accelerating geophysics research in a changing climate

Lindsey Heagy

University of British Columbia

Future of Applied Geophysics
Bay Area Geophysical Society & Colorado School of Mines

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

🚀 accelerating geophysics research in a changing climate

What are the “base layer” tools we can invest in as a community?

Where can we build positive feedback cycles?

Who is involved and how do we empower new contributors?

important problems

solutions & mitigating impacts: opportunities for geophysics

critical minerals

geologic storage of CO_2

geotechnical
(e.g. permafrost)

groundwater

important problems

solutions & mitigating impacts: opportunities for geophysics

- electromagnetics
  - highly conductive, magnetic infrastructure
  - upscaling & physical properties
  - natural source EM
- connecting physical properties & geology
  - joint inversions
  - opportunities with ML

- permafrost
  - Airborne EM to cover large areas
  - IP from AEM?
- groundwater
  - monitoring
  - developing groundwater models, connecting with flow modelling
  - low-cost methods, education

...

geologic storage of CO_2

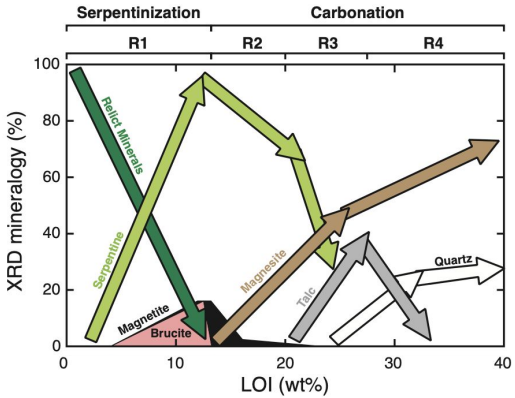
- sedimentary: depleted reservoirs, saline aquifers
- carbon mineralization: CO_2 reacts with mafic or ultramafic rocks to form carbonated minerals

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

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

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

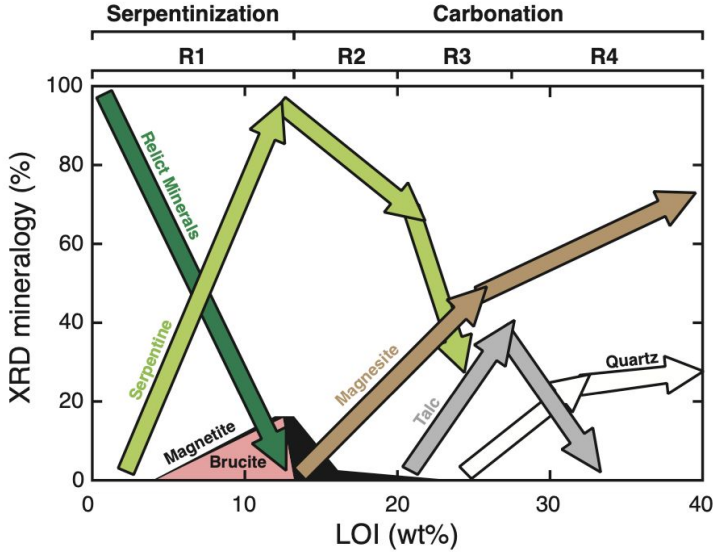
$$\text{R4: talc} + CO_2 \rightarrow \text{magnesite} + \text{quartz} + H_2O$$



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

carbon mineralization

- mafic, ultramafic rocks rich in Ca, Mg can react with CO_2 to form carbonated minerals
- approaches:
  - **ex-situ:** bring rocks to surface (e.g. in mine tailings) where they react
  - **in-situ:** circulate CO_2 charged fluid to react subsurface
- Ultramafics: serpentinized rocks are reactive

