

3D EM Modelling and Inversion with Open Source Resources



Doug



Seogi



Lindsey

Thanks to...

Don Van Nieuwenhuise



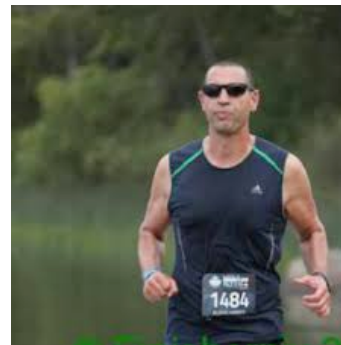
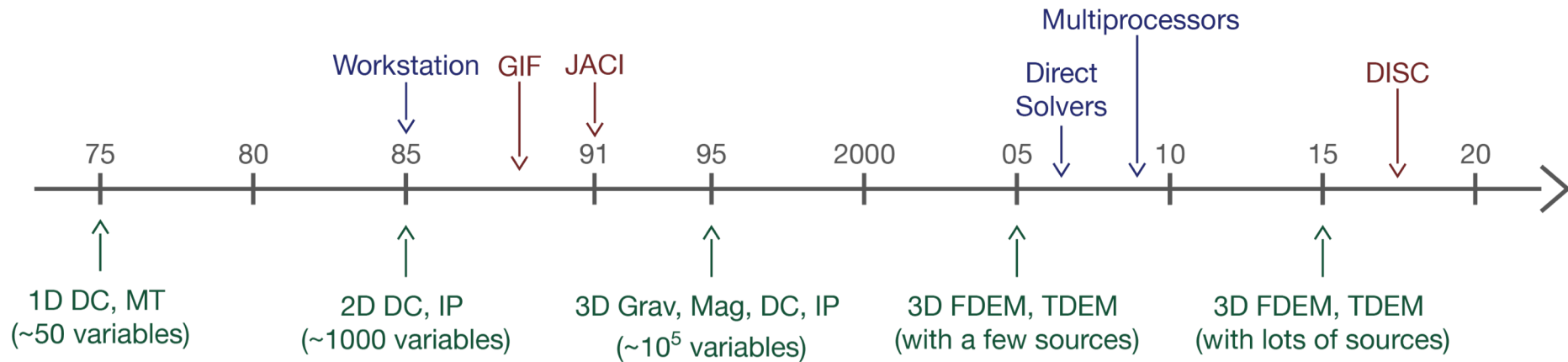
UNIVERSITY of
HOUSTON



Introduction

Some Background

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

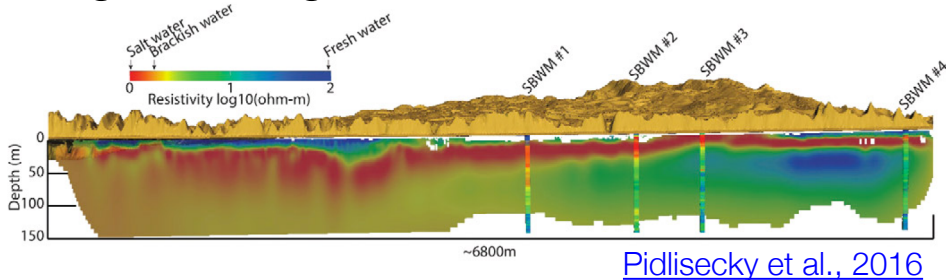


Result: Computing power + advances in inversion methodology
→ we can now solve most EM geophysics problems

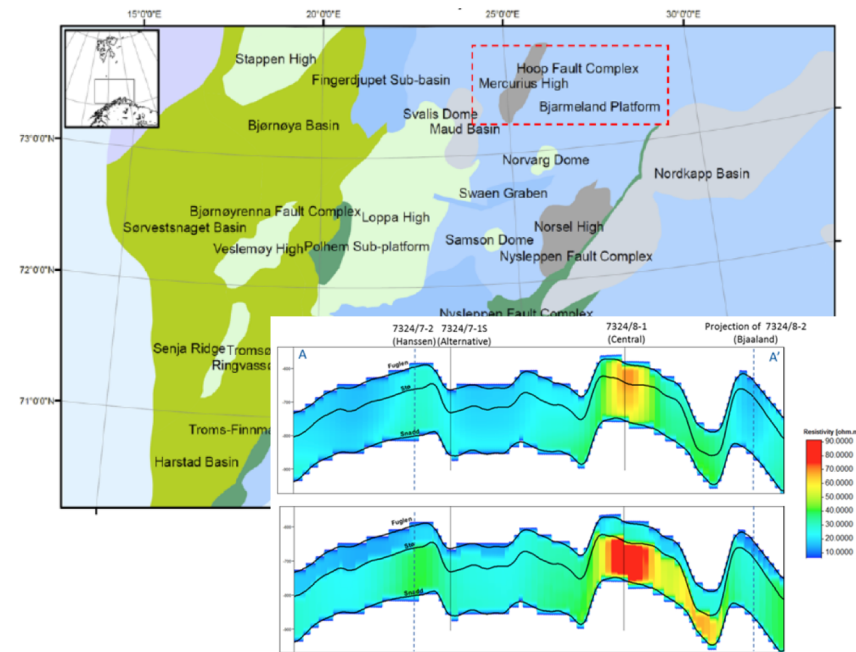
Instrumentation and Data

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

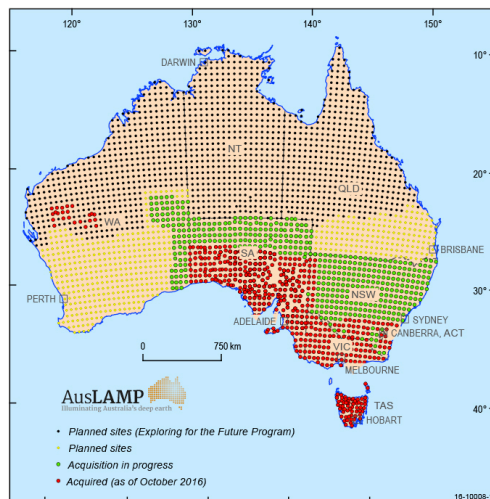
Large-scale ground water studies: California



Offshore: Hydrocarbon De-risking



AusLamp: Continental Scale MT



[Alvarez et al, EM.GeoSci](#)

