

accelerating geophysics research in a changing climate

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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 CO₂



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

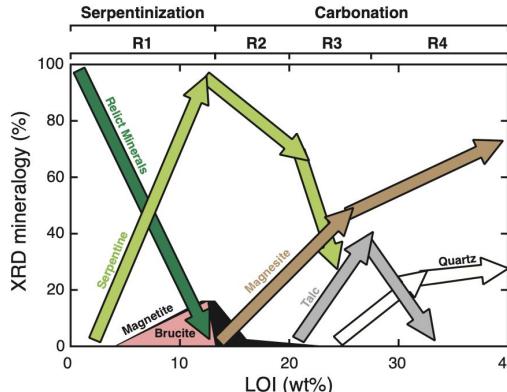
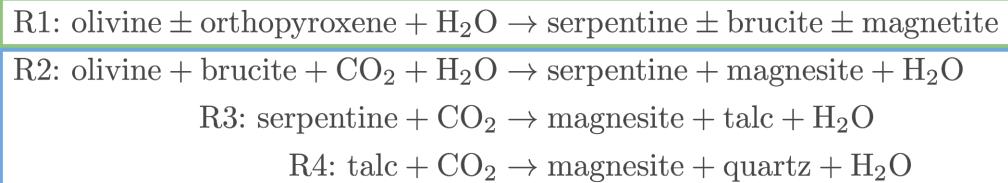


- permafrost
 - Airborne EM to cover large areas
 - IP from AEM?
- groundwater
 - monitoring
 - developing groundwater models, connecting with flow modelling
 - low-cost methods, education

...

geologic storage of CO₂

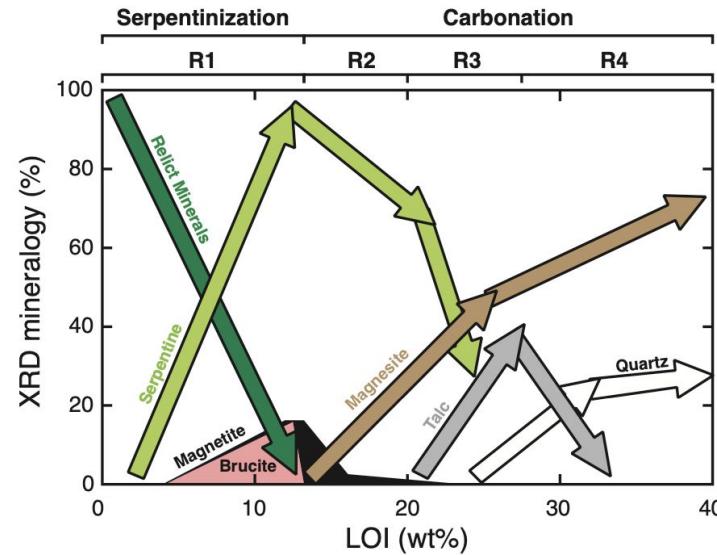
- sedimentary: depleted reservoirs, saline aquifers
- carbon mineralization: CO₂ reacts with mafic or ultramafic rocks to form carbonated minerals



