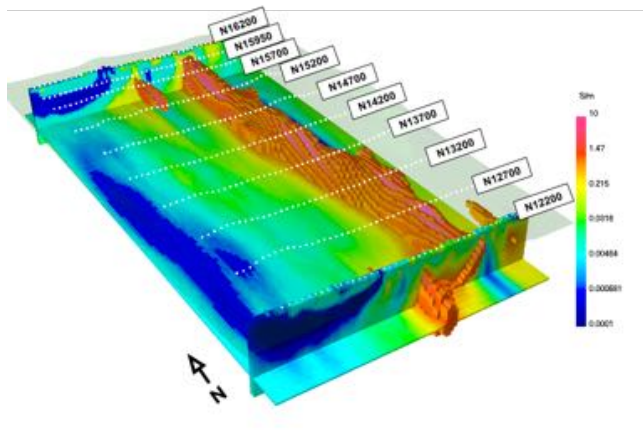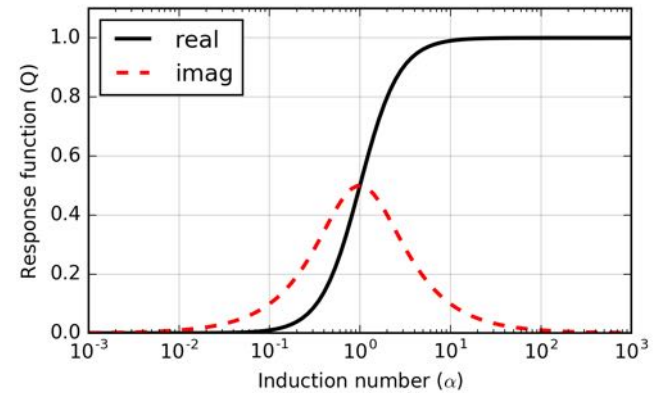# Summary and the Future

What have we covered?
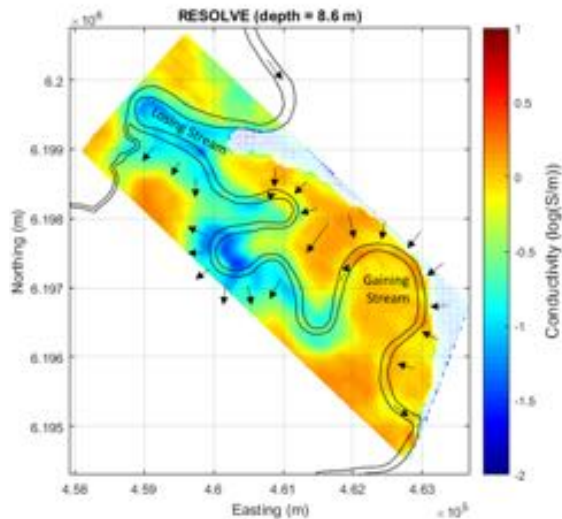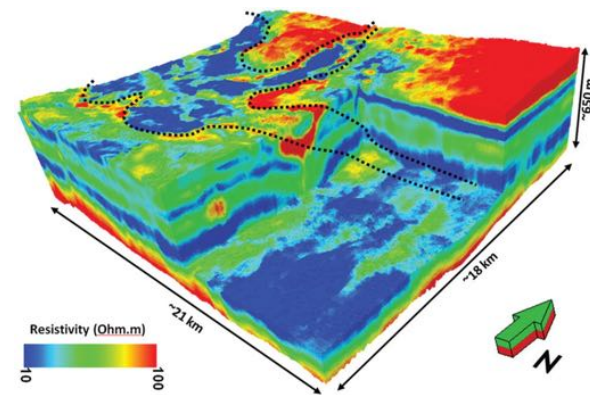
DC Resistivity

EM Fundamentals
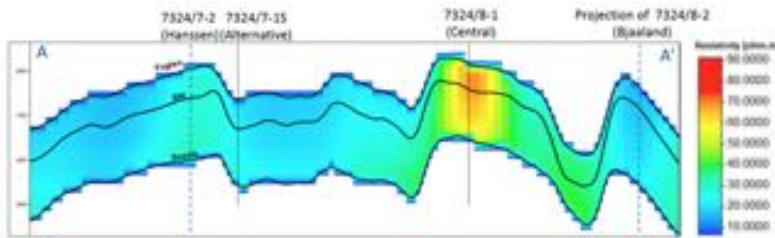

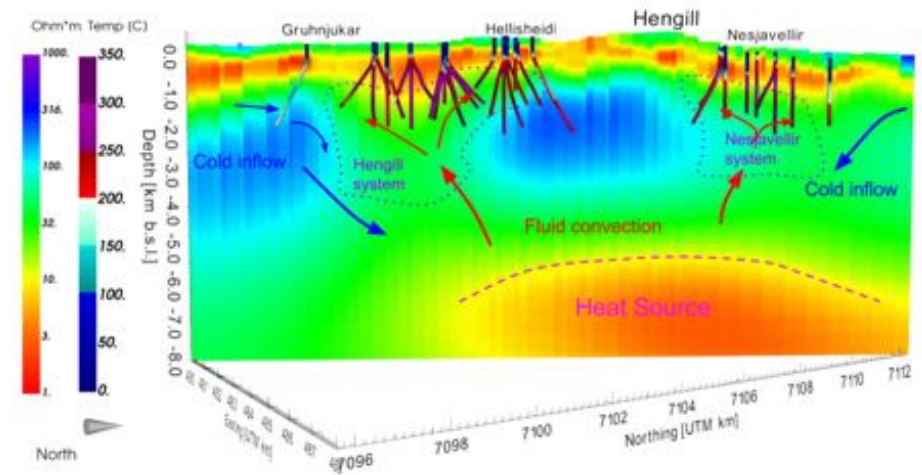## Inductive Sources: Frequency

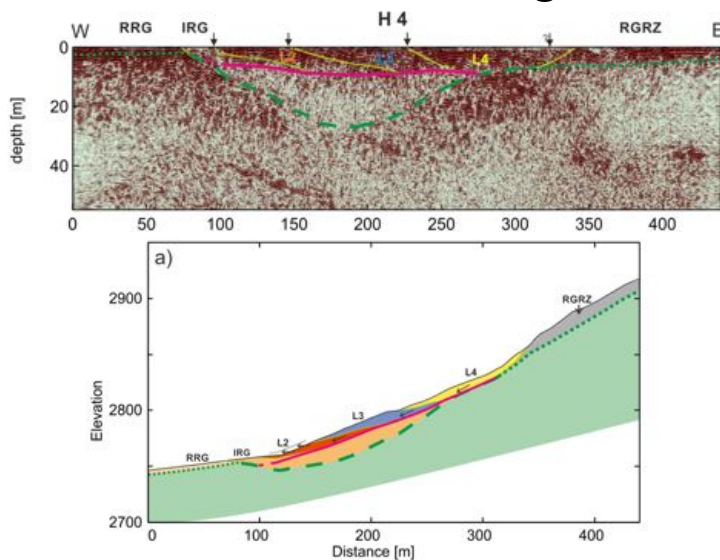

Inductive Sources: Time

What have we covered?
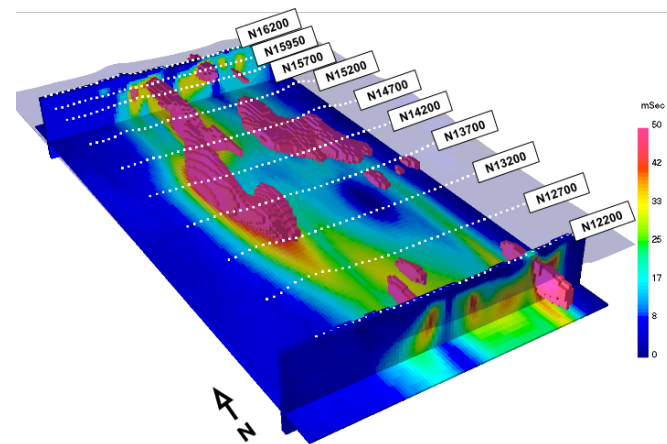
Grounded Sources

Natural Sources

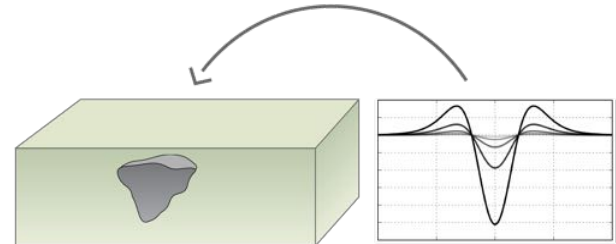## Ground Penetrating Radar

Induced Polarization

3

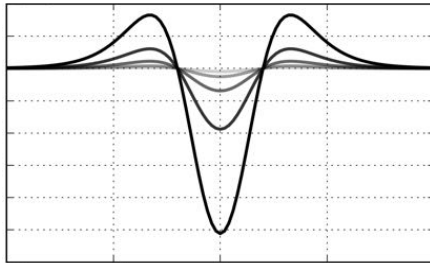# What does the future hold?

What does the future hold?

Problems

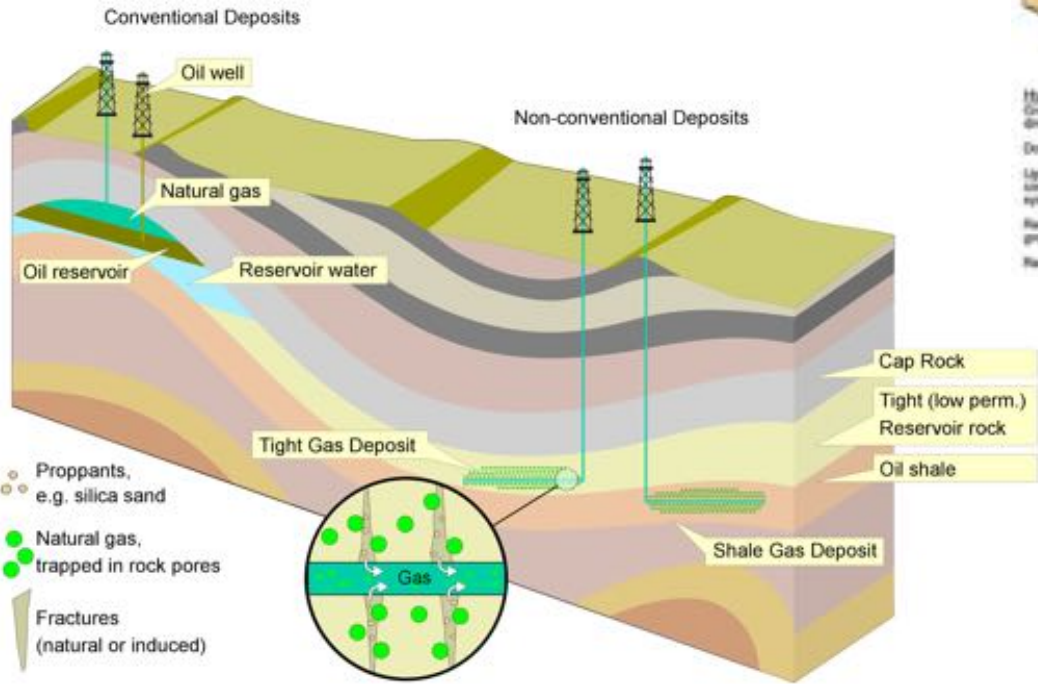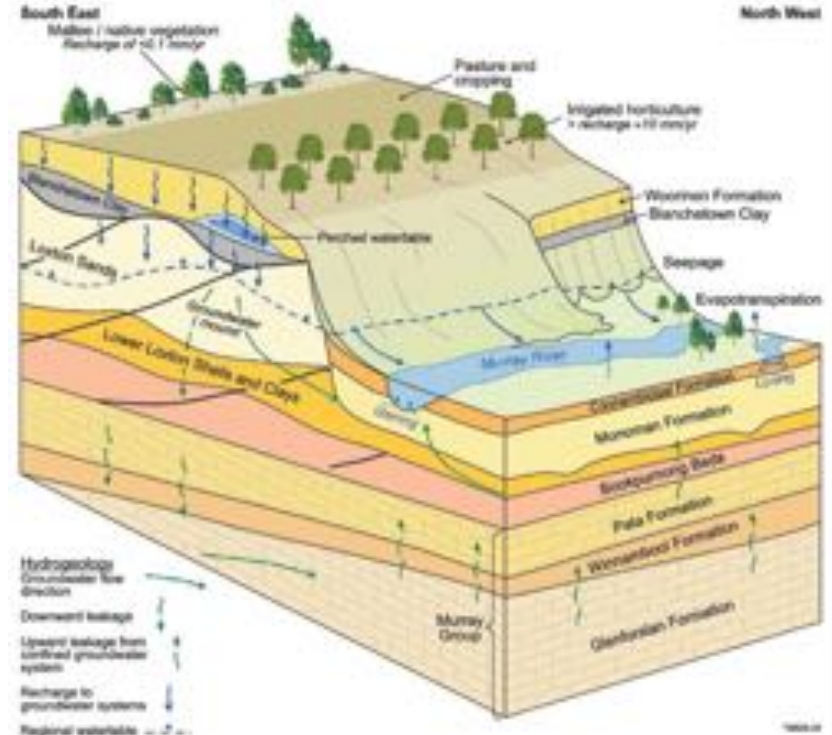Inversion capabilities