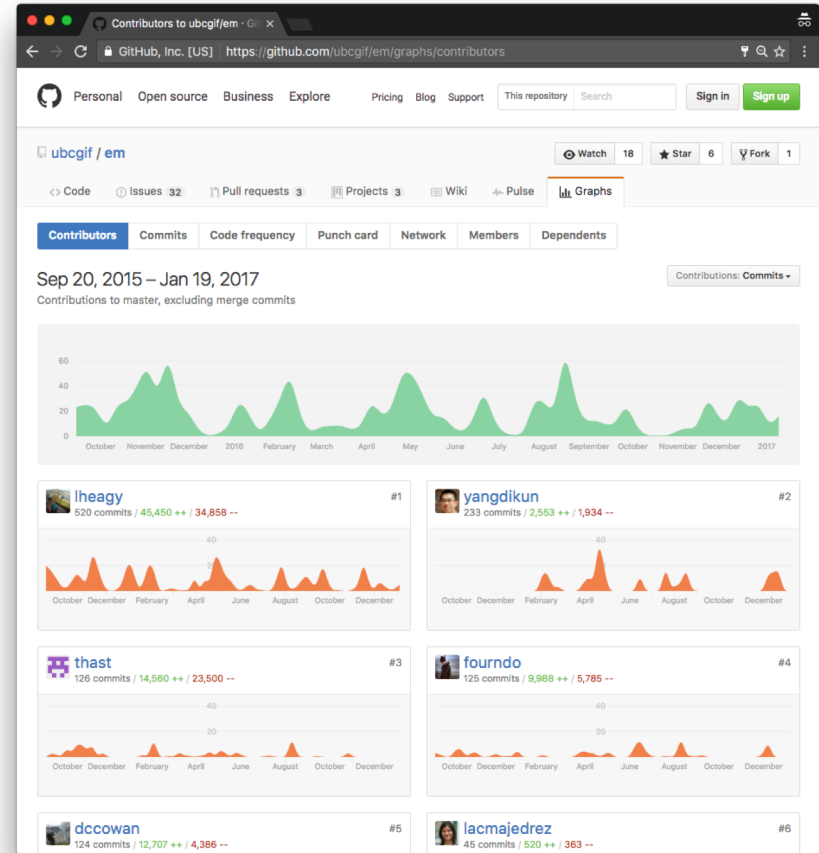
Web and Open Source Resources

- 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

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?

Course Goals: Remove Roadblocks

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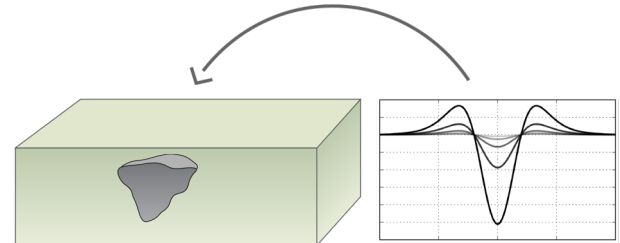
Are there situations, similar to mine, in which EM has been applied?

Take advantage of a Perfect Storm

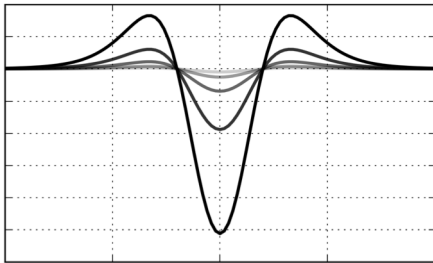
Problems



Inversion capabilities



High quality data



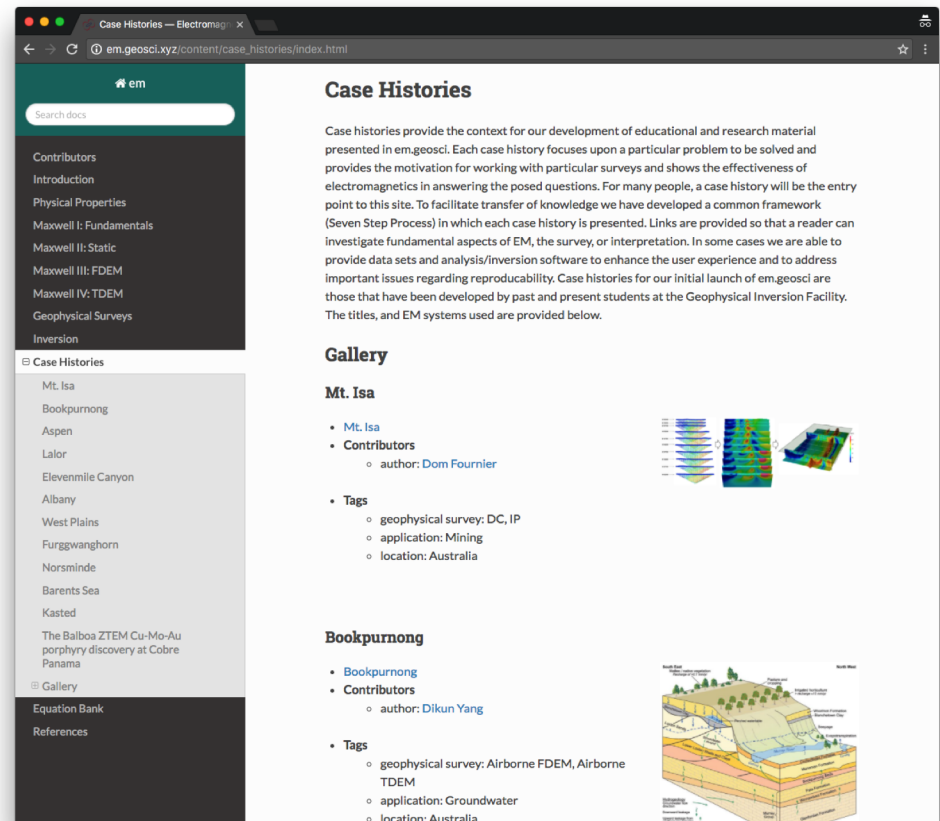
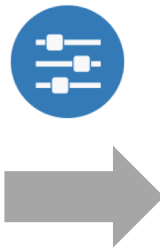
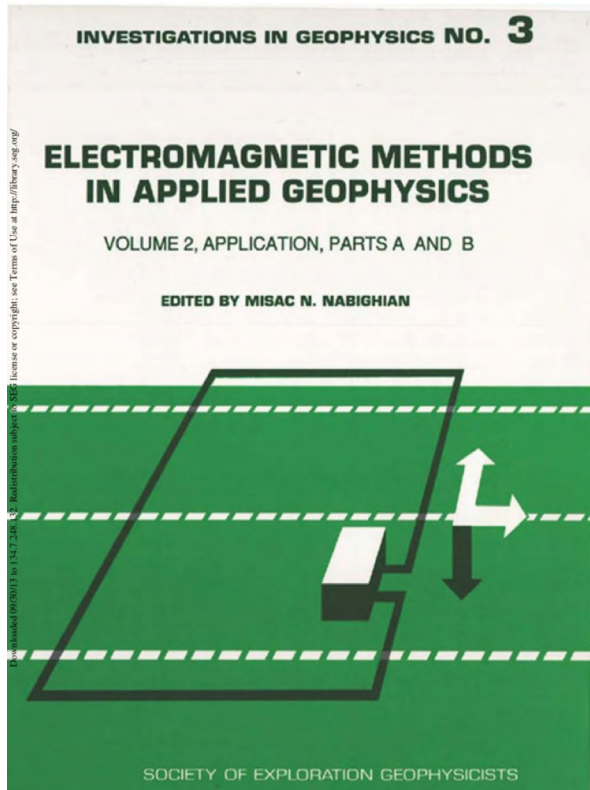
Web tools to
communicate



