geophysics in a changing climate

Lindsey Heagy
UBC Geophysical Inversion Facility

BCGS Breakfast Feb 1, 2022

UBC Vancouver is located on the traditional, ancestral, and unceded territory of the xʷməθkʷəy̓əm people

Hover Collective / UBC Brand & Marketing

climate crisis

solutions & mitigating impacts: opportunities for geophysics

critical minerals

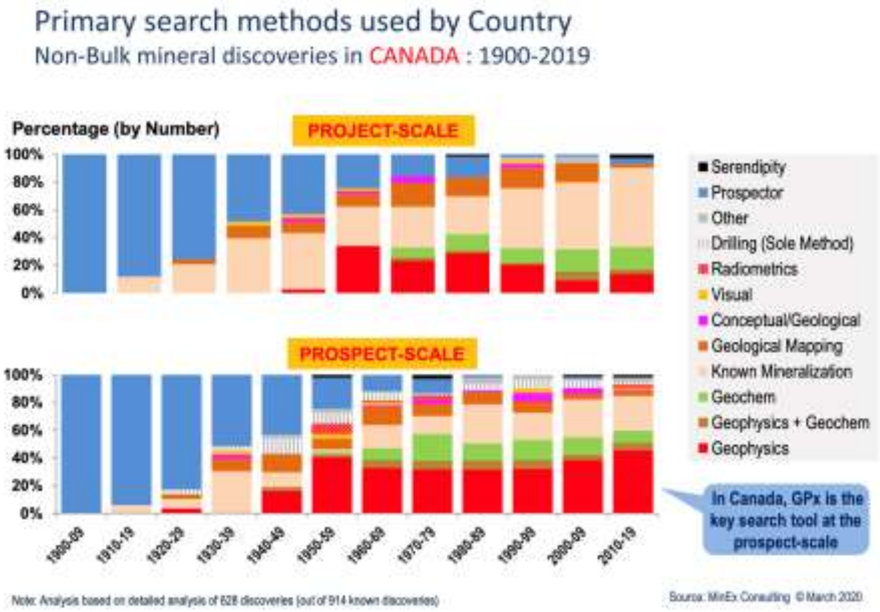
geologic storage of CO_2

geotechnical
(e.g. permafrost)

groundwater

critical minerals

- connecting geologic questions to geophysics
- depth: imaging under cover



Alan Jones talk:
youtube.com/watch?v=T2mZpV6-8-o

[Schodde, 2020]()

geologic storage of CO_2

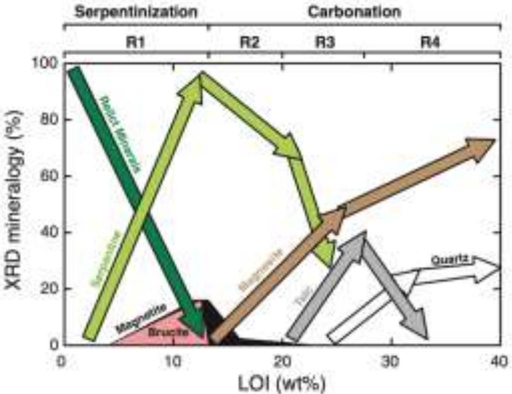
- sedimentary: depleted reservoirs, saline aquifers
- carbon mineralization: CO_2 reacts with mafic or ultramafic rocks to form carbonated minerals

$$\text{R1: olivine} \pm \text{orthopyroxene} + H_2O \rightarrow \text{serpentine} \pm \text{brucite} \pm \text{magnetite}$$

$$\text{R2: olivine} + \text{brucite} + CO_2 + H_2O \rightarrow \text{serpentine} + \text{magnesite} + H_2O$$

$$\text{R3: serpentine} + CO_2 \rightarrow \text{magnesite} + \text{talc} + H_2O$$

$$\text{R4: talc} + CO_2 \rightarrow \text{magnesite} + \text{quartz} + H_2O$$



Cutts et al., 2021;
Mitchinson et al., 2020

managing impacts: permafrost, groundwater…


- permafrost
  - opportunities for AEM to cover large areas
  - IP from AEM?
- groundwater
  - monitoring
  - developing groundwater models, connecting with flow modelling
  - low-cost methods, education in emerging countries

research opportunities: advancing methods in geophysics

- questions in electromagnetics
- integrating geology, physical properties, and geophysics
- joint inversions
- role of machine learning

electromagnetics

- impacts of permeability in EM
- highly conductive targets
- upscaling & physical properties

Magnetic on-time transient electromagnetic (MoTEM) method: A feasibility study at the Raglan nickel mine

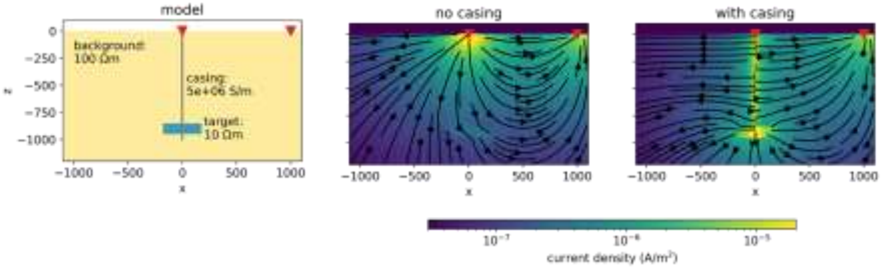
Aline Tavares Melo[*†] *and Yaoguo Li*[†]
[*]*Departamento de Geologia, Universidade Federal de Minas Gerais (UFMG), Brazil*
[†]*Center for Gravity, Electrical & Magnetic Studies (CGEM), Department of Geophysics, Colorado School of Mines*

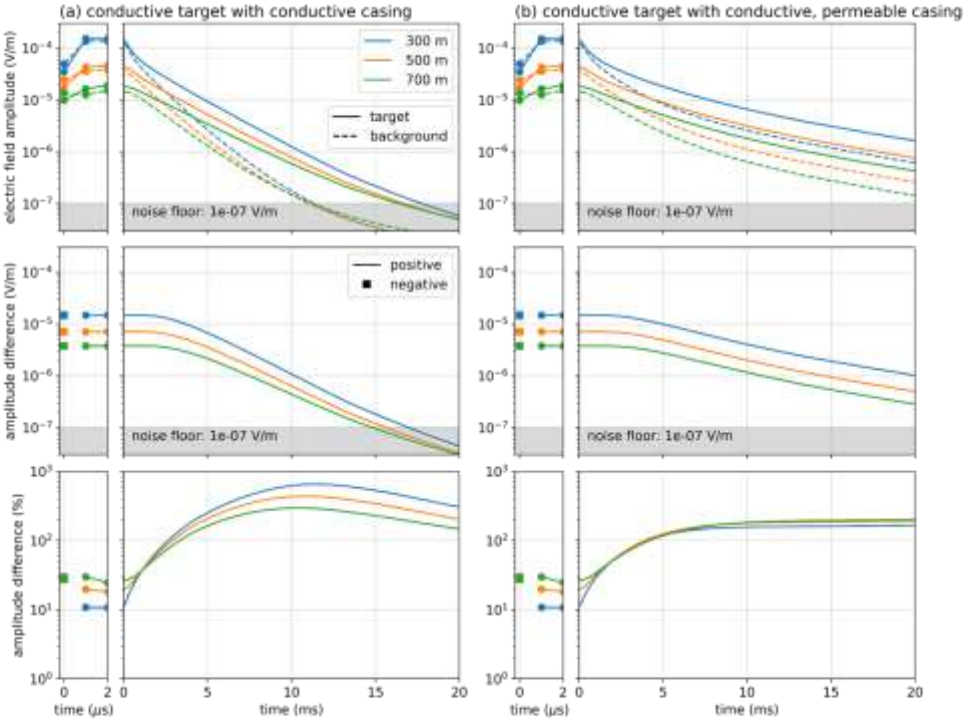
SUMMARY

Magnetic susceptibility imaging is fundamental for mineral exploration, and on-time transient electromagnetic (MoTEM) method provides an active-source alternative to the traditionally geomagnetic method for this purpose. We present a nu-