High quality data

Web tools to communicate
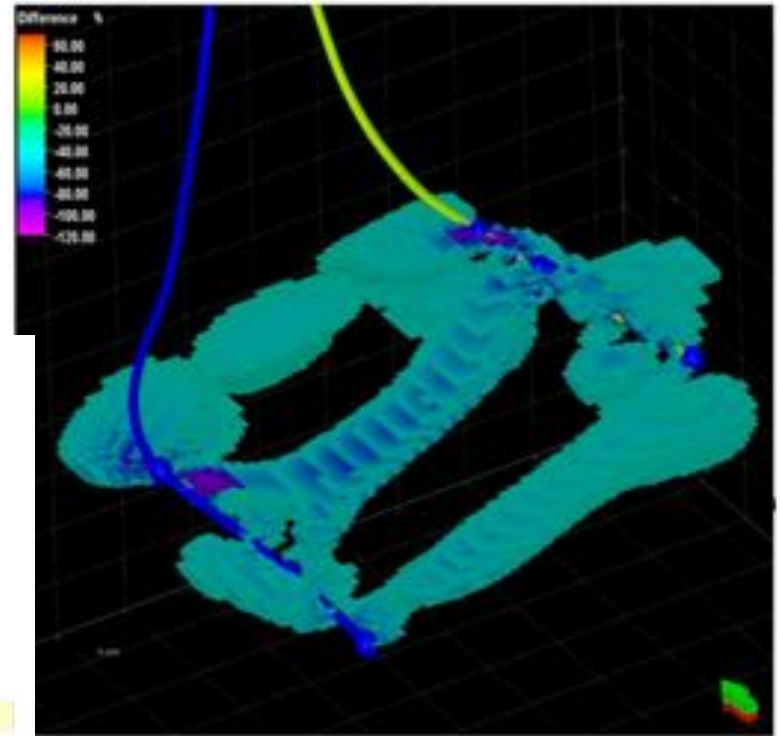
The Future: Monitoring

- Aquifers
- Enhanced oil recovery
- Hydraulic Fracturing
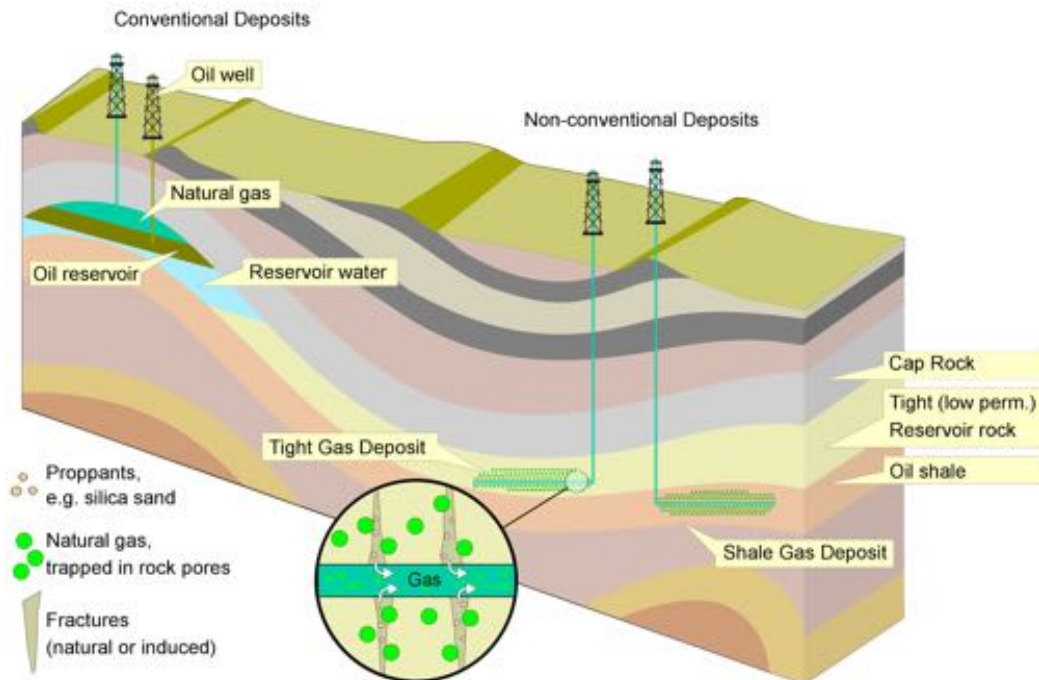- CO_2 sequestration
- Coal seam gas

The Future: Monitoring

- Water flood
  - Cross-well EM
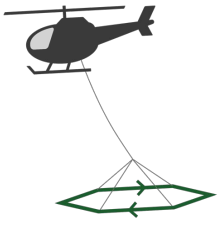 - Image swept and missed regions of reservoir

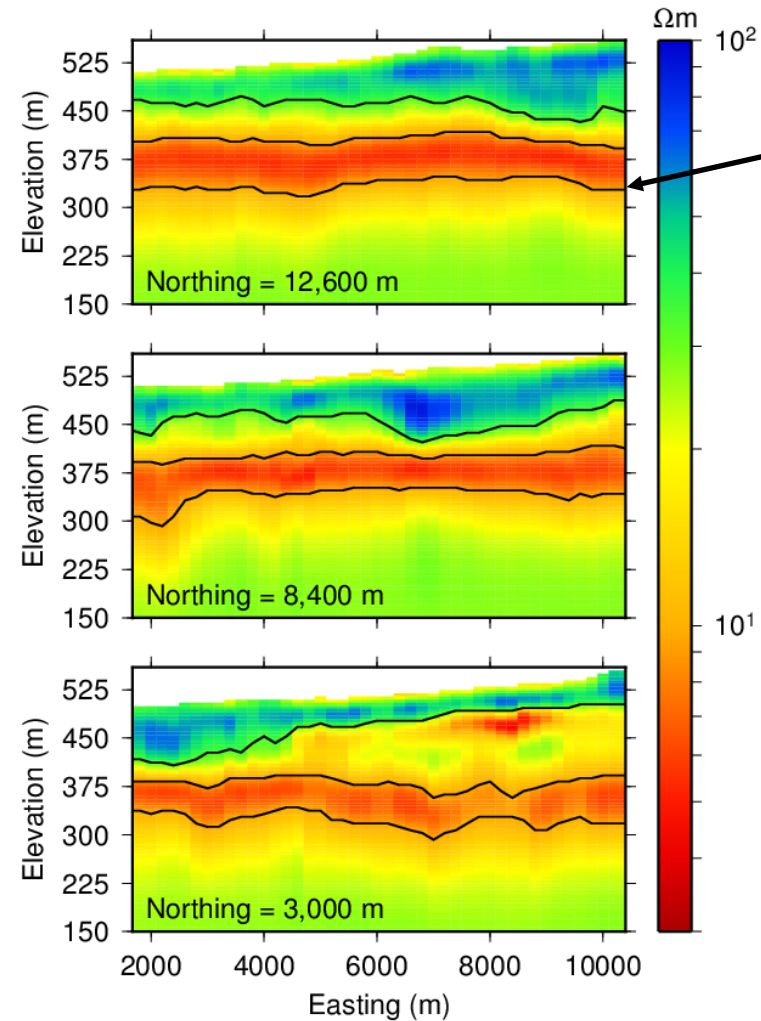Resistivity isosurface – water flood
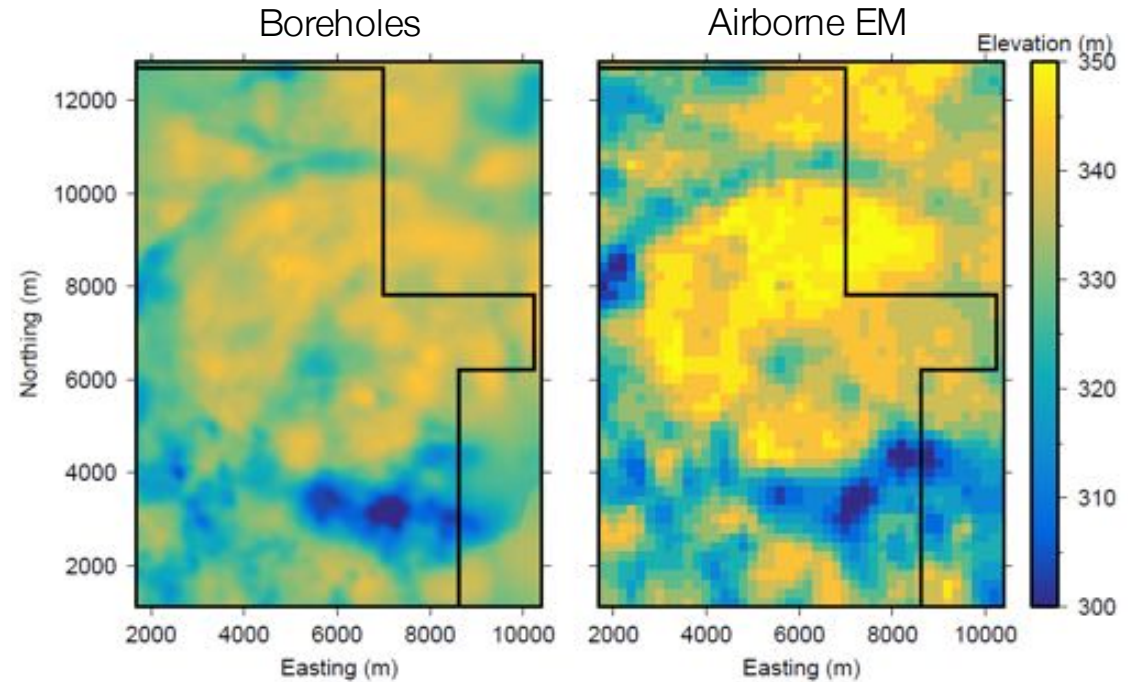

