Compositional Variations Within the Moon: What Are They and the Way Forward

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The Apollo and Luna era sent spacecraft to the Moon to study its surface and eventually return surface samples. Since the last sample return mission in 1972 spacecraft have further investigated the Moon's surface. While studying the surface has yielded important insights into the formation and evolution of the Moon, the samples have proven to be invaluable, not least in the calibration of orbital data. However, even with sample return and continued orbital examination of the Moon, the state of knowledge of the lunar interior is at best, rudimentary. Information regarding the lunar interior has been obtained from the Apollo seismic network (e.g., [1,2]), basaltic samples (e.g., [3,4]), measurements of the lunar induced magnetic dipole moment and moment of inertia [5], and rotational dissipation measured by lunar laser ranging (e.g., [6]). The Apollo seismic network allowed examination of the lunar interior via indigenous or induced seismic waves. Unfortunately, the small areal extent of this network has meant that below depths of $\sim$500 km data interpretation becomes somewhat equivocal. For example, the Apollo seismic data tell us little about the lunar core. Also, while a seismic discontinuity is apparent at $\sim$500 km, the increased velocities at depths $>$500 km could be due to an increased proportion of Mg-rich olivine [7,8] or the presence of garnet [9-11]. Hood et al. [5] used Lunar Prospector magnetometer data to calculate the induced magnetic dipole moment and estimated a metallic lunar core with a radius of 340+/-90 km. However, the composition of the core has also been postulated to be ilmenite on the basis of density considerations for the late stage ilmenite-rich magma-ocean cumulates and buoyancy estimates of Ti-rich mare magmas [12,13]. In fact, existing geophysical data are consistent with either a metallic or ilmenite lunar core [14]. Multiple saturation experiments of returned basaltic samples suggested depths of origin between 100-250 km for crystalline basalts, and between 360-520 km for volcanic glass beads (e.g., [4,15]). However, depths for the basalts are generally minimum depths because the experiments were conducted on fractionated samples. The depths of origin of some glasses may be beneath the base of the lunar magma ocean if it is assumed it had a maximum depth of 500 km (which is consistent with the limited seismic data). Interestingly, garnet is stable below depths of 500 km in the Moon and certain glass groups may contain the chemical signature of garnet [16-18]. The Way Forward: Better understanding of elemental variations on the lunar surface will permit more constrained modeling of the lunar bulk composition. The ongoing SMART-1 mission is leading the way in this endeavor and future missions will add to this database. However, orbital missions need to be supplemented by the establishment of a long-lived geophysical network (e.g., [19]), which is particularly significant with the proposed establishment of a permanent human presence on the Moon [20], and sampling from the farside of the Moon. While the recognition of lunar meteorites has certainly added to the sample collection, exact locations for these remain unknown. This integrated approach forms a template for exploring other planetary bodies and it would be remiss not to learn from the successes and failures of ∼40 years of lunar exploration.

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