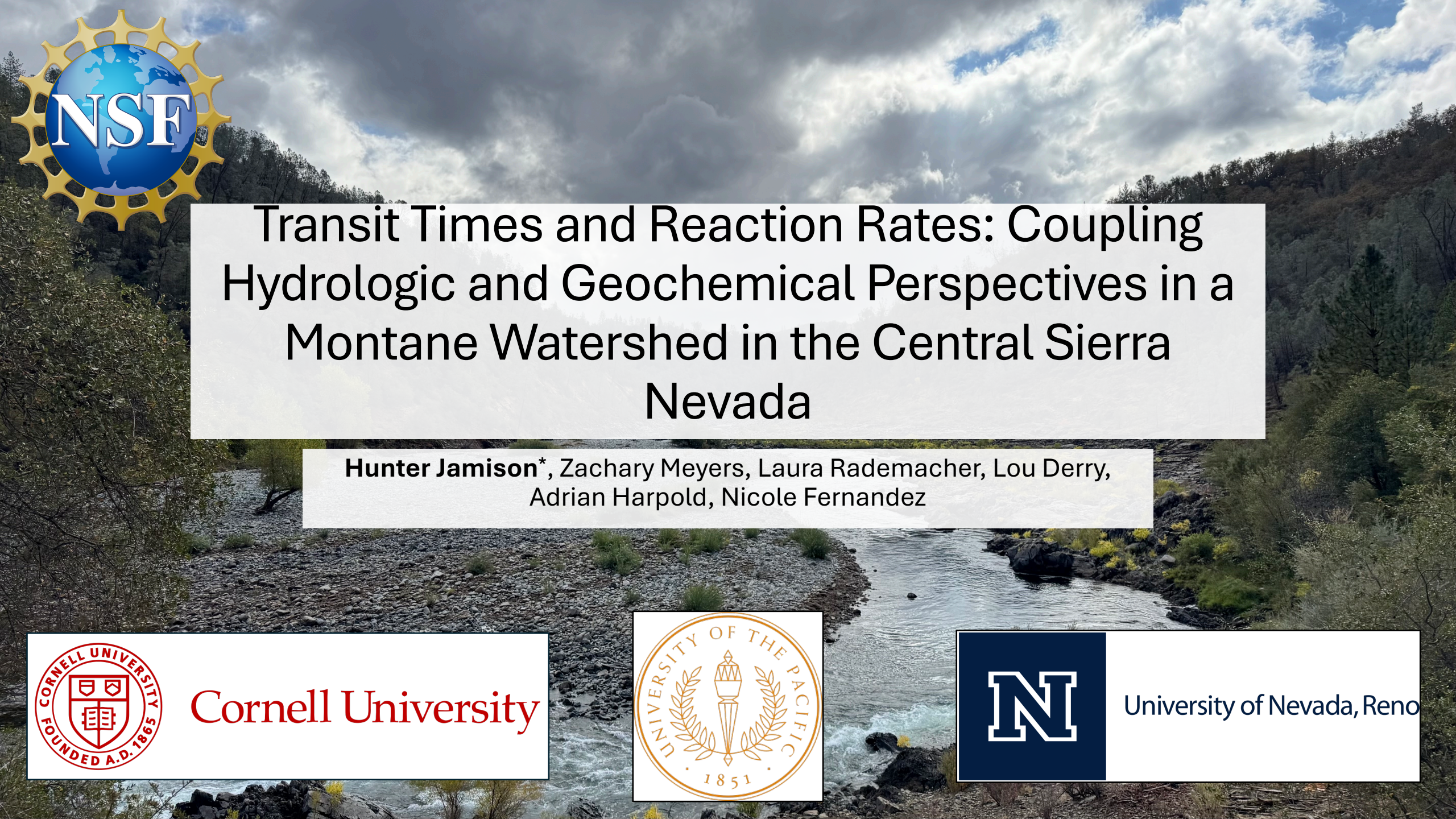
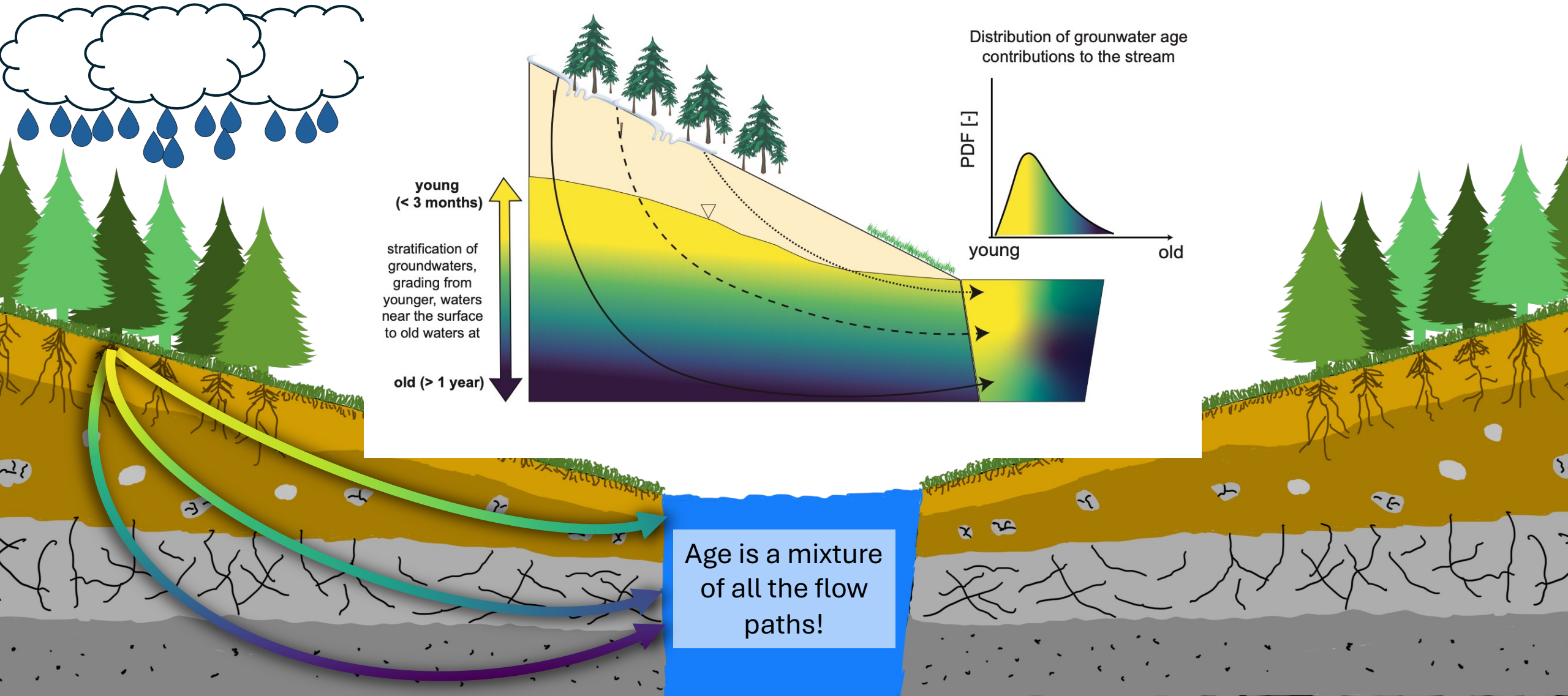


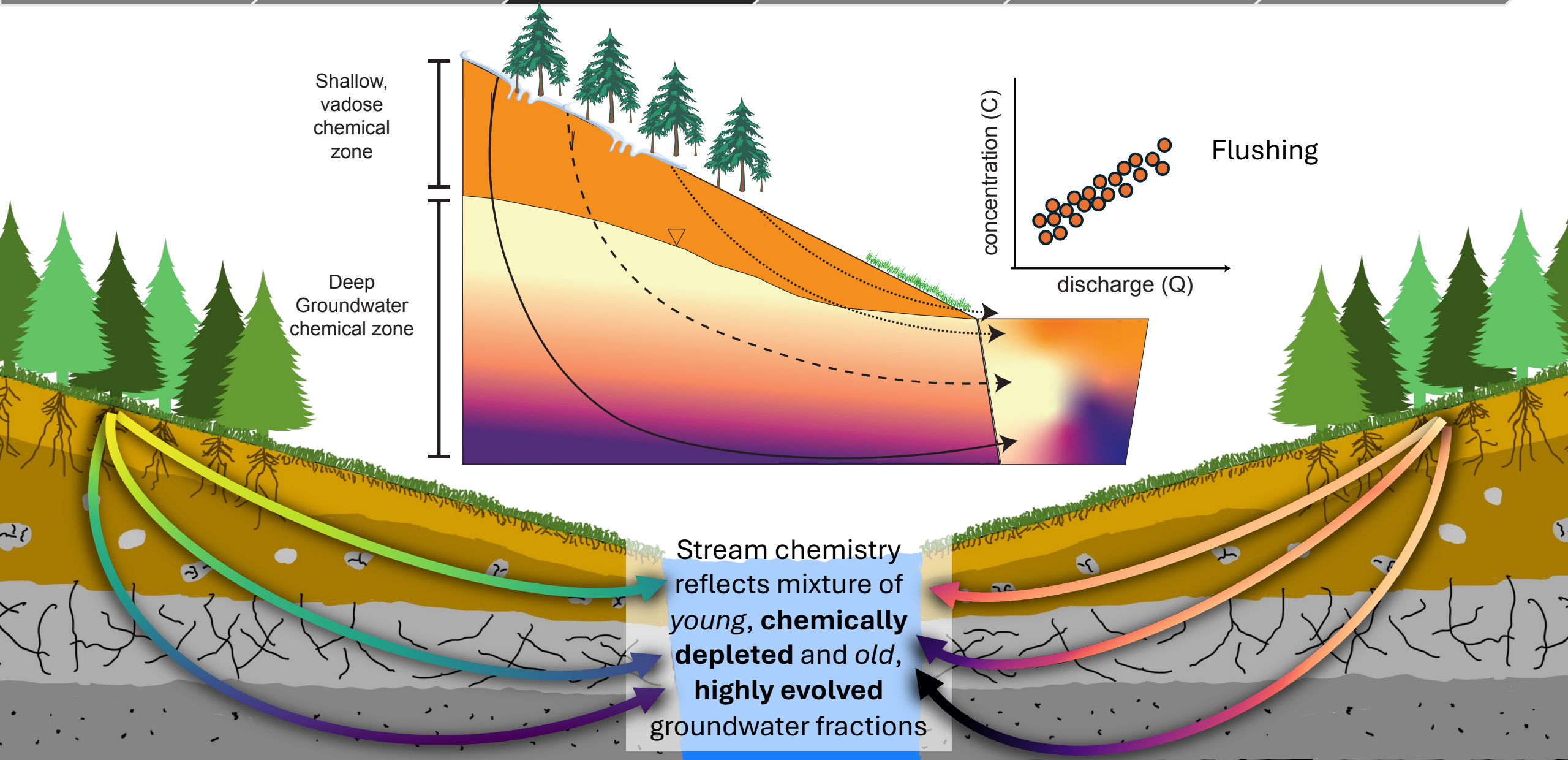
Transit Times and Reaction Rates: Coupling Hydrologic and Geochemical Perspectives in a Montane Watershed in the Central Sierra Nevada