Saudi Arabia: Marsala et al., 2015

Conventional Deposits

Oil well

Natural gas

Oil reservoir

Reservoir water

Non-conventional Deposits

Cap Rock

Tight (low perm.) Reservoir rock

Oil shale

Proppants, e.g. silica sand

Natural gas, trapped in rock pores

Tight Gas Deposit

Gas

Shale Gas Deposit

Fractures (natural or induced)

Multi-stage EM for monitoring

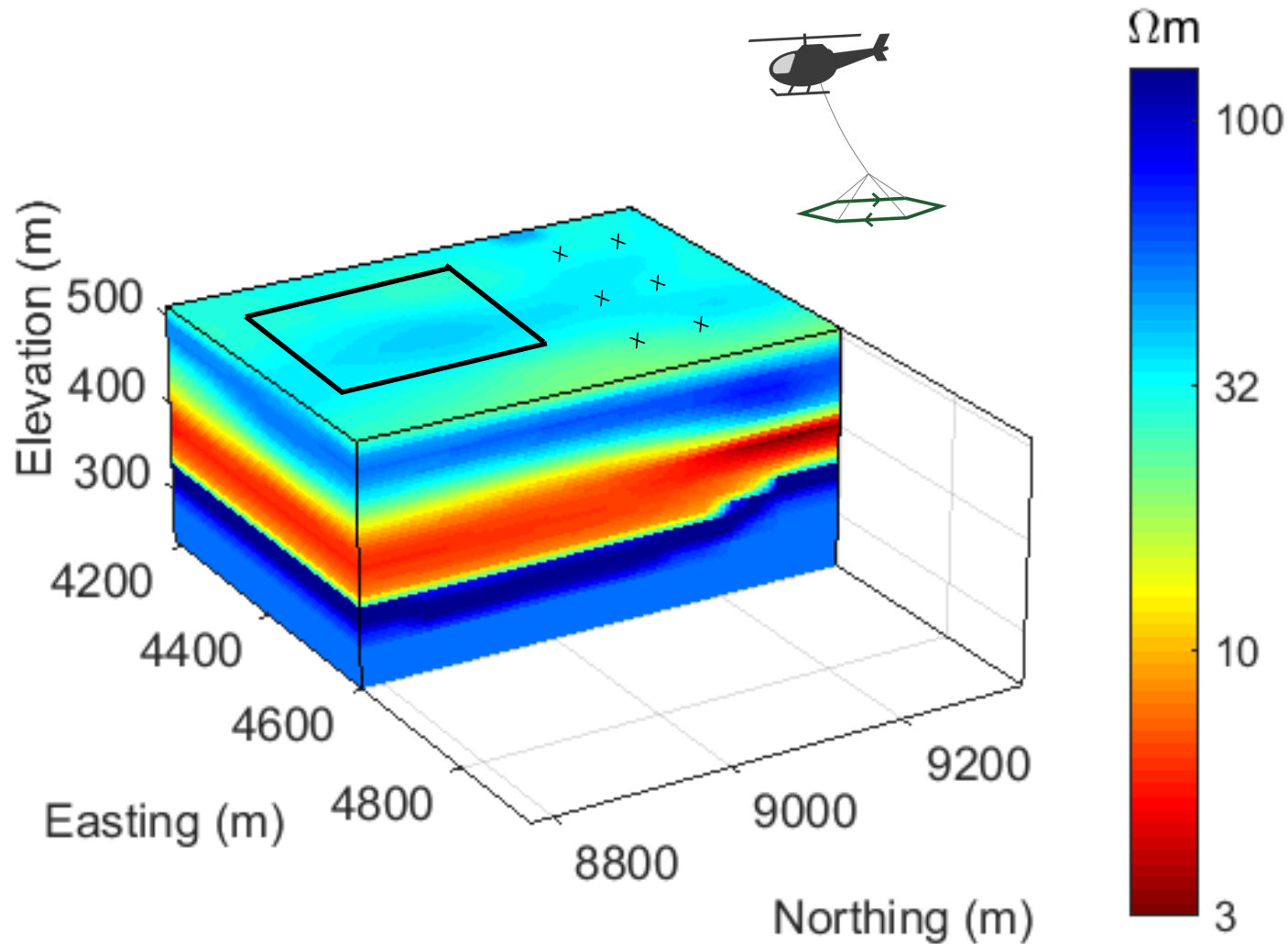Large-scale: airborne

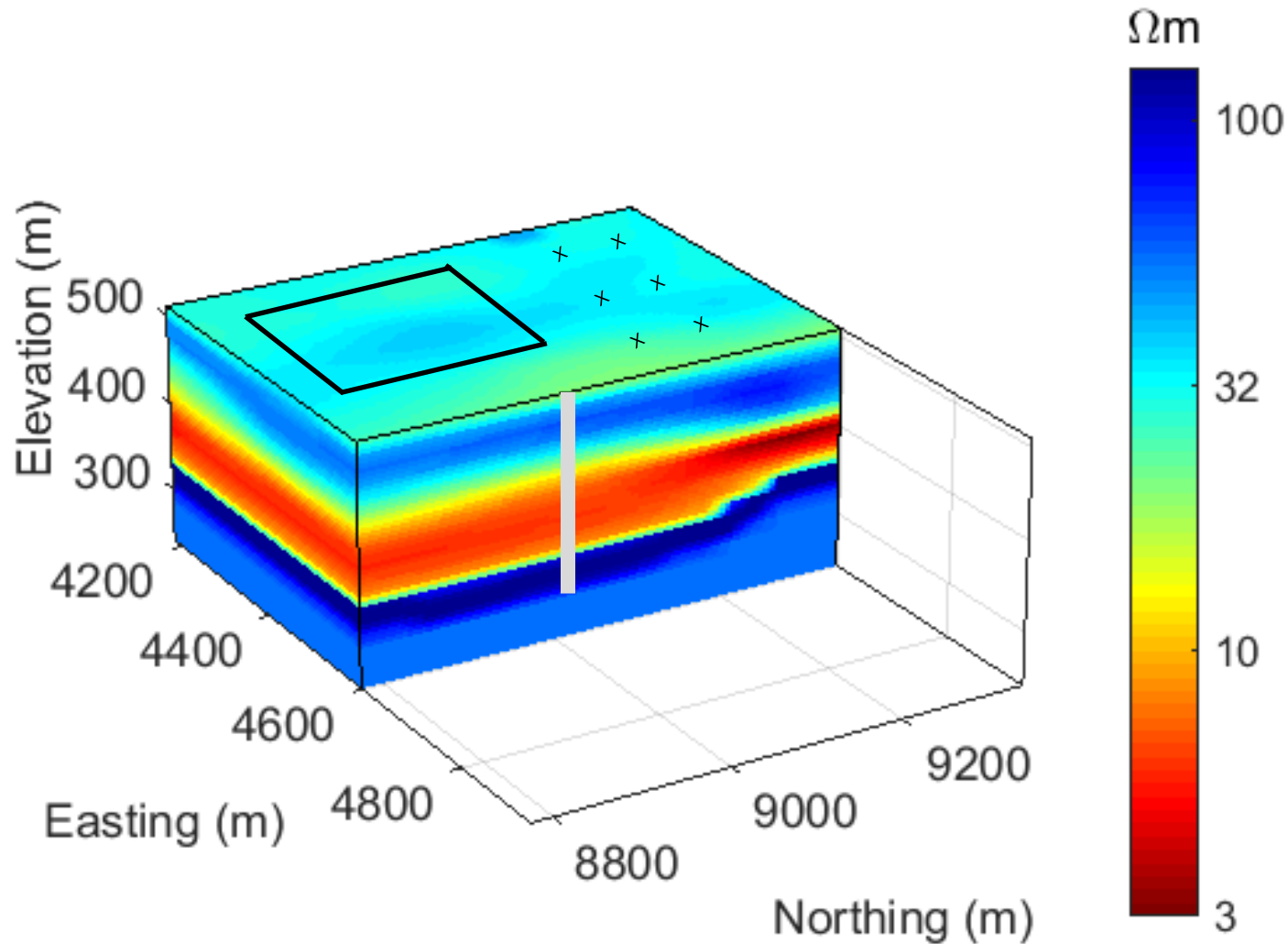Top of McMurray

Boreholes

Airborne EM

Multi-stage EM for monitoring

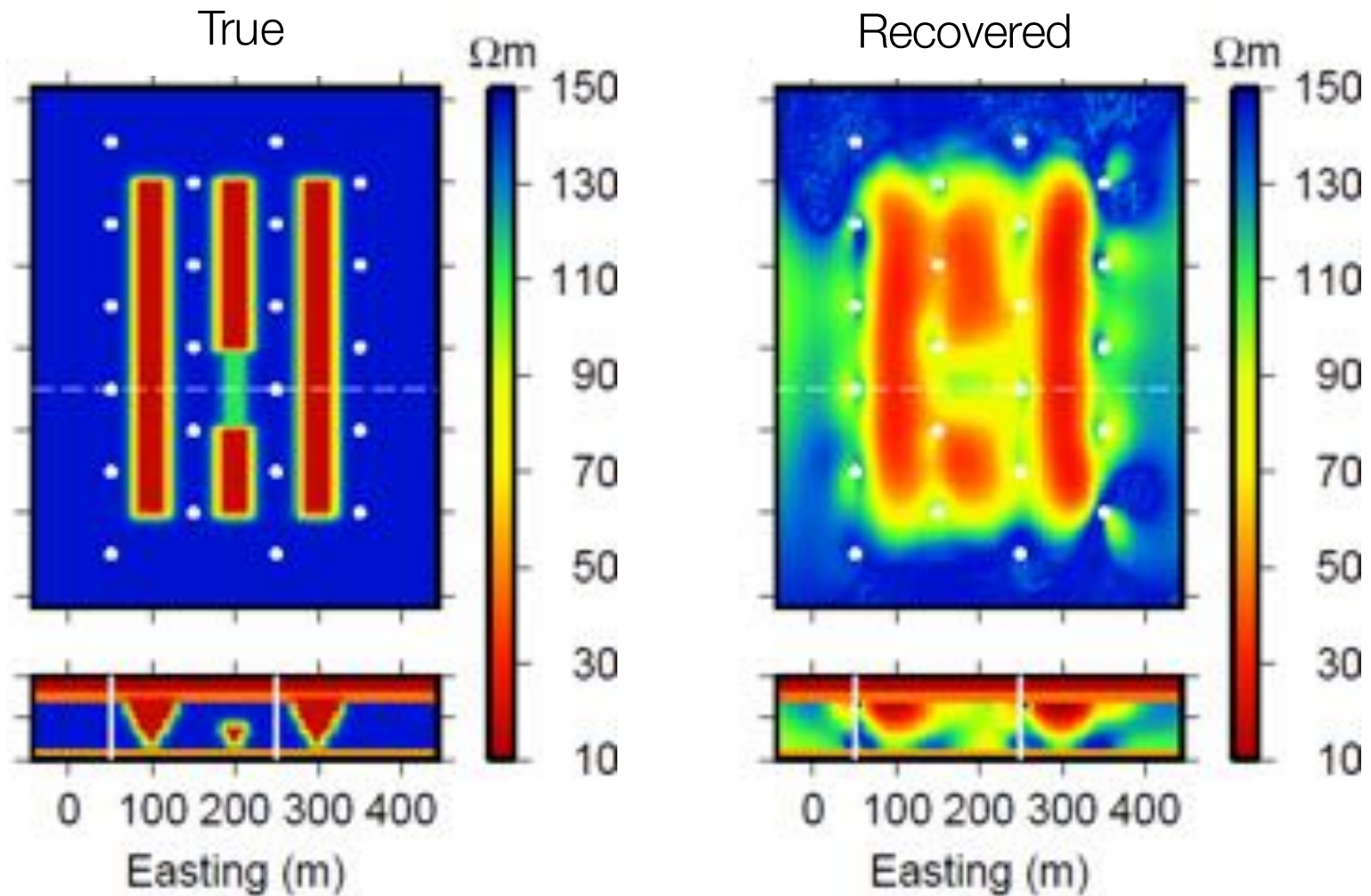## Local background: airborne + ground

Multi-stage EM for monitoring

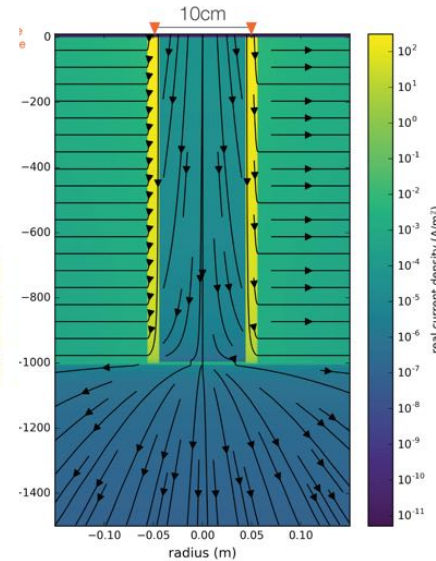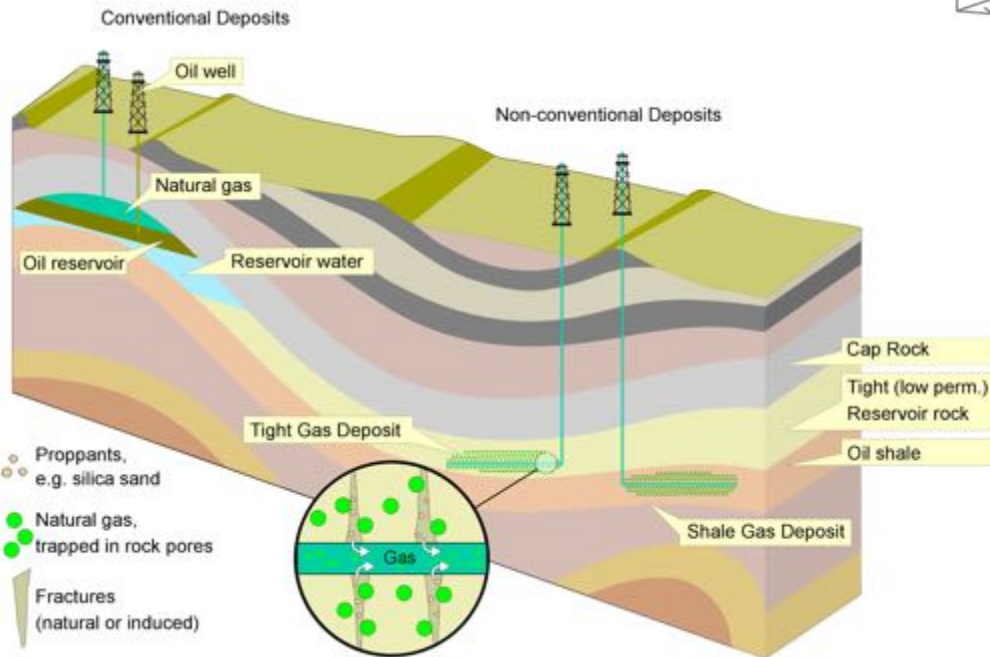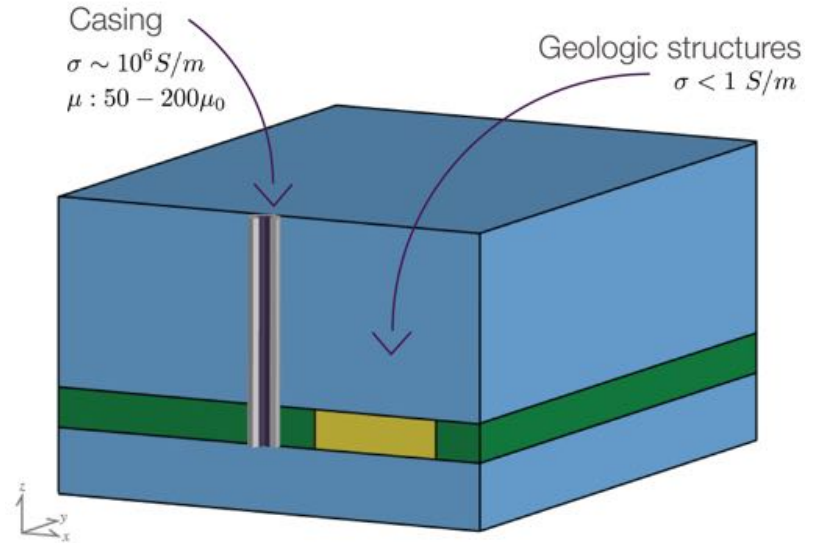Pre-injection: surface sources, borehole receivers

