MARE BASALT VOLCANISM: GENERATION, ASCENT, ERUPTION AND HISTORY OF EMPLACEMENT OF SECONDARY CRUST ON THE MOON.

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Numerous advances have been made in the understanding of mare basalt volcanism and secondary crustal emplacement on the Moon in the last decade since NVM-1. We utilize a theoretical analysis of the generation, ascent, intrusion and eruption of basaltic magma on the Moon [1-7] to develop new insights into magma source depths, supply processes, transport and emplacement mechanisms via dike intrusions, and effusive and explosive eruptions (Fig. 1, 2).

Generation: Density contrasts between the bulk mantle and regions with a greater abundance of heat sources will cause larger heated regions to rise as buoyant melt-rich diapirs that generate partial melts that can undergo collection into magma source regions; diapirs could rise to the base of the anorthositic crustal density trap (when the crust is thicker than the elastic lithosphere) or, later in history, to the base of the lithospheric rheological trap.

Ascent: Residual diapiric buoyancy, and continued production and arrival of diapiric material, enhances melt volume and overpressurizes the source regions, producing sufficient stress to cause brittle deformation of the elastic part of the overlying lithosphere; a magma-filled crack (dike) initiates and propagates toward the surface as a convex upward, blade-shaped dike. The volume of magma released in a single event is likely to lie in the range 10^2 km^3 to 10^3 km^3, corresponding to dikes with widths of 40-100 m and both vertical and horizontal extents of 60-100 km, favoring eruption on the nearside. As the Moon cools with time, the lithosphere thickens, source regions become less abundant and rheological traps become increasingly deep; the state of stress in the lithosphere becomes increasingly contractional, inhibiting dike emplacement and surface eruptions.

Effusive Eruptions: Relatively low effusion rate, cooling-limited flows lead to small shield volcanoes (e.g., Tobias Mayer, Milicius); higher effusion rate, cooling-limited flows lead to compound flow fields (e.g., most mare basins) and even higher effusion rate, long-duration flows lead to thermal erosion of the vent, effusion rate enhancement, and thermal erosion of the substrate to produce sinuous rilles (e.g., Rimae Prinz). Extremely high effusion rate flows on slopes lead to volume-limited flow with lengths of many hundreds of kilometers (e.g., young Imbrium basin flows).

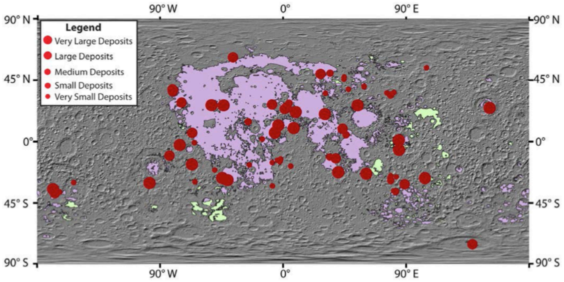

Fig. 1. Maria (purple), cryptomaria (green) [5-6] and pyroclastic deposits (red dots; [7]).

Explosive Eruptions: Dikes penetrating to the surface produce a wide range of explosive eruption types whose manifestations are modulated by lunar environmental conditions: 1) terrestrial strombolian-style eruptions map to cinder/spatter cone-like constructs (e.g., Isis and Osiris); 2) hawaiian-style eruptions map to broad flat pyroclastic blankets (e.g., Taurus-Littrow Apollo 17 dark mantle deposits); 3) gas-rich ultraplinian-like venting can cause Moon-wide dispersal of gas and foam droplets (e.g., many isolated glass beads in lunar soils); 4) vulcanian-like eruptions caused by solidification of magma in the dike tip, buildup of gas pressure and explosive disruption, can form dark-halo craters with admixed country rock (e.g., Alphonsus Crater floor); 5) ionian-like eruptions can be caused by artificial gas buildup in wide dikes, energetic explosive eruption and formation of a dark pyroclastic ring (e.g., Orientale dark ring); 6) multiple eruptions from gas-rich fissures can form regional dark mantle deposits (e.g., Rima Bode).

Summary: Early high-Ti, middle low-Ti, late high-Ti lavas suggest heterogeneity of mantle source regions in space and time; we see no evidence for asymmetrical (e.g., nearside/farside) distribution of source regions. The total volume of lunar extrusive secondary crust is miniscule compared with primary crust. This improved paradigm for the generation, ascent, intrusion and eruption of basaltic magma provides the basis for a more detailed understanding of lunar thermal evolution.

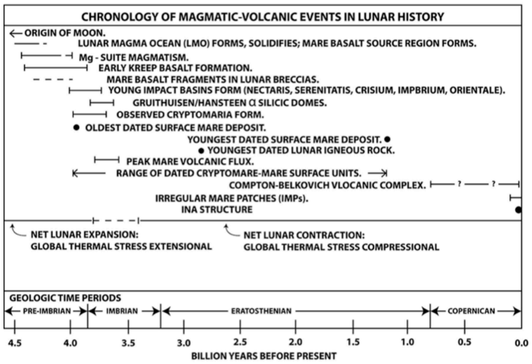

Fig. 2. Chronology of lunar magmatic-volcanic events.

References: [1] Wilson and Head (2015) *Icarus*, in press. [2] Head and Wilson (2016) *Icarus*, in review. [3] Hiesinger et al. (2011) *GSA SP 477*, 1. [4] Shearer et al. (2006) *RMG* 60, 365. [5] Whitten and Head (2015a) *Icarus* 247, 150. [6] Whitten and Head (2015b) *PSS* 106, 67. [7] Gaddis et al. (2003) *Icarus* 161, 26.