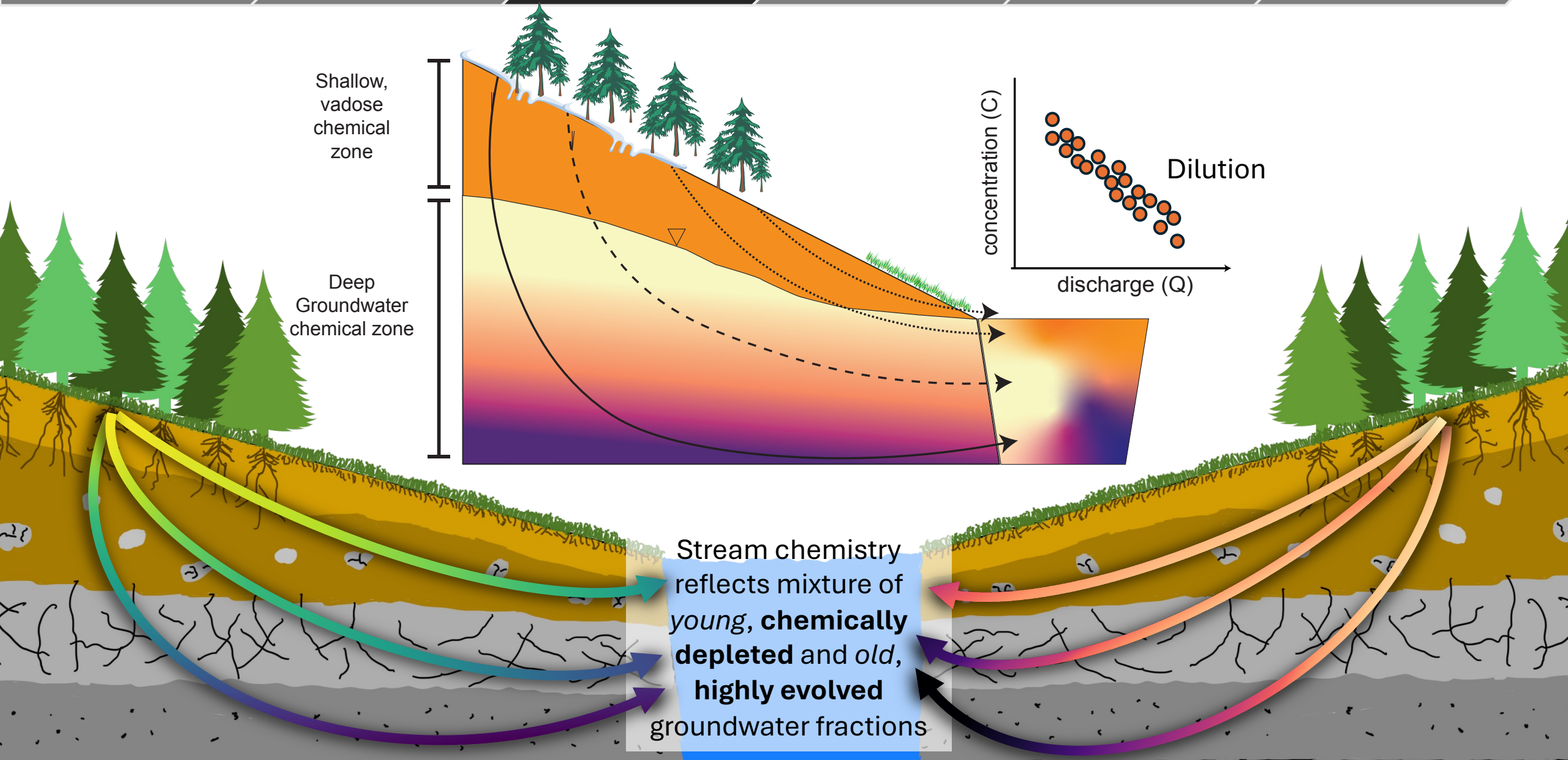
Hunter Jamison*, Zachary Meyers, Laura Rademacher, Lou Derry, Adrian Harpold, Nicole Fernandez

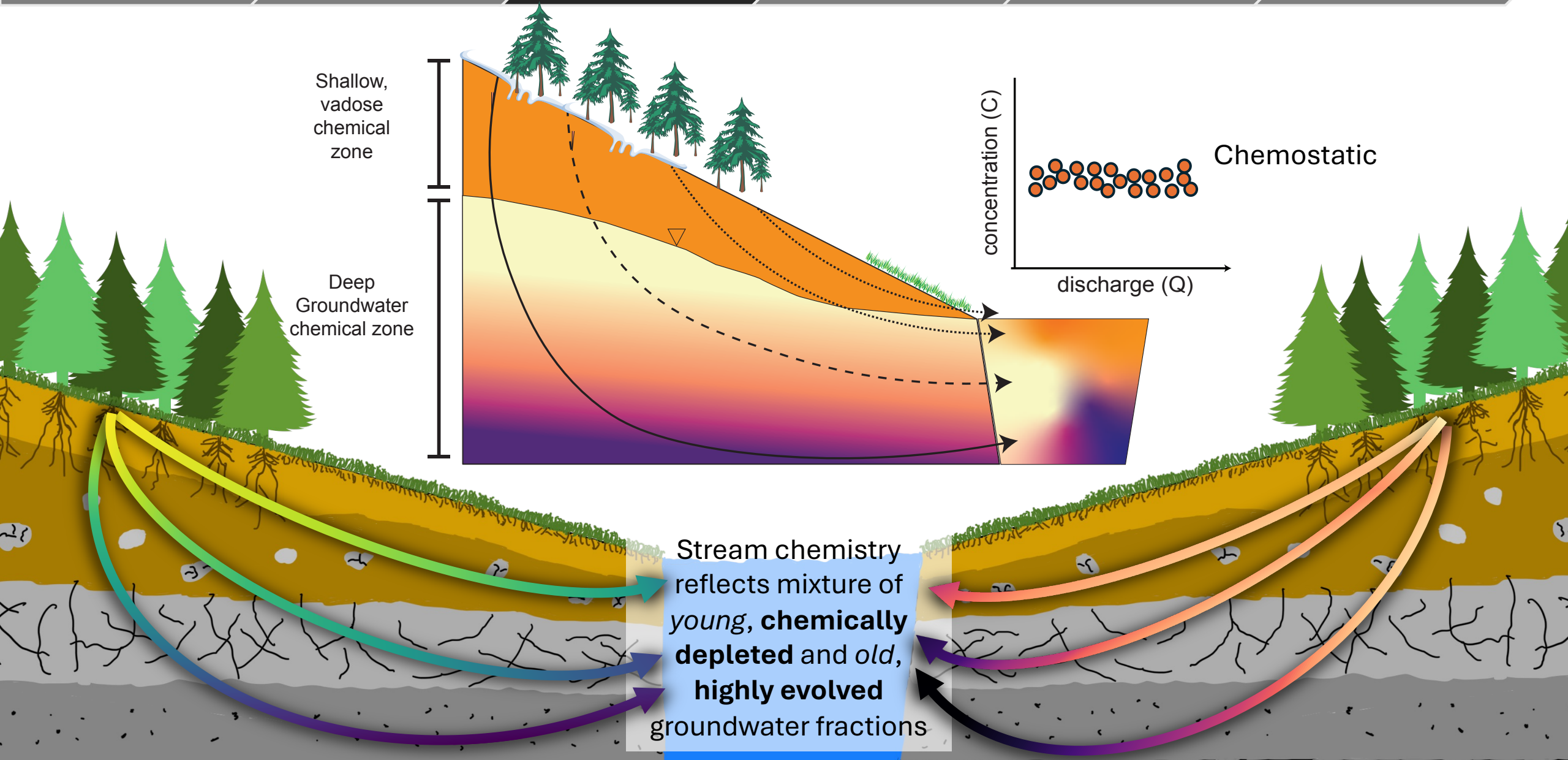
Cornell University

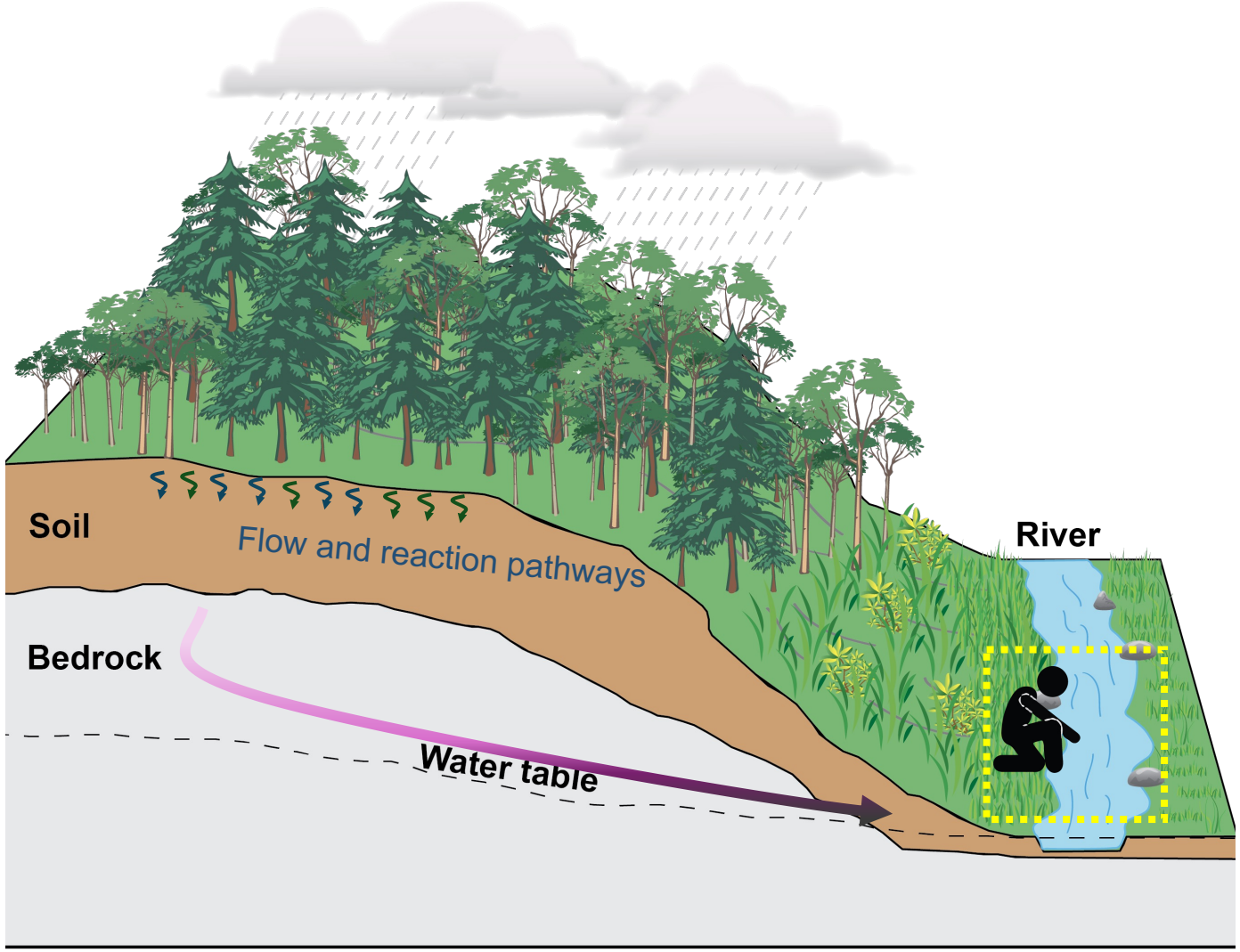
University of Nevada, Reno

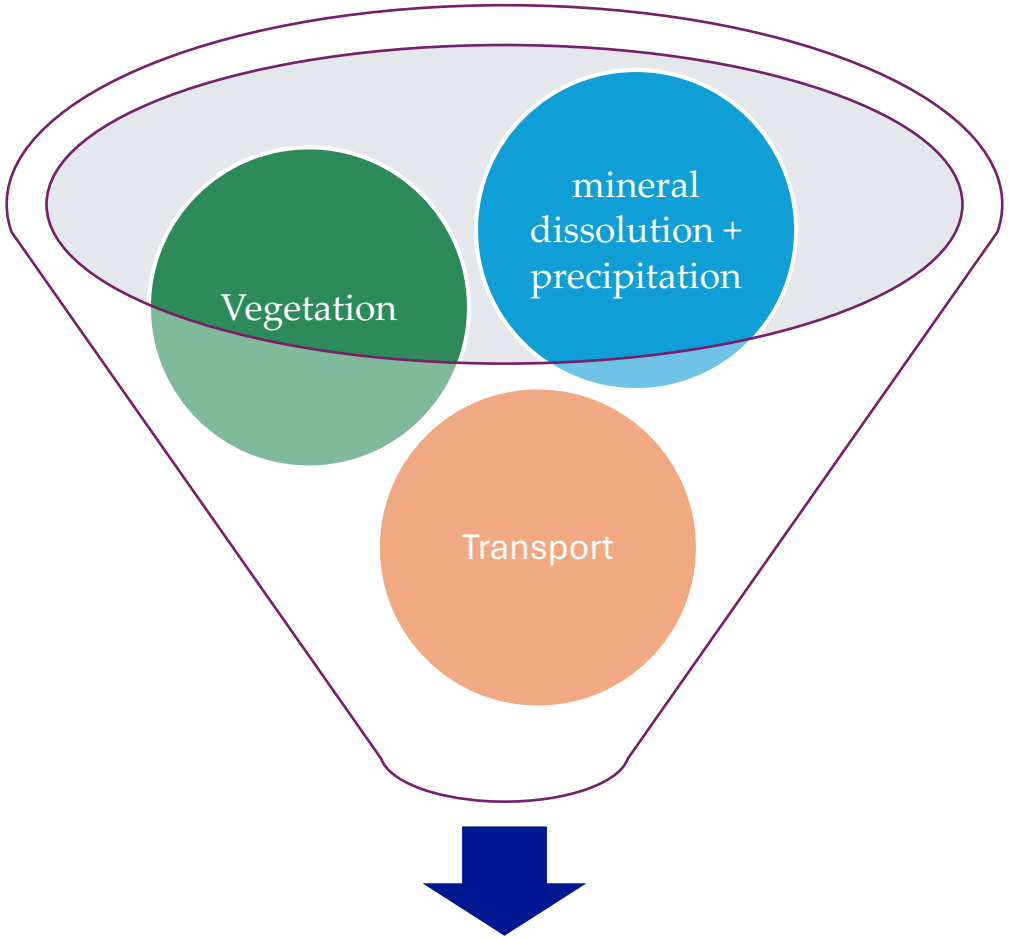

young
(< 3 months)
stratification of groundwaters, grading from younger, waters near the surface to old waters at
old (> 1 year)
Distribution of grounwater age contributions to the stream
PDF [-]
young
old
Age is a mixture of all the flow paths!