1997). The field from magnetization decreases the amplitude of the anomaly caused by eddy-currents if the body of high conductivity also has high magnetic susceptibility ($\kappa = \mu/\mu_0 - 1$). Thus, not taking into account the correct magnetic susceptibility can lead to erroneous modeling of conductivities. To avoid this problem, simultaneous mapping of and inversion

(Melo & Li, 2020)





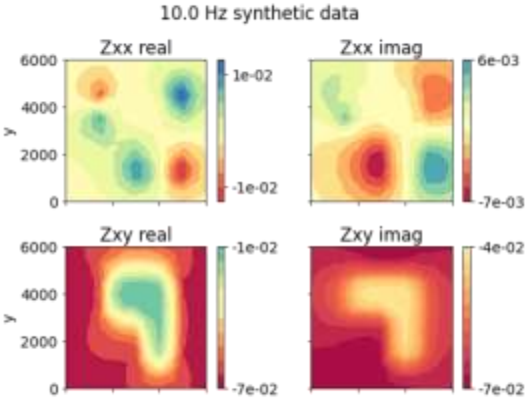
(Heagy & Oldenburg, 2021)

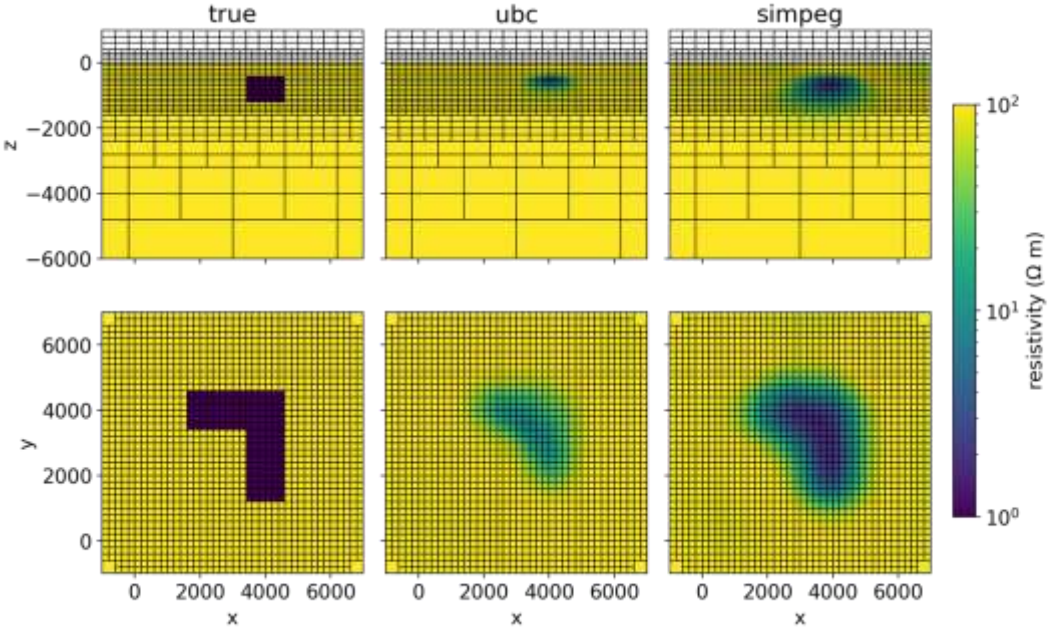
electromagnetics

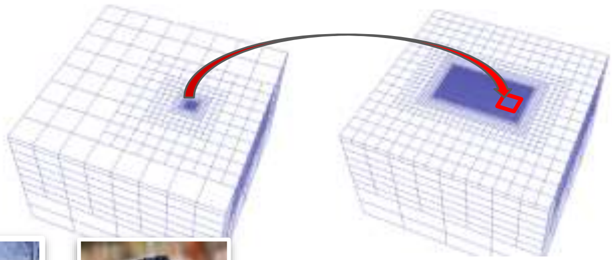
- large scale
- remanent magnetization
- natural source EM
- sparse, compact norms


