Deconvolving weathering and provenance in the composition of the modern and ancient continental crust

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Introduction

- Sediment geochemistry holds information of past crustal composition and weathering intensity.

- But the data is multidimensional, affected by many processes, and dominated by local effects.

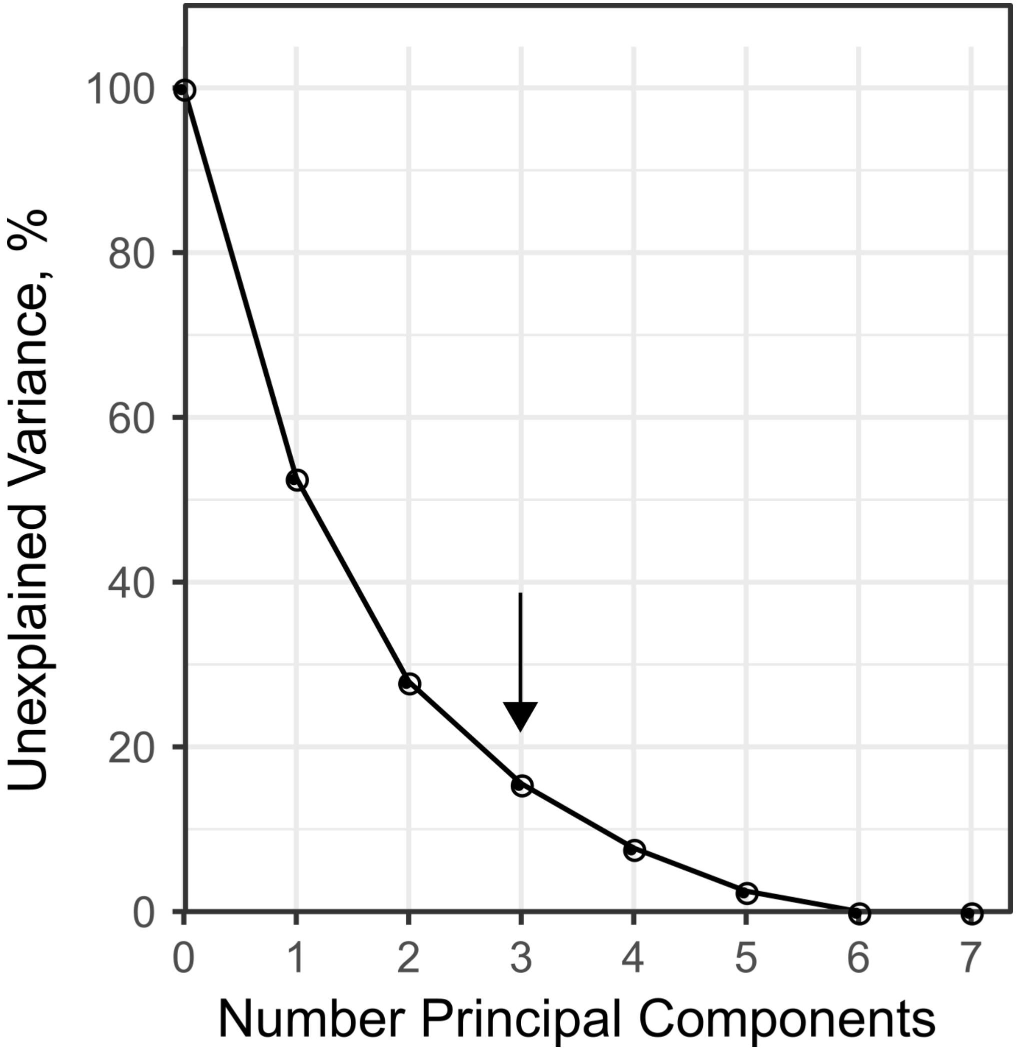
- Signals must be unravelled to resolve ongoing debate over composition of earliest crust[1,2,3].

- We use principal component analysis on a sediment composition compilation to investigate how the data can be simplified.

[1] Tang et al. (2016), DOI:10.1126/science.aad5513; [2] Greber et al. (2017), DOI:10.1126/science.aan8086; [3] Greber & Dauphas (2019), DOI:10.1016/j.gca.2019.04.012

Principal Component Analysis

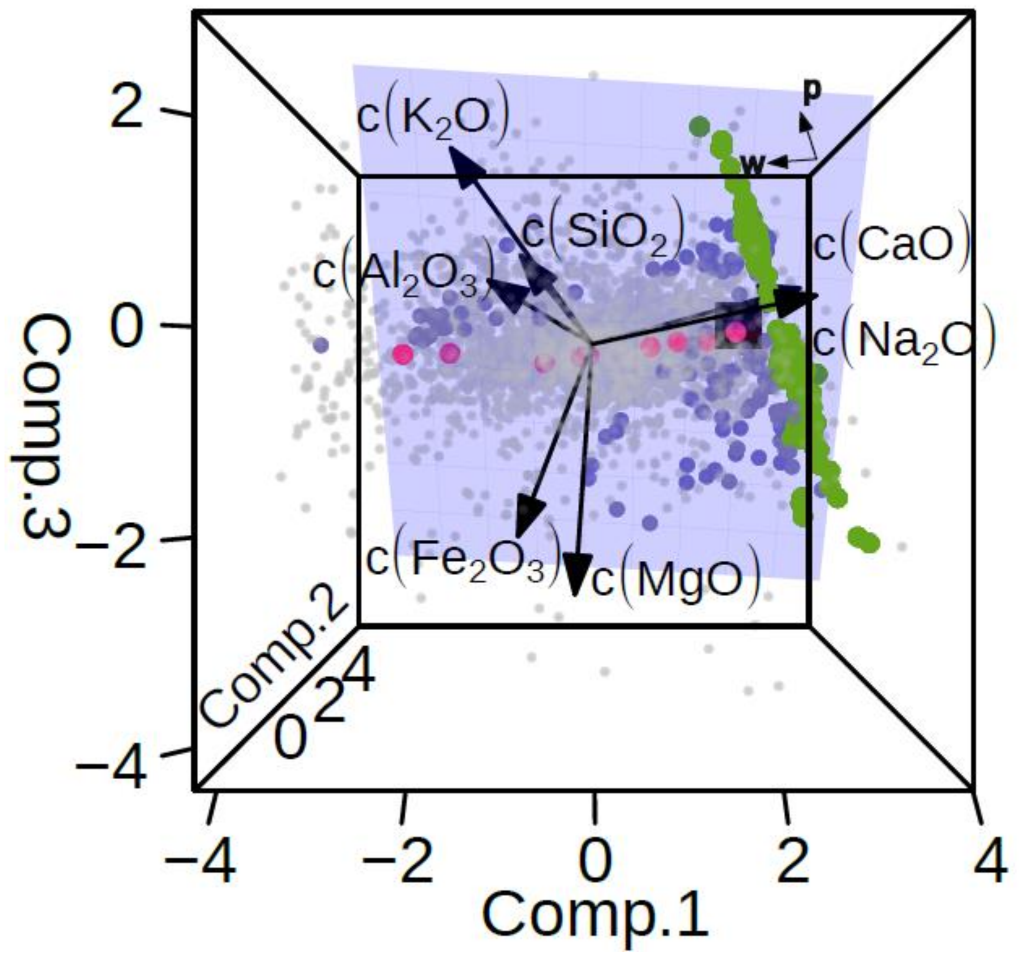
- PCA applied to dataset of 3,000 sedimentary rock compositions.
- 7 Major element oxides (SiO_2, Al_2O_3, Fe_2O_3, MgO, Na_2O, CaO, K_2O).
- Utilised centred log-ratio transform[1].
- Simplifies to 3 components.