Shallow, vadose chemical zone
Deep Groundwater chemical zone
concentration (C)
discharge (Q)
Flushing
Stream chemistry reflects mixture of *young*, **chemically depleted** and *old*, **highly evolved** groundwater fractions


Shallow, vadose chemical zone
Deep Groundwater chemical zone
concentration (C)
discharge (Q)
Dilution
Stream chemistry reflects mixture of *young*, **chemically depleted** and *old*, **highly evolved** groundwater fractions

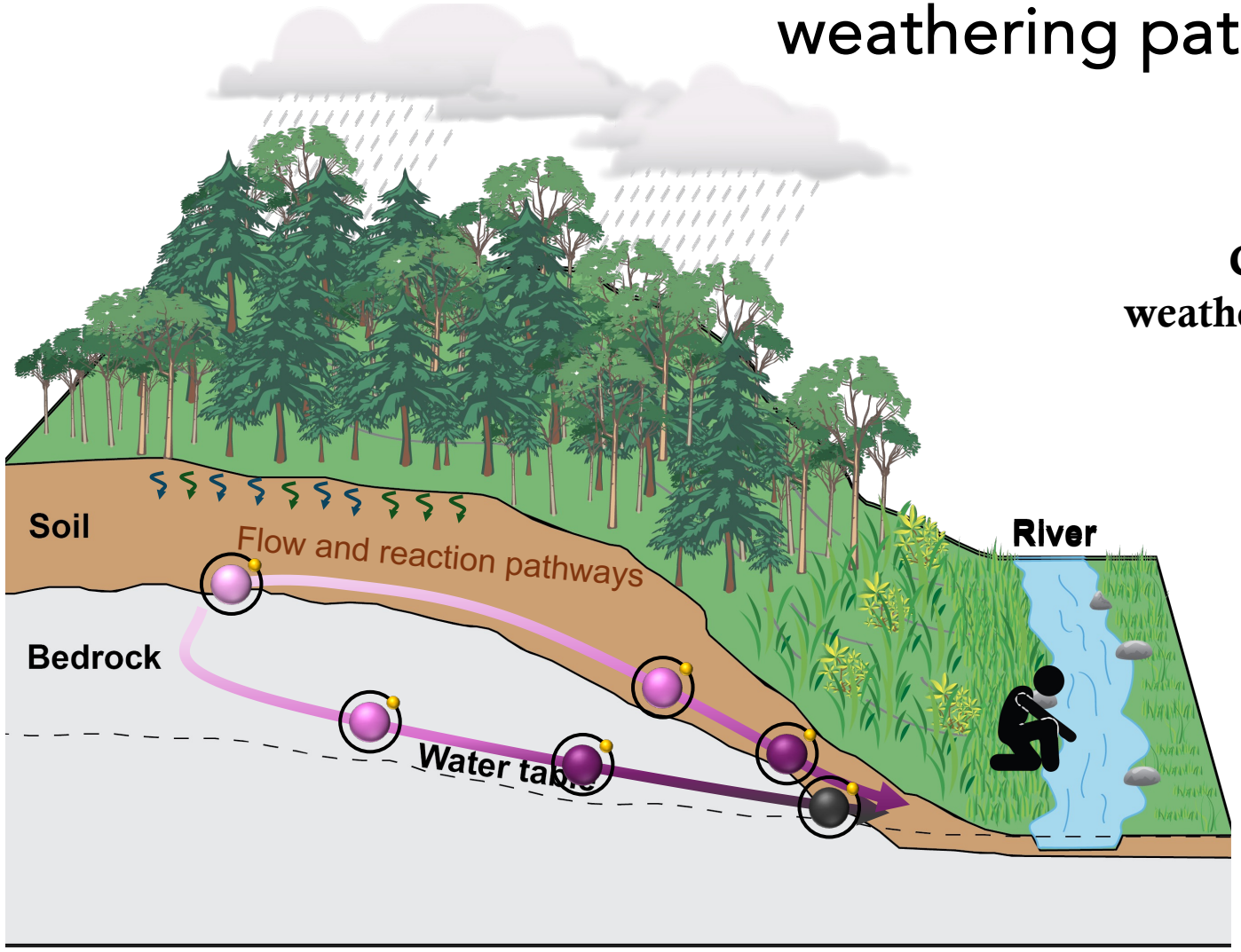

Shallow, vadose chemical zone
Deep Groundwater chemical zone
concentration (C)
discharge (Q)
Chemostatic
Stream chemistry reflects mixture of *young*, **chemically depleted** and *old*, **highly evolved** groundwater fractions





Observed solute flux

Si stable isotopes ($\delta^{30}Si$) and Germanium (Ge/Si) to trace silicate weathering pathways

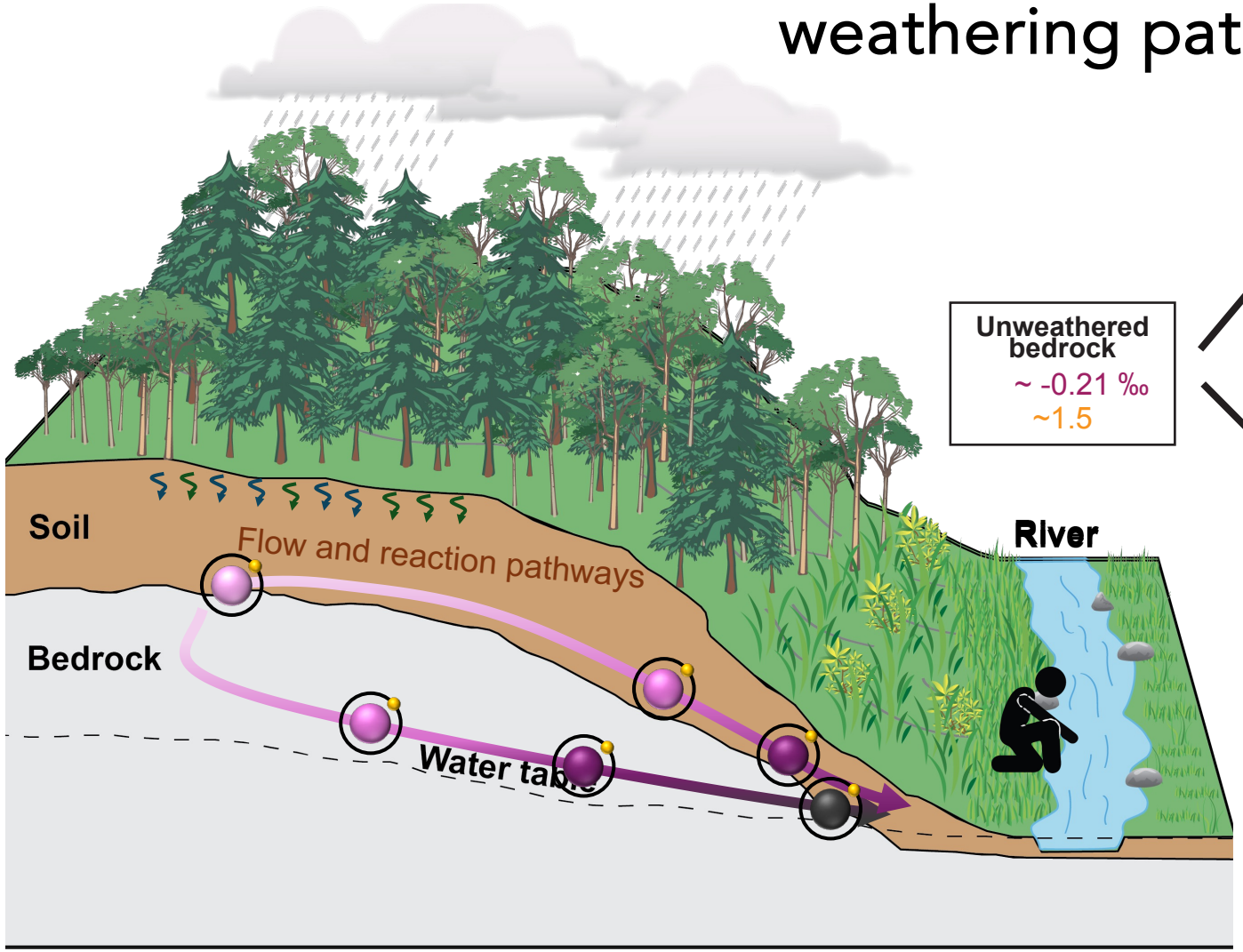


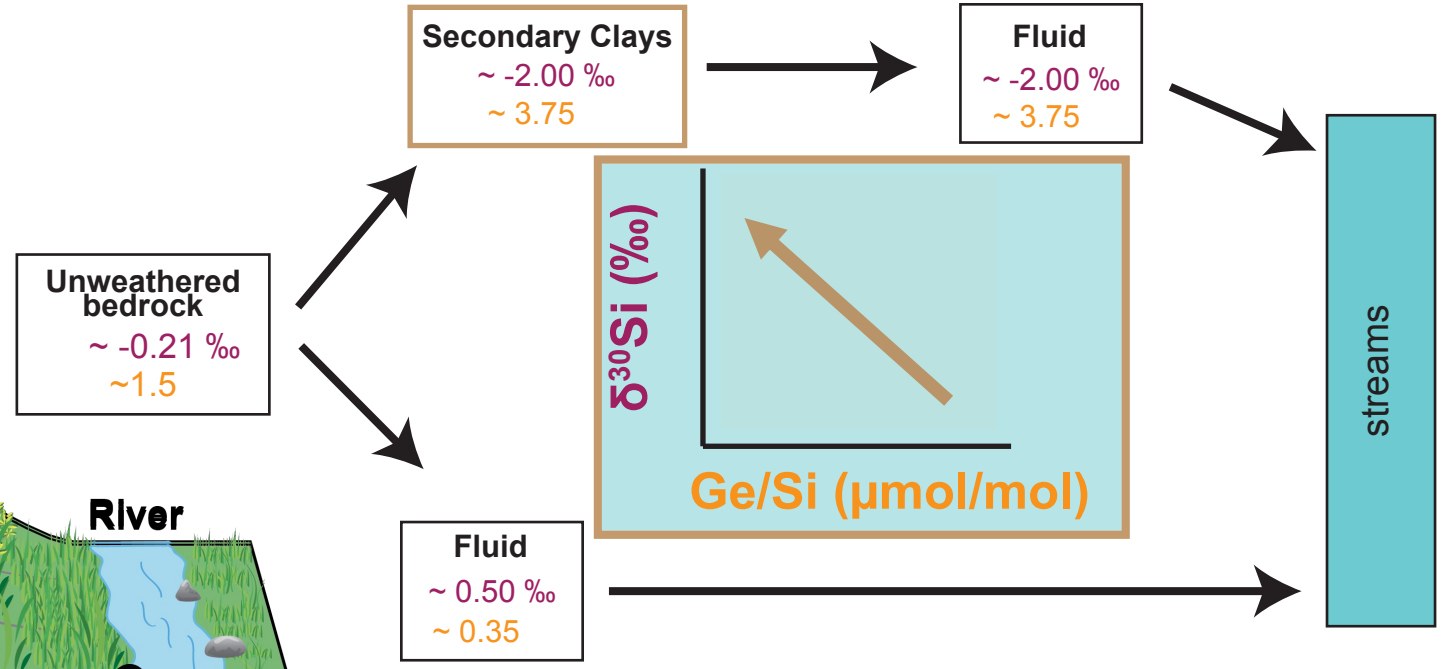
Chemical weathering reactions ← α → **Observed isotopic/trace element shifts**

α = fractionation factor

$$\alpha_{aq\text{—}solid} = \frac{\left({}^{30}Si/{}^{28}Si\right)_{aq}}{\left({}^{30}Si/{}^{28}Si\right)_{solid}}$$

Si stable isotopes ($\delta^{30}Si$) and Germanium (Ge/Si) to trace silicate weathering pathways





Modified from Kurtz et al. (2001)

Silicate Weathering Tracers

Silicon Stable Isotopes ($\delta^{30}Si$)

- Silicon isotope fraction is not affected by bedrock dissolution
- Sensitive to both clay formation
- Amorphous Silica can reach equilibrium on time scales of weeks (SO FAST)!

