Understanding Glacier Thinning and Retreating During the Last Glacial Maximum in Yosemite to Predict Contemporary Deglaciation

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November 24, 2022

Abstract

We describe new cosmogenic Be-10 and C-14 exposure age dating on previously glaciated bedrock samples from Lyell Canyon as constraints to model the glacier's rate and timing of thinning and retreat after the Last Glacial Maximum (LGM). Close analysis of deglaciation following the LGM (22-12 ka) can offer insight into how glacier retreat proceeds in a warming climate. The extent and age of the LGM glaciation in Yosemite National Park, California are relatively well-constrained. Our new exposure ages from Yosemite can quantify the change of the glaciation after the LGM. This is important because the rate and timing of glacier retreat after the LGM allows us to learn about the LGM-Holocene climate transition. We collected 16 granodiorite bedrock samples from the Lyell Canyon walls in three vertical transects: at the end, in the middle, and near the head of Lyell Canyon. Sample elevations range from 2781m to 3388m. The samples are being processed for cosmogenic Be-10 and C-14 concentrations (for the lower and higher elevations in the transects, respectively). Together with previously acquired Be-10 exposure ages from glacial polished bedrock and boulders at the canyon floor, our vertical transects will help to define the relationship between glacier retreat and thinning along the valley. The combination of different nuclide measurements has the potential to reveal whether the glacier melted rapidly or went through multiple thinning and thickening cycles. We created several simple forward models of cosmogenic Be-10 and C-14 exposure ages on the valley wall for different glacier thinning patterns: (i) rapid thinning, (ii) thinning and thickening cycles during the melting, (iii) thickening first, followed by thinning, and (iv) breaking an upper small cirque glacier from the main glacier during the thinning. After we have obtained all our data, we will compare the exposure age data to our modeled scenarios, as well as local paleoclimate records, to quantify the glacier's geometry and mass balance during the climate warming period. Understanding the timing, rates, and patterns of LGM retreat and thinning constitute a useful test case that aids mountain glacier melting predictions and water budget planning under contemporary climate change in analogous environments.

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Tulane University Cosmogenic Nuclide Laboratory