Goals for the Course

- 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

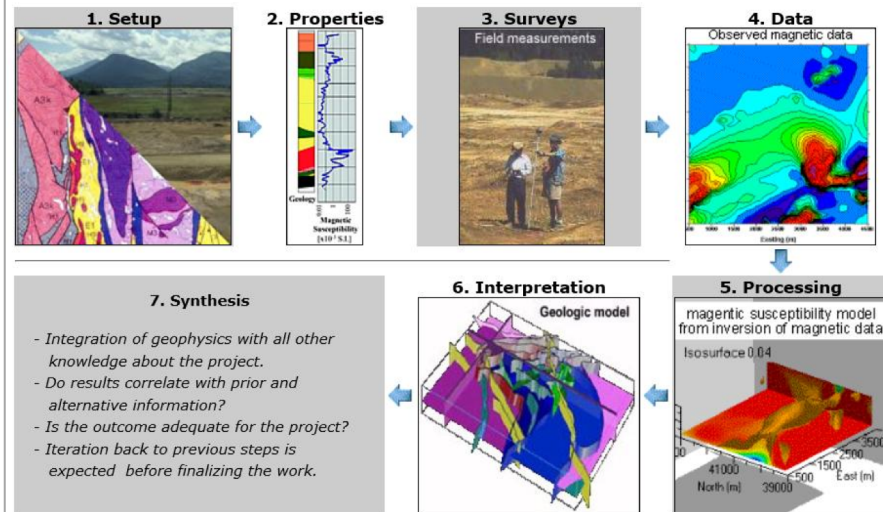
Resources: em.geosci.xyz



<http://em.geosci.xyz>

Resources: em.geosci.xyz

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

Furggswanghorn

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

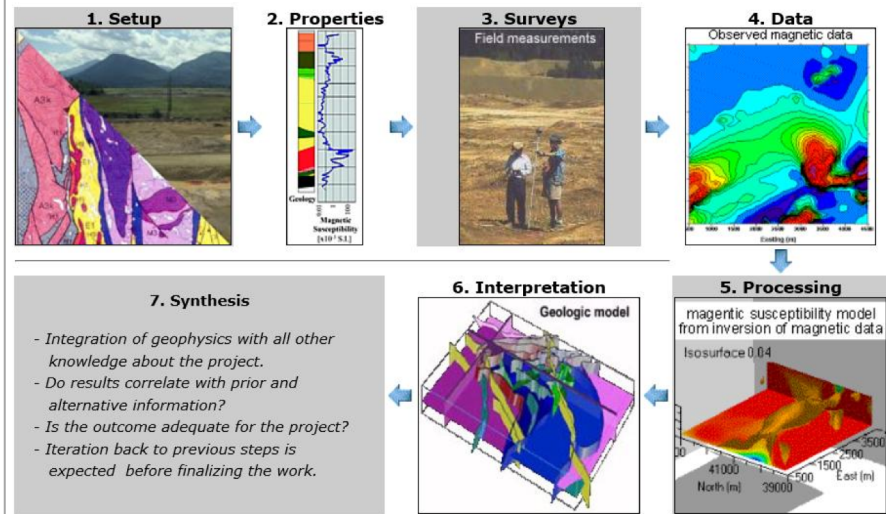
- [Mt. Isa](#)
- [Contributors](#)
 - author: Dom Fournier
- [Tags](#)
 - geophysical survey: DC, IP
 - application: Mining
 - location: Australia

Bookpurnong

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

Resources: em.geosci.xyz

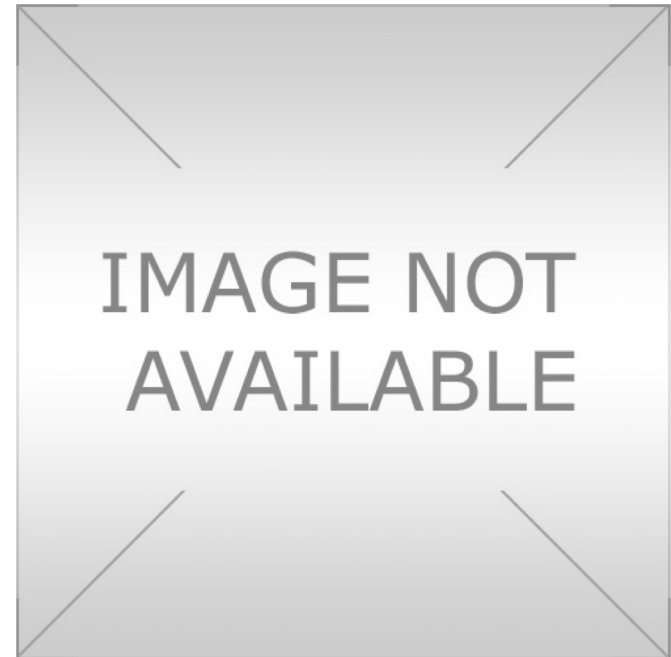
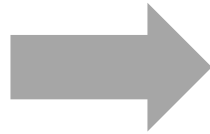
7 step framework for Case Histories



Why Apps

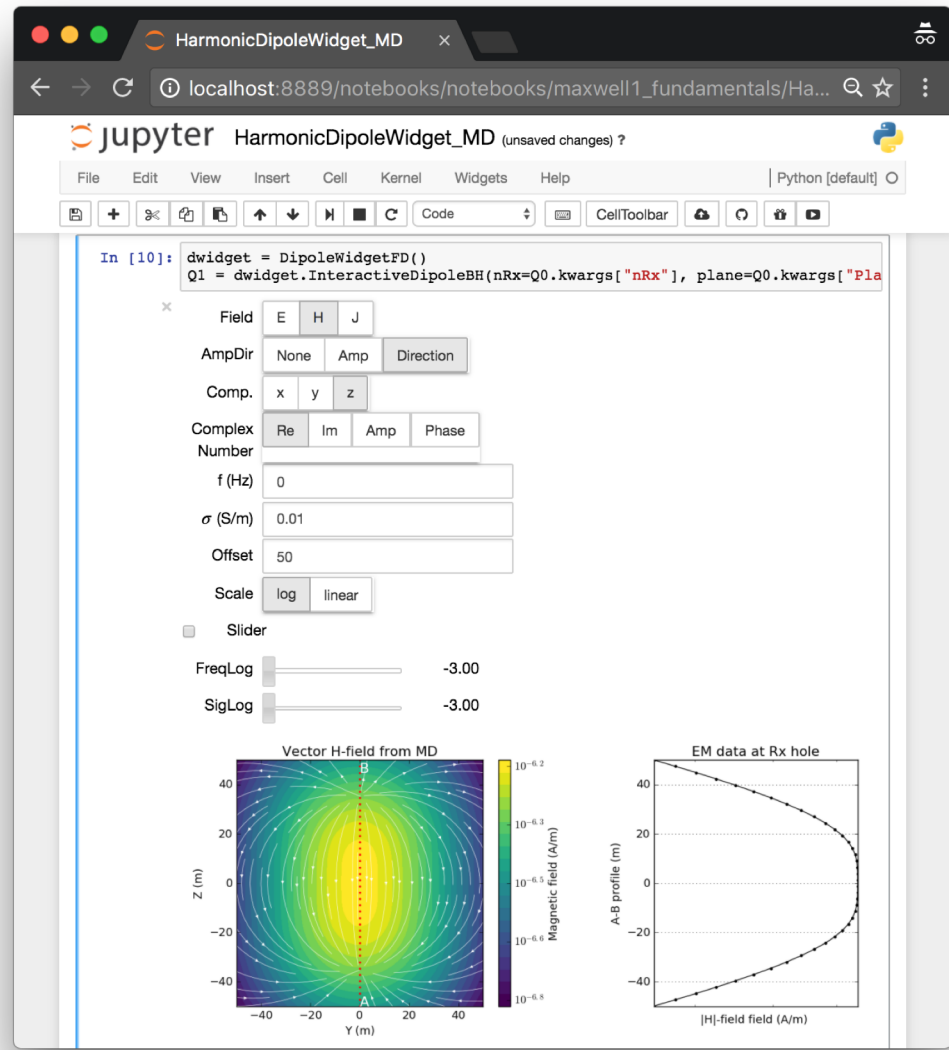
$$\nabla \times \mathbf{e} = -\frac{\partial \mathbf{b}}{\partial t}$$