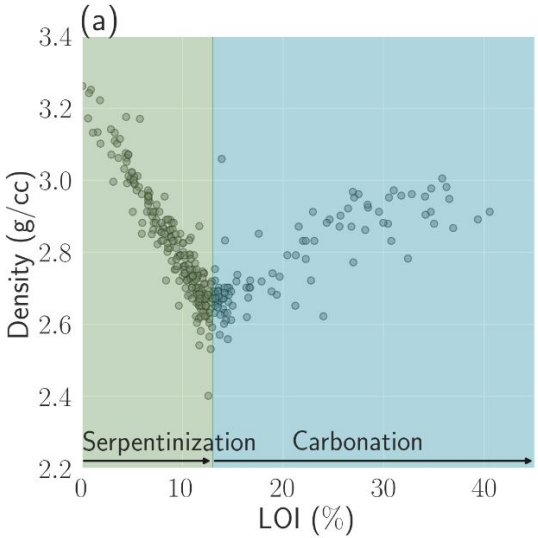


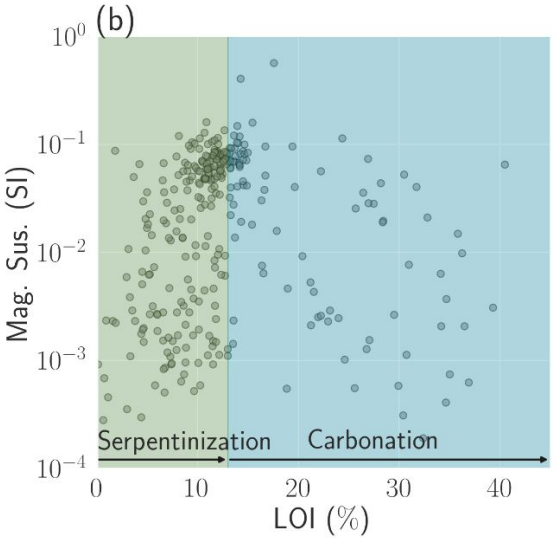
(Mitchinson et al, 2020)

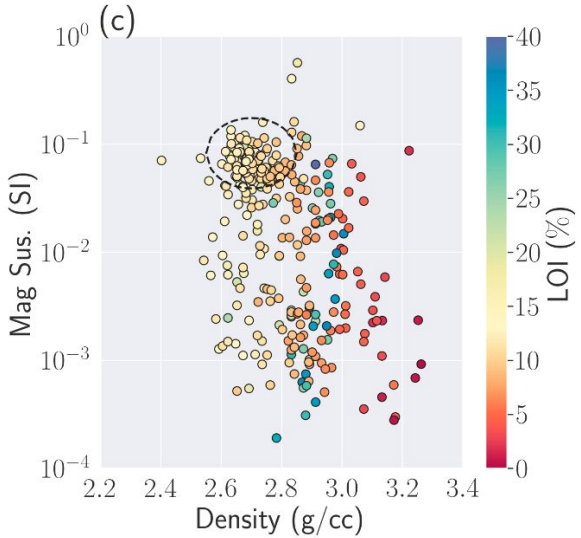
$\mathrm{R1:\ olivine \pm orthopyroxene + H_2O \rightarrow serpentine \pm brucite \pm magnetite}$	serpentinization
$\mathrm{R2:\ olivine + brucite + CO_2 + H_2O \rightarrow serpentine + magnesite + H_2O}$ $\mathrm{R3:\ serpentine + CO_2 \rightarrow magnesite + talc + H_2O}$ $\mathrm{R4:\ talc + CO_2 \rightarrow magnesite + quartz + H_2O}$	carbonation

carbon mineralization: physical properties

- LOI: proxy for alteration
- density, susceptibility change with LOI
- goals: delineate serpentinized rock, estimate volume (and alteration?)
- motivates joint inversion, including a-priori information in the inversion







(Data from Cutts et al, 2021)

carbon mineralization: simulations and inversions

Forward simulation:

