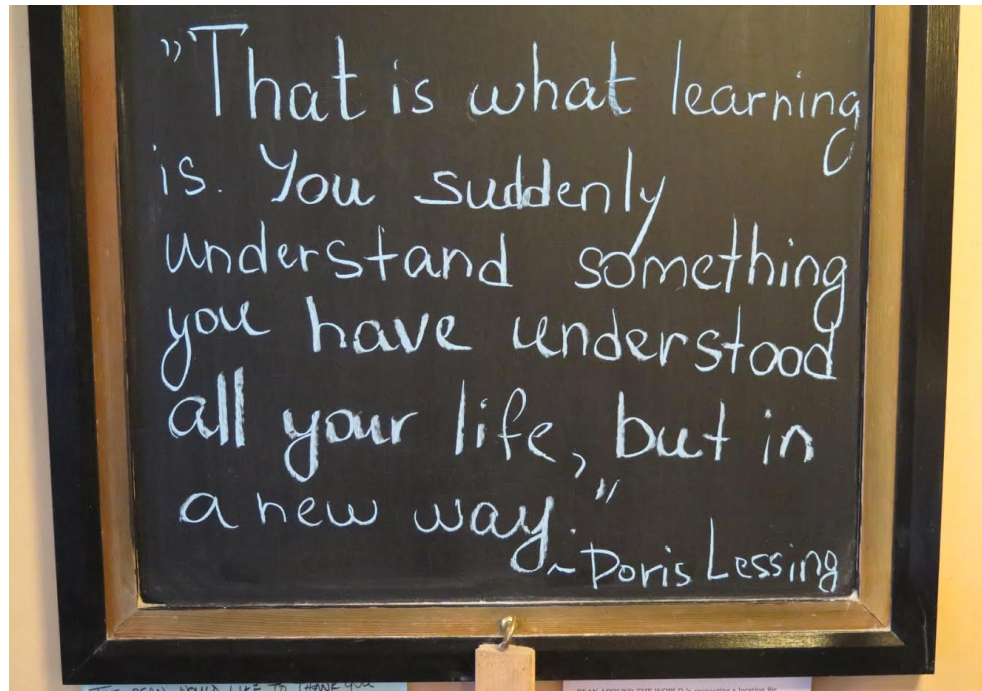


The
Future

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
- 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 navigation 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'. The main content area is titled 'Case Histories' and contains introductory text about the purpose of case histories. Below this is a 'Gallery' section with two entries: 'Mt. Isa' and 'Bookpurnong'. Each entry includes a list of 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'. Small images of geophysical data and diagrams are shown next to each entry.

Introduction to EM



Three problems

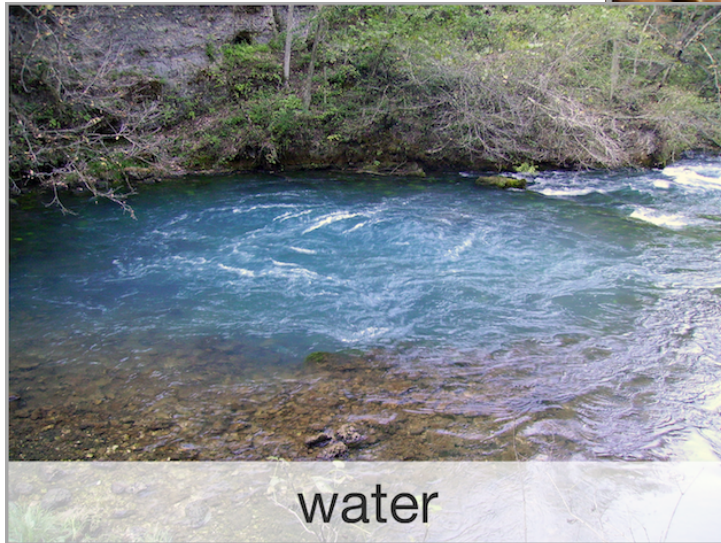
How do we locate and characterize ...



