Mantle heterogeneity and the onset of melting beneath mid-ocean ridges revealed by lead isotopes

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Earth's oceanic crust is formed by partial melting of the mantle as it wells up beneath mid-ocean ridges. Melting is thought to be strongly controlled by compositional variations in the mantle, where more fusible rock types melt first yielding high melt proportions and nucleating channels that allow melts to remain chemically isolated and rapidly transported to the surface. Mid-Ocean Ridge Basalts (MORB) preserve variations in their radiogenic isotope compositions or ratios of incompatible elements that point to a signficiant chemical heterogeneity in the mantle source, but the composition of the earliest melts is difficult to determine, and melt aggregation and melt-rock reaction act to mask the actual extent of chemical variability in the source. However, MORB also experience extensive fractional crystallisation, and the chemistry of the earliest melts may be preserved by phenocryst phases (that is, the first minerals to crystallise) or the melt inclusions that they contain.

This study presents high-precision Pb isotope data for the constituent phases of MORB from the FAMOUS region (36°50'N) on the mid Atlantic ridge. MORB glass yields the typical varations in Pb isotope composition seen for this area, but plagioclase, clinopyroxene and sulfide globules, within individual samples, preserve extremely unradiogenic Pb compositions that are not seen in the final quenched glass. These data demonstrate a spectacular evolution in melt composition over the timescale of igneous crystallisastion, where minerals from individual samples preserve $^{206}Pb/^{204}Pb$ isotope variations > 2 times greater than those seen in glass (alone) for the entire ridge segment.

Overall, these results indicate that the onset of MORB melting is strongly controlled by mantle heterogeneity. The earliest melts are sourced by both continental crustal material and ancient refractory peridotite, with melts progressively evolving towards the composition of the final quenched glass, that largely reflects the chemistry of the "ambient" upper mantle.