Multi-stage EM for monitoring

Post-injection: surface sources, borehole receivers

The Future: Monitoring

- Steel Casing
  - Mechanism for getting current to depth
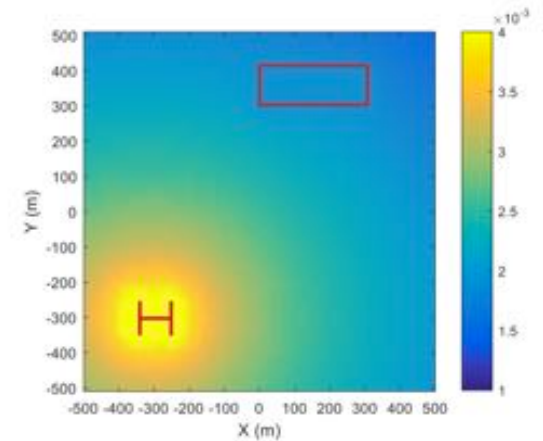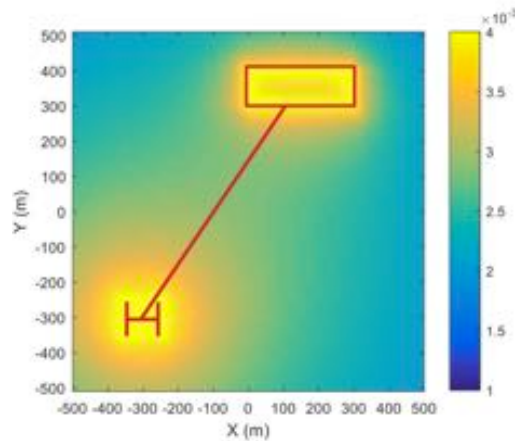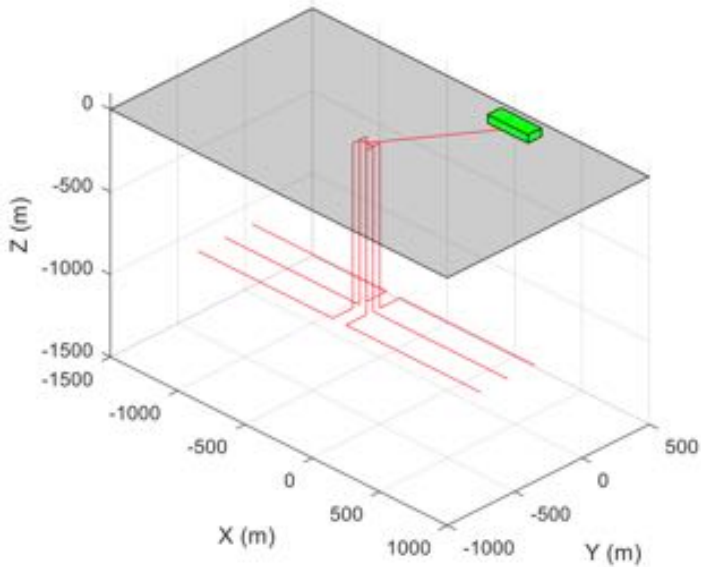 - Challenges:
    - Scales
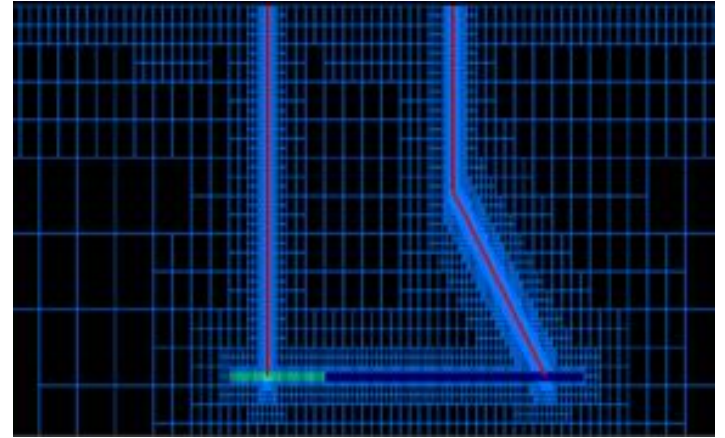   - Physical properties

Casing
$\sigma \sim 10^6 S/m$
$\mu : 50 - 200\mu_0$

Geologic structures
$\sigma < 1 S/m$

Conventional Deposits

Oil well

Natural gas

Oil reservoir

Reservoir water

Non-conventional Deposits

Cap Rock

Tight (low perm.)
Reservoir rock

Oil shale

Tight Gas Deposit

Shale Gas Deposit

Proppants, e.g. silica sand

Natural gas, trapped in rock pores

Gas

Fractures (natural or induced)

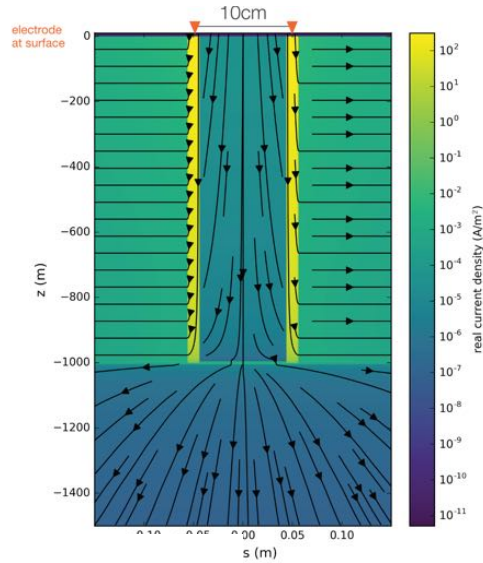10cm

radius (m)

