Geochemistry in the Age of Open Data

New insights into the formation and evolution of Earth's continental crust.

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Princeton University, Department of Geosciences

Motivation

1. Understanding how the Earth system operates

- There is still a lot we don't know about our own planet

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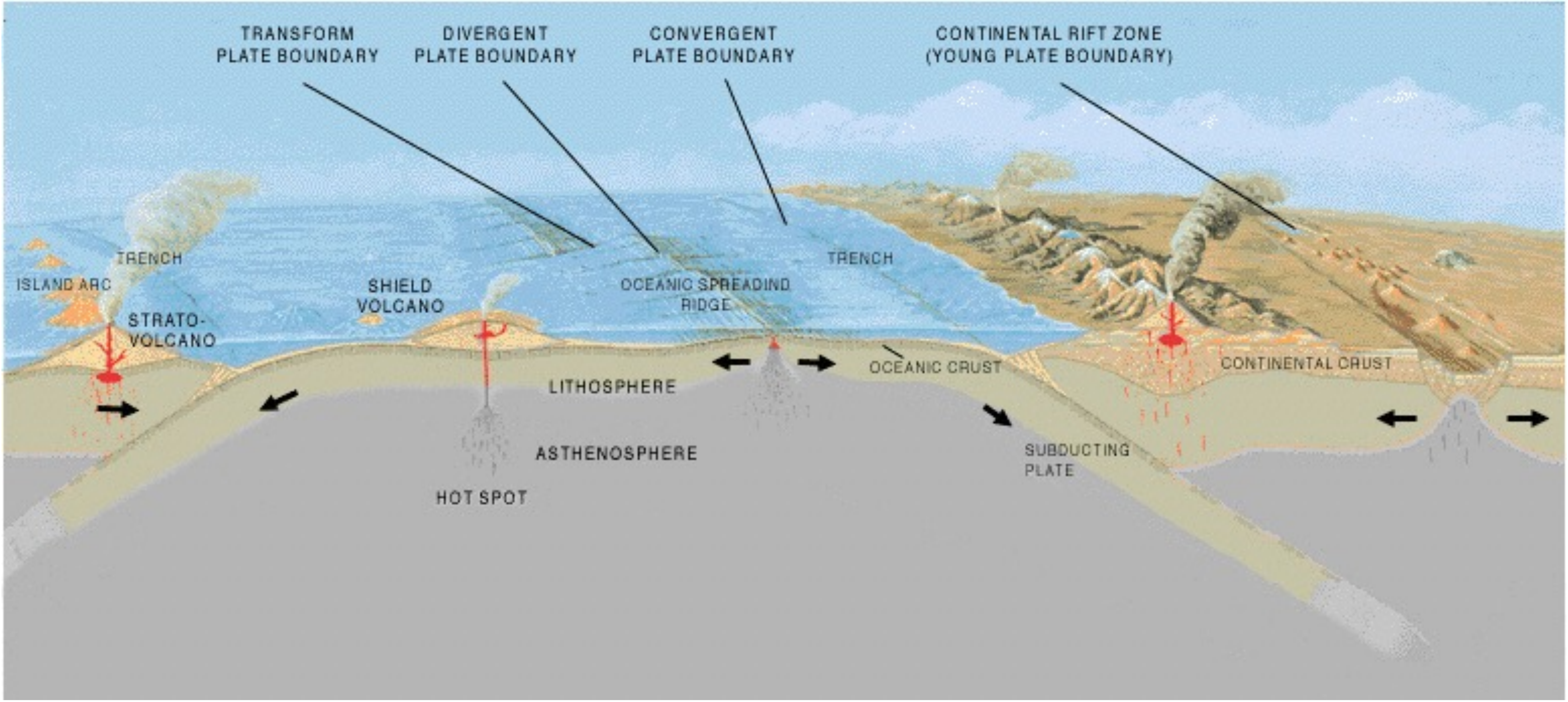
EarthChem

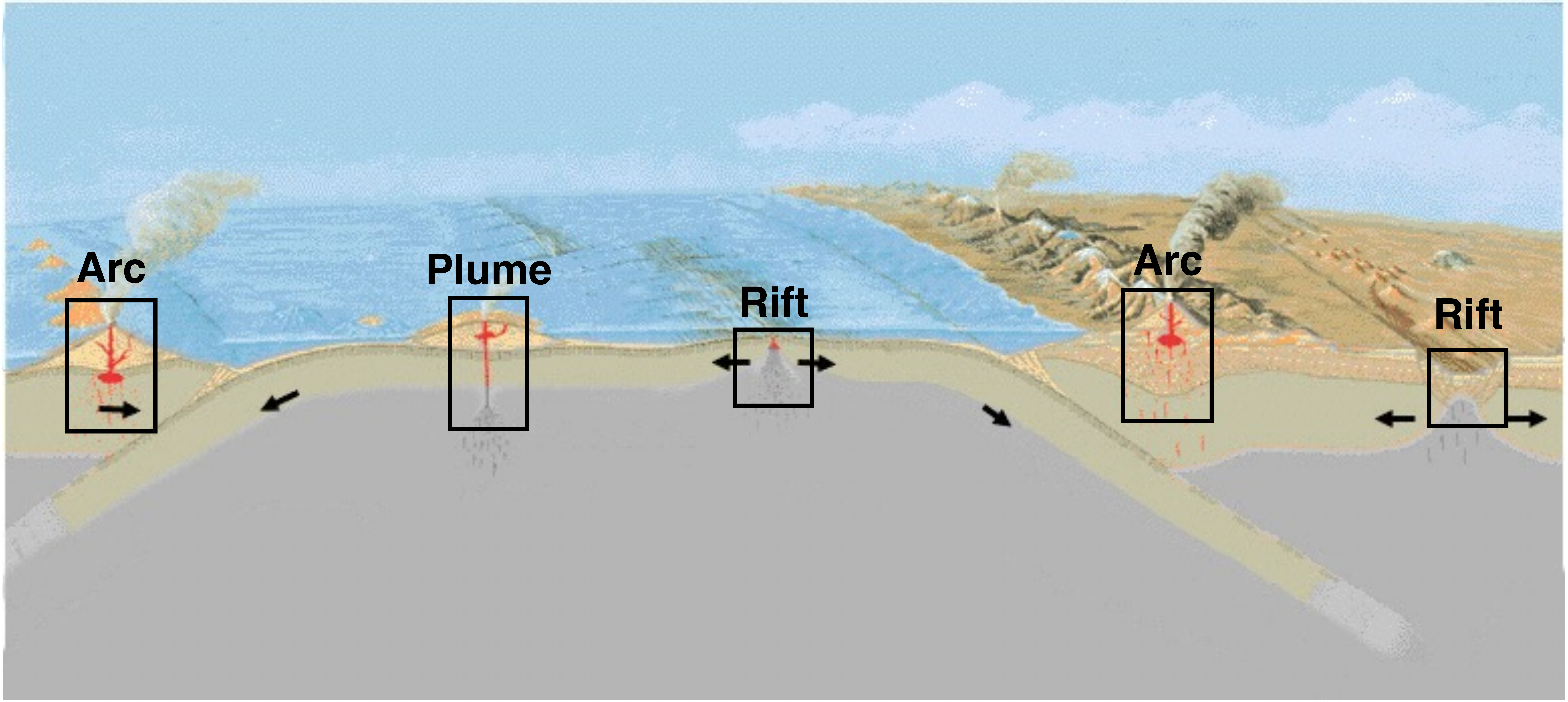
Plate Tectonics



USGS

Plate Tectonics

Sites of magmatism



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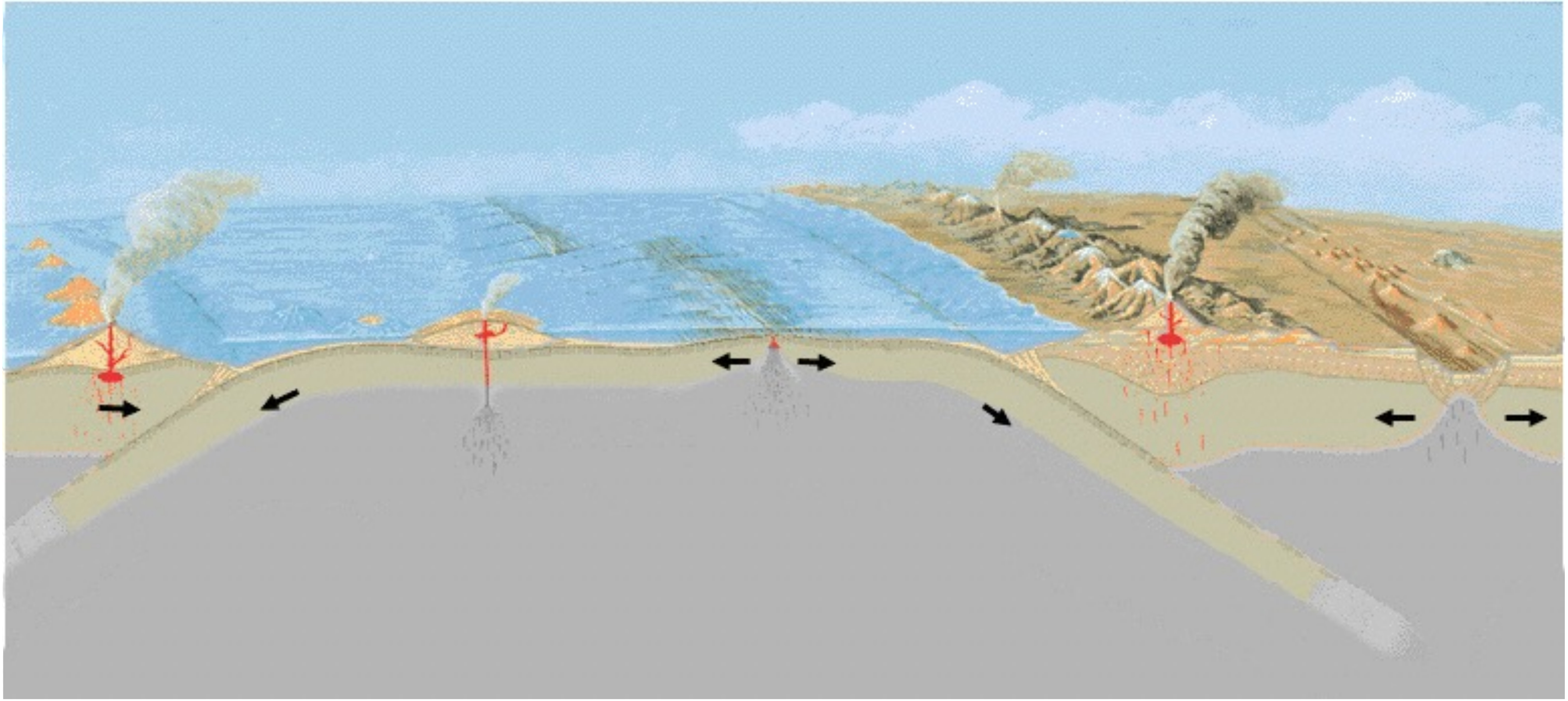

USGS

T ↑

Plate Tectonics

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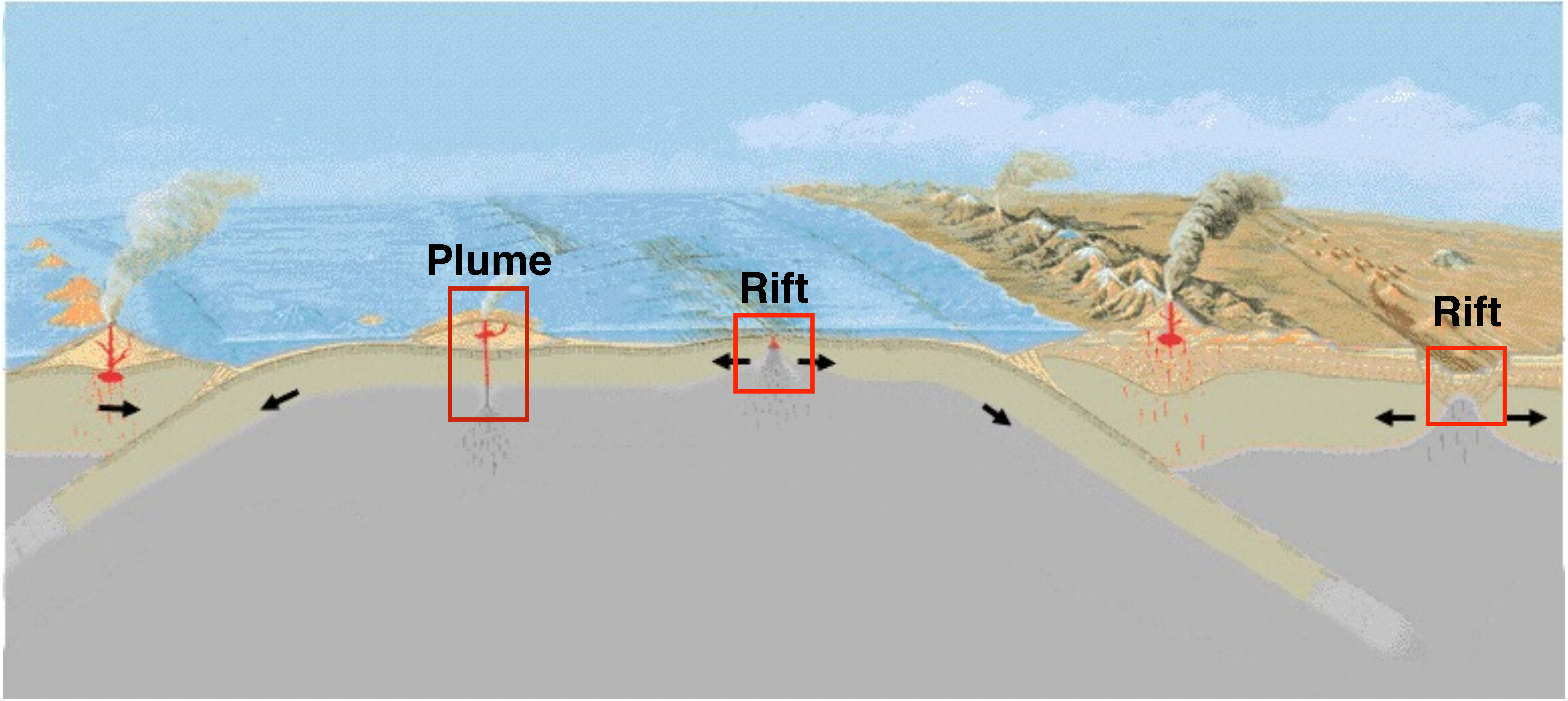
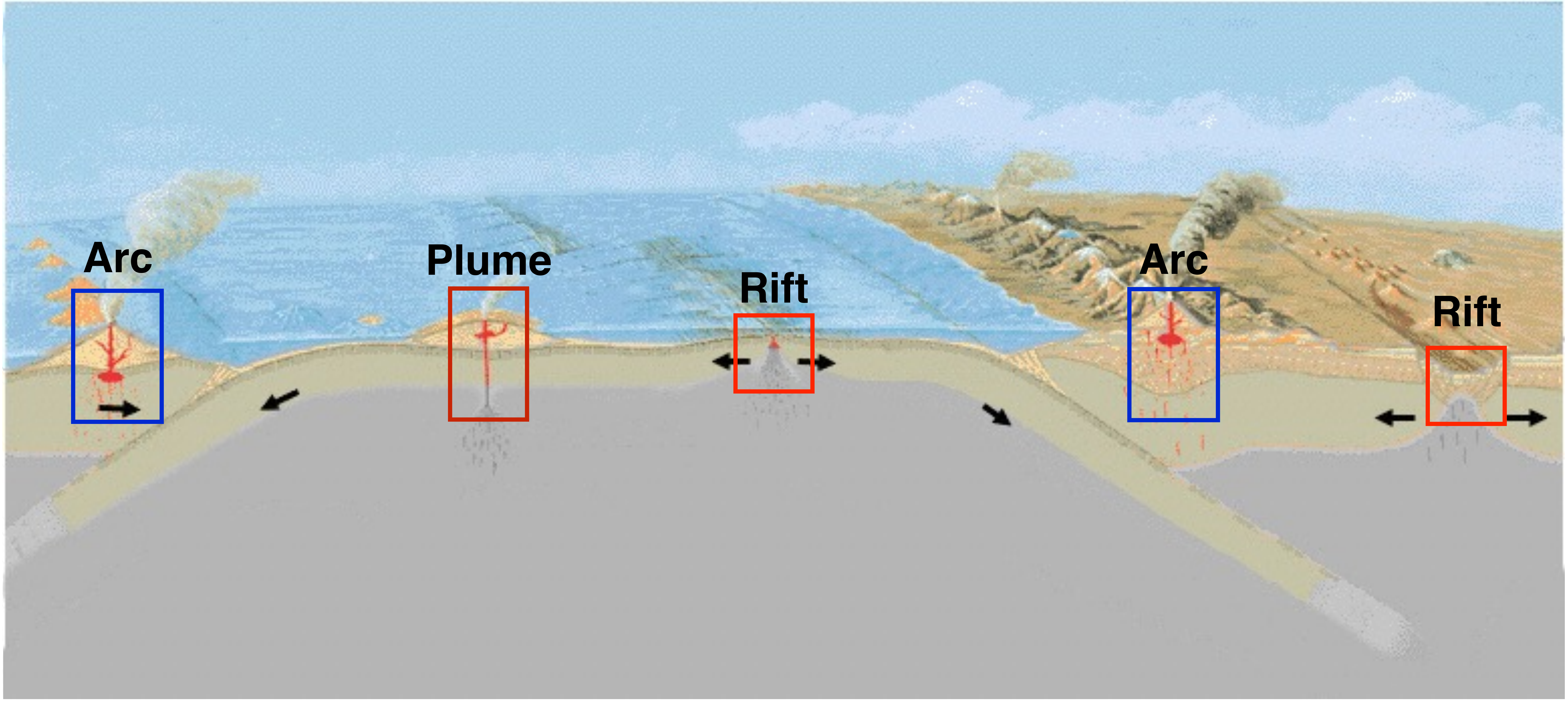