[1] Aitchison (1986); "The Statistical Analysis of Compositional Data."

Principal Component Analysis

- Toorongo Soil Profile[1]
- Soils
- Sedimentary Rocks
- Upper Continental Crust[2]
- Crater Lake igneous rocks



- Sediments are offset relative to igneous rocks parallel to soil trend.
- Sediments are also distributed along igneous rock trend.
- Interactive 3D plot

[1] Nesbitt & Marcovics (1997), DOI:10.1016/S0016-7037(97)00031-8; [2] Rudnick & Gao (2003), DOI:10.1016/B0-08-043751-6/03016-4

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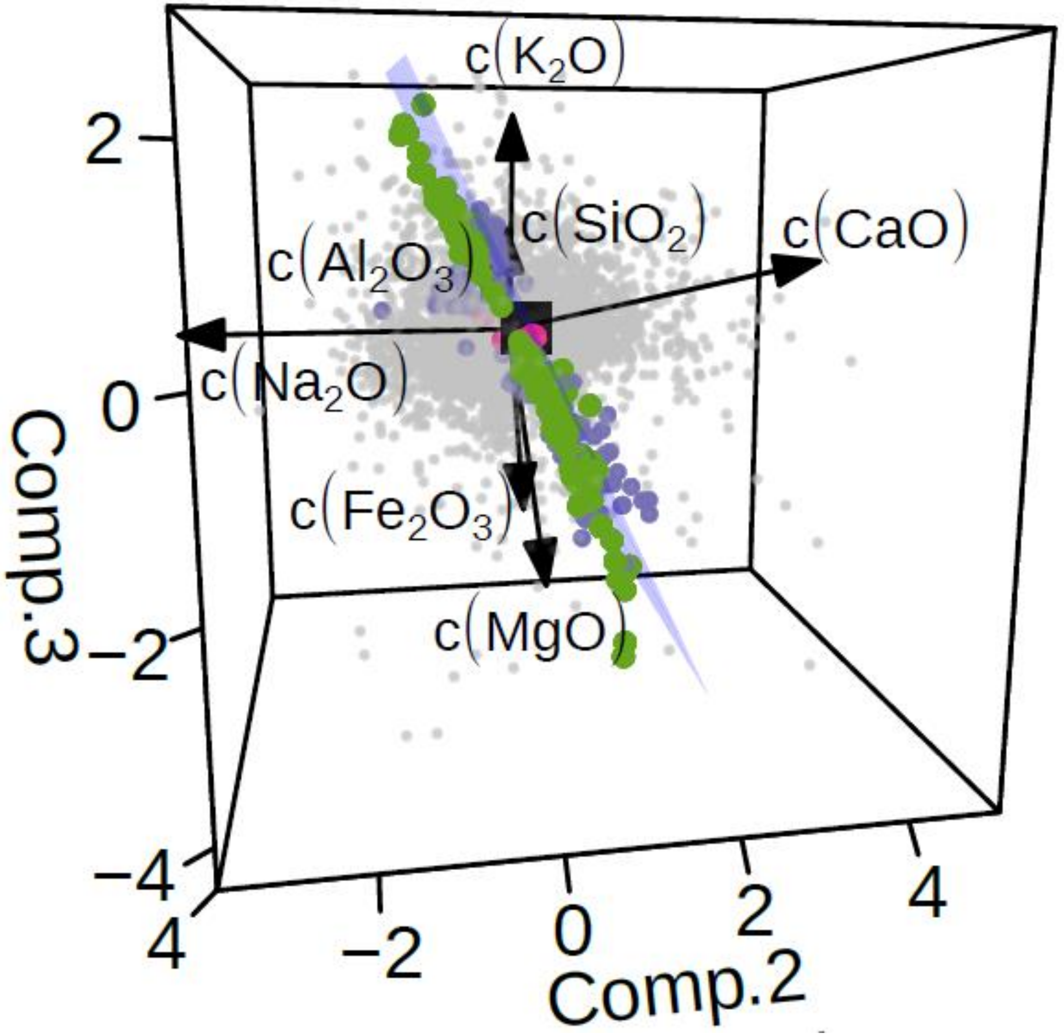