J. Kuttai


D. Cowan





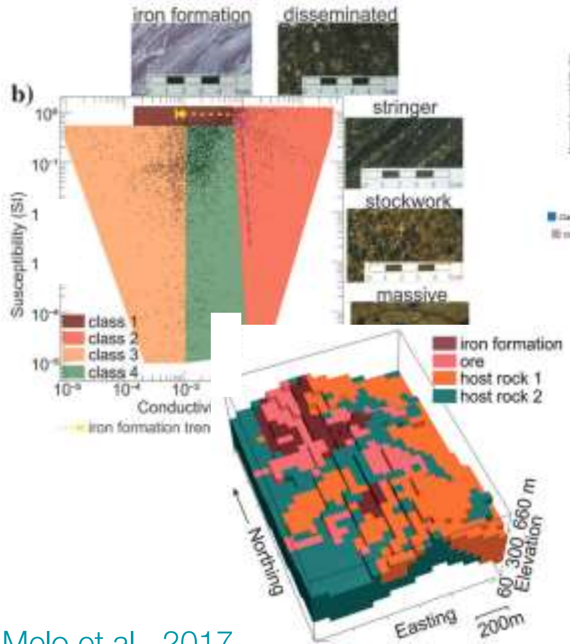



D. Fournier

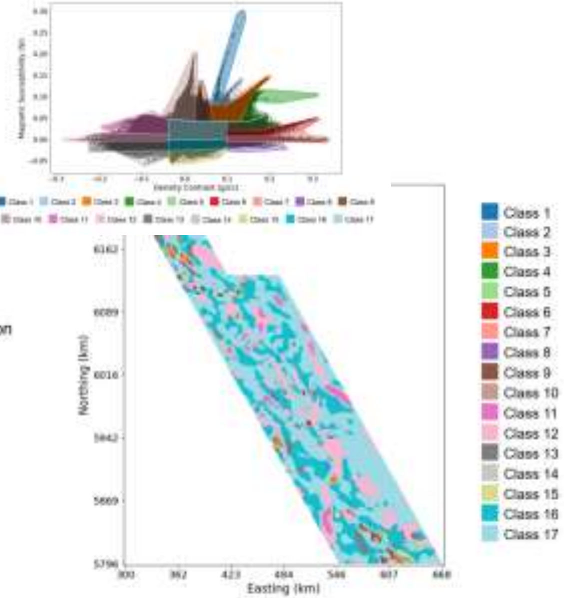

J. Capriotti

integrating geology, physical properties, geophysics

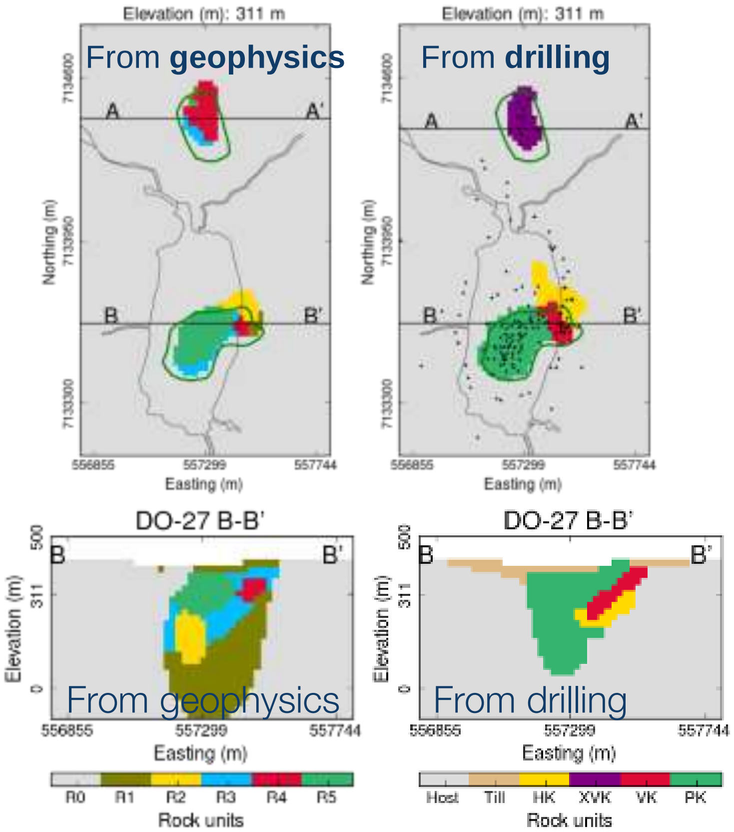
- post-inversion classification
- opportunities with machine learning



[Melo et al., 2017](#)



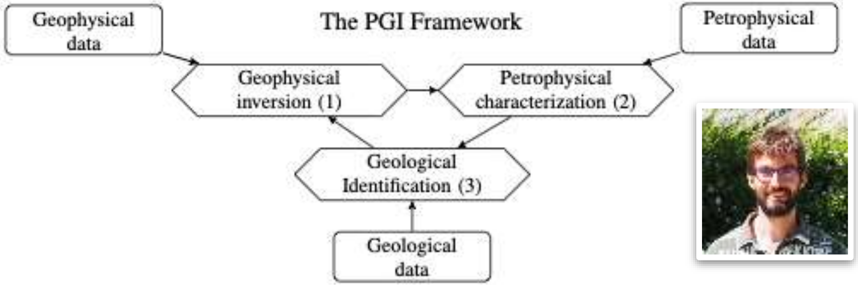
[Kim et al., 2020](#)



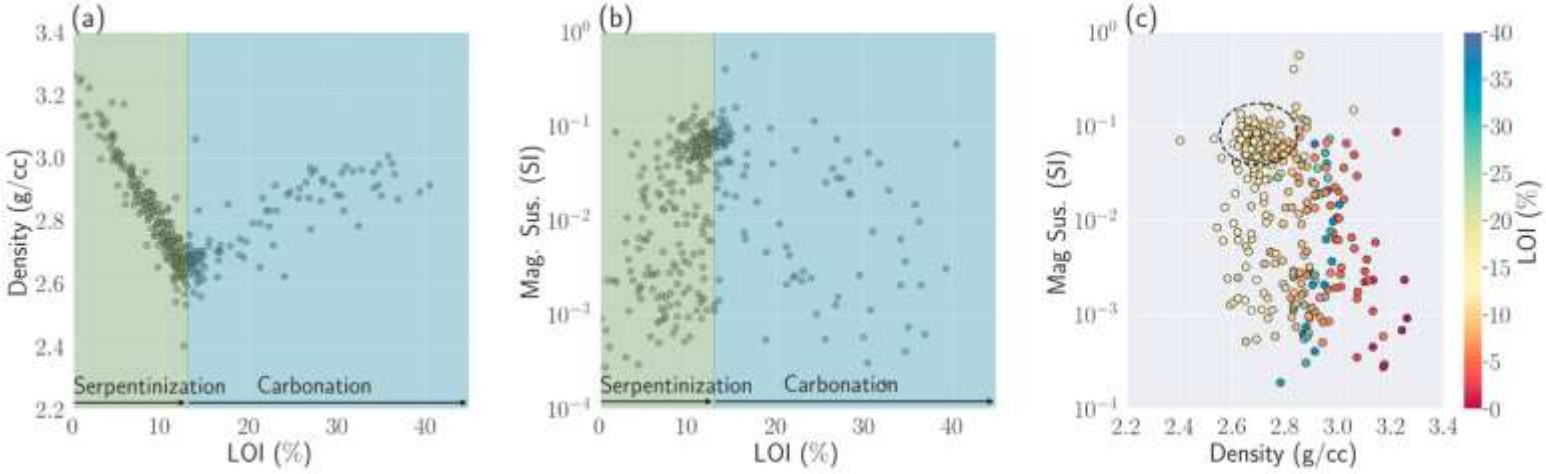
[Devriese et al, 2017](#); [Fournier et al, 2017](#); [Kang et al, 2017](#)

integrating geology, physical properties, geophysics

- including physical property & geologic information in inversions
- Petrophysically and Geologically Guided Inversion (PGI)