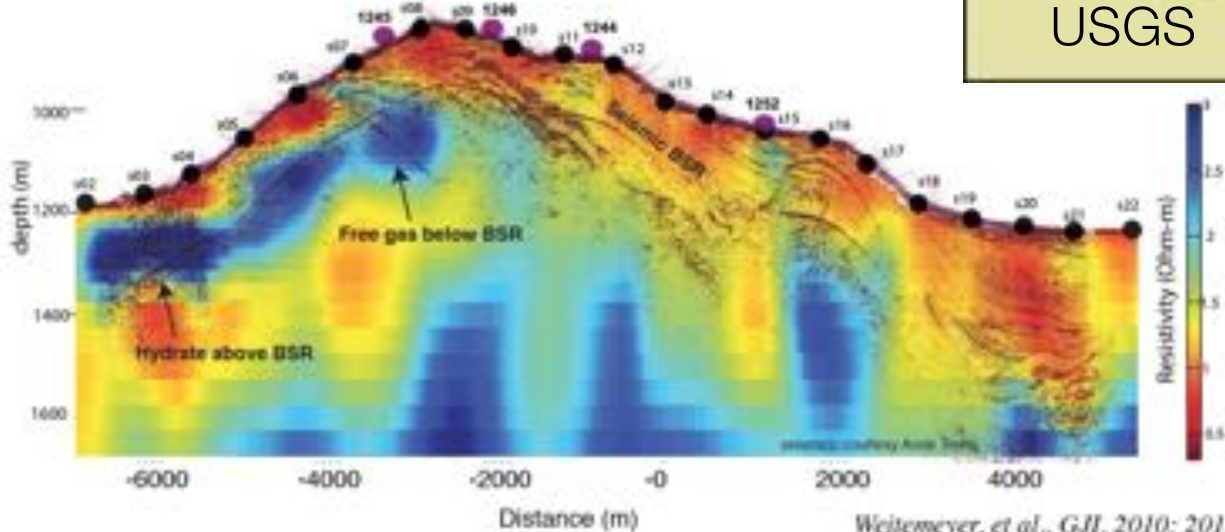real current density (A/m²)

Corrosion

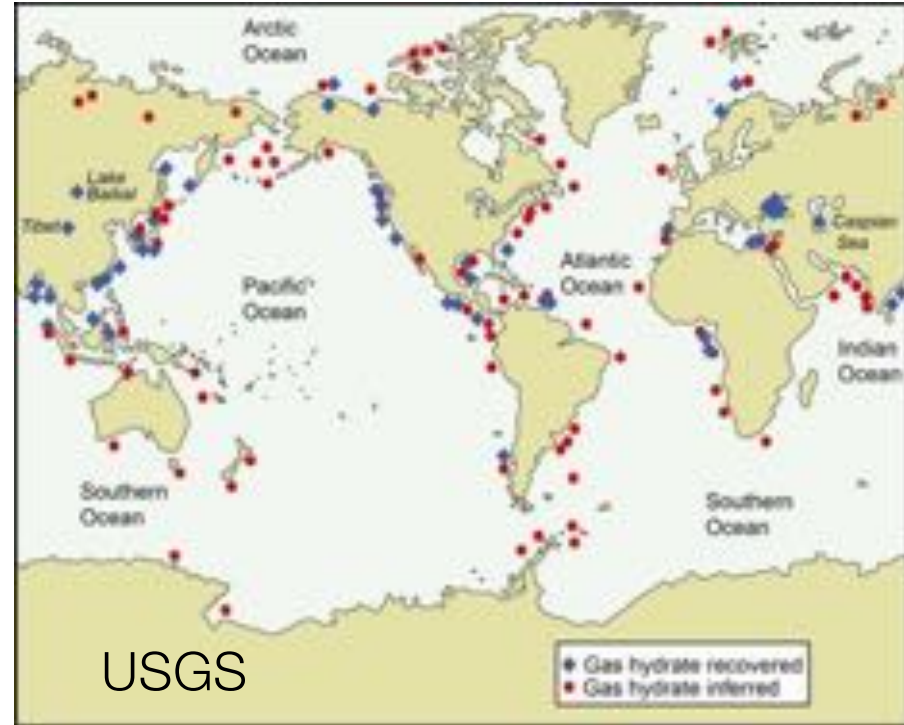# The Future: Monitoring

- Steel Casing

The Future: Marine EM

- Gas hydrates
  - Resistivity is diagnostic

USGS
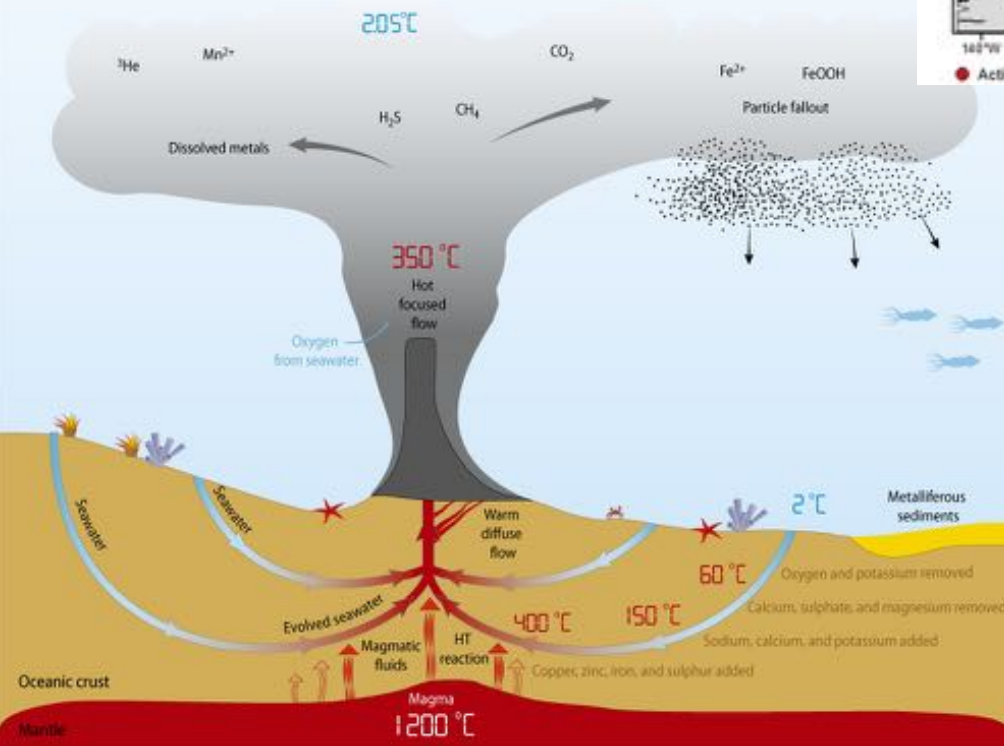

Weitemeyer, et al., GJI, 2010; 2011
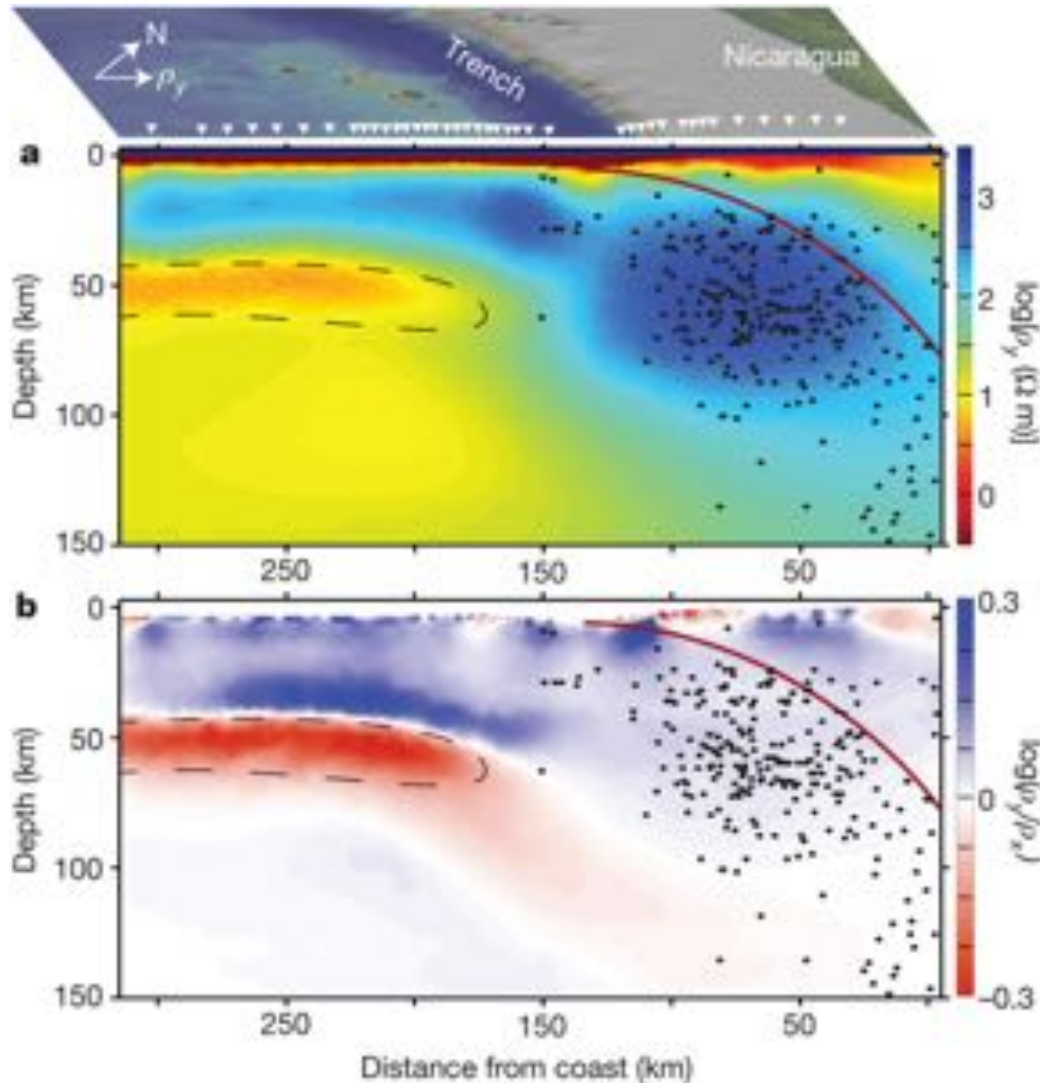
The Future: Marine EM

