非传统稳定同位素在表生地球过程的应用: Li和K为例

THE UNIVERSITY *of* NORTH CAROLINA *at* CHAPEL HILL

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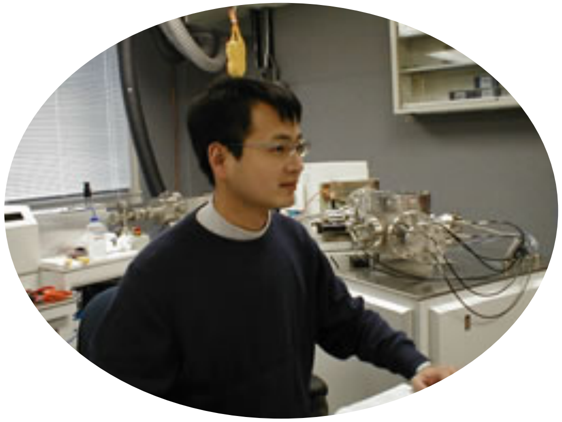

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Earth and Planetary Science Letters 243 (2006) 701 – 710

EPSL

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Diffusion-driven extreme lithium isotopic fractionation in country rocks of the Tin Mountain pegmatite

Fang-Zhen Teng *, William F. McDonough, Roberta L. Rudnick, Richard J. Walker

Geochemistry Laboratory, Department of Geology, University of Maryland, College Park, MD 20742, U.S.A.

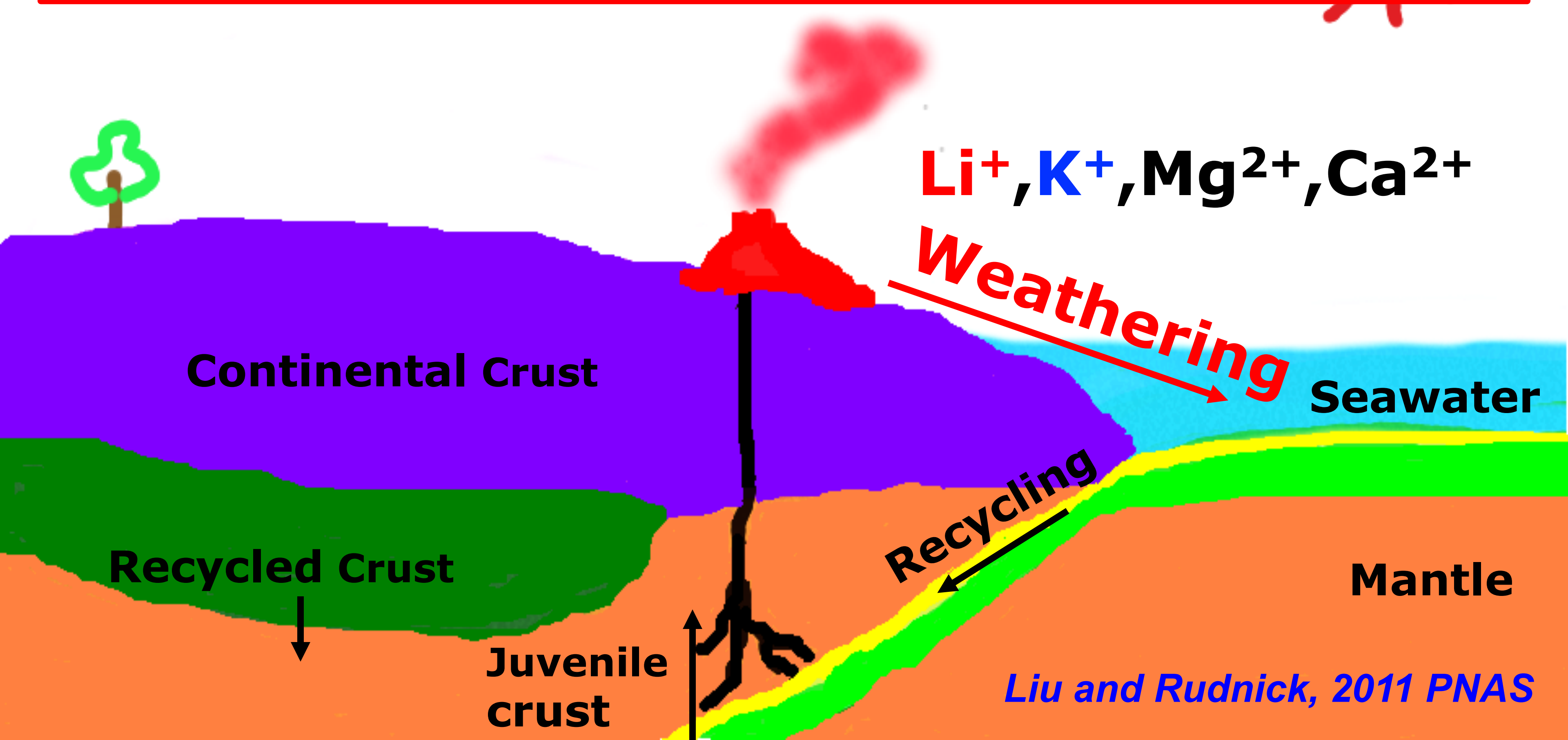
Outline

1. Introduction
2. Chemical weathering in modern environments
3. Weathering and global ocean cycle in Earth's history
4. Conclusions and outlook

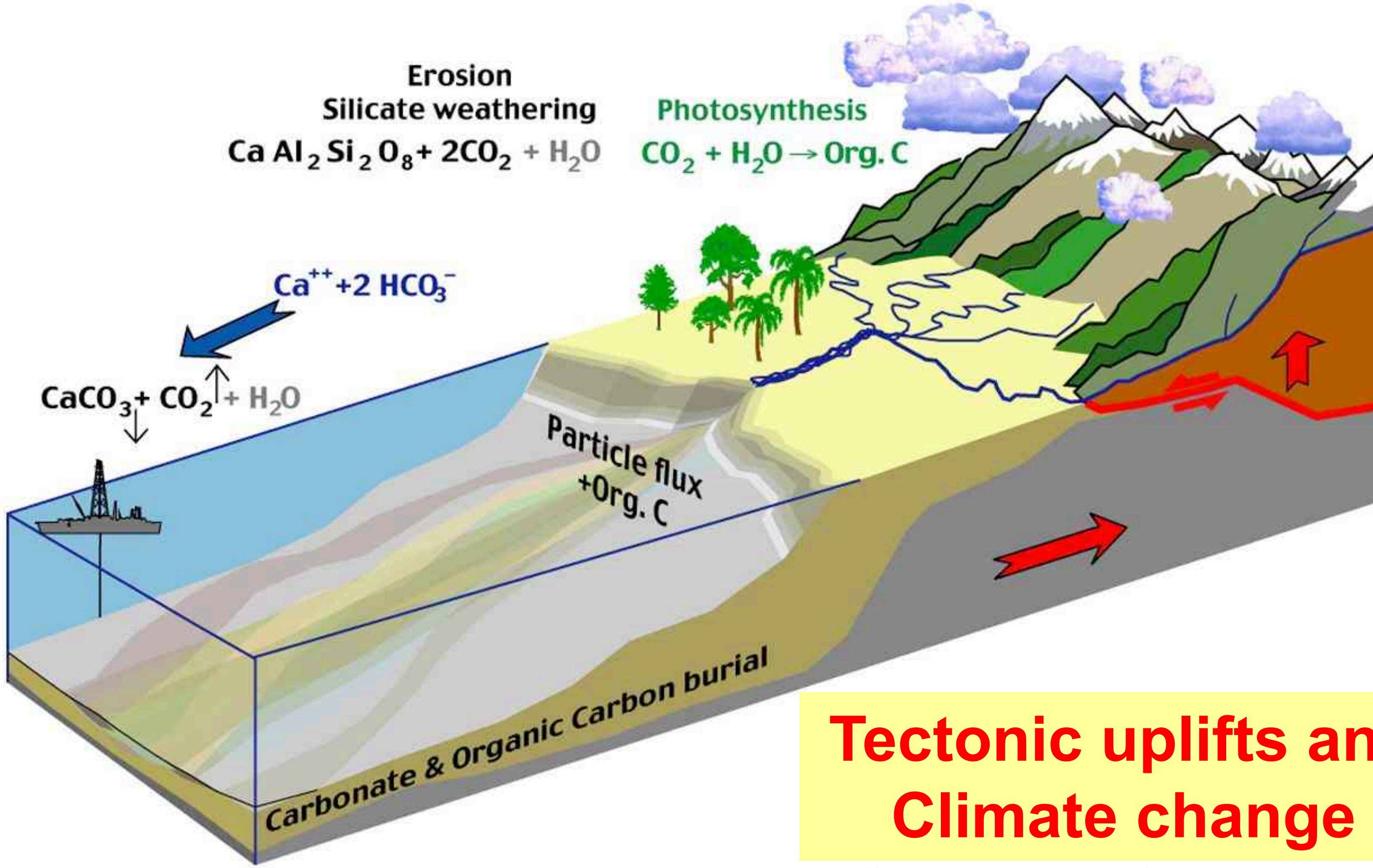
1. Introduction

Why study chemical weathering?

>15% mass of original juvenile crust lost due to continental weathering and erosion



Why study chemical weathering?



Tectonic uplifts and Climate change

http://recherche.crpg.cnrs-nancy.fr/spip.php?article1150&lang=fr

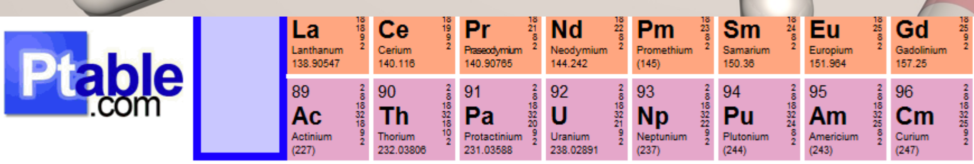
Why lithium?

FirstView

Association between naturally occurring lithium in drinking water and suicide rates: systematic review and meta-analysis of ecological studies

Anjum Memon (a1), Imogen Rogers (a1), Sophie M. D. D. Fitzsimmons (a1), Ben Carter (a2) ...

DOI: https://doi.org/10.1192/bjp.2020.128 Published online by Cambridge University



Lithium pioneer: Lui-Hueng Chan (1939-2007)

Geochimica et Cosmochimica Acta Vol. 52, pp. 1711–1717 0016-7037/88/$3.00 + .00

Variation of lithium isotope composition in the marine environment: A preliminary report

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and

JOHN M. EDMOND
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(*Received September* 2, 1987; *accepted in revised form March* 22, 1988)

Abstract—The Li isotopic compositions of ocean waters, lake waters, hydrothermal solutions, altered and unaltered basalts have been determined using the technique of thermal ionization mass spectrometry of lithium tetraborate. Seawater appears to be homogeneous in Li isotopic composition. The mean δ^6Li value is -32.3 ± 0.5‰, relative to an isotopic standard. Three lakes studied (Lake Tanganyika, Caspian Sea and Dead Sea) yield δ^6Li similar to the seawater isotopic composition. A fresh basalt glass from 21°N, East Pacific Rise displays a δ^6Li value of -4.7‰. A hydrothermal solution from a 21°N vent field has δ^6Li of -10‰, indicating incomplete extraction of Li from the igneous minerals or partial retention in secondary phases. The alteration margin of a basalt from the Mid-Atlantic Ridge has δ^6Li of -8.4‰. The isotope data of submarine basalts suggest preferential removal of ^{6}Li from seawater into alteration minerals during low temperature weathering. The δ^6Li values of two hydrothermal solutions from Guaymas Basin were found to be -5‰ and -10‰. The results can be interpreted as the net effect of Li addition from basalt and sediments and incorporation in hydrothermal precipitates as the hydrothermal fluids interact with basin sediments.

The observed enrichment of ^{7}Li in seawater relative to submarine hydrothermal solutions, its principal Li input, is tentatively attributed to isotopic fractionation associated with low temperature alteration of seafloor basalt and incorporation in authigenic sediments. It appears that the Li isotope system may have characteristics that can resolve the mass balance of Li in the ocean.

Potassium pioneers:

Contents lists available at ScienceDirect

Chemical Geology

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High-precision analysis of potassium isotopes by HR-MC-ICPMS

Yan Hu[a,*], Xin-Yang Chen[a], Ying-Kui Xu[a,b], Fang-Zhen Teng[a,*]

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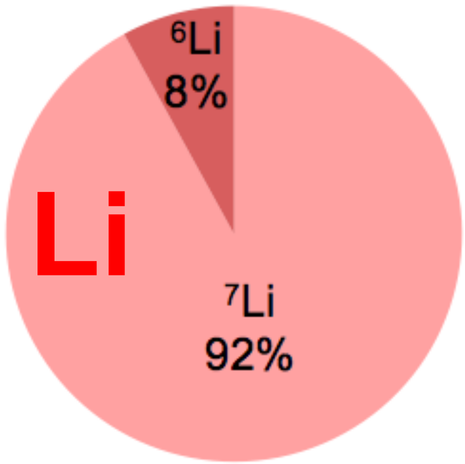
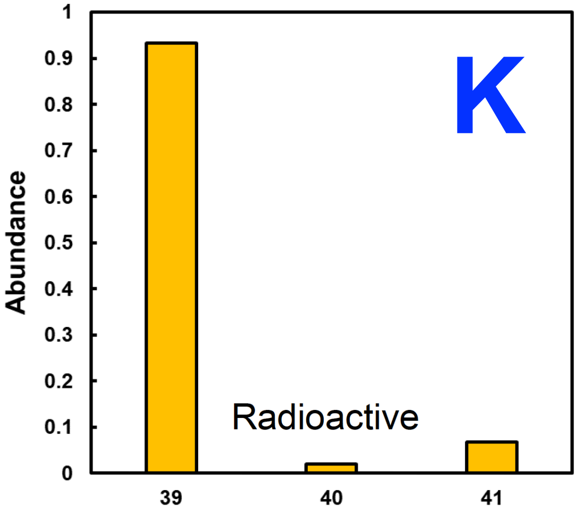
Cite this: *J. Anal. At. Spectrom.*, 2019, **34**, 160

High-precision potassium isotopic analysis by MC-ICP-MS: an inter-laboratory comparison and refined K atomic weight†

Heng Chen, Zhen Tian, Brenna Tuller-Ross, Randy L. Korotev and Kun Wang *

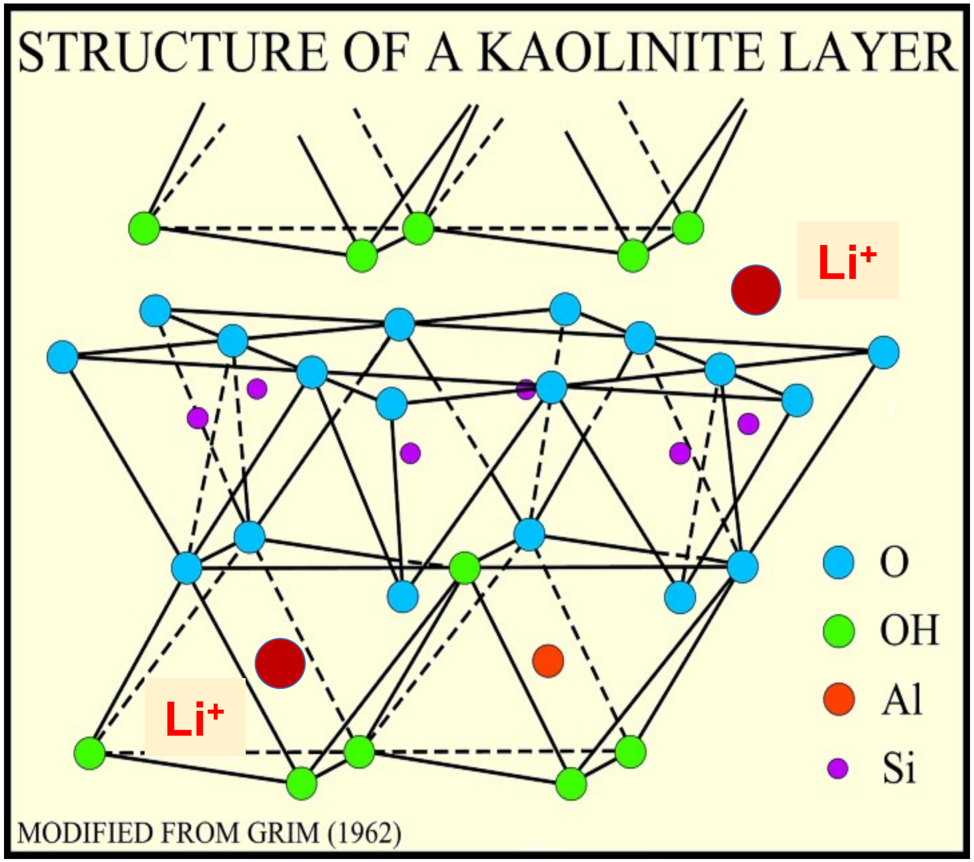
Why Li and K?





- Incompatible – enriched in continental crust
- Soluble in fluid and can be incorporated/sorbed to clay
- Monovalent (not affected by redox)
- Enriched in silicates, poor in carbonates
- K – important nutrient, Li – NOT a nutrient

How do Li isotopes fractionate?



Heavy isotope

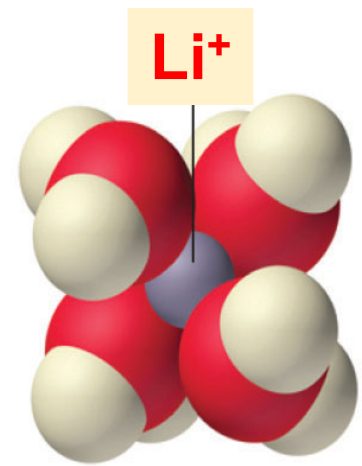
High bonding energy site

Low coordination number

Bigeleisen and Mayer (1947)

Tetrahedra, CN=4

Octahedral, CN=6



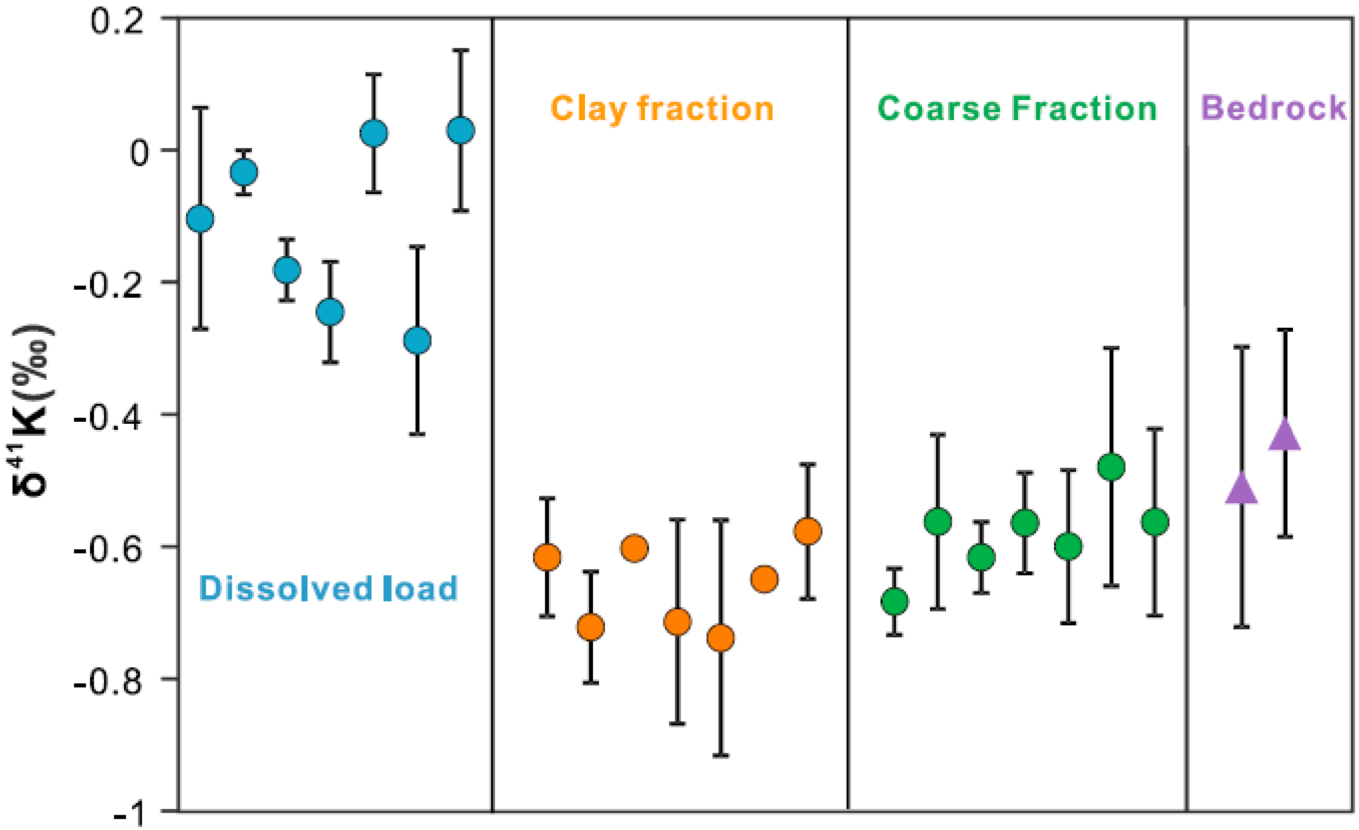
H_2O

heavy isotope (^{7}Li) in tetrahedral sites of water

light isotope (^{6}Li) in octahedral sites of secondary minerals

Huh et al., 1998; Liu et al., 2013; 2015; Pistiner and Henderson, 2003; PvS et al., 2006; 2009; Rudnick et al., 2004; Teng et al., 2004; Williams and Hervig, 2005; Vigier et al., 2008; Wimpenny et al., 2015

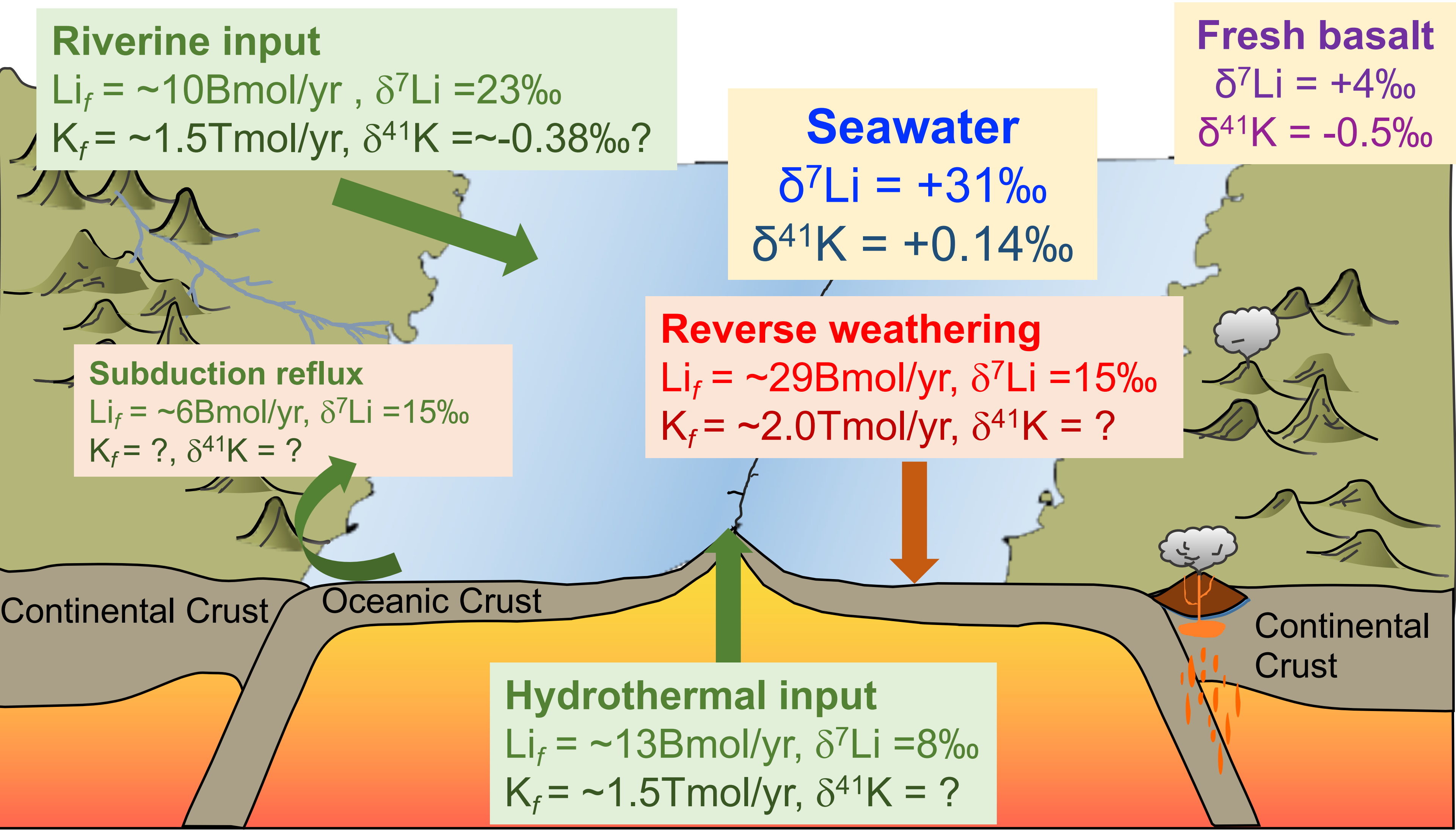
How do K isotopes fractionate?