SURF SUMMER UNDERGRADUATE RESEARCH FELLOWSHIPS

DEPARTMENT OF EARTH & PLANETARY SCIENCE

Background

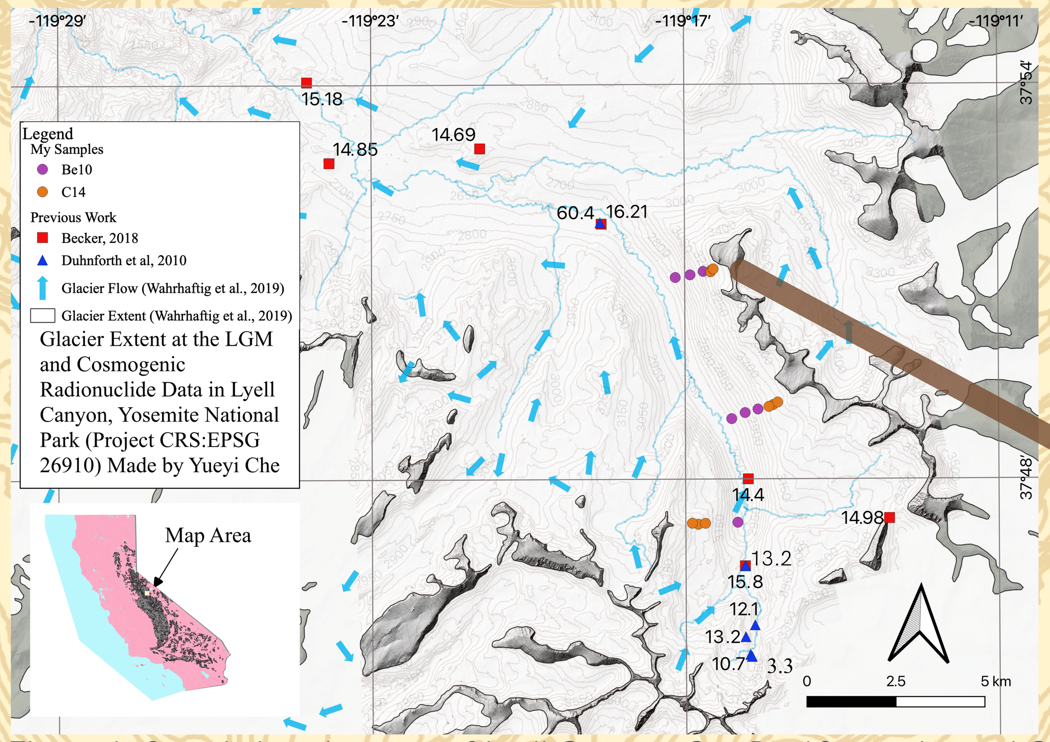


Figure 1. Sample location map of Lyell Canyon. Our Be-10 samples and C-14 samples are in three verticle transects on the valley wall (16 samples total). The map also shows previous studies' Be-10 exposure ages on the valley floor in thousands of years (Becker, 2018; Duhnforth et al, 2010). The base map is generated from USGS data, as well as the river flowline in the valley. The small map at the lower left shows the map area in the middle of the Sierra Nevada batholith (Jennings et al., 1977).

Figure 2. The U-shaped Lyell Canyon. Photo by Yueyi Che.

FROM PREVIOUS STUDIES WE KNOW...

- Timing of deglaciation in Yosemite after the Last Glacial Maximum (LGM): around 20 thousand years to 13 thousand years ago
- Rapid retreat from cosmogenic Be-10 samples on the valley floor

WHAT IS NEW IN OUR STUDY:

- Sampling on valley wall to reflect the thinning rate and pattern
- Relationship between thinning and retreating
- Using two cosmogenic nuclides, Be-10 and C-14

In-situ Cosmogenic Exposure Age Dating

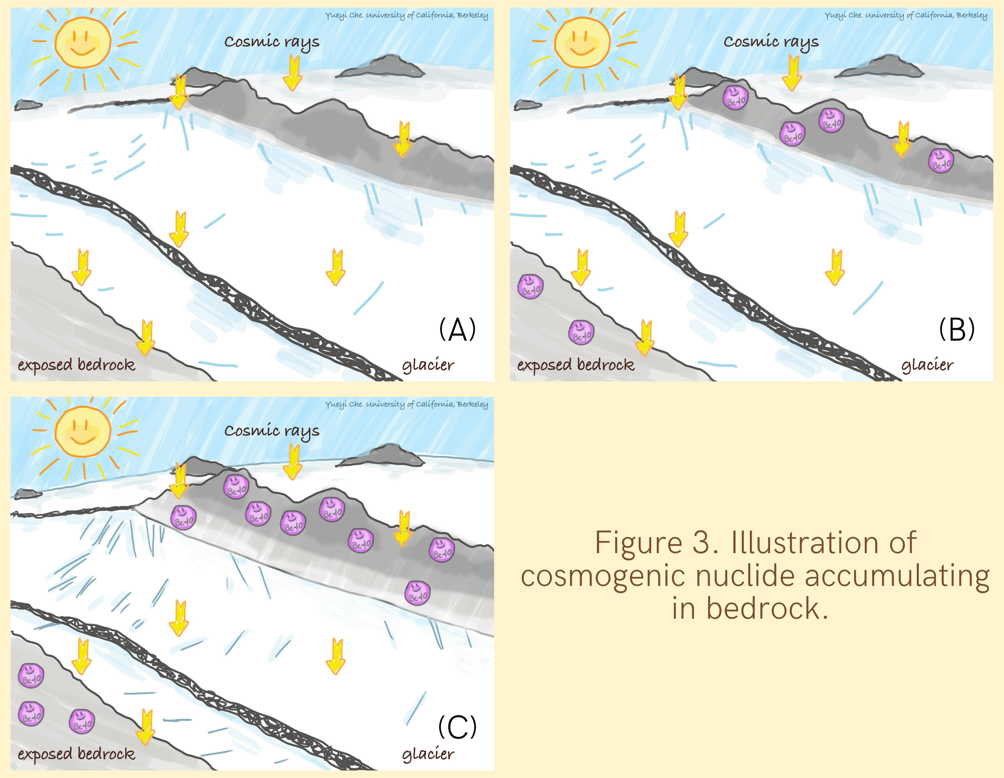


Figure 3. Illustration of cosmogenic nuclide accumulating in bedrock.

