VOLATILES IN LUNAR FIRE FOUNTAINING ERUPTIONS AND THE EFFECT OF ROTATION ON DROPLETS IN FREE FLIGHT.

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Introduction: It is widely accepted that the moon formed as a result of a Mars-sized body striking the Earth. In the process of formation, highly volatile elements were supposedly lost due to extremely high temperatures [1]. However, through the analysis of volcanic glass beads brought back from the Apollo missions it has recently been proven that the moon retained some volatile elements, e.g. hydrogen [2]. The glass beads were formed during fire fountaining events [3], in which the magma droplets were quenched extremely quickly upon eruption. In the Apollo 17 glasses, there is a visible difference in the color of the beads depending on the cooling rate. Those beads that were quenched quickly appear glassy and orange, while beads that cooled more slowly appear black, due to ilmenite crystal formation [1]. There should be a strong correlation between the optical density of the eruption plume and the number of glassy versus black beads. If the plume is optically dense, beads in the center of a hot gas cloud will have a longer time to cool, giving time for olivine and ilmenite crystals to form [4]. Those magma droplets in the center of an optically dense eruption are therefore more likely to be black, while droplets on the fringes of a gas plume are quenched quickly and form the orange glass. Due to the rapid cooling time of the orange glass, complete degassing would not have been able to take place, leaving volatile elements trapped within the beads.

Future Analysis: Using samples 74220, 15426, and 14259 from the Apollo missions, we will analyze the glass beads for volatile content using the secondary ion mass spectrometry (SIMS) technique at the Carnegie Institution for Science. Of particular interest are several individual olivine crystals with melt inclusions that we have obtained from sample 74220. These melt inclusions represent the primitive magma composition, since they would have undergone very little degassing, if any, during the eruption. Also of interest are the very large glassy beads from sample 74220, and the red, yellow-brown, and green beads from 15426. Both the olivine with melt inclusions and the specified sample beads from 74220 and 15426 will be of significant value when we use the SIMS to analyze them, as they could possibly reveal more about the initial lunar volatile content.

Sample 74220 formation: We have observed several unique shapes from the Apollo 17 beads, ranging from spheres and teardrop shapes to flat-looking beads with a shape like a button. It has been suggested that the elongated beads could be the result of either crystals altering the shape of the bead, or the bead shape influencing the way the crystals grew [5].

We propose that rotation could have been another deciding factor determining bead shape. There is a striking similarity between the bead formations that we are seeing from 74220 and a theoretical mathematical model of the shape of a liquid droplet while rotating in flight [6]. Displayed in **Fig. 1** are examples of the various shapes seen in sample 74220. The order of the shapes represents the progression we think the magma goes through as a result of rotation and turbulence before the beads cool. There were proportionally many more elongated beads, which may be a result of faster cooling times due to the thinner "neck" of the bead.

Implications: Once the analysis of the chosen bead and olivine samples from all three missions is complete, new constraints can be put on the initial lunar volatile content. Since to date only one analysis of an olivine melt inclusion has been done, the results from the 74220 olivine grains will be particularly enlightening. The effect of rotation on the shape of magma droplets during free flight may help in understanding the mechanics of fire fountain eruptions, and will provide very useful information for future modeling.