heavy isotope (^{41}K) in water
light isotope (^{39}K) in secondary minerals

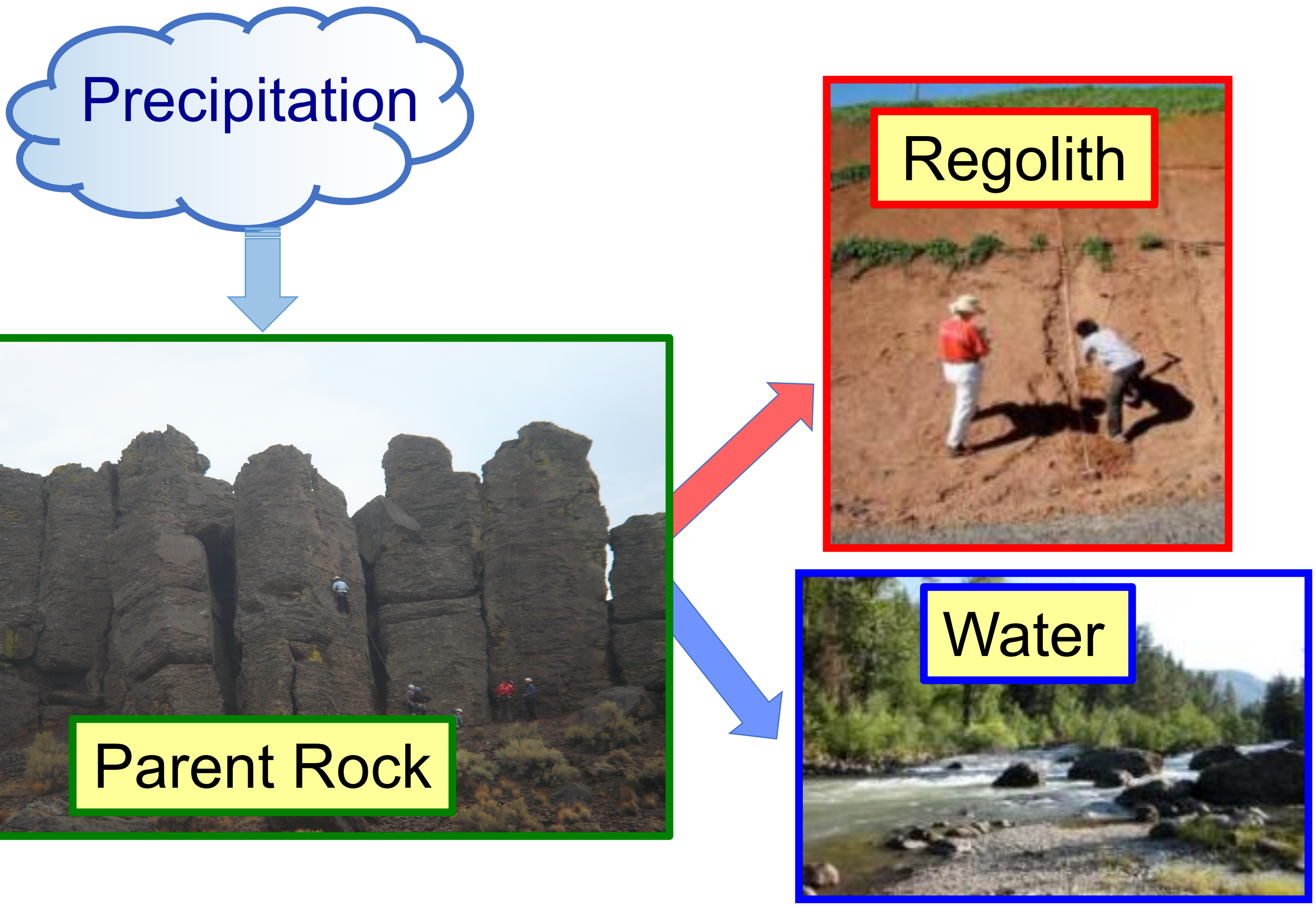
Chen et al., 2020; S. Li et al., 2019; Teng et al., 2020; Zeng et al., 2019

Global Li and K cycle



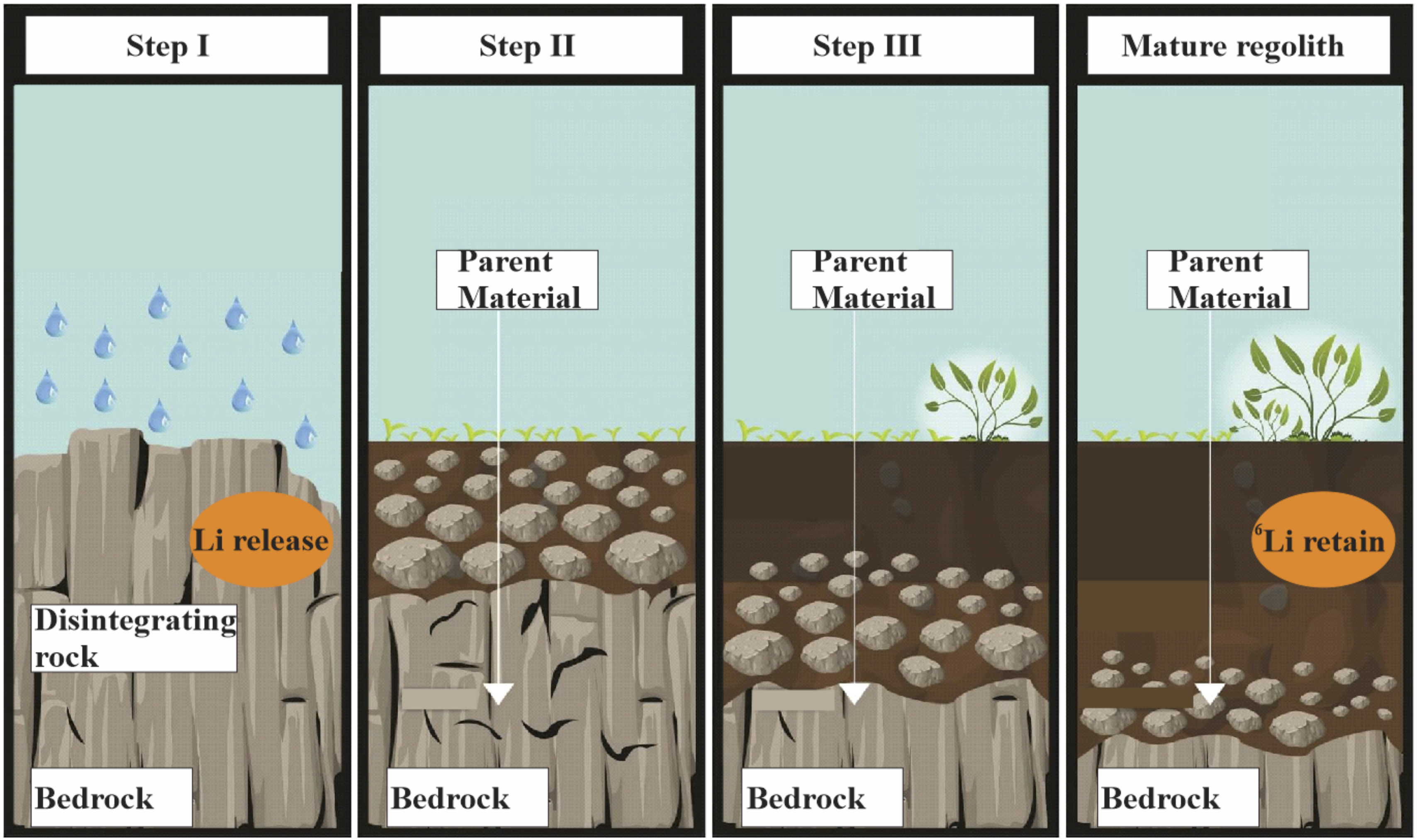
2. Chemical weathering in modern environments

Weathering process

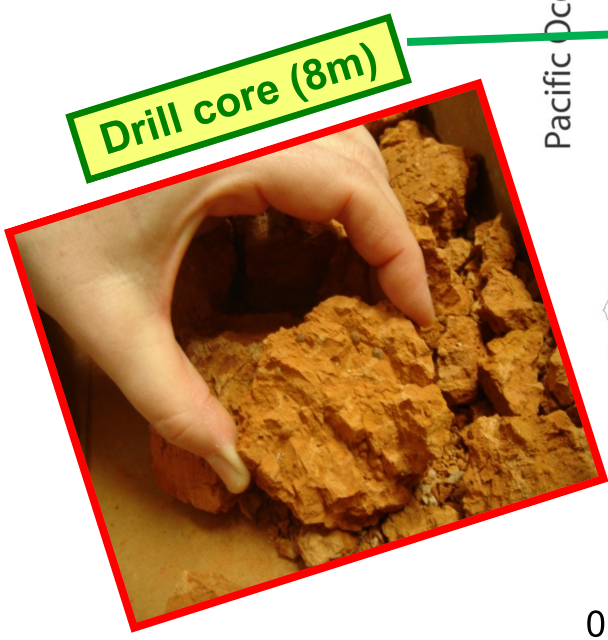


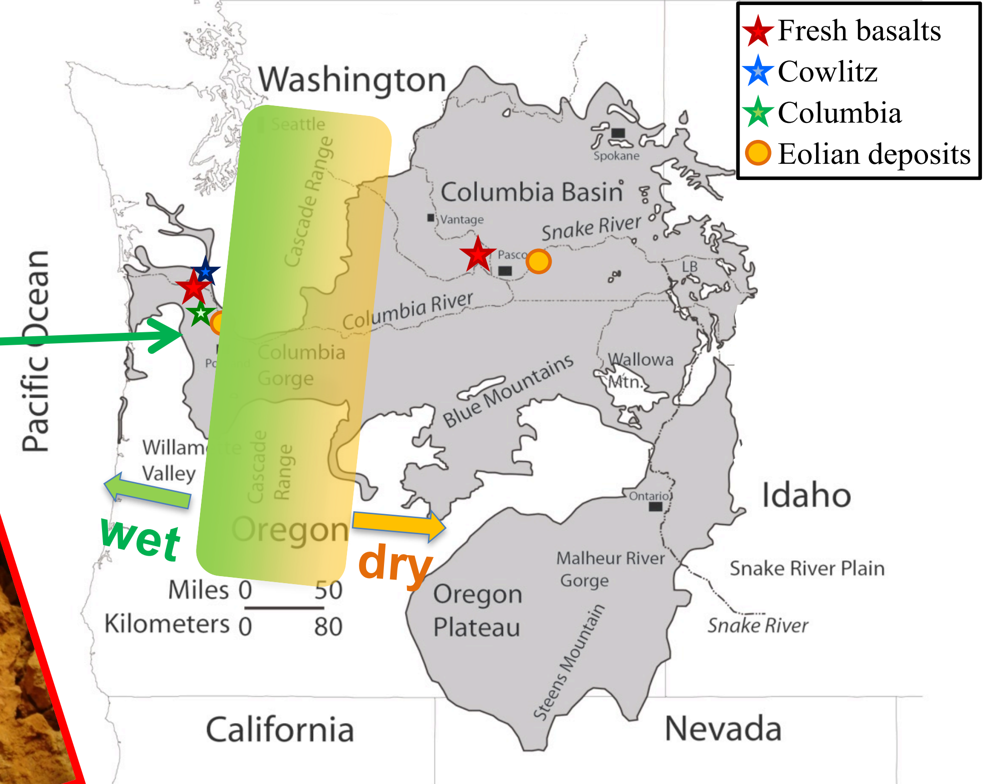
Why study regolith?

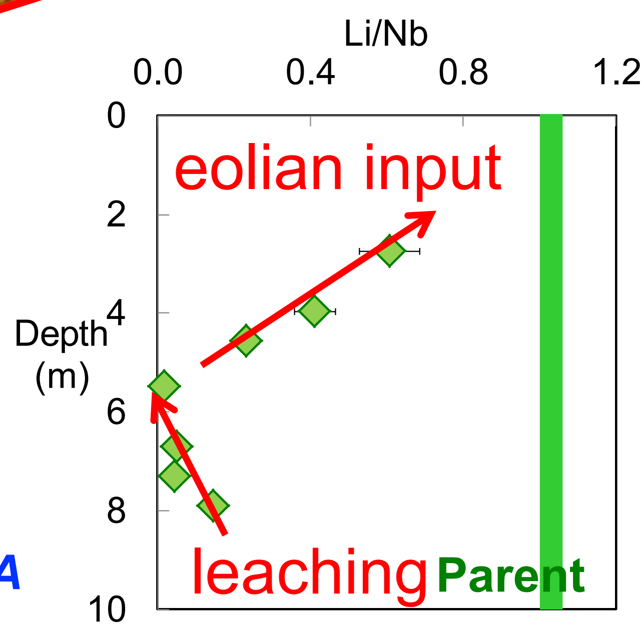
Regolith provide accumulated knowledge during weathering.

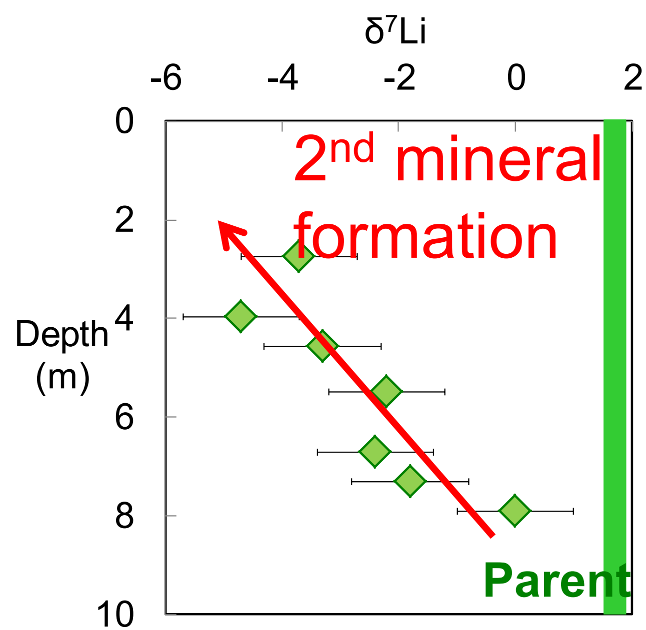


Regolith
Li isotopes







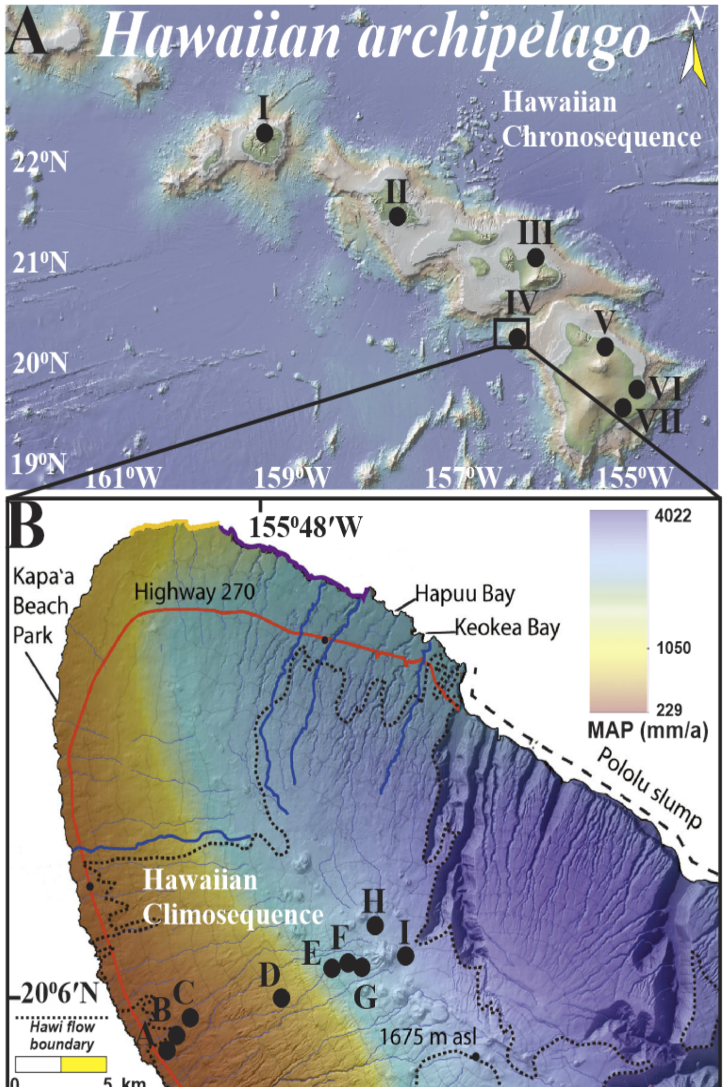


Liu et al., 2013 GCA

Hawaii Islands

Previous work on Li in Hawaiian regolith

MAP=2500 mm (Age=0.3~4100 kyr)



	Age (kyr)
I	4100
II	1400
III	400
IV	150
V	20
VI	0.3
VII	0.3

1. Clay mineral formation controls Li geochemistry.

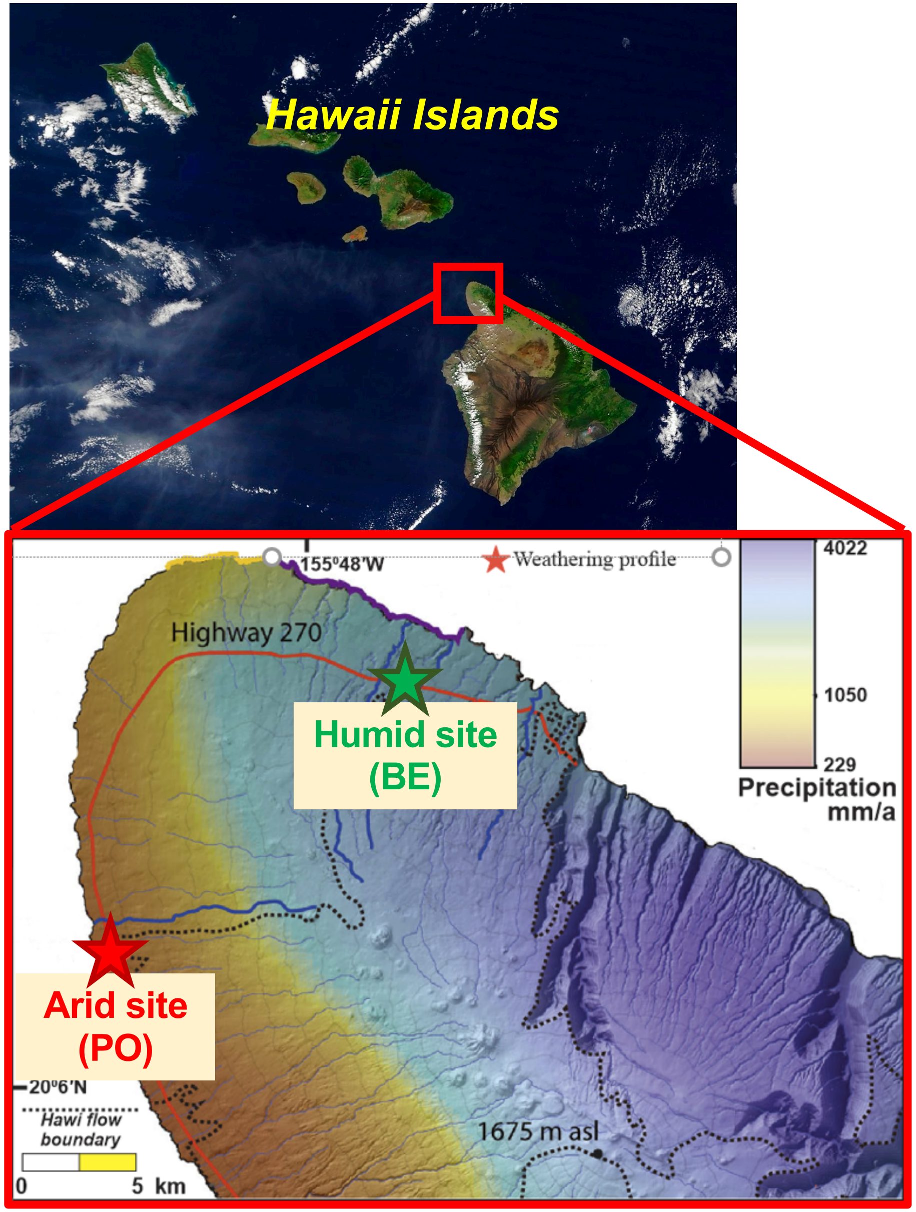
Age=170 kyr (MAP=160~3000 mm)

	MAP (mm/a)
A	160
B	180
C	210
D	570
E	992
F	1260
G	1380
H	2500
I	3000

2. Eolian addition affect Li geochemistry.

Huh et al., 2004 G^3
Ryu et al., 2014 GCA

Regolith

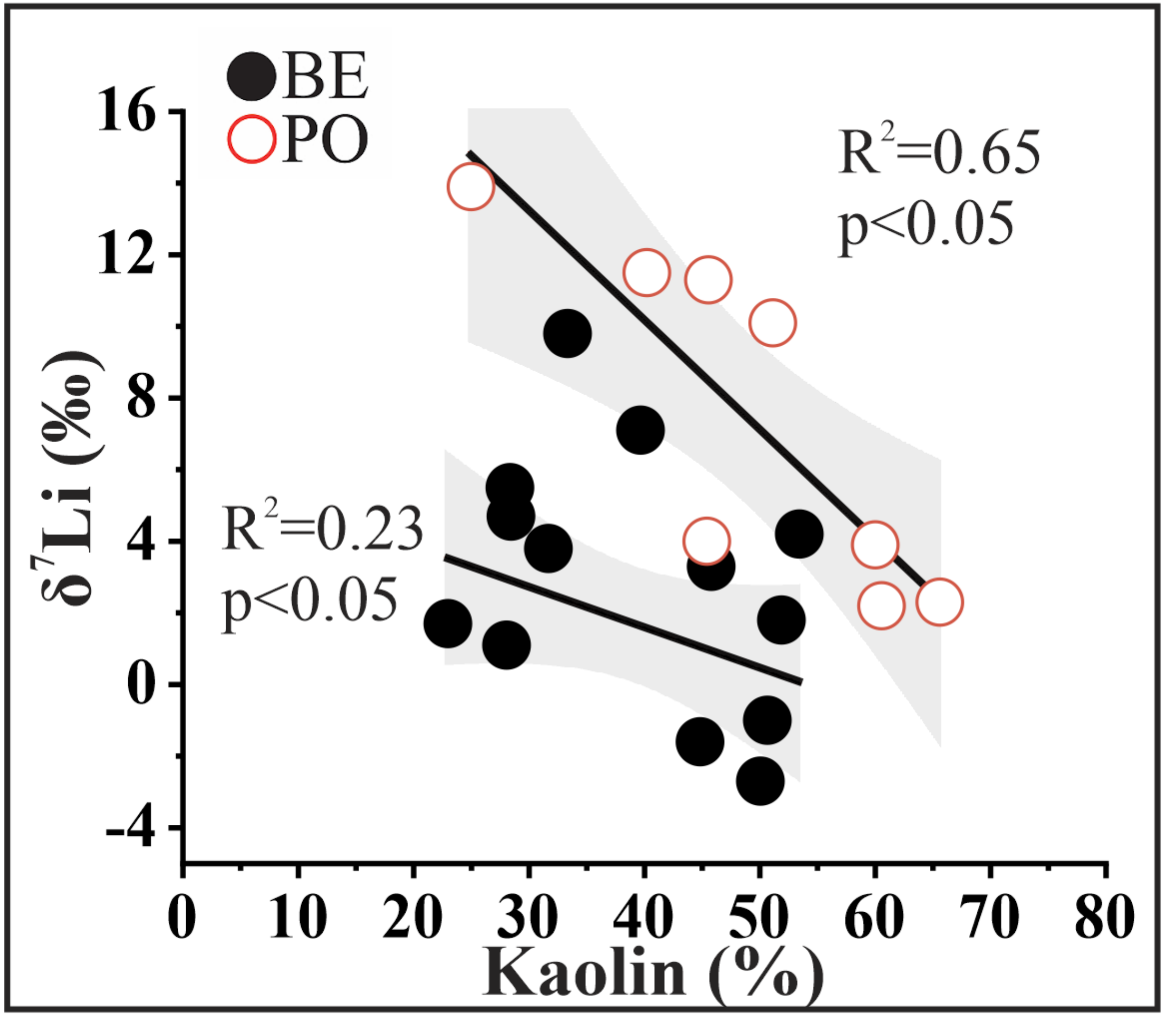

Hawaii Islands
155°48'W
Weathering profile
Highway 270
Humid site
(BE)
Arid site
(PO)
4022
1050
229
Precipitation
mm/a
20°6'N
Hawi flow
boundary
0
5 km
1675 m asl