USGS

T ↑, P ↓

Plate Tectonics

Sites of magmatism



USGS

T↑, P↓, H_2O↑

Plate Tectonics

Two types of crust

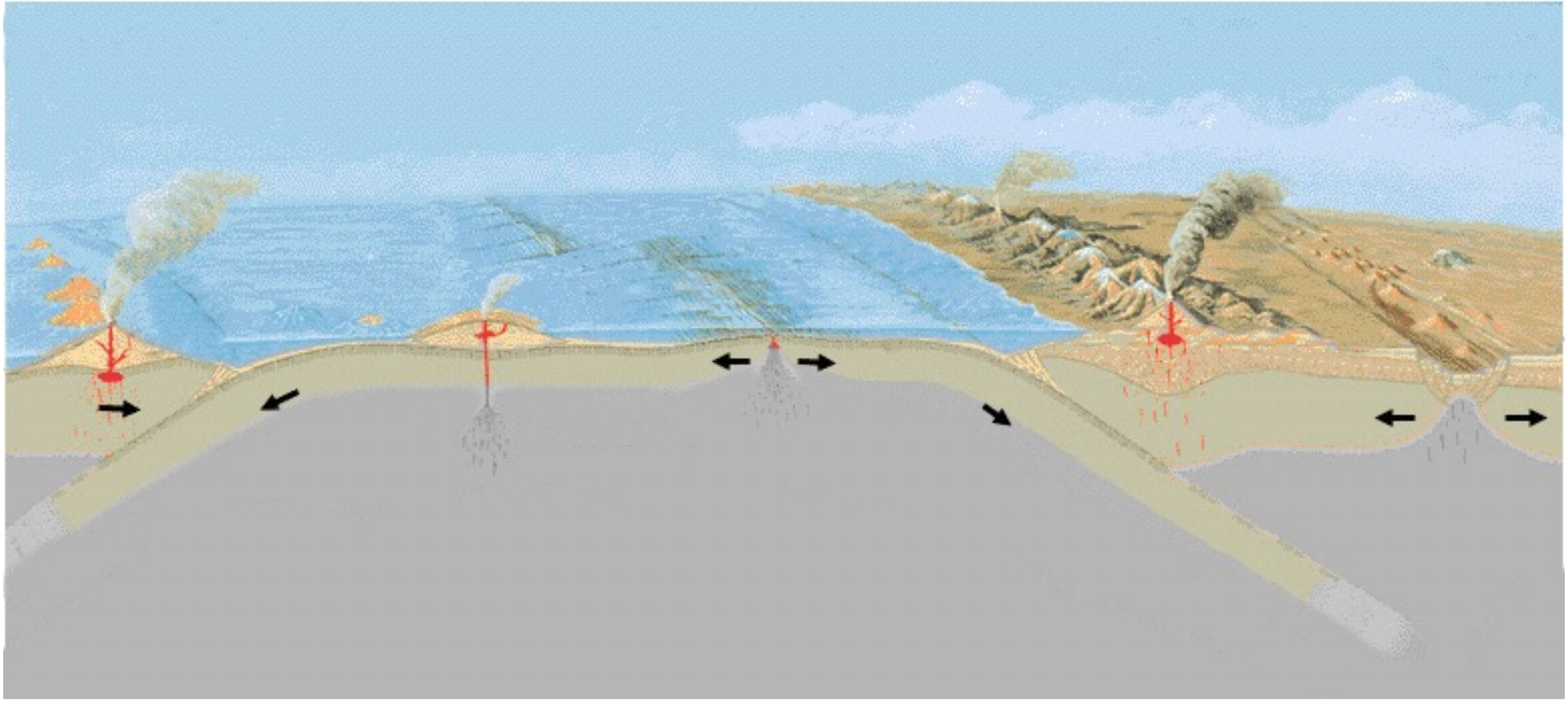


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Plate Tectonics

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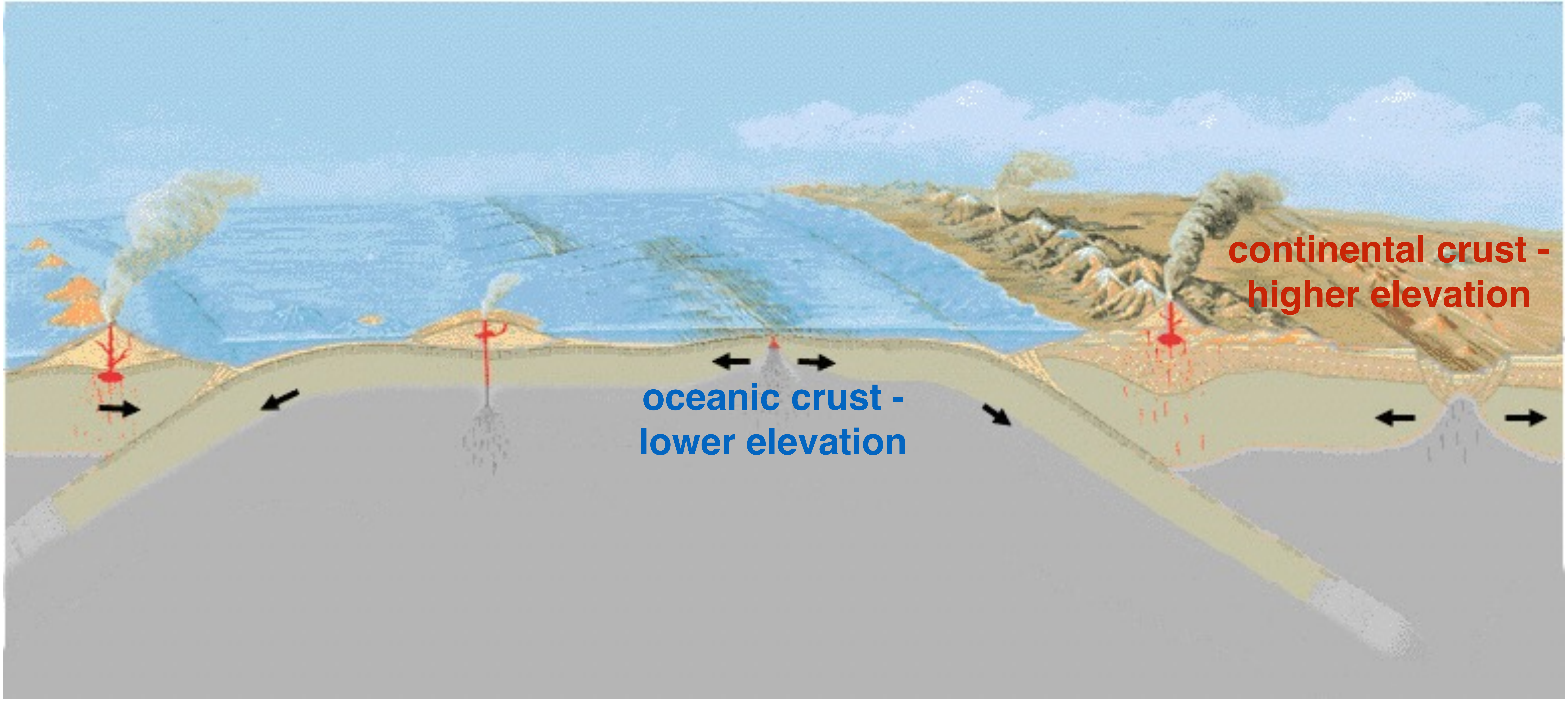


USGS

Mineralogy & Composition

high $[SiO_2]$, low density

Felsic

Mafic

low $[SiO_2]$, high density

Quartz
SiO_2

Orthoclase
$KAlSi_3O_8$

Plagioclase
$(Na,Ca)(Si,Al)AlSi_2O_8$

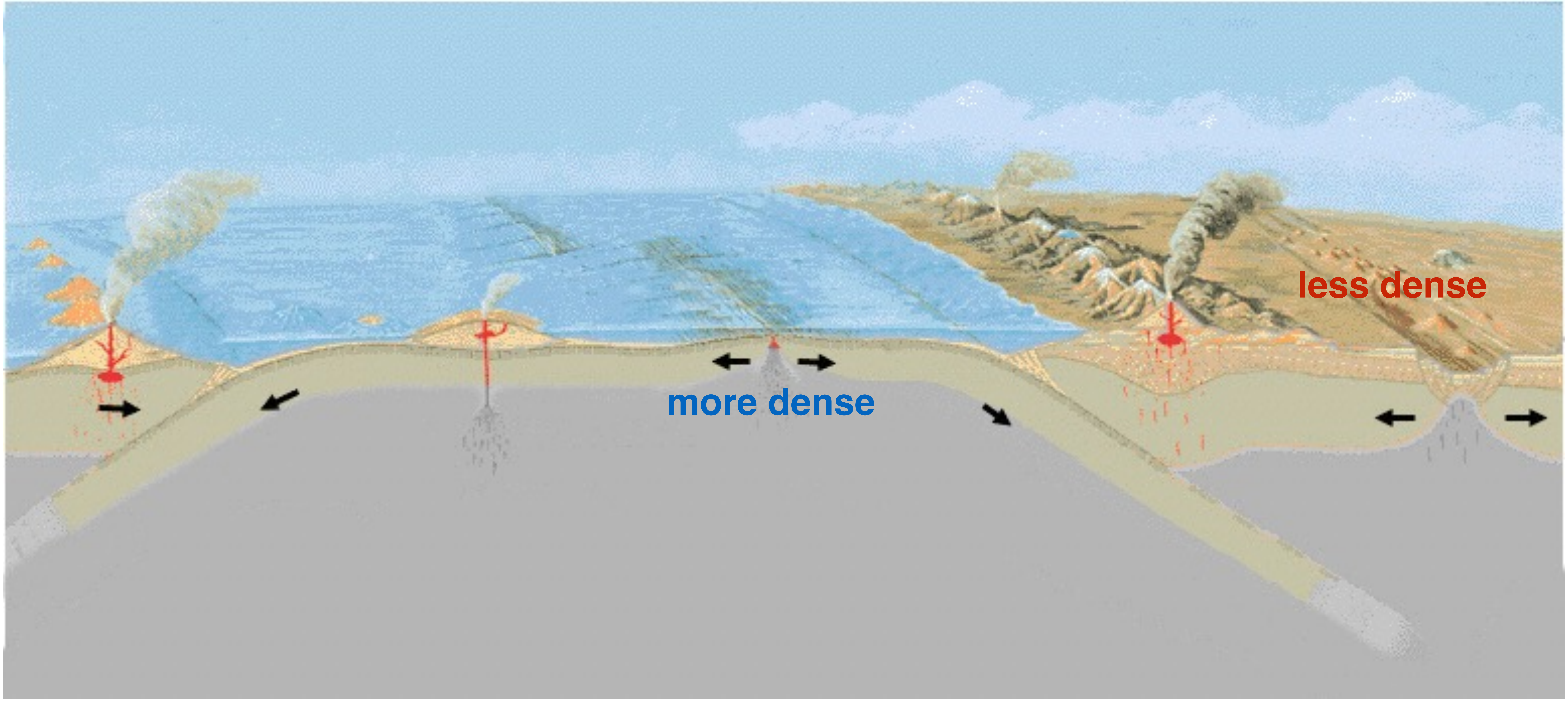
Pyroxene
$(Fe,Mg,Ca)_2Si_2O_6$

Olivine
$(Fe,Mg)_2SiO_4$

Photo Credit:
Rob Lavinsky

Bimodal Topography

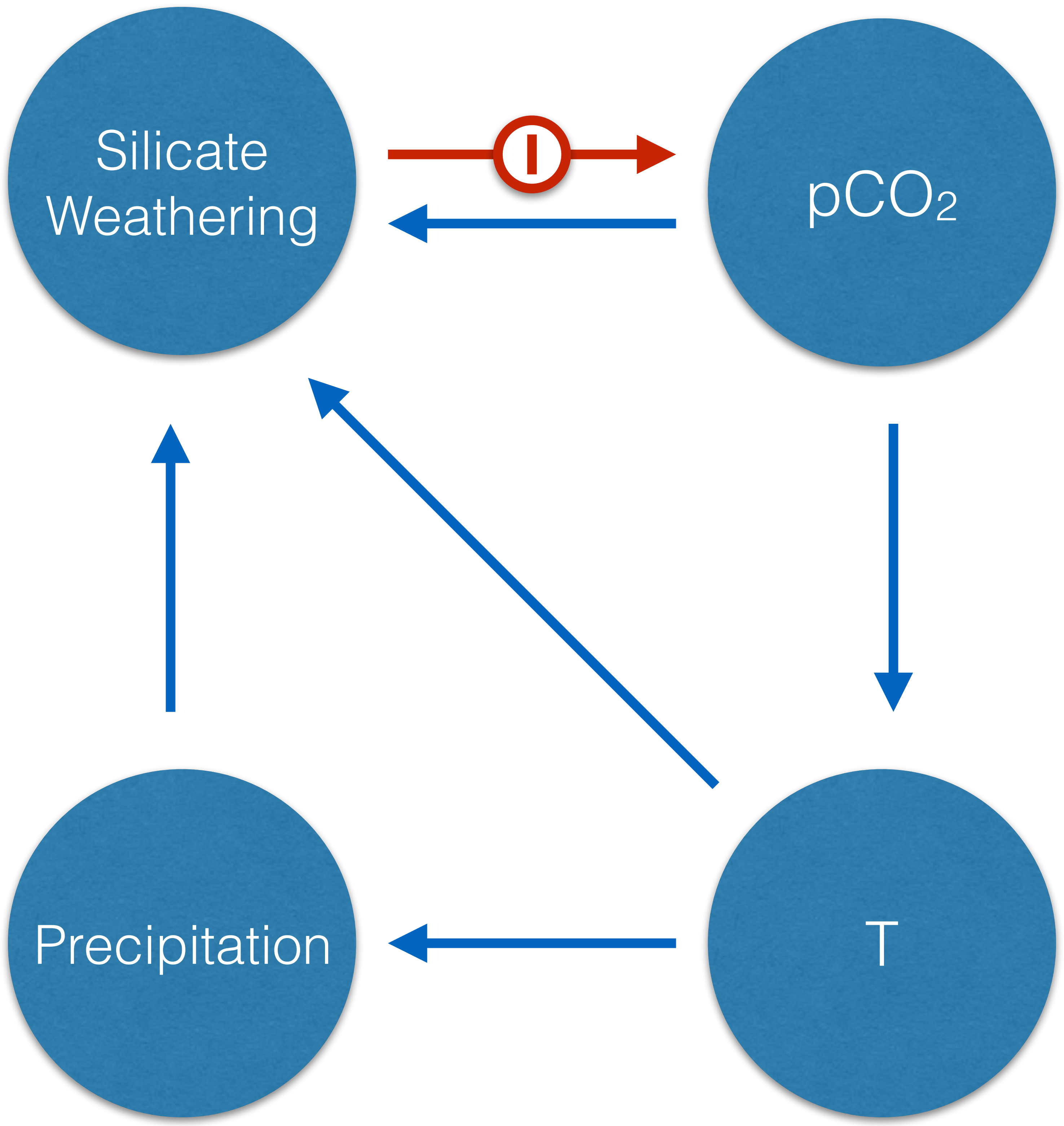
Required for efficient silicate weathering