Why C-14 and Be-10?

C-14 AT HIGH ELEVATION: AVOID INHERITANCE

Samples at higher elevation experience a lower glacial erosion rate and would inherit nuclides. By the time our post-LGM deglaciation started, because C-14 has a short half-life compared to Be-10, there will be no C-14 inherited from before the LGM.

BE-10 AT LOWER ELEVATION: ACCURACY

We choose Be-10 for lower elevation samples because it is more accurate for our timeframe. Be-10 is also what used in previous studies, which can help us compare our study to previous ones. Using two nuclides in one elevation transect and also inform us about the burial history during the thinning process.

We aim to use cosmogenic Be-10 and C-14 exposure age dating to address the timing, rate, and pattern of glacier thinning and retreating in Lyell Canyon, which may help us understand today's mountain glacier melting.

Results

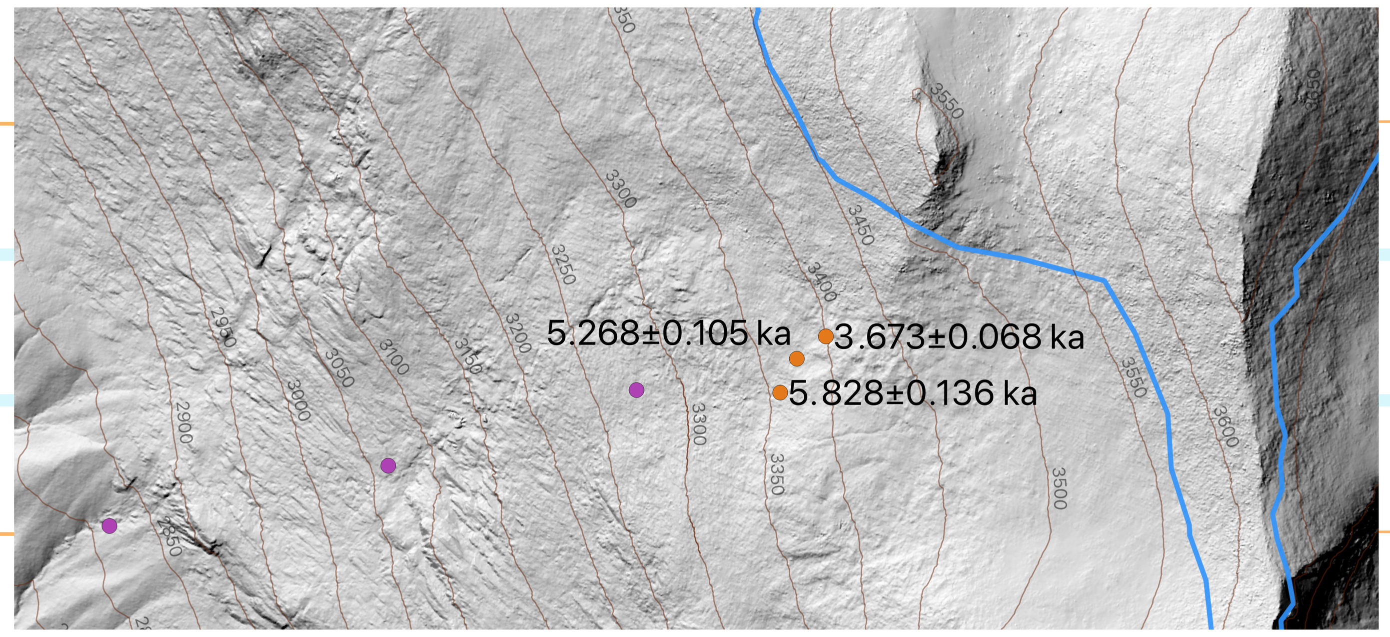


Figure 4. The zoomed-in transect from the north side of the Lyell Canyon. The blue line is the LGM glacier extent. Right now we only have the three C14 bedrock exposure age data in thousands of years (ka) at the higher elevation.