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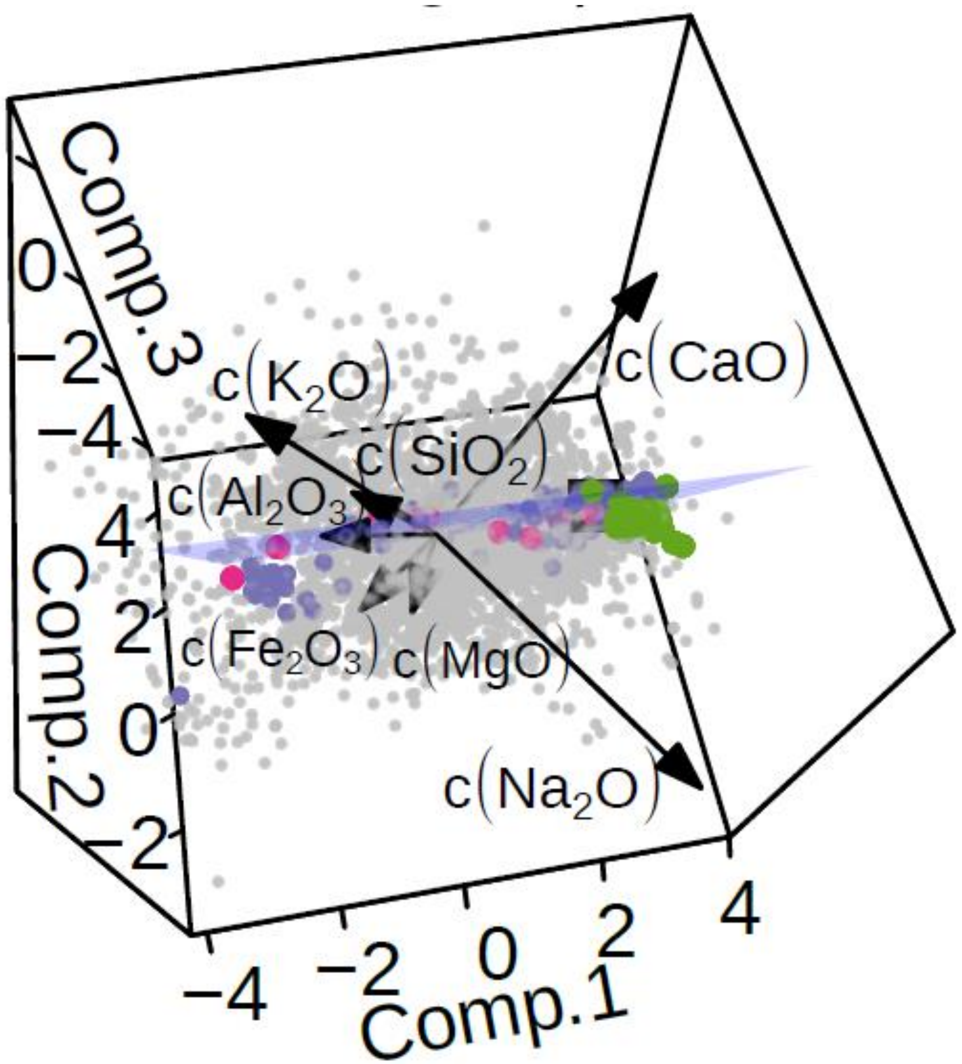

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A model for sediment compositions

Upper Continental Crust

Sediment composition

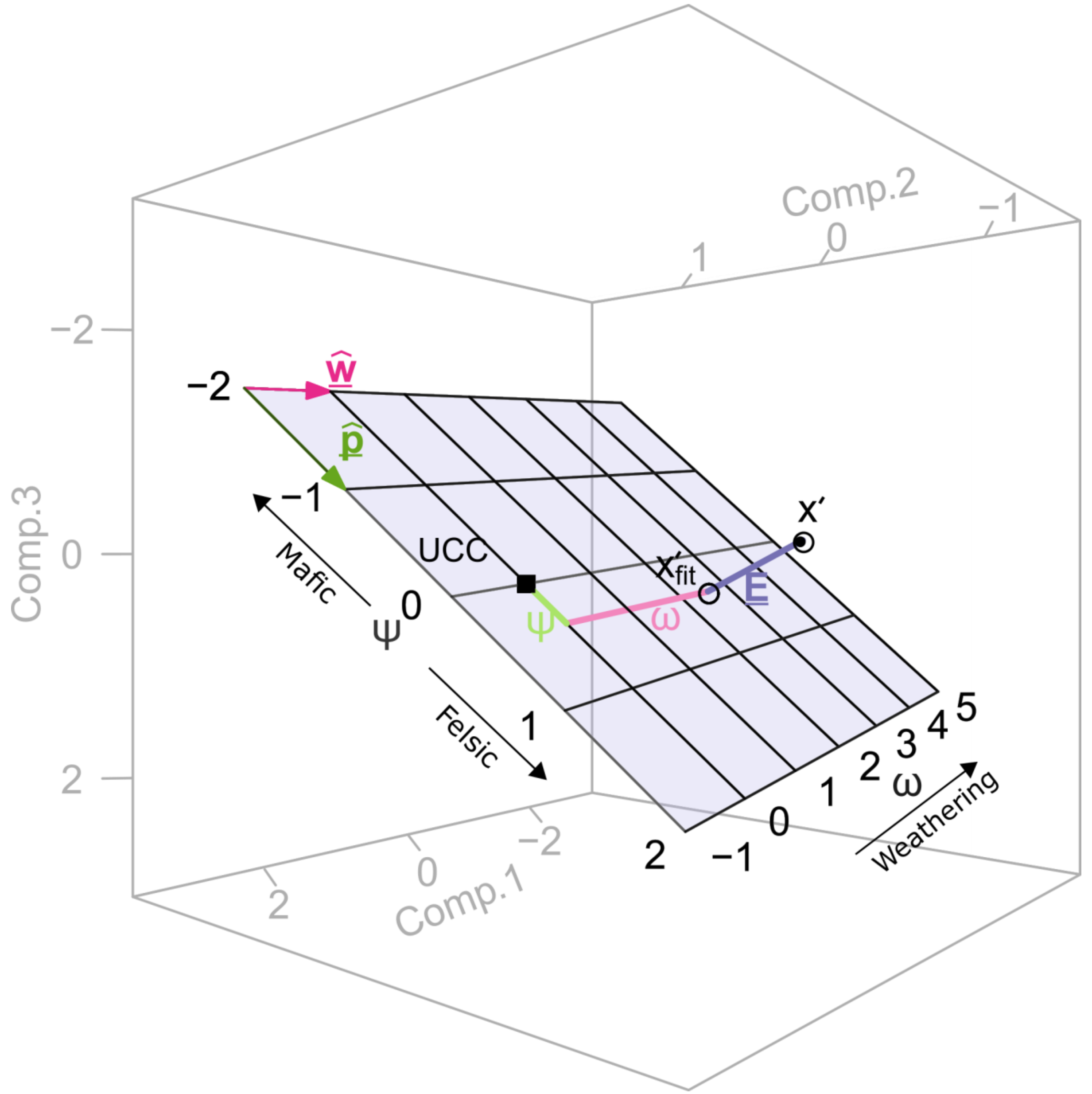
Residuals

$$\boldsymbol{x}' = \boldsymbol{UCC} + \psi\boldsymbol{p} + \omega\boldsymbol{w} + \boldsymbol{E}$$

