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Crustal growth, thermal evolution of the Earth, and Archaean emerged land surface

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In the long term, the total amount of emerged land at Earth's surface and the depth of mid-oceanic ridges are controlled by the growth of the continental crust and by the secular cooling of Earth's mantle that implies changes in the isostatic balance between continents and oceans. The evolution of the area of emerged land and of oceanic bathymetry are of fundamental importance to the geochemical coupling of mantle, continental crust, ocean and atmosphere.

We developed a model to evaluate the area of emerged continental crust as a function of mantle temperature, continental area and hypsometry. For constant continental hypsometry and for three different thermal evolution models, we find that a constant continental freeboard ($\pm$ 200 m) throughout Earth's history is possible as long as the potential temperature of the upper mantle never exceeded its present value by more than 110–210°C. This implies either a very limited cooling of the planet or, most likely, a change in continental freeboard since the Archaean. As for the area of emerged land, our calculations suggest that less than $\sim$12% of Earth's surface were emerged in the Archaean, compared to $\sim$28% at present.

Of importance to the evolution of the area of emerged land is the shape of the continents. During the Archaean, a greater radiogenic crustal heat production and a possibly greater mantle heat flow would have reduced the strength of the continental lithosphere, thus limiting crustal thickening due to mountain building processes and the maximum elevation in Earth's topography (Rey and Coltice, 2008). Taking this effect into account, we show that the continents were mostly flooded until the end of the Archaean, with 2-3% of Earth's area emerged by 2.5 Ga. These results are consistent with the widespread occurrence of submarine continental flood basalts in the Archaean, and with the appearance and strengthening of the geochemical fingerprint of felsic sources in the sedimentary record from 2.5 Ga. In order to investigate the influence of crustal growth models on the area of emerged land and on the evolution of oceanic $^{87}Sr/^{86}Sr$, we developed an integrated model based on the thermal evolution model of Labrosse and Jaupart (2007). Modelling results suggest that the area of emerged land does not closely depend on crustal growth models, and that less than 5% of Earth's area was emerged in the Archaean. Furthermore, our models reconcile early crustal growth models with the evolution of oceanic $^{87}Sr/^{86}Sr$ as recorded by marine carbonates when a reduced emerged area and lower continental elevations are accounted for. Thus, a delayed crustal growth model is not needed to account for the observed trend in oceanic $^{87}Sr/^{86}Sr$.

References

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