Ge/Si

- Ge/Si tends to be enriched in bedrock
- Ge behaves like Si, can be incorporated into clays
- On long timescales, can replace silicon in clay minerals
- Useful to providing context to $\delta^{30}Si$ measurements!

- Sagehen Creek is a small, montane catchment found in the Central Sierra Nevada
- It receives about 850mm of annual precipitation
  - ~80% of which is snow
- Its elevation ranges from 2663m to 1877m at the USGS station
- Underlying lithology is comprised of mixed volcanics (basaltic andesite) and granodiorite

Kirchner et. al., (2020)

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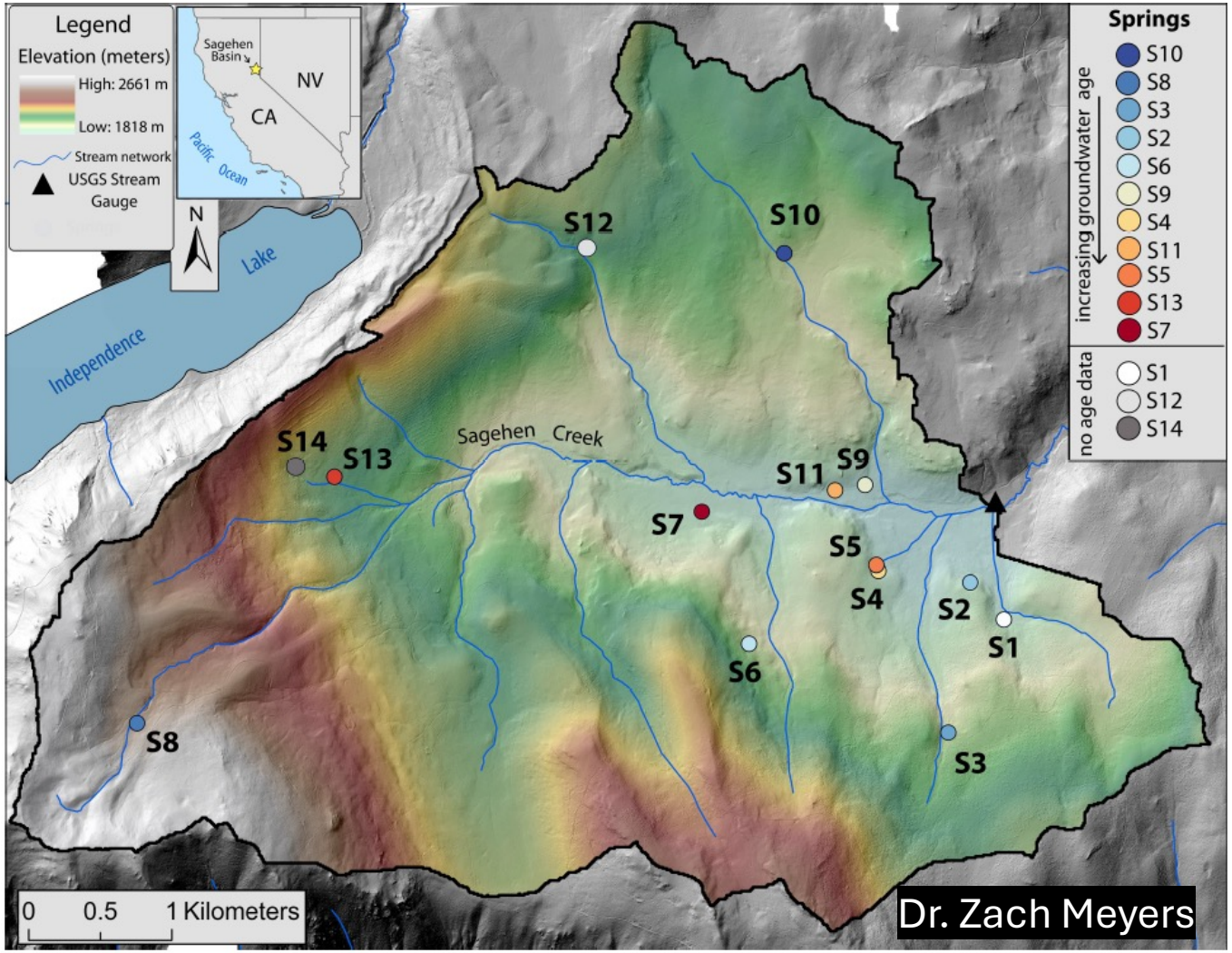
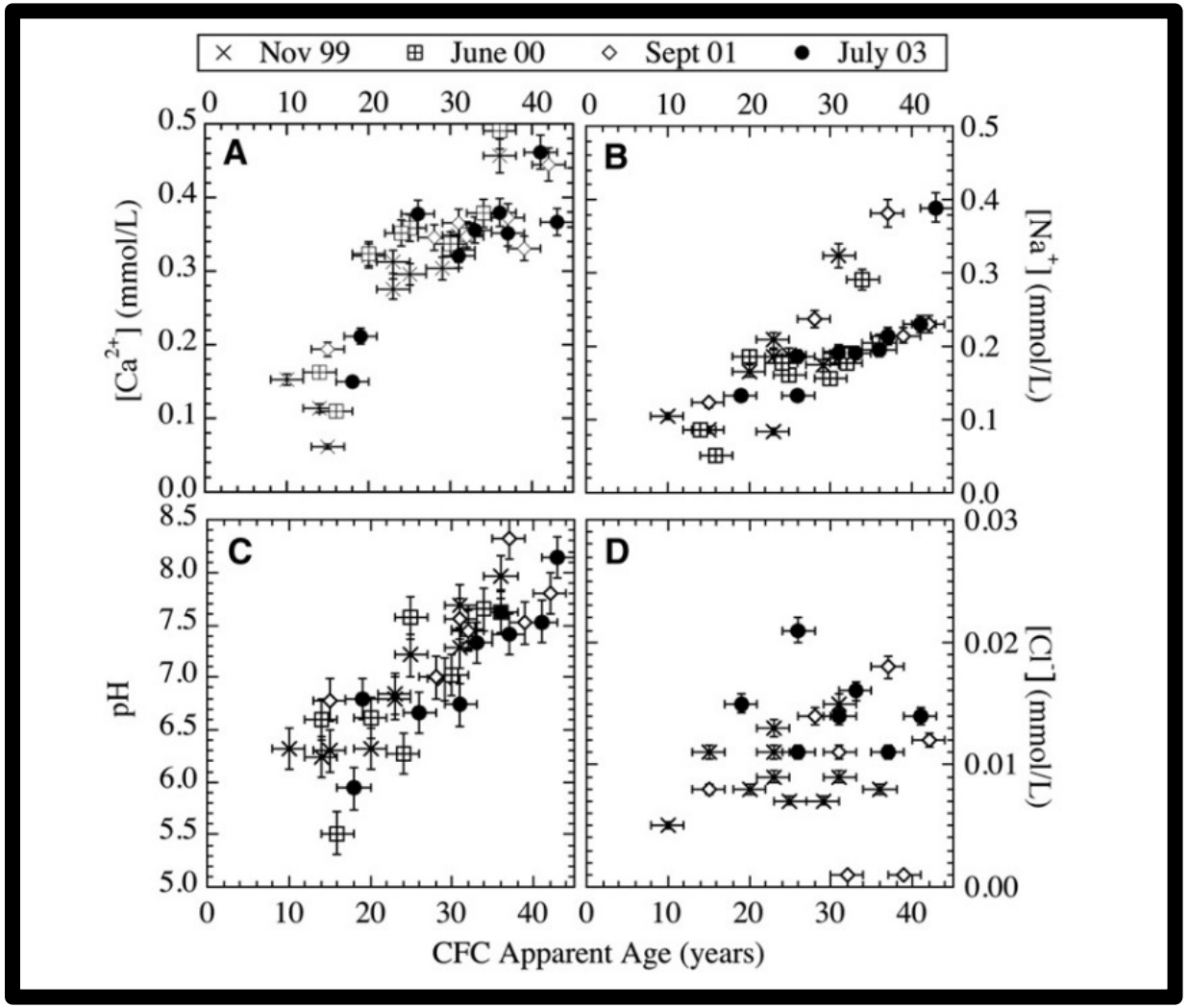


*Kirchner et. al., (2020)

- Dr Laura Rademacher has done extensive work at Sagehen Creek, looking at **groundwater ages** of spring waters, and stream waters across the watershed **since 1997**

- They found that **pH, temperature, and major cations correlate with water ages**



Rademacher et. al., (2005), Rademacher et. al., (2001)