Protolith

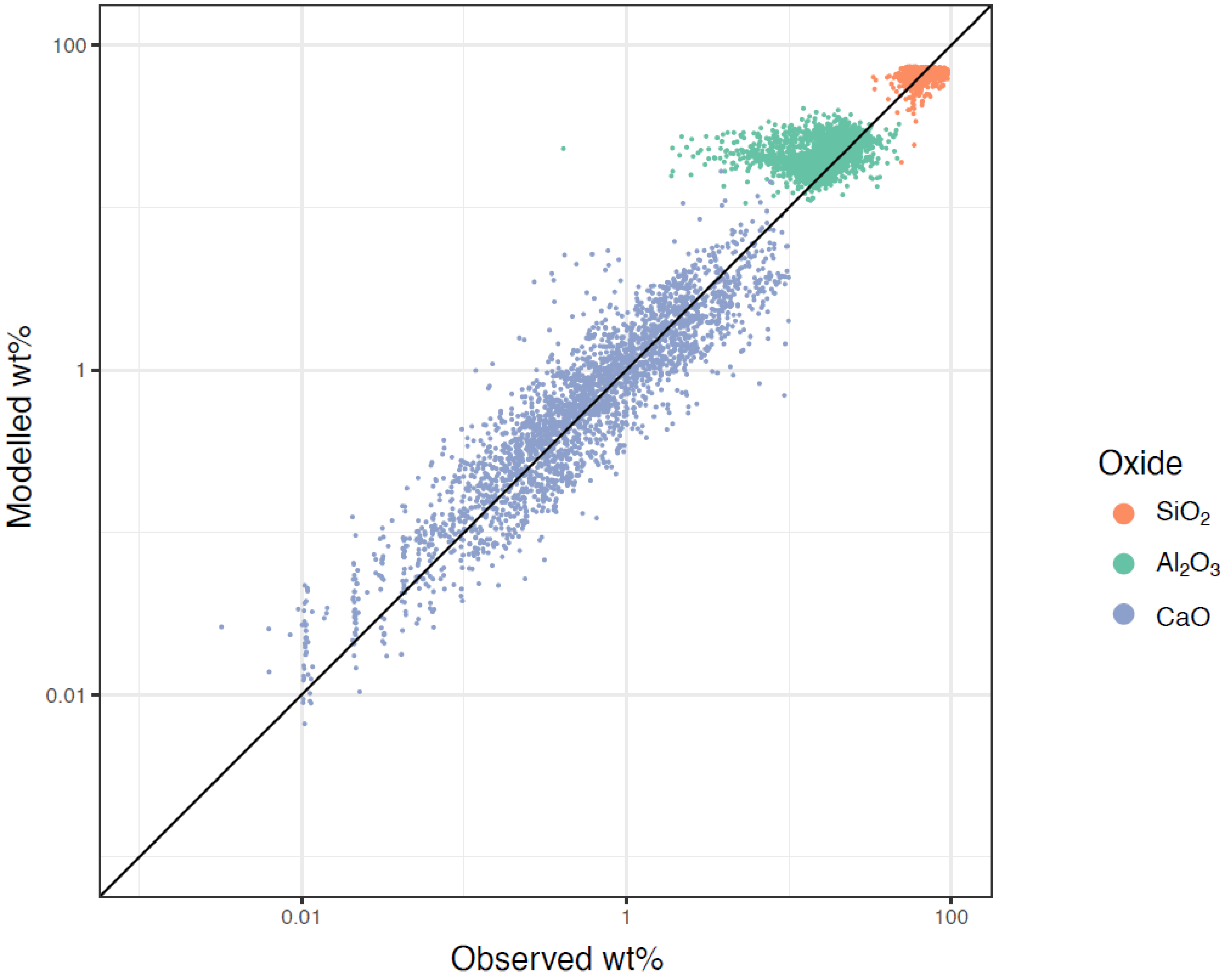
Weathering

- Derive a model for compositions.
- Weathering trend, $\boldsymbol{w}$, calibrated using Toorongo soil profile.
- Igneous protolith trend, $\boldsymbol{p}$, calibrated using Crater Lake igneous suite.