Humid site: MAP~1800 mm/yr
~15 m thickness


Arid site: MAP~300 mm/yr
~3.5 m thickness

Regolith
Li isotopes

1. 2nd mineral formation

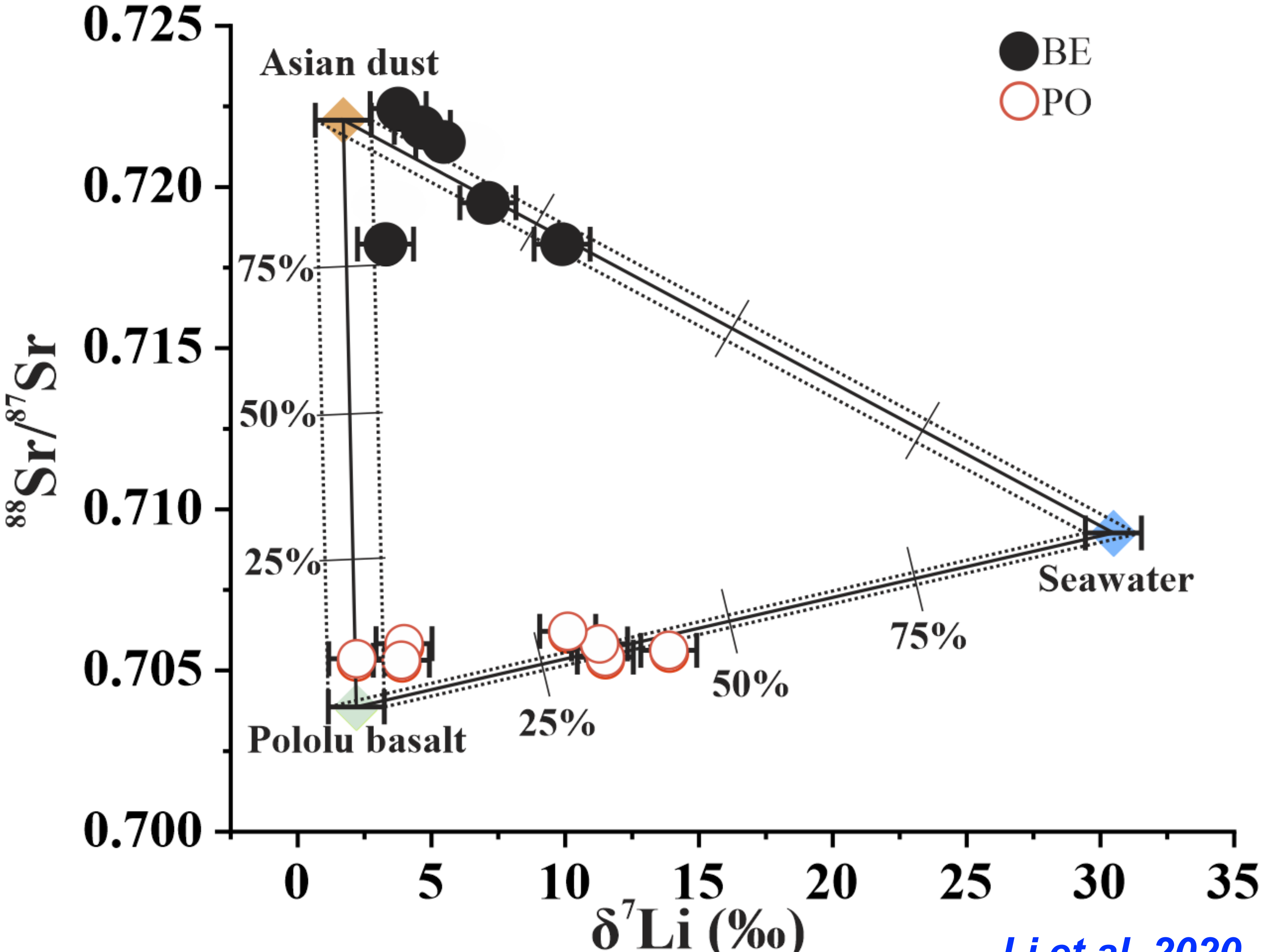


Li et al. 2020, GCA

Regolith

Li isotopes

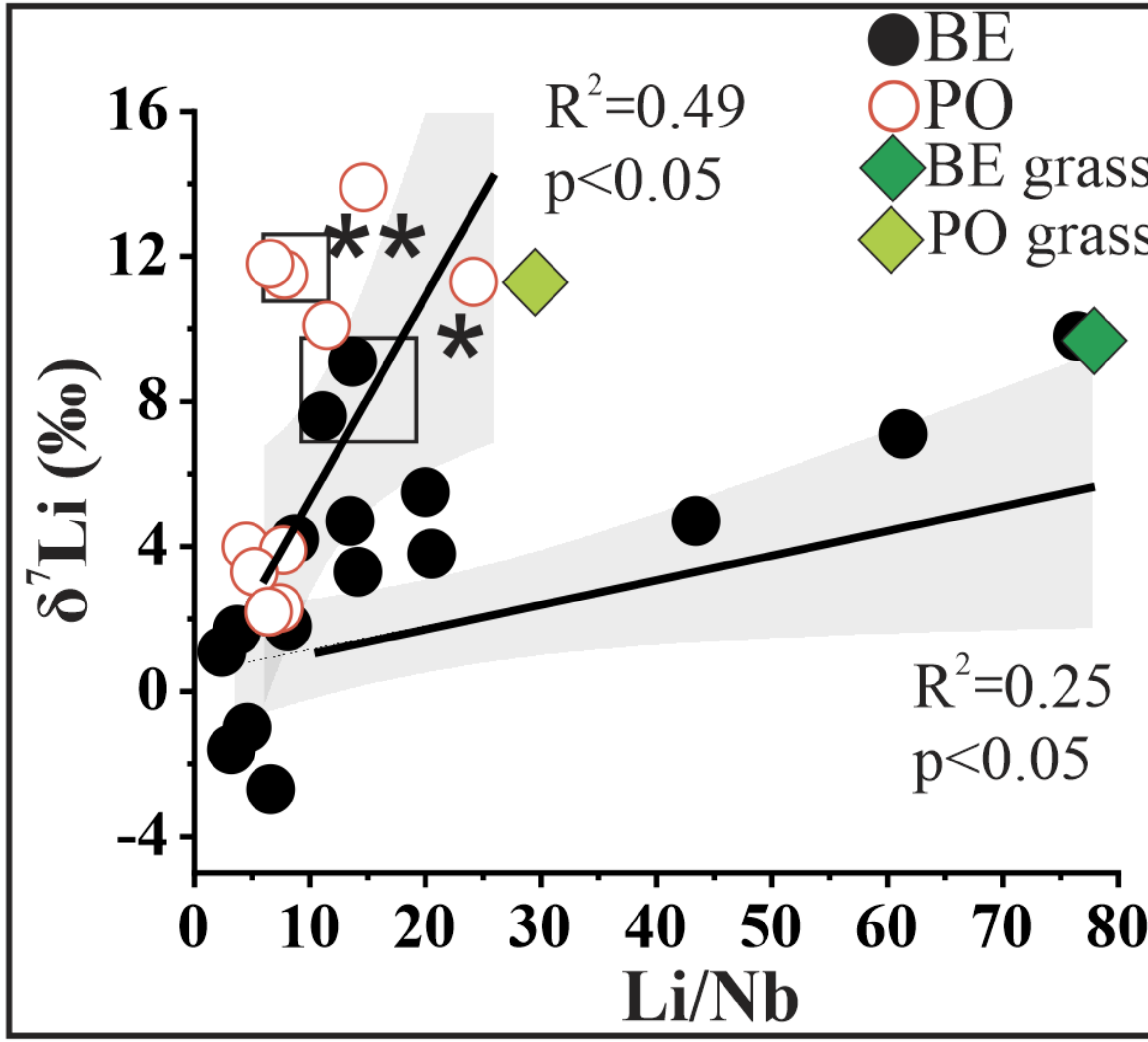
2. Eolian inputs



Li et al. 2020, GCA

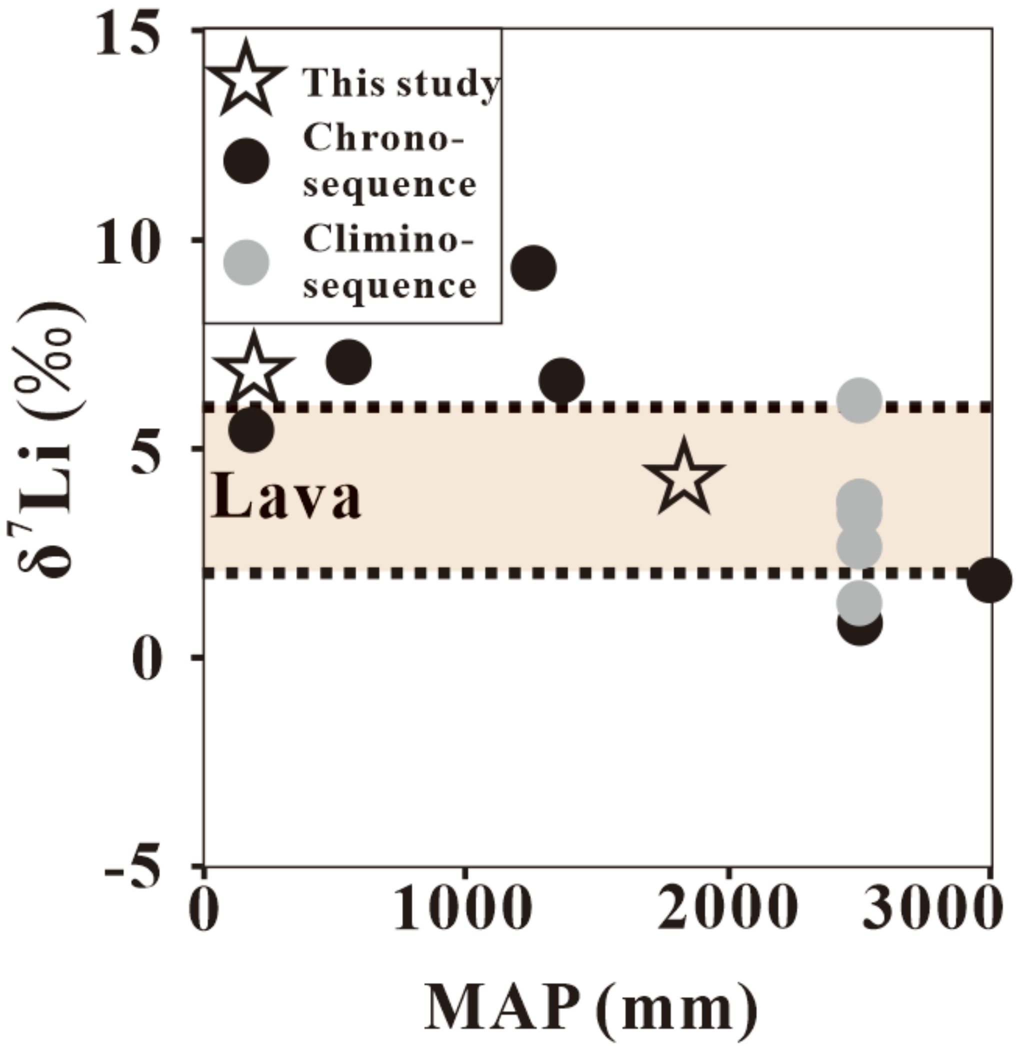
Regolith
Li isotopes

3. Biological control



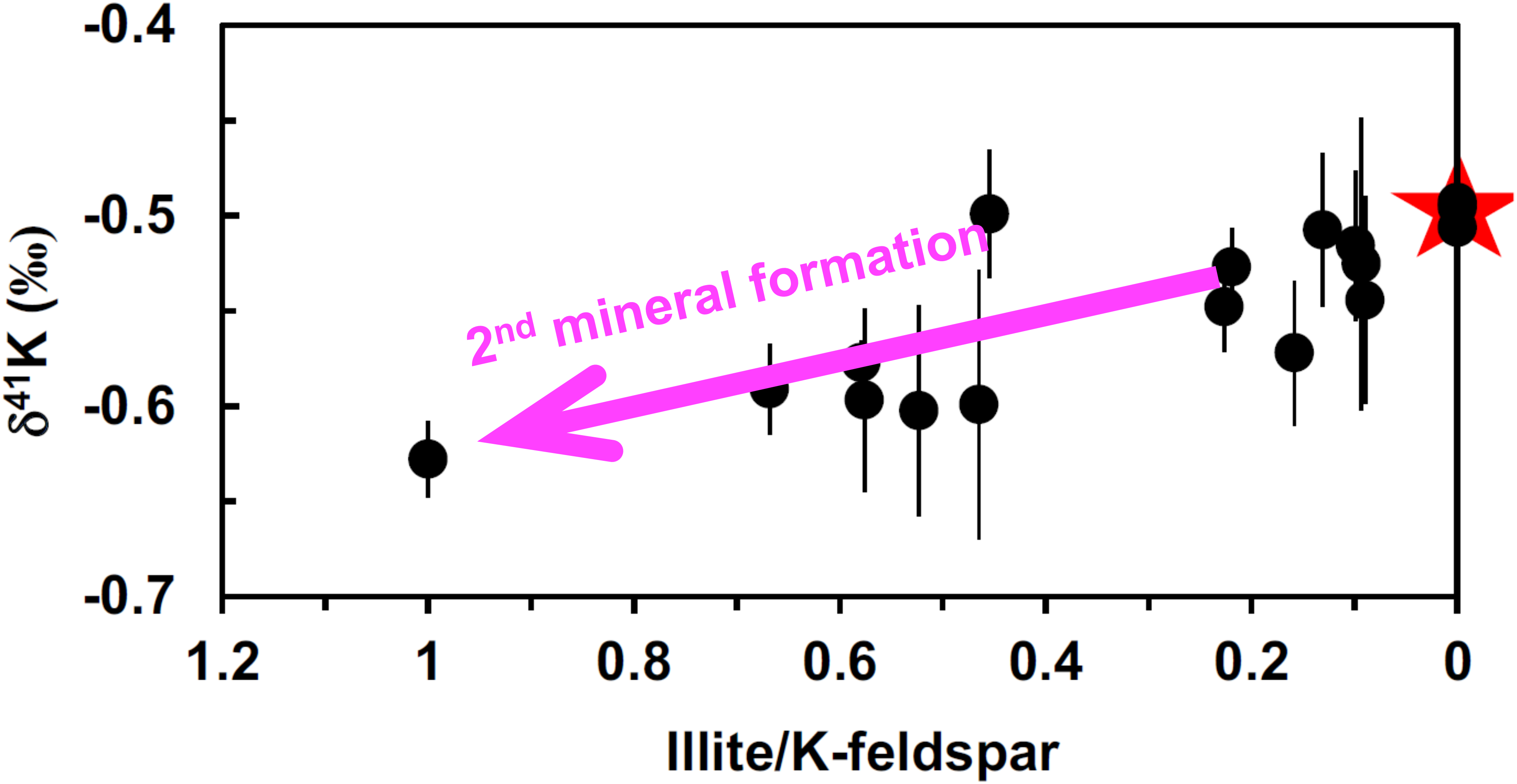
Li et al. 2020, GCA

Hawaii Li summary – Climate/Weathering intensity



Huh et al., 2004 G^3; Ryu et al., 2014 GCA; Li et al., 2020 GCA

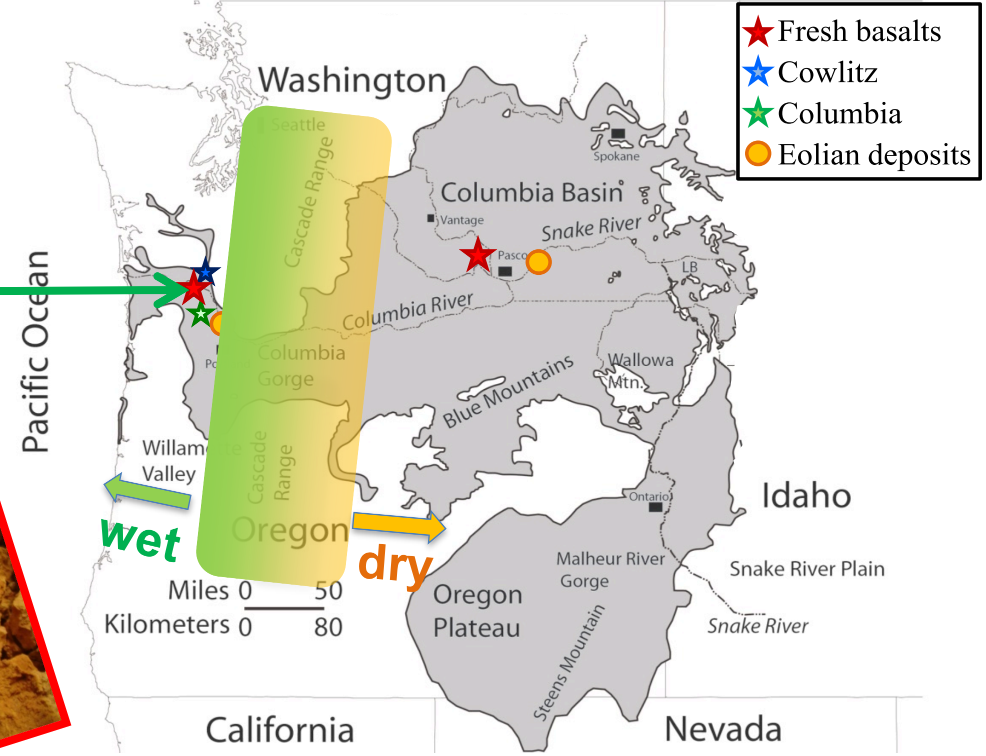
Regolith
K isotopes

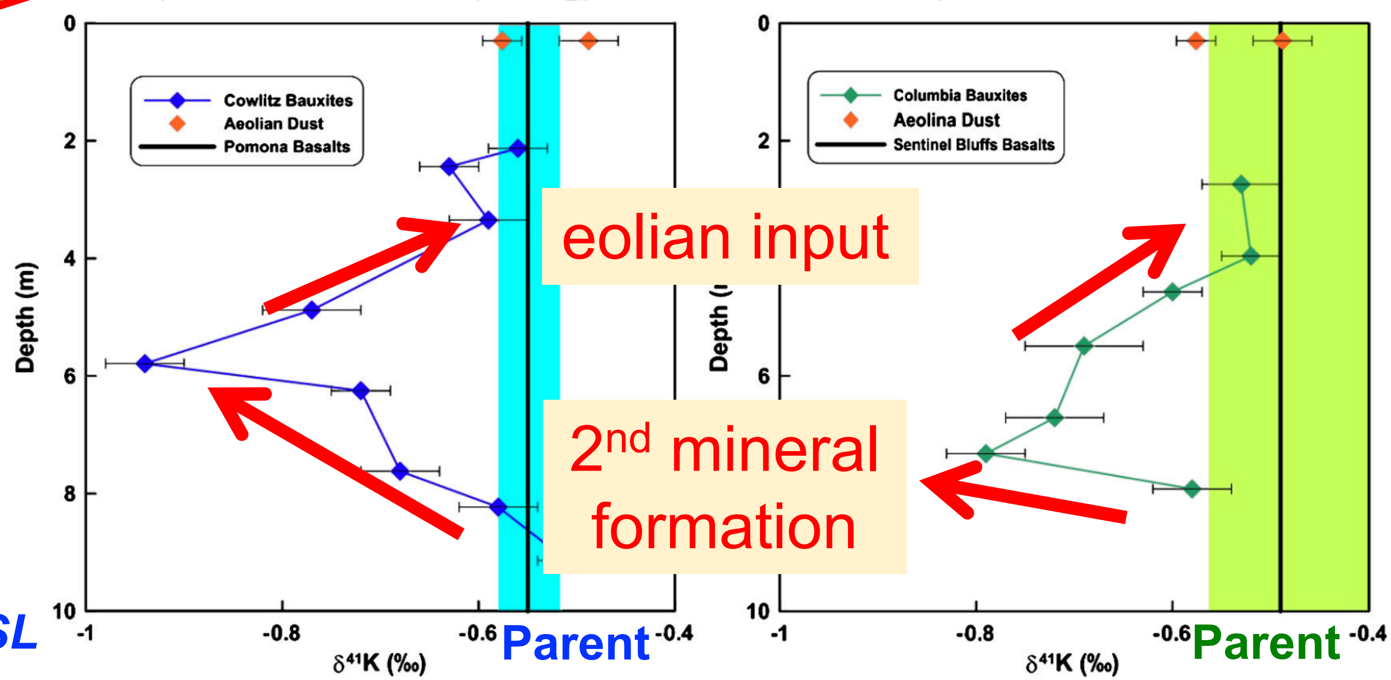


Teng et al. 2020, GCA

Regolith
K isotopes

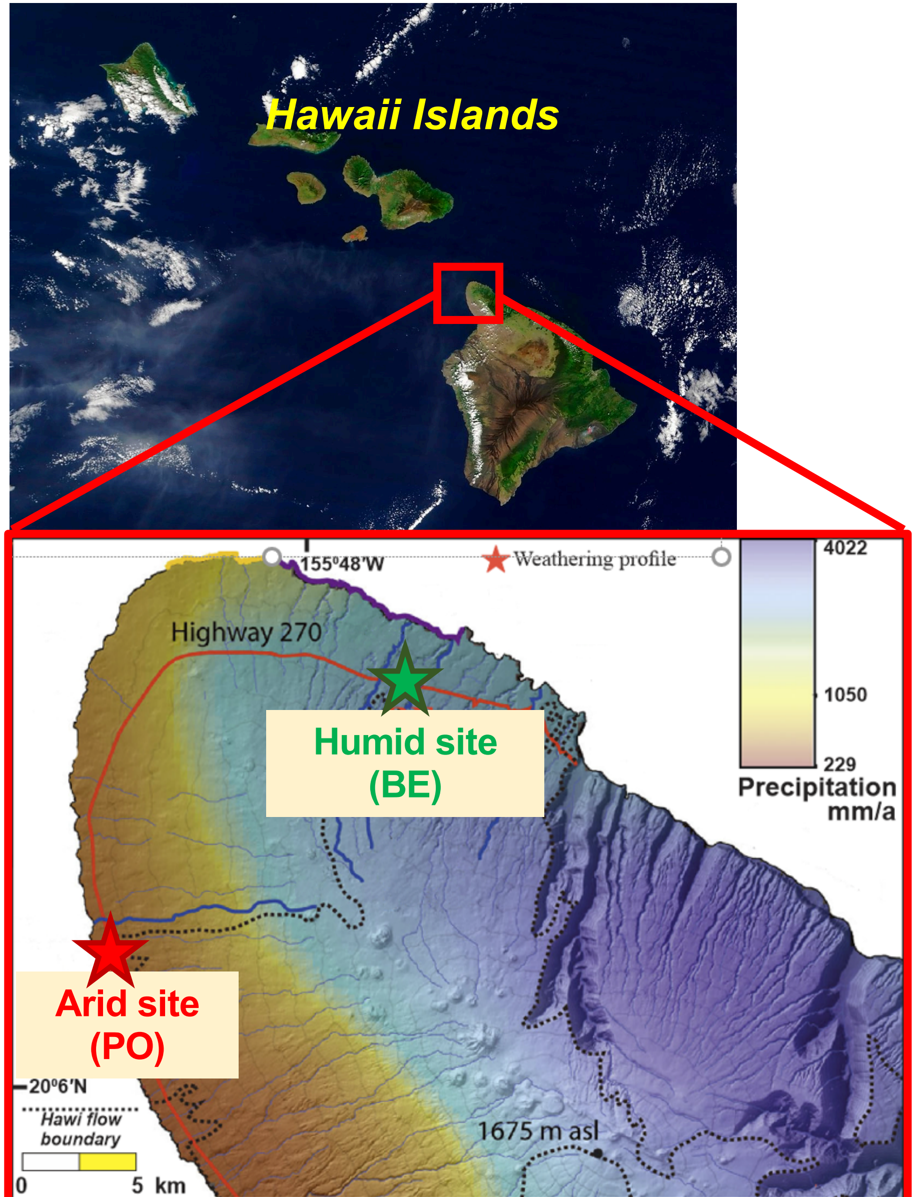
Drill cores



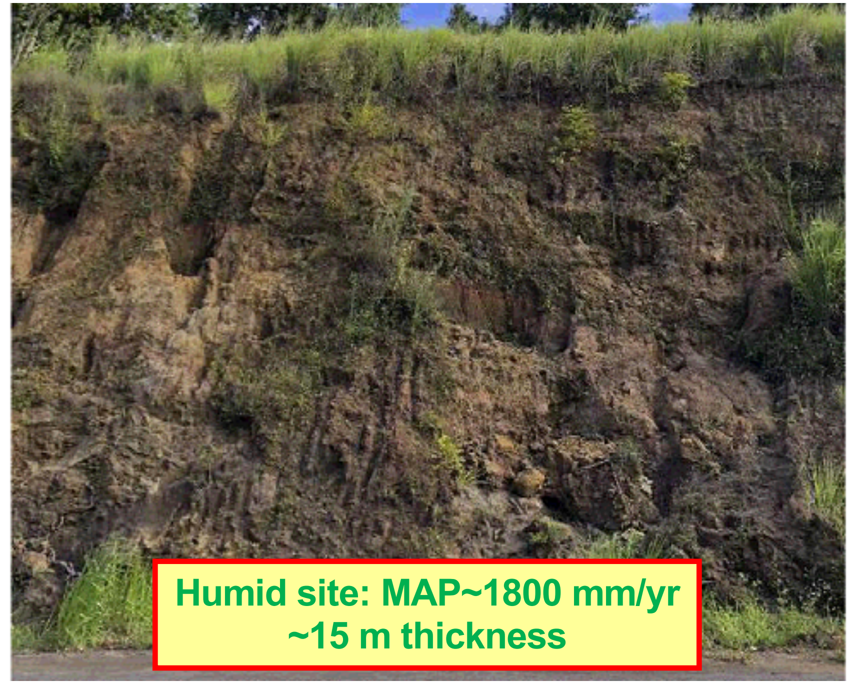


Chen et al. 2020, EPSL

Regolith



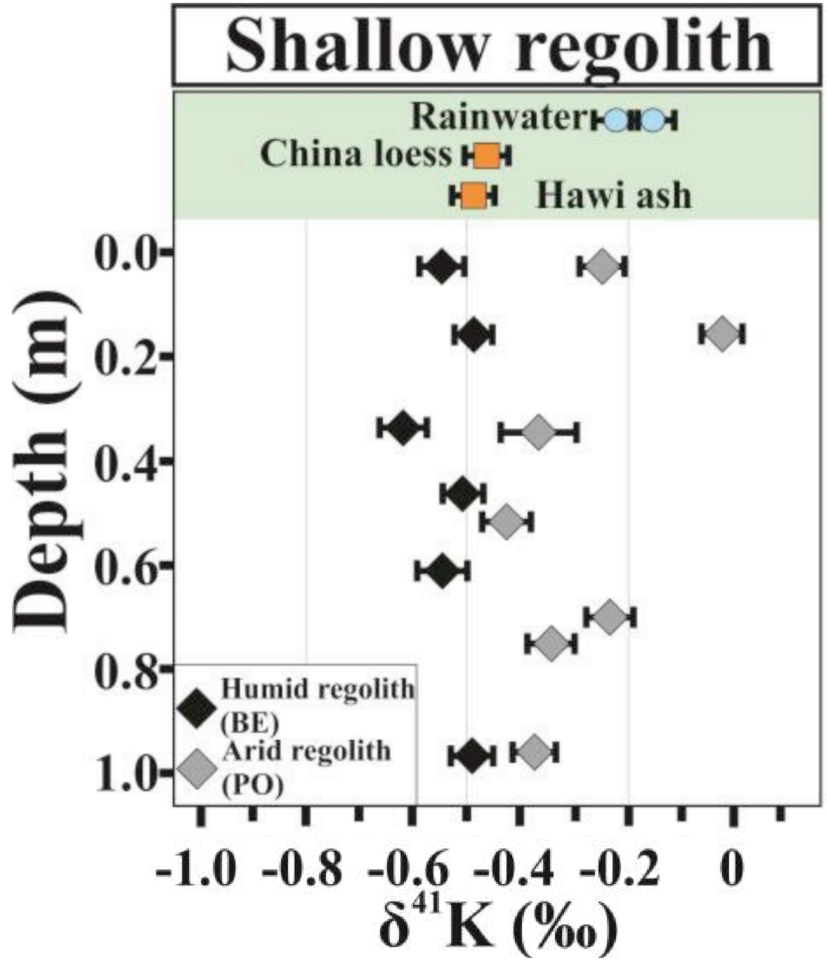
Hawaii Islands
155°48'W
Weathering profile
4022
1050
229
Precipitation mm/a
Highway 270
Humid site (BE)
Arid site (PO)
20°6'N
Hawi flow boundary
0 5 km
1675 m asl

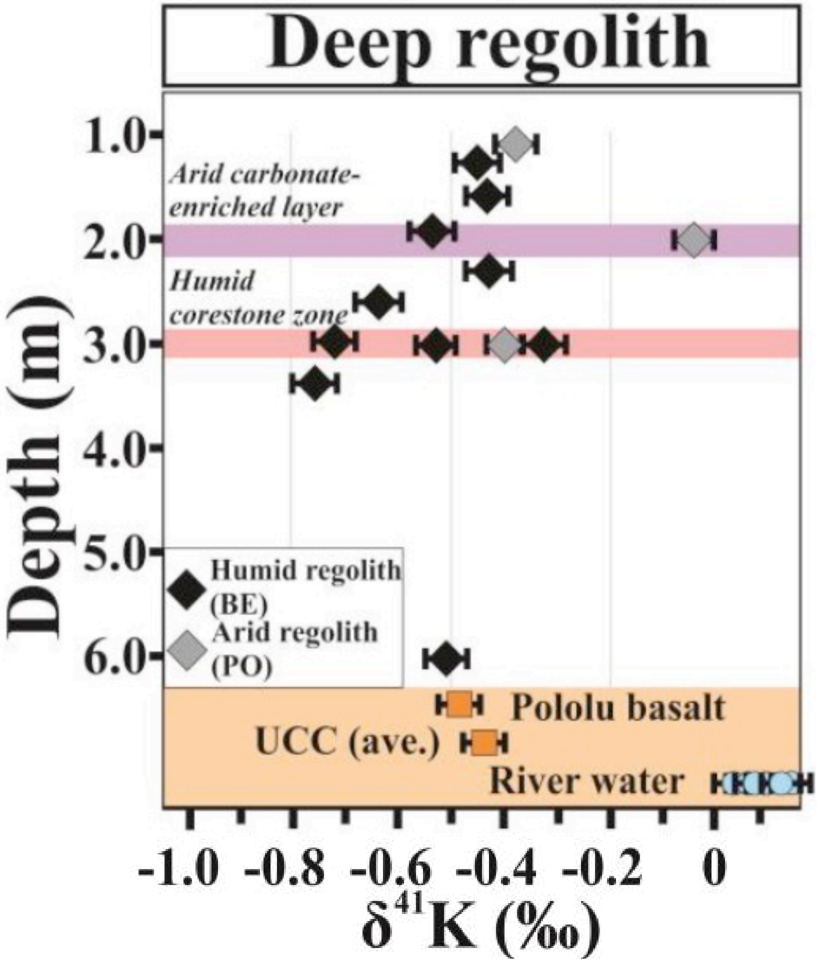


Humid site: MAP~1800 mm/yr
~15 m thickness

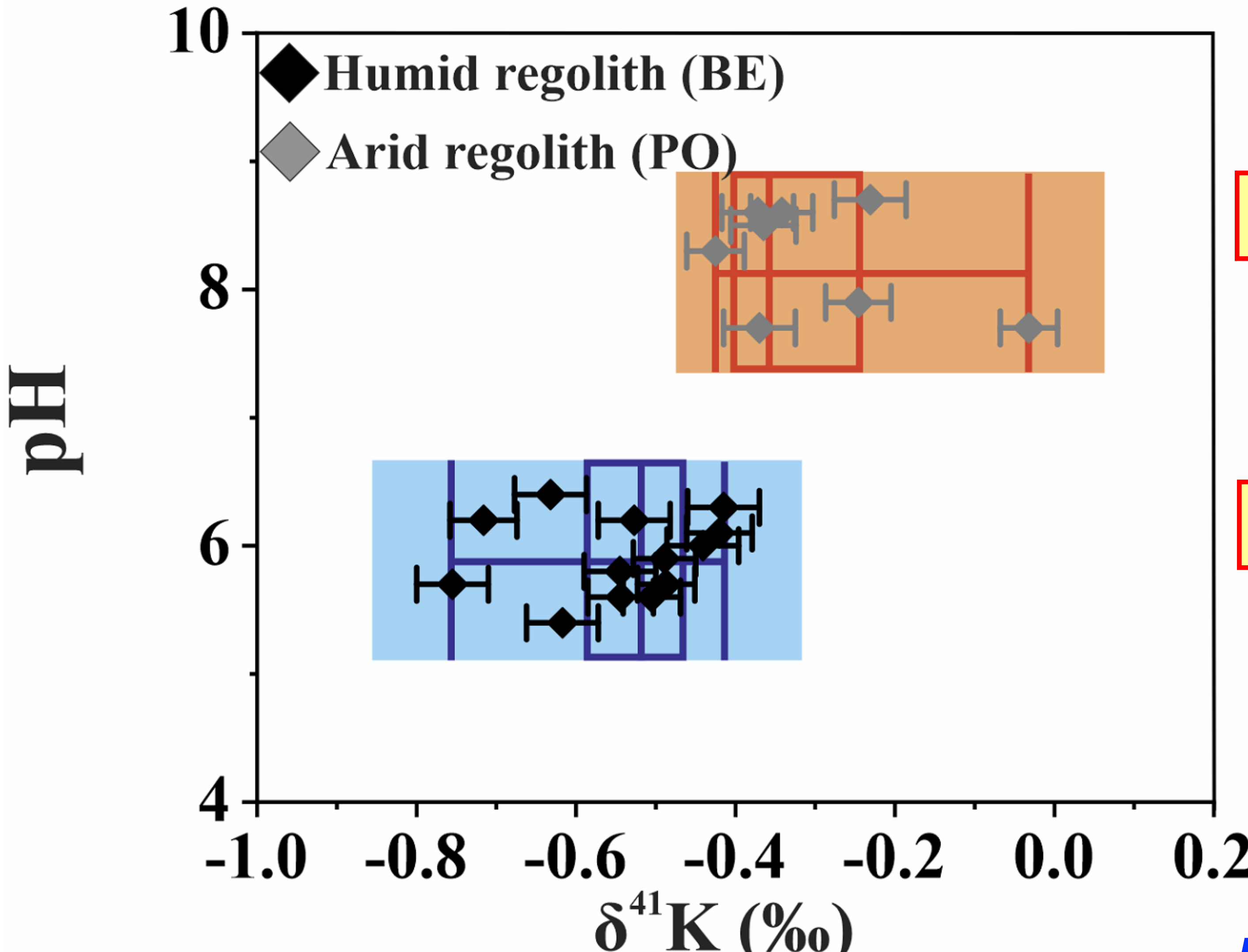
Arid site: MAP~300 mm/yr
~3.5 m thickness