Figure 5. Photo of Yueyi and Colin sampling granodiorite glacier bedrock at a sample site. Photo by Gus Tovalin.

Interpretations

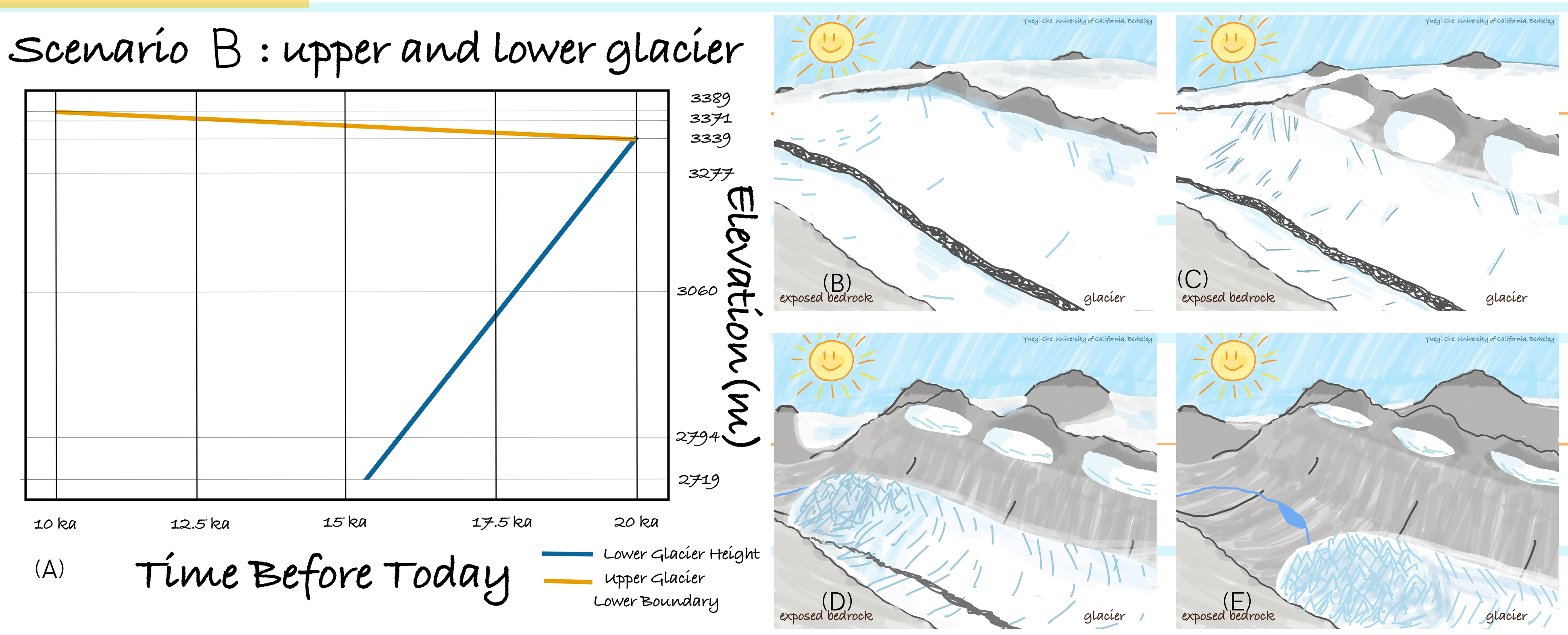


Figure 6. (A): Glacier coverage at different elevations over time for scenario B. In this model, the glacier broke off an upper glacier at the earlier stage of thinning and retreats upwards, while the lower main glacier thinned steadily downwards. (B) to (E): Illustration of the glacier melting process in the valley for scenario B.