minerals

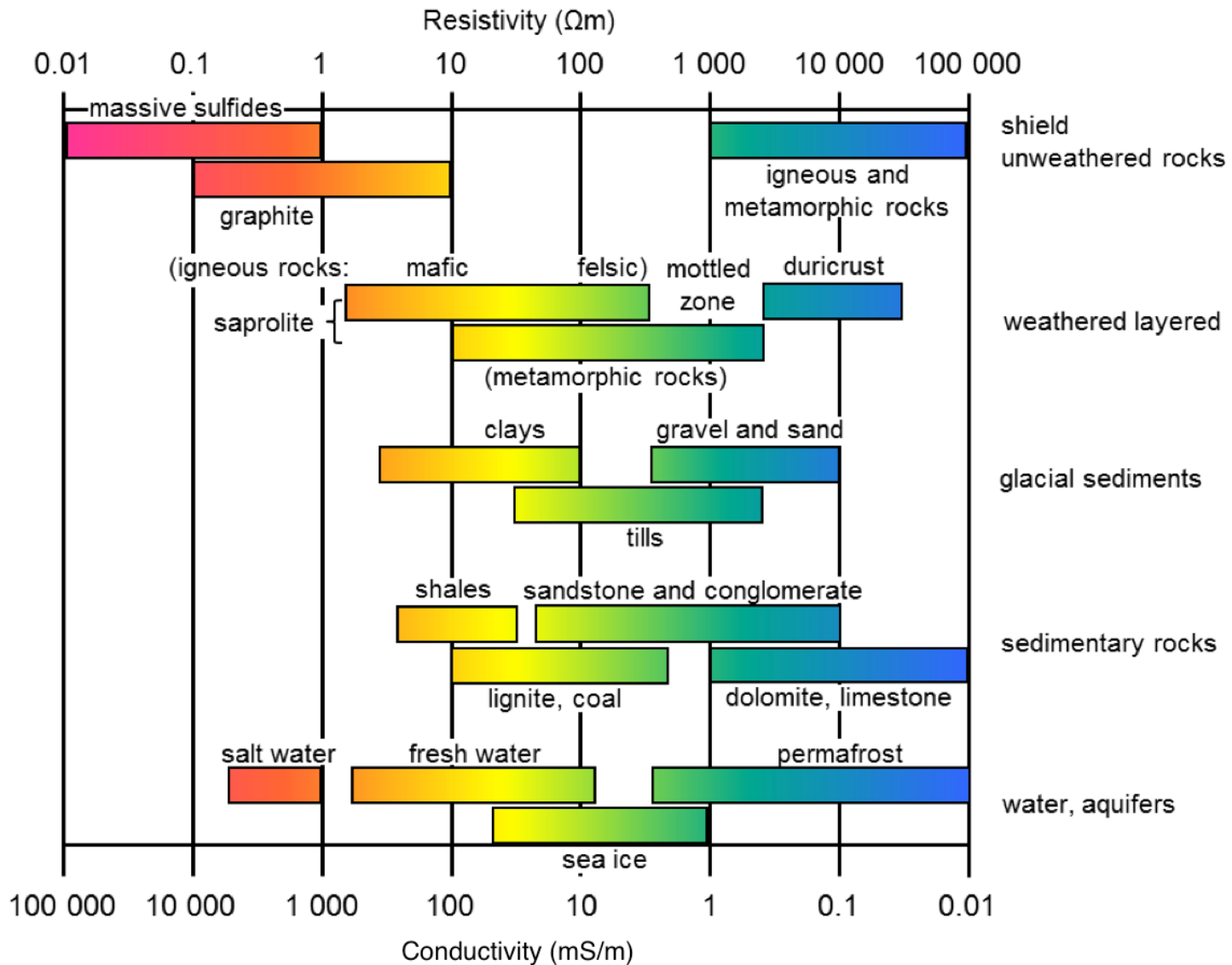


unexploded ordnance



water

Electrical Resistivity / Conductivity

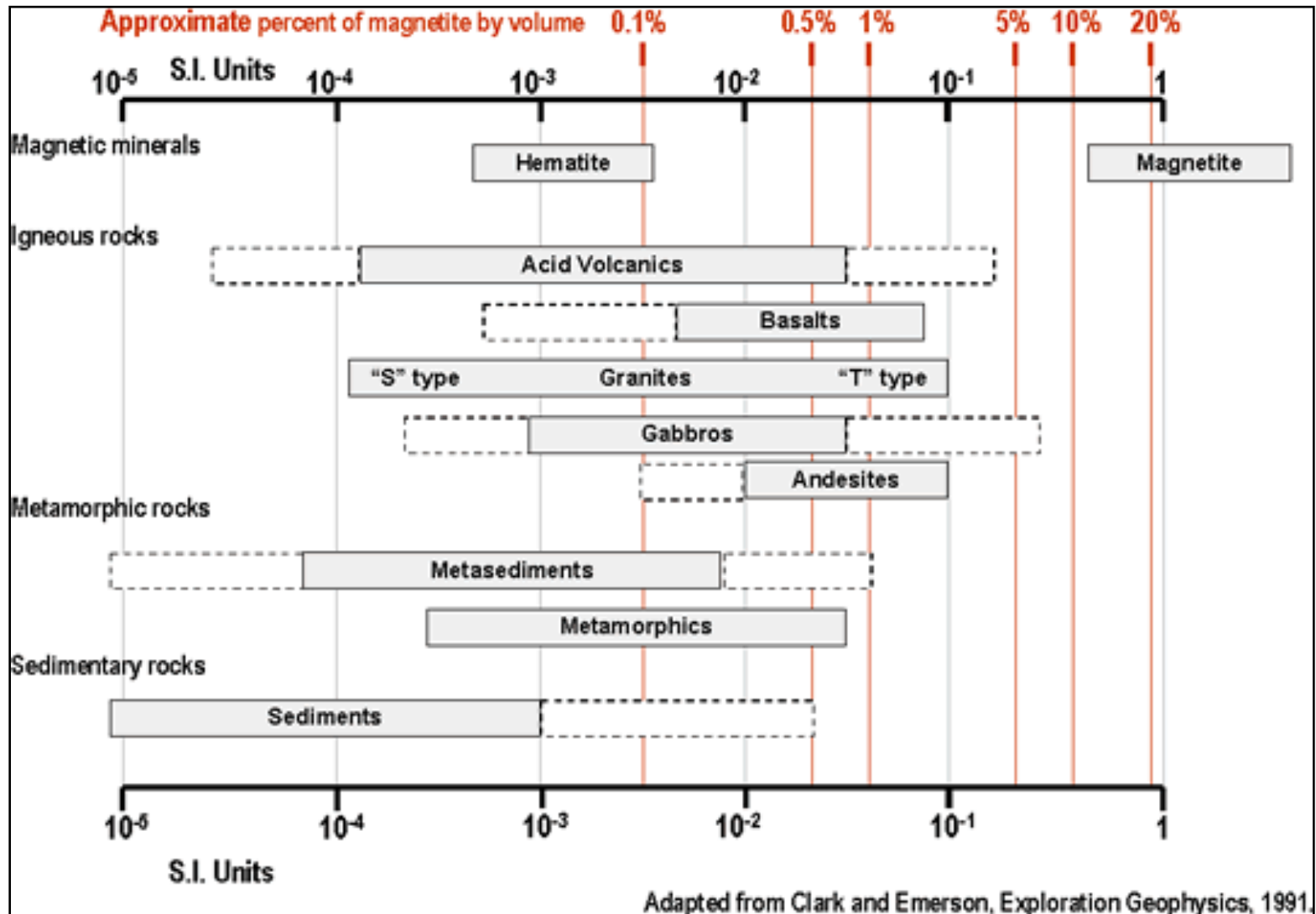


Dielectric constant

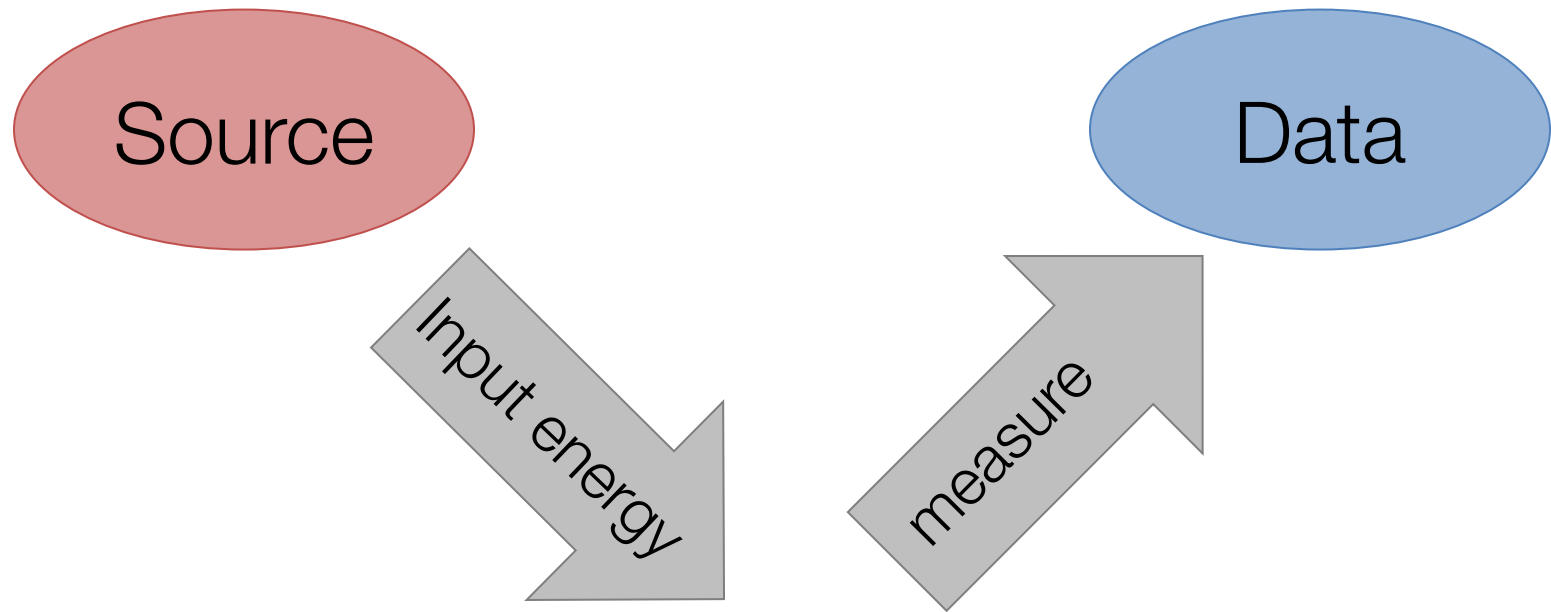
Material	Relative Permittivity	Conductivity (mS/m)
Air	1	0
Fresh Water	80	0.5
Sea Water	80	3000
Ice	3-4	0.01
Dry Sand	3-5	0.01
Saturated Sand	20-30	0.1-1
Limestone	4-8	0.5-2