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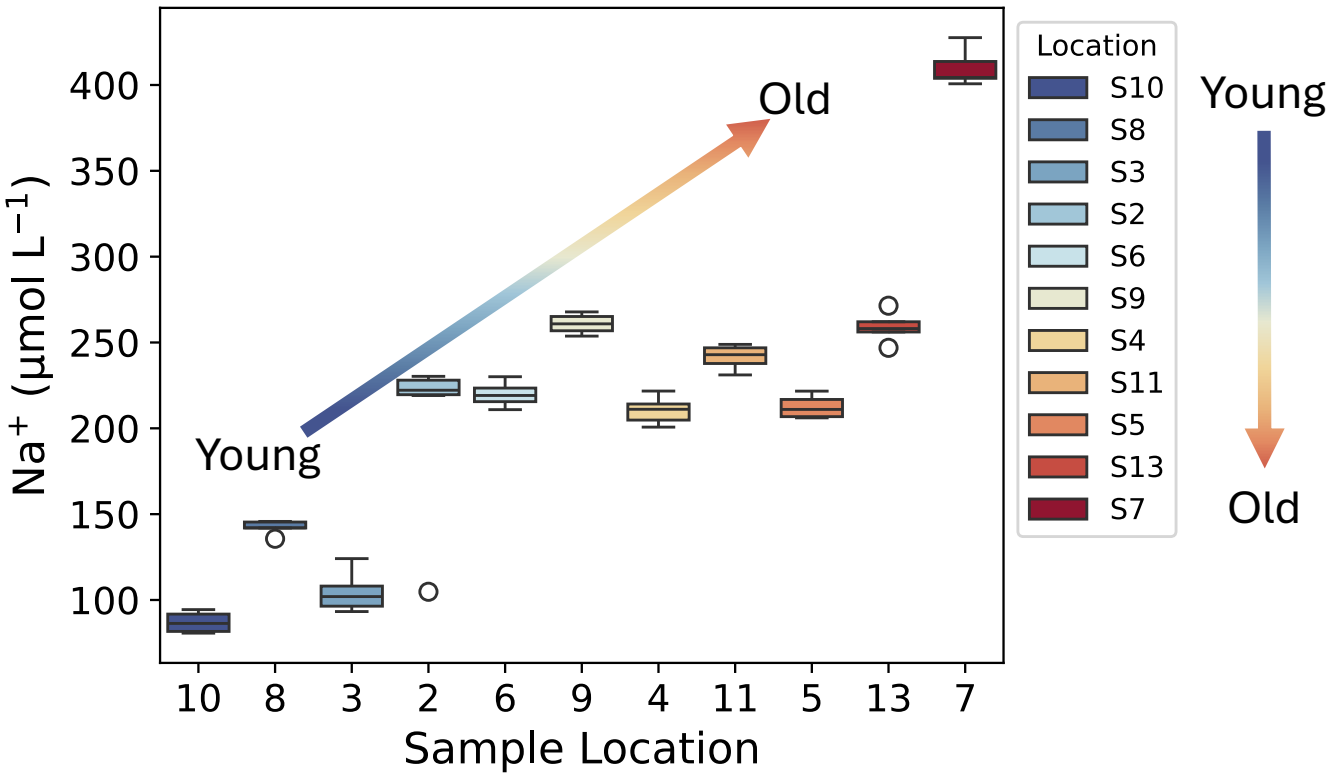
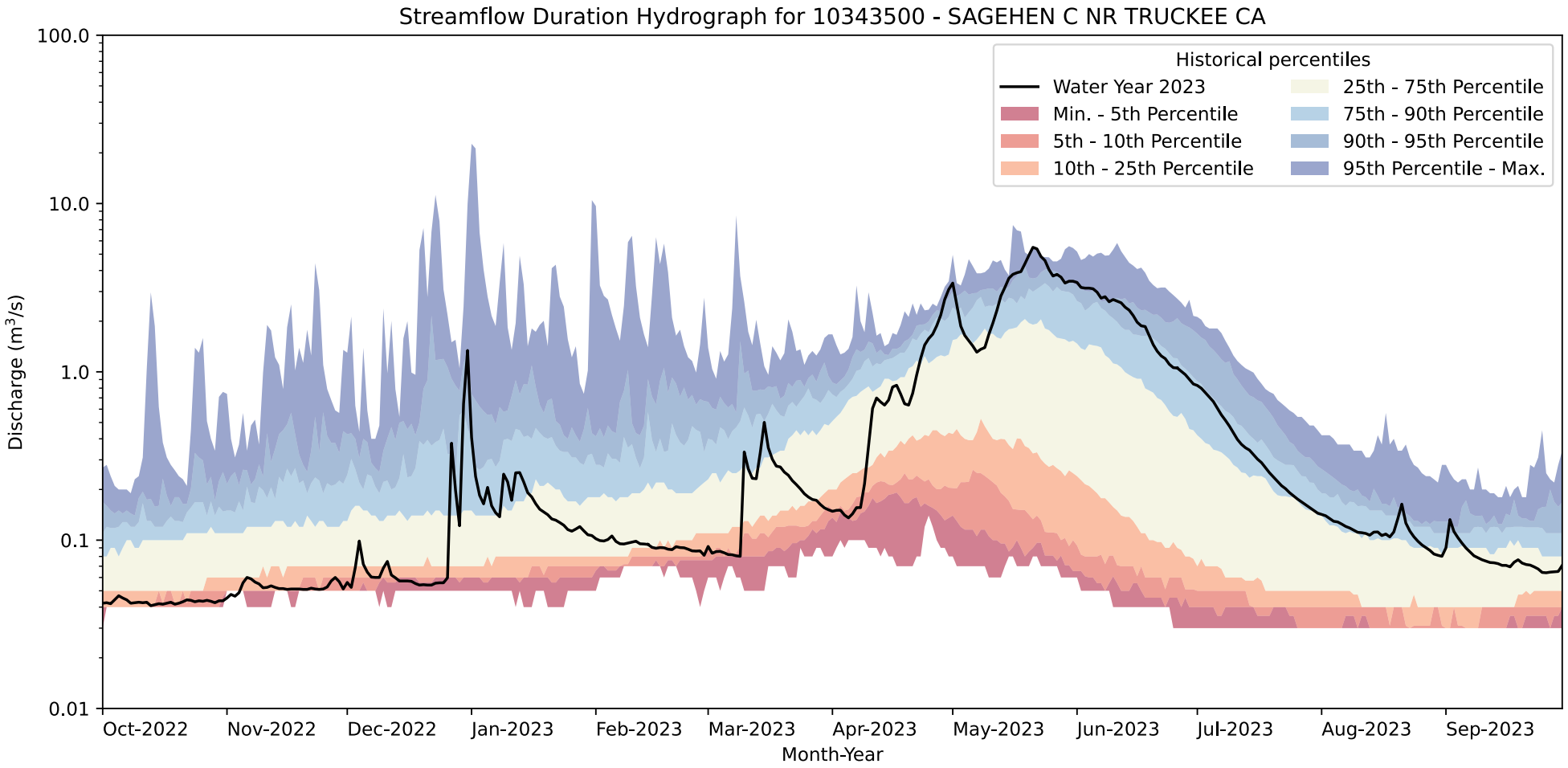
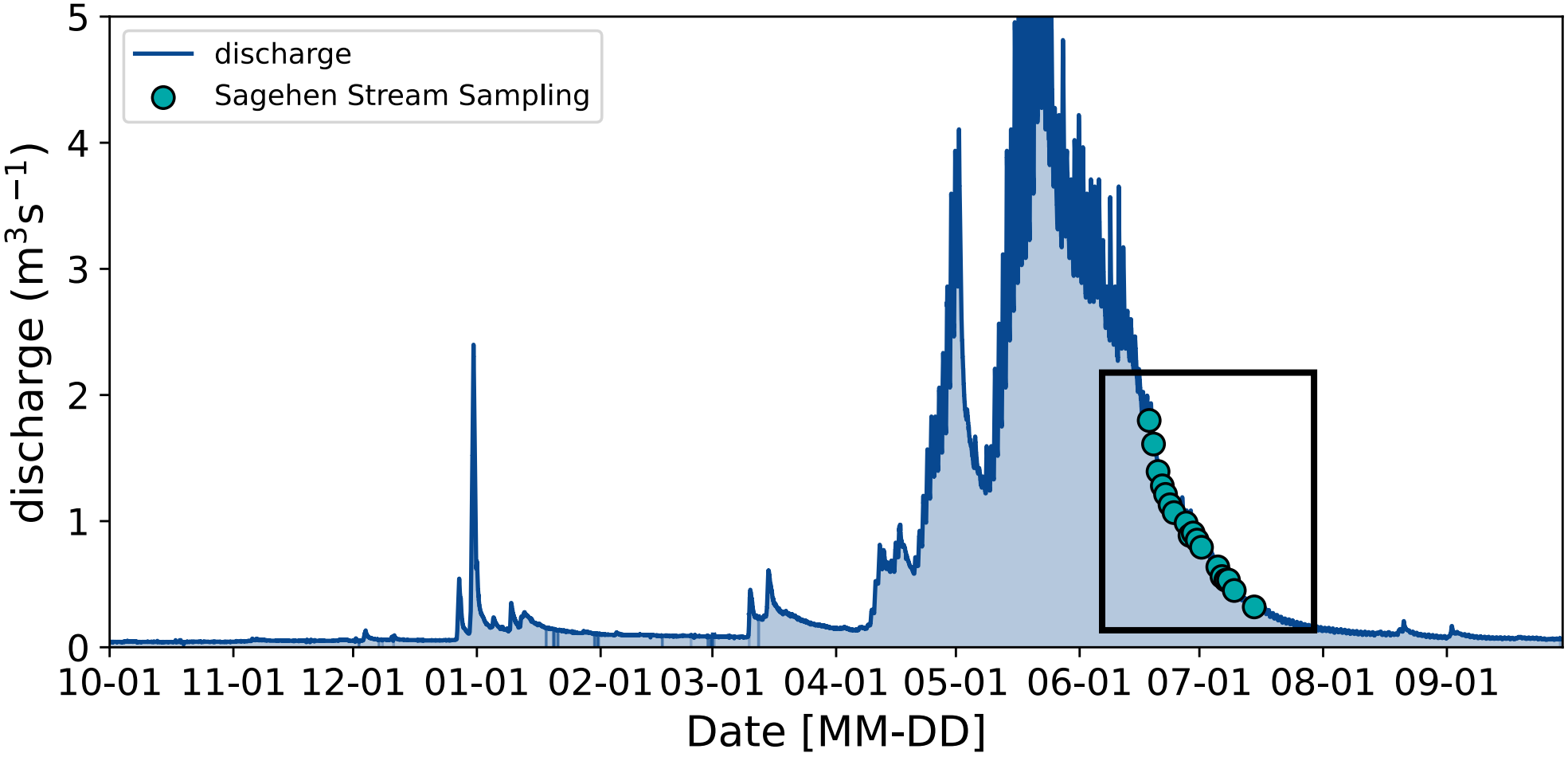
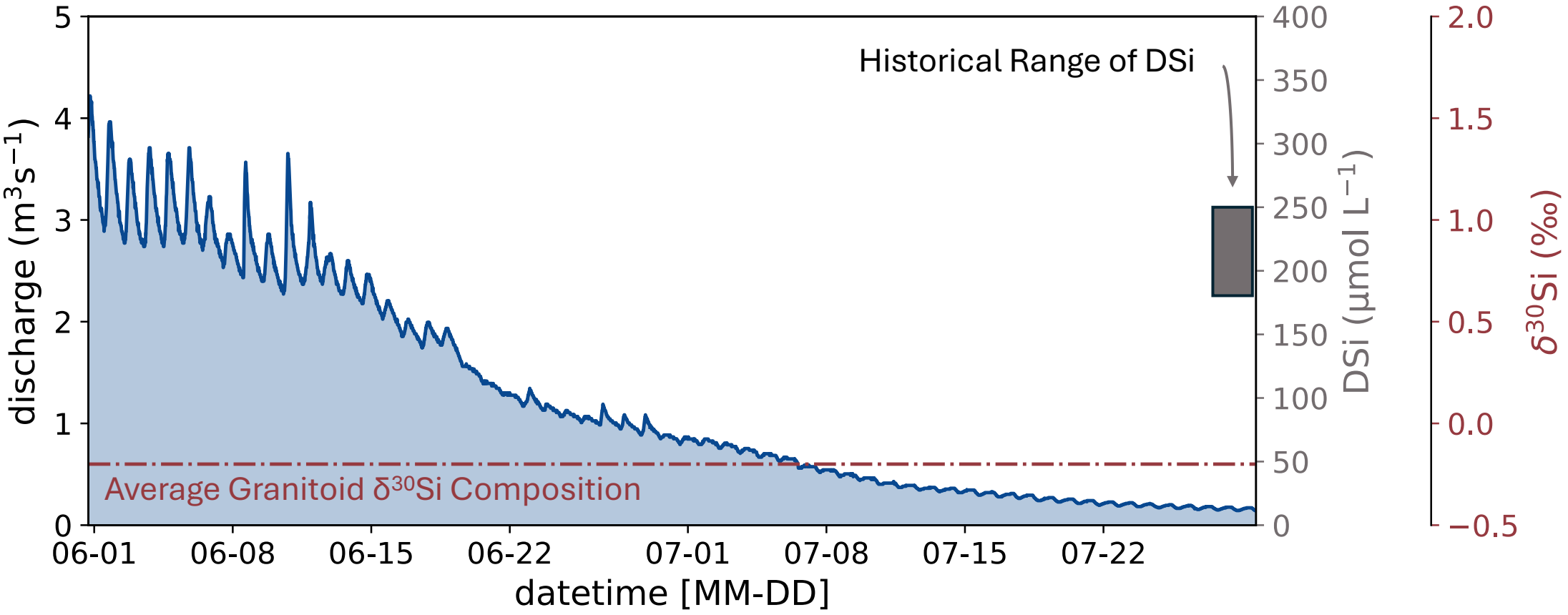


Rademacher et. al., (2005), Rademacher et. al., (2001)

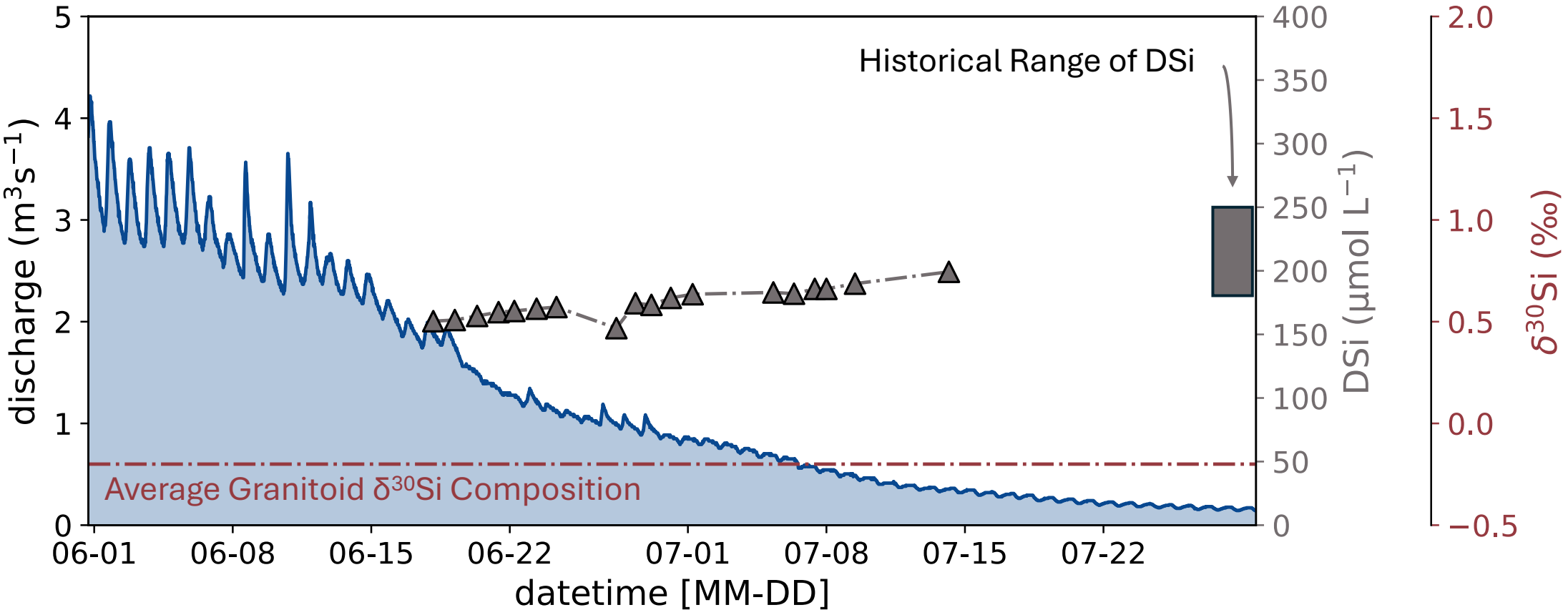
Water Year 2023




discharge
Sagehen Stream Sampling
discharge (m^3s^{-1})
0
1
2
3
4
5
10-01
11-01
12-01
01-01
02-01
03-01
04-01
05-01
06-01
07-01
08-01
09-01
Date [MM-DD]



