Evidence for garnet in the lunar mantle

CLIVE R. NEAL[1] AND CHARLES K. SHEARER[2]

[1]Department of Civil Engineering and Geological Sciences, University of Notre Dame, Notre Dame, IN 46556, USA (neal.1@nd.edu)
[2]Institute of Meteoritics, Dept. of Earth and Planetary Sciences, University of New Mexico, NM 87131, USA (cshearer@unm.edu)

Volcanic glass beads returned from the Moon are derived from greater depths than crystalline mare basalts and afford a unique opportunity to study the deep lunar interior. Experimental studies have shown that garnet is, hypothetically, possible in the source of some glasses, but that that they were never saturated with ilmenite, even those containing >16 wt% TiO_2.

SIMS analyses of a variety of volcanic glass beads (VLT-High-Ti) have been undertaken, concentrating on the garnet compatible elements Sc, Y, and Yb, as well as the garnet incompatible elements Zr, Nb, Ce, and Sm. Results demonstrate that the high-Ti glasses from Apollo 12 (the red glasses) and Apollo 14 (the black and orange glasses) have compositions consistent with garnet being retained in the source region (elevated Sm/Yb and Zr/Y ratios above KREEP).

Modeling shows that the compositions of the Apollo 12 and 14 high-Ti glasses can be generated by 5-10% batch melting from a source of olivine and Opx + 2% garnet that has a bulk Moon composition. The glass compositions cannot be generated if ilmenite is included in the source. The high-Ti compositions require assimilation of a late stage, ilmenite-rich cumulate by a superheated magma. This has been modeled using an ilmenite + KREEP component as the assimilant, an r-value of 0.9, and crystallization of olivine + spinel (9:1).

The source for these glasses would need to be located deeper than 500 km within the Moon and would not contain a Ti-rich phases, such as ilmenite. Garnet is retained in the residue in order to account for the Sm/Yb & Sc/Sm ratios. Subseuqent assimilation of an ilmenite-rich component is required to generate the Nb/Zr, Nb/Ce, and Zr/Y ratios. It is possible that these glasses were derived from a source that escaped processing by the Lunar Magma Ocean. Such a source could represent a “primitive Moon” composition.

How and when did the Earth inherit its volatile signature?

WILLIAM F. MCDONOUGH

Department of Geology, University of Maryland, College Park, MD, 20742, mcdonoough@geol.umd.edu

Models for the composition of the Earth (core + mantle) describe a relatively systematic pattern of decreasing normalized abundances of the volatile elements with decreasing half-mass condensation temperatures. The Earth’s normalized abundance pattern for the volatile lithophile elements mimics that of the carbonaceous chondrites, but with the Earth having greater volatile element depletions than CM, CV and CO chondrites relative to CI. This planetary chemical signature represents the integration of a spectrum of materials (oxidized to reduce, refractory- to volatile-rich) available during accretion and possibly some post-accretion loss of volatiles. Compositional models of the Earth’s core provide critical insights into resolving the nature of how and when the Earth inherited its volatile signature. Perhaps the most outstanding problem in this respect is the nature of the light element in the core. Invoking sulfur as the sole light element requires the core to have untenable quantities of lithophile elements. Based on the Earth’s volatility signature there is ~2% sulfur in the core. Thus, the outer core’s density deficit is consistent with a mixture of ~2% S and either ~3% O or ~6% Si. The mantle’s high Ni and depleted V characteristics are used to argue for models of heterogeneous accretion envisage an early stage involving a reducing environment and then later a more oxidized environment. Chondritic ratios of refractory lithophile elements found in the mantle restrict the level to which these elements were reduced and separated into the core as either siderophile or chalcophile components. Siderophile element abundances and ratios in the mantle are consistent with the bulk of core-mantle separation having been carried out at 10-30 GPa. There are however, several trace siderophile and chalcophile elements (e.g., Ga, In Cd) whose abundances in the mantle remain to be explained by the above model for the Earth.