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Stagnant-lid tectonics during the Archaean and delayed onset of plate tectonics

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It is well accepted that the Archean (between 4 to 2.5 billion years (Gyr) ago) was much hotter than the present time, because of higher rates of internal heat production. A traditional view is thus that the mantle was convecting faster, resulting in plates moving faster at the surface of the Earth. In order to understand how the Earth actually evolved during the Archean, short-lived isotope systems can be a powerful tool for investigating the geological processes that occurred during the Archean. As such, early Archean rocks show a progressive decrease for their μ^{142}Nd from +20 to 0 between 3.9 to 3.6 Gyr, until rocks younger than 3.5 Gyr show no μ^{142}Nd anomalies. This decrease is interpreted as the efficient remixing of the first primitive crust into the Archaean convecting mantle that ultimately produce a well-mixed present-day convecting mantle with μ^{142}Nd = 0 [1]. Such a timescale from 4.5 to 3.5 Gyr implies mixing time of 1 Gyr, longer than expected for a fast convective mantle (i.e. around 100 Myr [2]). In addition, the finding of a resolvable positive ^{142}Nd anomaly of μ^{142}Nd = +7 ± 3 ppm relative to the modern convecting mantle in a 2.7 Gyr old tholeiitic lava flow from the Abitibi Greenstone Belt in the Canadian Craton challenges even more a fast convective mixing of the mantle as it extends the early Archean convective mixing time to ~1.8 Gyr. This is even longer than present-day mantle mixing timescale of ~1 Gyr [3].

Using a numerical modelling, we show that a delayed mixing, even in a strongly convective mantle, is well explained by long periods of stagnant-lid plate tectonics, with scarce episodes of subduction throughout the Hadean and Archean [4]. This is because, when the viscosity of the mantle is lowered as a consequence of higher temperatures, the viscous coupling between the crust and mantle located underneath is actually very low [5]. The mantle was thus convecting faster as expected, but with no consequence on the crust and therefore a poor mixing of the mantle. We suggest that the predominant tectonic regime in the Archean was stagnant-lid regime, with sporadic subduction zones [4]. Modern plate tectonics, as observed today, could have started around or after 2.7 Gyr [4].

References:

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