*Savage *et al.*, 2012



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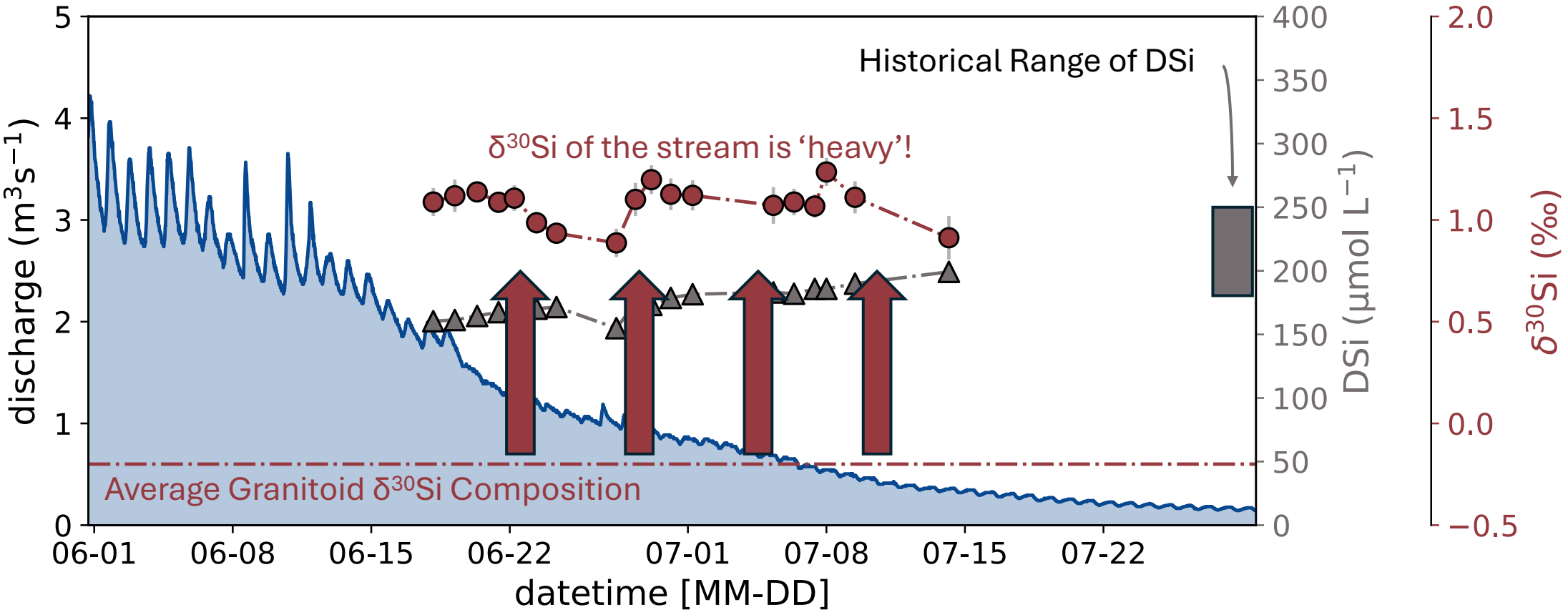

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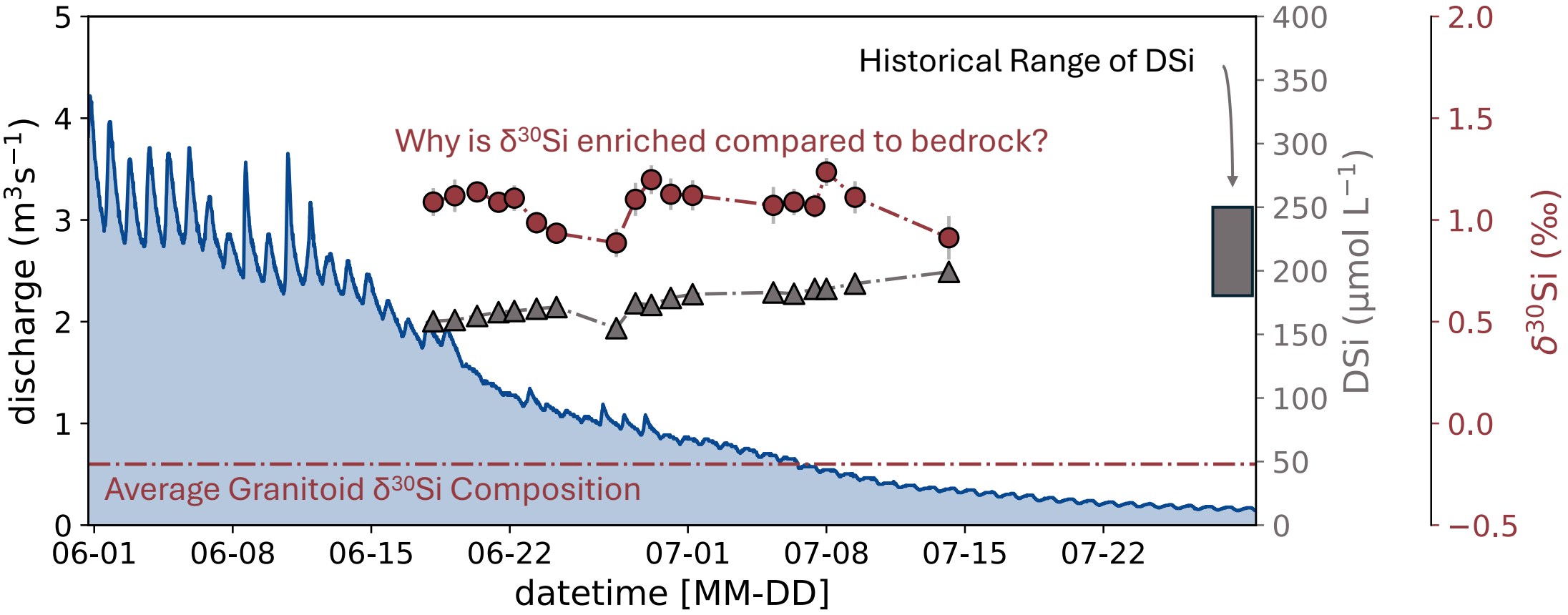

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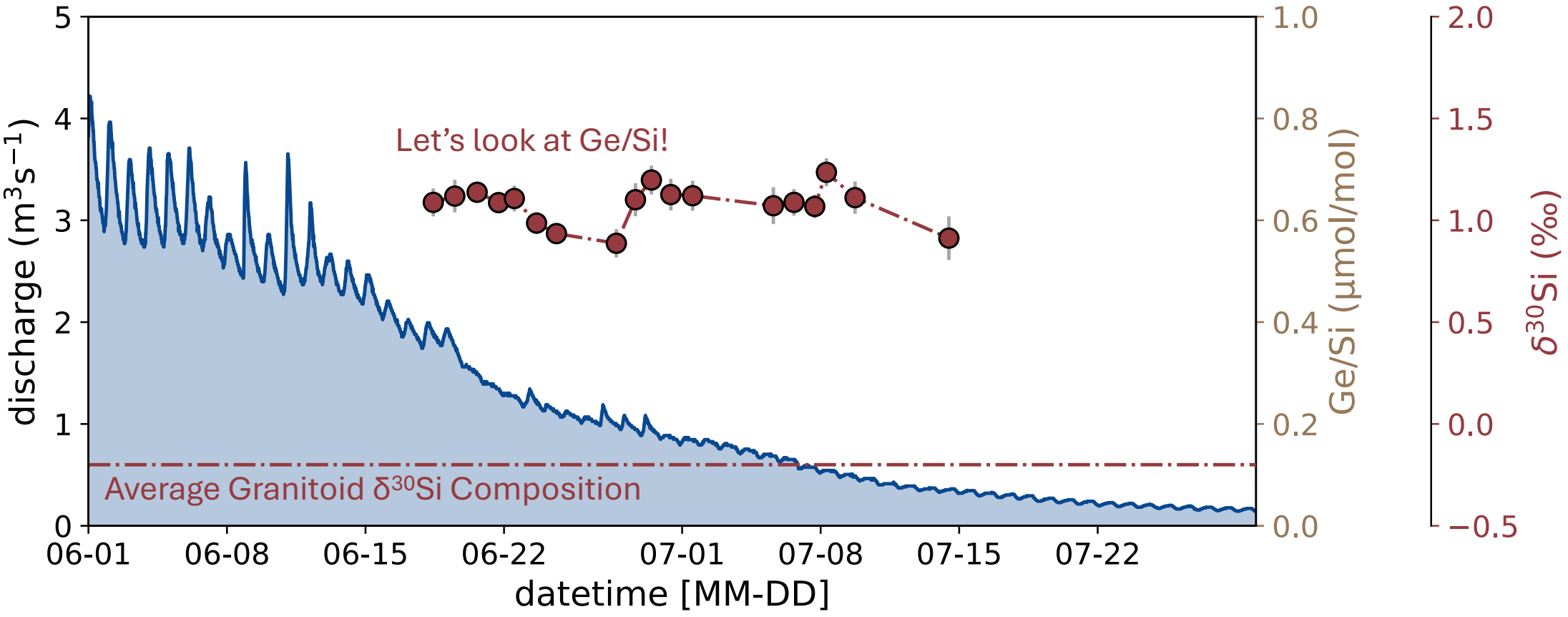