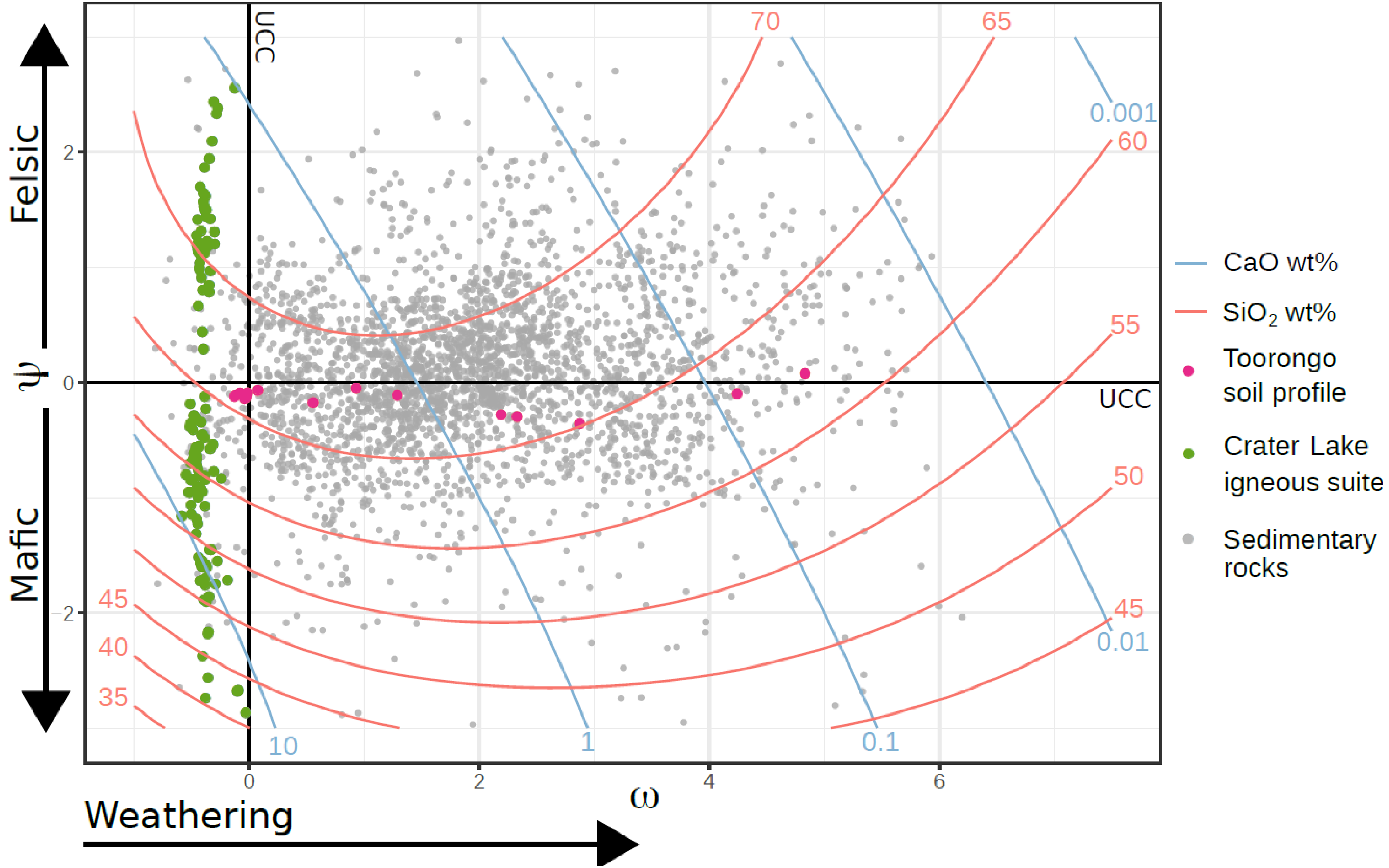


Predictions match observations

- This model successfully predicts sediment compositions.
- Some elements are better fitted than others.



Deconvolving weathering and provenance

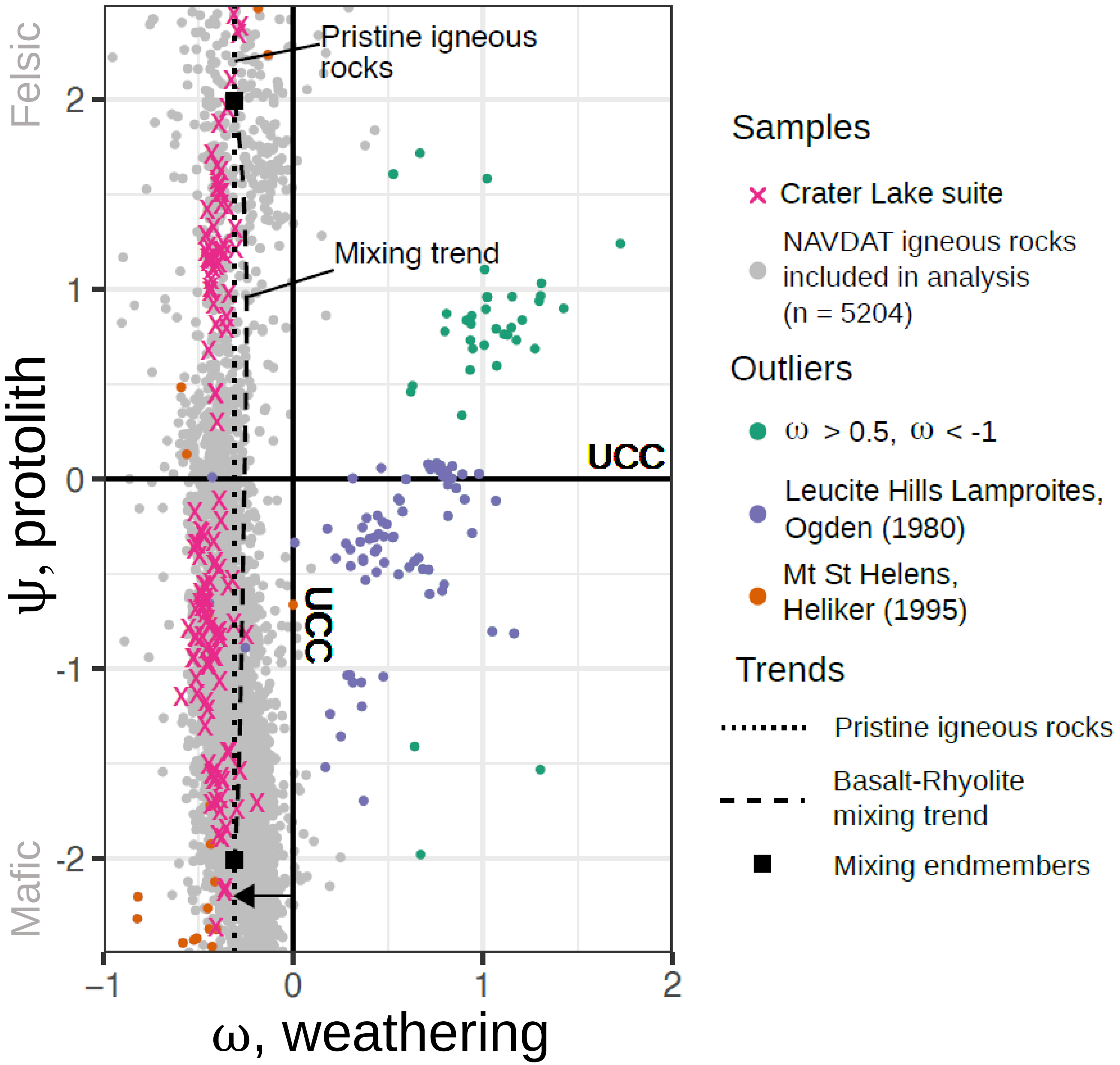


- Sedimentary compositions can be split into protolith composition, ψ, and weathering intensity, ω.