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

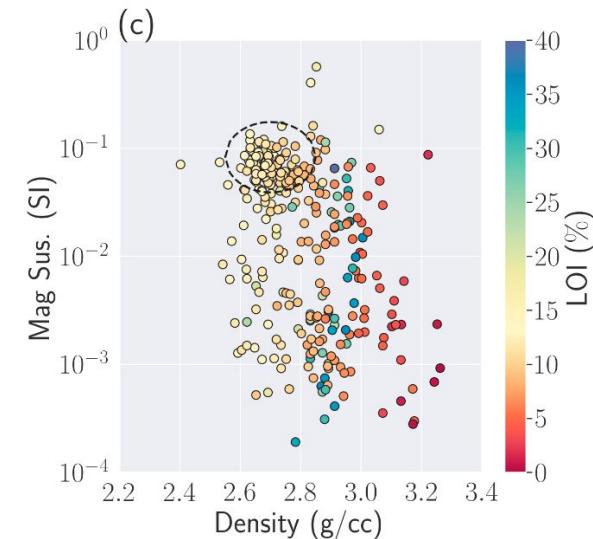
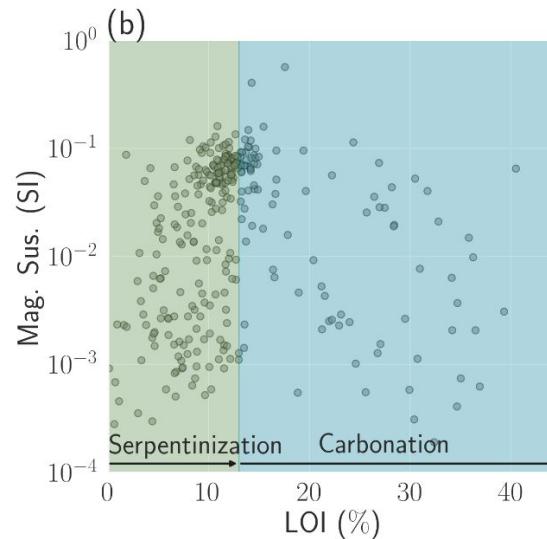
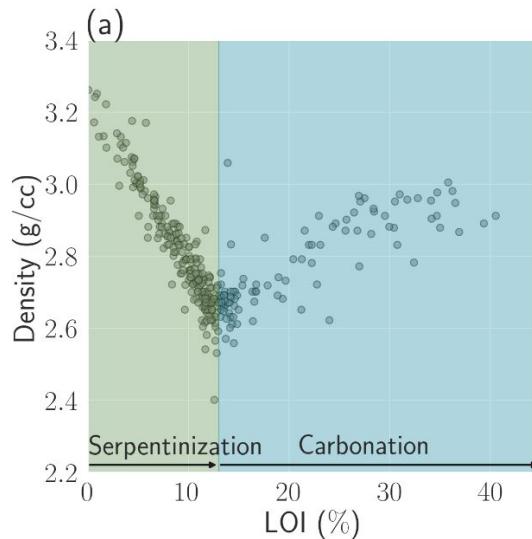


([Mitchinson et al. 2020](#))

R1: olivine \pm orthopyroxene + $\text{H}_2\text{O} \rightarrow$ serpentine \pm brucite \pm magnetite	serpentinization
R2: olivine + brucite + CO_2 + $\text{H}_2\text{O} \rightarrow$ serpentine + magnesite + H_2O	
R3: serpentine + $\text{CO}_2 \rightarrow$ magnesite + talc + H_2O	carbonation
R4: talc + $\text{CO}_2 \rightarrow$ magnesite + quartz + H_2O	

carbon mineralization: physical properties

- LOI: proxy for alteration
- density, susceptibility change with LOI
- goals: delineate serpentined 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:

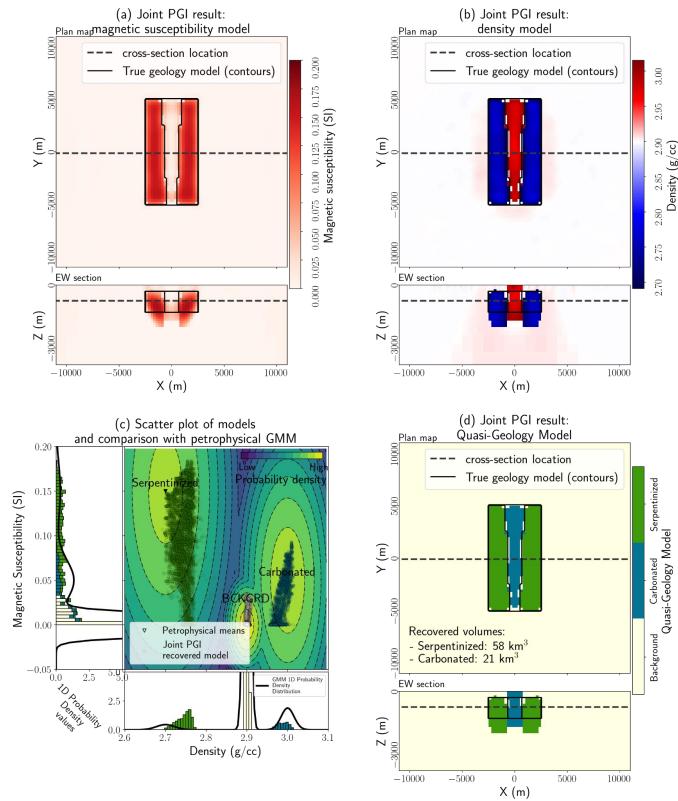
- Finite volume operators
- OcTree meshes