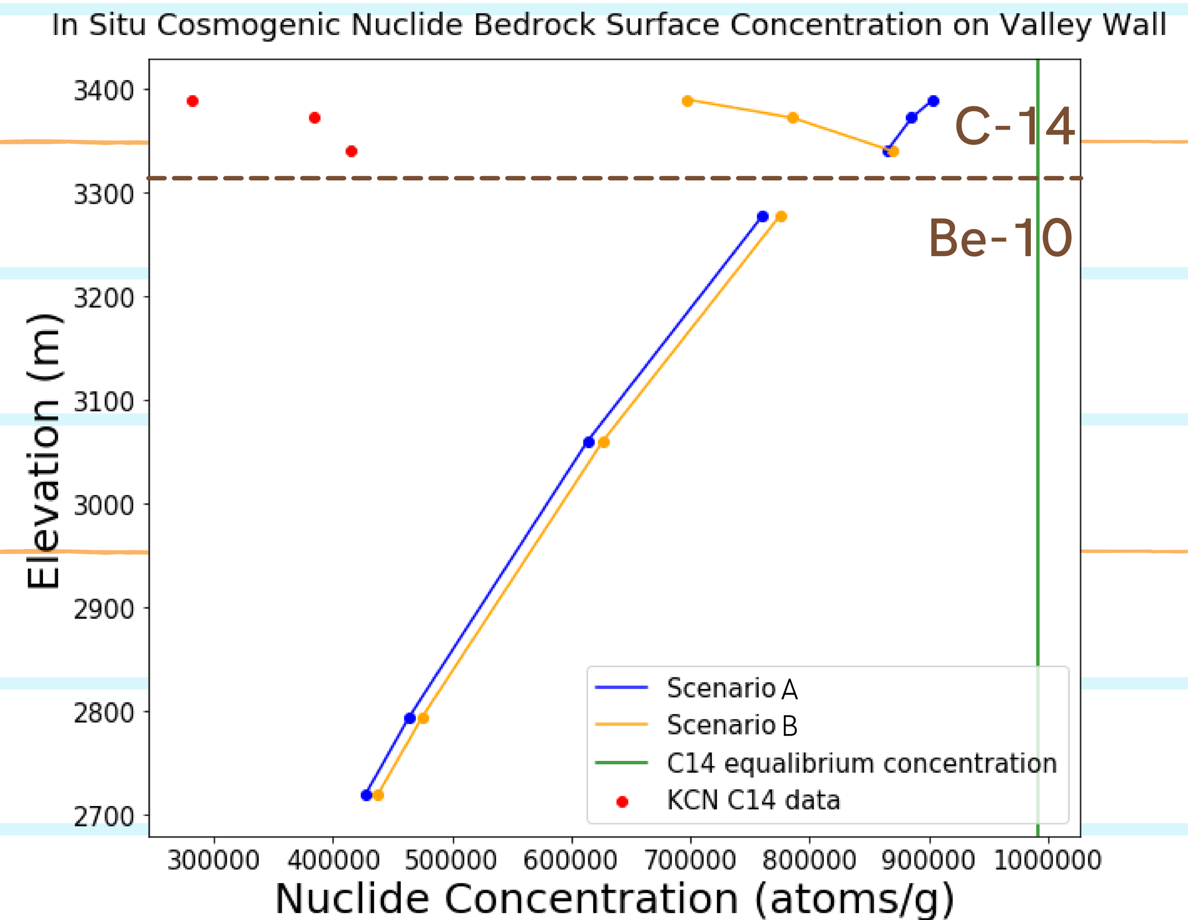


Figure 7. Modeled nuclide concentrations in bedrock in different scenarios compared to our actual measurement. The upper three samples are measured in C-14 and the lower four samples are measured in Be-10. We have our actual data in red (all three are measured in C14, the Be-10 samples from that transect are still processing), prediction of scenario 1 the original steady thinning in blue, prediction of scenario 6 the breaking into an upper and lower glacier in yellow.

AGE YOUNGER THAN EXPECTED

- Our data suggest glacier coverage at our sample sites during the LGM.
- There's still coverage above the samples after the initial melting.
  - Random events such as boulder coverage, rockfall, or exfoliation are unlikely due to the consistent trend in age.
  - Snow shielding is significant in this area, but it cannot completely explain why these ages are so young (correction should not be more than 20%).
  - A permanent snowfield or glacier at our sample sites is the most likely explanation since they provide consistent shading.