- Submarine massive sulfides
  - Conductive relative to background
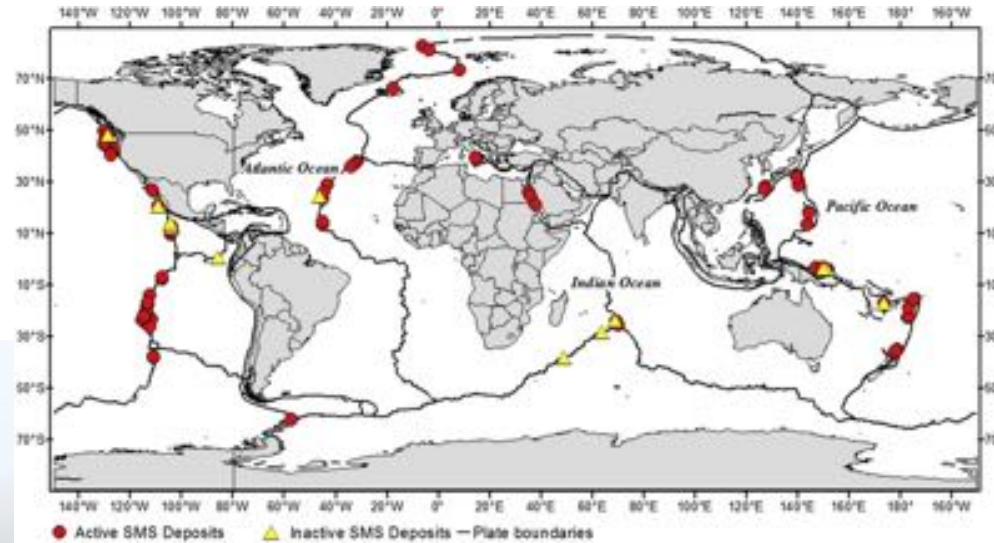
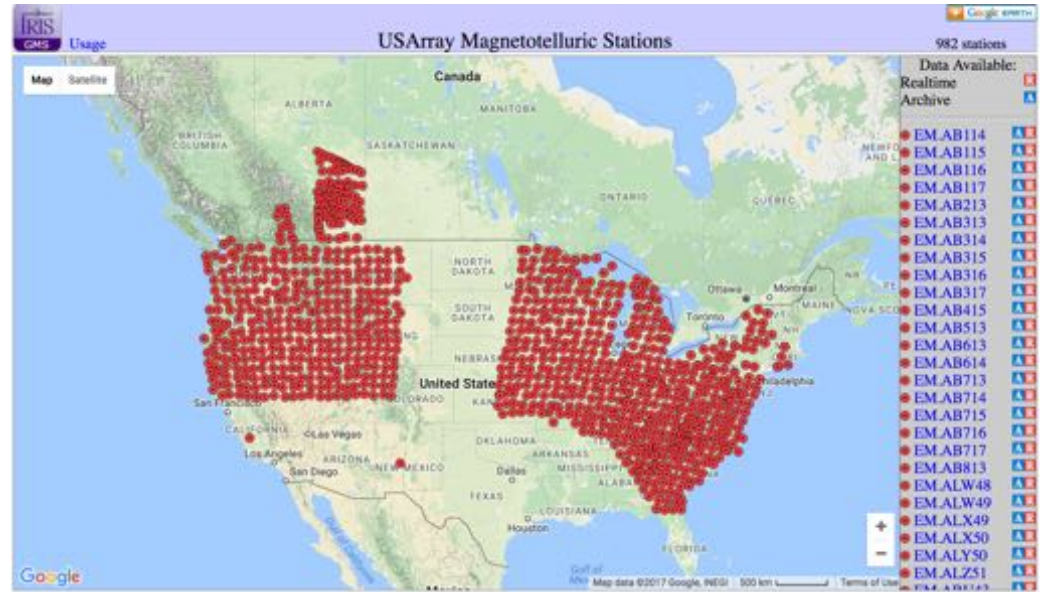Basics of a hydrothermal vent - a Black Smoker

The Future: Marine EM

- Tectonic studies

- Natural Hazard

- Large anisotropy
  - indicative of melt-rich channel

Naif et al., 2013

16

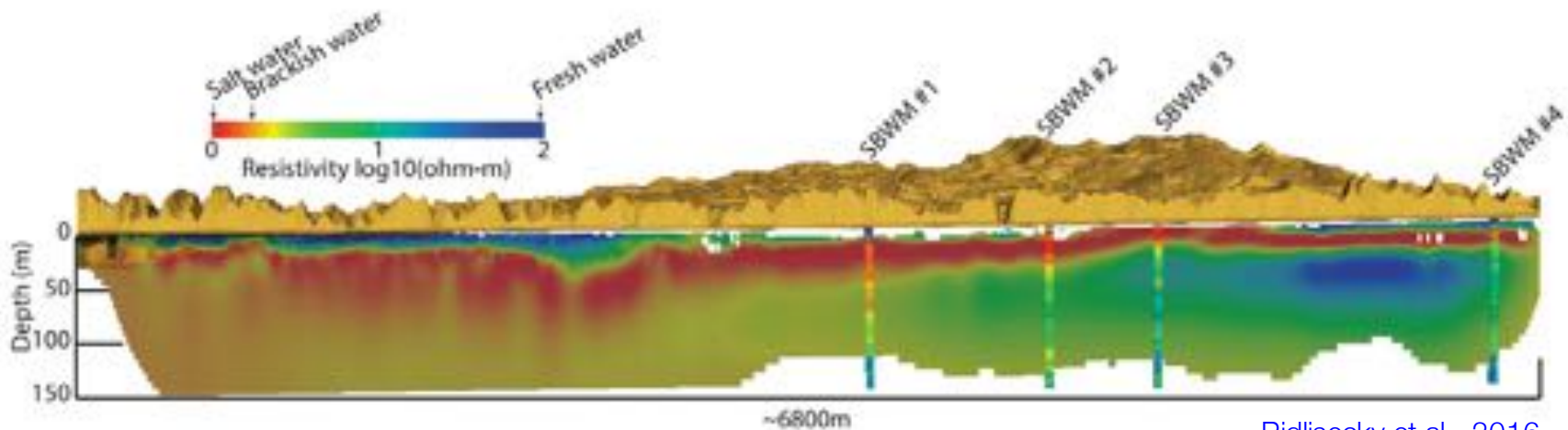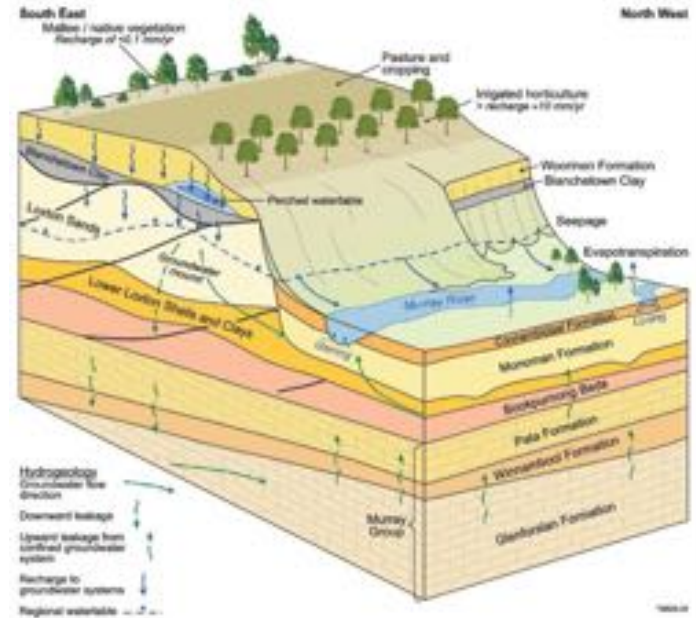# The Future: Large Scale MT

AusLamp

Earth scope

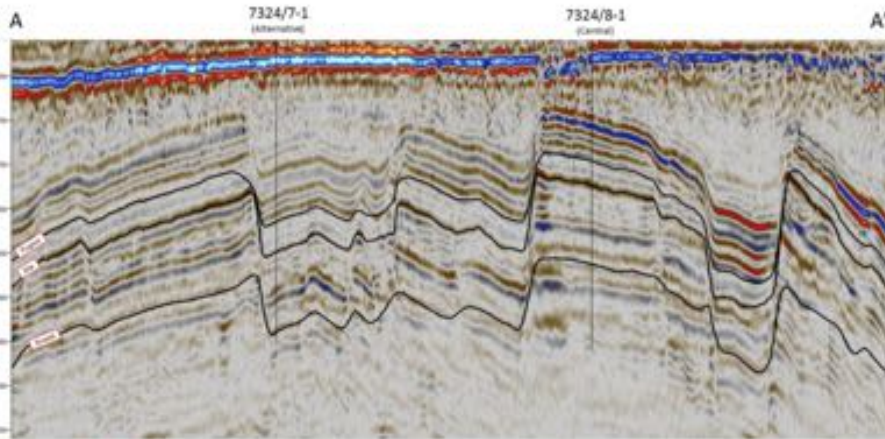# The Future: Water

- Finding and delineating water
- Aquifer monitoring and management
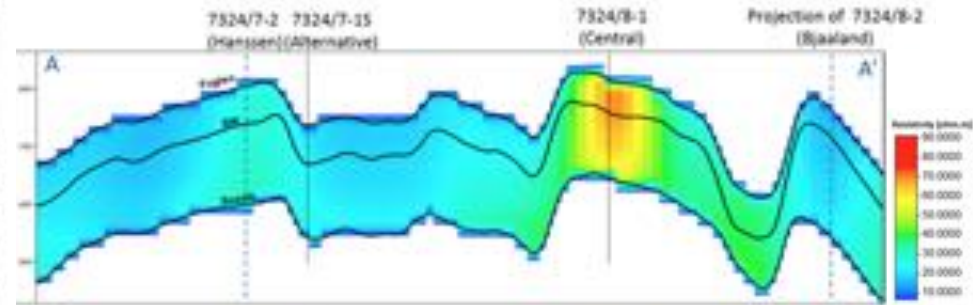- Salt water intrusions
- Pollutants