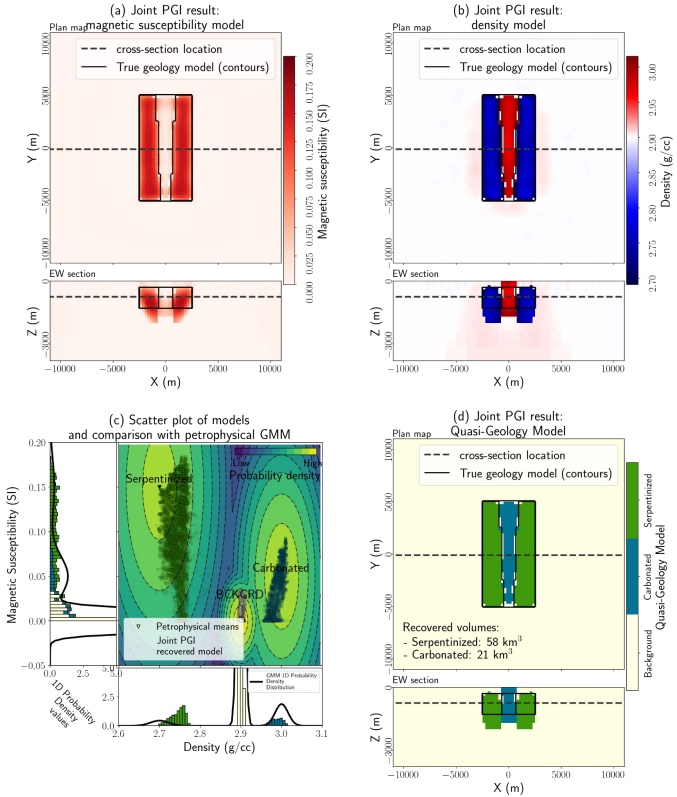
- Finite volume operators
- OcTree meshes

Inversion:

$$\min_{\mathbf{m}} \phi(\mathbf{m}) = \phi_d(\mathbf{m}) + \beta\phi_m(\mathbf{m})$$

$$\text{s.t. } \phi_d \leq \phi_d^* \quad \mathbf{m}_L \leq \mathbf{m} \leq \mathbf{m}_U$$

- Sparse, Compact norms
- Joint inversions:
  - Cross-gradient
  - Petrophysically & Geologically guided Inversion (PGI)
  - …



(Heagy et al., 2021)

carbon mineralization: simulations and inversions

Forward simulation:

- Finite volume operators
- OcTree meshes


R. Cockett


J. Capriotti


S. Kang

Inversion:

$$\min_{\mathbf{m}} \phi(\mathbf{m}) = \phi_d(\mathbf{m}) + \beta\phi_m(\mathbf{m})$$

$$\text{s.t. } \phi_d \leq \phi_d^* \quad \mathbf{m}_L \leq \mathbf{m} \leq \mathbf{m}_U$$

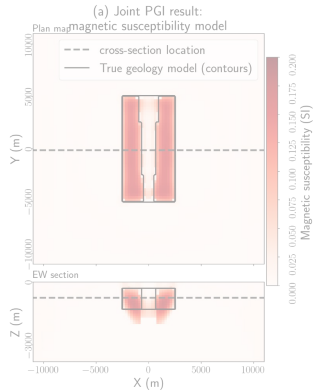
simpeg

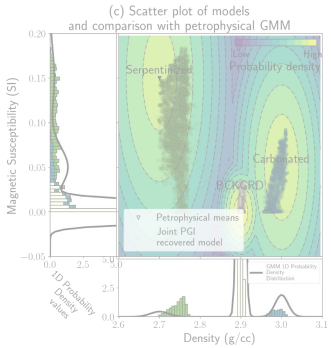
- Sparse, Compact norms
- Joint inversions:
  - Cross-gradient
  - Petrophysically & Geologically guid on (PGI)
  - …


D. Fournier


T. Astic


X. Wei





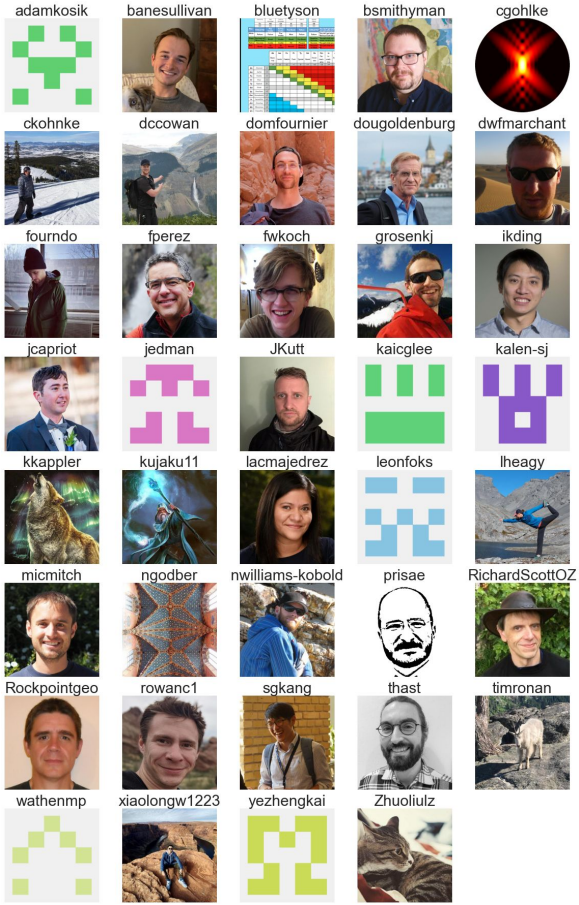
(Heagy et al., 2021)