Regolith
K isotopes





Strong climate (pH) control

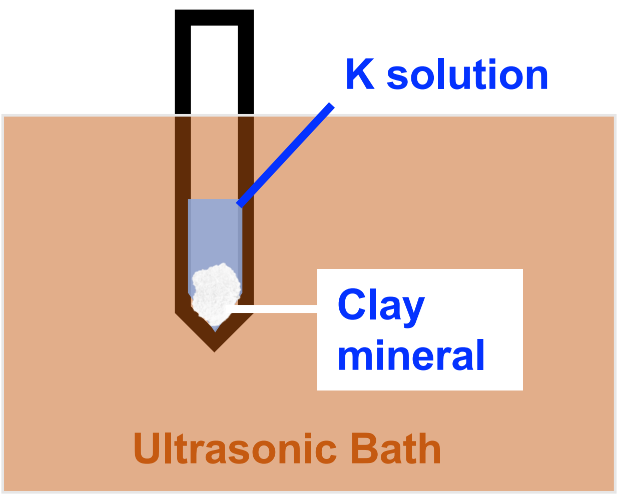


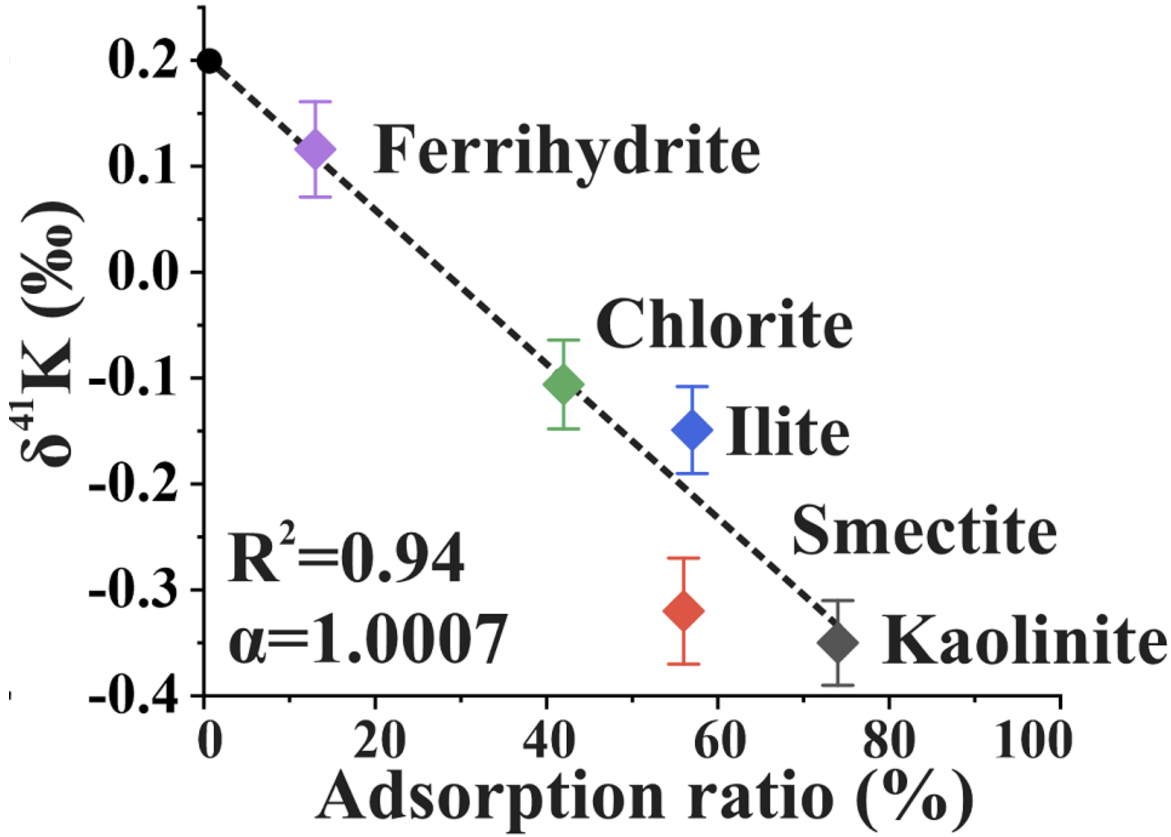
Heavy $\delta^{41}K$

Light $\delta^{41}K$

Li et al. in review

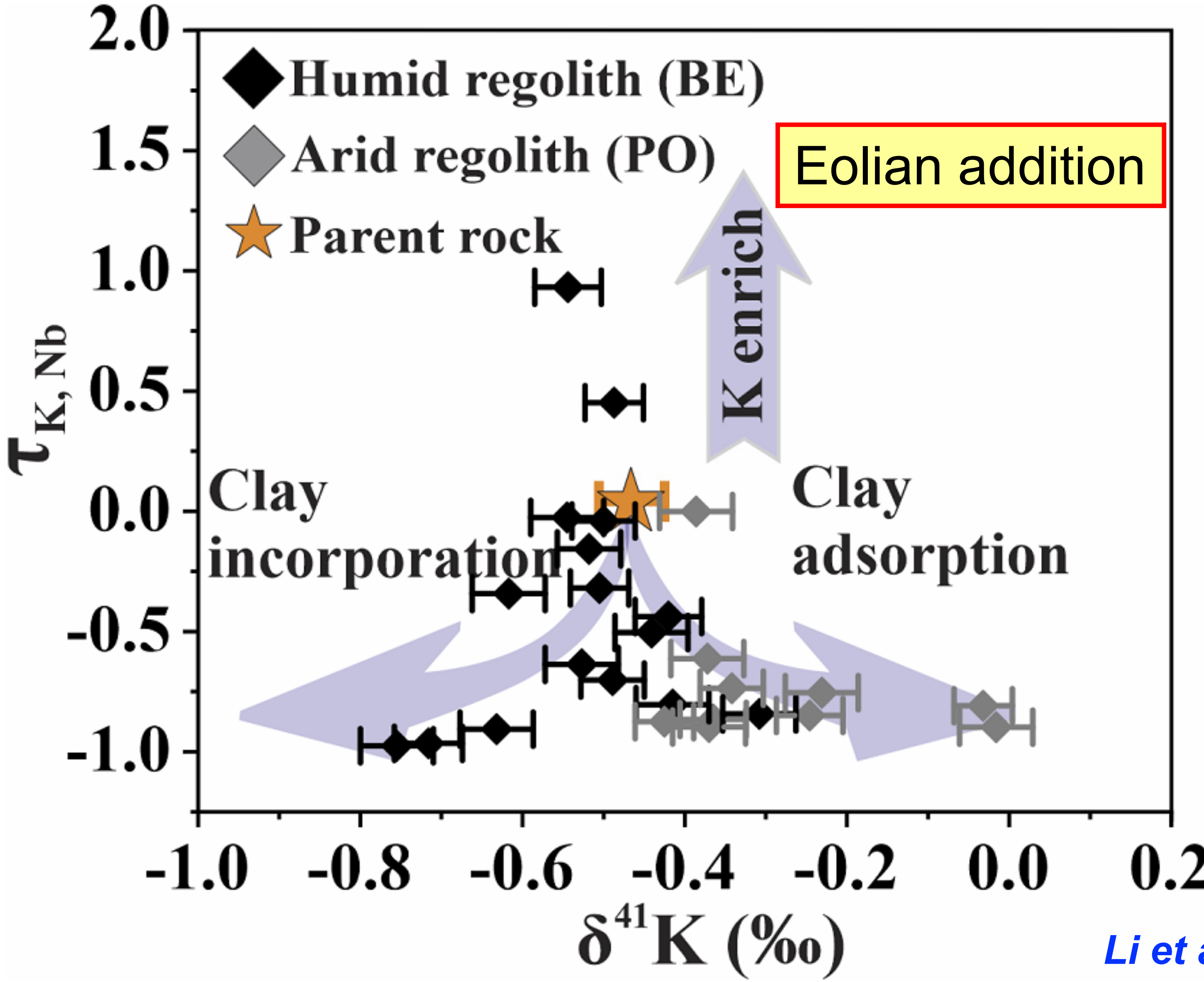
Adsorption experiment evidence





Li et al. in review

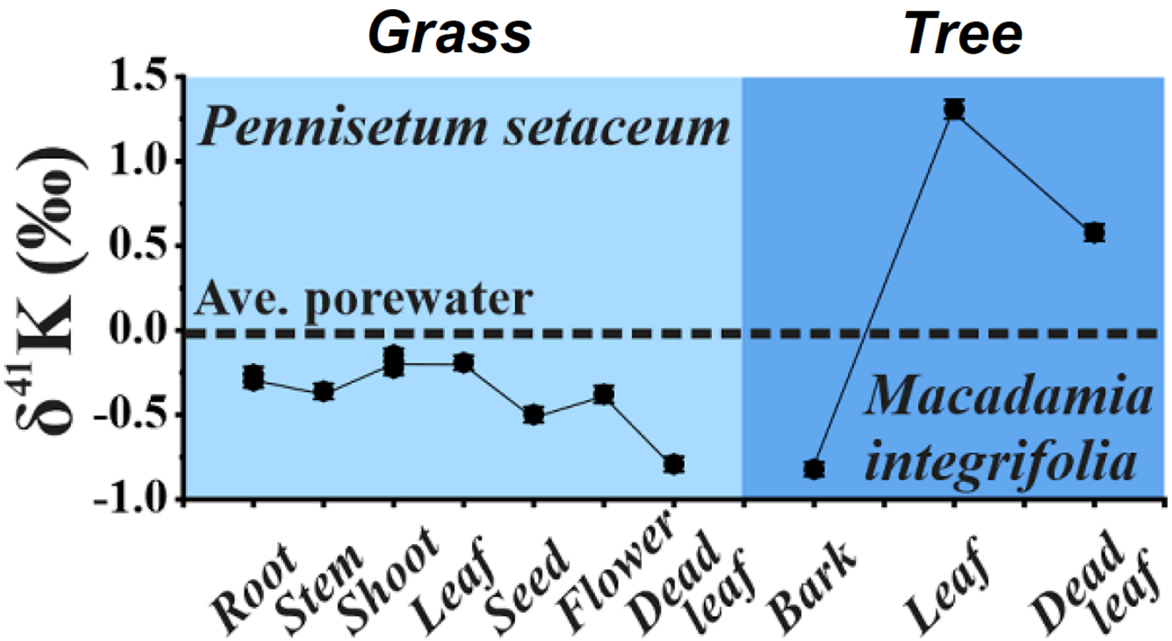
K isotope fractionation mechanisms



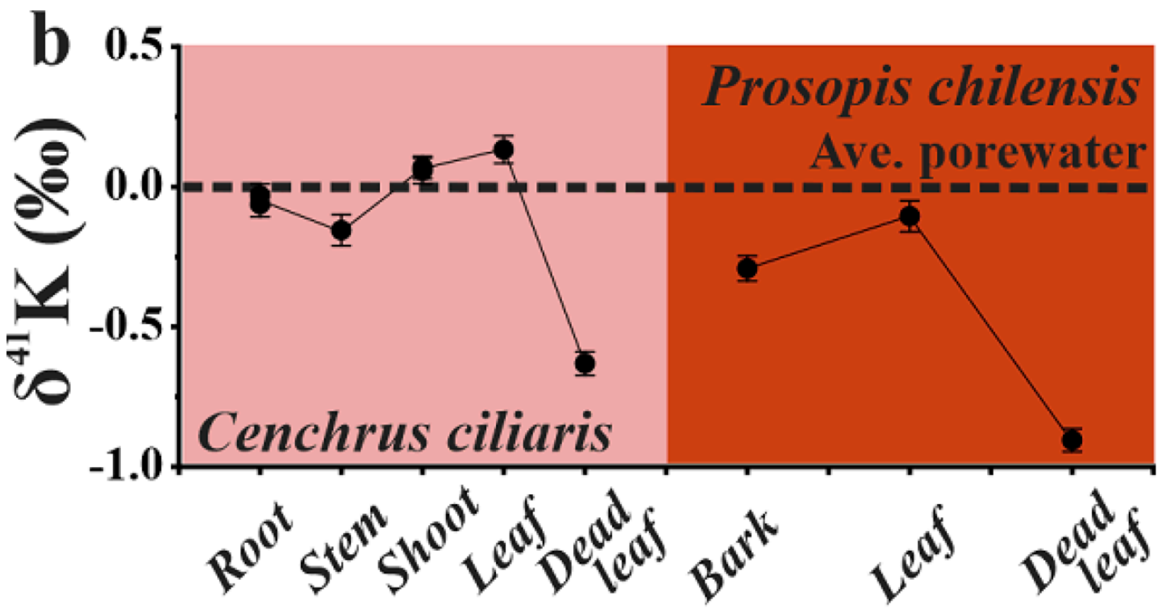
Li et al. in review

Biological control

Humid



Arid

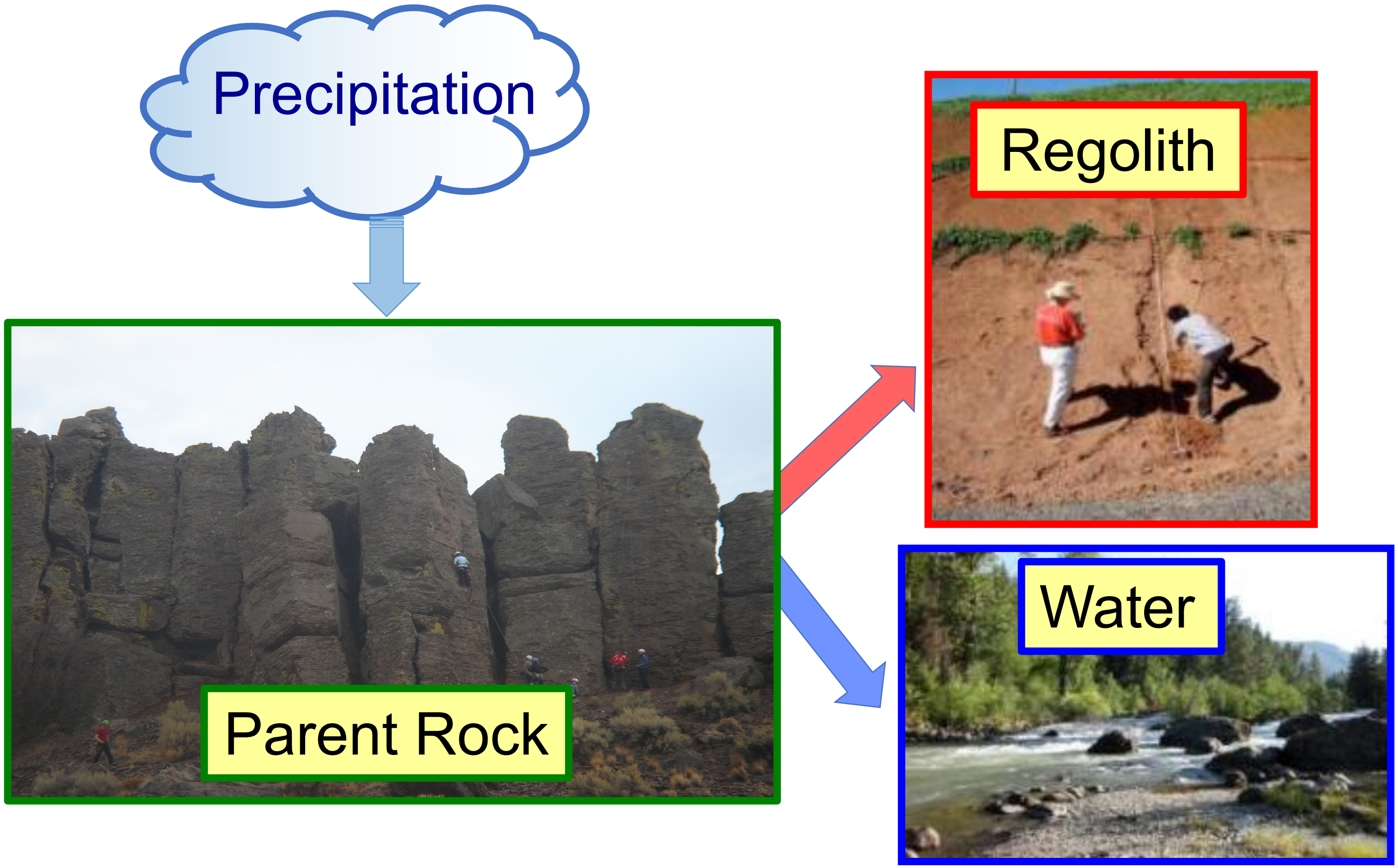


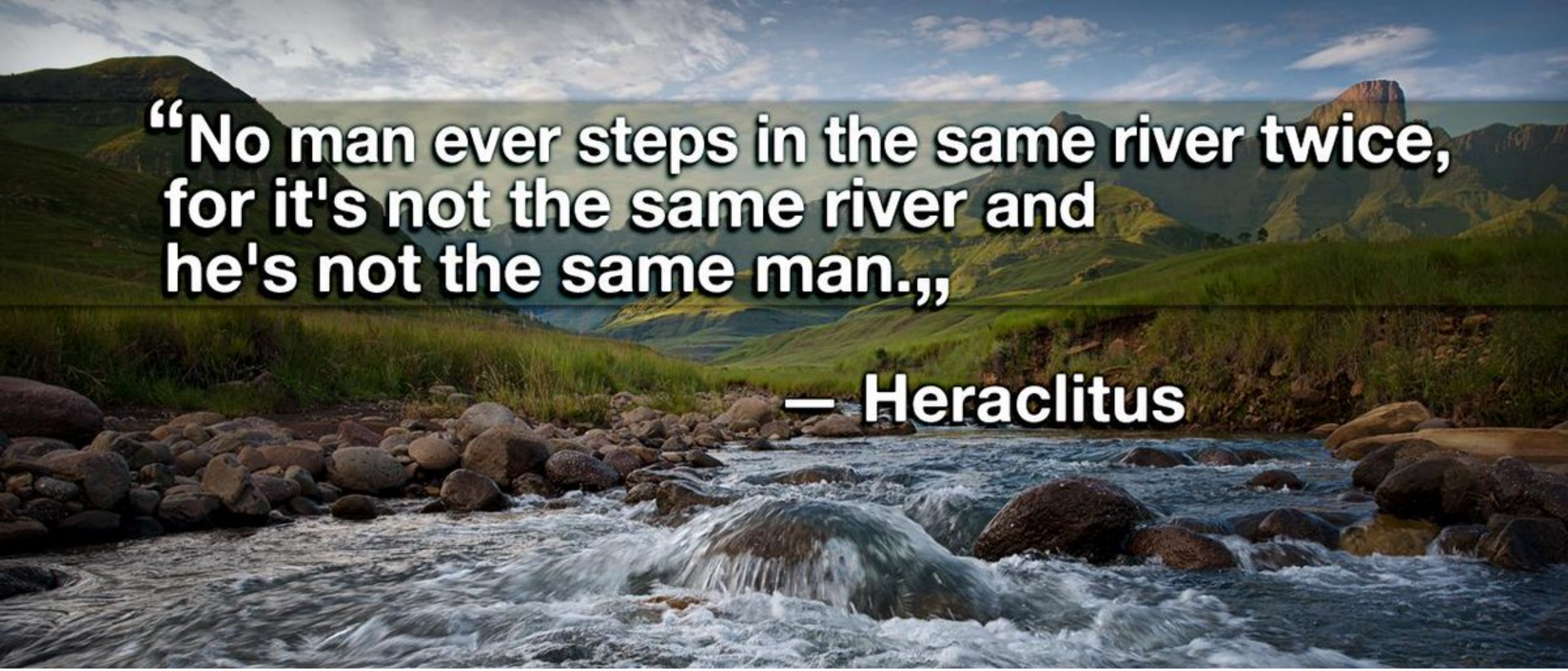
Li et al. in prep

Regolith Summary

- Regolith Li and K isotope signals reflects an interplay of 2nd mineral formation, eolian addition, and biological controls.
