Abstract

The Moon is thought to have accreted from the debris disk that resulted from a giant impact between a Mars-sized body and the early Earth. Accretion of the Moon at ~4.5-4.4 Ga is believed to have caused global-scale melting to form a Lunar Magma Ocean (LMO) that crystallized over the next 200 million years. A major part of the present-day lunar surface and interior are attributed to crystallization from the LMO, although magmatism is recorded on the Moon long after LMO solidification. Mare basalts ranging in age from ~4.0-1.0 Ga, and much rarer 4.07-3.45 Ga old lunar silicic/felsic constructs represent two enigmatic types of post-LMO magmatism that volumetrically peaked between 3.8-3.6 Ga. Both these lithologies have aspects that are as yet inadequately unexplained by existing models – a remarkable variation in the TiO_2 content (0-18 wt.%) of lunar mare basalts, and the origin of evolved silicic lithologies on the Moon. This study addresses these two problems by using experimental petrology and thermodynamic modelling to replicate high Ti-basalt compositions, and integrating information extracted from a variety of remote sensing methods to holistically characterize two lunar silicic constructs. The models developed in this study can lead to better understanding of the magmatic evolutionary history of the Moon.

High-pressure experiments were performed using a piston cylinder apparatus to simulate melting of a dense Fe-Ti-rich 'ilmenite-bearing cumulate (IBC)' layer, that is believed to have formed at shallow depths towards the end of LMO solidification, as it sinks down to depths corresponding to 1-3 GPa pressure during gravitational overturning of the lunar mantle. The experimentally obtained partial melts have appropriate TiO_2 contents, but are mostly relatively MgO-poor (<6 wt.%) compared to lunar high-Ti basalt magmas (5-15 wt.% MgO). Most of these partial melts are likely to have been heterogeneously stranded within the lunar mantle, as indicated by their high-pressure densities computed using the third-order Birch-Murnaghan equation of state. The MgO-discrepancy can be resolved by a thermodynamic model that involves fractional crystallization of the partial melts followed by their mixing with ascending high-Mg, low-Ti basalt magma, and further fractionation of the mixed magma during continued ascent. The resultant melt compositions resemble lunar high-Ti basalt magmas. The high-pressure densities of the partial melts and the modelled mixed magmas indicate that high-Ti basalt magmas may be either positively or negatively buoyant with respect to the ambient mantle. Magmas that are negatively buoyant at 2 and 3 GPa pressures may sink down and potentially form a partially molten Ti-rich layer at the lunar core-mantle boundary, as predicted by some workers. This model can explain the large variation of ages and random spatial distribution of the high-Ti mare basalts, and provides support to the postulated theory of a lunar mantle overturn.

To understand lunar silicic magmatism, a hitherto less studied lunar silicic construct – the Wolf crater complex – has been holistically characterized by morphological, compositional, gravity anomaly and chronological studies using remotely sensed data. Morphological studies reveal features indicating viscous lava flows such as domes with lobate flow fronts and steep slopes. Domes, pits and irregular depressions aligned along dominantly NE-SW and NW-SE oriented ridges, from which lava flows emanate, indicate that the eruption occurred through structurally controlled pathways. Arcuate faults and escarpments at the rims of the central depression and three broad levels of topographic elevation on the central depression indicate collapse structures. Domal features interrupting the rims of the central depression represent post-collapse structures consistent with continuing felsic volcanism. Compositional analyses reveal evolved silicic lithologies with high Th content (~8 ppm) and low FeO contents. Gravity studies indicate a low density-signature in the Wolf crater region that is surrounded by high-density features up to a depth of 30 km. Theses features establish the Wolf crater complex as a lunar silicic volcanic caldera. Based on the occurrence of Mg-spinel and the overall low FeO-content of the pyroxenes in the Wolf crater complex, it is suggested that lunar silicic magmas were generated by melting of appropriate crustal protoliths, where available, by basaltic underplating. The limited duration of the silicic magmatism may be explained by the extensive melting of the mantle driven by the lunar mantle overturn around 4 Ga, and the onset of the Late Heavy Bombardment, during which large impact events created crustal pathways facilitating eruption of the viscous silicic magmas.

(**Keywords:** Lunar magma ocean; lunar high-Ti basalts; lunar mantle overturn; lunar silicic volcanism; Wolf crater complex; crustal melting; basaltic underplating, magma mixing, high-pressure experiments)