(almost!) 10 years of SimPEG

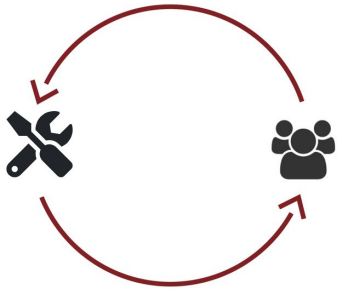
simpeg

Some components for success

- **Openness:** free to use, adapt, extend
- **Framework:** organize ideas, inherit from base layers
- **Modular:** separate components into self-contained pieces
- **Interoperable:** enable the components to interact
- **Extensible:** build with the idea that others will do new things
- **Tested:** build confidence, scenarios where you trust the work
- **Documented:** provide entry points
- **Community:** it is about enabling people

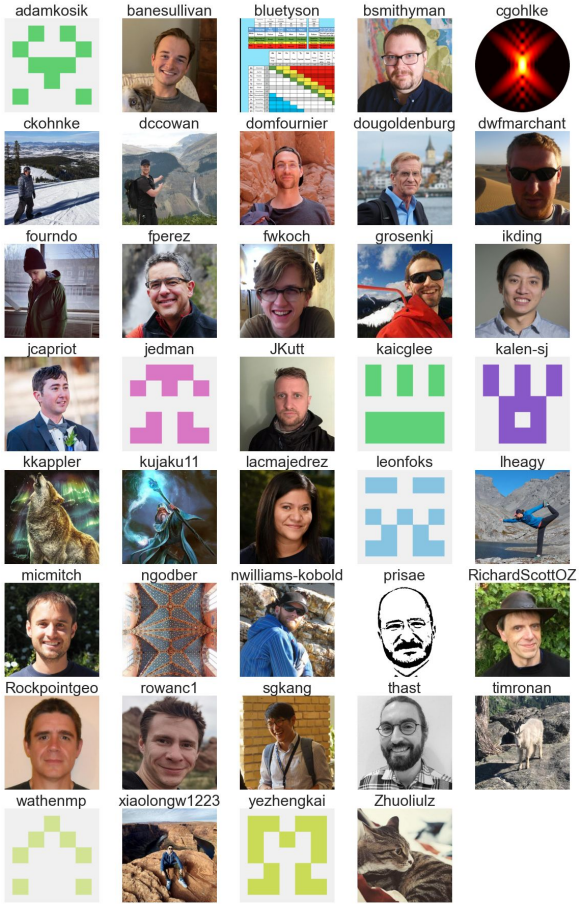


(almost!) 10 years of SimPEG

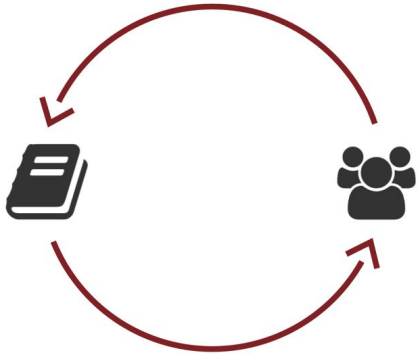


Some transferable ideas(?)

- **Openness:** free to use, adapt, extend
- **Framework:** organize ideas, inherit from **base layers**
- **Modular:** separate components into self-contained pieces
- **Interoperable:** enable the components to interact
- Extensible: build with the idea that others will do new things
- Tested: build confidence, scenarios where you trust the work
- Documented: provide entry points
- **Community**: it is about enabling people



parallels in research?



What are the **“base layer” tools** we can invest in as a community?

