Multi-scale geochemical time series constraints on Archean lithosphere formation

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Robsust comparisons of lithosphere formation processes in the Archean, Proterozoic and Phanerozoic require: 1) geochronology of adequate resolution to sequence magmatic and stuctural processes with precision relevant to tectonic processes (~1 Ma), which has been difficult in older terranes; 2) an unbiased and continuous assessment of secular change in, for example, petrologic processes through Earth history.

Recent advances in chemical abrasion ID-TIMS U-Pb geochronology permit sub-million year precision on $^{207}Pb/^{206}Pb$ dates of single closed system Archean zircons. Applied to the pristine ca. 3.2 Ga Usutu magmatic system in the eastern Kaapvaal craton, such high-precision geochronology permits evaluation of geochemical evolution during piecewise batholith construction over <20 Ma. Combined with structural data and placed into the context of the adjacent Barberton greenstone belt, these constraints are used to construct a model where regional subhorizontal contraction occurred synchronous with emplacement of an evolving magmatc system. The temporal resolution provided by this work is unprecedented in Archean systems, and allows direct comparison with Phanerozoic arc- and plume-related magmatic systems.

In order to reconstruct billion-year records of secular variation in the continental rock record, we have compiled a database of over 70,000 igneous samples from various sources, each with age, spatial coordinates, and major and trace element data. Monte Carlo simulations with weighted bootstrap resampling significantly reduces sample collection and temporal biases, and allows precise estimation of mean global igneous geochemistry for 3.8 Ga. Both low SiO_2 (basalts) and evolved high SiO_2 rocks show statistically significant trends through time, the former being consistent with decreasing mantle melt fraction in the present and the latter showing increased importance of deep crustal fractionation/partial melting and TTG production in the Archean. Mean values of many geochemical proxies from both SiO_2 ranges show step functions near 2.5 Ga. These data support a model linking high degree mantle melting and lower crustal delamination and TTG production as being more important in the Archean; this process is largely independent of driving plate tectonic models but can be used to inform them.

Our geochemical dataset can be directly linked with geophysical models estimating crustal and lithospheric thickness, heat flow, and seismic velocities. Doing so reveals correlations between, for example, mean crustal thickness and mean geochemistry of continental igneous rocks, that change through time. This secular variation can provide a connection between the formation of continental lithosphere and magma production and evolution, and be used to inform tectonic models for specific terranes. Conversely, inferences from long term average records must be consistent with detailed structural, geochronological, and geochemical studies of preserved crust.

Was more continental crust destroyed than created during Phanerozoic time?

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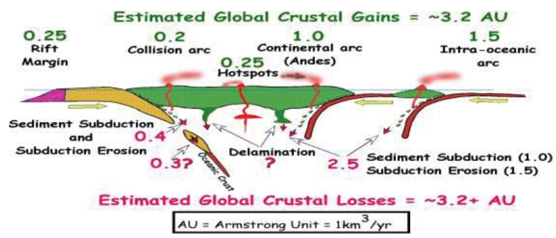
Introduction

It is easy to study what exists but not what has disappeared, so it is generally assumed that the volume of continental crust has increased with time. Field observations can be used to estimate how much new, (juvenile) mantle-derived continental and island arc (CIA) crust is generated and how much CIA material is lost (recycled) to the mantle. Greatest additions (via arc magmatism) and losses (via sediment subduction and subduction erosion) occur at ocean-margin and crust-suturing (collisional) subduction zones (SZs). Lesser volumes are added to plate interiors at rifted margins and hotspots and removed by lower crust delamination.

Estimated Phanerozoic Gains and Losses

The best estimates for additions and losses come from geophysical, geological, and drilling studies of modern SZs and, less reliably, from fossil Cenozoic and older ones. We have estimated that long-term average gains and losses for the Phanerozoic are similar at ~3.2 km^3/yr (i.e. 3.2 AU--Armstrong Units) [1]. These estimates, which do not include a term for



crustal foundering, are comparable to, but distinctly lower than, those of Clift et al. [2] (additions <5 AU, losses ~4.9 AU) or losses (5.25 AU) assessed by C. R. Stern [3]. The range of these estimates usefully captures our present understanding and uncertainty. Losses are least constrained for deeply subducted continental crust, for example Africa, Arabia, India, and northern Australia today, and at older collisional SZs, and by crustal delamination.

Plausible Net Phanerozoic Crustal Loss

It seems likely that at crust-suturing SZs estimated losses of deeply subducted CIA crust (based chiefly on two examples, the Paleoproterozoic Wopmay orogen of NW Canada and the Cenozoic Melanesian orogen of New Guinea), could easily be higher than our [1] estimate of 0.3 AU, and certainly a loss must be considered for our un-estimated volume of lower crust delamination. In consideration of these concerns, the uncorrected-for component of remelted older crust in continental (Andean) arc magma, and the higher volumes of recycled crust estimated by Cliff et al. [2] and C. R. Stern [3], it is plausible that during at least the Phanerozoic the net product of gains and losses has been to reduce Earth's inventory of CIA crust.

[1] Stern and Scholl (2010) Inter. Geology Rev. **52**, 1–31. [2] Cliff, Vannucchi, & Morgan (2009) Earth Sci. Rev. **97**, 80-104. [3] C.R. Stern (2011) Gondwana Research **20**, 284-308.