TIMESCALE OF MARTIAN MANTLE OVERTURN RECORDED IN NAKHLITE MARTIAN METEORITES.
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Solidification of a magma ocean may result in a mantle overturn where the Fe-rich upper but denser cumulates sink to the bottom of the silicate mantle and the lower but lighter Mg-rich cumulates rise to shallower levels [1,2]. This is because Mg-rich lighter cumulates are expected to crystallized first, starting at the bottom of the silicate mantle while the denser Fe-rich cumulates will crystallize later upwards. This creates an inverse density gradient that can potentially result in a mantle overturn. Investigating whether or not a mantle overturn actually occurred, and dating the end of the magma ocean crystallization that possibly resulted in a mantle overturn are important for our understanding of the early differentiation processes in terrestrial planets.

In Mars, the duration of the martian magma ocean (MMO) has been estimated to being less than 40 Myr [3-5], while recent and precise $^{142}Nd/^{144}Nd$ data suggest the longevity of the MMO to ~100 Myr after the Solar System formation [6]. New $\varepsilon^{176}Hf$, $\varepsilon^{143}Nd$ and $\varepsilon^{142}Nd$ obtained for three nakhlites (Nakhla, MIL 03346 and Yamato 000593) are combined to existing $\varepsilon^{182}W$ data to track the timescale of martian mantle overturn. The low $\varepsilon^{176}Hf/\varepsilon^{143}Nd$ of nakhlites (0.8 to 1.2); their complex source evolution recorded by their $\varepsilon^{143}Nd$ vs. $\varepsilon^{142}Nd$ systematics; and the inconsistency between their high ^{182}W (~+3) [4,7] but intermediate and shergottite-like $\varepsilon^{142}Nd$ (~+0.6; [6,8], this study) is best explained by the removal of majoritic garnet from their source when ^{182}Hf was extinct but ^{146}Sm still extant.

Garnet segregation can occur in highly molten cumulates [9]. A new numerical model indicates that deep cumulates brought up to shallower levels during a mantle overturn can melt up to 65 % by adiabatic decompression, allowing garnet to be segregated. A multi-stage model is developed for the source of nakhlites, where the first stage represents core segregation, the second stage silicate mantle differentiation, the third stage garnet segregation as a consequence of the mantle overturn and the fourth stage production of nakhlite magmas from their mantle source. A good agreement between the multi-stage model and the values observed in nakhlites can be achieved for a garnet segregation occurring ~ 100 Myr after the Solar System formation. Such a protracted timescale for the mantle overturn is similar to a previous but independent estimation of the longevity of the MMO [6].

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