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



Why Apps

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



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



SOCIETY OF EXPLORATION
— GEOPHYSICISTS —

Background: DISC 2017

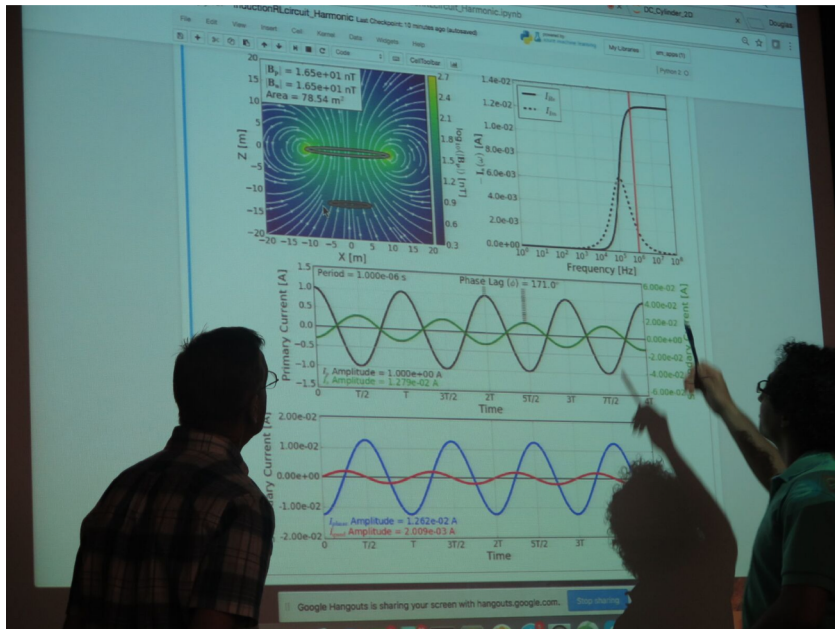


DISC
2017

Electromagnetics
Fundamentals and Applications

Geophysical Electromagnetics: Fundamentals and applications

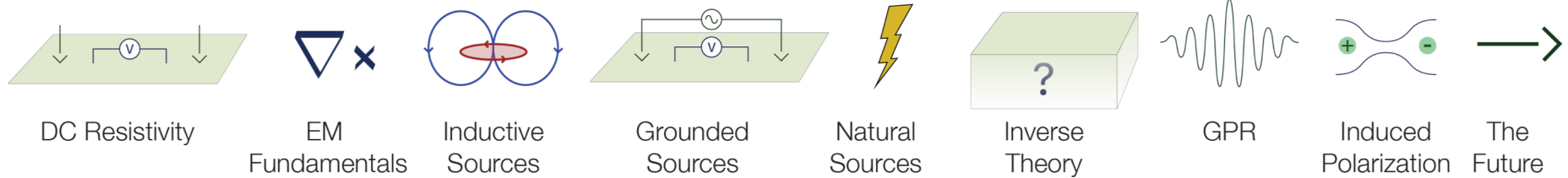
- 25 presentations
- 20 countries



<https://disc2017.geosci.xyz>

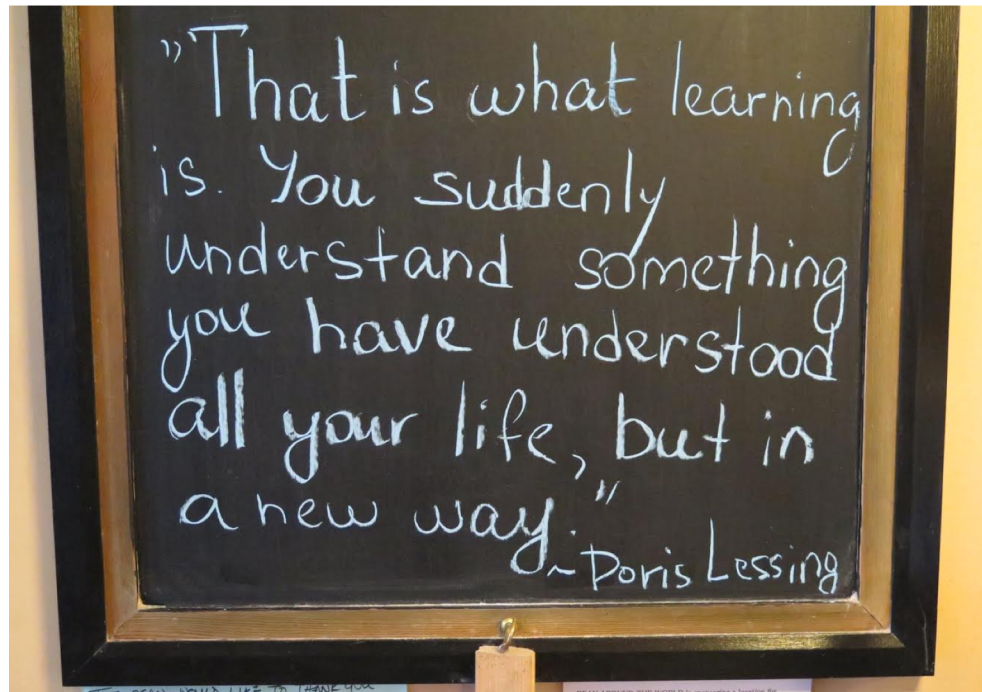
blog: <https://medium.com/disc2017>

Agenda for this week



A touch of realism

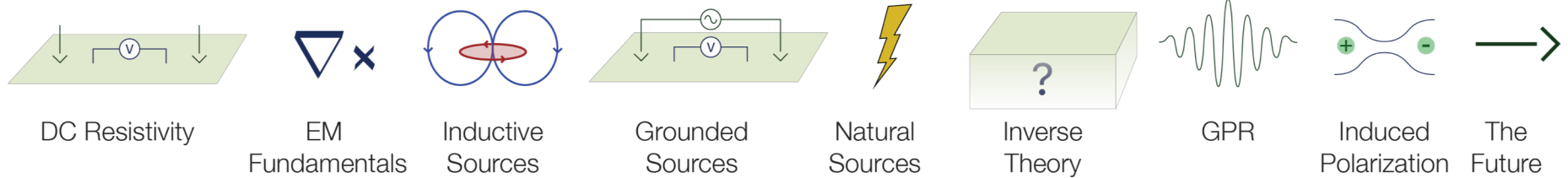
- Ambitious schedule
- Wide variety of backgrounds but hope there is something for everybody
- Not really targeting the experts but even them...