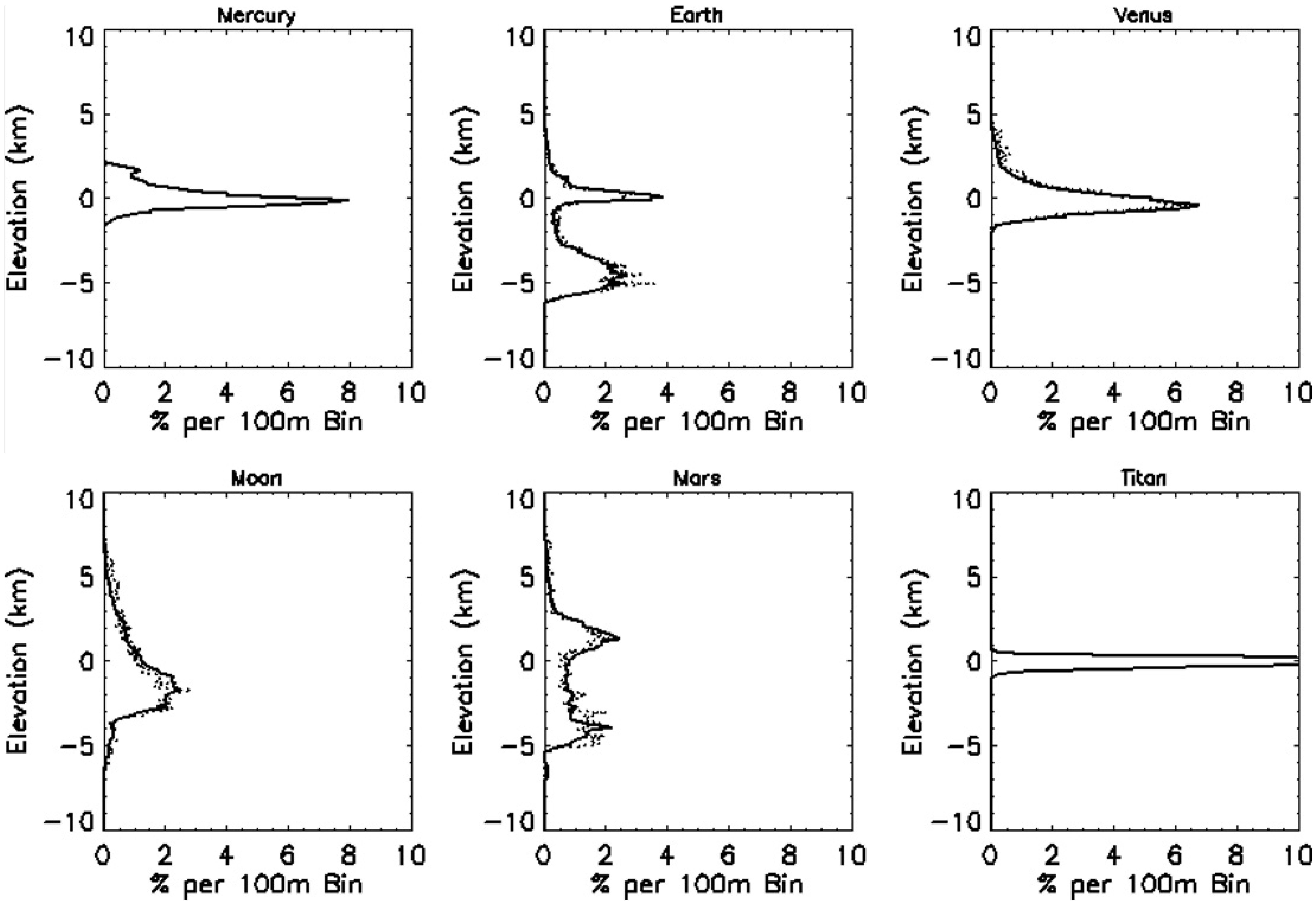
USGS

Silicate Weathering Feedback

$$CO_2 + CaSiO_3 \rightleftharpoons CaCO3 + SiO_2$$

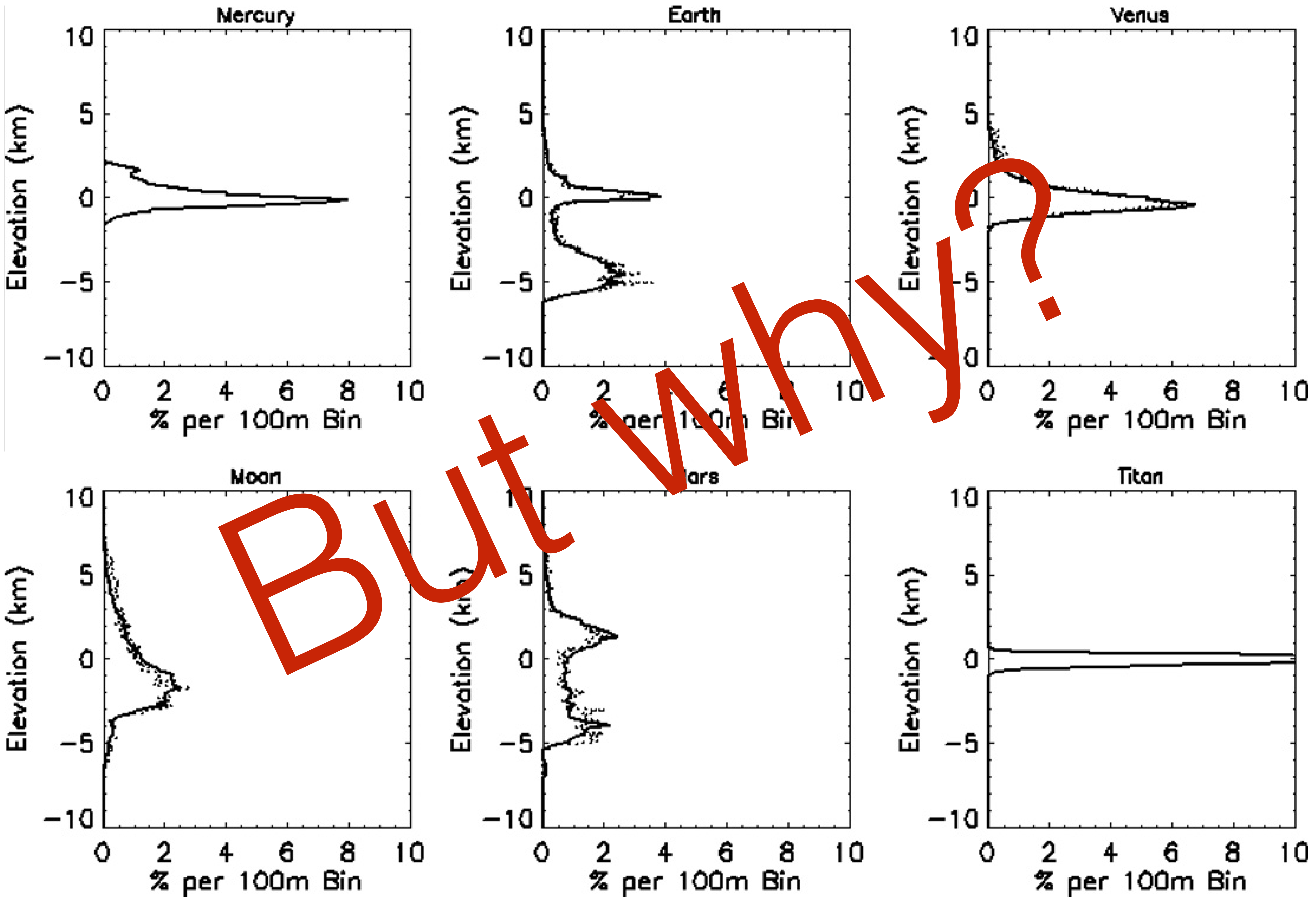


Bimodal Topography



Lorenz et al. (2011) *Icarus*

Bimodal Topography



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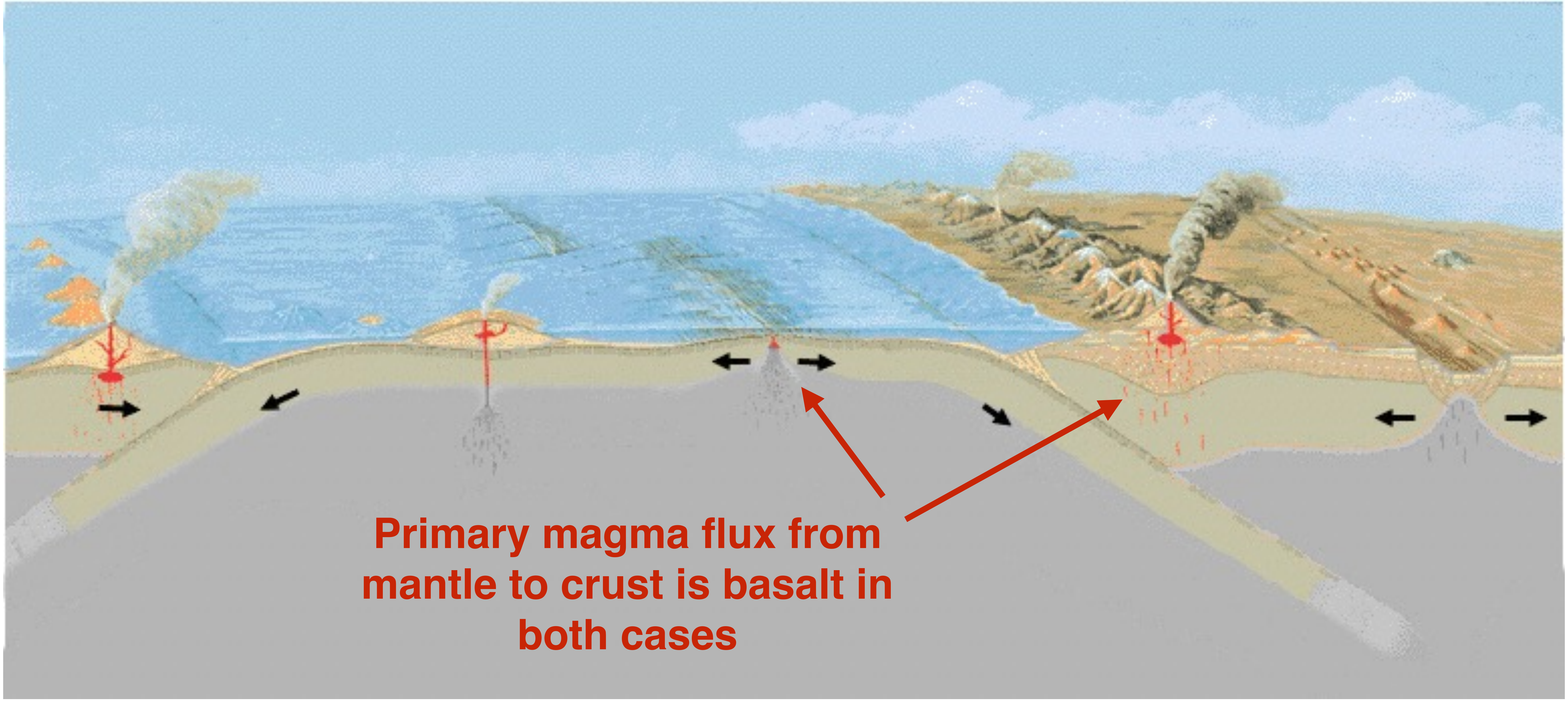
Production & Evolution of Continental Crust

Why is continental crust less dense than oceanic crust?



USGS

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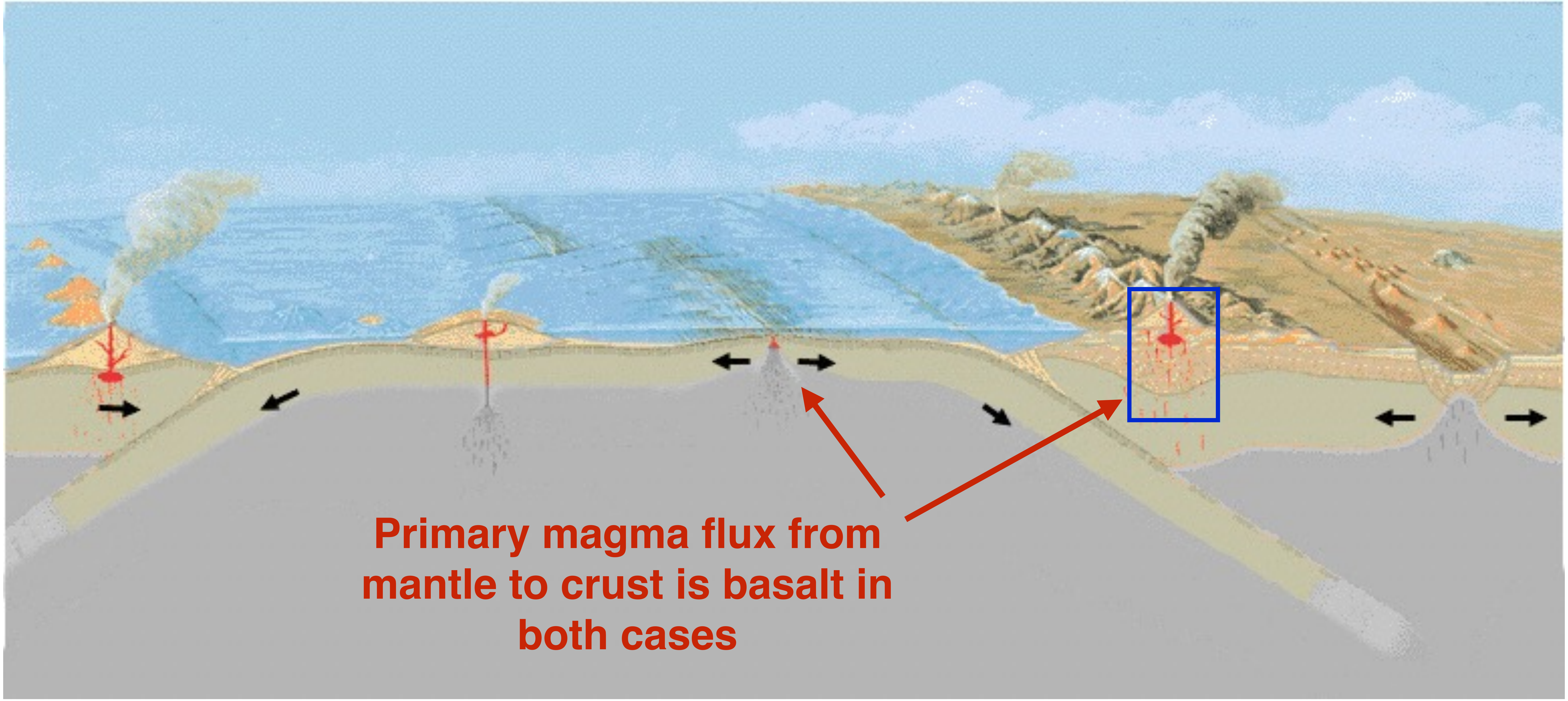
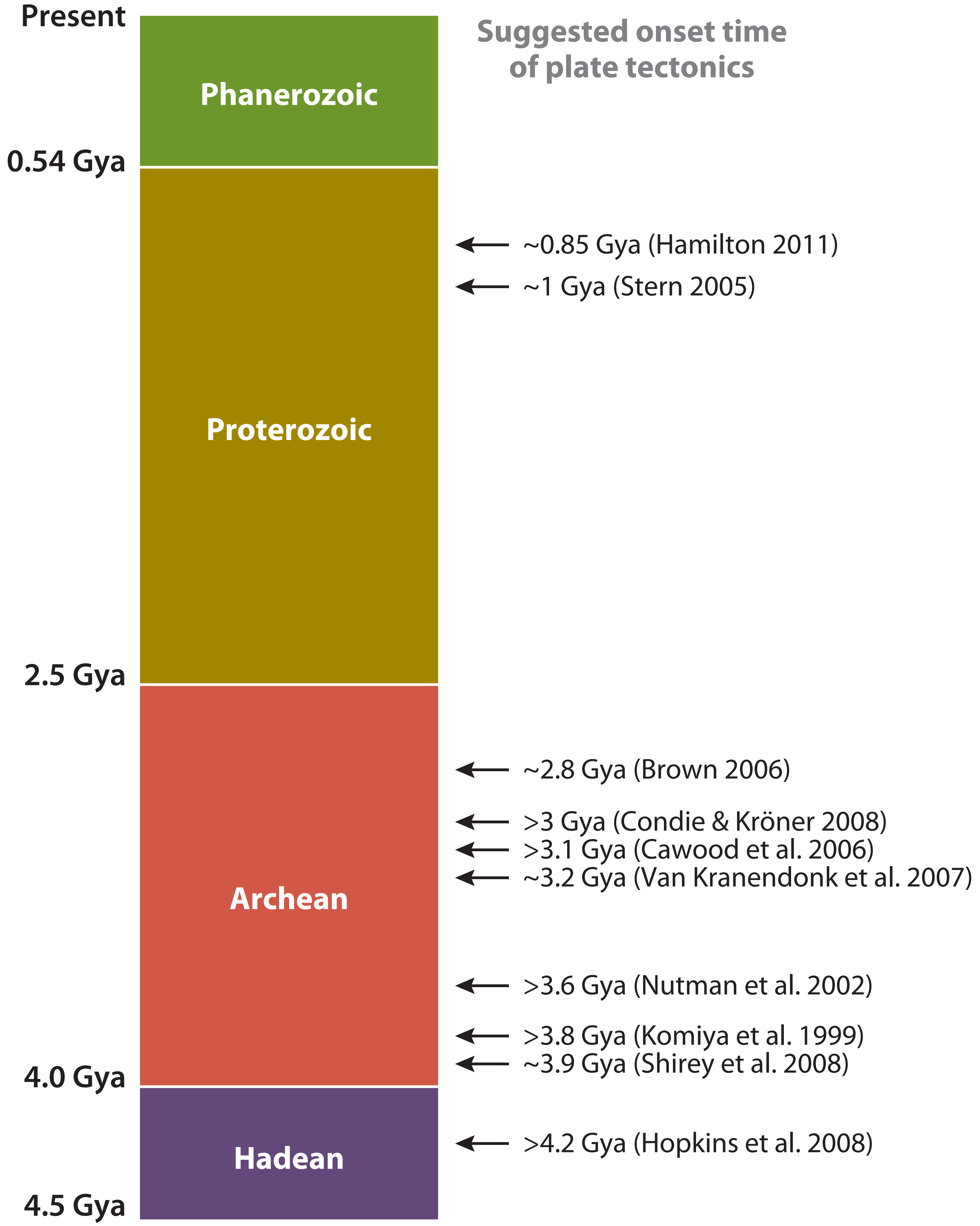


USGS

Fundamental question:

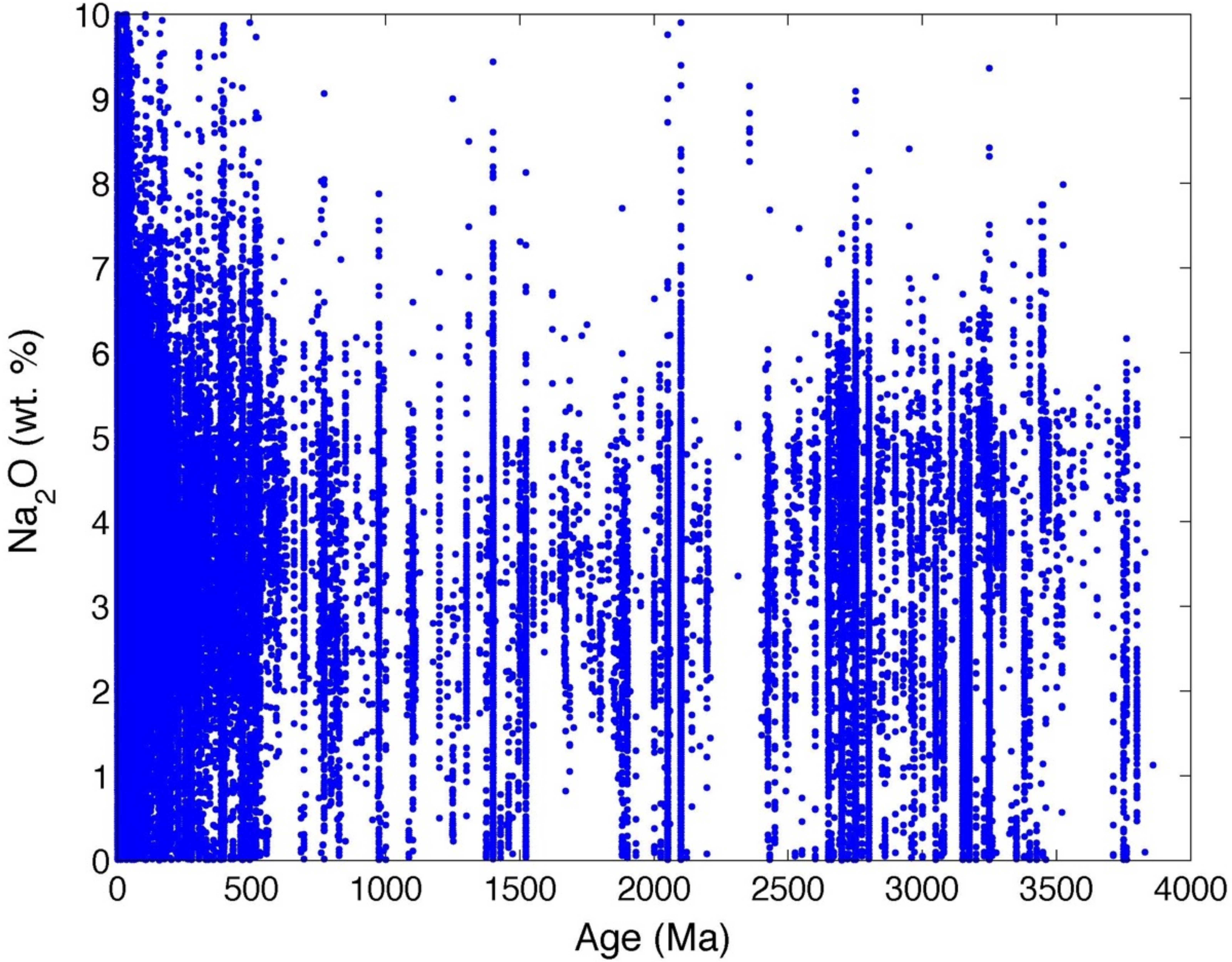
- How long has plate tectonics been operating on Earth?

