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$_2$O$_3$, Fe$_2$O$_3$, MgO, Na$_2$O, CaO, K$_2$O).
- Utilised centred log-ratio transform$^1$.
- Simplifies to 3 components.

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$^1$ Aitchison (1986); “The Statistical Analysis of Compositional Data.”
Principal Component Analysis

- 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/B0-8-043751-6/03016-4
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A model for sediment compositions

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

\[
x' = UCC + \psi p + \omega w + E
\]
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, $\psi$, and weathering intensity, $\omega$. 
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

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\(^1\) 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
- 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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