Global Agenda

- Day I:
 - Introduction to EM
 - DCR
- Day II: Inductive Sources
- Day III: Grounded Sources
- Day IV
 - Natural Sources
 - Fundamentals of Inverse Theory
- Day V
 - GPR
 - Dispersive properties
 - Summary

Global Agenda



day 1

day 2

day 3

day 4

day 5

Daily Agenda

- Introduction to EM
- DC Resistivity
 - Theory
 - Case Histories
- Apps
 - Demos
 - Hands-on
- EM Fundamentals

Connecting & Contributing

- Today: Slack
 - <http://slack.geosci.xyz/>



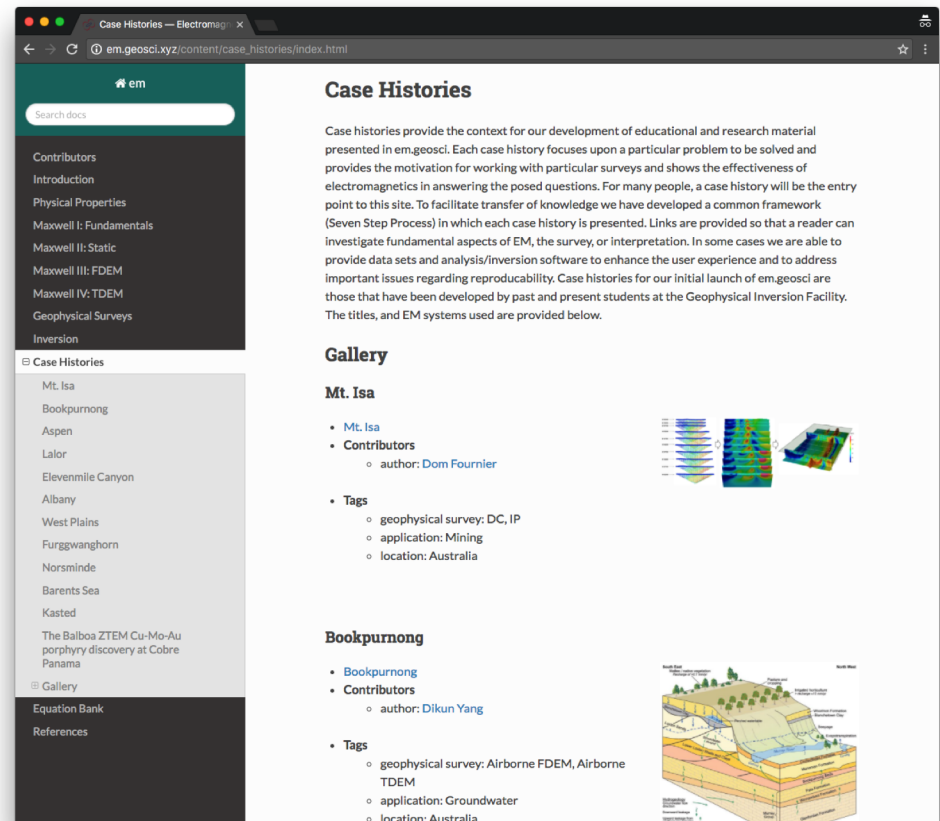
Join **GeoSci** on Slack.

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

you@yourdomain.com

GET MY INVITE

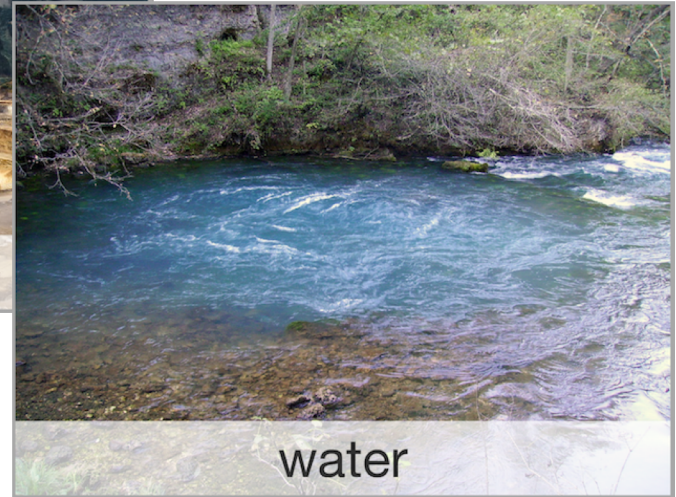
- Contributing:
 - EM GeoSci
 - Case histories
 - Content
 - SimPEG
 - Software