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)

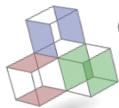
carbon mineralization: simulations and inversions

Forward simulation:

- Finite volume operators
- OcTree meshes

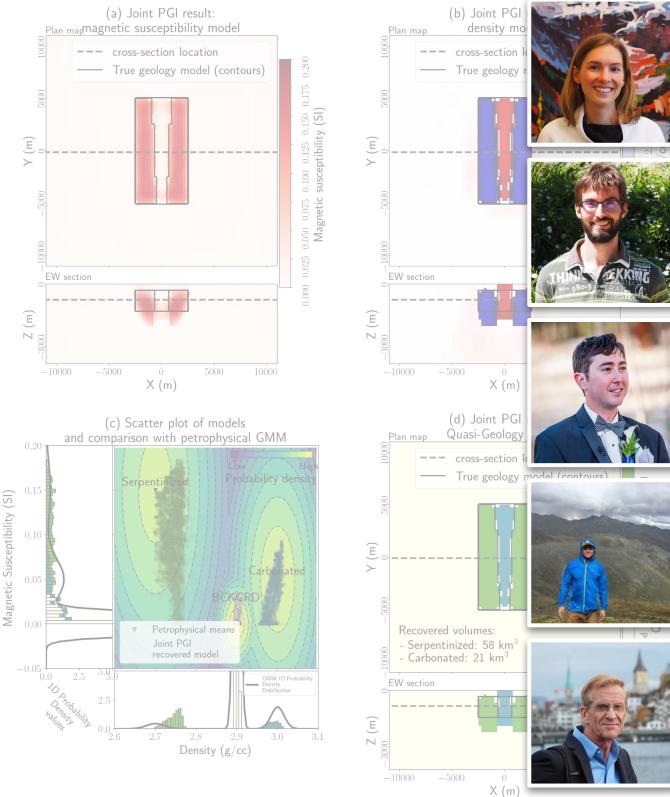


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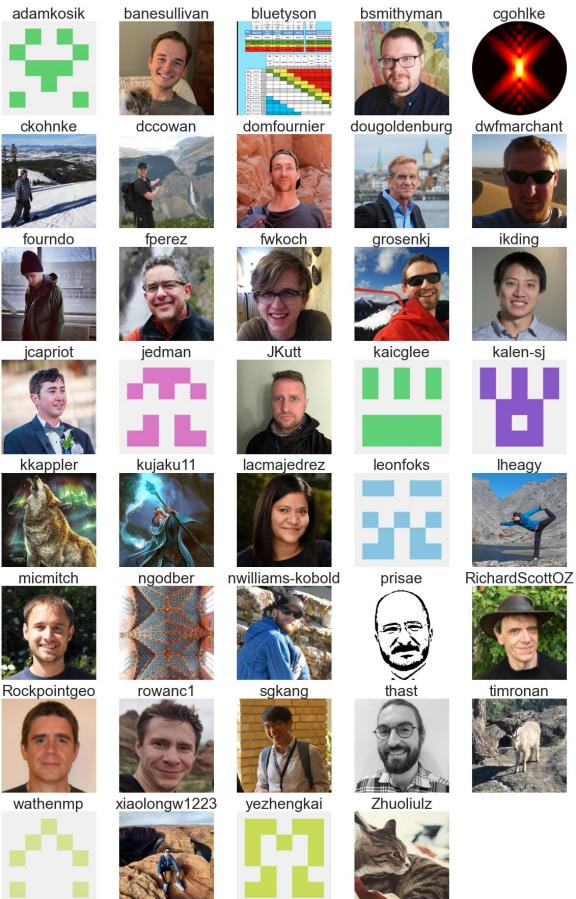