Proposed initiations of plate tectonics

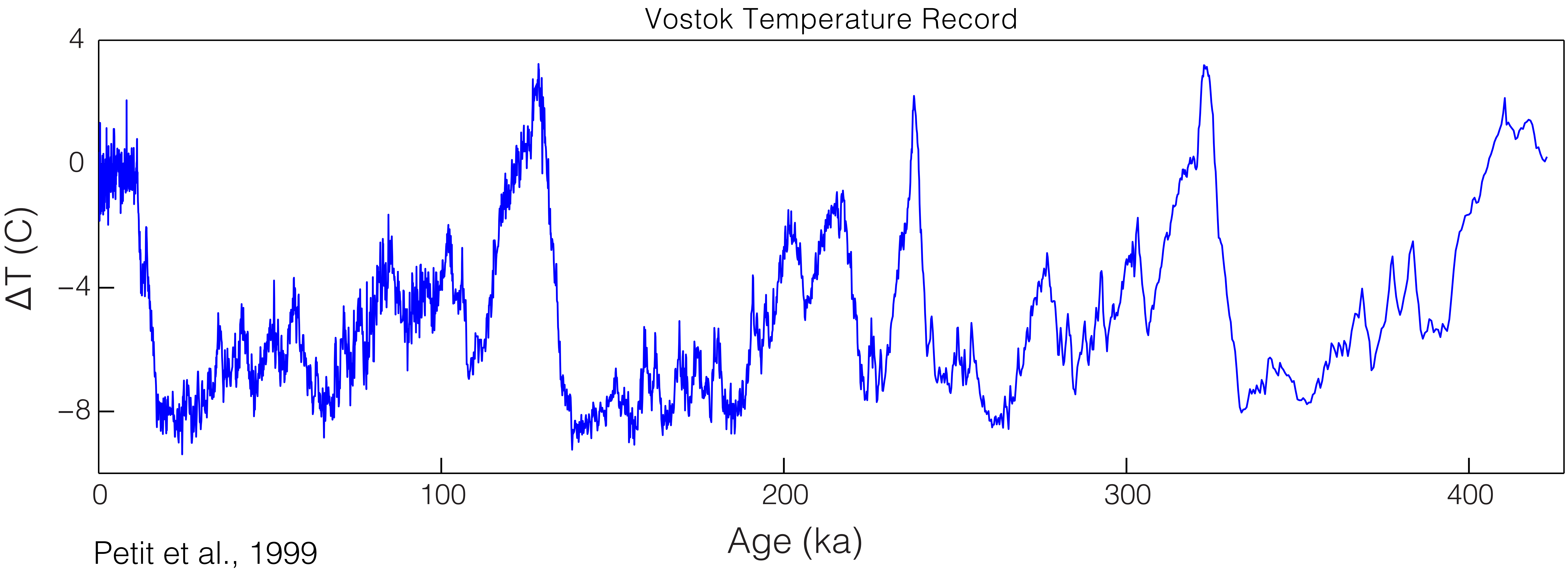


Korenaga, 2013

Earth's crust is chemically heterogeneous



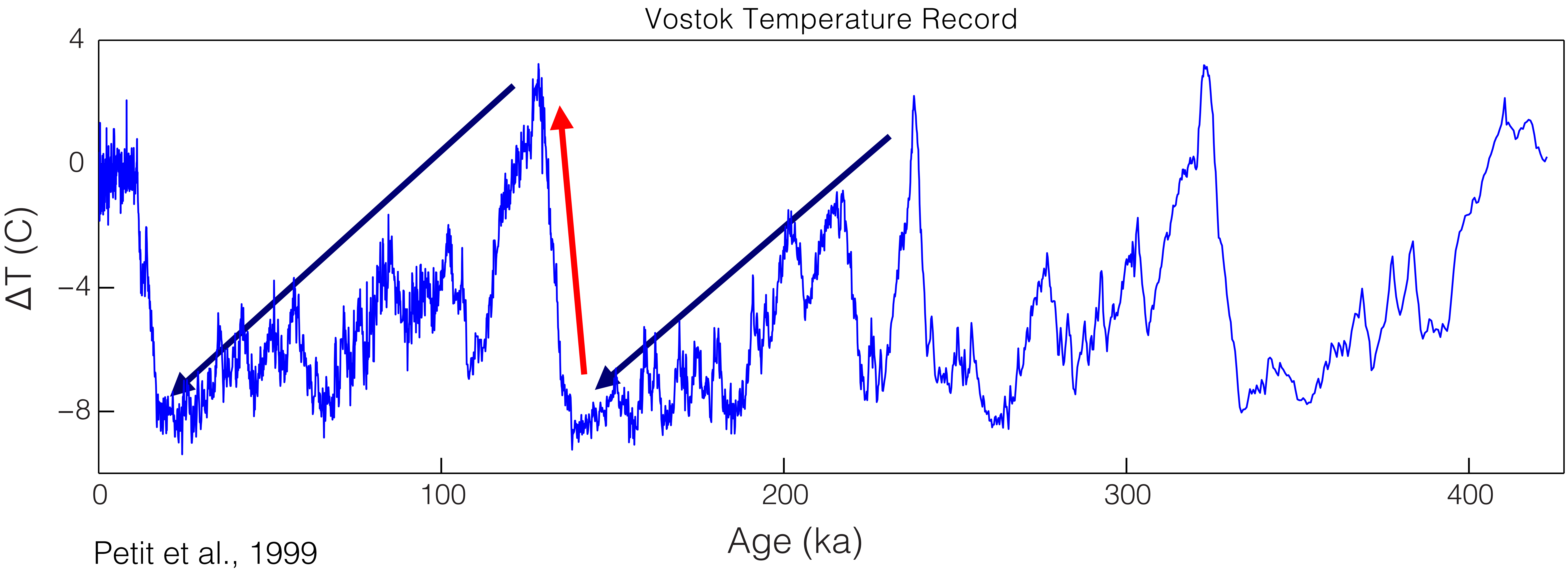
Average Temporal Trends



Petit et al., 1999

Average Temporal Trends

Change over time can resolve process



Petit et al., 1999

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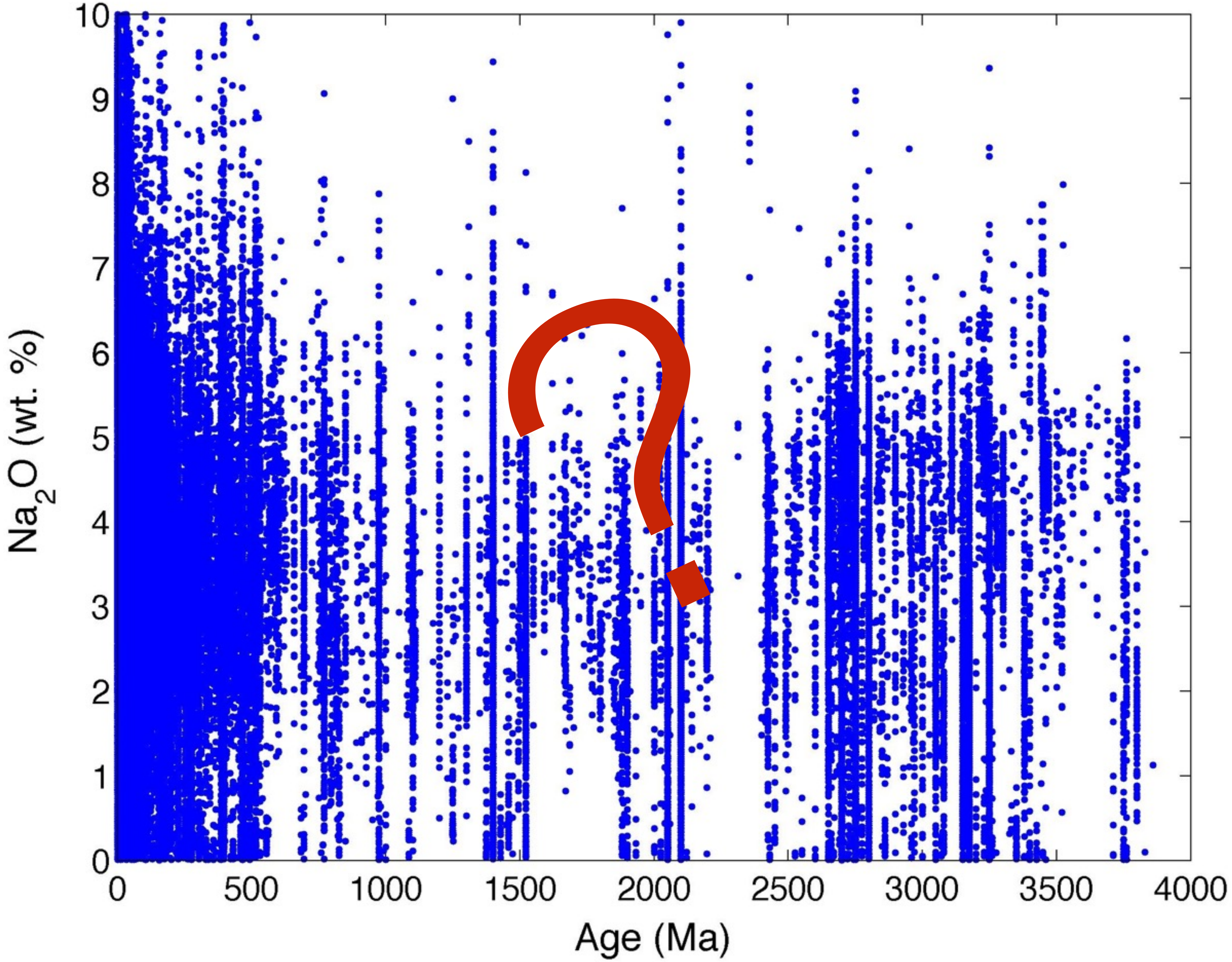
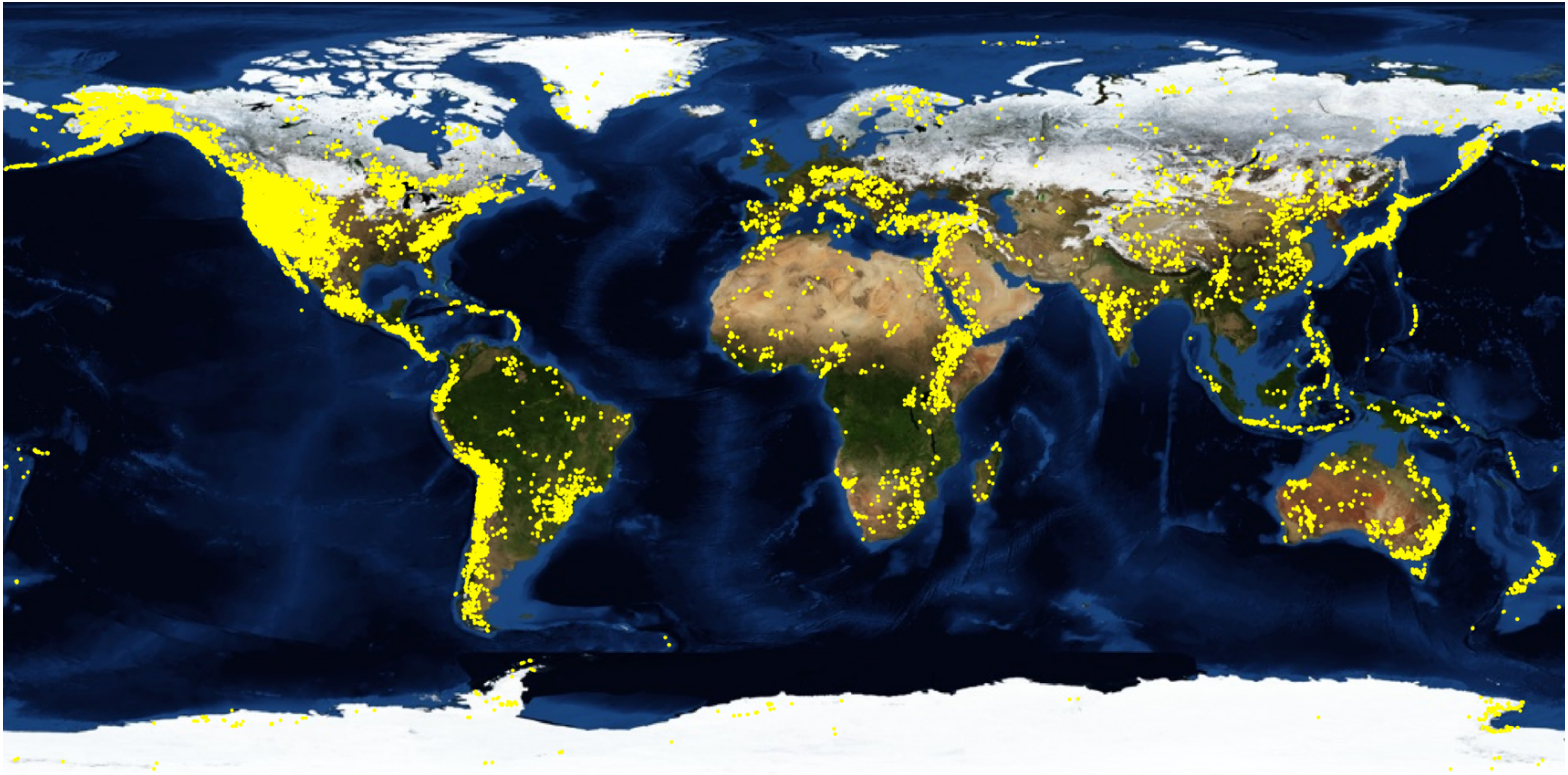
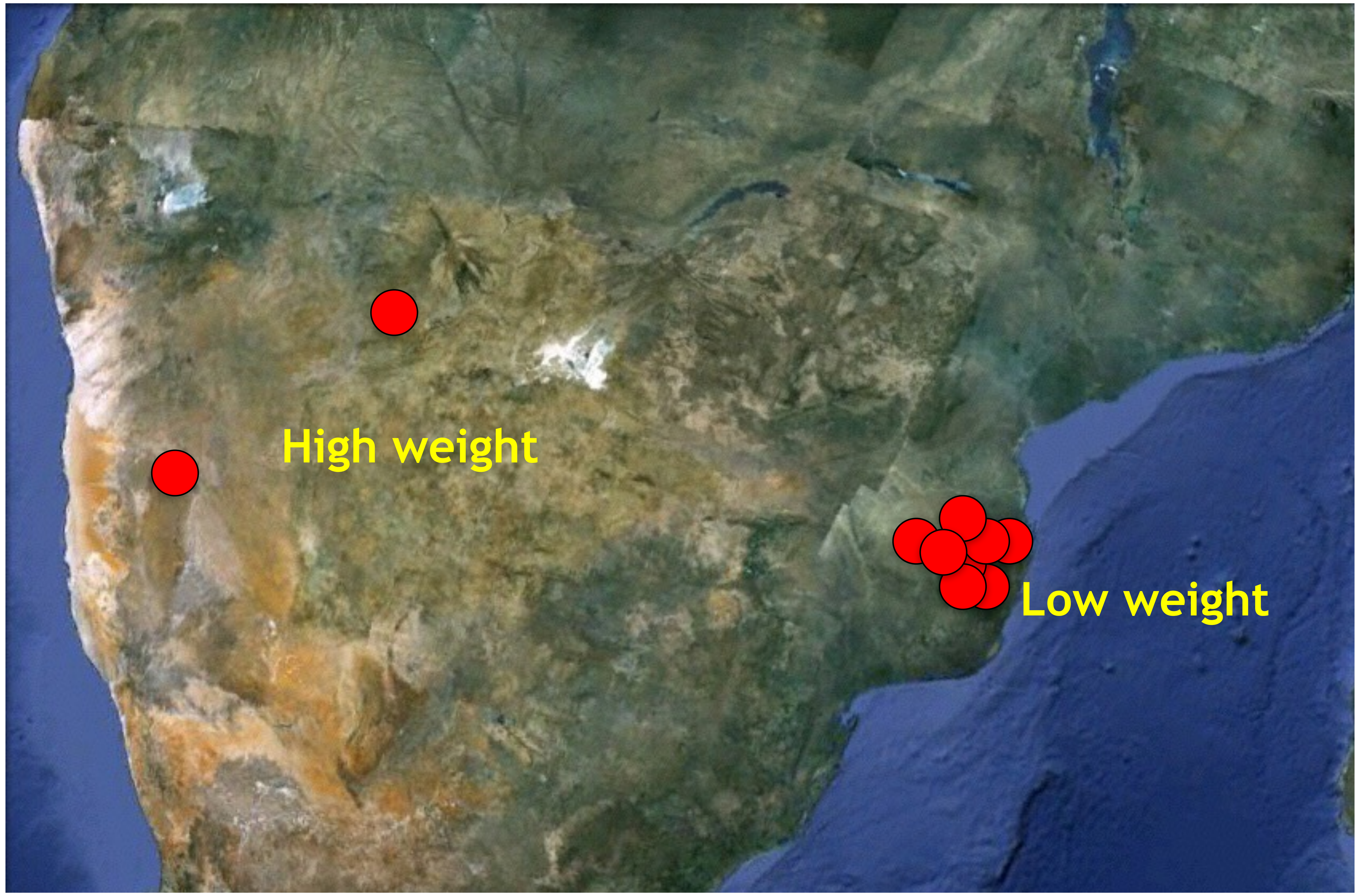