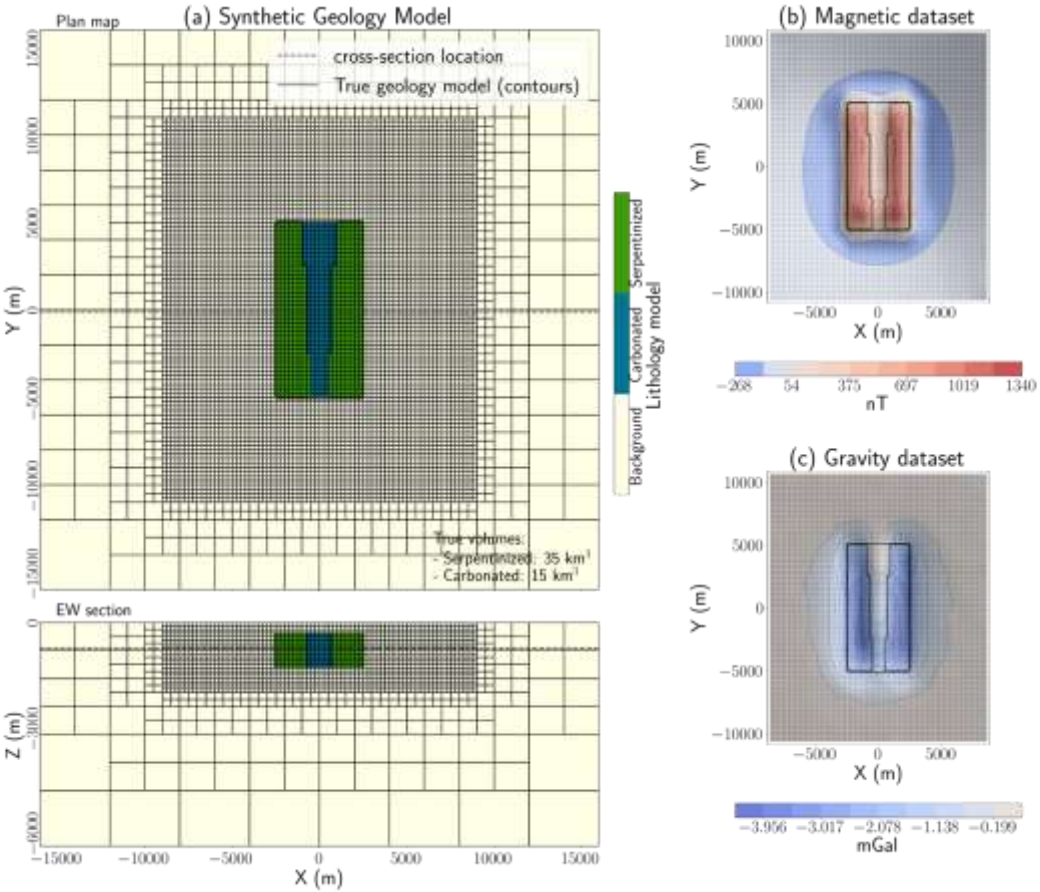
T. Astic



an example: carbon mineralization

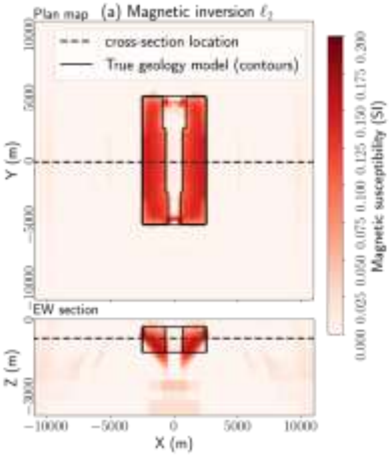
- example motivated by Decar, BC
- goals: delineate, estimate volumes
- future goal: alteration information?

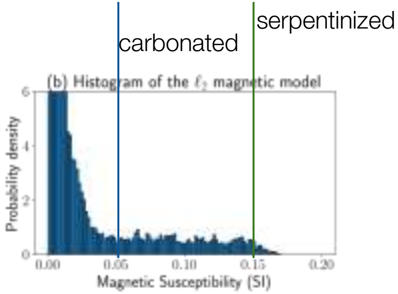
	mag susc (SI)	density (g/cc)	dens contrast (g/cc)
background	0	2.9	0.0
serpentinized	0.15	2.7	-0.2
carbonated	0.05	3.0	0.1