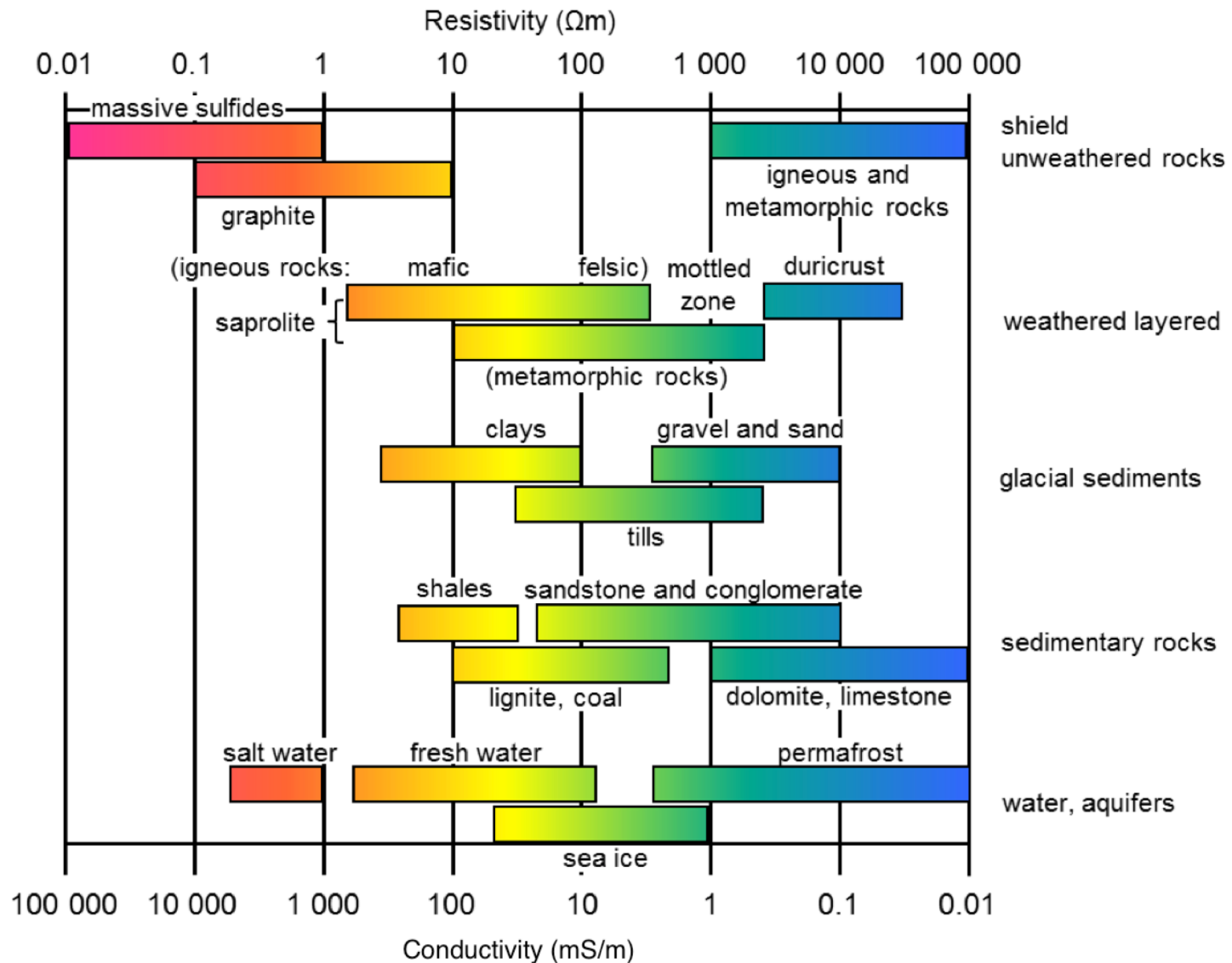
Introduction to EM

Some applications

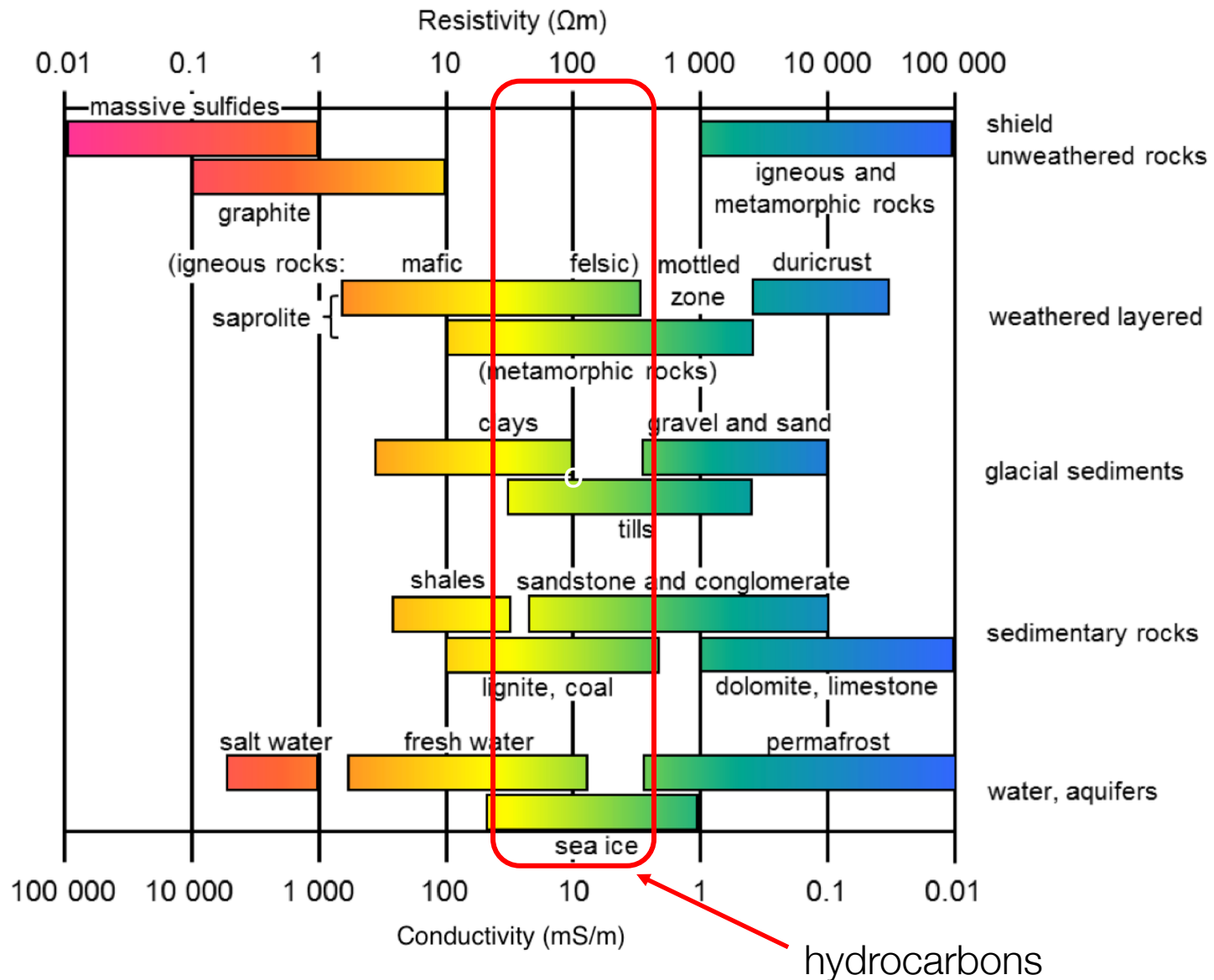
How do we locate and characterize ...