Pidlisecky et al., 2016

The Future: Data Integration & Multi-physics

Seismic

EM

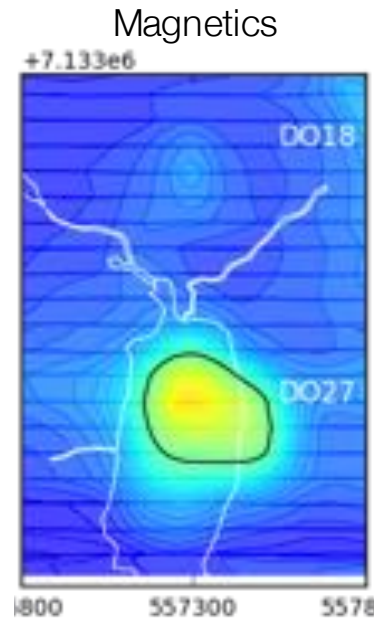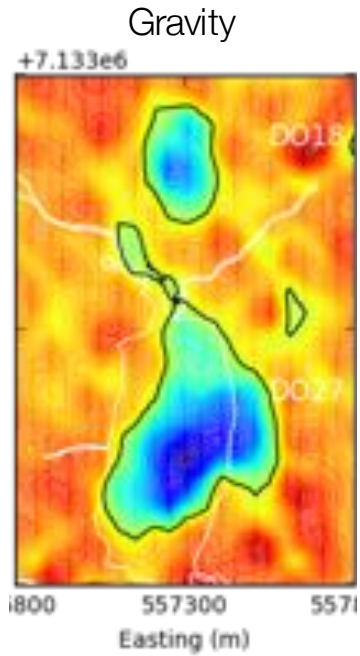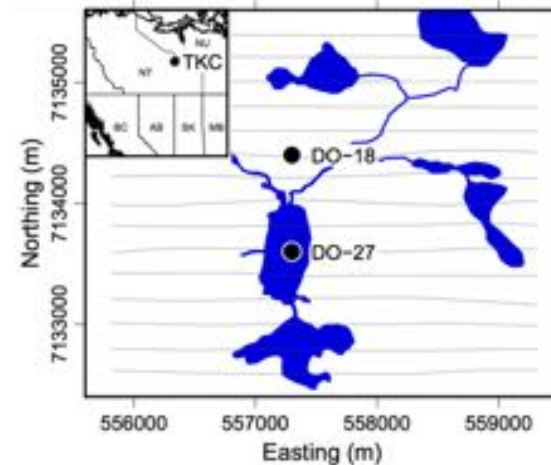Final hydrocarbon saturation model
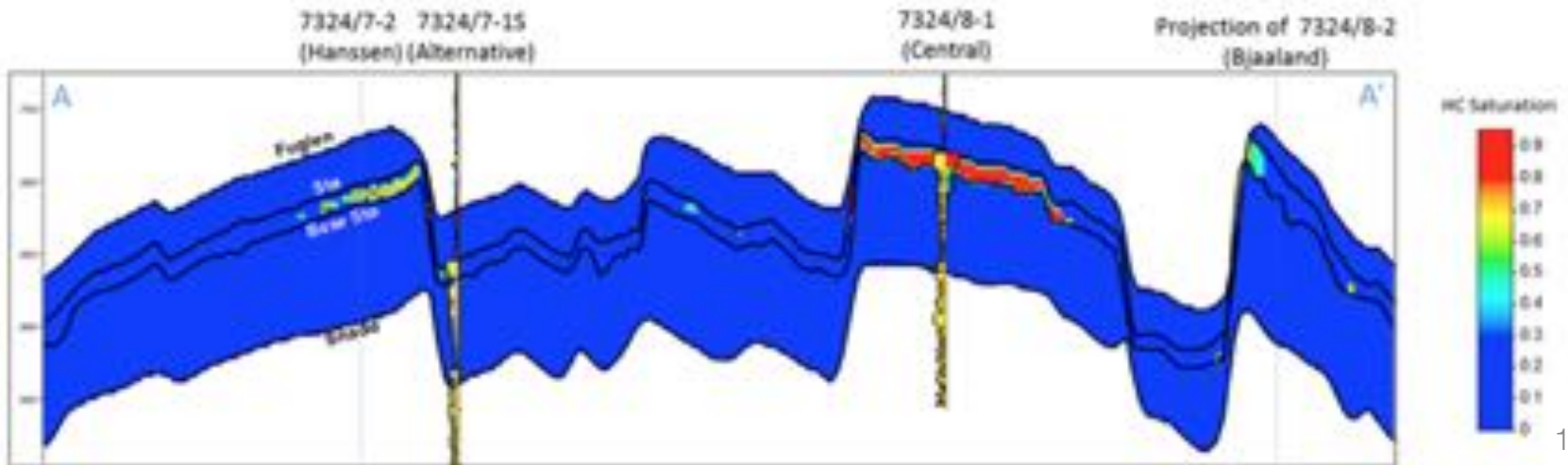
The Future: Data Integration & Multi-physics
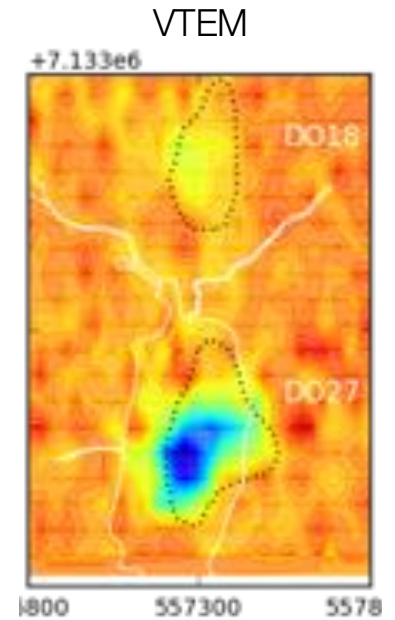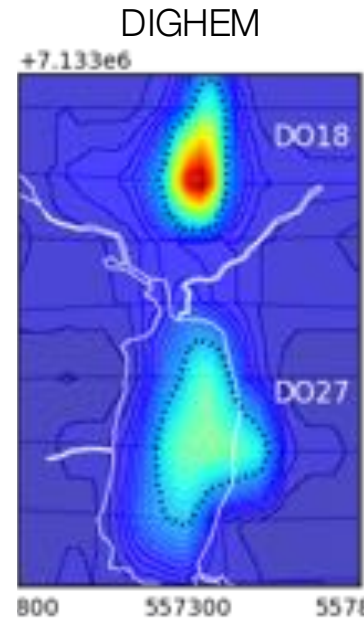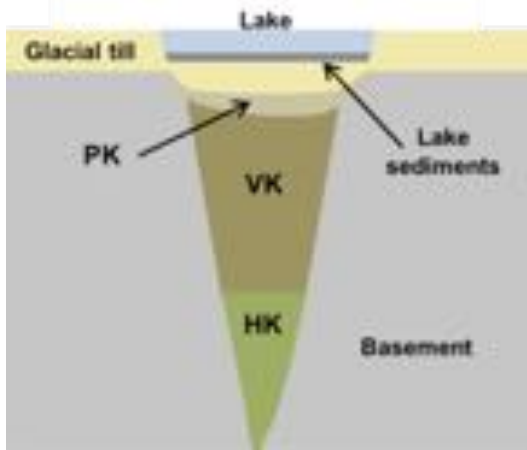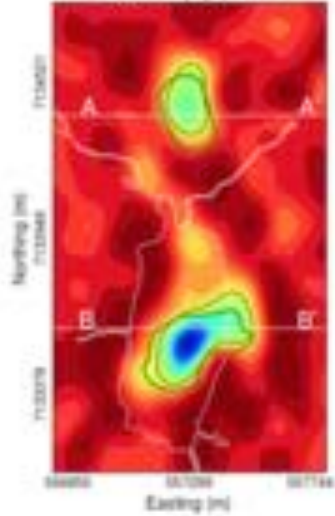

Gravity

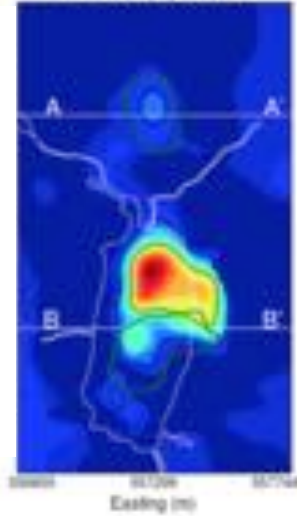Magnetics

DIGHEM

VTEM

Kimberlite Model

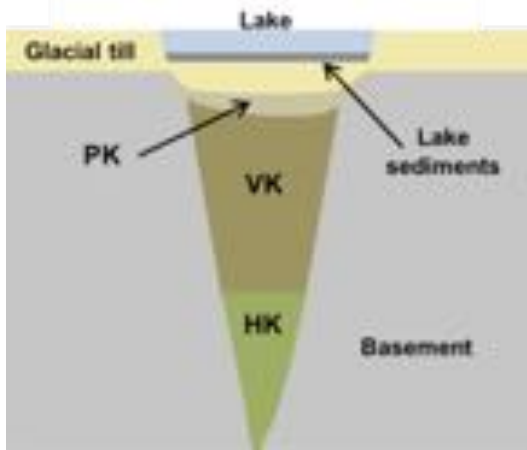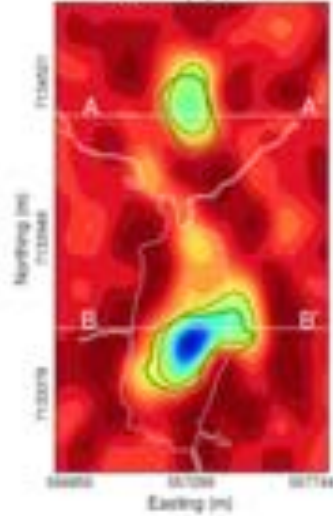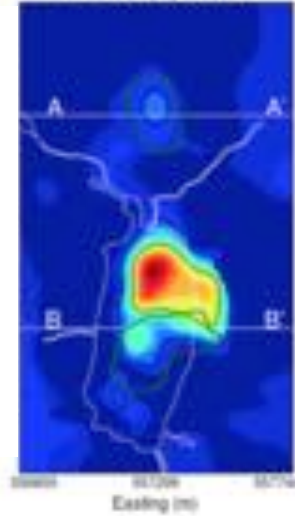# The Future: Data Integration & Multi-physics

Density

Susceptibility

Conductivity

Chargeability

Kimberlite Model

The Future: Data Integration & Multi-physics

Density

Susceptibility

Conductivity

Chargeability

Kimberlite Model
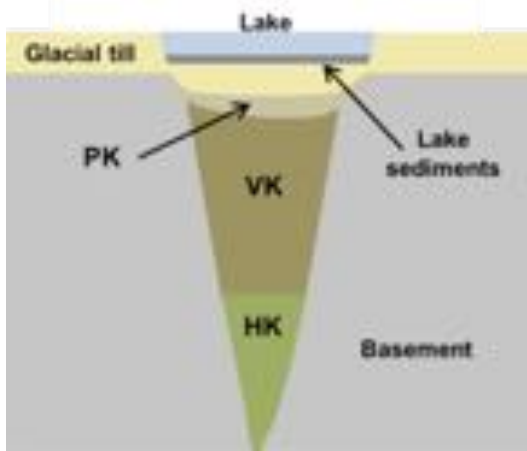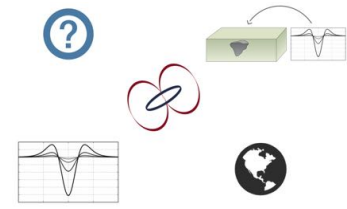

Rock Model from Geophysics
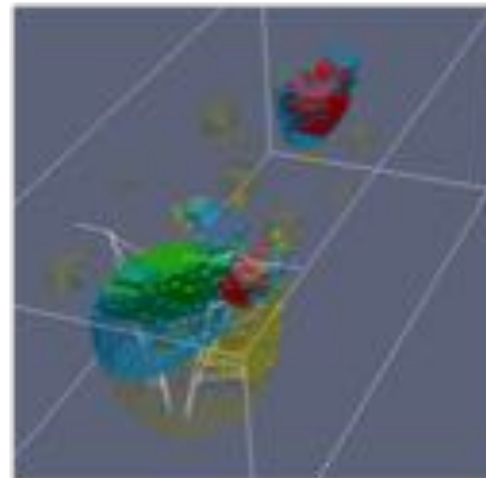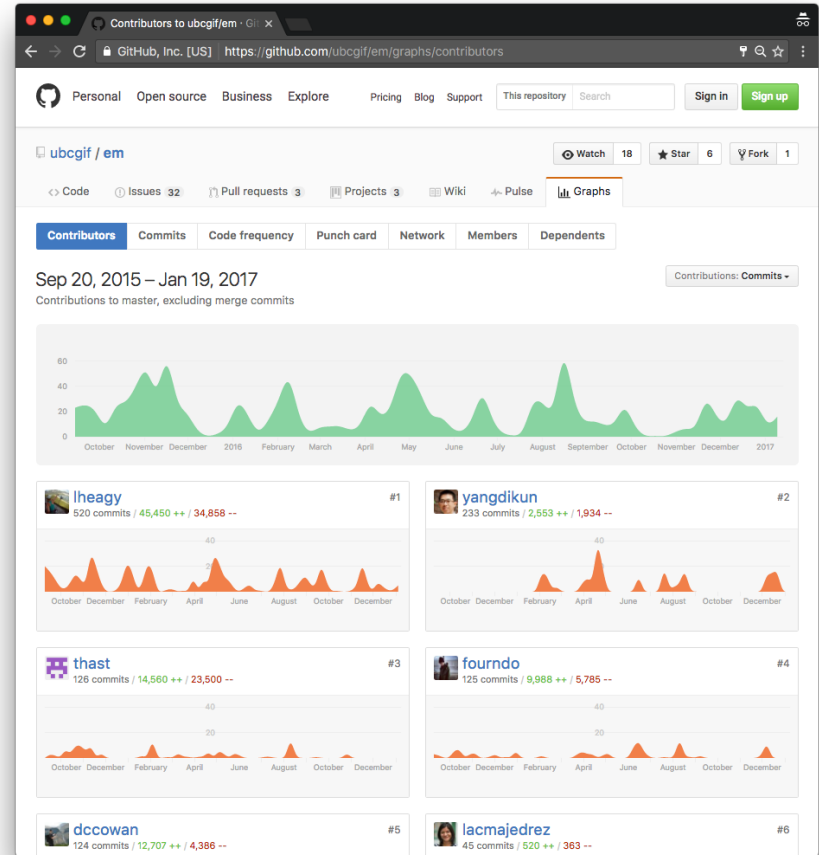