OUR MODEL IS EFFECTIVE

- The variation of nuclide concentration from the model shows leverage to eliminate some thinning scenarios.
- Our C14 data supports the separation of upper and lower glaciers (see scenario B predictions). Forthcoming Be10 data will provide more insight.
- The similarity in the yield nuclide concentration reflects the similarities among assumptions. Other scenarios have different cases for the lower elevation glaciers and they behave differently than these three. The different scenarios are helpful for interpreting the other two transects.

Previous Study's Melting Pattern

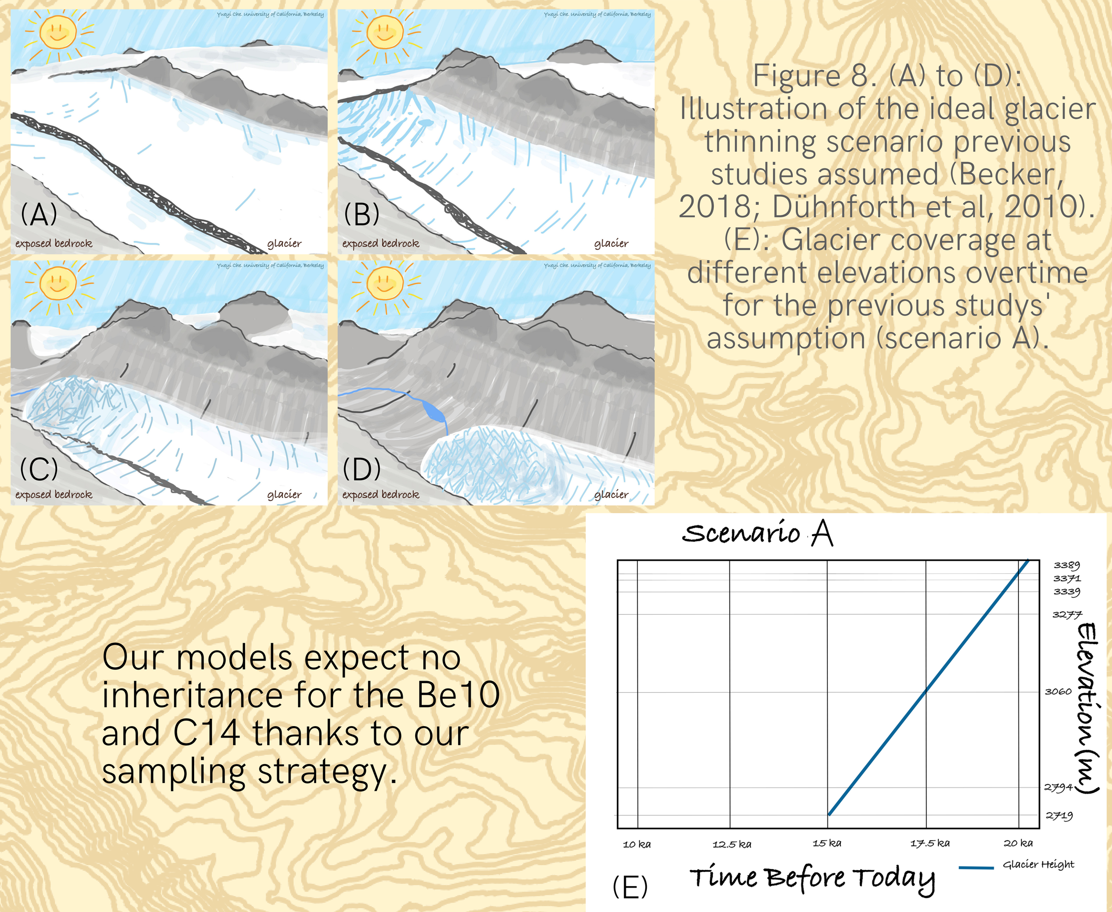


Figure 8. (A) to (D): Illustration of the ideal glacier thinning scenario previous studies assumed (Becker, 2018; Dühnforth et al, 2010). (E): Glacier coverage at different elevations overtime for the previous studys' assumption (scenario A).