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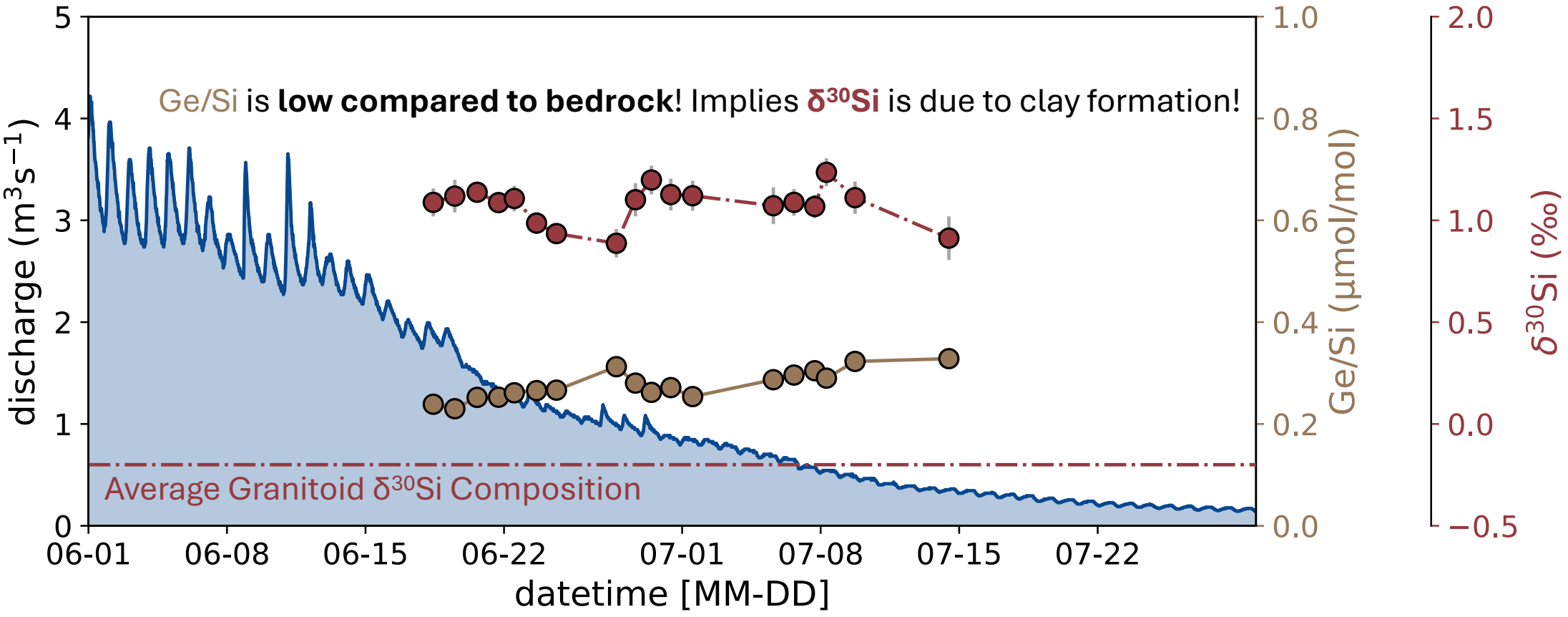
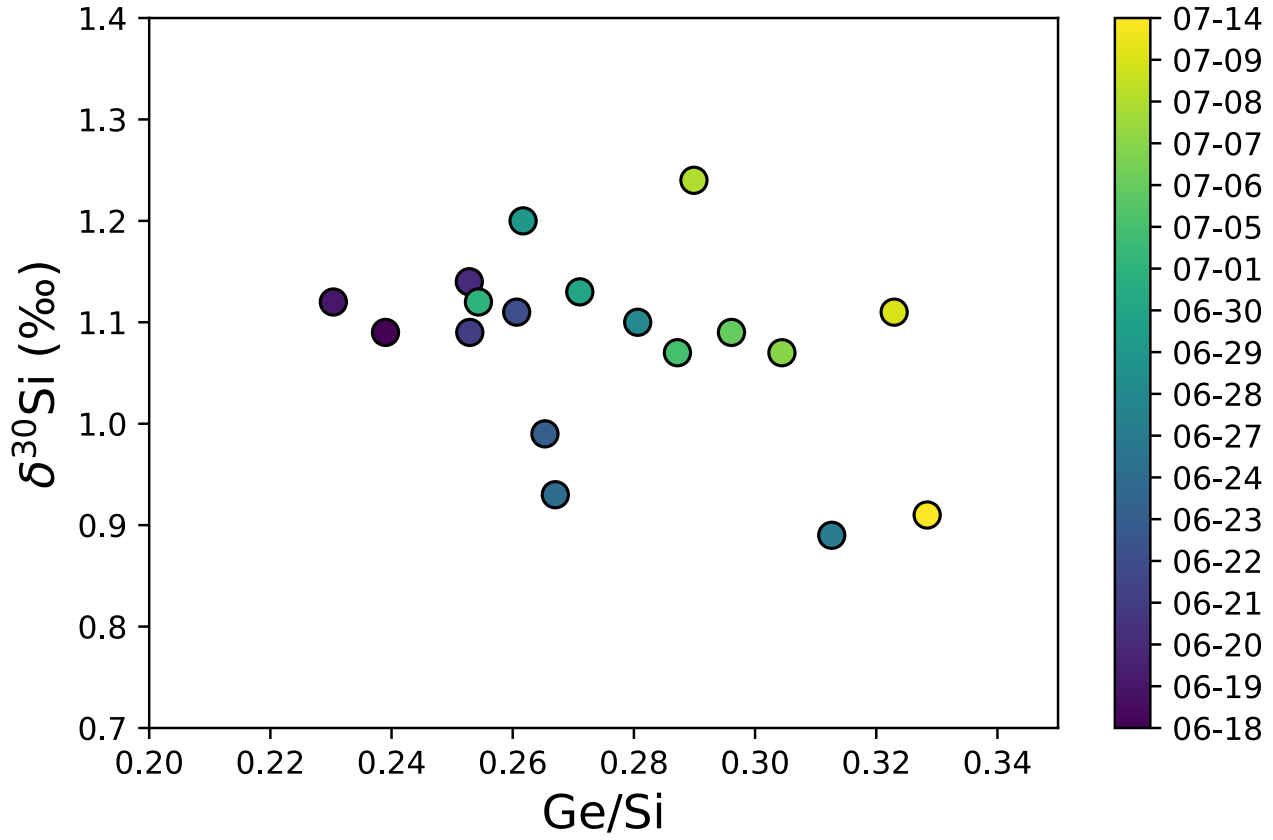
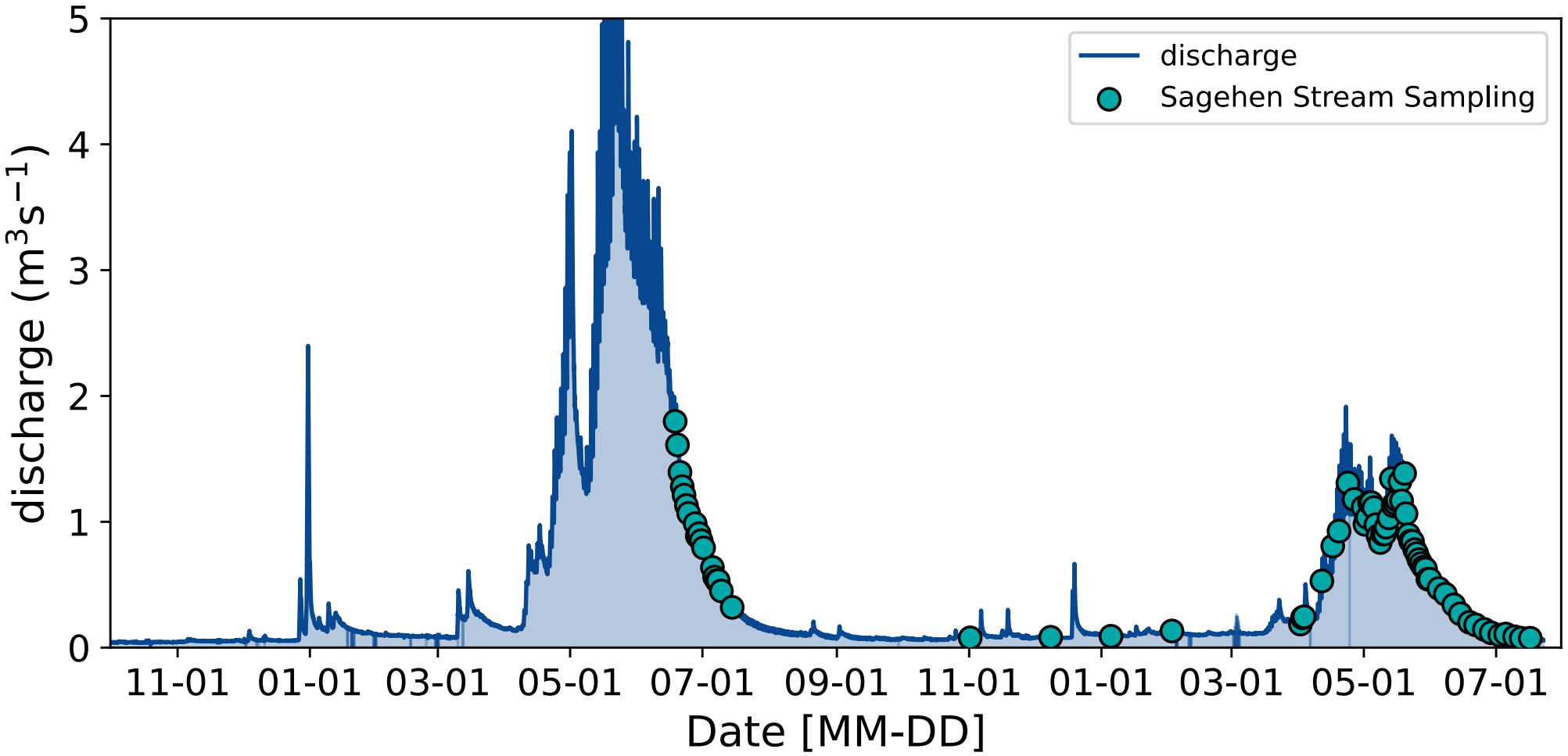


