Chemical heterogeneities survive giant impacts and mantle convection

S. MUKHOPADHYAY, S.T. STEWART, J. M. TUCKER, R. PARAI AND S. LOCK

[1]Dept. of Earth & Planetary Sciences, Harvard University, Cambridge, MA 02138, USA sujoy@eps.harvard.edu

The giant impact phase of Earth's accretion likely produced multiple magma oceans. In particular, the Moon-forming giant impact is often thought to have produced a whole mantle magma ocean, which should have erased pre-existing chemical heterogeneities within the Earth. We argue that the ratio of ^{3}He to ^{22}Ne in the present day mantle does record multiple magma ocean episodes during Earth's accretion. However, the ^{3}He/^{22}Ne ratio of the Earth's shallow depleted mantle is significantly higher than the deep mantle indicating that the last giant impact did not generate a whole mantle magma ocean. Although the energy associated with the Moon-forming giant impact was sufficient to melt the whole planet, the impact energy is heterogeneously deposited; the impacted hemisphere is shocked to the point of partial vaporization, but the opposite hemisphere experiences modest heating that does not result in completely melting. As a result, chemical heterogeneities persist through the giant impact phase of accretion.

Additional evidence for the preservation of early-formed heterogeneities in the deep mantle is provided by ^{129}Xe/^{130}Xe ratios. Deep mantle plumes have a lower ratio of ^{129}Xe/^{130}Xe compared to the source of mid-ocean ridge basalts (MORBs). The Xe signature requires a region of the deep mantle to be less degassed and to have separated from the shallower MORB source by 4.45 Ga (since ^{129}I, which produces ^{129}Xe, is extinct after ~100 Ma); i.e., neither the giant impact phase nor mantle convection has efficiently homogenized the mantle.

The persistence of noble gas signatures produced very early in Earth history, such as those associated with the ^{129}I-^{129}Xe system, may appear to be in conflict with other extinct nuclide systems such as ^{146}Sm-^{142}Nd or ^{182}Hf-^{182}W. While isotopic anomalies in ε^{142}Nd and ε^{182}W are present in the Hadean and Archean mantle, the present-day mantle appears to be homogeneous. The observation requires Sm-Nd and Hf-W fractionation within the first few hundred Ma but also the subsequent destruction of the chemical fractionation through recycling and mantle mixing. A simple explanation for why the noble gas signature still persists in the present-day mantle may be the lower recycling efficiency of the noble gases compared to elements like Nd and W.