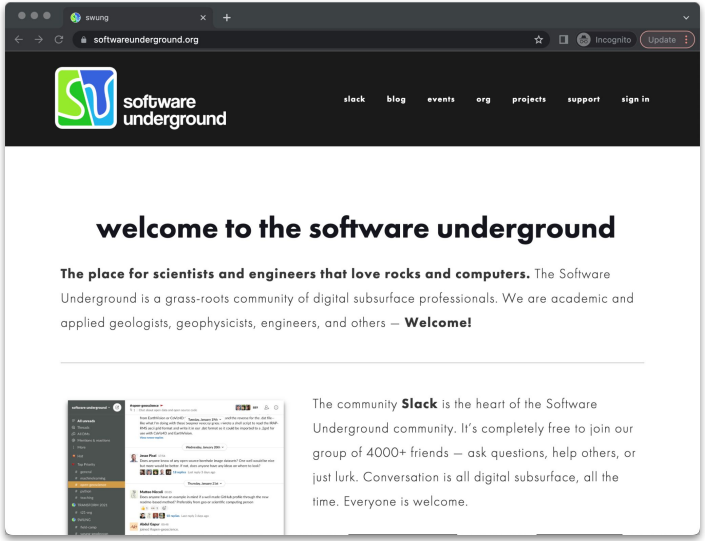
Where can we build **positive feedback** cycles?

Who is involved and how do we empower new contributors?

parallels in research?

Base layers:

- **software**
- educational resources?
- others?



simpeg

GemPy

emcig

subsurface

Fatiando a Terra

pyGIMLi

Geophysical Inversion & Modelling Library

GMT

THE GENERIC MAPPING TOOLS

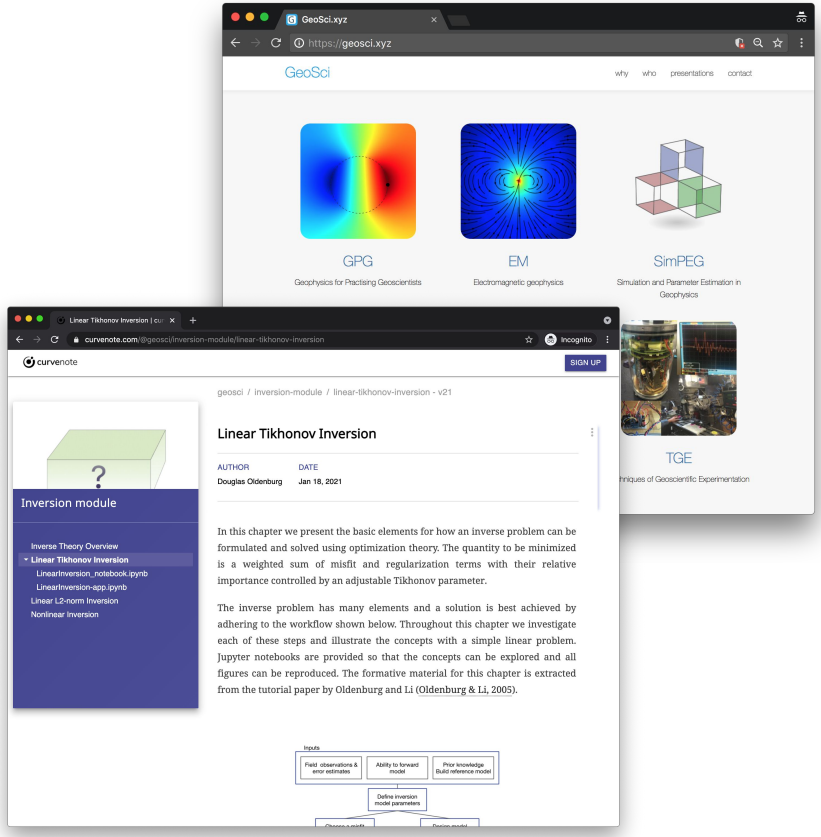
PyGMT

PyVista

parallels in research?

Base layers:

- software
- **educational resources?**
- others?