- Li and K isotope fractionations during weathering highly depend on climate conditions.

Weathering process



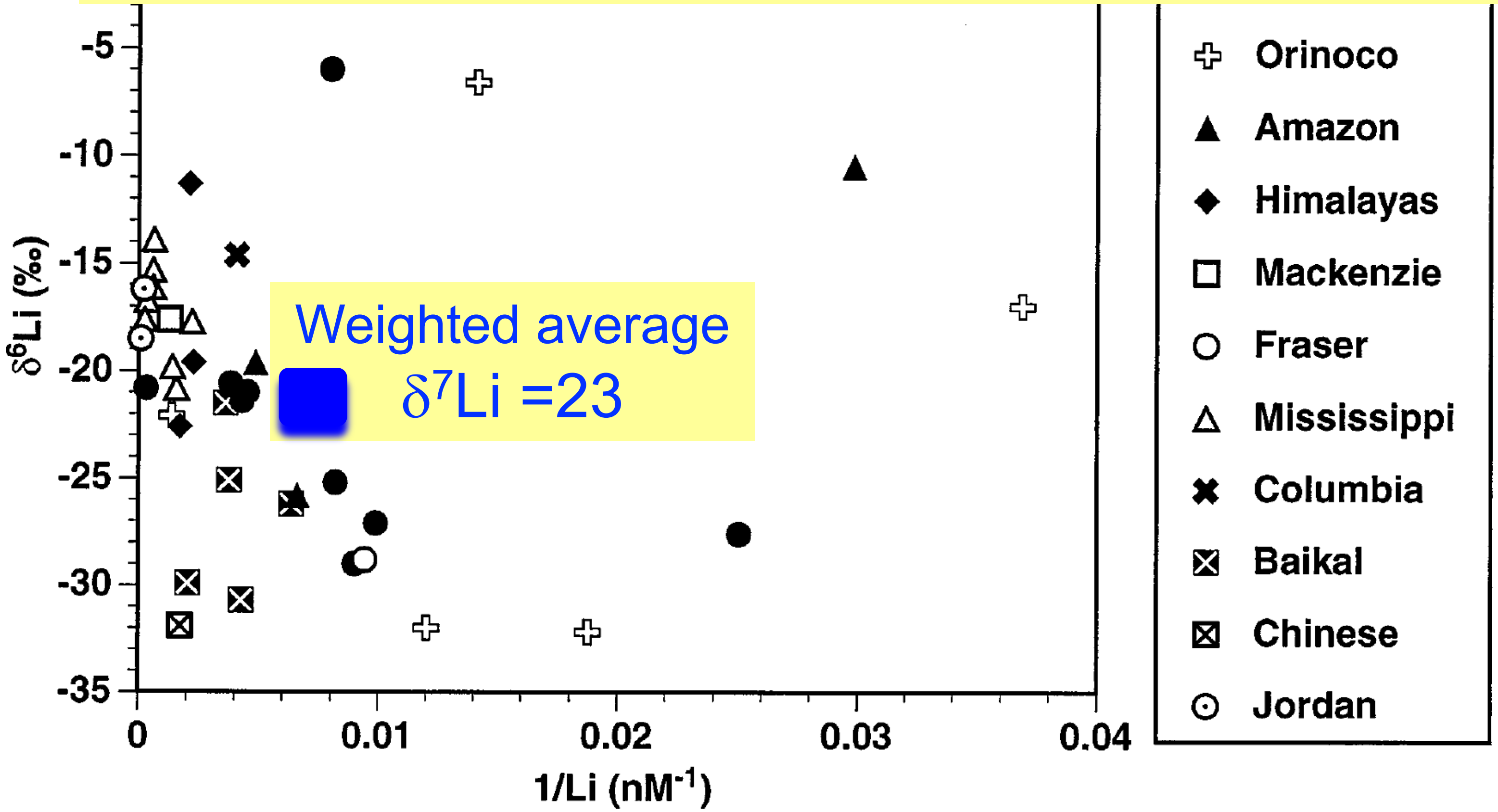


Why study (river) water?

Water provides instantaneous knowledge during weathering.

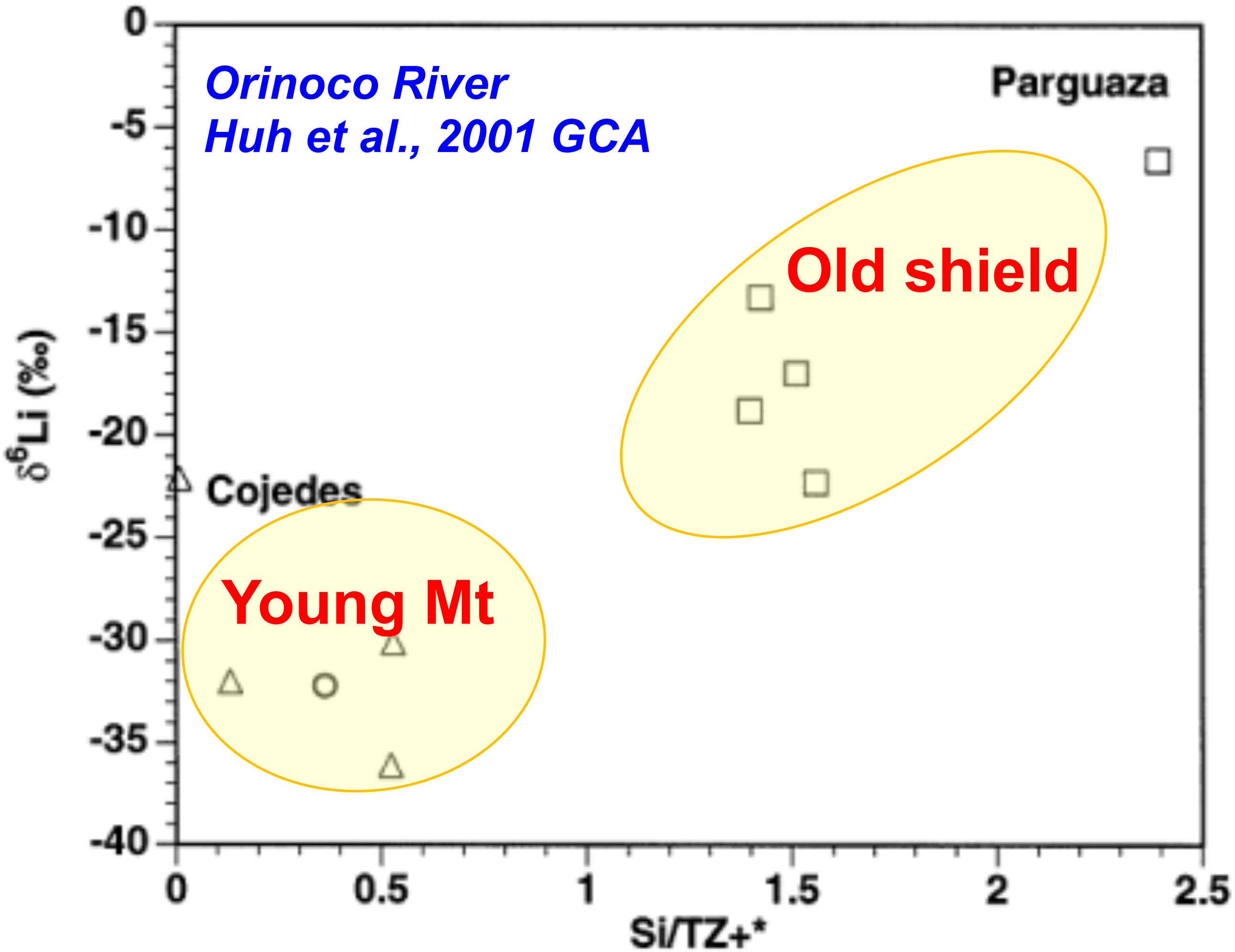
Water – World rivers

Why is δ^7Li in rivers so variable?



Huh et al., 1998, EPSL

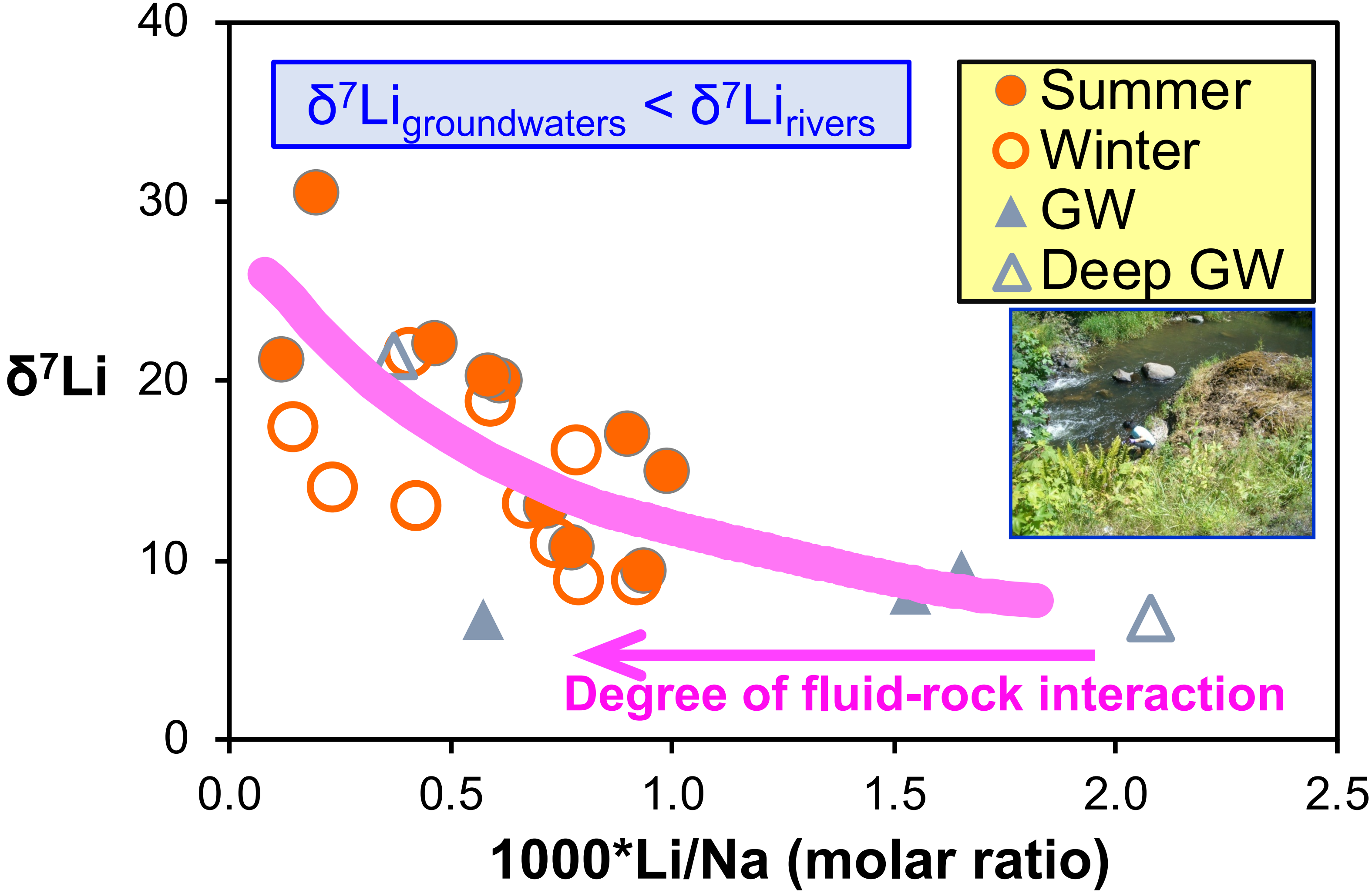
What controls δ^7Li in rivers?



δ^7Li depends on degree of weathering/weathering intensity

δ^7Li as a weathering intensity tracer?

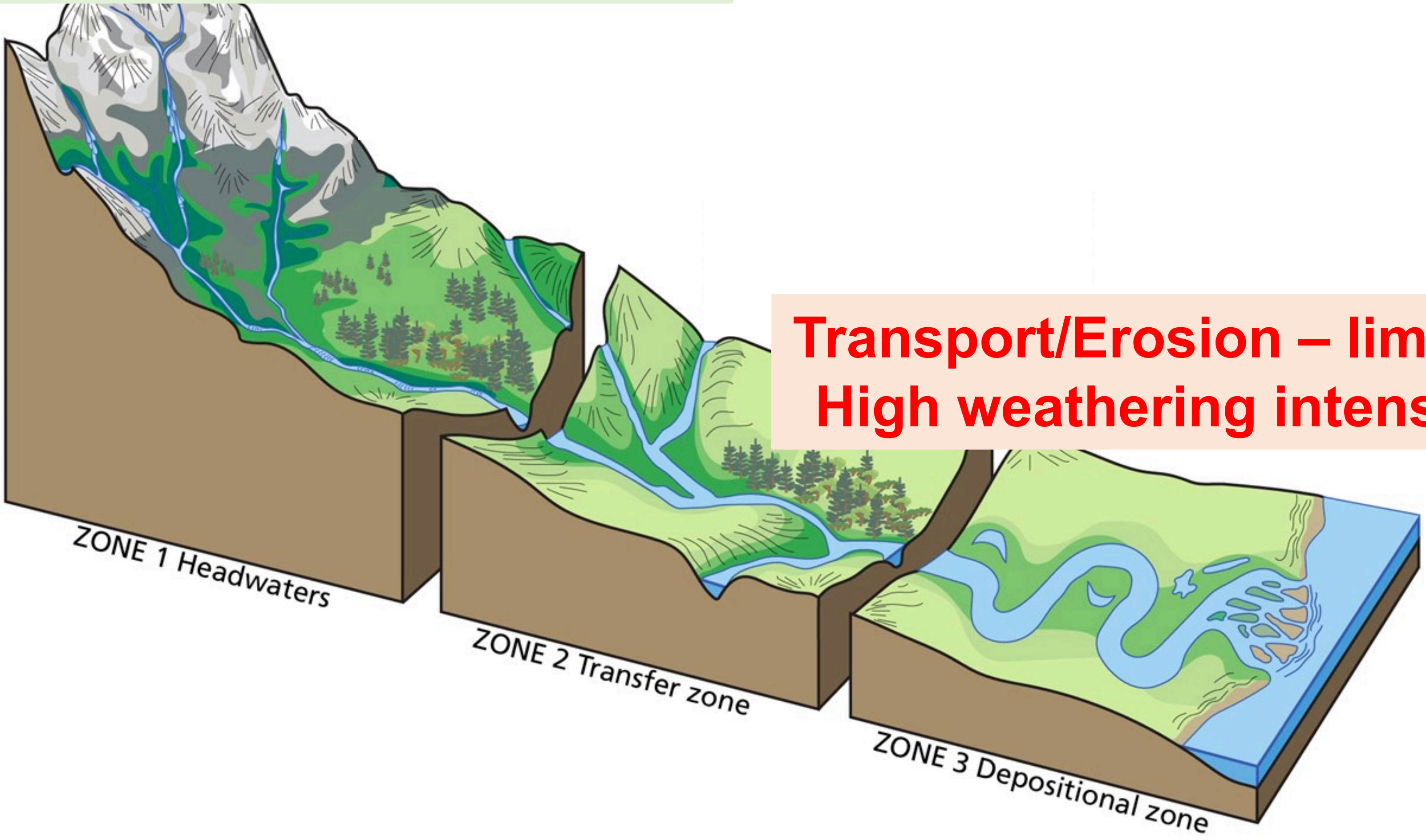
– Small streams



Liu et al., 2015, EPSL

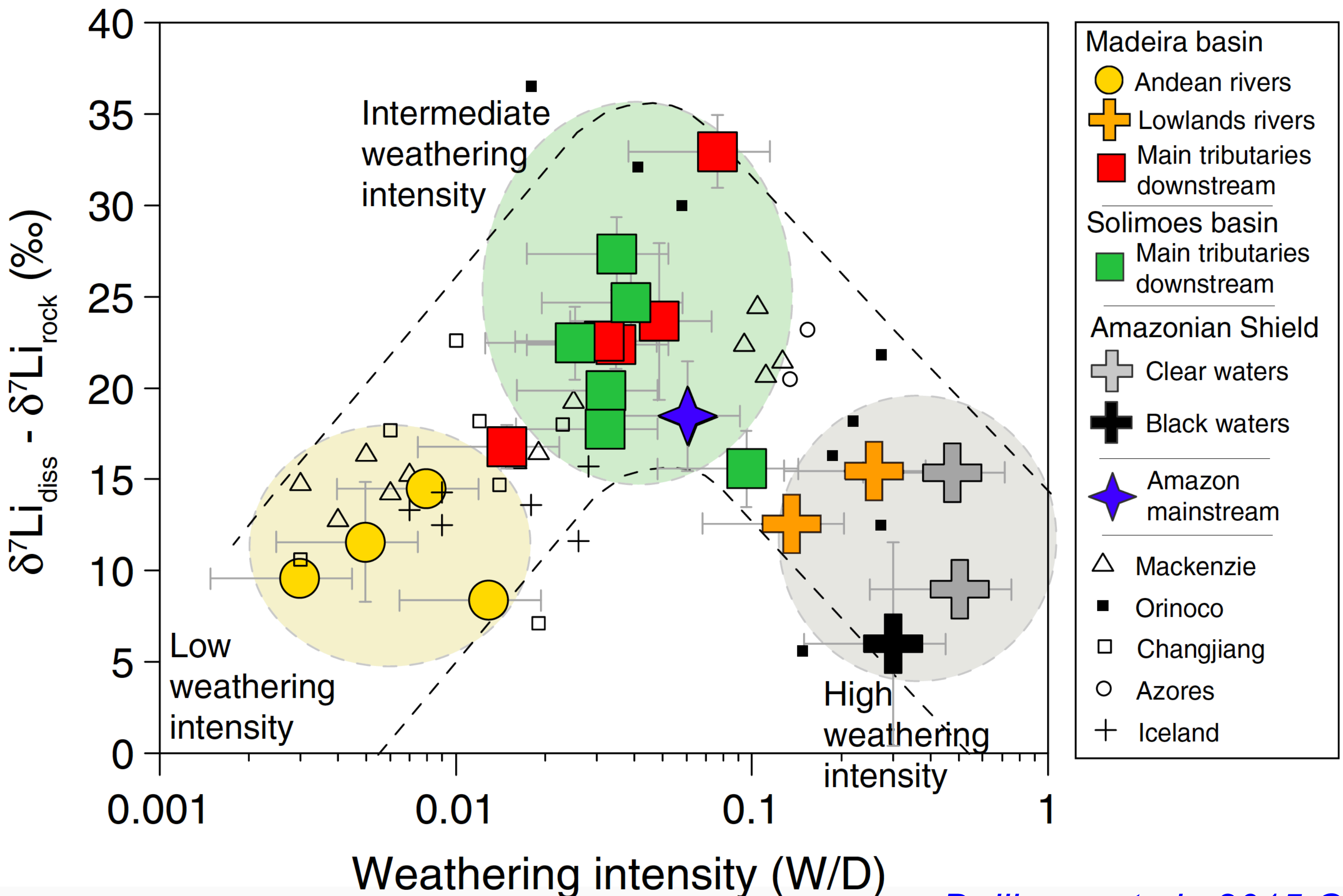
What controls δ^7Li in rivers? – Large rivers