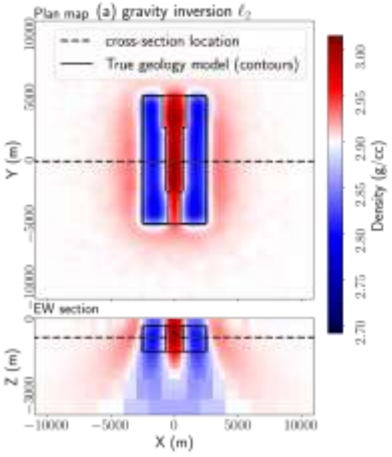


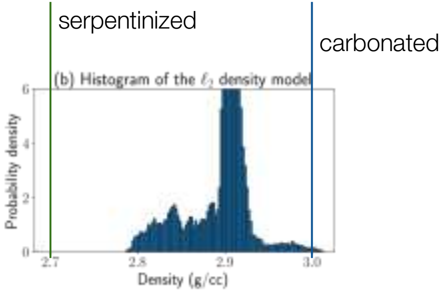
an example: carbon mineralization

ℓ_2

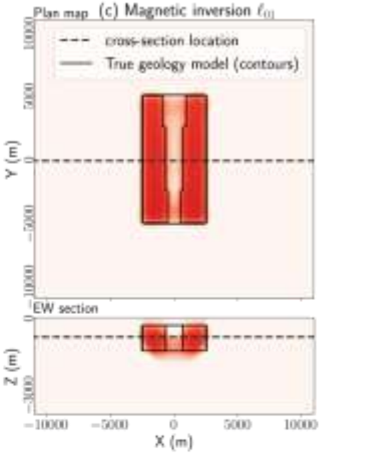


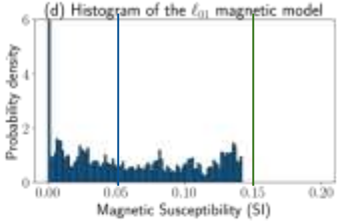


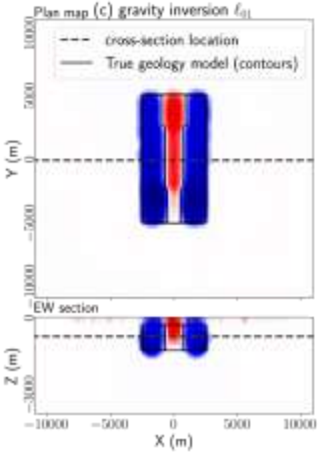


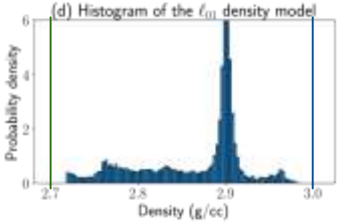


ℓ_{01}



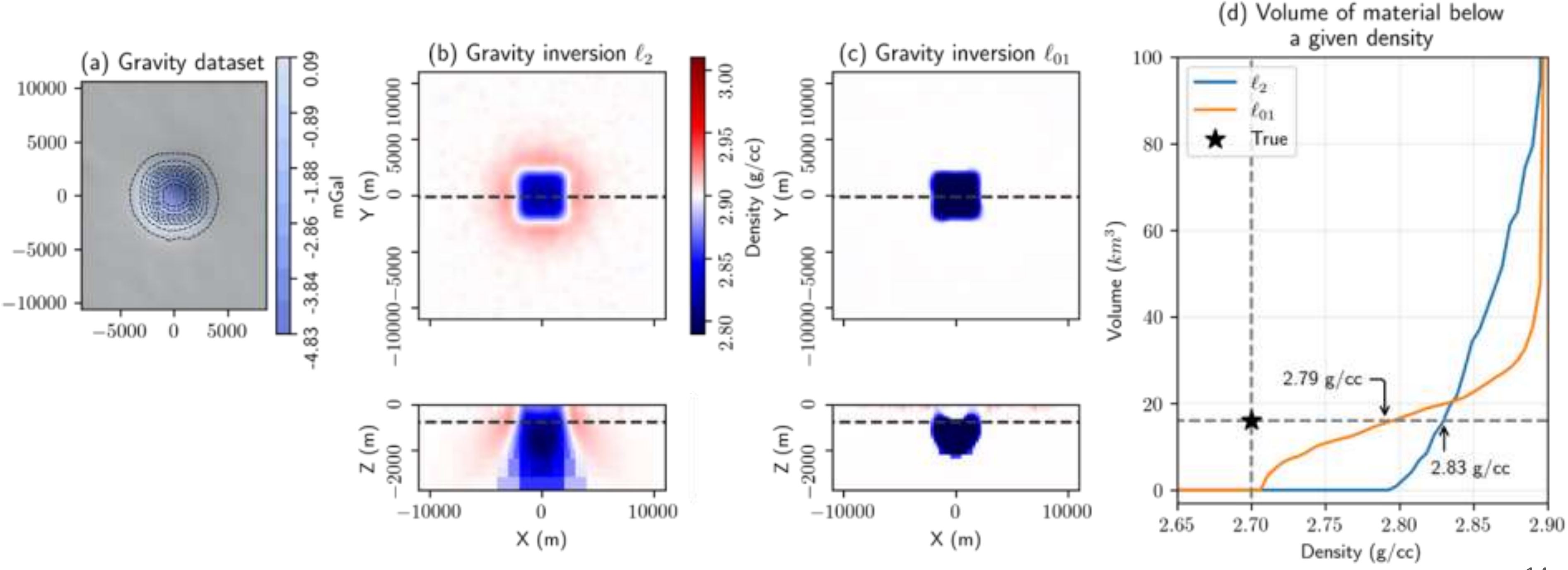






how do we choose a threshold?

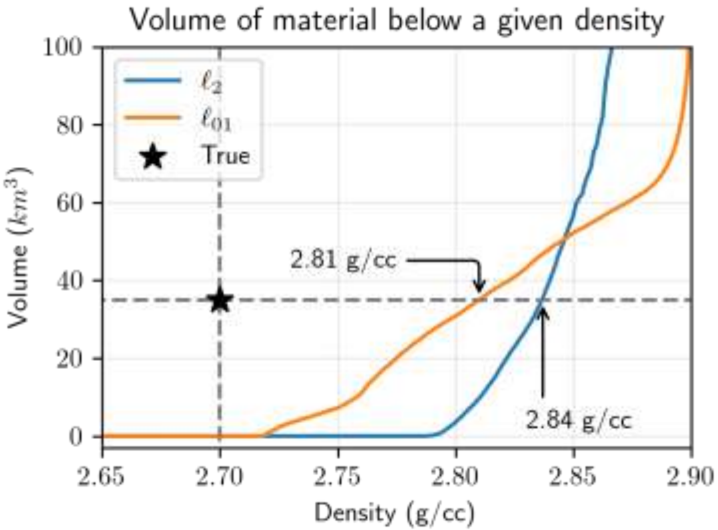
using: identical mesh, survey, inversion parameters, perform simulations and inversions with a representative block.

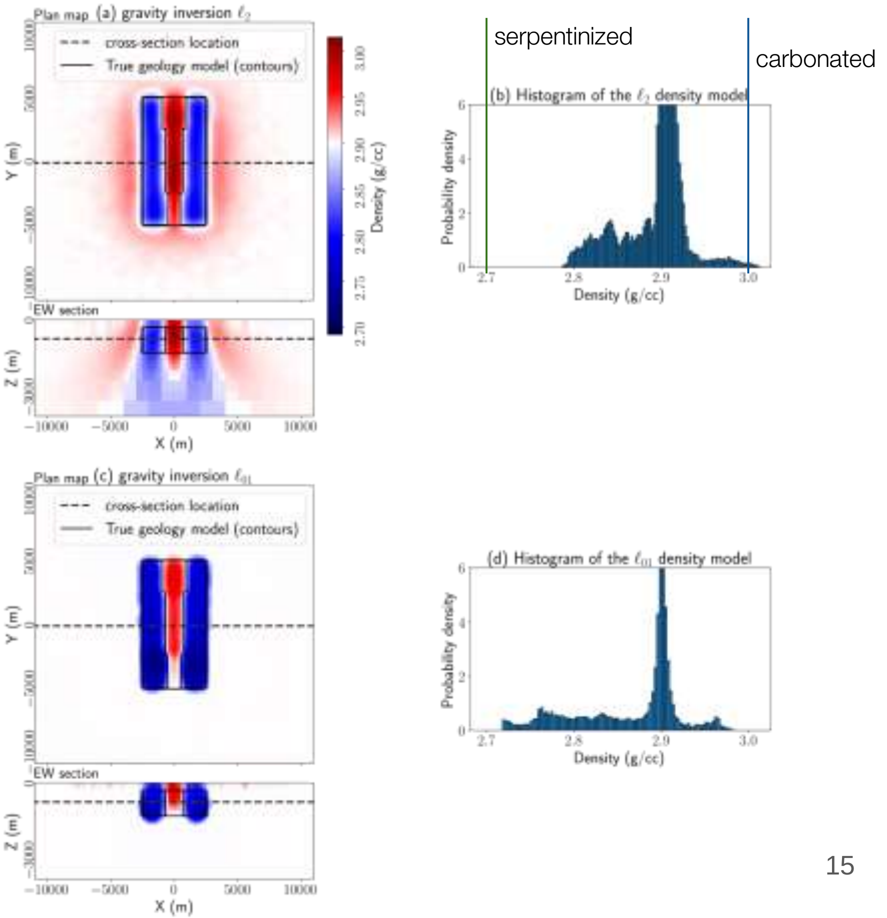


how do we choose a threshold?

Threshold from proxy: 2.83, 2.79 g/cc

- ℓ_2 : 27 km^3
- ℓ_{01}: 27 km^3



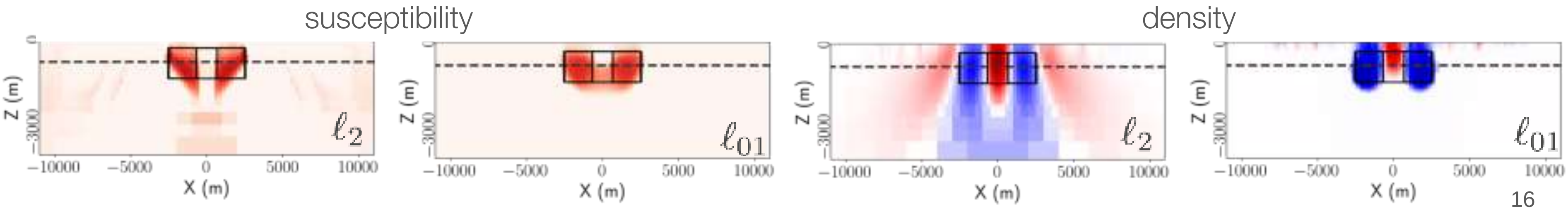


how do we choose a threshold?