Shales	5-15	1-100
Silts	5-30	1-100
Clays	5-40	2-1000
Granite	4-6	0.01-1
Anhydrites	3-4	0.01-1



Magnetic Susceptibility



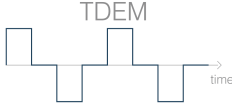
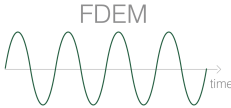
EM Survey & Physical Properties



Physical
Properties

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

Basic Equations

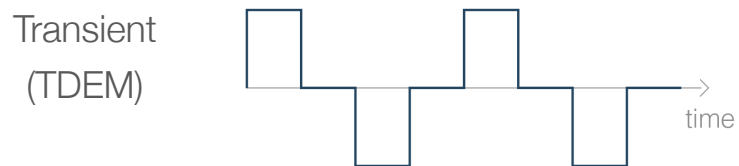
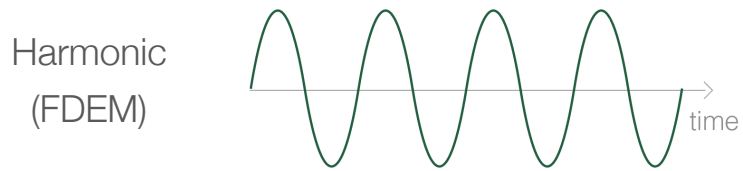
	Time 	Frequency 
Faraday's Law	$\nabla \times \mathbf{e} = - \frac{\partial \mathbf{b}}{\partial t}$	$\nabla \times \mathbf{E} = - i\omega \mathbf{B}$
Ampere's Law	$\nabla \times \mathbf{h} = \mathbf{j} + \frac{\partial \mathbf{d}}{\partial t}$	$\nabla \times \mathbf{H} = \mathbf{J} + i\omega \mathbf{D}$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