(almost!) 10 years of SimPEG

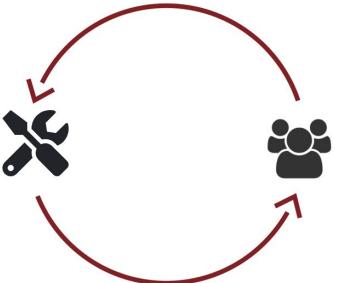


Some components for success

- **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

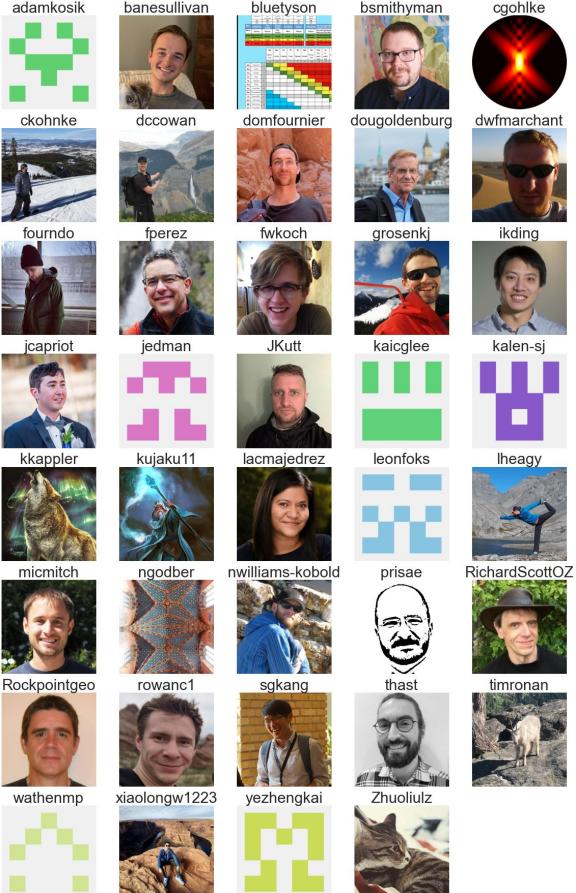


(almost!) 10 years of SimPEG

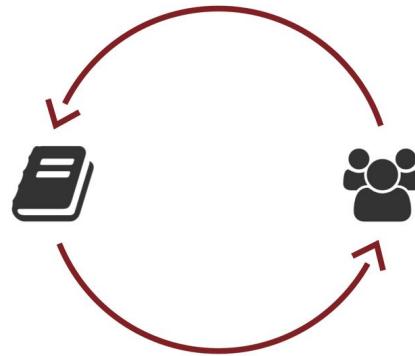


Some transferable ideas(?)

- **Openness:** free to use, adapt, extend
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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?

The screenshot shows the homepage of softwareunderground.org. At the top, there's a navigation bar with links for slack, blog, events, org, projects, support, and sign in. Below the navigation is a logo consisting of a green 'S' and a blue 'U' followed by the text "software underground". The main heading "welcome to the software underground" is in bold. Below it, a sub-headline reads "The place for scientists and engineers that love rocks and computers." A brief description follows: "The Software Underground is a grass-roots community of digital subsurface professionals. We are academic and applied geologists, geophysicists, engineers, and others — **Welcome!**" A horizontal line separates this from a section about Slack. On the left, there's a screenshot of the Slack interface showing a channel named "general" with several messages. To the right, a text block explains that the Slack community is the heart of the Software Underground, consisting of over 4000 members who ask questions, help others, or just lurk, all in a digital subsurface environment.



simpeg



GemPy



subsurface



Fatiando
a Terra



pyGIMLI
Geophysical Inversion & Modelling Library



PyGMT
THE GENERIC MAPPING TOOLS

PyVista

parallels in research?