Reaction/Weathering – limited
Low weathering intensity



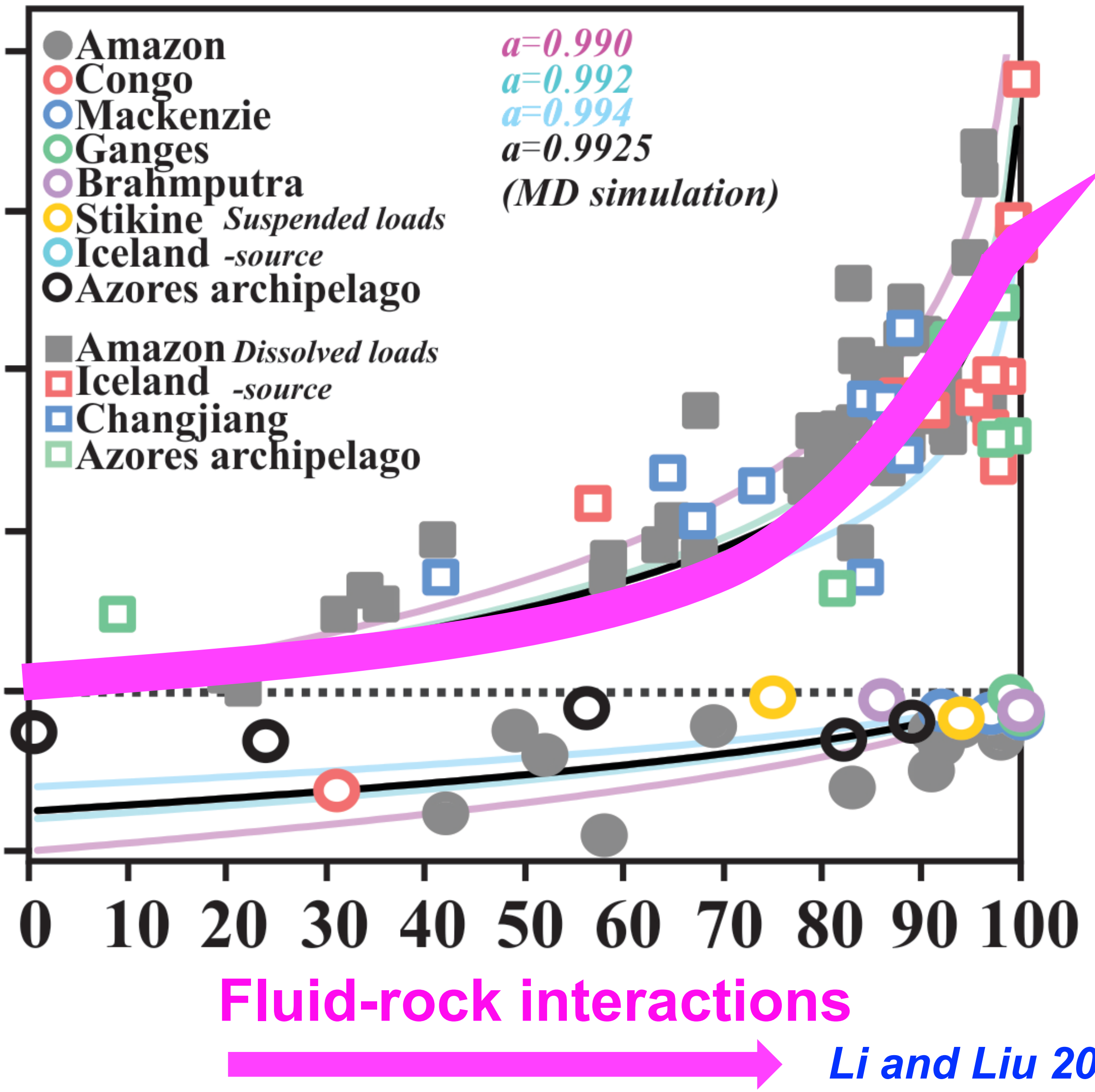
Transport/Erosion – limited
High weathering intensity

δ^7Li as a weathering intensity tracer? – Large rivers



Dellinger et al., 2015 GCA

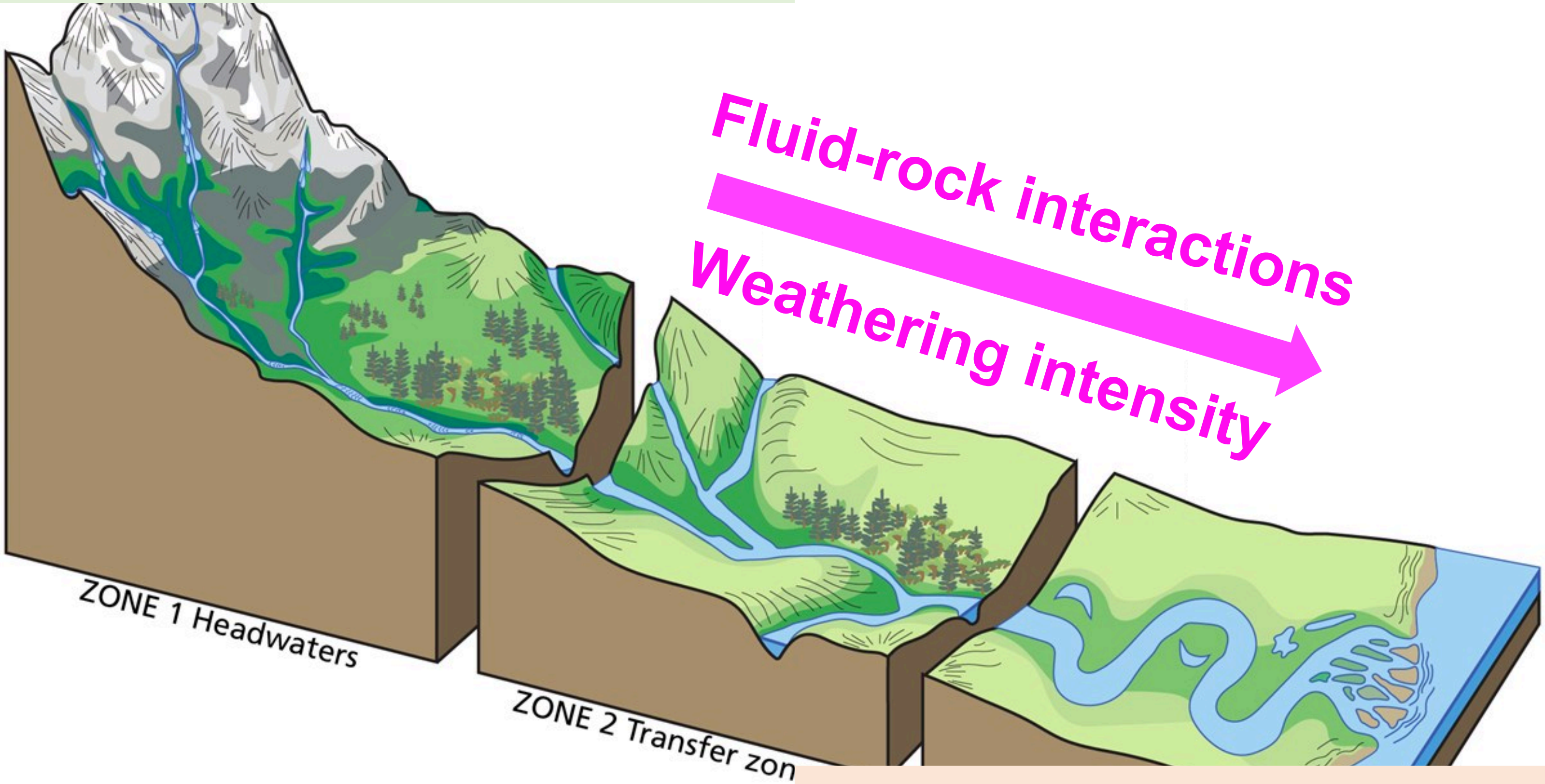
δ^7Li as a weathering intensity tracer?



Li and Liu 2020, GCA

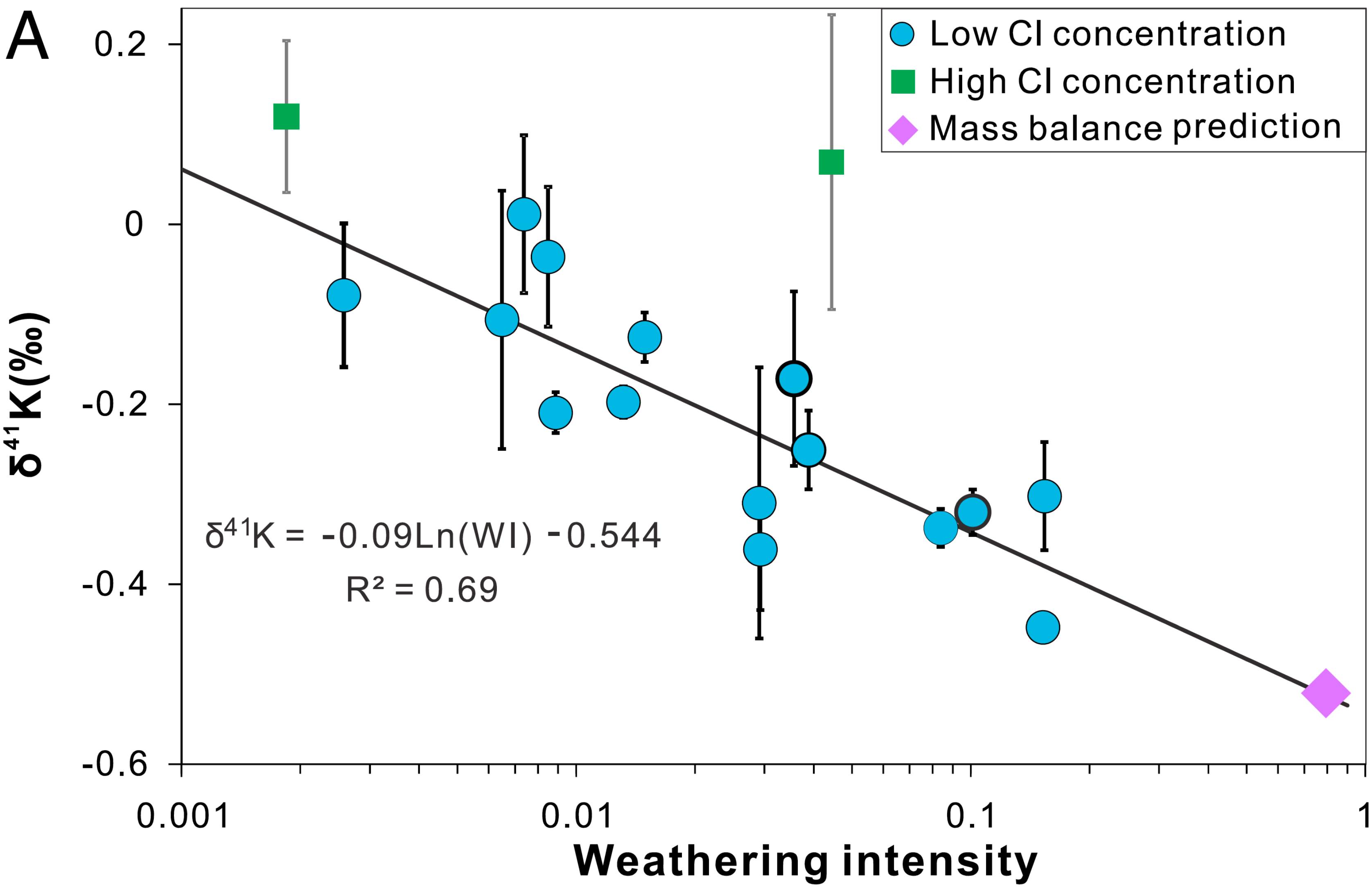
Summary:
What controls δ^7Li in rivers?

Reaction/Weathering – limited
Low WI – Low δ^7Li, high [Li]



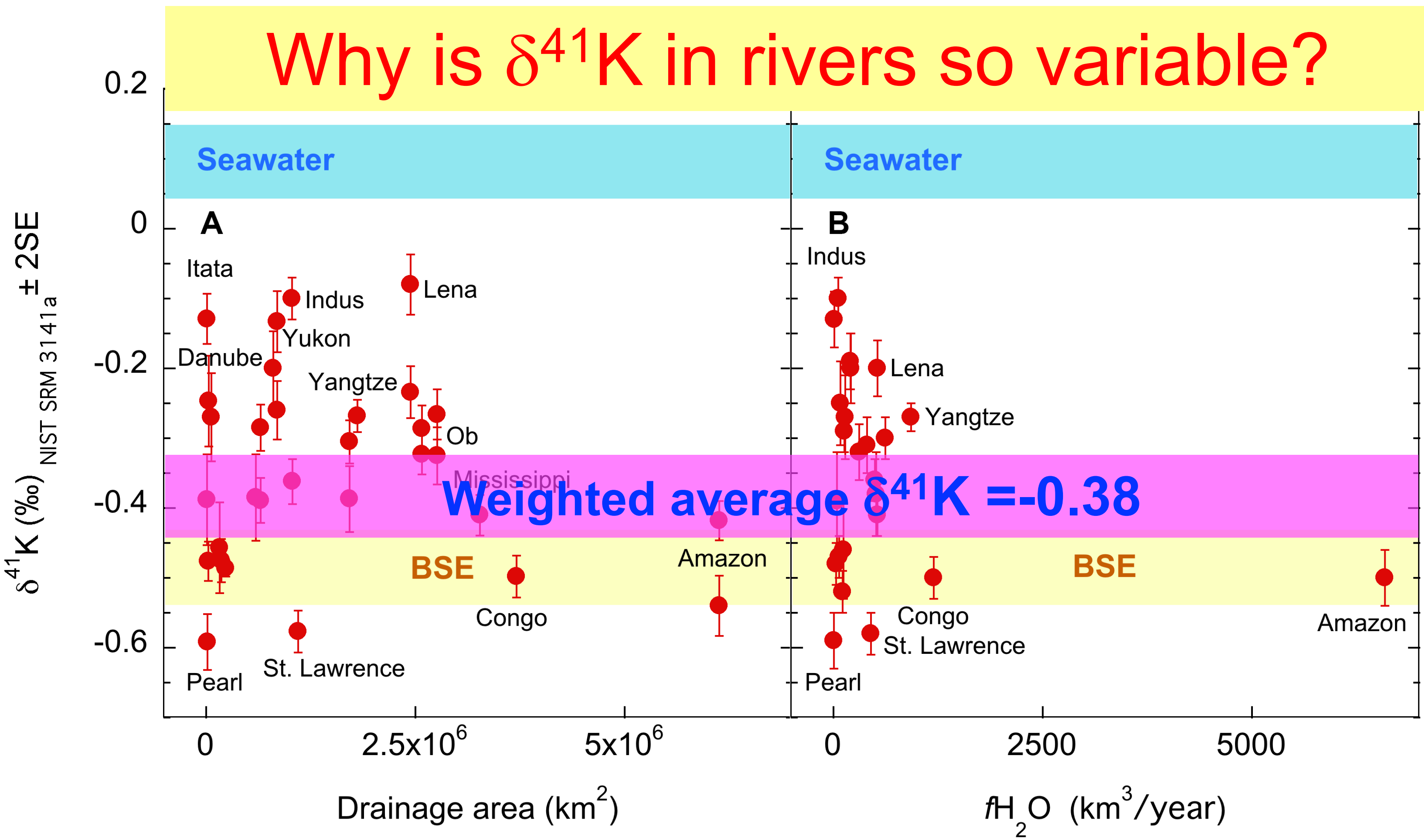
Transport/Erosion – limited
High WI – High δ^7Li, low [Li]

$\delta^{41}K$ as a weathering intensity tracer?



S. Li et al., 2019, PNAS

Water – World rivers



Wang et al., in review

REVIEWS in
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Volume 82

NON-TRADITIONAL STABLE ISOTOPES

EDITORS:
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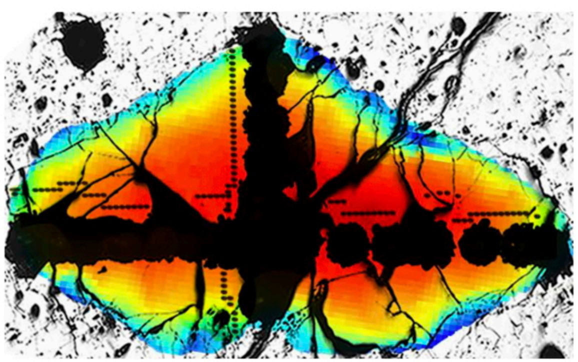
and
Nicolas Dauphas



MINERALOGICAL SOCIETY OF AMERICA
GEOCHEMICAL SOCIETY
Series Editor: Ian P. Swainson

2017 *ISSN 1529-6466*

Reviews in Mineralogy & Geochemistry
Vol. 82 pp. 165-217, 2017

6

Lithium Isotope Geochemistry

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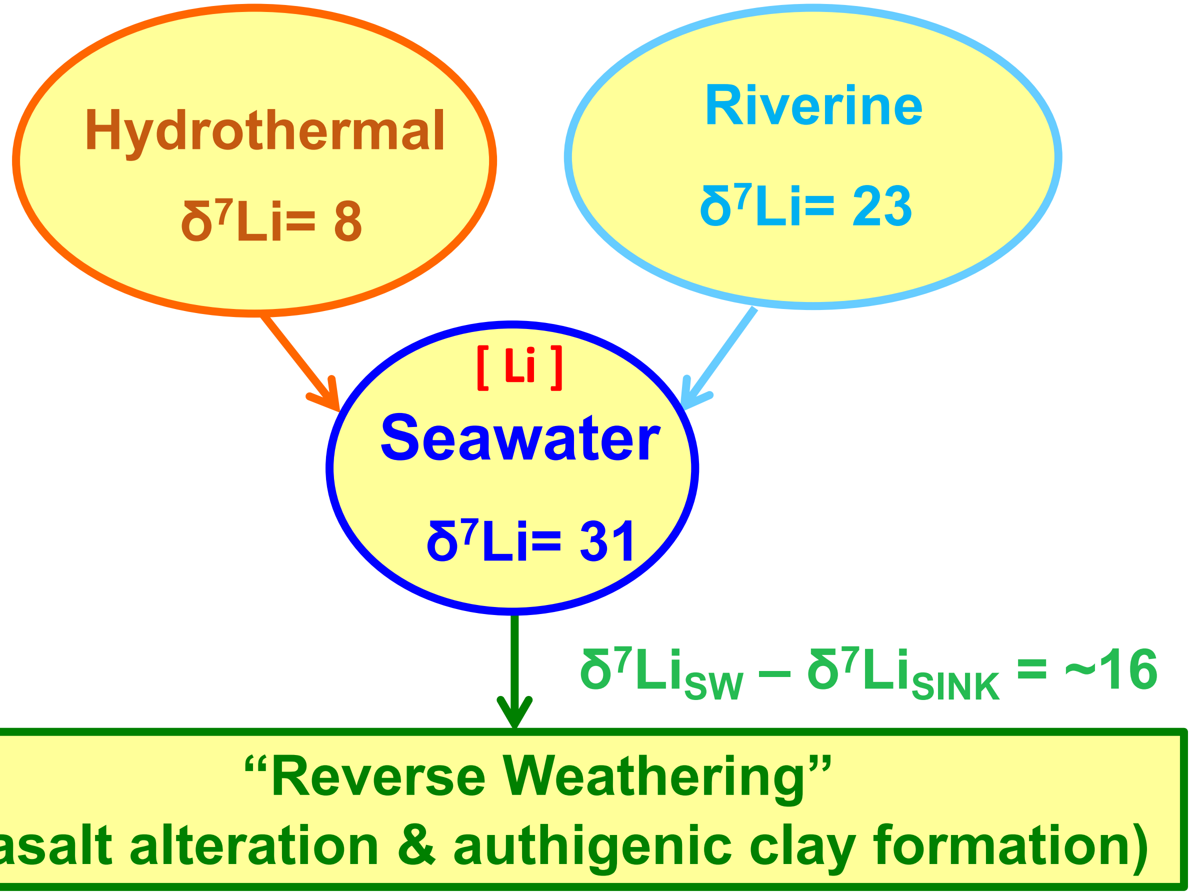
3. Weathering and global ocean cycle in Earth's history

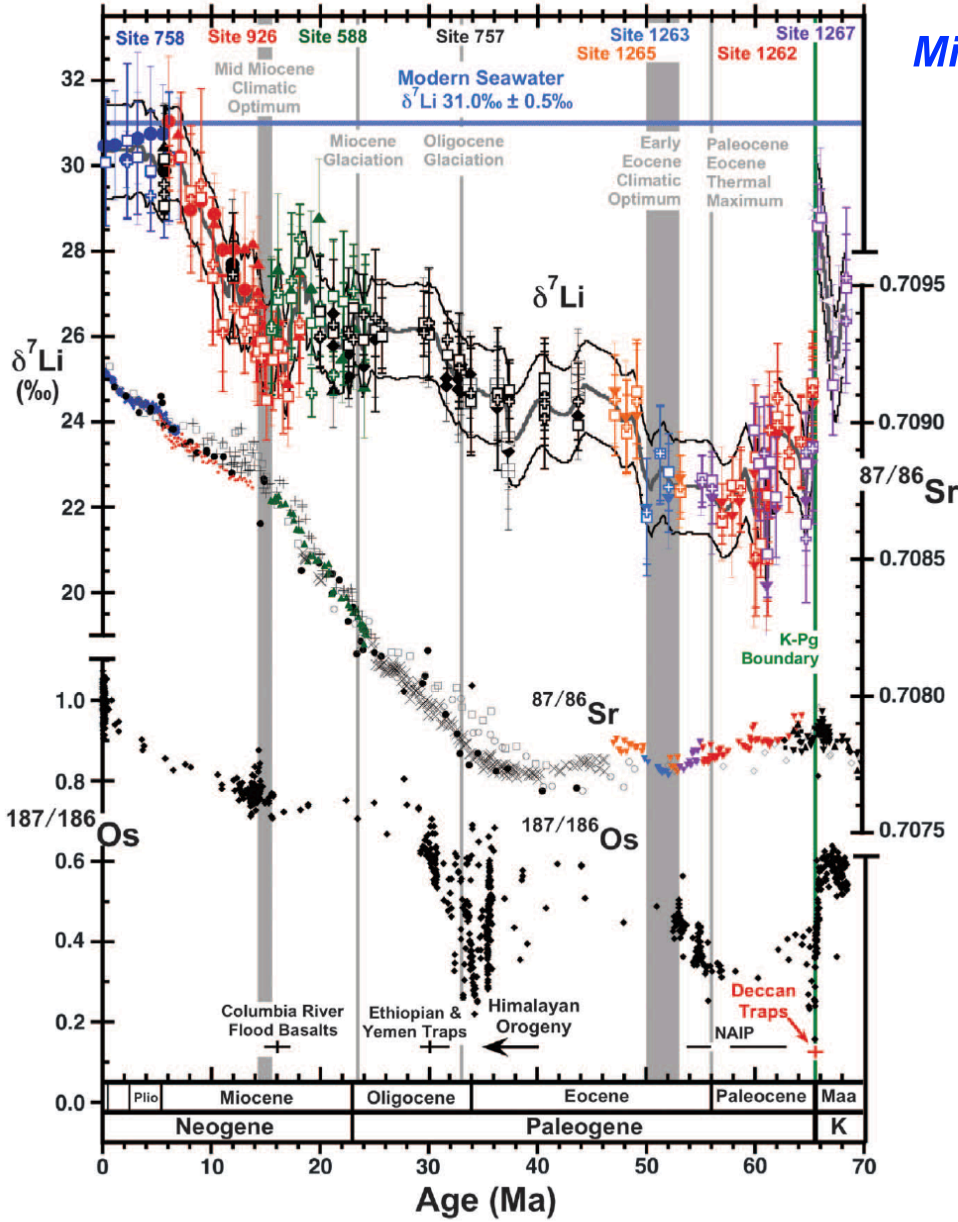
Why does seawater have high δ^7Li?