References: [1] Jolliff, B.L., Weiczorek, M.A., Shearer, C.K. and Neal, C.R (2006) *New Views of the Moon, Vol. 60* (4-5) and (83-219). [2] Saal, A.E. et al. (2008) *Nature 454, 192-195*. [3] Heiken, G.H., McKay, D.S., and Brown, R.W. (1974) *Geochim. Chosmochim. Acta,* 38, Suppl. 5, 1703-1718. [4] Weitz, C.M., Rutherford, M.J., Head, J.W. III, and McKay, D.S. (1999) *Meteoritics & Planetary Science*, 34 (4), 527-540. [5] Arndt, J. and von Engelhardt, W. (1987) JGR, 92, E372-E376. [6] Brown, R.A. and Scriven, L.E. (1980) *Proc. Royal Society London*, Series A. (331-357). [7] Wilson, L. and Head, J.W. (1981) Ascent and eruption of basaltic magma on the Earth and Moon. JGR 86, 2971-3001.
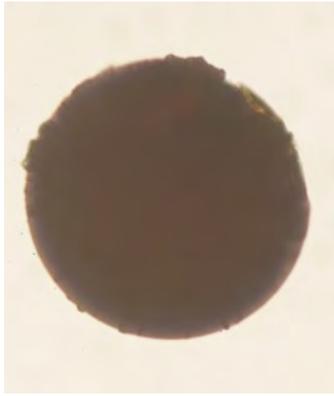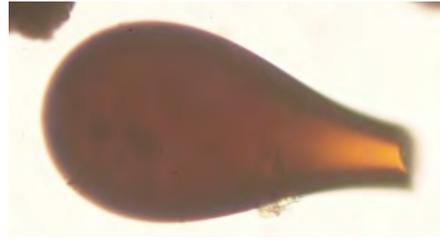
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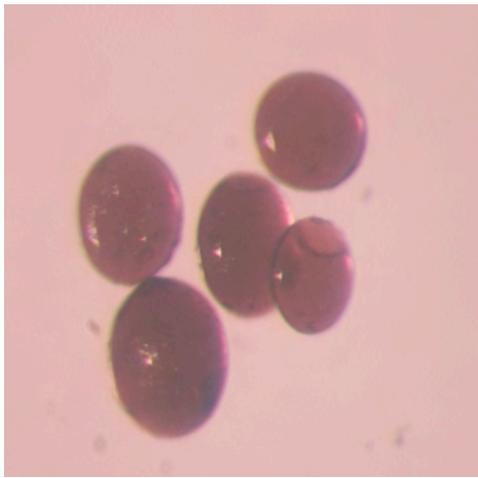
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C.

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Fig. 1. The progression magma droplets go through during flight. Starting as spheres (A), droplets are deformed through turbulence and rotation, and may also be affected by crystal growth [5]. As a result, the magma droplets are stretched (C, D) and eventually break into two separate beads. If it cools slowly, a bead may form a sphere once again, or it may form a teardrop shape (D) if cooled quickly.
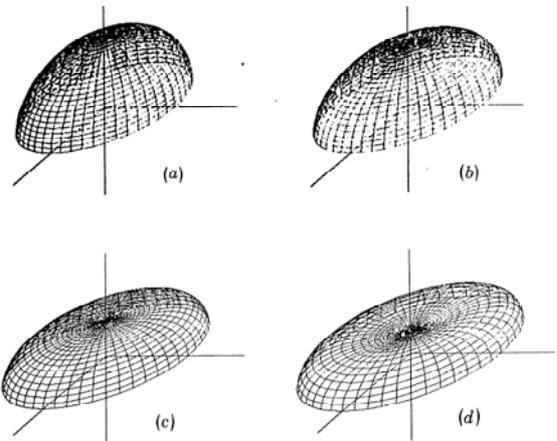
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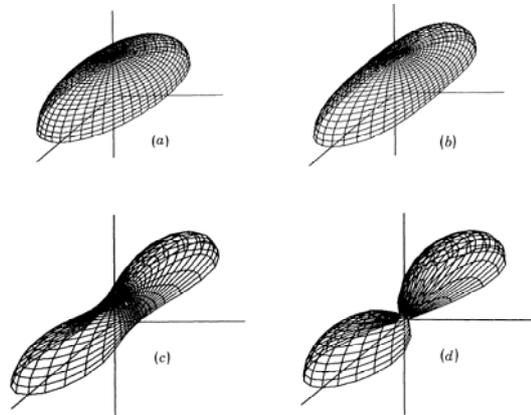
B.

Fig. 2. Shapes calculated by [6], all of which seem to accurately represent the formations seen in the Apollo 17 sample. Interestingly, the majority of the elongated, teardrop, and button shaped beads do not show any signs of ilmenite crystallization. This represents a very specific location and condition in the eruption plume where these shapes occur. The magma droplets have to be hot and malleable enough for the rotation to change their shapes, while they must also be able to cool rapidly thereafter to prevent ilmenite crystallization. These important new factors will be incorporated into an improved version of the lunar pyroclast eruption model of [7]. A (top) and B (bottom) are representations of the formations liquid drops will make while rotating in free flight.