Sample Locations



~66,000 samples via EarthChem, ~2500 via K. Condie, ~1500 via J-F. Moyen

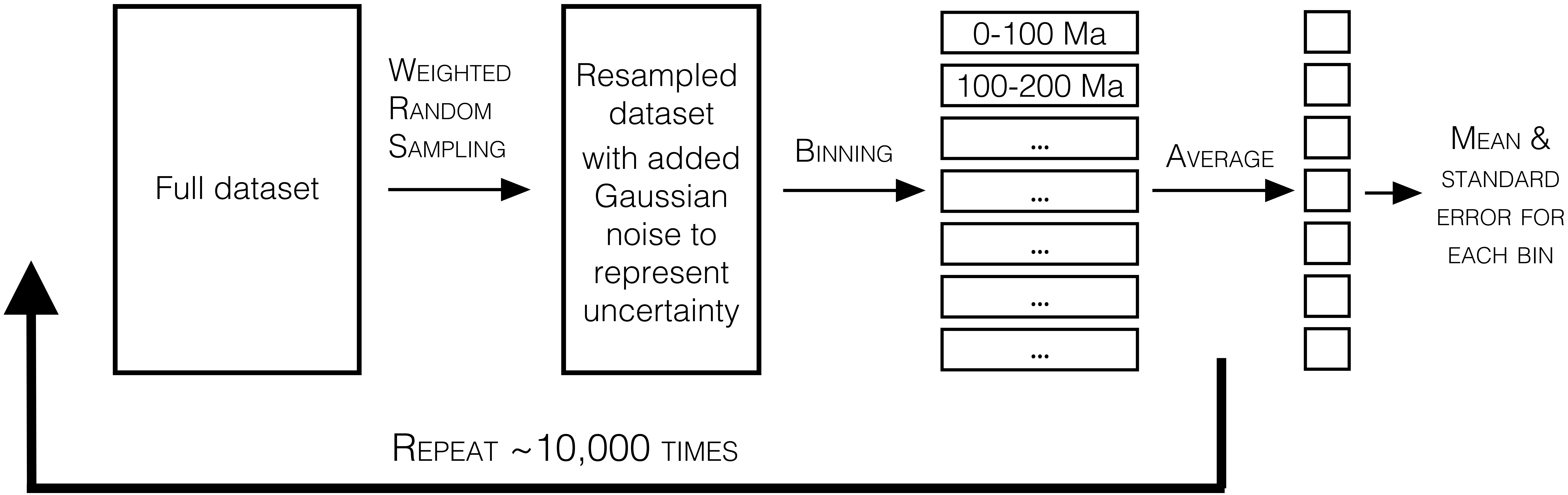
Weighted Bootstrap Resampling Monte Carlo Analysis



$$W_i \propto 1 \Big/ \sum_{j=1}^{n} \left(\frac{1}{((z_i - z_j)/a)^2 + 1} + \frac{1}{((t_i - t_j)/b)^2 + 1} \right)$$

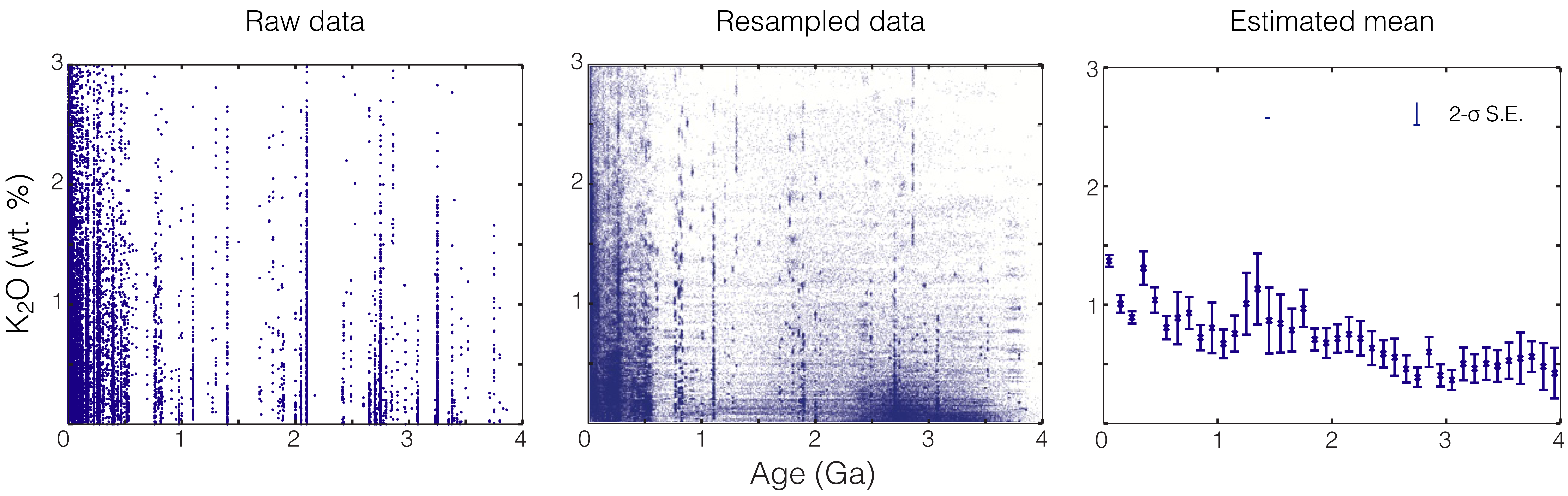
Minimizing sampling bias by sample weighting

Weighted Bootstrap Resampling

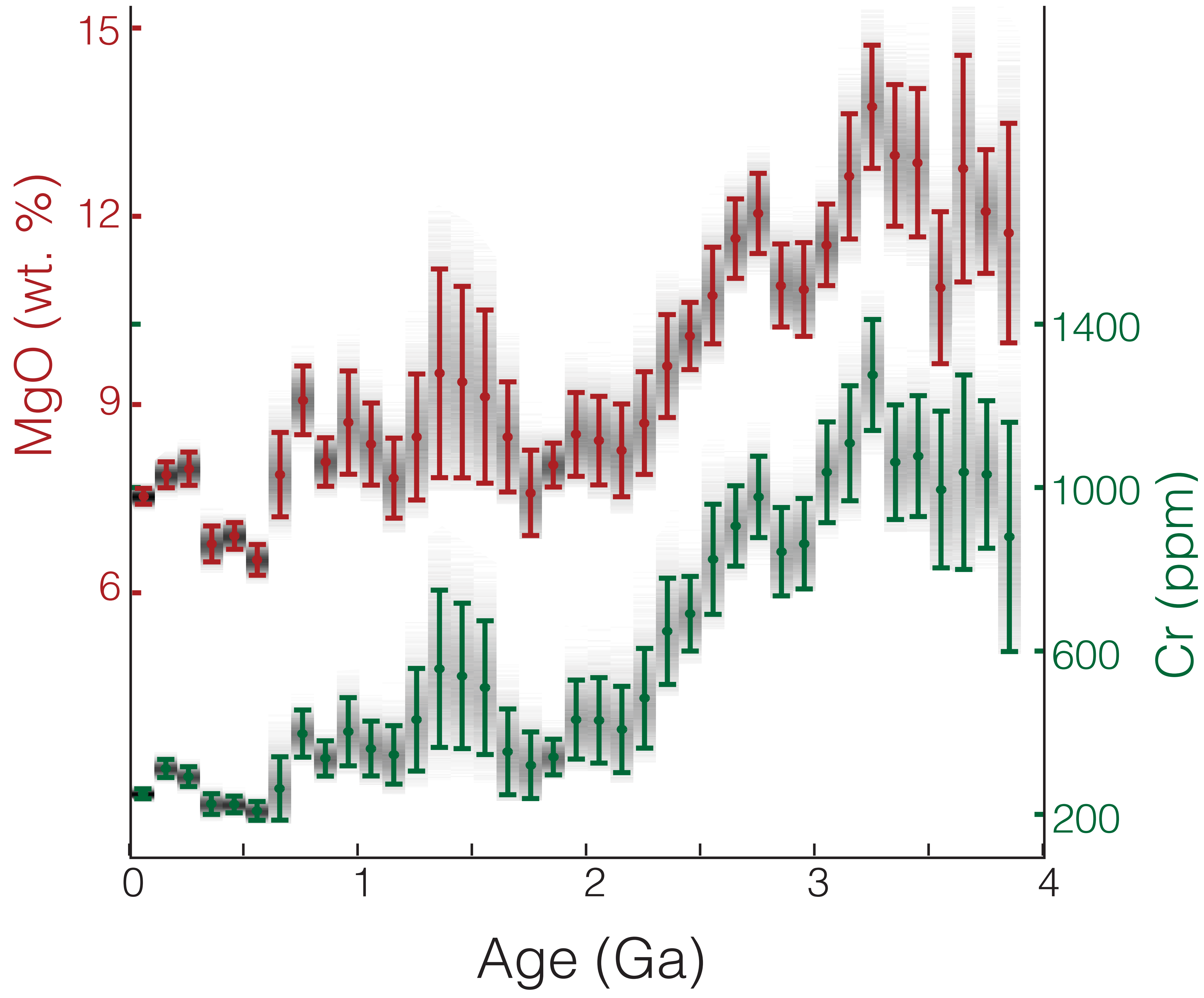


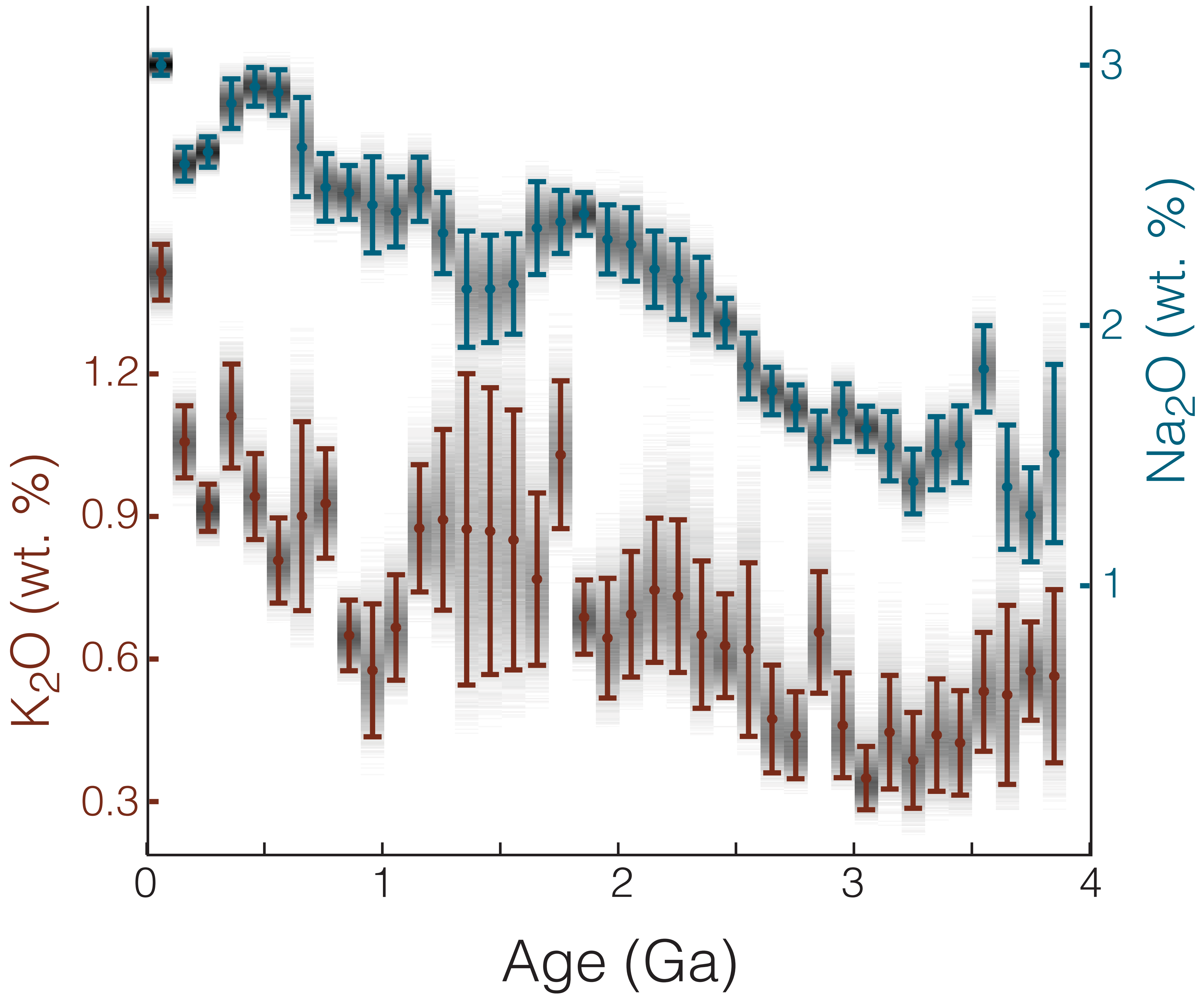
Weighted Bootstrap Resampling Monte Carlo Analysis