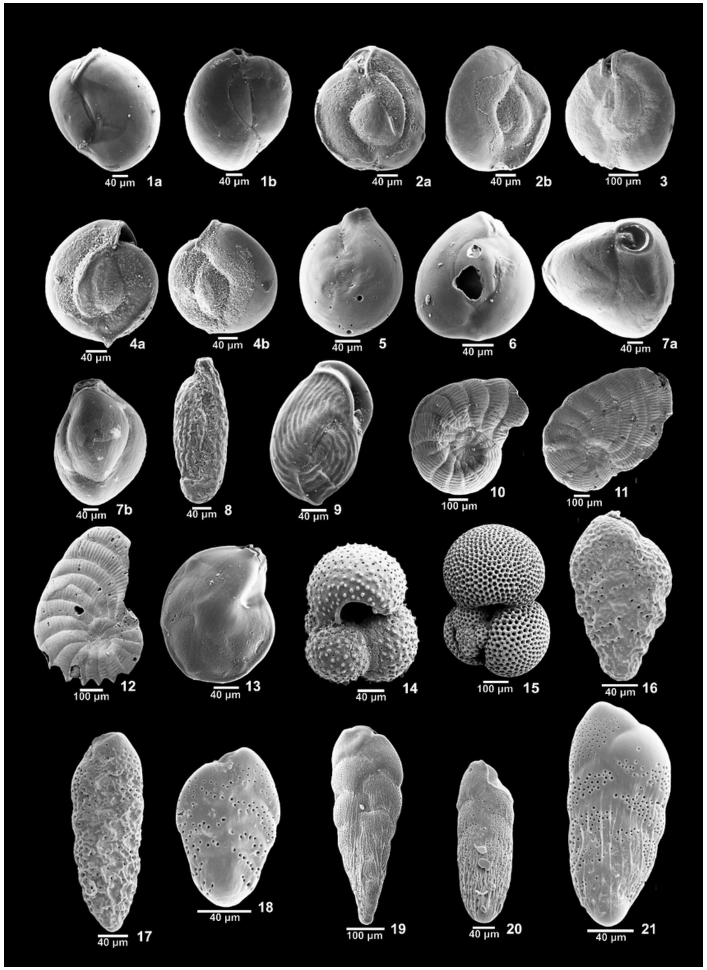
Chan et al., 1992 EPSL

δ^7Li in forams: proxy for silicate weathering?

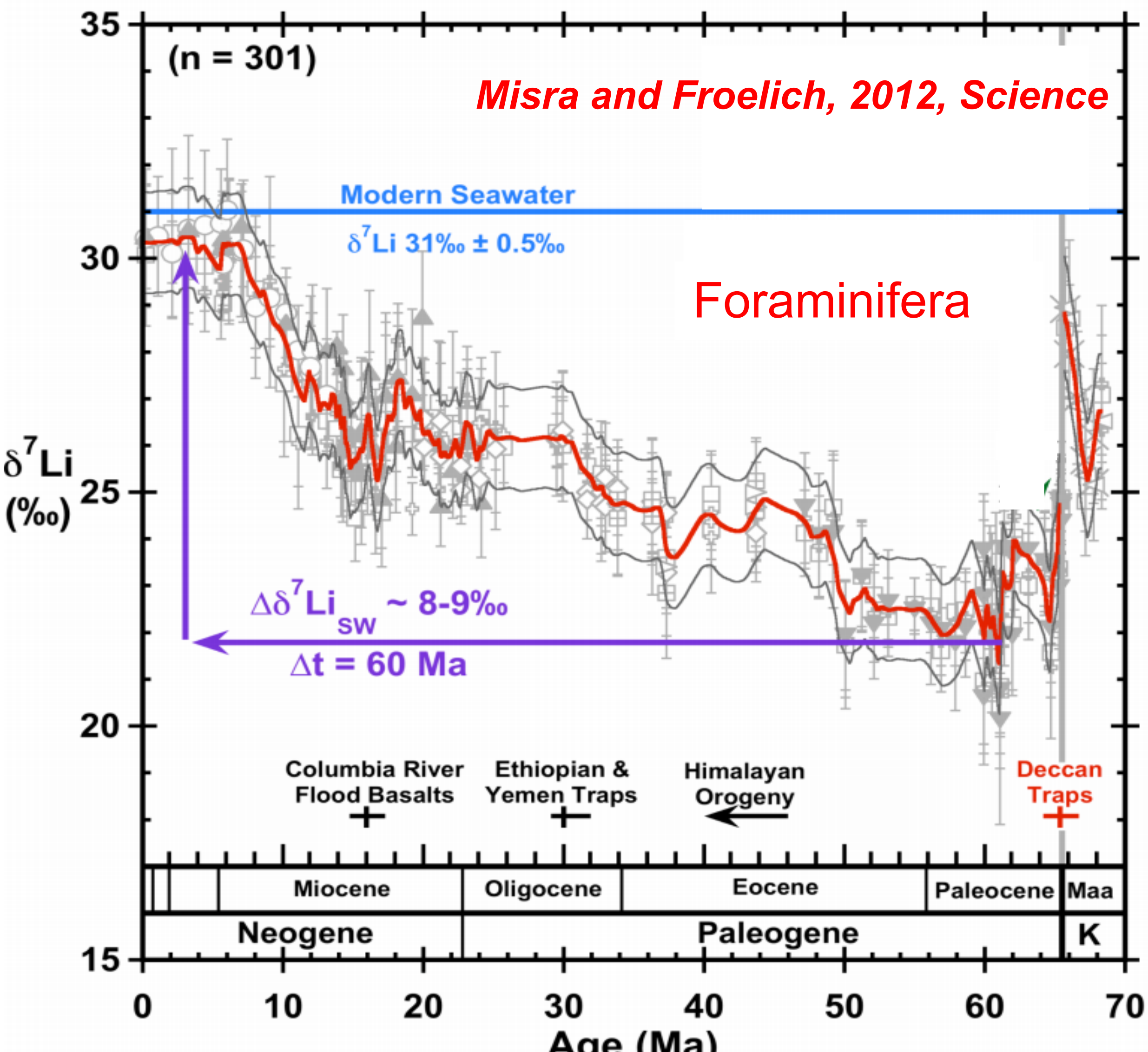
Misra and Froelich, 2012 Science

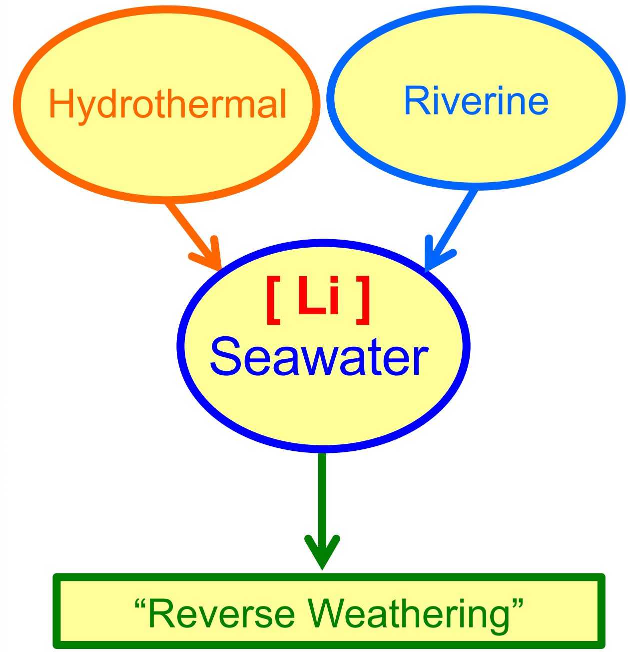


Foraminifera



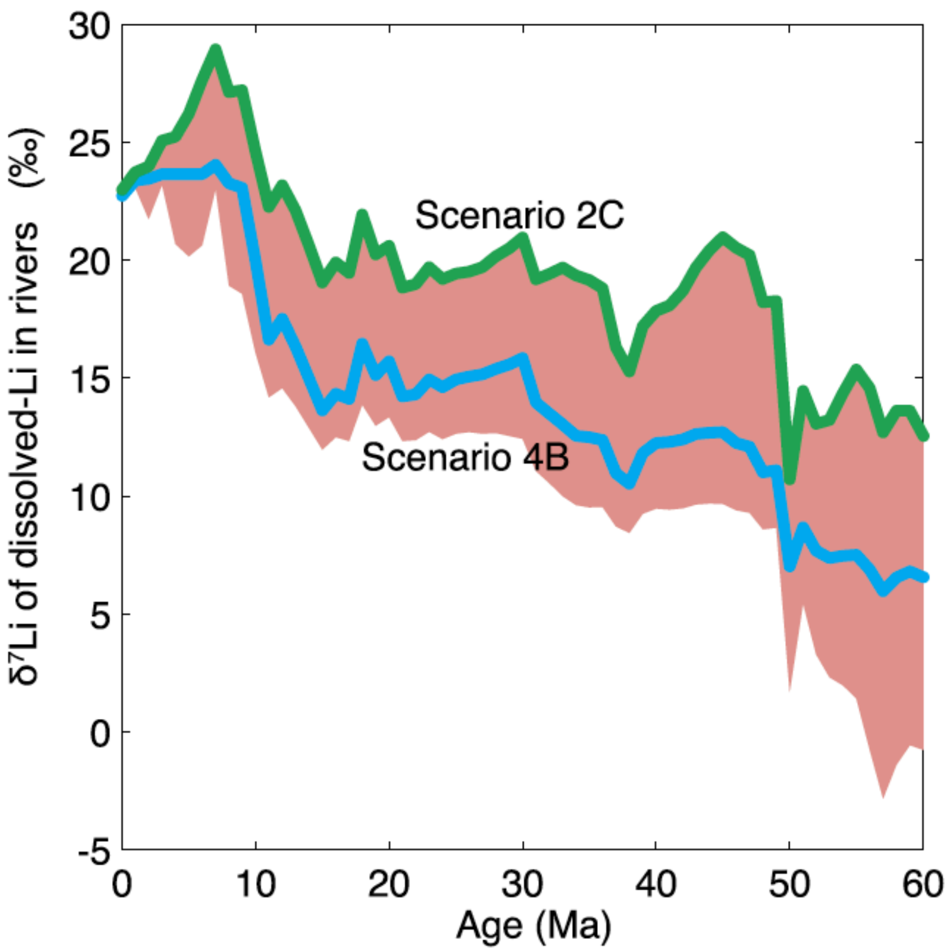
δ^7Li in forams: proxy for silicate weathering?



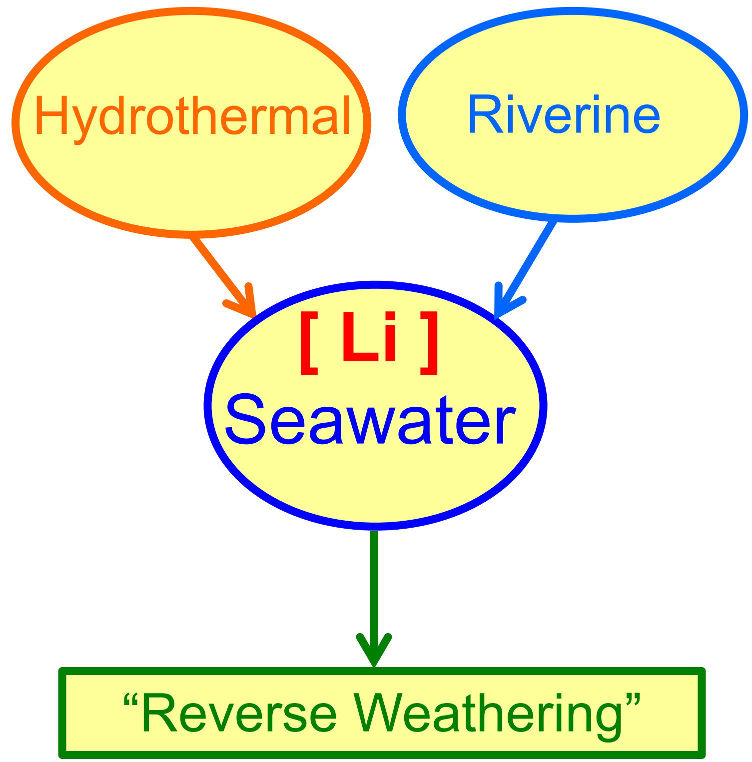


An increase of riverine δ^7Li due to "weathering regime" change?

Other Interpretations

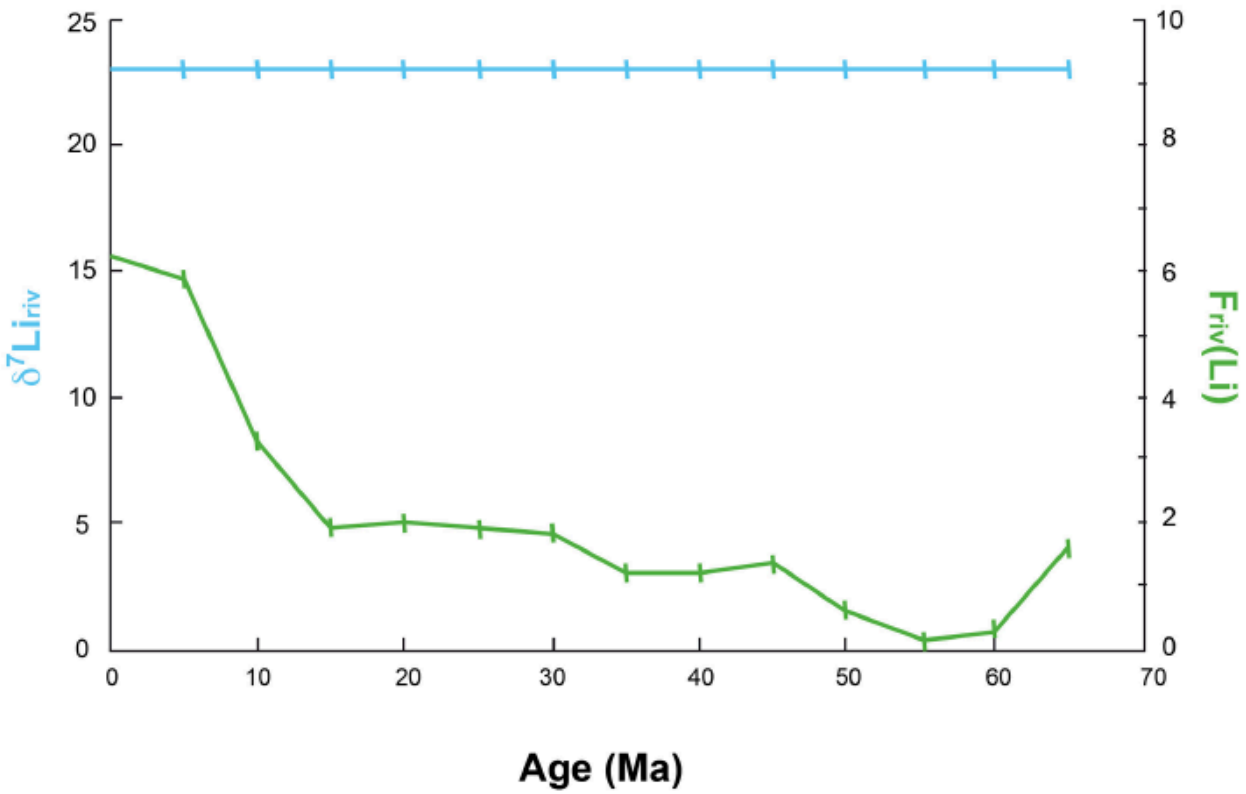


Requires a change in dissolved riverine δ^7Li ***(Li and West, 2014 EPSL)***



variations in ocean sinks

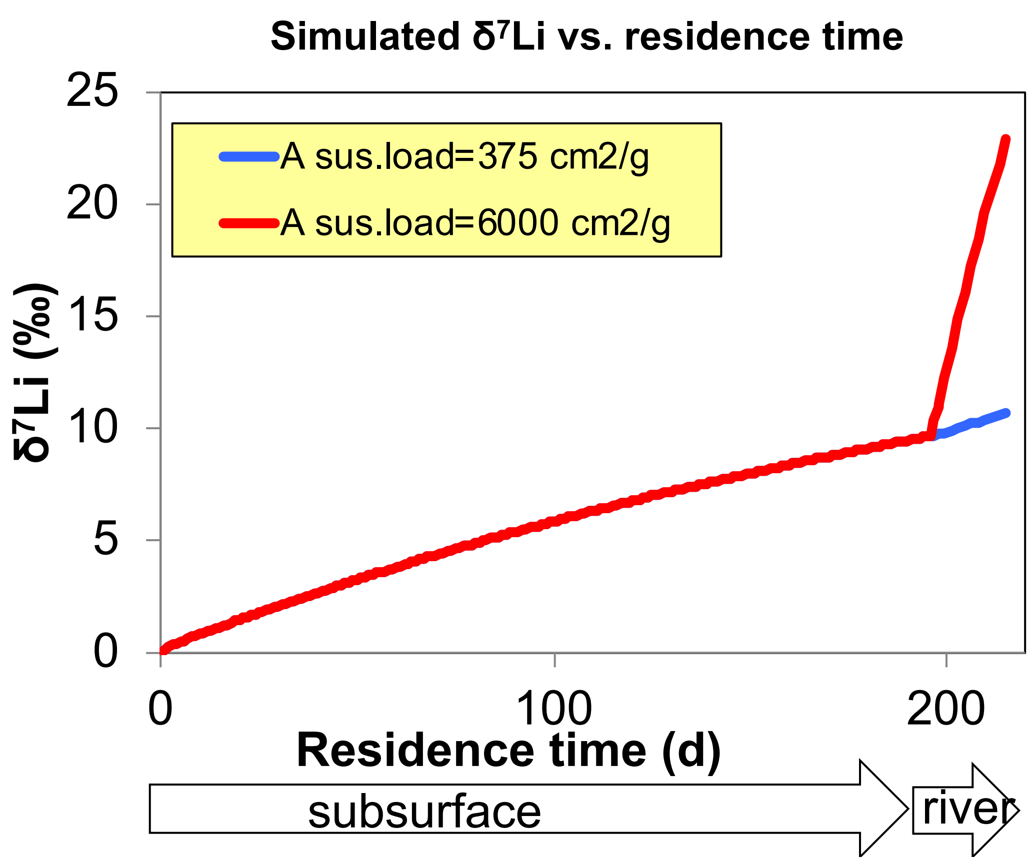
Other Interpretations



An increase in riverine Li flux

Vigier and Godderis, 2015 Clim. Past

Other Interpretations



δ^7Li increase due to increasing riverine suspended loads from erosion

Wanner et al., 2014, Chem. Geol.; Liu et al., 2015, EPSL

δ^7Li in forams as proxy for silicate weathering in Cenozoic

Increased seawater δ^7Li is probably dominated by increased riverine/weathering input (either Li flux or δ^7Li).

Seawater δ^7Li can be influenced by changes in other sinks like reverse weathering.

δ^7Li in marine carbonates as tracer of silicate weathering in the past

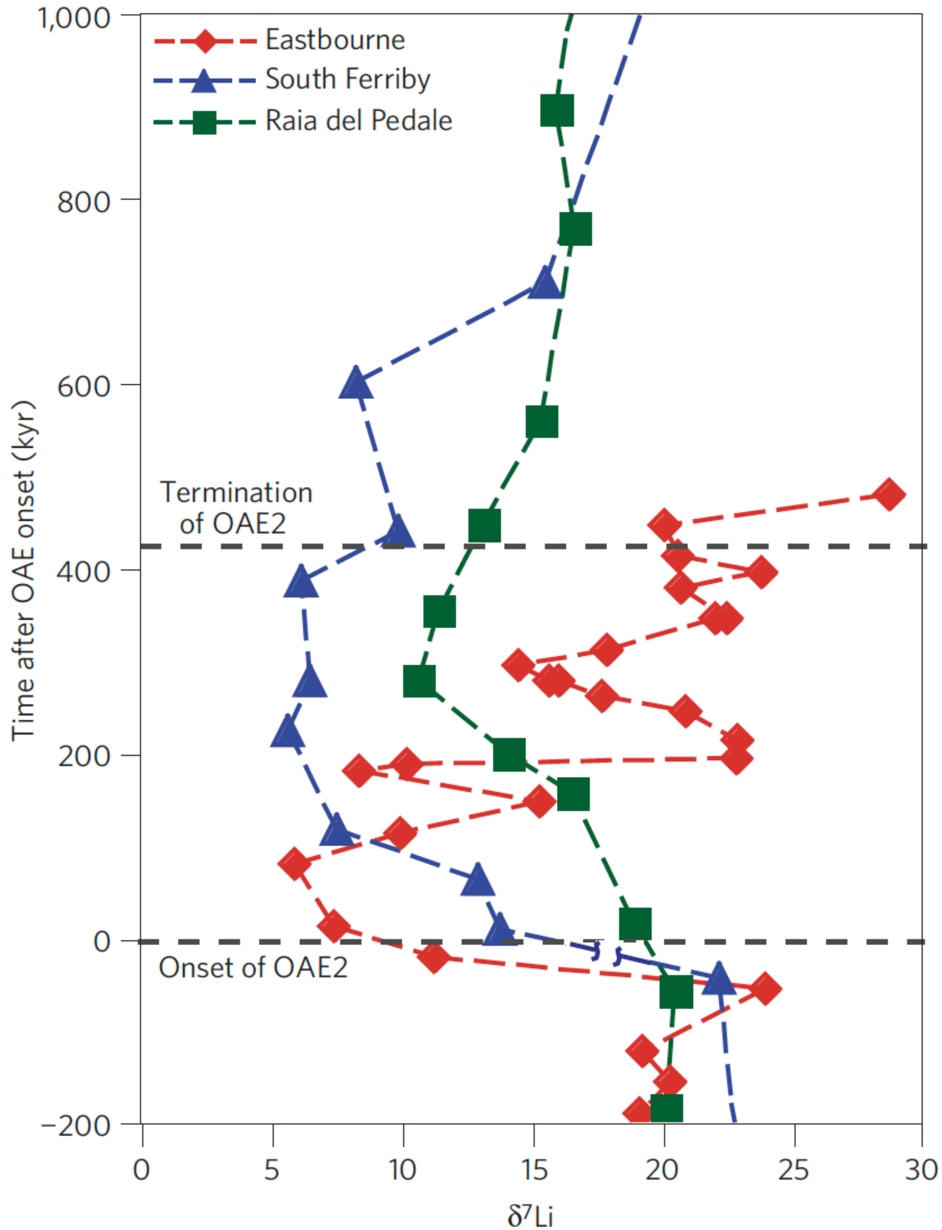
Assumptions:

1. Li is entirely controlled by weathering of silicates
2. We can extract marine signal from bulk carbonates

Hypothesis:

Increased δ^7Li in seawater is dominated by increased riverine input/weathering intensity (Li flux and/or δ^7Li).