Base layers:

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

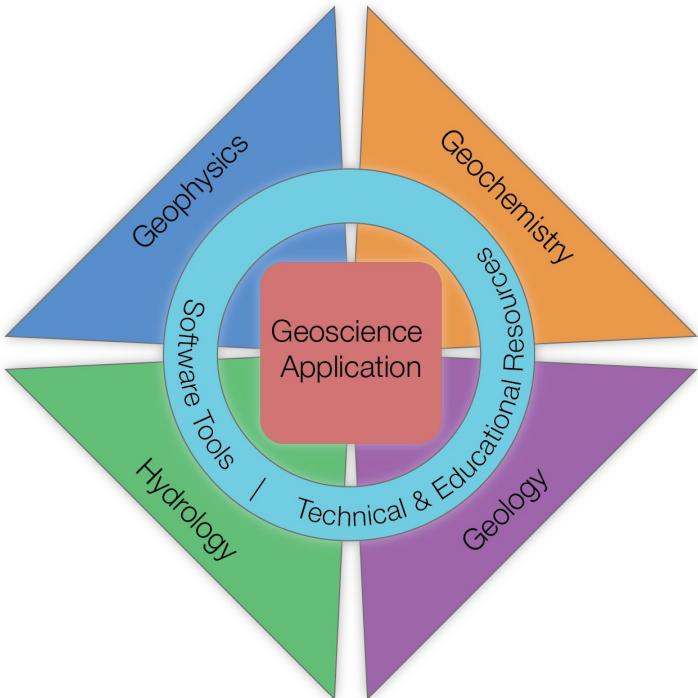
The screenshot shows two browser windows side-by-side. The top window is the GeoSci.xyz homepage, featuring sections for GPG (Geophysics for Practising Geoscientists) and EM (Electromagnetic geophysics), each with a corresponding visualization (heatmaps) and a 3D cube icon for SimPEG. The bottom window is a Jupyter notebook titled 'Linear Tikhonov Inversion' from the 'Inversion module' chapter. It includes a sidebar with navigation links like 'Inverse Theory Overview', 'Linear Tikhonov Inversion', 'Nonlinear inversion', and 'Inputs' (Field observations & error estimates, Ability to forward model, Prior knowledge, Build reference model). The main content area describes the basic elements of an inverse problem and its workflow.

geosci.xyz

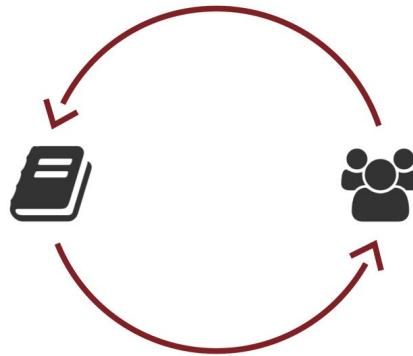
parallels in research?

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**?

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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

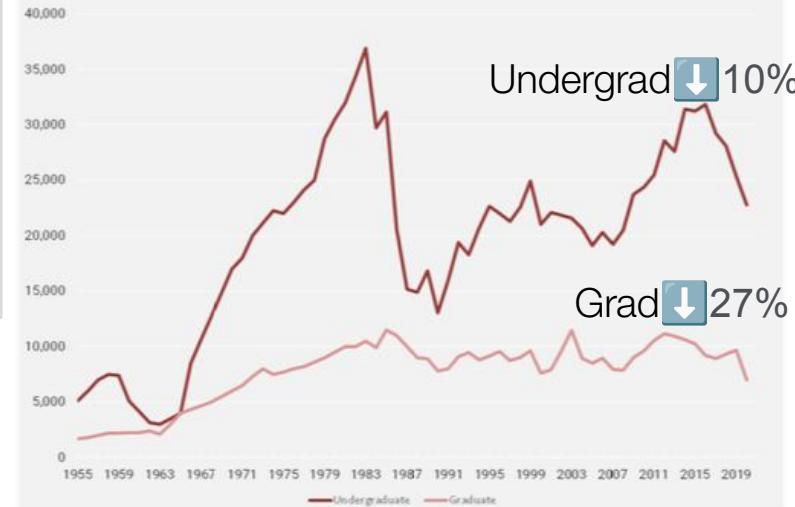
In 2016, only 6% of geoscience doctorates awarded to US citizens and permanent residents went to students from underrepresented minorities, a group who made up 31% of the US population that year⁶



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
 - scholarships / internships
- amplifying positive initiatives
- ...?





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thank you!

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Yaoguo Li



Mike Wilt