Example: basaltic K_2O content

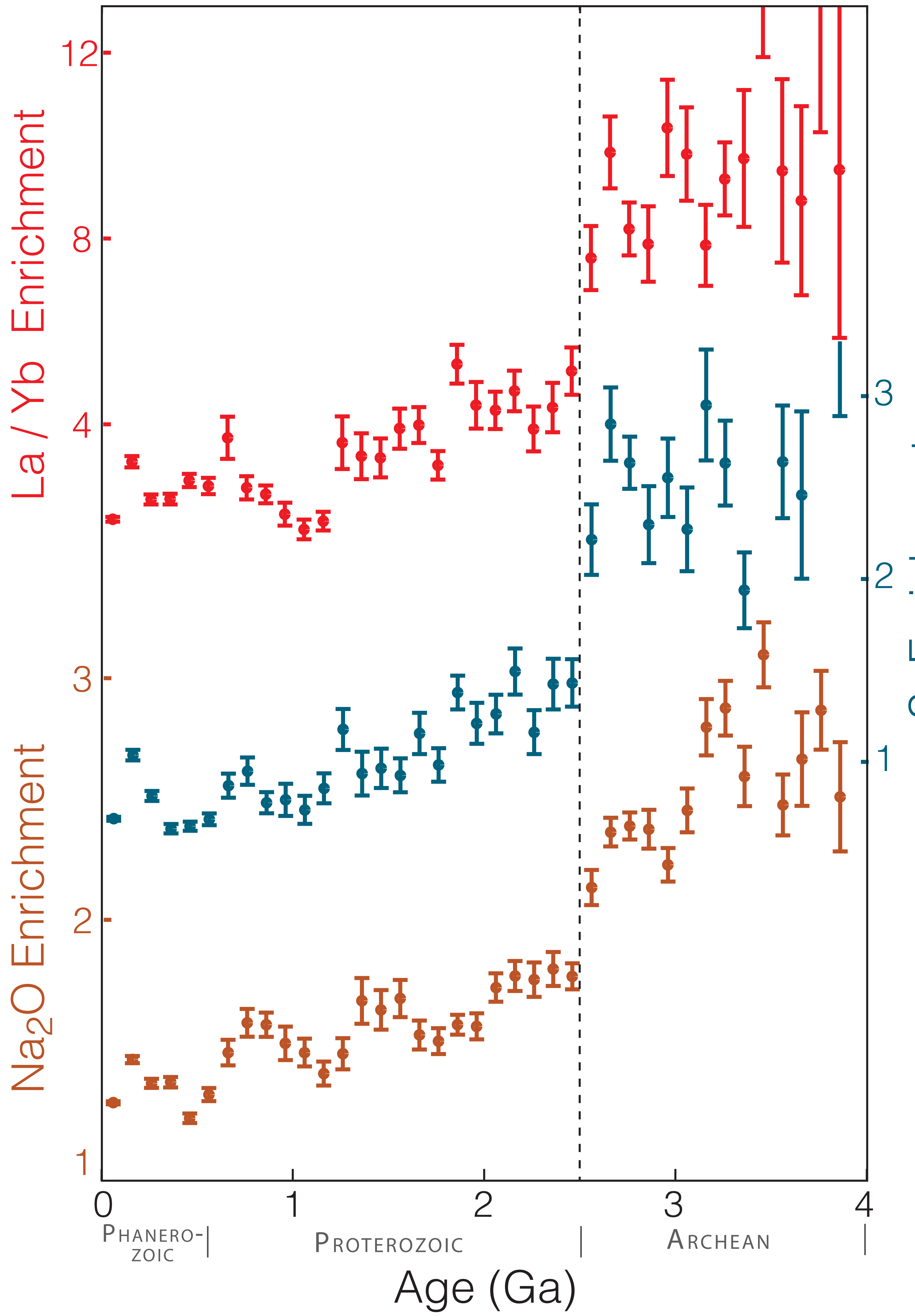


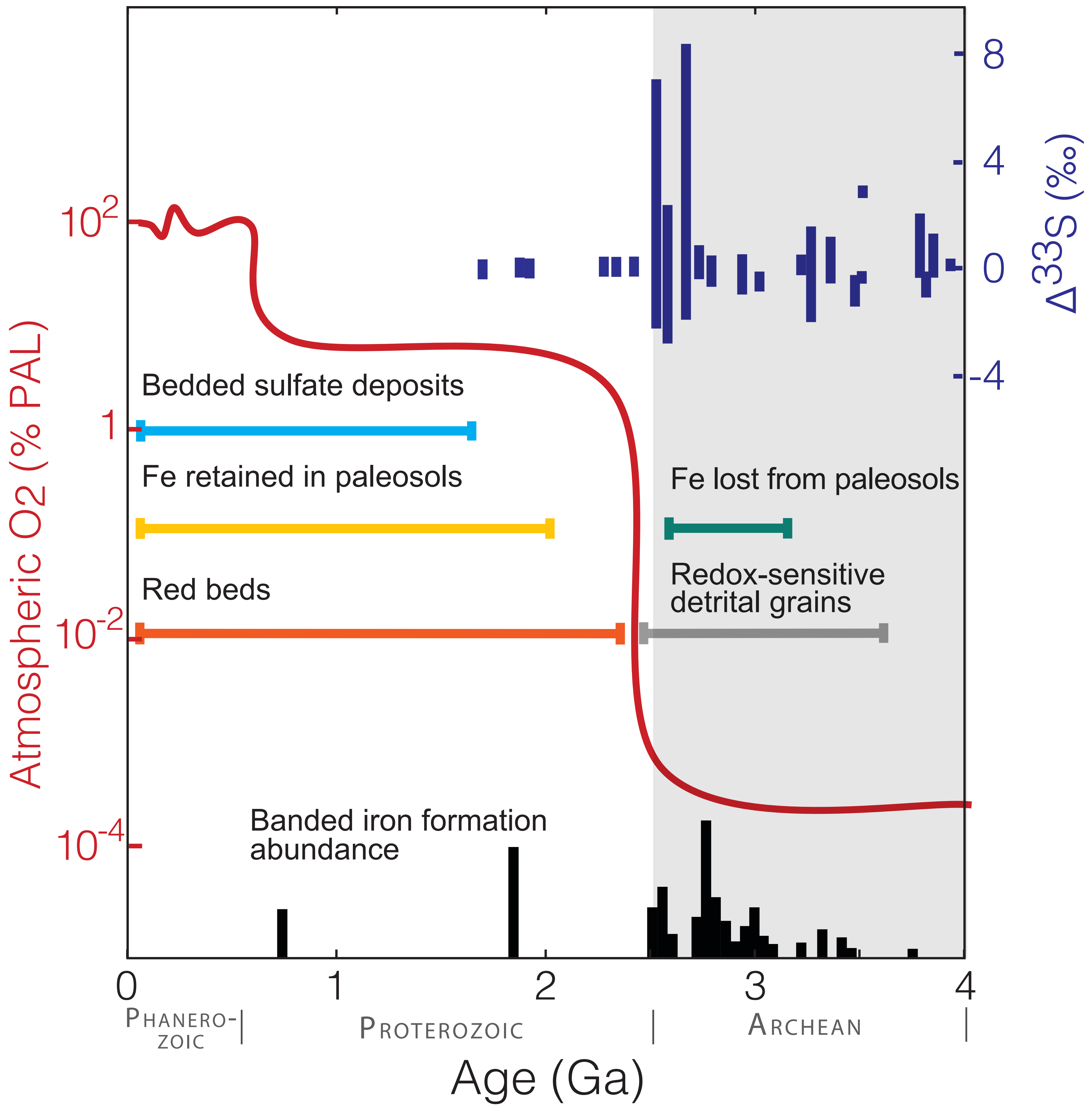
Temporal trends in basalt geochemistry (43-51% SiO_2)





Temporal correlation with Great Oxidation Event





Fundamental question:

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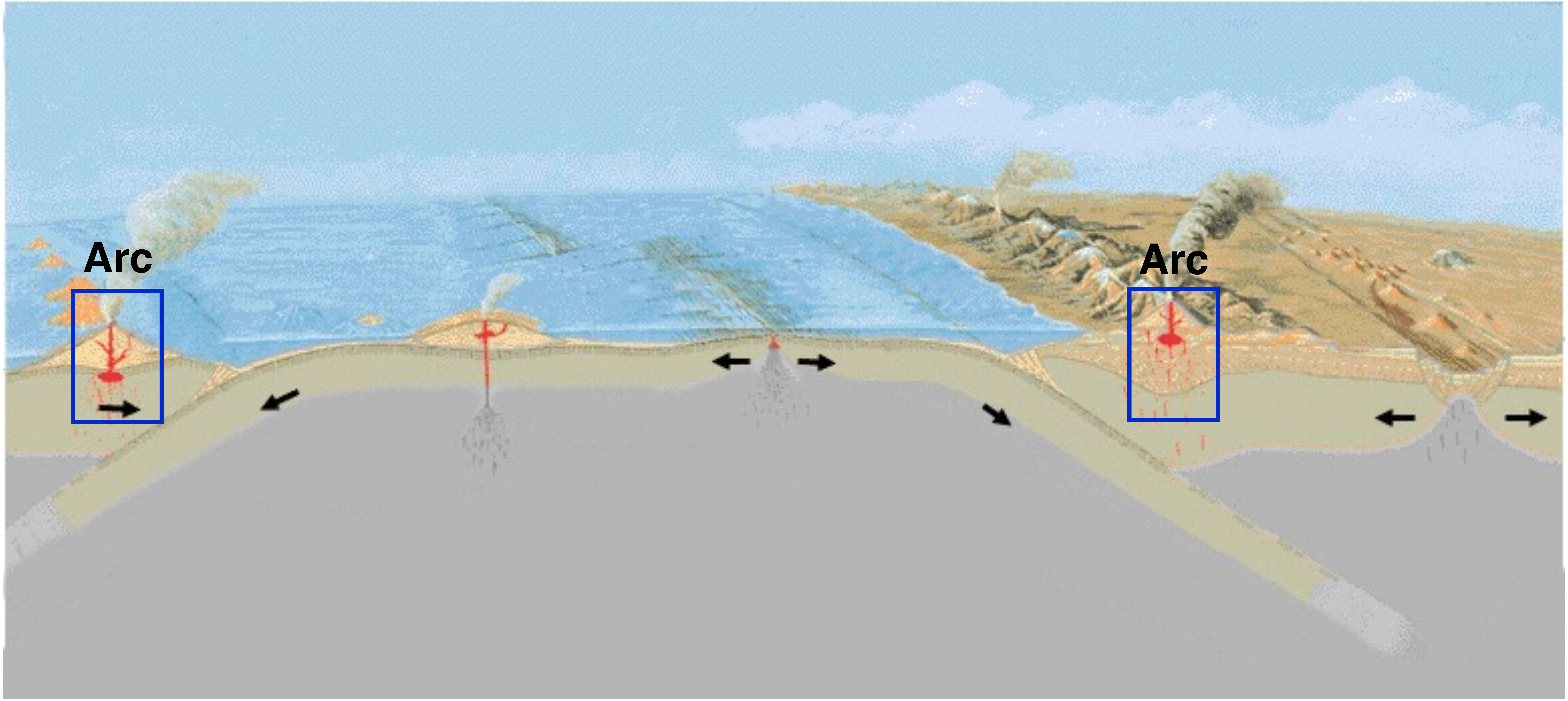
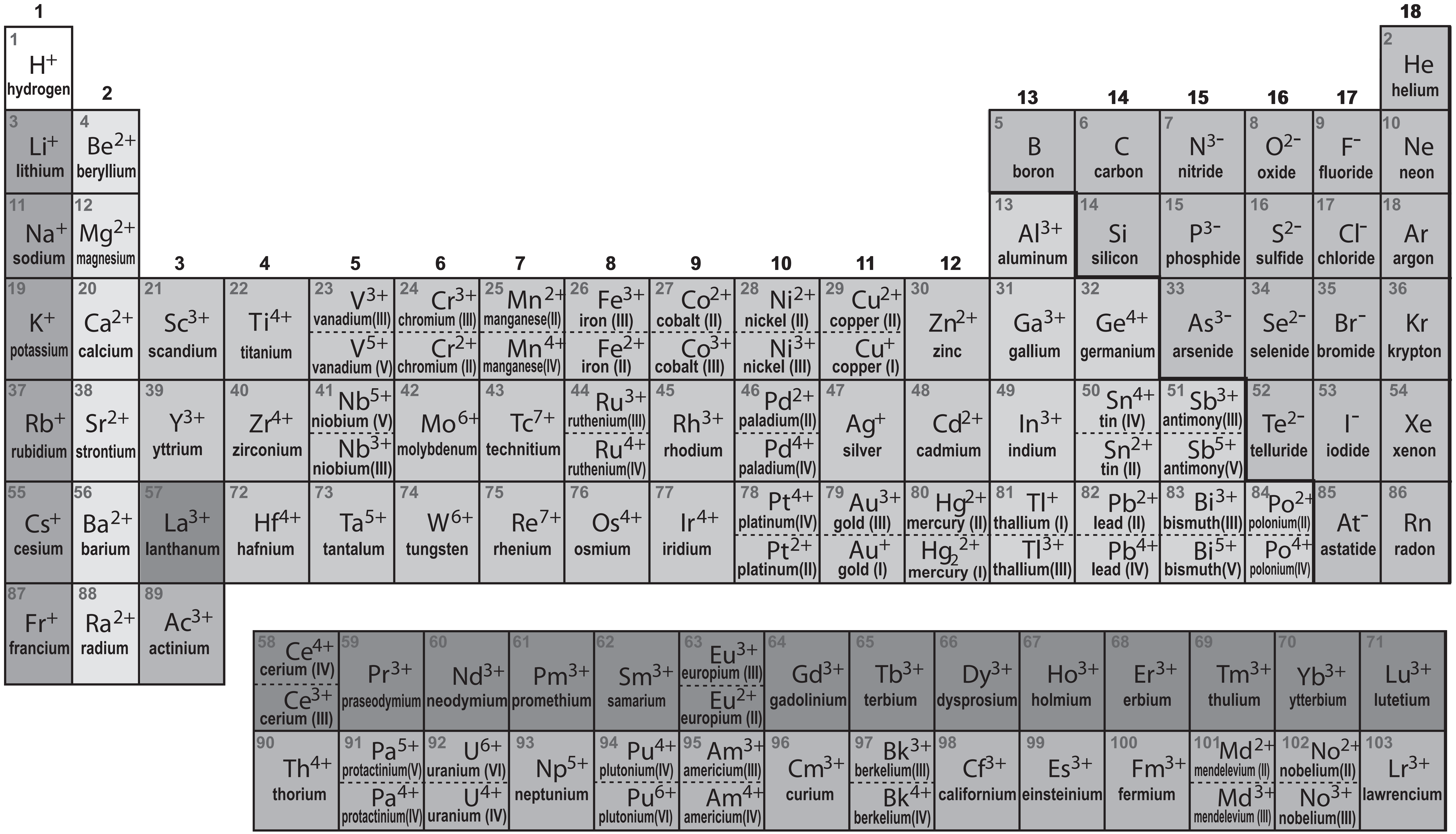
Flux melting