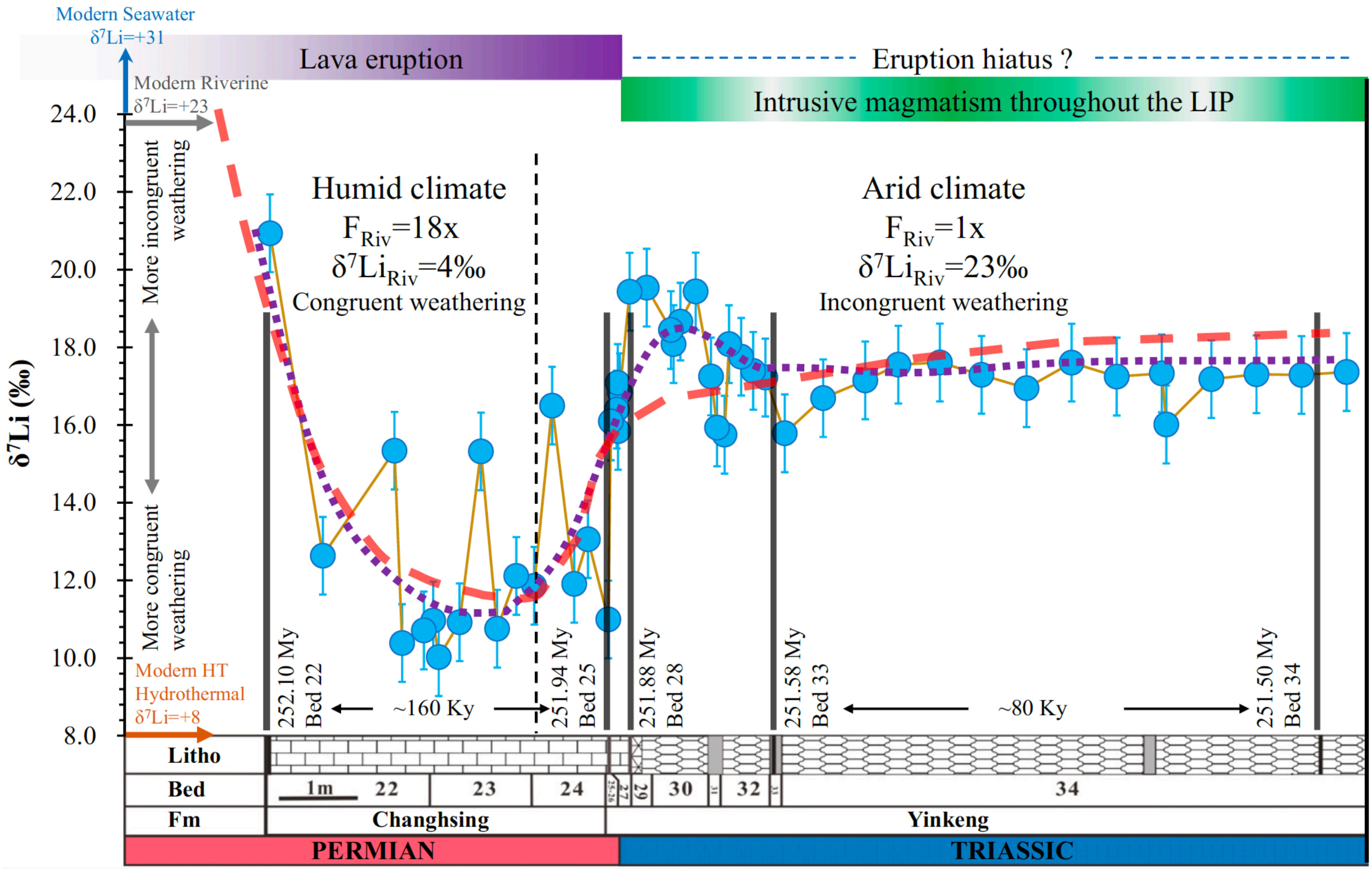
Case studies – OAE2



Eruption of a **large igneous province** led to high atmospheric **CO_2** and **rapid global warming**, which **initiated OAE2**. The warming was accompanied by a roughly **accelerated weathering of mafic silicate rocks.**

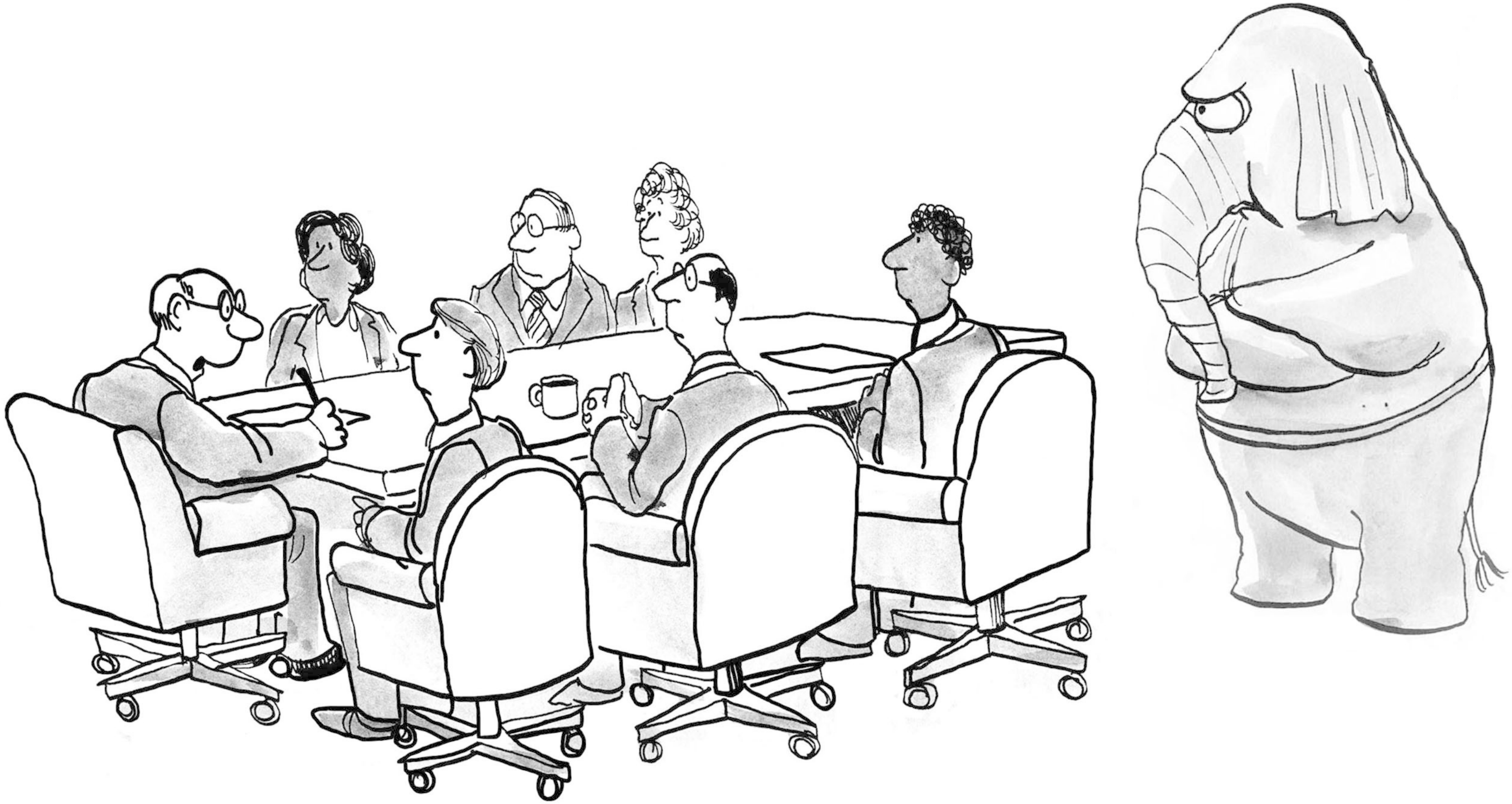
Pogge von Strandmann et al., 2013 Nat. Geo.

Case studies – P-T boundary



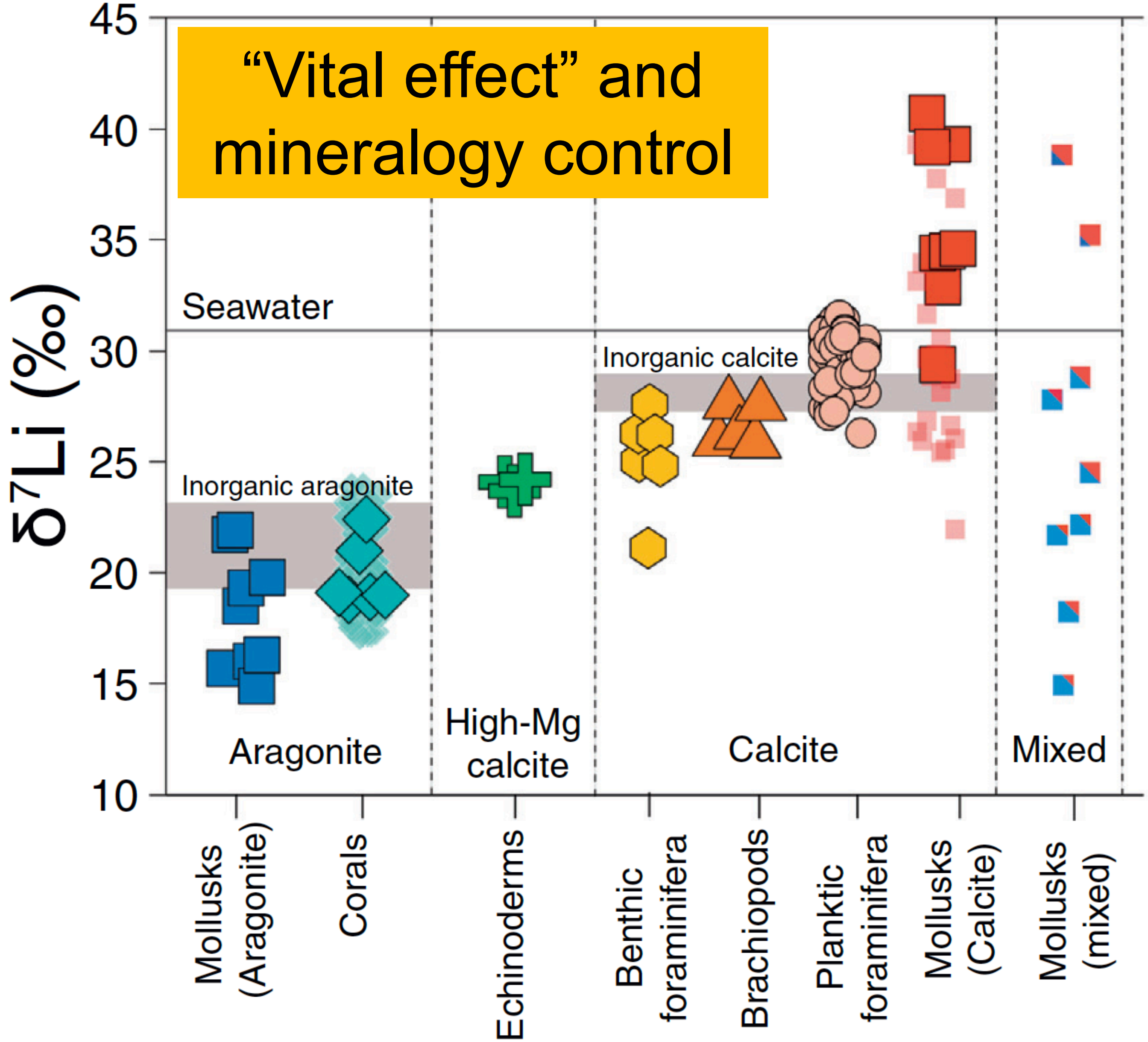
Sun et al., 2018 PNAS

Extract marine signal from bulk carbonate rocks is nontrivial!



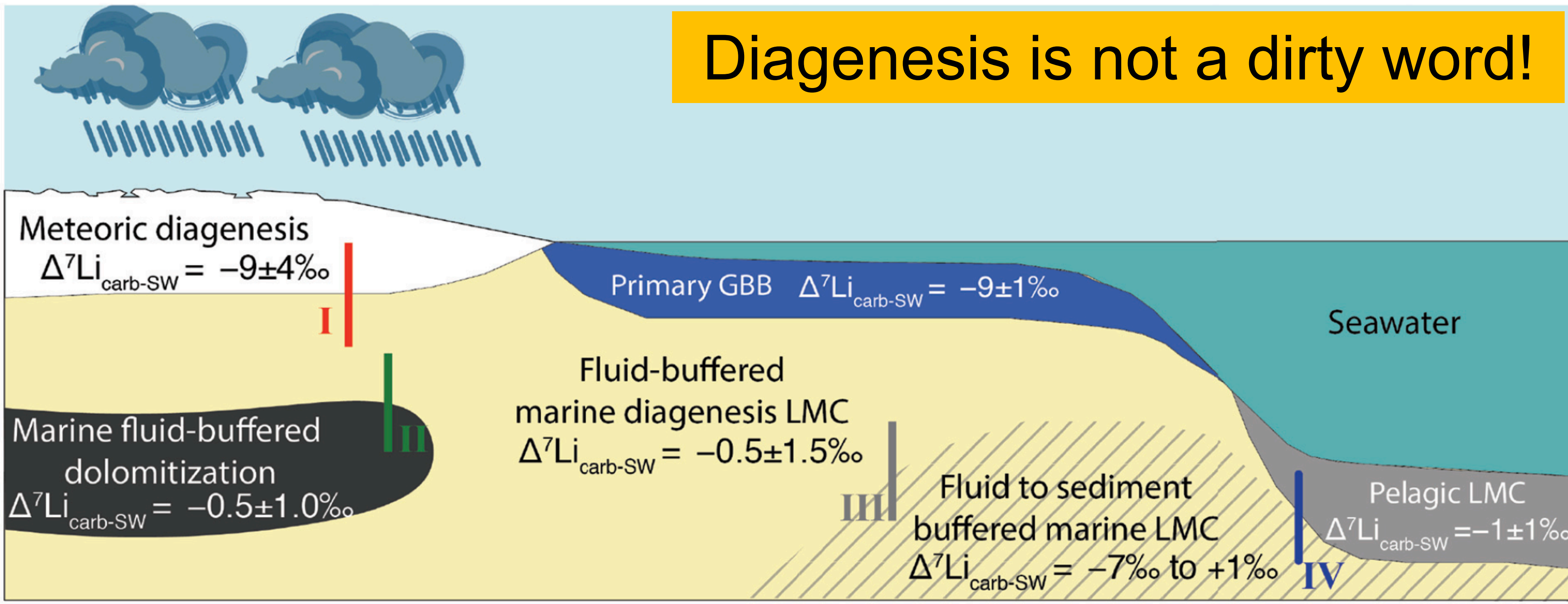
"I suppose I'll be the one
to mention the elephant in the room."

Marine carbonate = seawater?: Nature



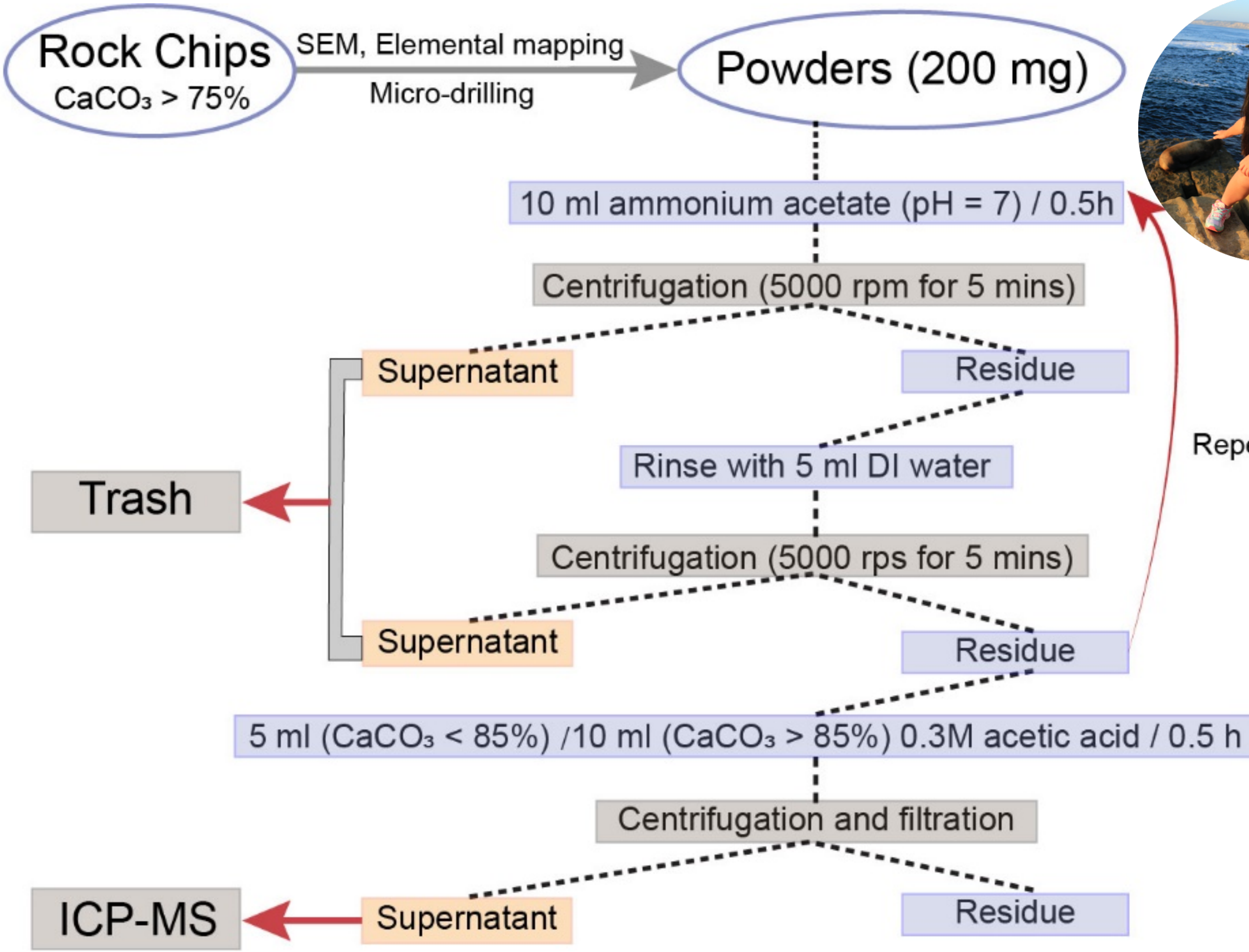
Dellinger et al., 2018 GCA

Marine carbonate = seawater?: Nature



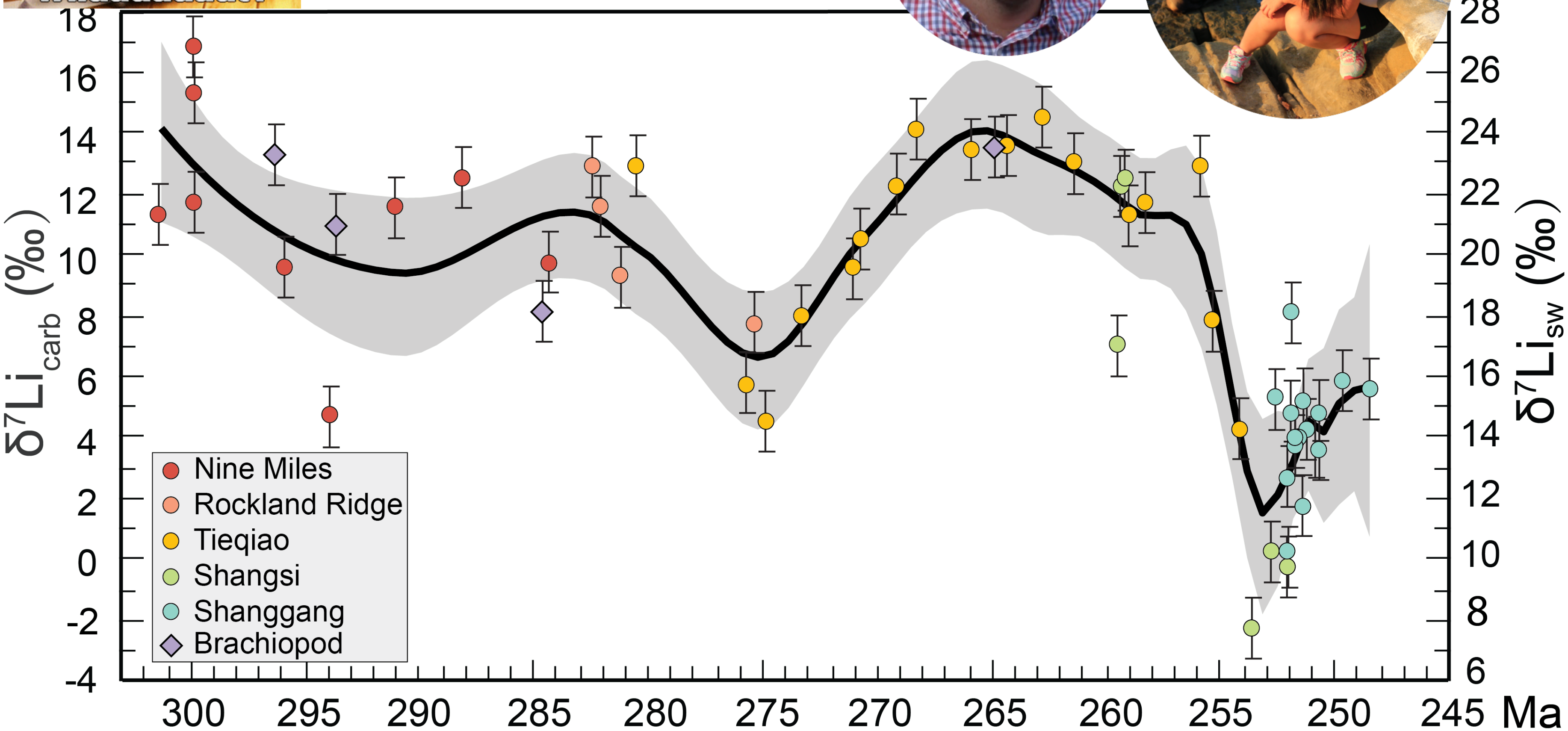
Dellinger et al., 2020 AJS

Marine carbonate = seawater?: Lab



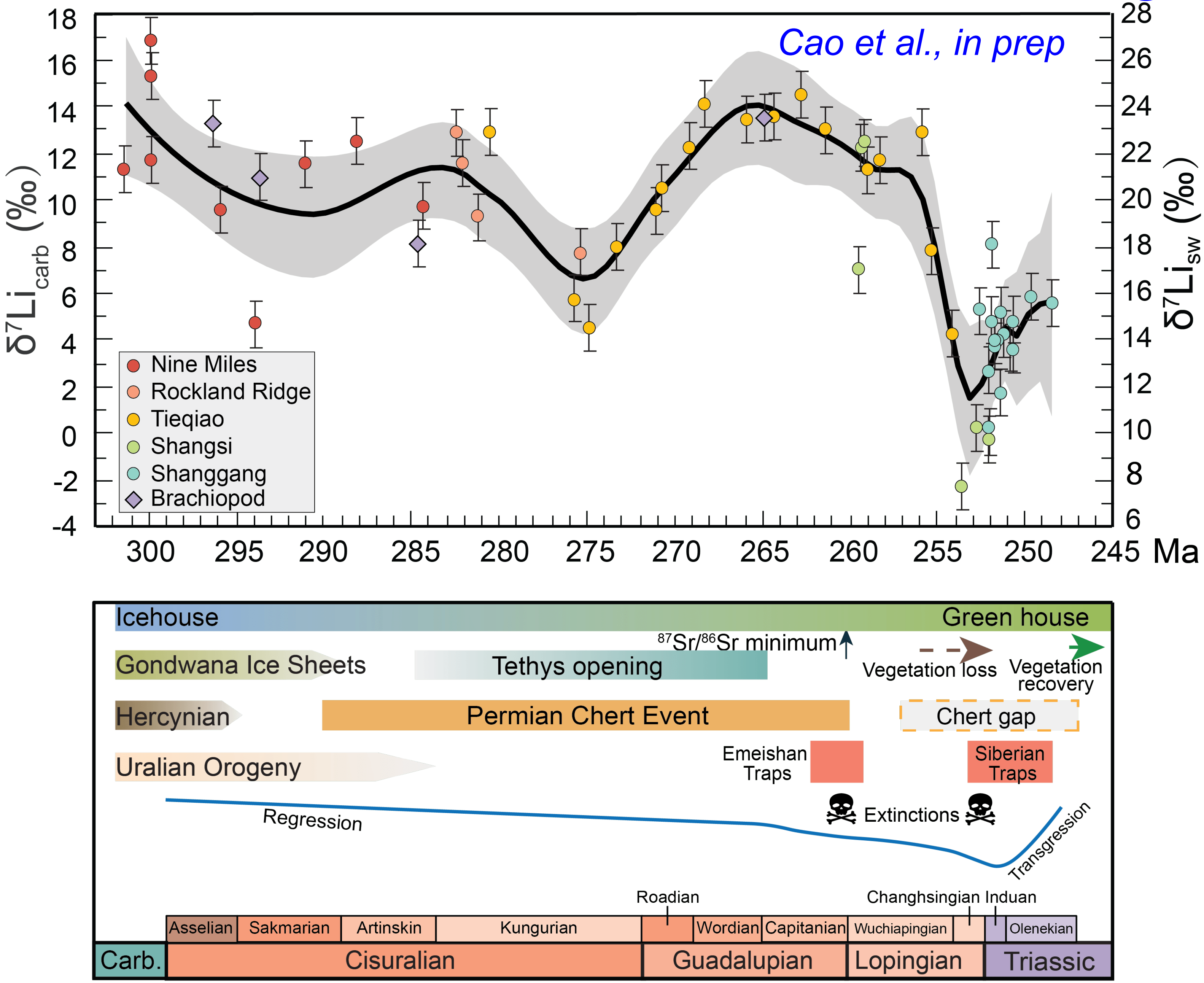
Cao et al., 2020 CG

Case studies – P-T boundary



Cao et al., in prep

Case studies – P-T boundary



4. Conclusions and outlook

1. Li and K isotopes may be good proxy for continental silicate weathering

2. Li and K isotopes may have potential to trace weathering/reverse weathering and global ocean cycles in Earth's history

3. Need to understand Li and K isotope fractionation mechanisms in Earth's surface

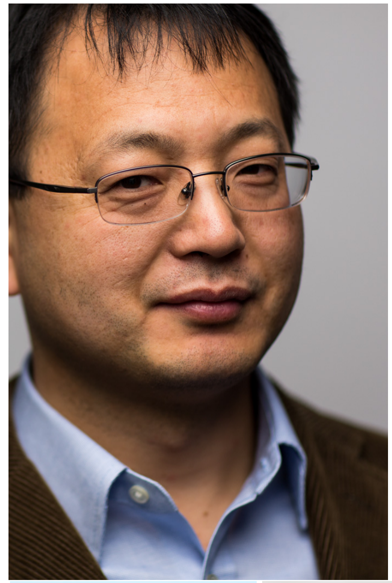

Thank you!

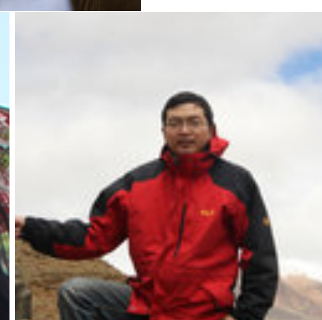
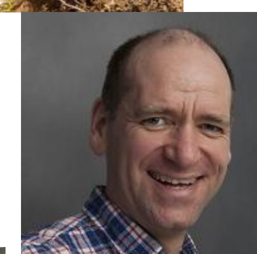


My postdoc and students contributed to this talk

Collaborators





PMS is always looking for motivated students and scholars!

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