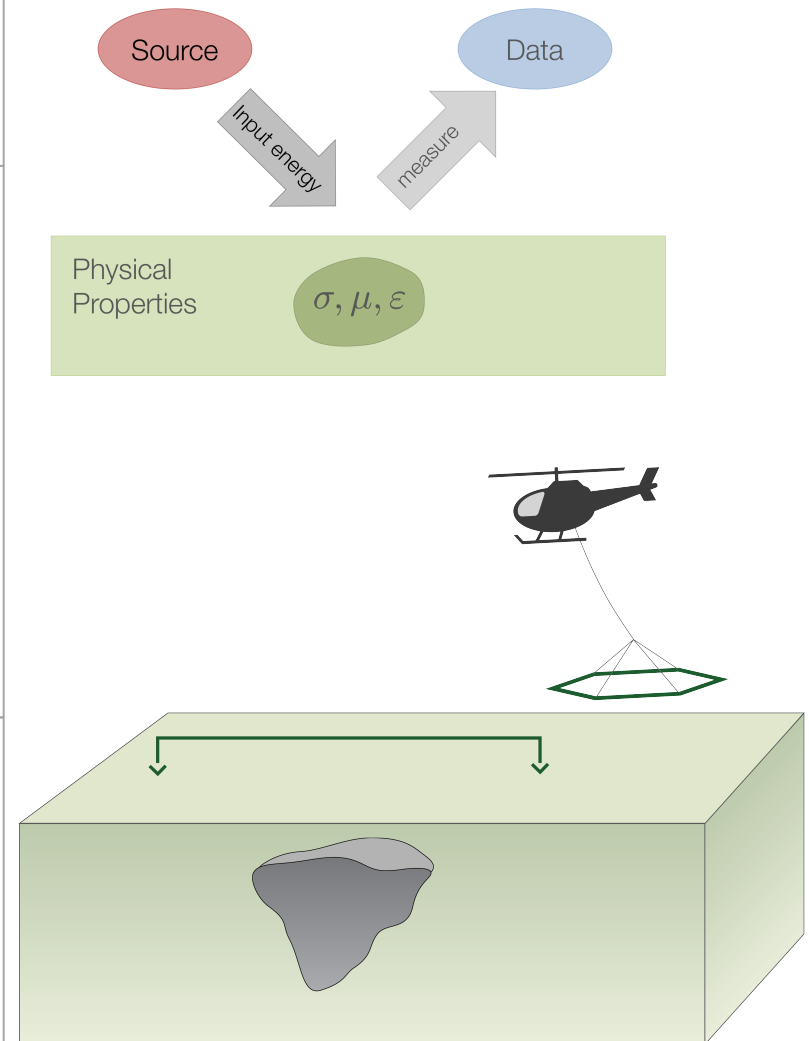
Electromagnetic Survey: Sources

- Type
 - Inductive
 - Grounded

- Waveform

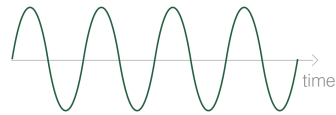


- Location
 - Airborne
 - Ground
 - Borehole

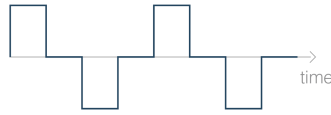


Electromagnetic Survey: Data

- Which field?

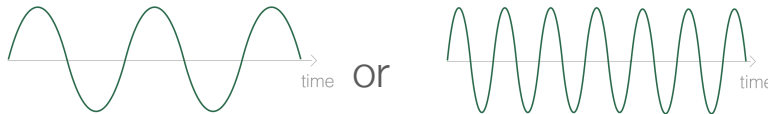


E, B

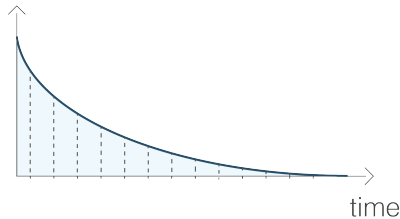


e, b, $\frac{db}{dt}$

- Which frequencies?