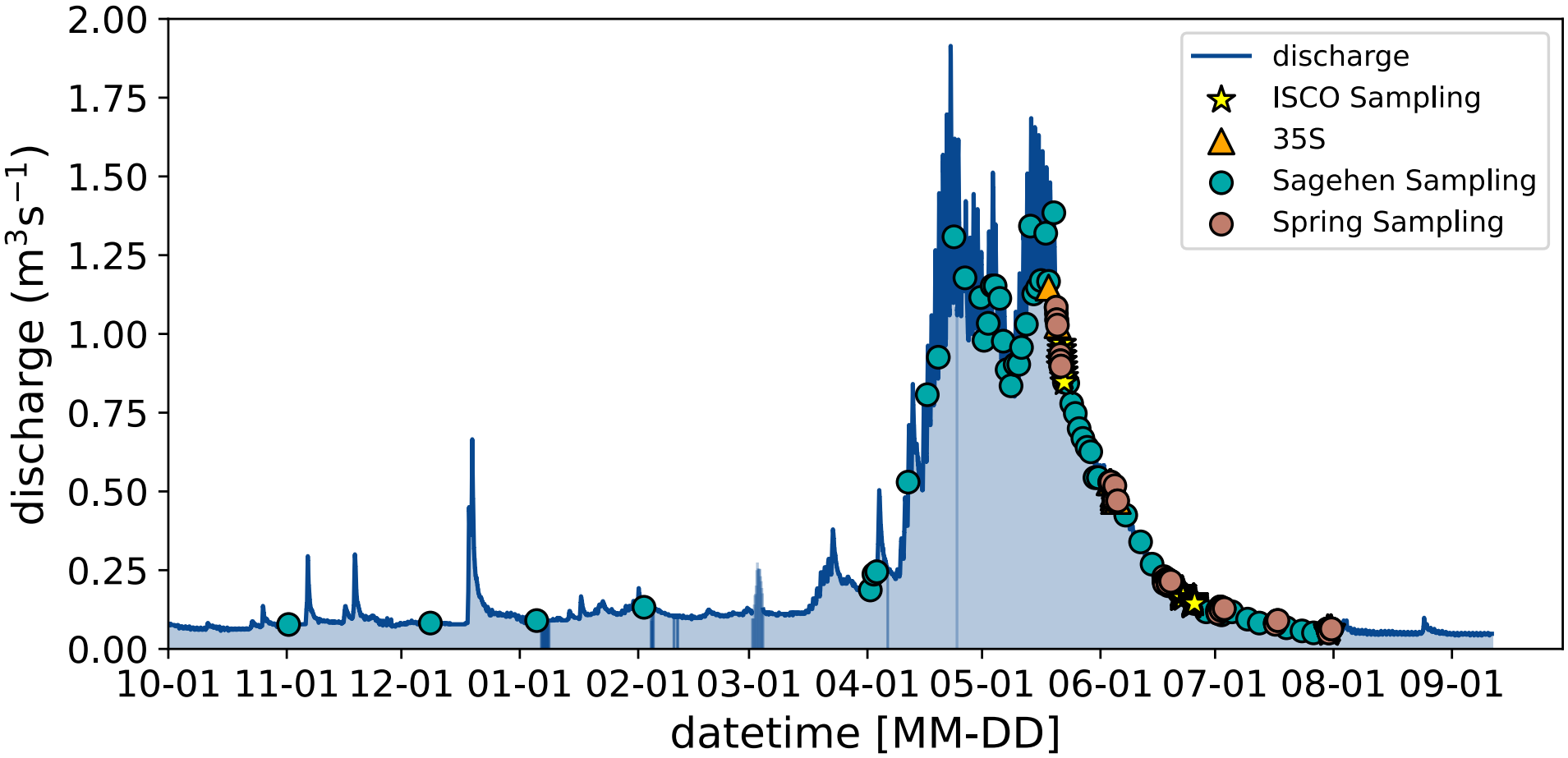
*Savage *et al.*, 2012

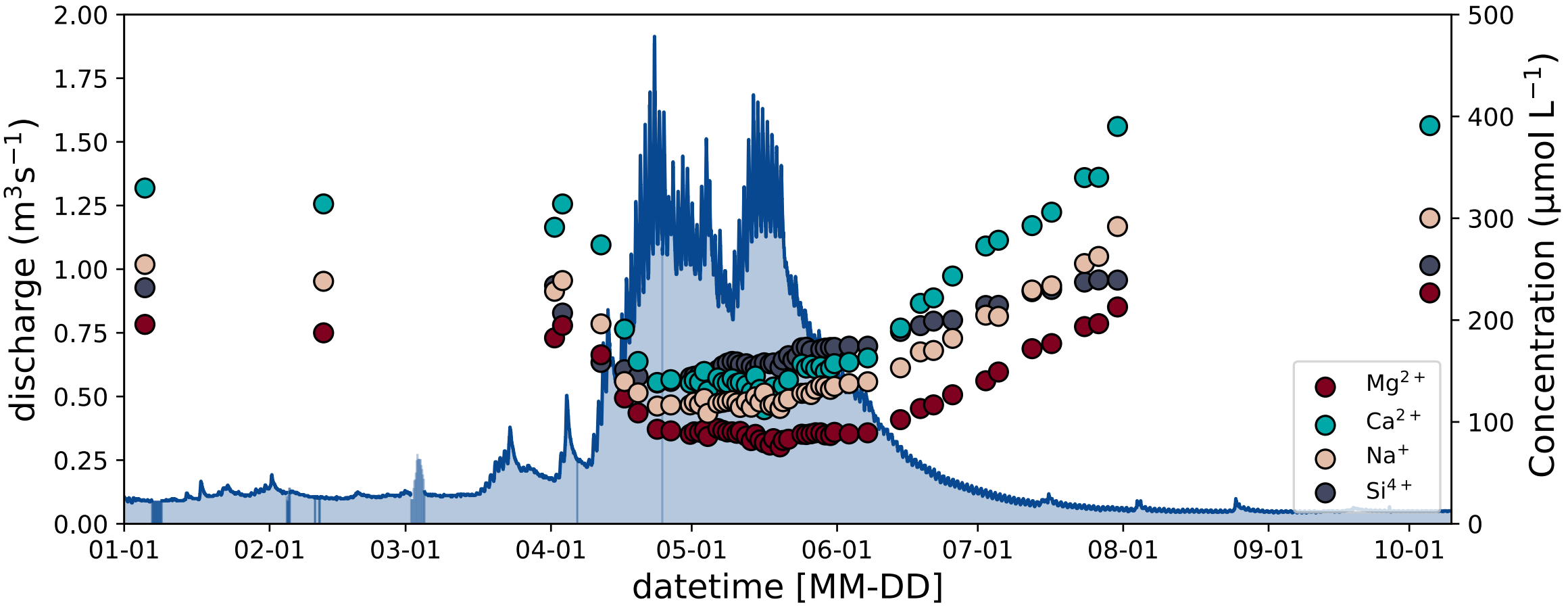
Key Findings

1. **Ge/Si** ratios are **low**, while **δ^{30}Si** is **high**
2. Suggests stream water is supplied by **older groundwater**
3. These results are in agreeance with apparent groundwater ages!



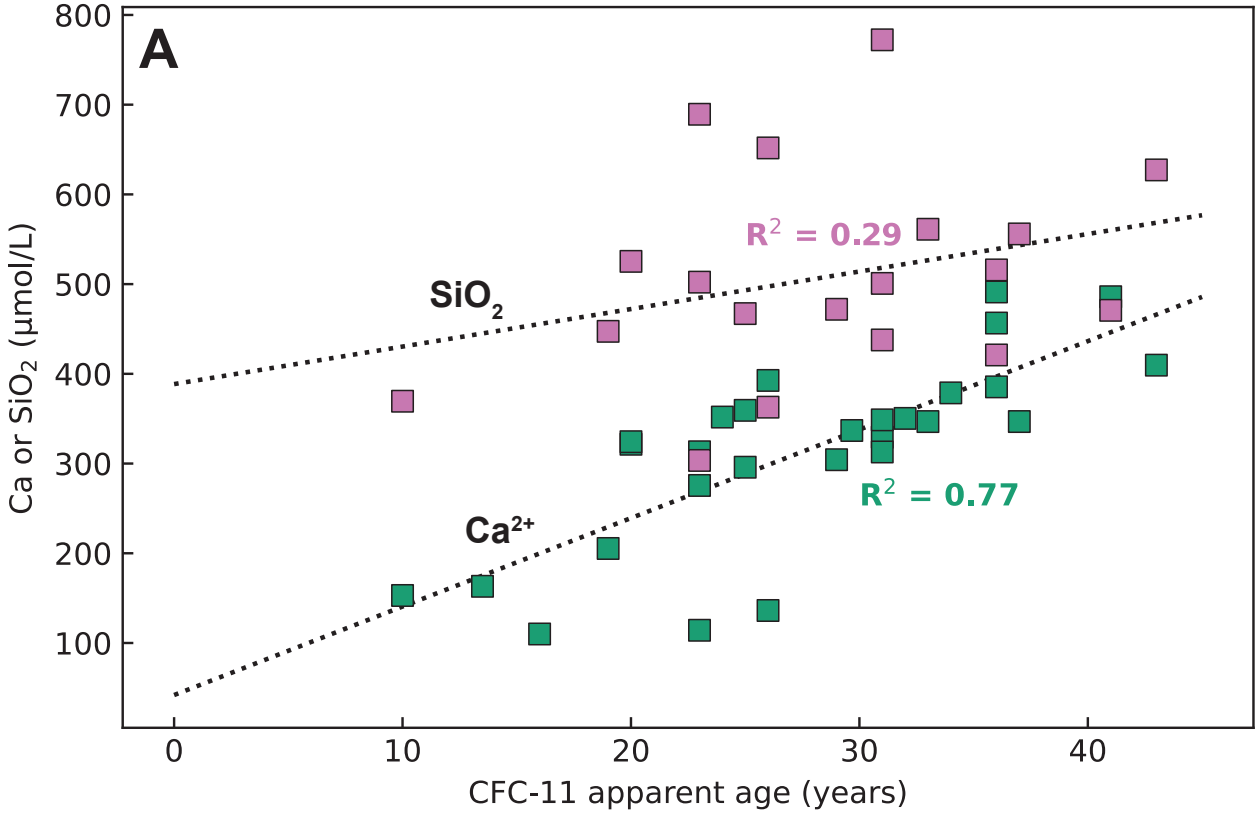

discharge
Sagehen Stream Sampling
discharge (m^3s^{-1})
0
1
2
3
4
5
11-01
01-01
03-01
05-01
07-01
09-01
11-01
01-01
03-01
05-01
07-01
Date [MM-DD]


discharge
ISCO Sampling
35S
Sagehen Sampling
Spring Sampling
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
discharge (m^3s^{-1})
10-01
11-01
12-01
01-01
02-01
03-01
04-01
05-01
06-01
07-01
08-01
09-01
datetime [MM-DD]


discharge (m^3s^{-1})
Concentration (µmol L^{-1})
datetime [MM-DD]
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
500
400
300
200
100
0
01-01
02-01
03-01
04-01
05-01
06-01
07-01
08-01
09-01
10-01
Mg^{2+}
Ca^{2+}
Na^{+}
Si^{4+}

Future Work:

1. Look at seasonal variation of both Ge/Si and $\delta^{30}Si$
2. Focus on daily variation of streamflow to better understand contributions from riparian zone vs deep groundwater



References:

1. Kirchner JW, Godsey SE, Solomon M, Osterhuber R, McConnell JR, Penna D. 2020. The pulse of a montane ecosystem: coupling between daily cycles in solar flux, snowmelt, transpiration, groundwater, and streamflow at Sagehen Creek and Independence Creek, Sierra Nevada, USA. *Hydrology and Earth System Sciences* **24** (11): 5095–5123 DOI: 10.5194/hess-24-5095-2020
2. Rademacher LK, Clark JF, Clow DW, Hudson GB. 2005. Old groundwater influence on stream hydrochemistry and catchment response times in a small Sierra Nevada catchment: Sagehen Creek, California. *Water Resources Research* **41** (2): 2003WR002805 DOI: 10.1029/2003WR002805
3. Rademacher LK, Clark JF, Hudson GB, Erman DC, Erman NA. 2001. Chemical evolution of shallow groundwater as recorded by springs, Sagehen basin; Nevada County, California. *Chemical Geology* **179** (1–4): 37–51 DOI: 10.1016/S0009-2541(01)00314-X
4. Savage PS, Georg RB, Williams HM, Turner S, Halliday AN, Chappell BW. 2012. The silicon isotope composition of granites. *Geochimica et Cosmochimica Acta* **92**: 184–202 DOI: 10.1016/j.gca.2012.06.017
5. Manning AH, Clark JF, Diaz SH, Rademacher LK, Earman S, Niel Plummer L. 2012. Evolution of groundwater age in a mountain watershed over a period of thirteen years. *Journal of Hydrology* **460–461**: 13–28 DOI: 10.1016/j.jhydrol.2012.06.030

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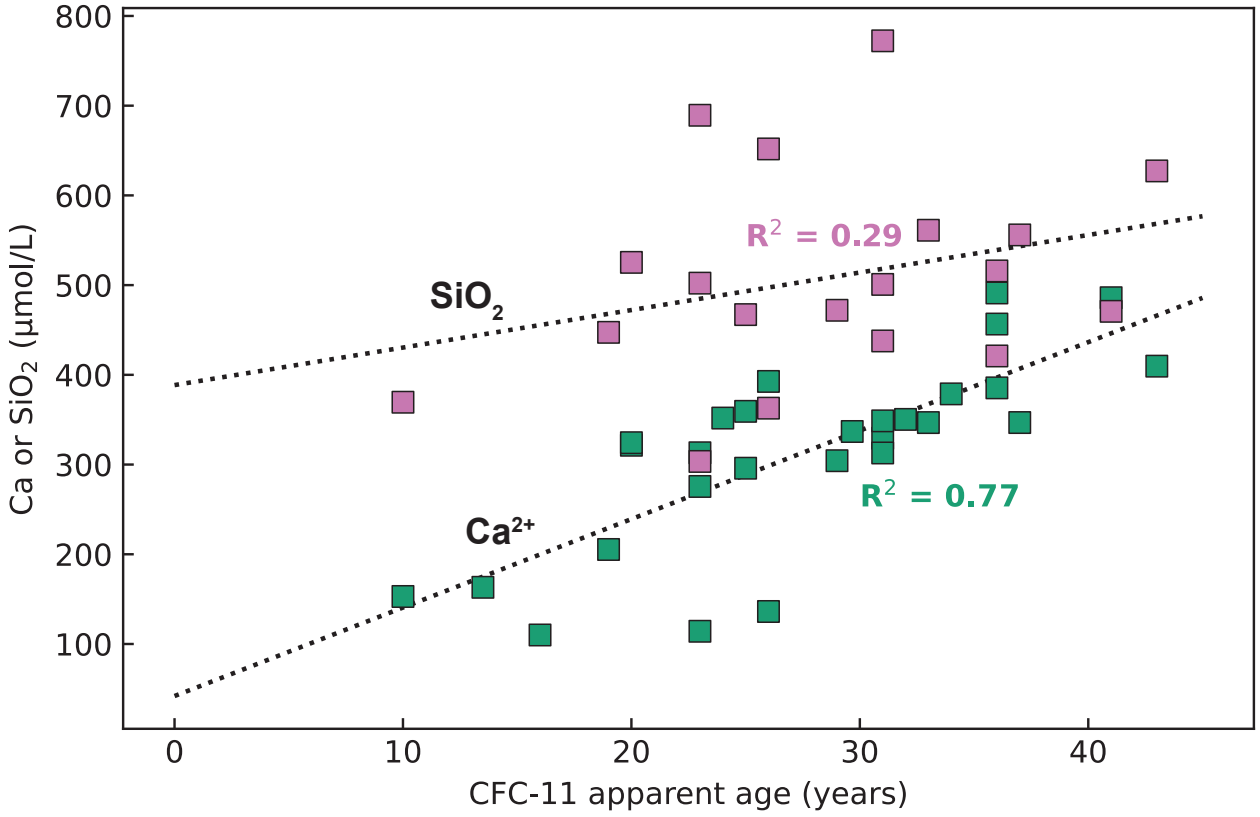

Rademacher et. al., (2005), Rademacher et. al., (2001)

- Mean groundwater ages of the springs range from 28 years (baseflow) to 15 years (snowmelt)
  - (Rademacher et al., 2005)
  - (Manning et al., 2012)
- There is a significant groundwater aquifer with groundwater circulation depths exceeding 100m based on geothermal data
  - (Brumm et al., 2009)