Crystal fractionation in a deep magma ocean

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Most of Earth's mass accreted by numerous impacts between large bodies and proto-Earth, and a giant impact with a Mars-sized object is the most plausible explanation for a Moon forming event [1]. Physical models show that large impacts would have caused high degrees of melting, resulting in a global magma ocean [2]. Isentropic cooling in a magma ocean would lead to crystallization from the bottom up. A relic layer of early crystalline differentiates may have been resistant to homogenization due to intrinsic high density, and could have remained buried in the deep lower mantle until the present. Such a deep layer may now reside as the D" layer that extends as much as a few hundred kilometers above the core-mantle boundary, or could be a thicker layer responsible for a transition in lateral seismic heterogeneity observed at ~ 1600 km depth [3]. A buried layer is a potential storehouse for trace elements, including radioactive, heat-producing elements that could provide the missing heat required to satisfy surface heat flux. We present new geochemical models for the effects of crystal differentiation based on mineral phase relations and element partitioning behavior at the liquidus of fertile model peridotite at pressures corresponding to the uppermost lower mantle (~ 23-25 GPa).

A set of heuristic mass balance models using major elements indicates that within present uncertainties about 20% crystallization of a mineral assemblage with the proportions 89Mg-Pv:6.5CaPv:4.5Fp is plausible. We use this result to model the effects of crystal fractionation on refractory lithosphile trace element abundance ratios. Sc/Sm, Sc/Yb, Zr/Y, Zr/Yb, Sm/Nd, Sm/Yb, and Lu/Hf all remain within about 20% of the chondritic ratio for 20% crystallization of liquidus phases in the proscribed proportions. For an entirely molten mantle, a crystal pile comprising 20% of the mantle by volume would result in a layer extending some 750 km above the core mantle boundary.

References

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Study on Si and O Isotopes of Principal Nephrite Ore Deposits in China

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The nephrite ore deposit is one of the most important jade resources in the world. The nephrite ore deposits in China are primarily located in Hetian County Xinjiang, and Xiuyan County Liaoning. Hetian jade, Manasi green jade and Xiuyan old jade are the famous nephrite, also called Chinese jade. Their main mineral components are tremolite and belong to the tremolite jade. Study on these jades in China has been carried out by means of O and Si isotope analyses. 18 samples of Hetian jade, Manasi green jade and Xiuyan old jade, which come separately from Hetian County, Xinjiang, and Xiuyan County, Liaoning Province, have been investigated by the BrF_5 method.

The analytical results show that the $\delta^{18}O$ values of Hetian jade change narrowly from +2.3‰ ~ +6.5‰, and the $\delta^{30}Si$ values change from -0.1‰ ~ +0.3‰. The $\delta^{18}O$ values of Xiuyan old jade range from +8.7‰ ~ +12.4‰, the $\delta^{30}Si$ values of the jade range narrowly from +0.1‰ ~ +0.3‰. The $\delta^{18}O$ and $\delta^{30}Si$ of Hetian jade and Xiuyan old jada are all lower than the values of the host rocks, the $\delta^{30}Si$ values lie in the region of those granite and differ from sedimentogenic carbonates. So it can be concluded that most silicon atoms in Hetian jade and Xiuyan old jade came primarily from the late-Hercynian granite. The δD values of Hetian and Xiuyan jades change from -70‰ ~ -78‰ (Duan, T.Y. and Wang, S.Q., 2002), while the $\delta^{18}O$ values of the jades change from +2.3‰ ~ +12.4‰. The study shows that the compositions of hydrogen and oxygen isotopes in the ore-forming solution of the jades are in metamorphic water region, therefore the jades were formed in a metamorphic solution.

The δD of Manasi green jade range from -59‰ ~ -72‰ (Tong, Y.L., 2002), while the $\delta^{18}O$ of the jade change from +9.1‰ ~ +9.8‰, therefore it suggests that the water of ore-forming solution was not derived from magma or meteoric water, but from metamorphic water. The $\delta^{30}Si$ values of the jade range from -0.5‰ ~ -0.3‰, the $\delta^{18}O$ and $\delta^{30}Si$ values are obviously lower than the host rocks, and the $\delta^{30}Si$ values of Manasi green jade lie in the region of the ferromagnesian rocks.

It is suggested that the nephrite ore deposits in Hetian and Xiuyan County may be the magmatic hydrothermal replacement deposit, and the jade ore deposit in Manasi may be the metamorphic ore deposit.