

## What does Hadean mantle mixing tell us about Hadean geodynamics?

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A hot Hadean mantle is suggested from high internal heat production, high rates of impact bombardment, and significant primordial heat from accretion. Consequently, extremely high internal temperatures argue for low internal viscosities, and extremely vigorous mantle convection. Mixing in such high-Rayleigh number convective environment should have efficiently remixed or erased chemically heterogeneous mantle anomalies on timescales of less than 100Myr.

However, platinum group elements concentrations in Archaean komatiites, purported due to the later veneer of meteoritic addition on the Earth, only achieve current levels at 2.7Ga – indicating a time lag of almost 1-2Gyr in mixing this material thoroughly in the mantle. <sup>142</sup>Nd and <sup>182</sup>W isotope studies also indicate that heterogeneous mantle domains survived, without mixing, for over 2Gyr – at odds with mixing rates expected.

Here we suggest the surface tectonic regime may have significantly retarded mixing efficiency in the Hadean. A number of lines of evidence suggest episodic resurfacing in the Archaean, and extrapolating back to Hadean times implies the Hadean was characterized by long periods of tectonic quiescence (albeit violently volcanic). We explore mixing times in 3D spherical-cap models of mantle convection, which incorporate vertically stratified and temperature-dependent viscosities. We show that mixing in stagnant lid regimes can be over an order of magnitude less efficient than mobile lid mixing, and for plausible Rayleigh numbers and internal heat production, the lag in Hadean convective recycling can be explained. This explanation not only explains the long-lived <sup>142</sup>Nd and <sup>182</sup>W anomalies, but also 1) posits an explanation for the delay between accretion of the late veneer – between 4.5-3.8Ga on a stagnant surface – and its fully mixed signature apparent in elevated PGEs in 2.7Ga komatiites, and 2) provides an explanation for the 400Myrs of immobility of the mafic protolith from which the Jack Hill zircons were sourced, and 3) retards early heat loss from the mantle, providing a solution to the “Archaean thermal catastrophe” of parameterized Earth evolution models.

## The effects of silicate melt composition and sulfur on the solubilities of PGEs in silicate melts

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Experimental studies of PGE solubilities at conditions directly relevant to natural basaltic melts are difficult because the low solubilities are often masked by variable amounts of micronuggets suspended in the melts. Experiments in simple haplobasaltic melts appear to establish that solubilities at low pressures are less than ~1 ng g<sup>-1</sup> at typical terrestrial oxygen fugacities and temperatures, raising questions as to how PGEs are transported from the mantle and concentrated into economic ore deposits. The applicability of the simple system experiments is sometimes queried because, it is claimed, missing ingredients like Fe or S might enhance solubilities. To address this issue directly, the effect of melt composition on Ir and Pd solubilities has been determined at ambient pressure. Samples were equilibrated in a 1-atm. gas-mixing furnace using Ir and Pd metal loops, quenched to glasses and analysed by laser ICP-MS (detection limits < 1 ng g<sup>-1</sup>), with EMPA for major elements and sulfur. The compositional dependence was studied first at high temperatures (1500°C for Ir and 1400°C for Pd), which reduces the micronugget problem, and compositions least affected by micronuggets were then selected to measure the effects of T and fO<sub>2</sub>. For Ir, ~40 melt compositions in CaO-MgO-Al<sub>2</sub>O<sub>3</sub>-SiO<sub>2</sub>±FeO±Fe<sub>2</sub>O<sub>3</sub>±Na<sub>2</sub>O±TiO<sub>2</sub> were investigated. The results show that Ir dissolves only as Ir<sup>3+</sup> over the experimentally accessible range of fO<sub>2</sub>, and solubilities are simply related to the melt composition through its optical basicity. The effects of FeO and Fe<sub>2</sub>O<sub>3</sub> are small but individually resolvable: fO<sub>2</sub>-corrected solubility decreases as Fe<sub>2</sub>O<sub>3</sub> replaces FeO. High Fe or Ti suppresses micronuggets. As regards sulfur, Ir solubility is too low for any effect to be seen at the fO<sub>2</sub>s needed to achieve measurable S<sup>2-</sup> in the melt in 1-atm experiments. Pd dissolves as Pd<sup>1+</sup> with some Pd<sup>2+</sup> at higher fO<sub>2</sub>, in agreement with literature results. The effect of melt composition on Pd solubility is much less than for Ir, and is not related to any simple compositional variable. To investigate the effect of S quantitatively, experiments on the solubility of Ru (as Ru<sup>3+</sup>), which is ~50 times more soluble at a given fO<sub>2</sub> than Ir, were undertaken using a high Fe-Ti picritic composition at 1500°C to eliminate micronuggets, in olivine capsules. Only a small effect was observed despite ~1000 μg g<sup>-1</sup> S<sup>2-</sup> in the melt.