Modern continental crust is weathered

- Modern upper continental crust (UCC) is proposed to be altered by weathering as well as igneous processes[1,2]

- Our method finds UCC to be more weathered than trend of igneous rocks

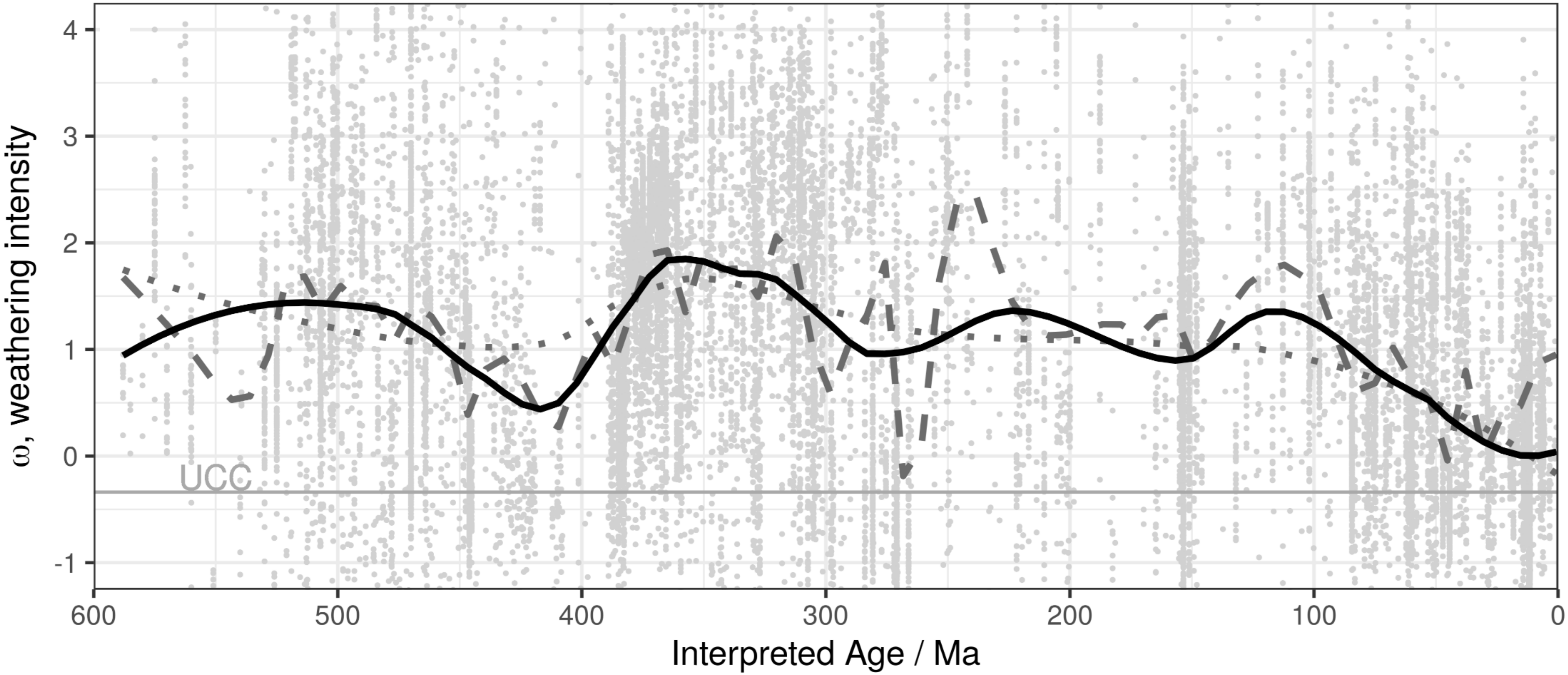


[1] Lee et al. (2008), DOI:10.1073/pnas.0711143105; [2] Liu & Rudnick (2011), DOI:10.1073/pnas.1115671108.

History of Phanerozoic weathering intensity

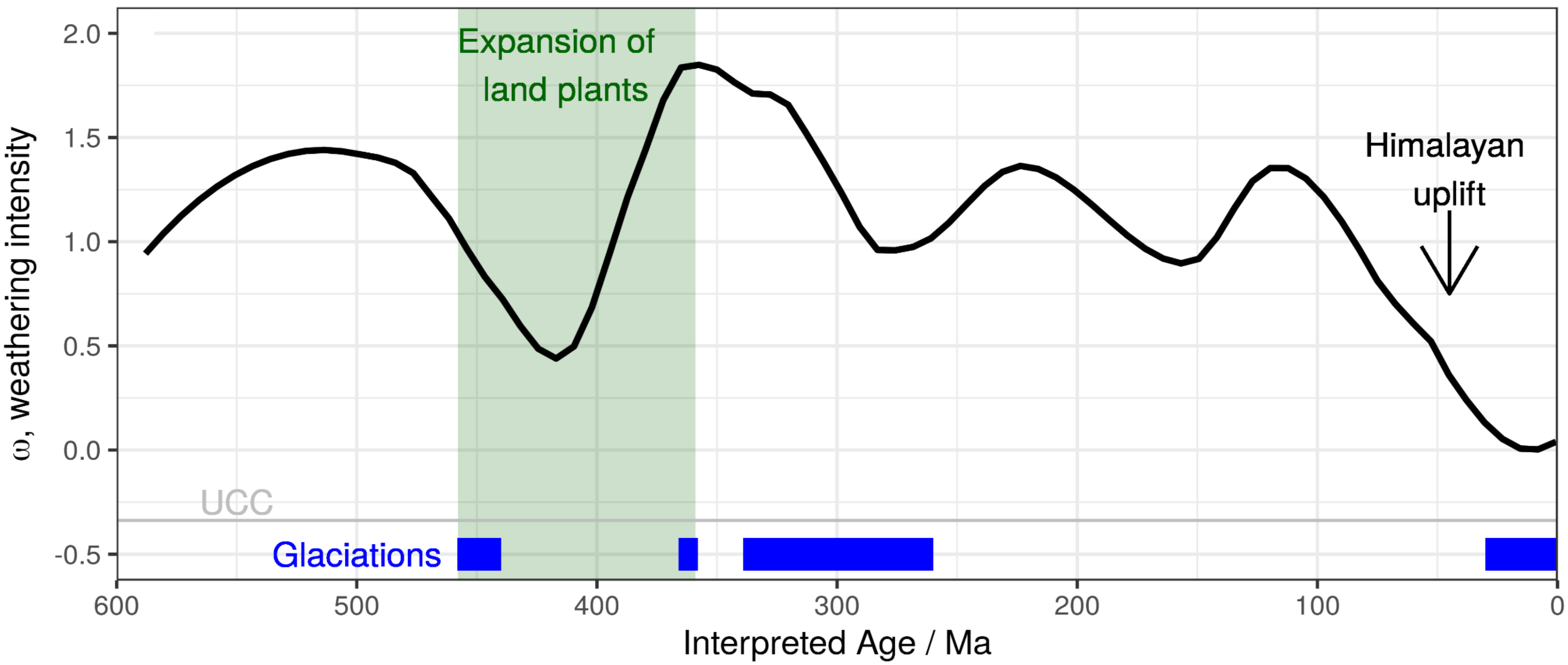
- Method applied to a large dataset of Phanerozoic sediment compositions
- Data compiled by Sedimentary Geochemistry & Paleoenvironments Project
- High data density allows ‘average’ weathering intensity to emerge from local effects