Electrical Resistivity / Conductivity



Electrical Resistivity / Conductivity

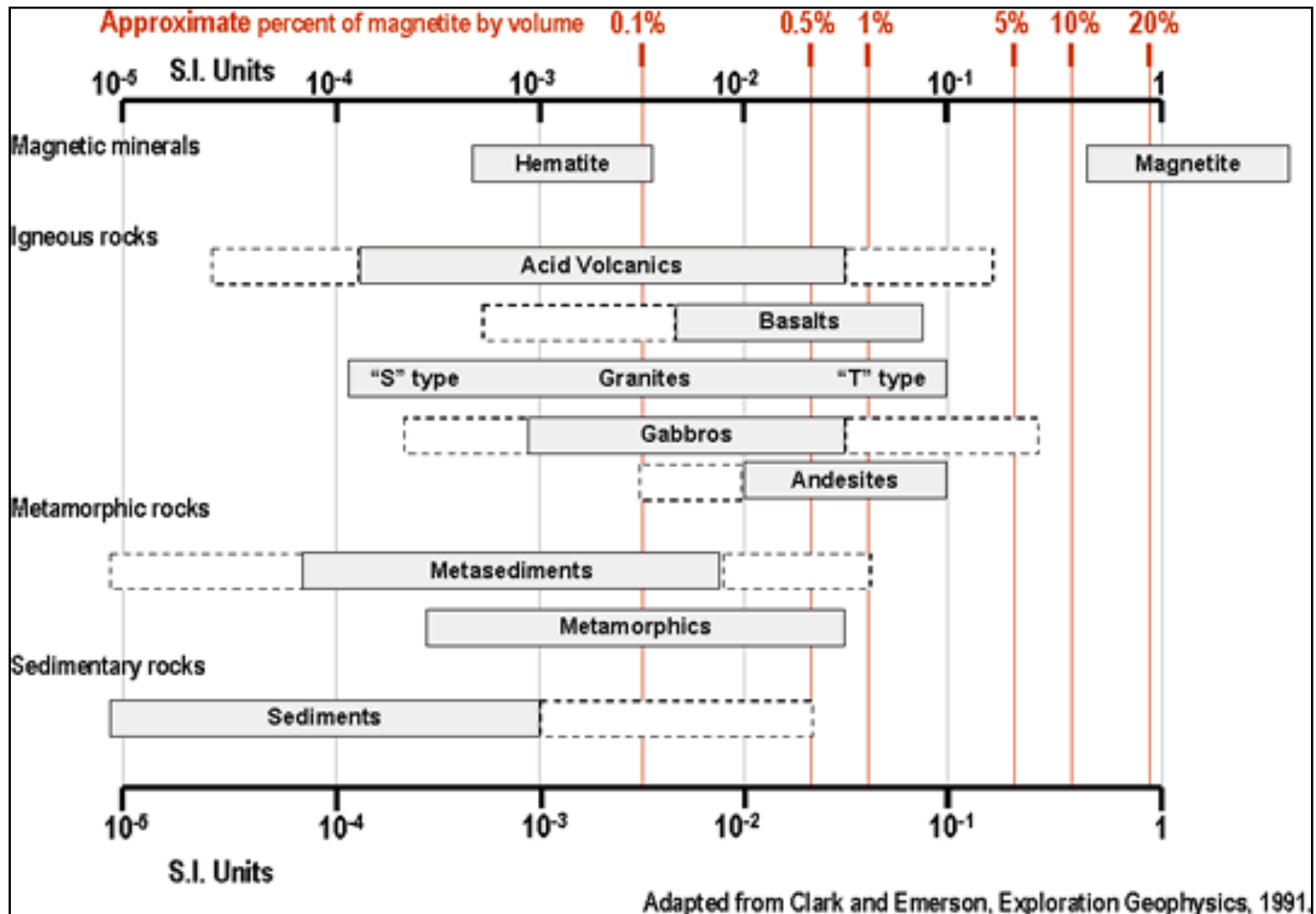


Dielectric constant

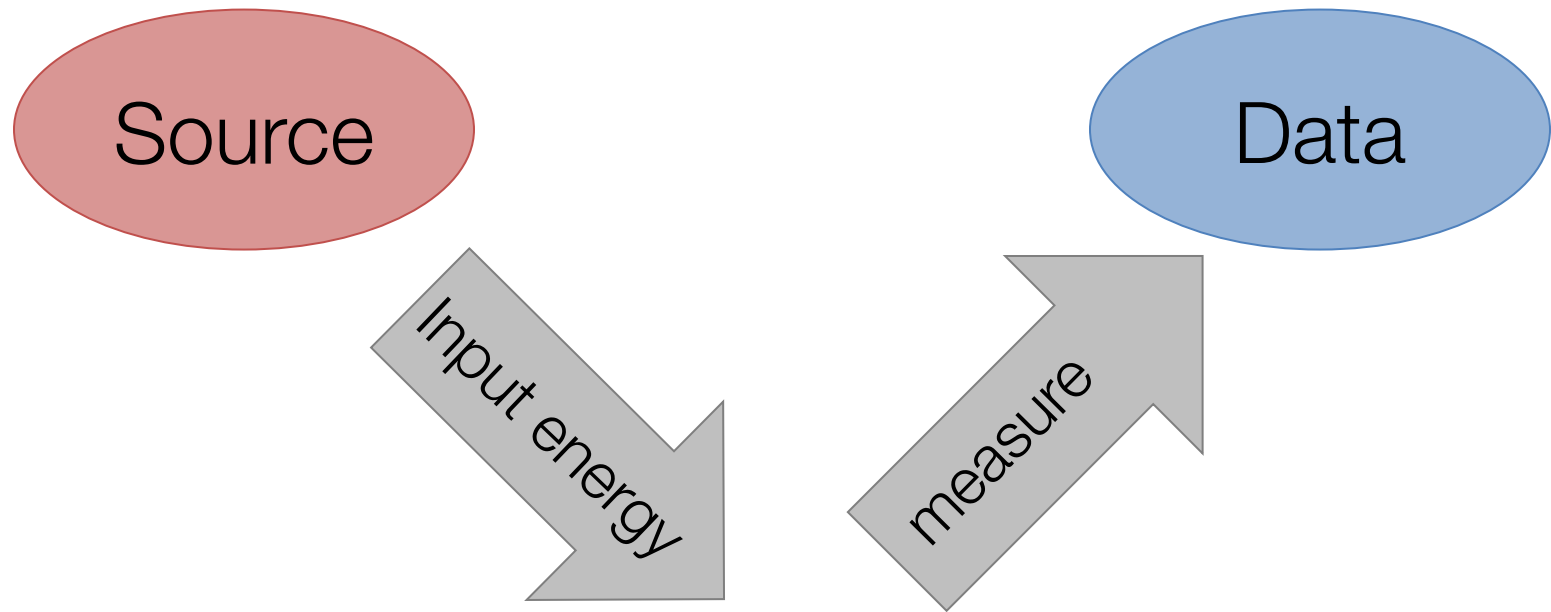


Material	Relative Permittivity	Conductivity (mS/m)
Air	1	0
Fresh Water	80	0.5
Sea Water	80	3000
Ice	3-4	0.01
Dry Sand	3-5	0.01
Saturated Sand	20-30	0.1-1
Limestone	4-8	0.5-2
Shales	5-15	1-100
Silts	5-30	1-100
Clays	5-40	2-1000
Granite	4-6	0.01-1
Anhydrites	3-4	0.01-1

Magnetic Susceptibility



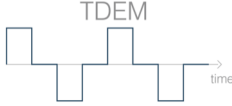
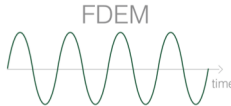
EM Survey & Physical Properties



Physical
Properties

σ, μ, ϵ

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)	$\mathbf{j} = \sigma \mathbf{e}$ $\mathbf{b} = \mu \mathbf{h}$ $\mathbf{d} = \varepsilon \mathbf{e}$	$\mathbf{J} = \sigma \mathbf{E}$ $\mathbf{B} = \mu \mathbf{H}$ $\mathbf{D} = \varepsilon \mathbf{E}$

* Solve with sources and boundary conditions

Electromagnetic Survey: Sources

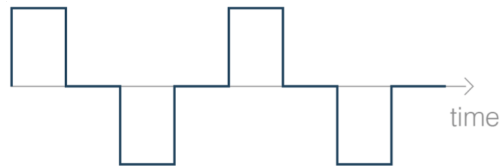
- Type
 - Inductive
 - Grounded

- Waveform

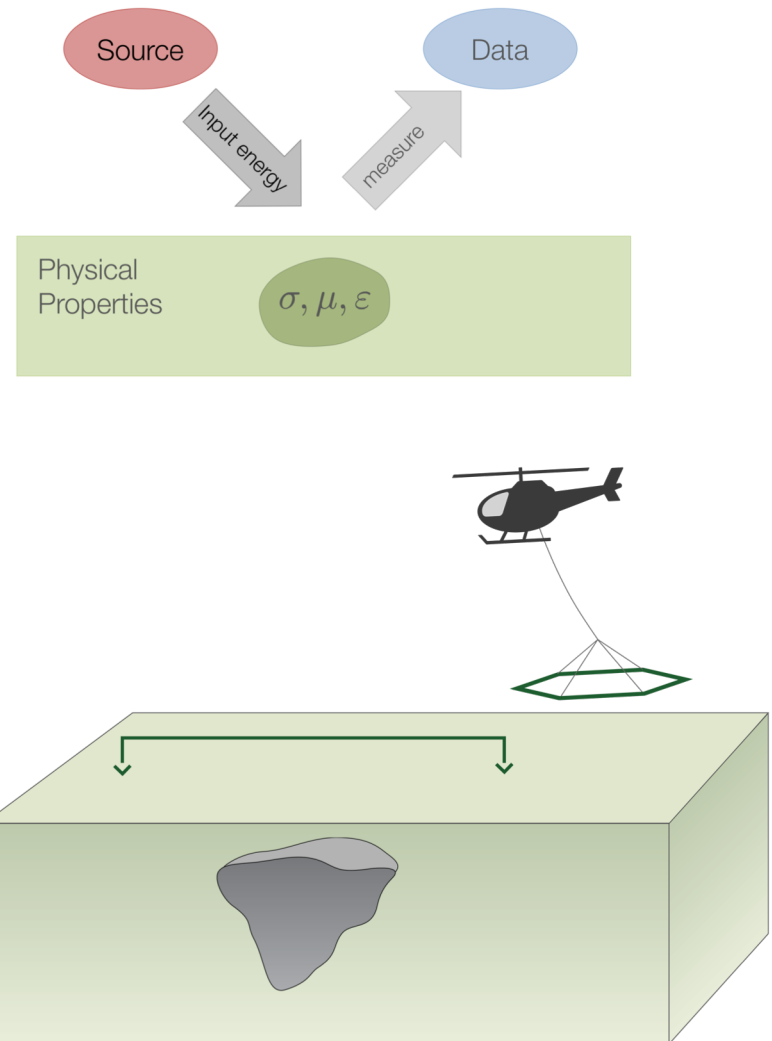
Harmonic
(FDEM)