Rock Model from Drilling
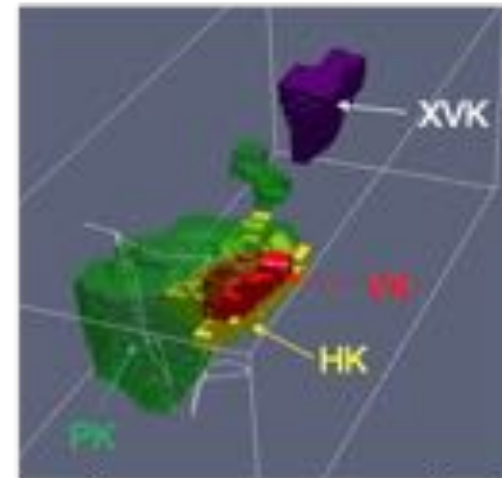
The Future: Modelling and Inversion

- HPC, Cloud computing

- Collaborative development

- Open source

simpeg

Simulation and Parameter Estimation in Geophysics
http://simpeg.xyz

Github
versioning, collaborating

Travis CI
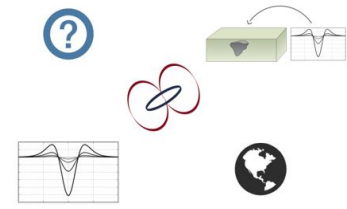testing, deploy

Jupyter
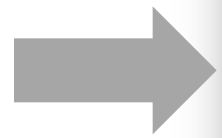interactive computing

Creative Commons
licensing, reuse

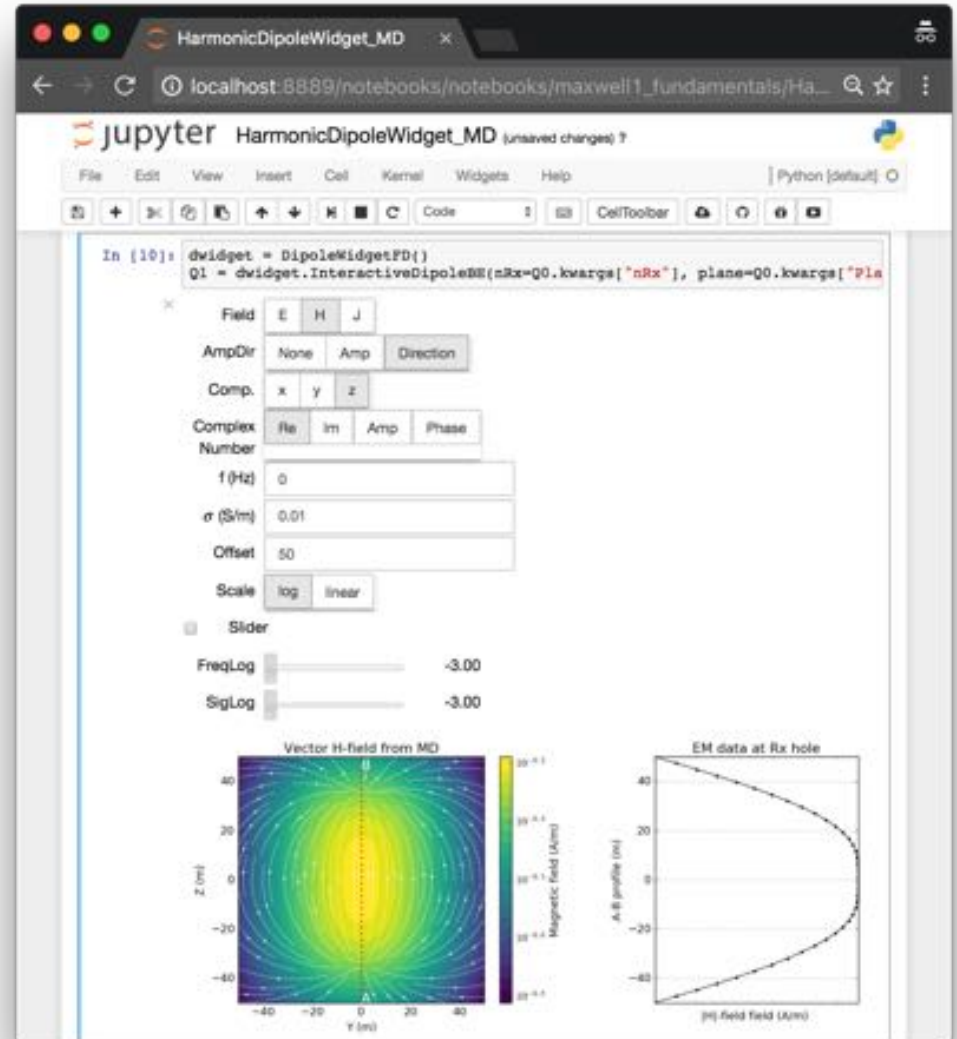Python
computation

The Future: Modelling and Inversion
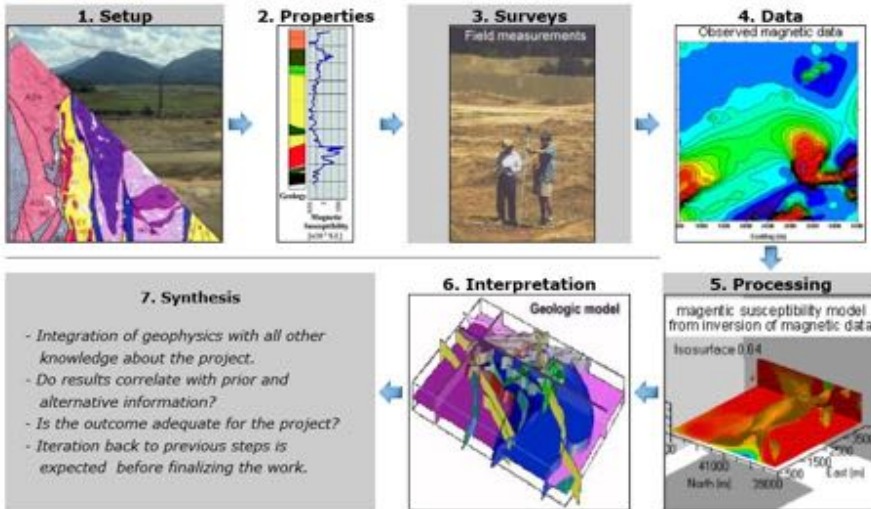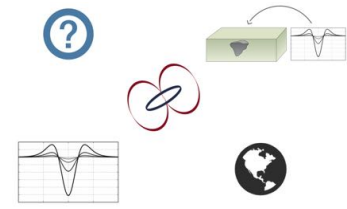
- Interactive computing

- Visualization

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

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

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

The Future: Collaboration

http://slack.geosci.xyz

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

- GeoSci

  http://geosci.xyz

  – Web-textbooks
  – Software
  – Apps

- Apps:

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

GIF DISC Team
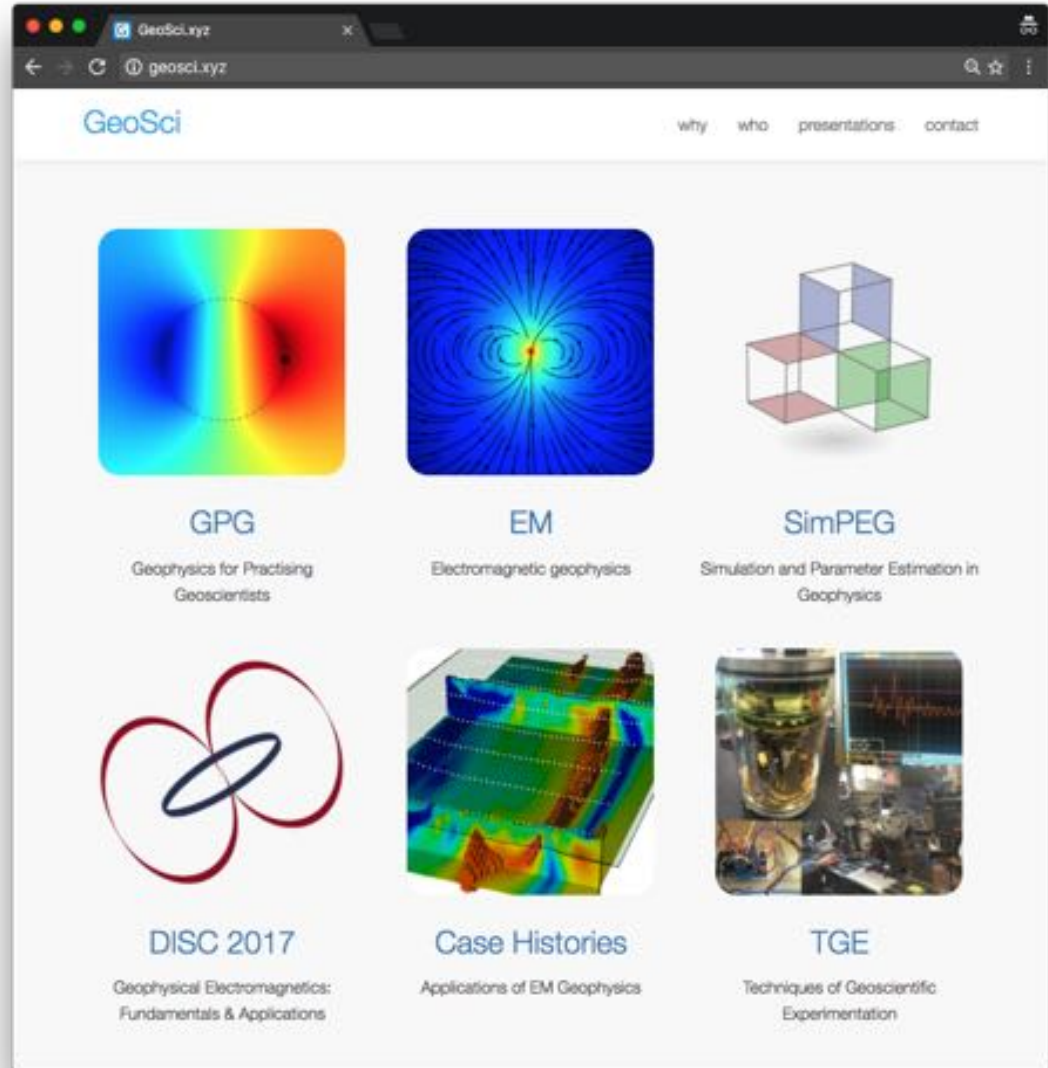
UBC GIF Team

Thibaut   Patrick   Rowan   Devin   Kris   Sarah

Dom   Mike   Mike   Gudni   Dikun

Join us tomorrow at DISC Lab

- Tell us what you are doing

- How EM is (or could!) play a role in the solution

- Continue the conversations

- Connect with other geoscientists

- Contribute to the development of a community

http://disc2017.geosci.xyz

minerals · contaminants · water · geothermal · geotechnical · slope stability · hydrocarbons · unexploded ordnance

Thank You!

http://disc2017.geosci.xyz