- proxy model → tool for estimating an appropriate physical property threshold

Inversion	Threshold for correct volume	Threshold from proxy	Volume estimate with proxy threshold
ℓ_2 magnetics	0.08 SI	0.07 SI	40 km^3
ℓ_{01} magnetics	0.08 SI	0.07 SI	43 km^3
ℓ_2 gravity	2.84 g/cc	2.83 g/cc	27 km^3
ℓ_{01} gravity	2.81 g/cc	2.79 g/cc	27 km^3

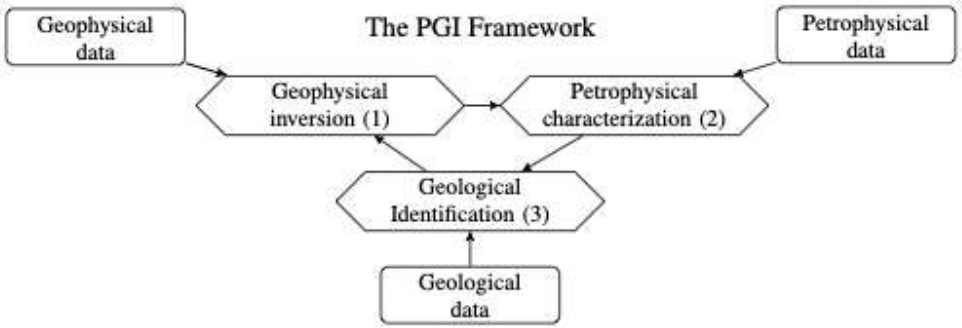
- Also of interest:
    - delineating the top → ex-situ vs. in-situ
    - joint inversion → consistent model?



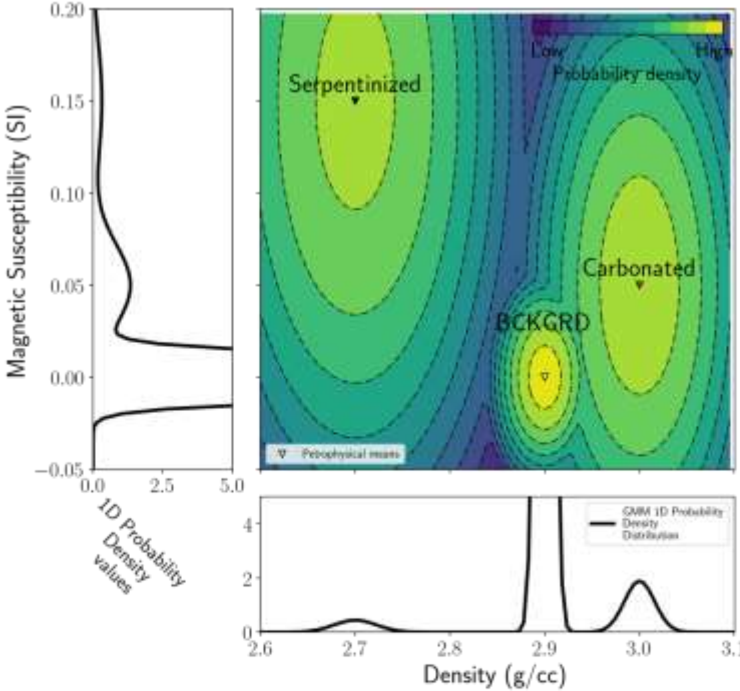
Petrophysically and Geologically Guided Inversion

Alternative approach to the inverse problem

- brings in petrophysical information (GMM)
- builds a quasi-geology model

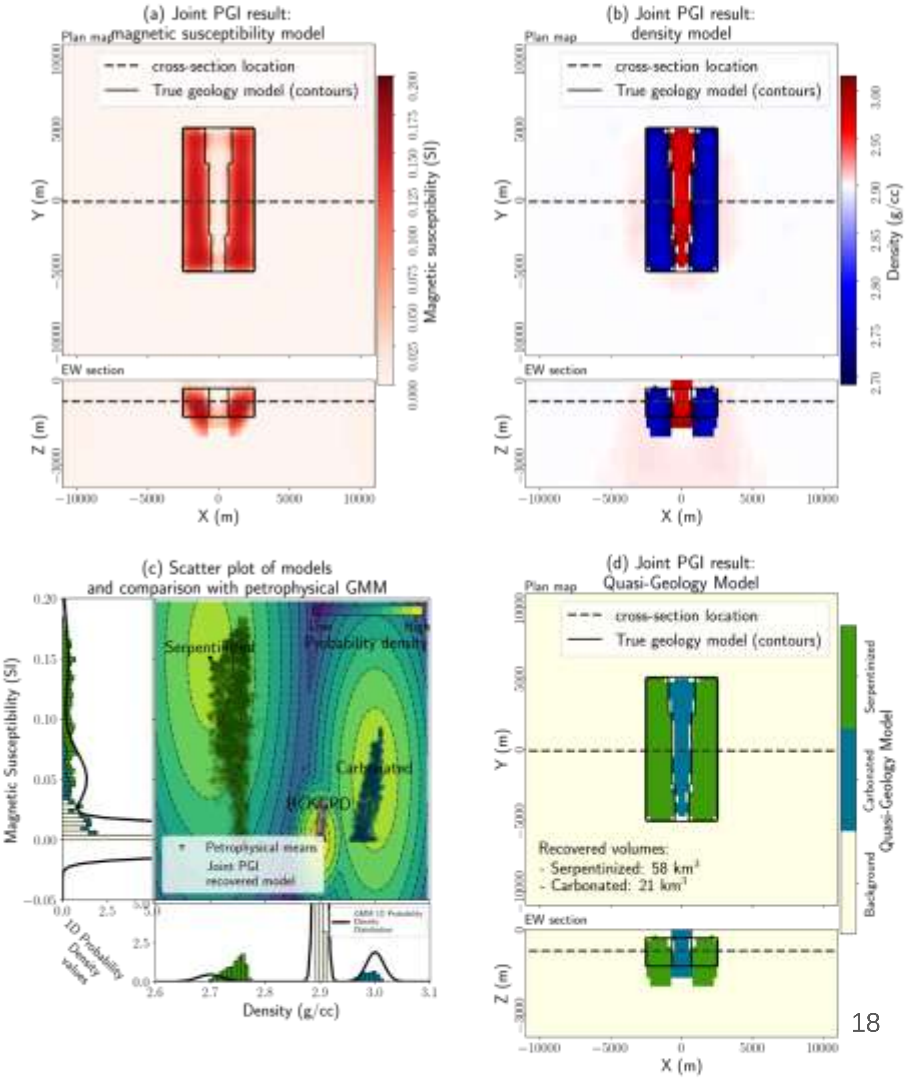


Gaussian mixture model (GMM)