History of Phanerozoic weathering intensity



- LOESS function used to smooth noisy data
- Major trends are insensitive to different smoothing parameters

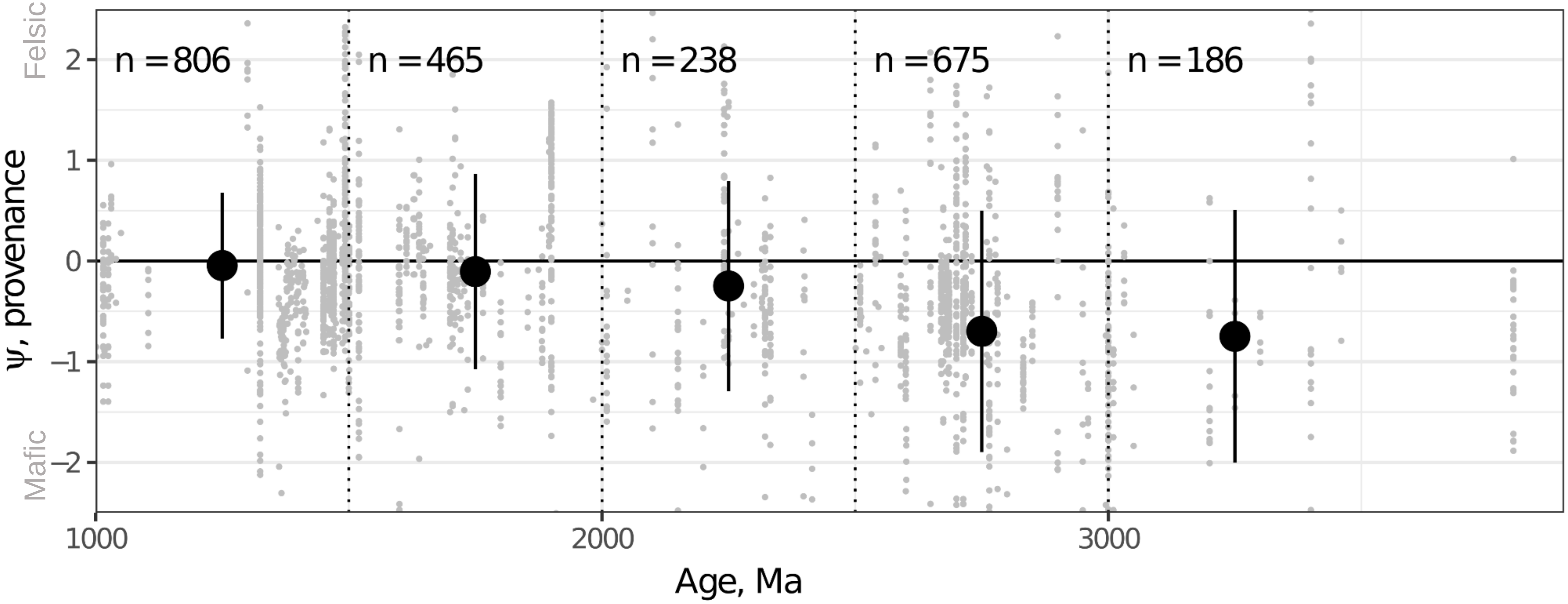
History of Phanerozoic weathering intensity



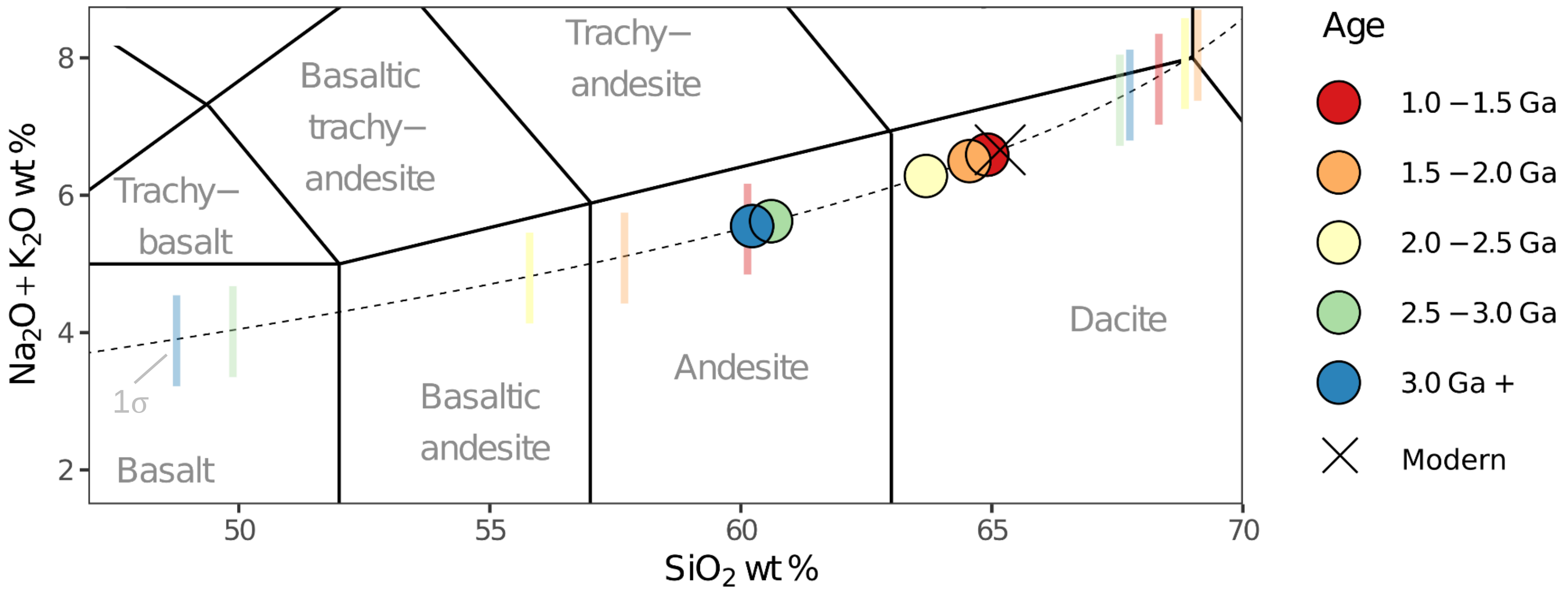
- No unidirectional change after evolution of land plants, only transient
- Present day intensity lowest in all Phanerozoic
- Possible relationship between weathering intensity and glaciations

Changing composition of continental crust

- Apply method to compilation of Archean sediments to reconstruct evolution of crustal composition.

