ERUPTION OF MAGMATIC FOAMS AND UNUSUAL REGOLITH PROPERTIES: ANOMALOUSLY YOUNG CRATER RETENTION AGES AND THE CASE OF INA.

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Introduction: The absence of any atmosphere on the Moon means that, on approaching the surface (Fig. 1), all magmas will attempt to release all of the volatile species that they contain in solution or can generate by chemical reactions at low pressures. A common component of mafic melts in the lunar mantle is graphite, and reactions between graphite and various metal oxides produce CO gas at a pressure of ~40 MPa which occurs at ~10 km depth. This gas production ensures that essentially all lunar eruptions begin with an explosive phase. The initial stage of the eruption is fed by a dike that is likely to extend completely through the lunar crust into the upper mantle and the great width of this dike ensures a high magma discharge rate [1-3]. As the initially high excess pressure in the dike is lost and the dike begins to close due to the elastic response of the crust, the discharge rate must decrease and eventually become very small. A uniform distribution of gas bubbles exists in the magma as it reaches the surface, and the expansion of these bubbles into the lunar vacuum causes the magma to fragment into sub-mm-sized droplets that emerge in a nearly steady Hawaiian-style eruption. As the magma rise speed at depth approaches zero, the remaining closure of the dike squeezes out magma in which the only gas production is the release of water vapor. At the several hundred ppm water contents typical of many lunar magmas the gas bubble sizes are so small that surface tension forces allow them to remain stable against the internal gas pressures and so to form a foam that can have a vesicularity up to ~95%. This is the last material to be extruded and can extend for a few to several hundred meters below the surface. This latter stage of foam development should be characteristic of dikes and conduits beneath summit pit craters on small shield volcanoes and extrusion and modification (Fig. 2) may provide an explanation for some of the unusual textures and features observed in these environments, such as in the Ina feature [4].

Application to Ina: The enigmatic Ina feature on the Moon, a 2×3 km D-shaped depression that consists of a host of unusual bleb-like mounds surrounded by a relatively optically fresh hummocky and blocky floor was recently interpreted to represent extrusive basaltic volcanic activity <100 million years ago, an extremely young age for volcanism on the Moon [4]. Documentation of magmatic-volcanic processes from shield volcano summit pit craters in Hawaii, and new insights into shield-building and dike evolution processes on the Moon provide important perspectives on the origin of Ina. The size, location, morphology, topography, and optical maturity of Ina are consistent with an origin as a subsided summit pit crater lava lake atop a broad ~22 km diameter, ~3.5 billion year old shield volcano. New theoretical treatment of lunar shield-building magmatic dike events predict that waning-stage summit activity was characterized by the production of magmatic foam in the dike and pond; the final stages of dike stress relaxation and closure caused the magmatic foam to extrude to the surface through cracks in the lava pond crust to produce the mounds. The high porosity of the extruded foams (>75%) altered the nature of subsequent impact craters (the aerogel effect), causing them to be significantly smaller in diameter, and leading to the buildup of a regolith formed predominantly from crushed micro-vesicular foam material. Accounting for the effects of the reduced diameter of craters formed in magmatic foam results in a shift of the crater size-frequency distribution model ages from <100 million years to ~3.5 billion years, contemporaneous with the underlying shield volcano. We conclude that extremely young mare basalt eruptions are not required.

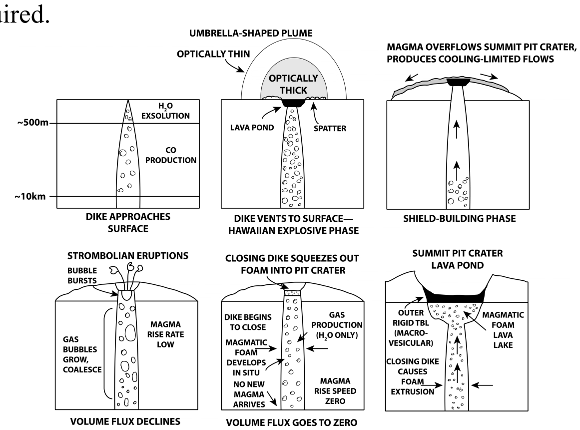

Fig. 1. Stages in summit pit crater formation and evolution.

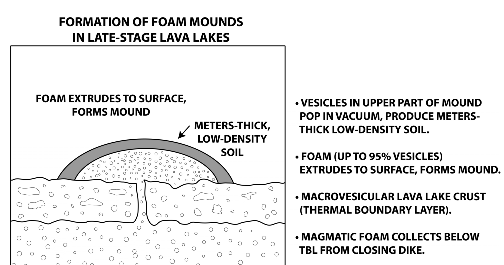

Fig. 2. Foam mound extrusion and regolith development.

Ref: [1] Wilson & Head, 2016a, Icarus, doi: 10.1016/j.icarus.2015.12.039. [2] Wilson & Head, 2016b, 7th Moscow Solar System Symposium, IKI. [3] Head & Wilson, 2016, Icarus, doi:10.1016/j.icarus.2016.05.031. [4] Braden et al., 2014, Nat. Geosci., doi:10.1038/ngeo2252.