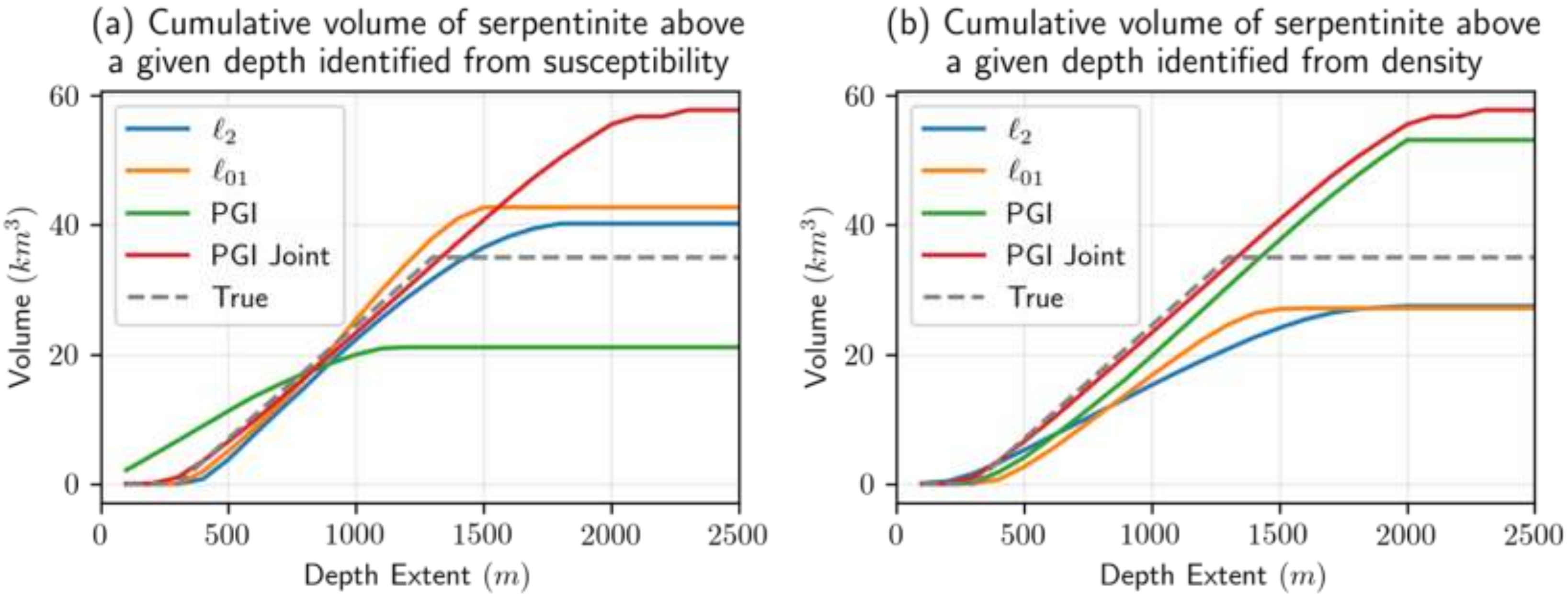
Joint PGI

- Inversion fits both geophysical data sets and petrophysical data
  - Weighting strategies to balance contributions (Astic et al, 2021)
- One quasi geology model consistent with both data sets
- Good estimate to top of serpentinized rock volume



cumulative volume estimates with depth

- Total volume of interest for CO_2 sequestration capacity
- Depth of practical importance for in-situ vs. ex-situ



a sampling of research avenues

- questions in electromagnetics
  - strong conductors
  - magnetic permeability
  - natural source EM
  - large scale
- integrating geology, physical properties, and geophysics & joint inversions
  - post inversion classification
  - PGI
  - non-linear inversions (EM)
- role of machine learning

critical minerals

geologic storage of CO_2

geotechnical (e.g. permafrost)

groundwater

geophysics in a changing climate

VOLUME 1 JANUARY, 1936 NUMBER 1

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A Journal of General and Applied Geophysics

Volume 20 | Issue 4 | October 1955

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geophysics in a changing climate

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geophysics in a changing climate

GEOPHYSICS

VOL. 87, No. 1 | January-February 2022

https://seg.org/WhatGeophysicistsDo

Energy

The energy demand of 9 billion people is enormous. Although alternative and renewable energy sources are growing in importance, hydrocarbons are needed to meet the majority of the energy demand and are expected to be required for decades to come. The majority of population growth is anticipated to be in developing nations. Assuming that everyone has the right to expect a good quality of life, we must strive to ensure that there is sufficient energy available to make this possible. Applied geophysics helps provide energy and can improve the efficiency and safety of oil and gas operations, while reducing the environmental impact.

Water

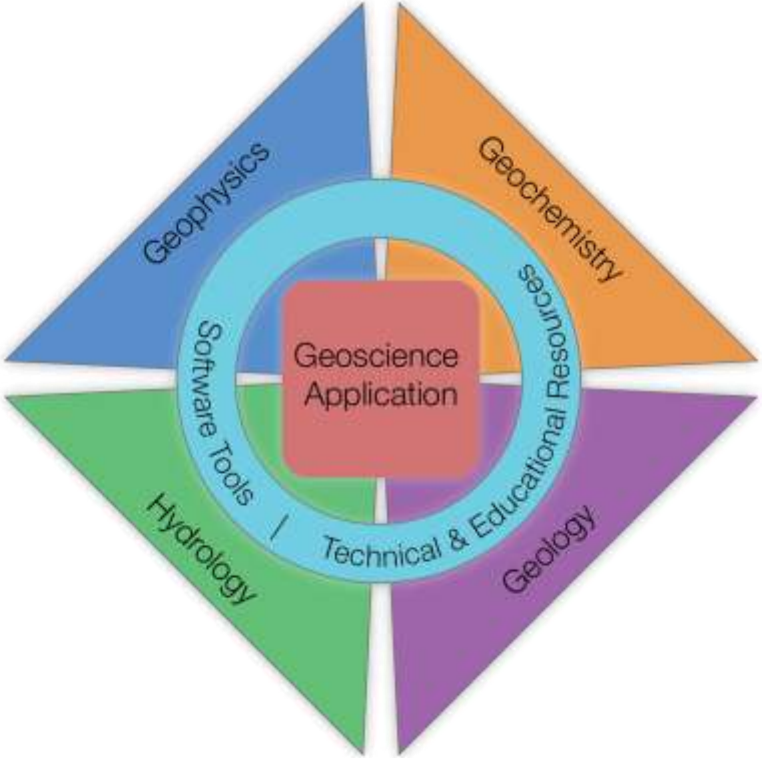
Although water is essential for life, more than 10% of the world's population lacks access to clean water. Without a change in water management practices, more than half of the world's population will live in areas with severely stressed water systems by 2050. Applied geophysics should play a major role in improved management of groundwater systems. SEG programs, such as Geoscientists Without Borders®, are making important contributions to this vital area of societal need.

Climate

The earth is continuously undergoing climate change, but the current rate of change is expected to have an increasing impact on humanity. Human produced CO2 emissions are a significant factor. Many SEG members play a role in both understanding climate change and in managing CO2 emissions, including observing glacier and ice sheet volume, studying glacier hydrology, evaluating permafrost degradation, and evaluating and monitoring reservoirs for CO2 sequestration.

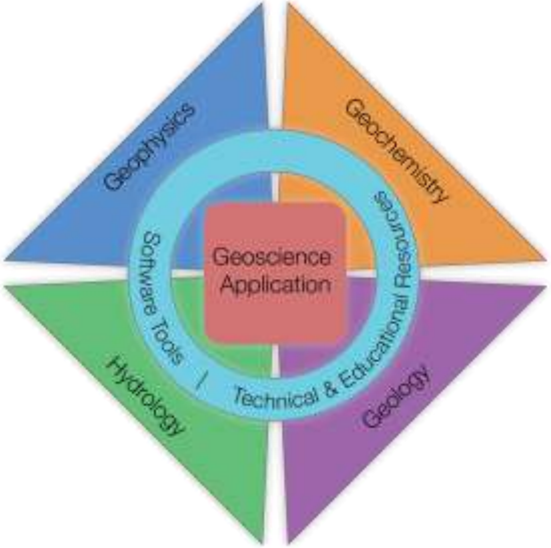
geophysics in a changing climate

- where does geophysics fit in interdisciplinary problems?
- who is involved?
- what is the brand of applied geophysics?



interdisciplinary questions

- Technical: machine learning + inversion for combining data
- Collaboration: between disciplines
- Role of open science, educational resources



simpeg GemPy emsig subsurface

Fatiando a Terra pyGIMLi Geophysical Inversion & Modelling Library THE GENERIC MAPPING TOOLS PyGMT PyVista

who is involved?

comment

Race and racism in the geosciences

Geoscientists in the United States are predominantly White. Progress towards diversification can only come with a concerted shift in mindsets and a deeper understanding of the complexities of race.