Transient
(TDEM)

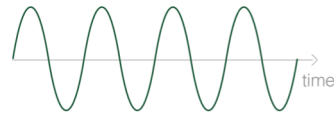


- Location
 - Airborne
 - Ground
 - Borehole

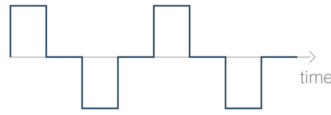


Electromagnetic Survey: Data

- Which field?

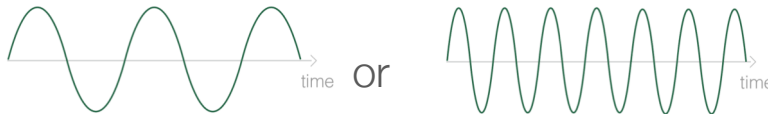


E, B

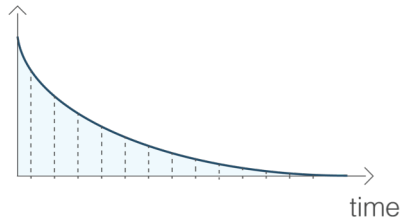


e, b, $\frac{db}{dt}$

- Which frequencies?



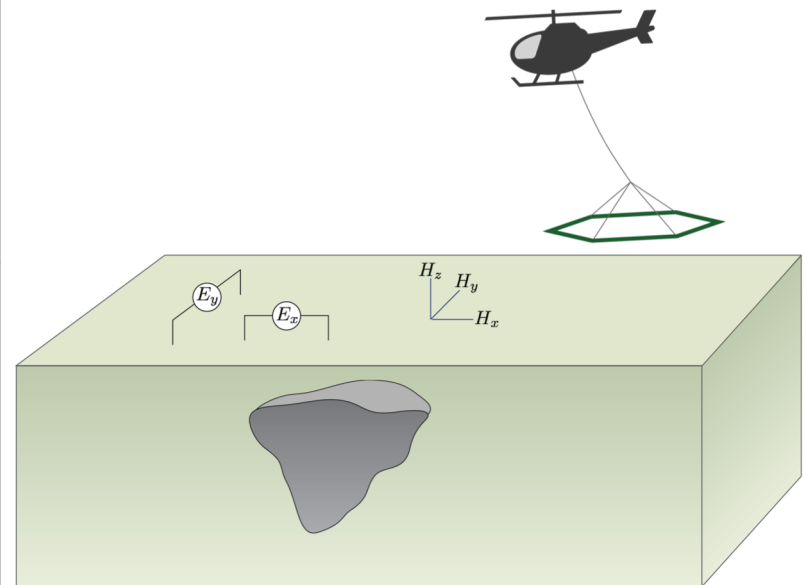
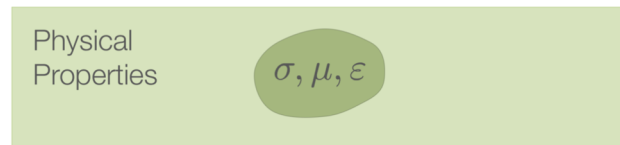
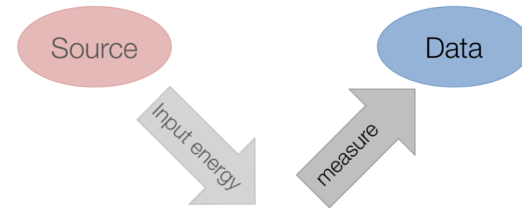
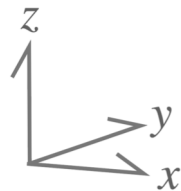
- times?



- Components?

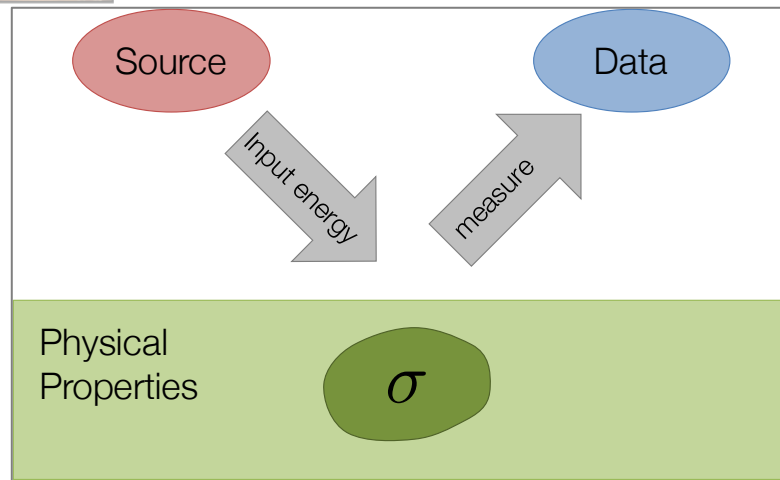
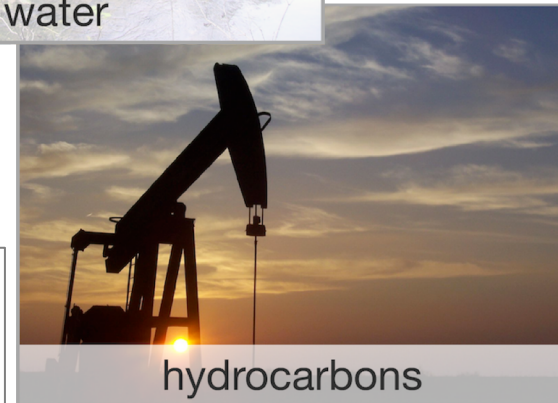
- Location?

- Airborne
- Ground
- Borehole



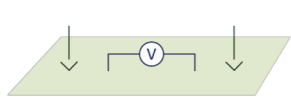
Some applications

Electrical conductivity is diagnostic



End of Introduction

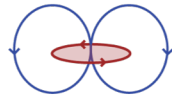
Next up



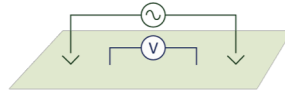
DC Resistivity



EM
Fundamentals



Inductive
Sources



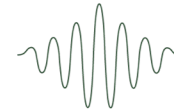
Grounded
Sources



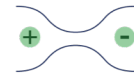
Natural
Sources



Inverse
Theory



GPR



Induced
Polarization



The
Future