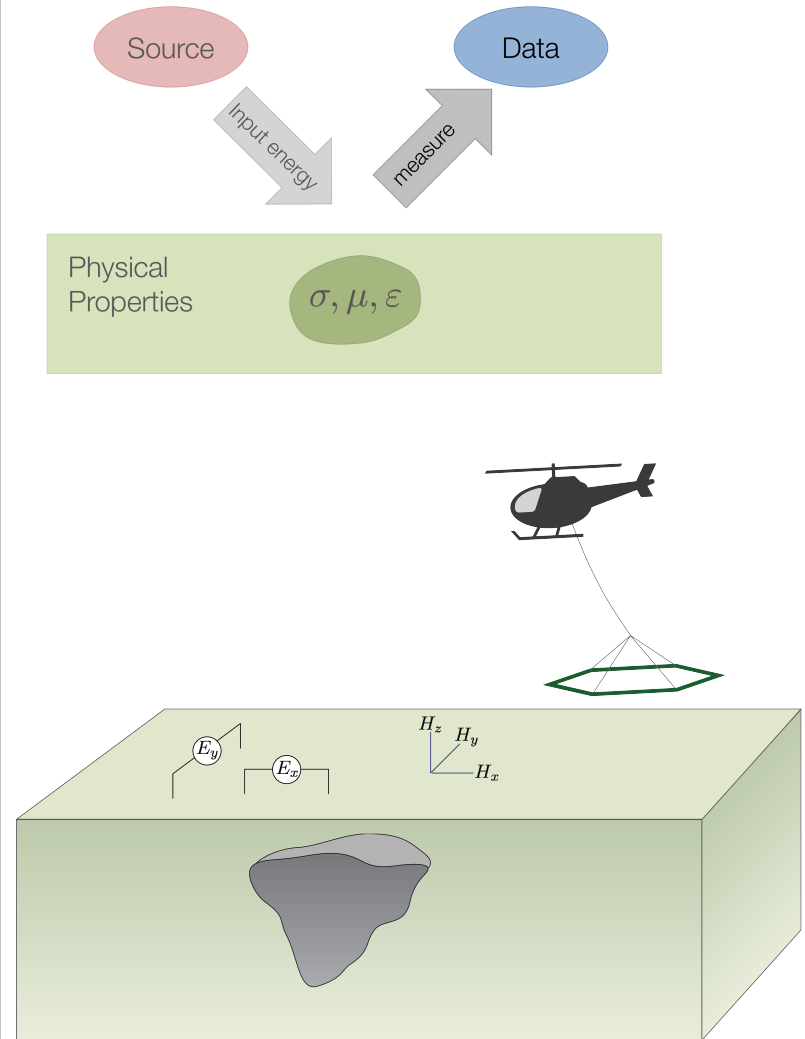
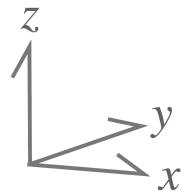
- times?



- Components?

- Location?

- Airborne
- Ground
- Borehole



Three problems

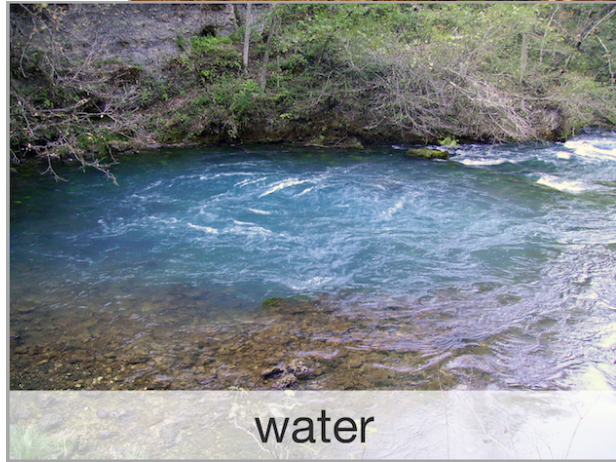
Electrical conductivity is diagnostic for all three



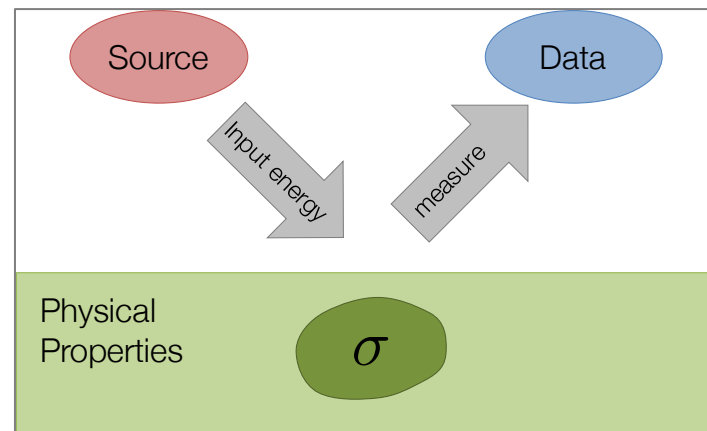
minerals



unexploded ordnance

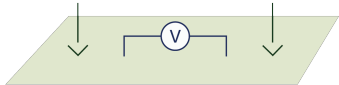


water



End of Introduction

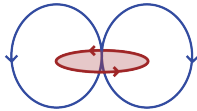
Next up



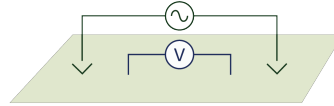
DC Resistivity



EM
Fundamentals



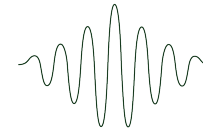
Inductive
Sources



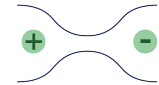
Grounded
Sources



Natural
Sources



GPR



Induced
Polarization



The
Future

Lunch: Play with apps