Kuheli Dutt

comment

No progress on diversity in 40 years

Ethnic and racial diversity are extremely low among United States citizens and permanent residents who earned doctorates in earth, atmospheric and ocean sciences. Worse, there has been little to no improvement over the past four decades.

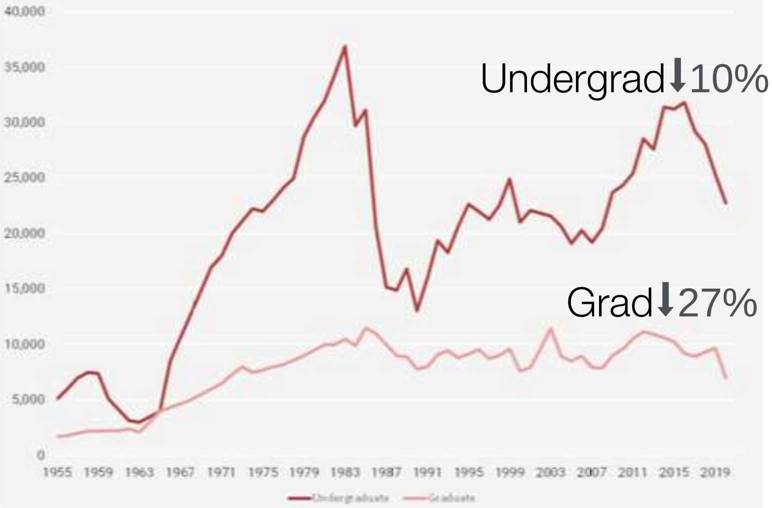
Rachel E. Bernard and Emily H. G. Cooperdock

The bigger picture
In 2016, only 6% of geoscience doctorates awarded to US citizens and permanent residents went to students from underrepresented minorities, a group who made up 31% of the US population that year[6]

AGI GEOSCIENCE CURRENTS

U.S. Geoscience Enrollments and Degrees Collapse in 2019-2020

Geoscience Enrollments in the United States, 1955-2020



ways forward?

- rebranding “applied geophysics”
  - connecting with values
  - proactive on climate change solutions
  - including emphasis on technology, computation
- role of societies
  - maintain / promote brand of applied geophysics
  - engage students
  - BCGS, KEGS scholarships / internships
- amplifying positive initiatives
- …?

Women Geoscientists in Canada

GeoLatinas

BLACK in GEOSCIENCE

thank you!

BCGS
BC Geophysical Society

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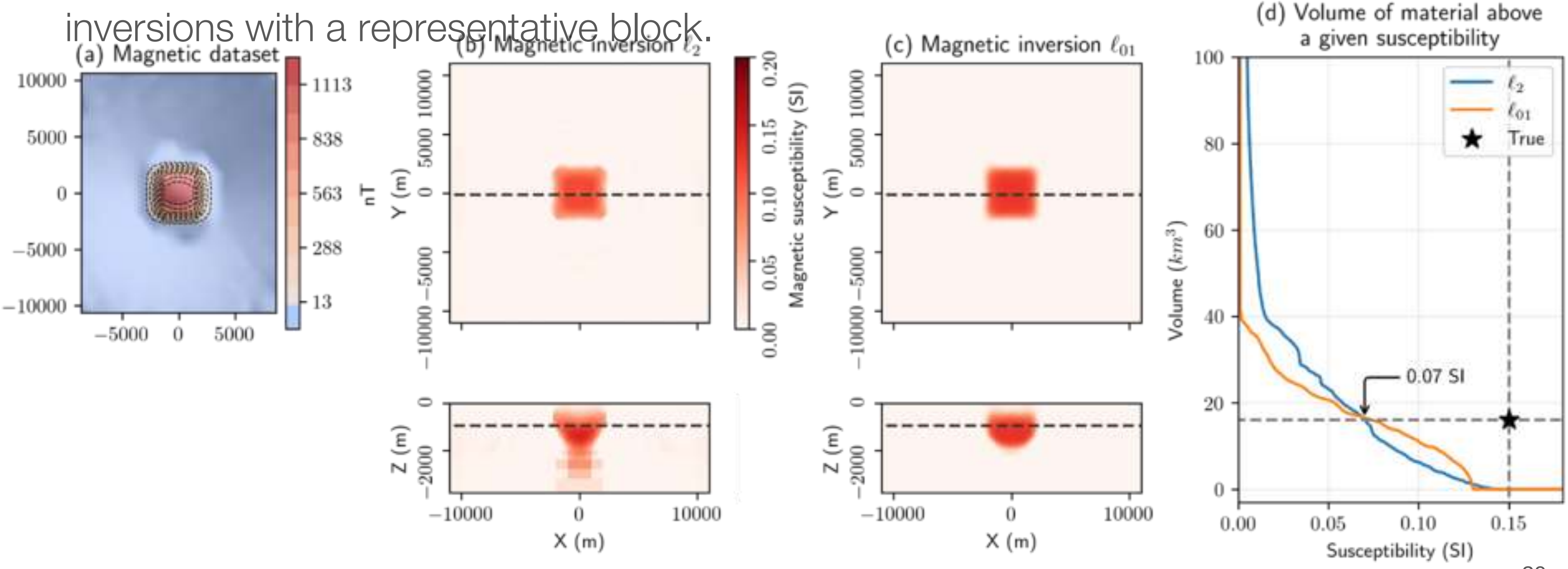
@lheagy

@lindsey_jh

Magnetics: proxy model

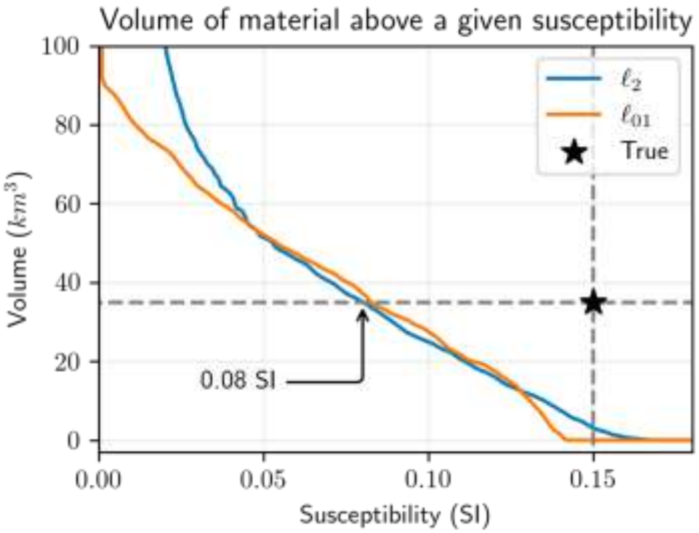
using: identical mesh, survey, inversion parameters, perform simulations and inversions with a representative block.



Magnetics

Use threshold from proxy: 0.07 SI

- ℓ_2 : 40 km^3
- ℓ_{01}: 43 km^3



ℓ_2

ℓ_{01}