Our models expect no inheritance for the Be10 and C14 thanks to our sampling strategy.

Future Work

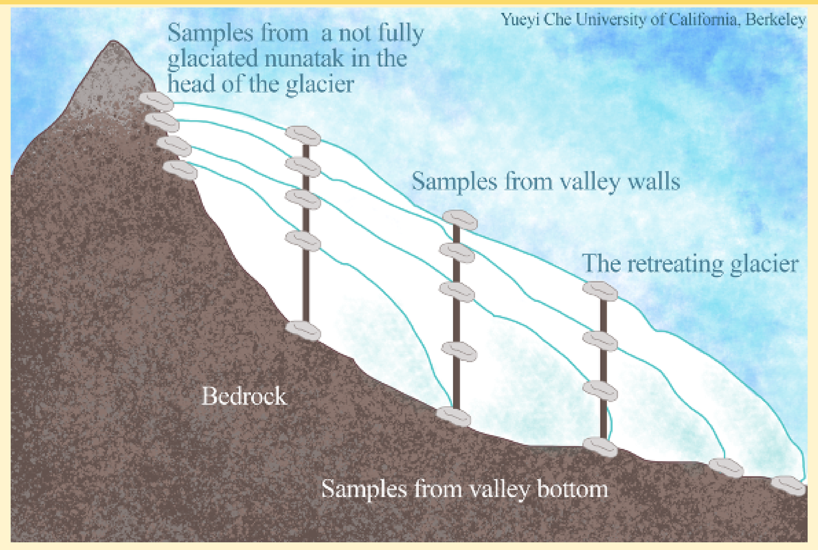


Figure 9. Side cross-section of the glacier valley. With the data and melting pattern described in the model, we will use the three vertical transects, previous studies' data on the valley floor, and DEM to reconstruct the glacier volume.

MORE DATA

1. Expect the rest of the Be-10 and C-14 data and see which model they fit in.

MASS BALANCE

2. Look at the relationship between glacier volume change and the temperature and precipitation change in the western US after the LGM.

COMPARE

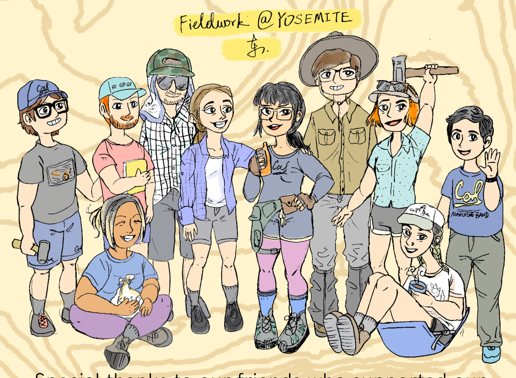
3. Compare the melting pattern after the LGM to those of today, and inform the prediction of the current glacier's mass balance change.

MORE ART

4. Continue to produce science communication content such as videos and comics to share our work at Yosemite.

Acknowledgment

We acknowledge the land on which we conducted fieldwork in the Yosemite National Park area, which is the home of the Me-Wuk, Western Mono/Monache, Eastern Mono/Monache, Numu, Chukchansi, Wašišiwʔítdeʔ, and Yokuts people. We take this opportunity to thank the original caretakers of this land. We take this opportunity to thank the original caretakers of this land. We also want to acknowledge the financial support from the following grants and scholarships: AGU Student Travel Grant, AWG Takken Student Research Presentation Travel Award, Charles H. Ramsden Endowed Scholarship Fund Research Fellowship, Free Seed Sample Analyses at PRIME Lab, Sigma Xi Berkeley Chapter Grants-in-Aid Research, Summer Undergraduate Research Fellowships - L&S, and Tulane University Cosmogenic Nuclide Lab.



Special thanks to our friends who supported our fieldwork: Eli Wade, Skylar Shulman, Daniel DeTone, Colin Chamberlin, Kathryn McNeal, Gus Tovalin, Dorothy Bechler, Mallen Clifton.

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