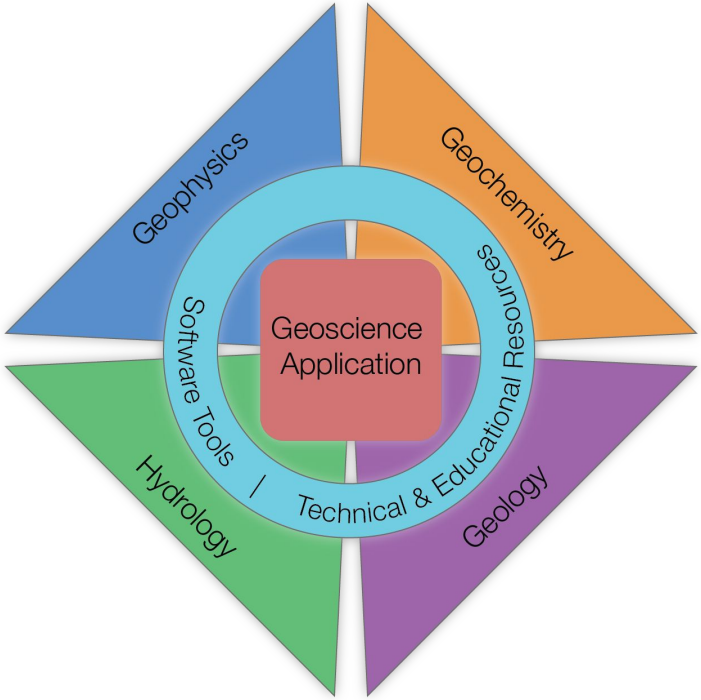


geosci.xyz

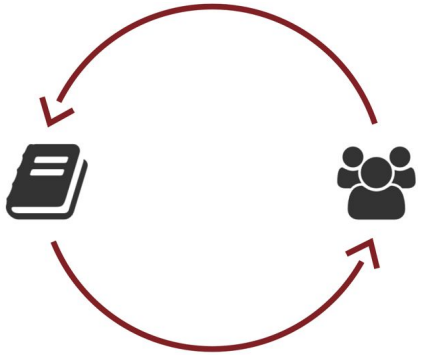
parallels in research?

Base layers:

- software
- educational resources?
- **others?**
  - connections to other disciplines: engineering & geotechnical applications, monitoring…
  - challenges: communicating expectations & uncertainty



parallels in research?



What are the “base layer” tools we can invest in as a **community**?

Where can we build positive feedback cycles?

Who is involved and **how do we empower new contributors**?

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.

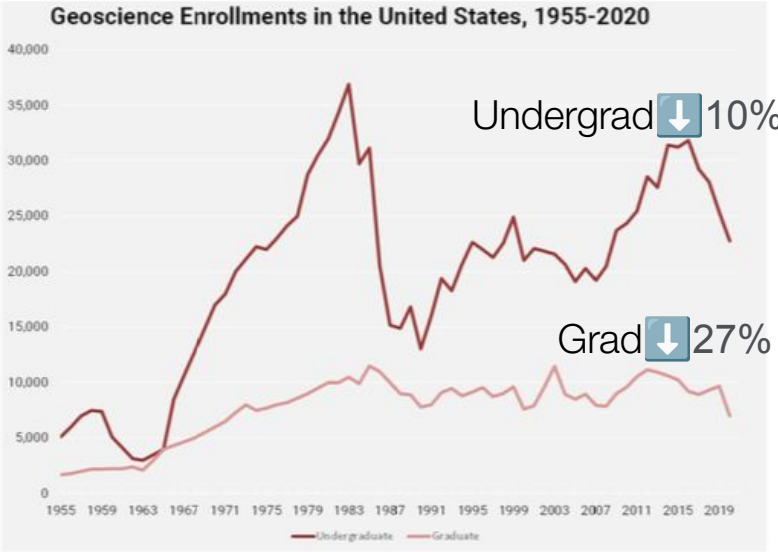
Rachel E. Bernard and Emily H. G. Cooperdock

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 american geosciences institute connecting earth, science, and people GEOSCIENCE CURRENTS

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



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
  - scholarships / internships
- amplifying positive initiatives
- …?

Women Geoscientists in Canada

GeoLatinas

BLACK in GEOSCIENCE

🚀 accelerating geophysics research in a changing climate

What are the “base layer” tools we can invest in as a community?

Where can we build positive feedback cycles?

Who is involved and how do we empower new contributors?

thank you!

lheagy@eoas.ubc.ca

@lheagy

@lindsey_jh

COLORADO SCHOOL OF MINES

BAGS
BAY AREA GEOPHYSICAL SOCIETY

Yaoguo Li

Mike Wilt