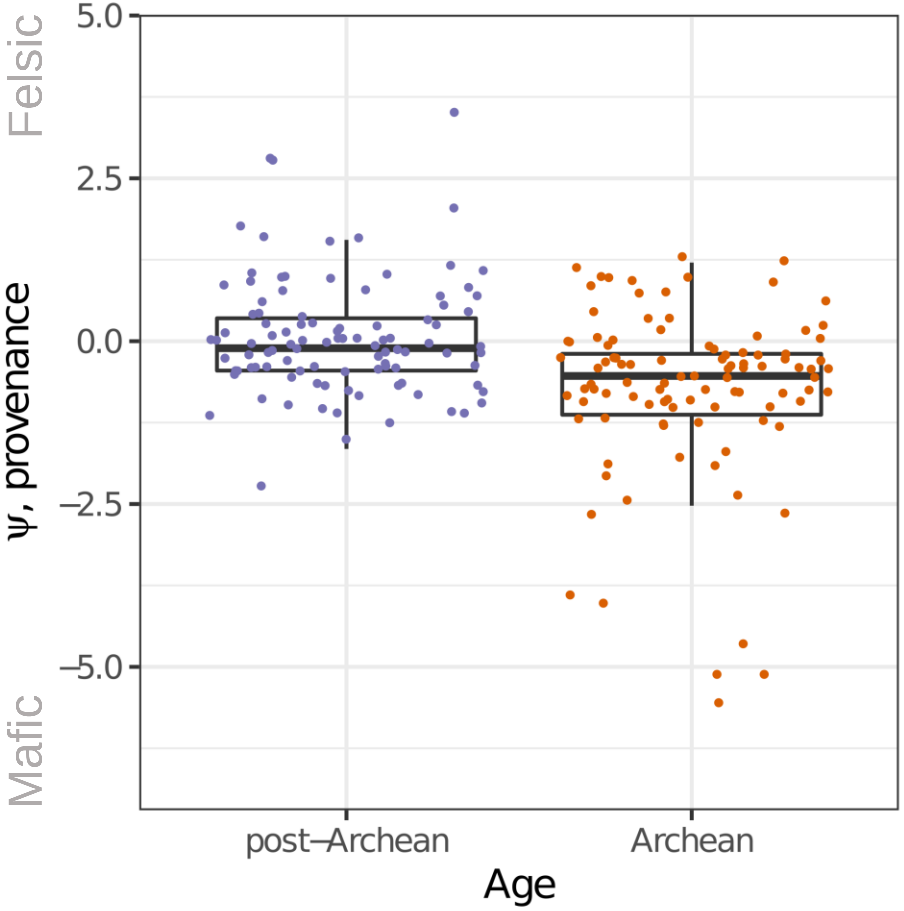


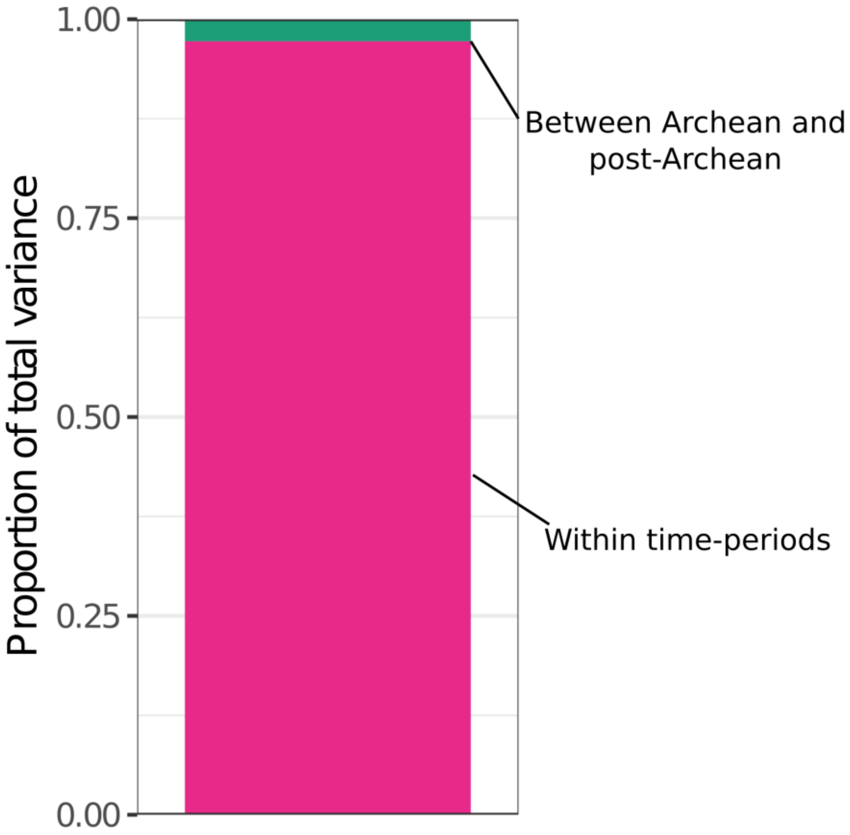
Average Archean upper crust was andesitic



- Model can 'undo' the effect of weathering to calculate sediment's protolith
- Archean average crust was andesitic
- Evolved to present dacitic composition by 2.0 Ga

Archean crust more similar than different





- Archean crustal composition was heterogeneous
- Significant overlap with post-Archean crustal composition
- Heterogeneity must be incorporated into models of crustal growth

Conclusions

- A novel method to deconvolve weathering and provenance from a sediment's major element composition
- The present day upper continental crust has been altered by weathering
- No unidirectional change in weathering intensity is observed after land plant evolution
- The average Archean upper continental crust was andesitic
- Upper crustal compositional diversity at any time exceeds its secular evolution

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