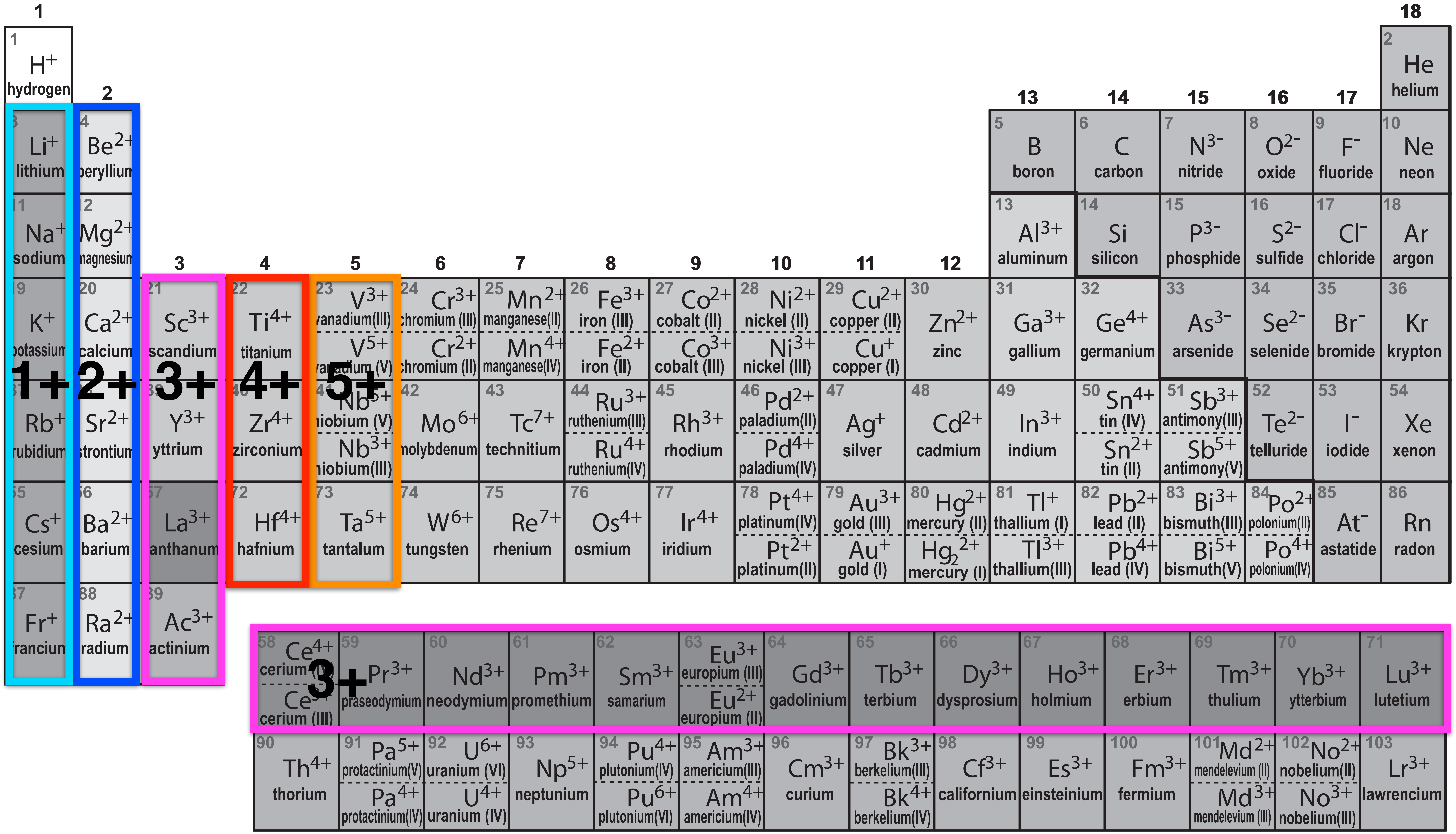
USGS

H_2O ↑

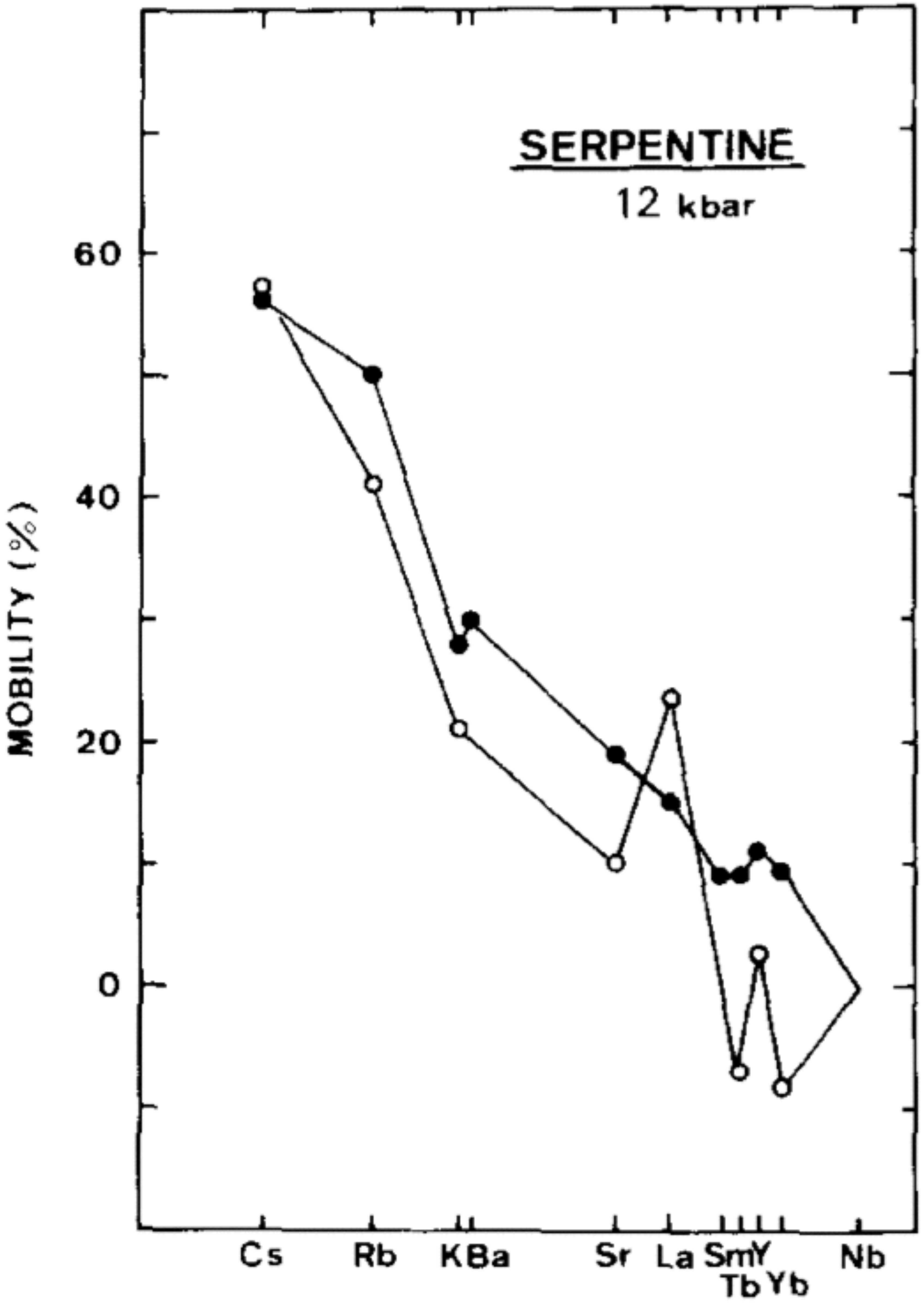
Fluid solubility



Fluid solubility

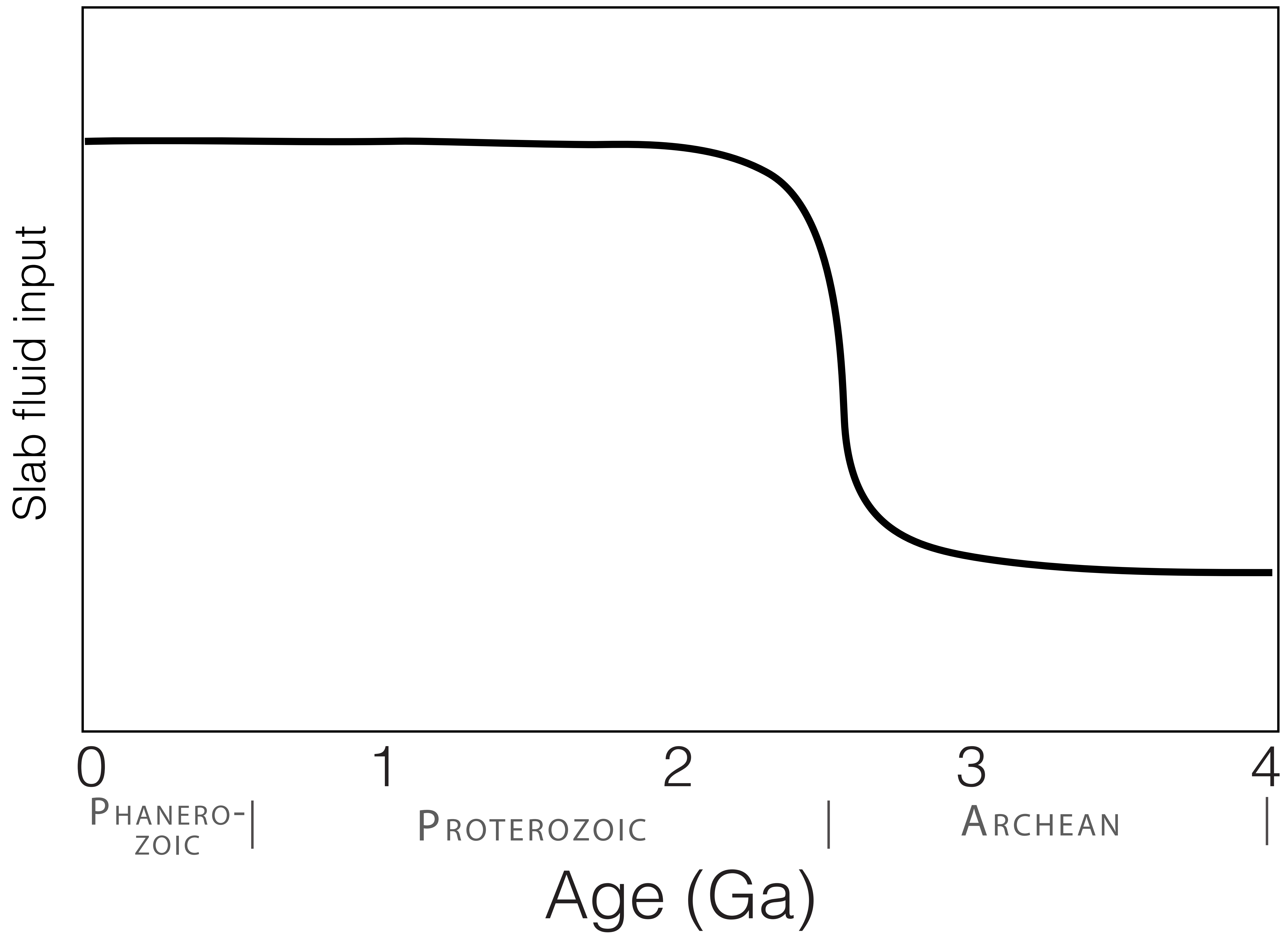


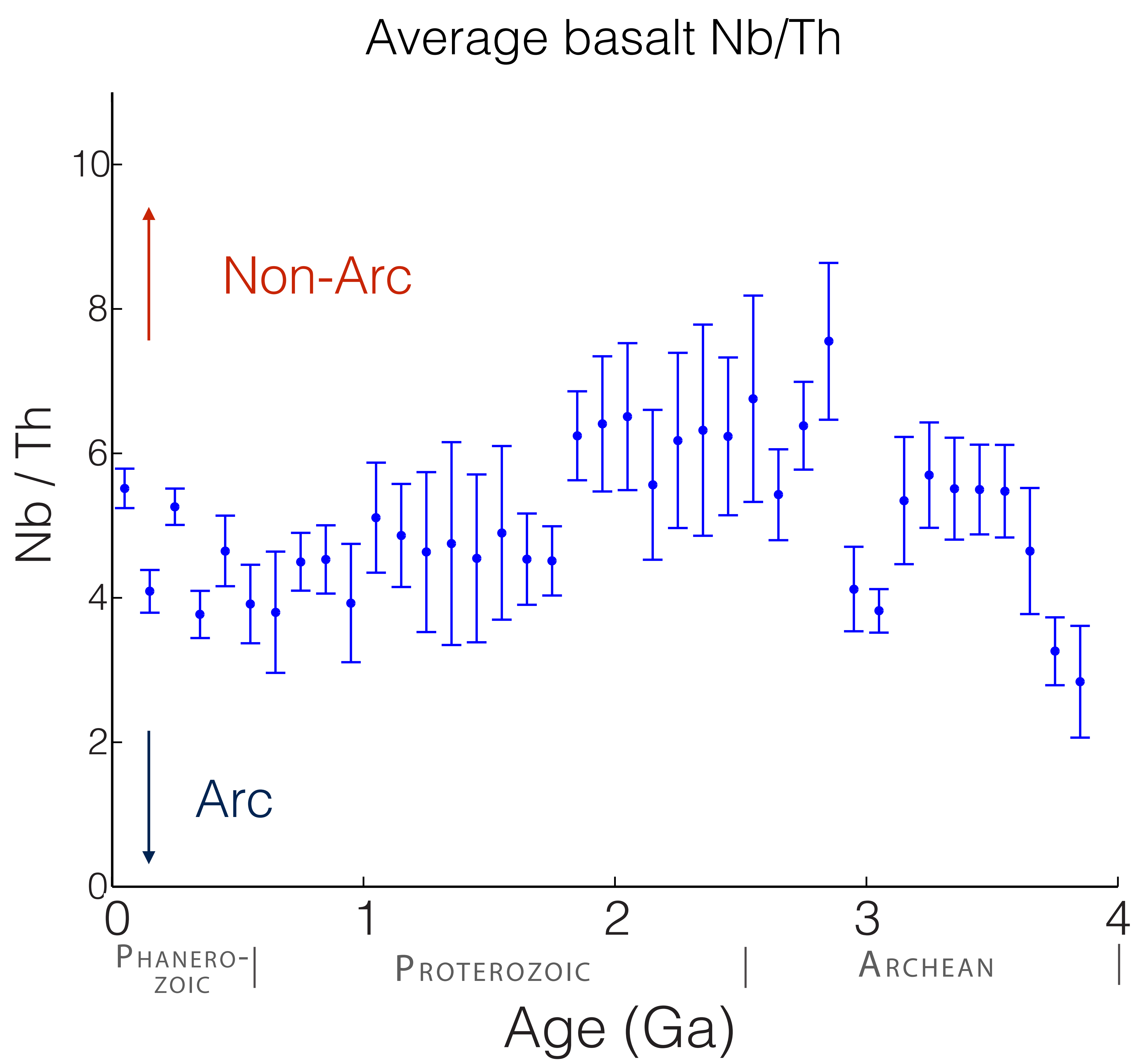
Element mobility in slab fluids



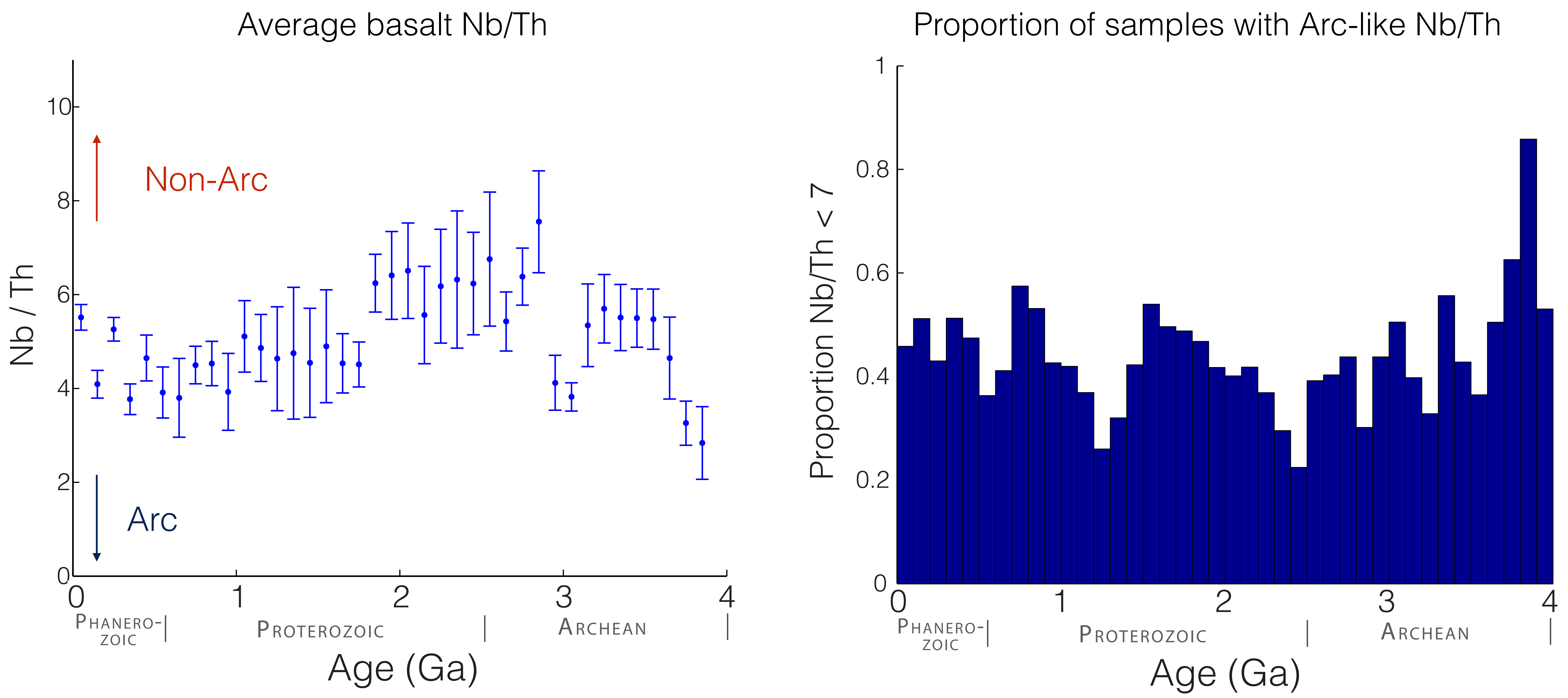
Tatsumi, 1986

Expectation for subduction initiation at 2.5 Ga



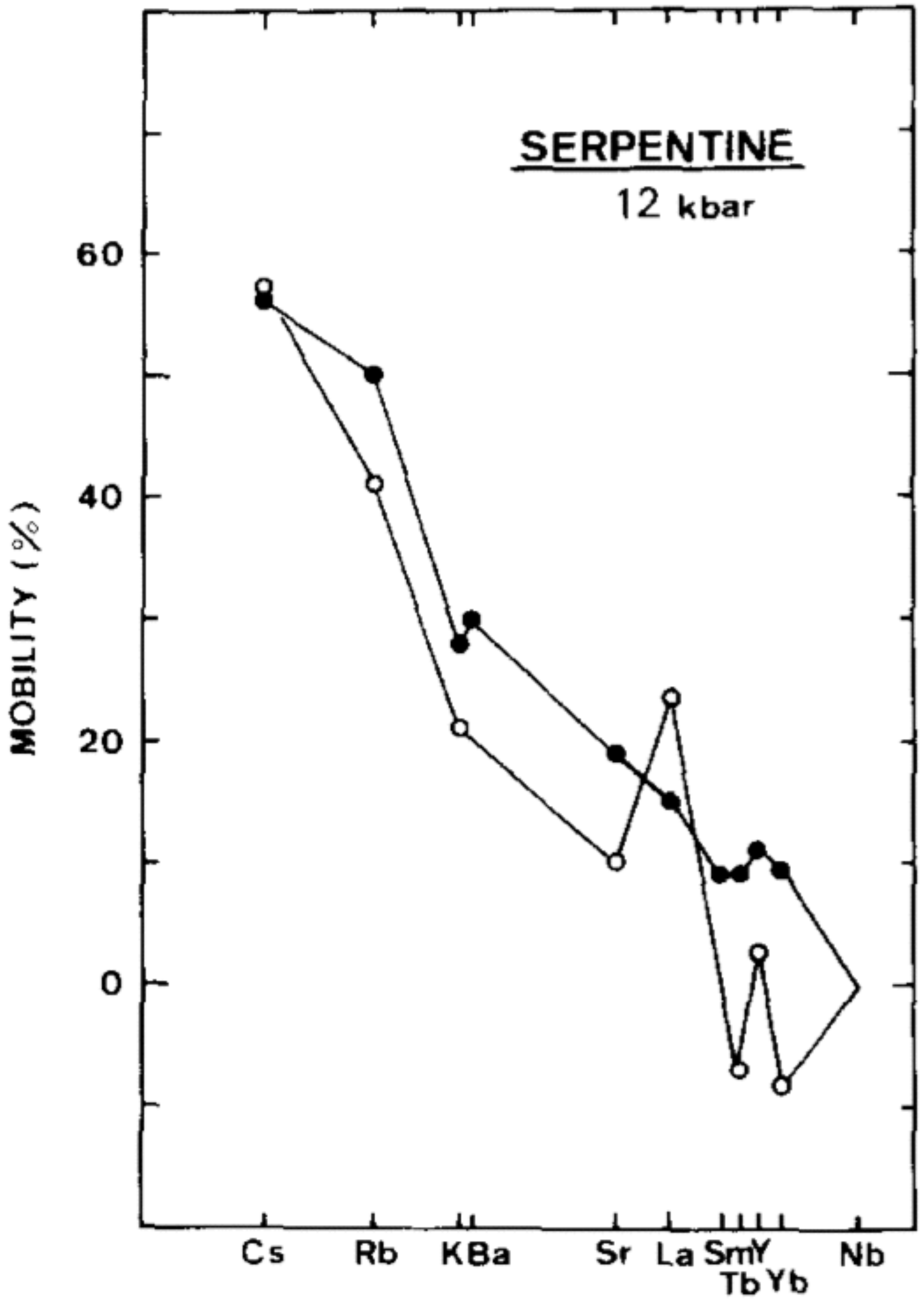


Average basalt Nb/Th
Nb / Th
Non-Arc
Arc
0
2
4
6
8
10
0
1
2
3
4
PHANERO-ZOIC
PROTEROZOIC
ARCHEAN
Age (Ga)



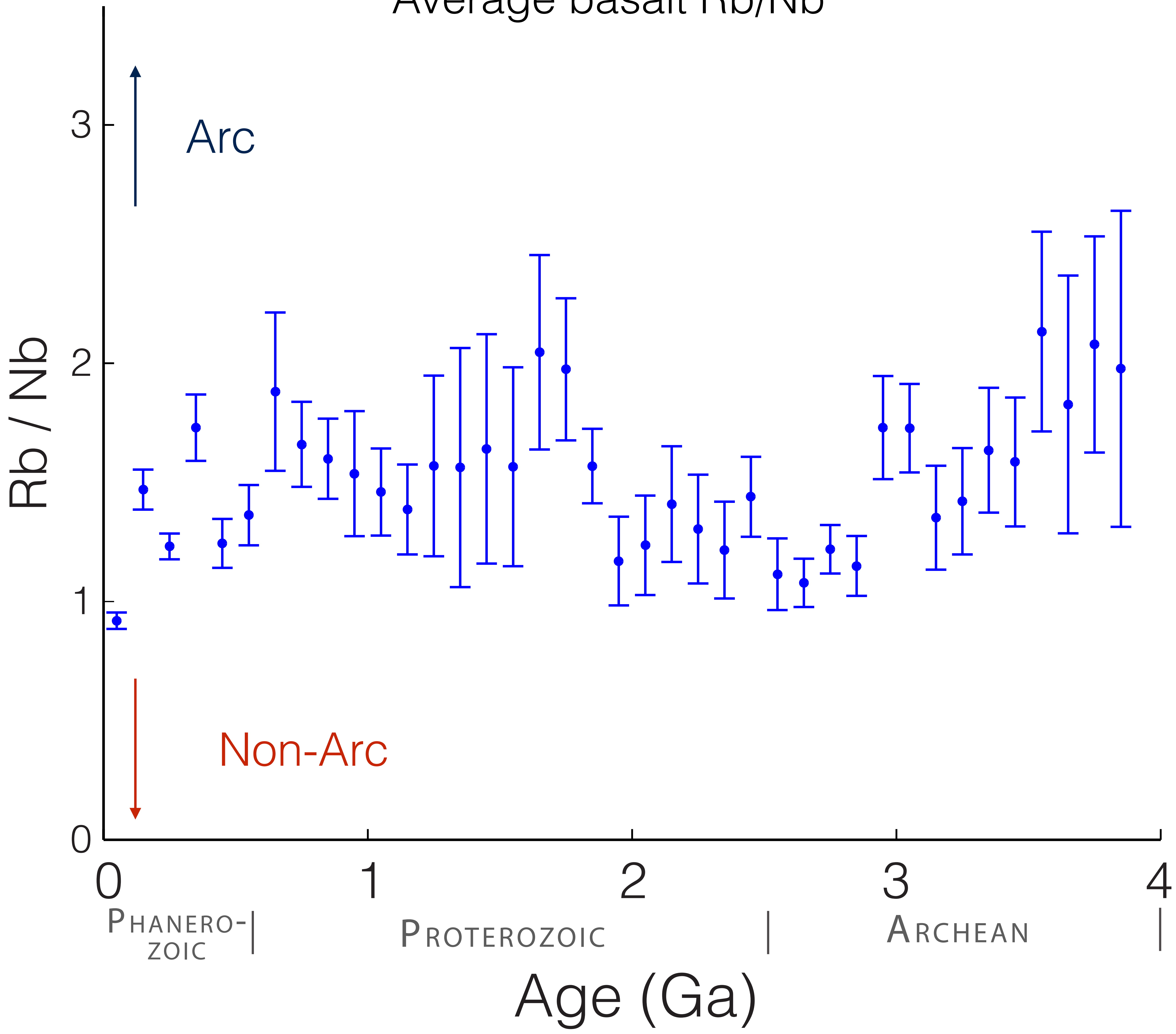
Average basalt Nb/Th
Nb / Th
Non-Arc
Arc
10
8
6
4
2
0
0
1
2
3
4
PHANERO-ZOIC
PROTEROZOIC
ARCHEAN
Age (Ga)
Proportion of samples with Arc-like Nb/Th
Proportion Nb/Th < 7
1
0.8
0.6
0.4
0.2
0
0
1
2
3
4
PHANERO-ZOIC
PROTEROZOIC
ARCHEAN
Age (Ga)

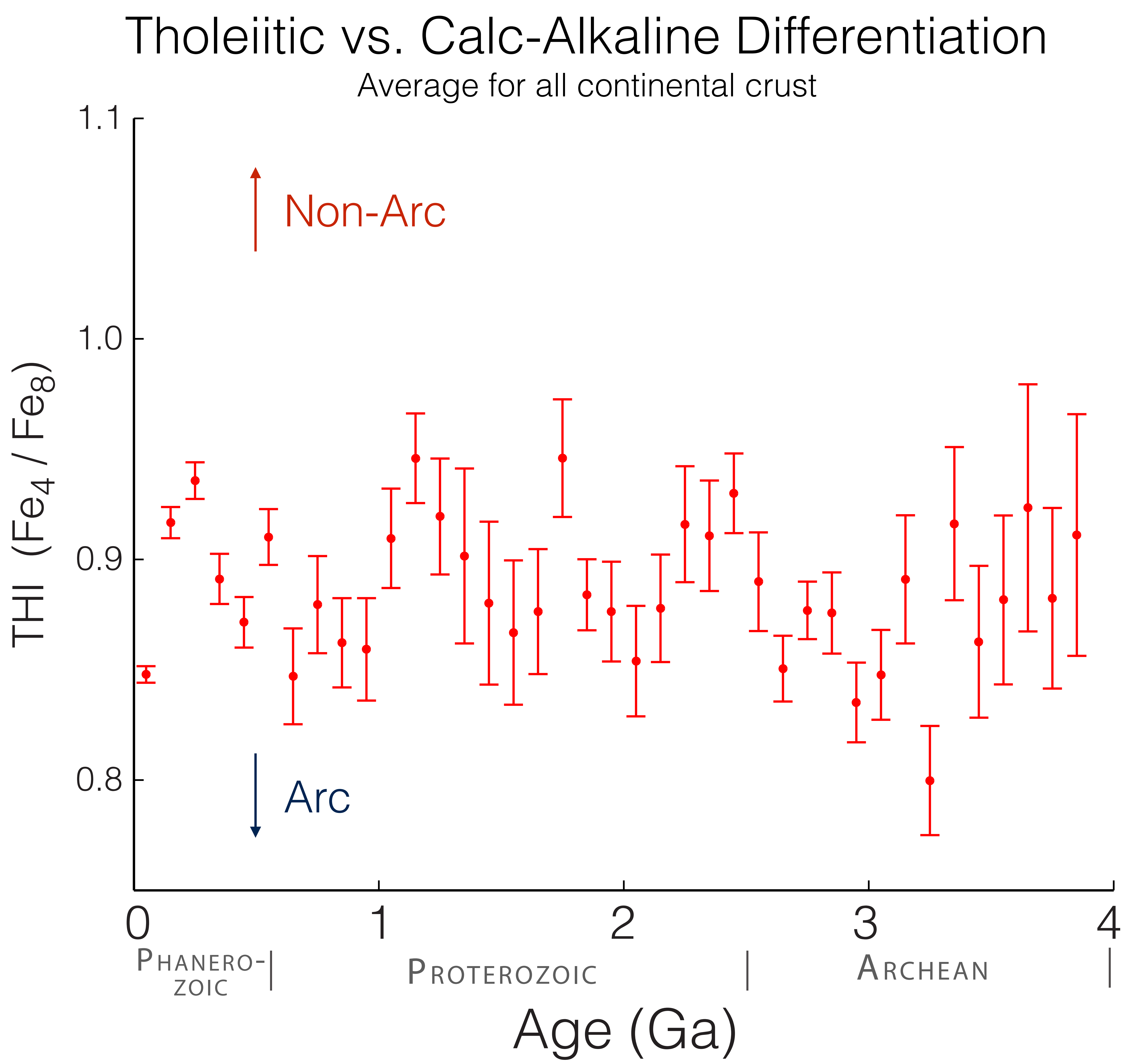
Mobility in slab fluids



Tatsumi, 1986

Average basalt Rb/Nb




Tholeiitic vs. Calc-Alkaline Differentiation
Average for all continental crust
THI (Fe4 / Fe8)
1.1
1.0
0.9
0.8
Non-Arc
Arc
0
1
2
3
4
PHANEROZOIC
PROTEROZOIC
ARCHEAN
Age (Ga)

Conclusions

Fundamental question:

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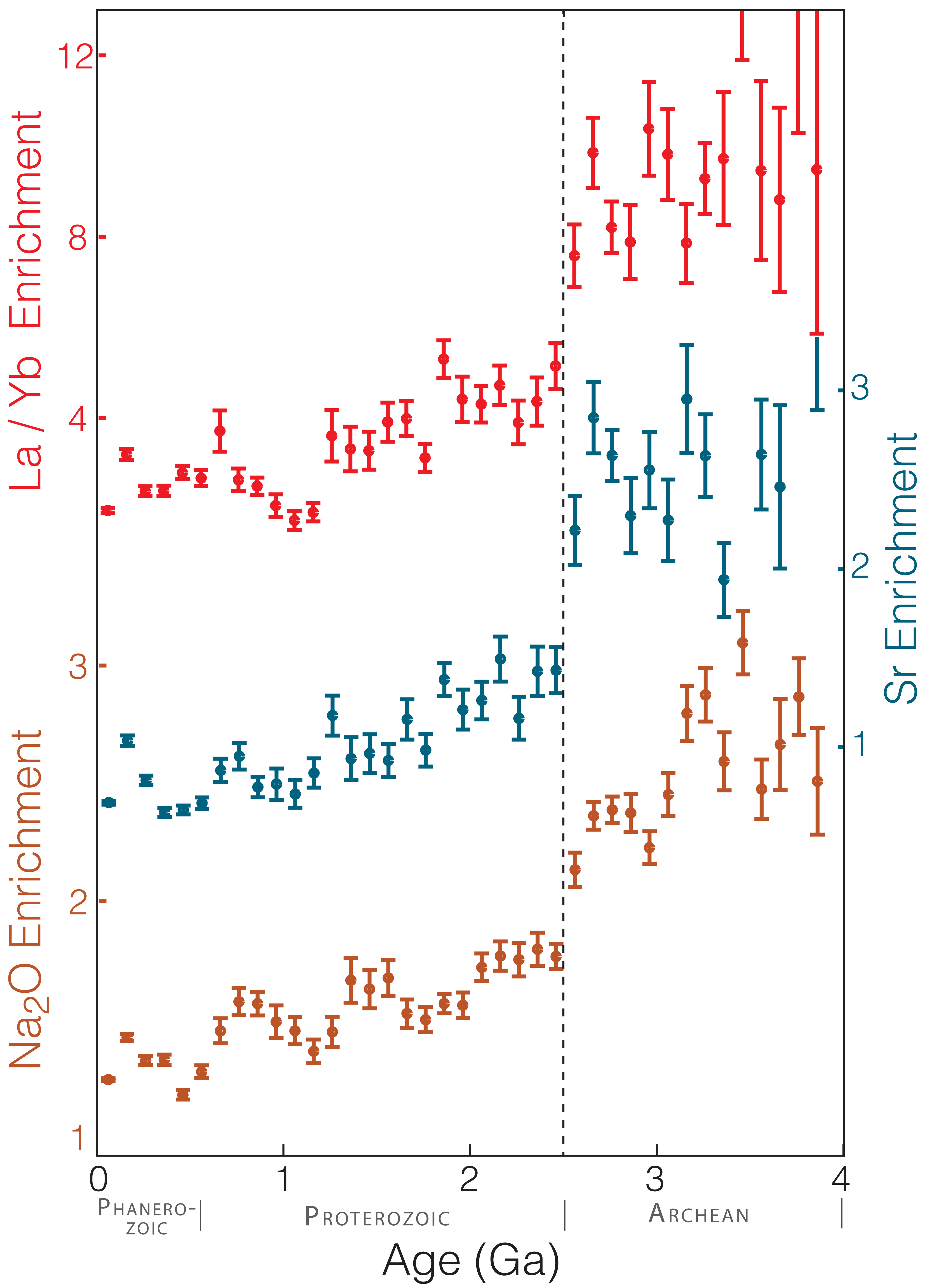
    Throughout the entire preserved rock record

Crustal differentiation?



Results from:

- Keller & Schoene (2012) “Statistical geochemistry reveals disruption in secular lithospheric evolution about 2.5 Gyr ago” *Nature* **485**, 490-493
- Keller et al. (2015) “Volcanic–plutonic parity and the differentiation of the continental crust ” *Nature* **523**, 301-307
- Keller & Schoene (*in preparation*) “Geochemical evolution of basalts preserved in the continental crust throughout Earth history”

Acknowledgements

DOE CSGF

DEPARTMENT OF GEOSCIENCES

Blair Schoene
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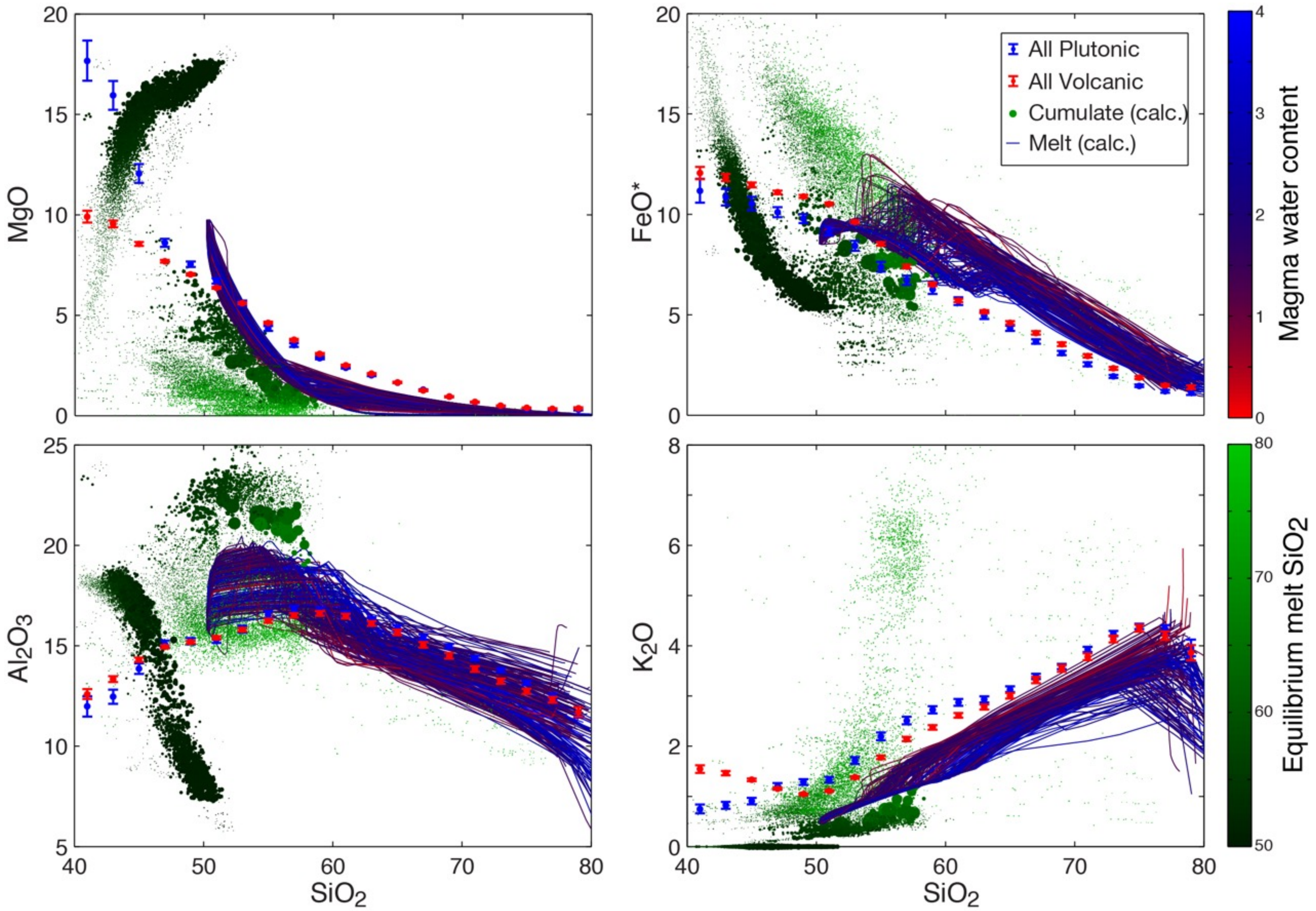
Jon Husson
Melanie Barboni
Frederik Simons
Blake Dyer

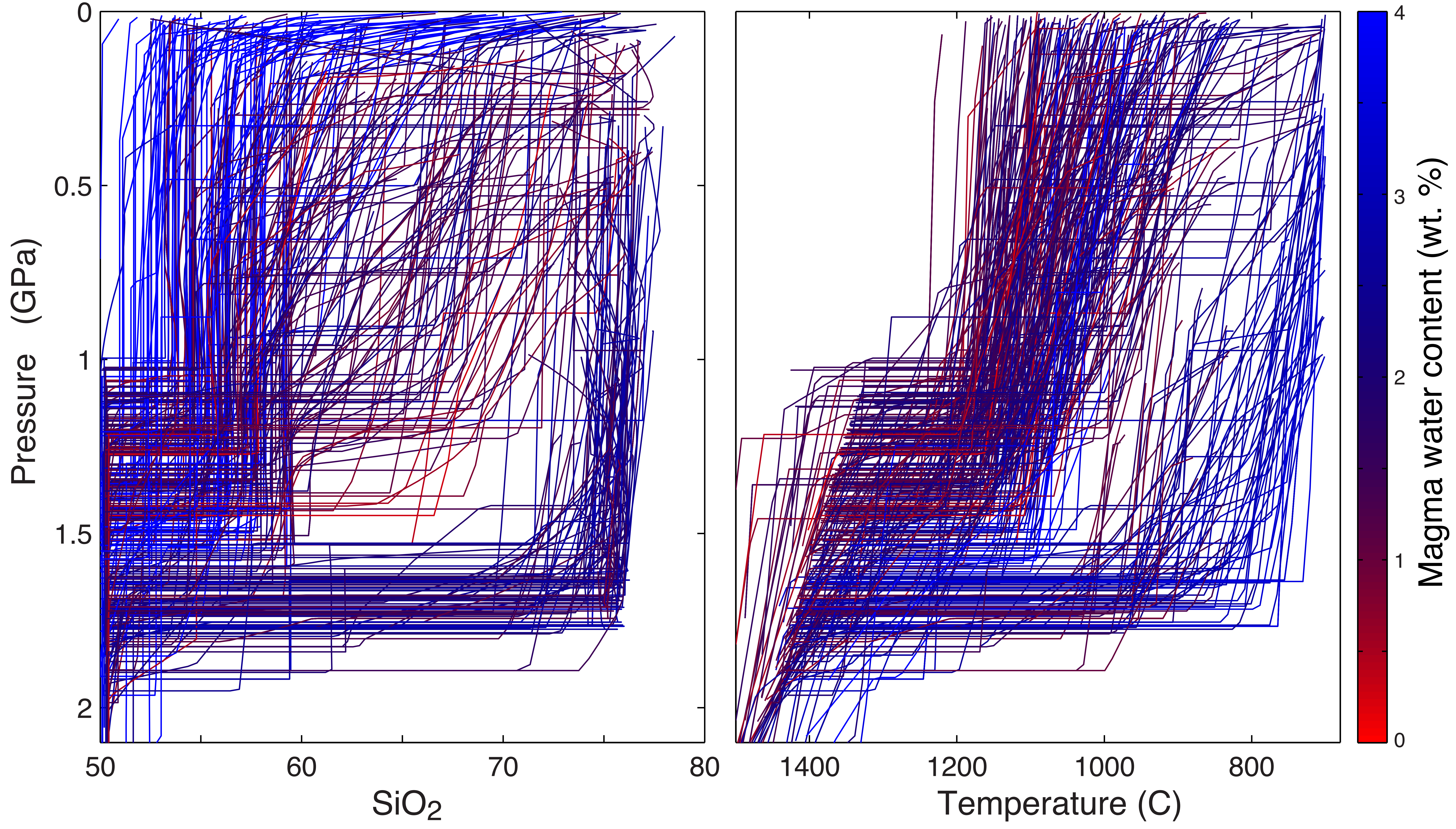
Simulation results

High-silica melts can leave a low-silica cumulate



Simulation results

Differentiation at the base of the crust may help



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