LUNAR ROTATION AND THE DISTRIBUTION OF DARK-HALO PYROCLASTIC DEPOSITS: A CAUSE FOR ASYMMETRIC EJECTA PATTERNS;

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The source vents of some lunar pyroclastic deposits are not located at the geometric center of thier associated dark-halos. Examples of this asymmetry have been documented (1), though not explained, for the dark-halo craters in Alphonsus. Lunar Orbiter and Apollo images show that most offset vents are displaced to the east from the geometric center of their associated ejecta blanket. It can be shown that some of this asymmetry is a direct result of lunar rotation during the ballistic flight of ejecta. Pyroclastic particles on the Moon can be subjected to very long, high-altitude, flights (2). Because of this, the otherwise minor effect of lunar rotational velocity (produced by the 27.32 day rotational period) may become a pronounced component of the ballistic flight equations which describe the trajectory of an erupted particle. This trajectory is directly determined by initial eruption conditions and any modifying forces acting on the particle during flight (3,4). Modeling of ballistic trajectories has been used previously (2,5) to infer basic eruption conditions such as ejection velocity and angle; these values can themselves be used to infer critical values of magma viscosity and volatile content (1,5,6). It has been shown previously (2) that lunar ejecta can reach extremely large heights and long downrange distances of hundreds of kilometers. In the low lunar gravity such ejecta are more widely dispersed than on Earth with low diffuse volcanic constructs spread over a larger area than the familiar steep-sided cinder cones of Earth (7). In the near-vacuum environment of the Earth's moon, erupted pyroclastic particles follow near-theoretical trajectories. If one assumes a symmetric eruption column (one in which the ejection angle is equal in all azimuth directions), the resulting ejecta deposits will form a circular blanket symmetric about the central source vent. As mentioned previously however, some lunar vents are offset to the east. If it is assumed that the system of ballistic equations (3,4) describes the trajectory of an erupted particle in a *static reference frame*, then some other factor must be causing the observed asymmetry.

The Moon is, in fact, rotating and the vent/ejecta system is part of a *rotating reference frame*. The ballistic limit (L) of lunar ejecta is governed by horizontal velocity (V_l) and total flight time (t). In all but the simplest of cases, the horizontal velocity component of the particle is a function of its height relative to the surface. The rotational velocity of the Moon may be a previously overlooked factor governing the distribution lunar ejecta. The rotational velocity (V_r) of the Moon is simply $V_r=C_z/P$; where C_z=circumfrence of Moon at latitude=z and P=lunar rotation period=2,362,100 seconds. This rotational velocity is planetary in extent and varies from 0 m/s at the poles to 4.62 m/s at the equator. Since the rotational vector is possessed by all volcanic vents at the time of eruption, it must be transmitted to any ejecta as a horizontal, east-directed velocity component tangent to the surface. If this component (V_r) is added to the horizontal vector of the ejecta (V_l) and allowed to vary with height (as required by the conservation of angular momentum), then individual ejecta particles will slow down relative to the surface. The high-altitude trajectories of many lunar ejecta clouds require long flight times of hundreds of seconds, during which the Δl (distance traveled by the vent minus the distance traveled by the ejecta) can accumulate as $\sum [V_r-V_l]t$ (see Figure 1).

Ballistic trajectories were calculated for a series of lunar eruption conditions with varying ejection velocities (50-1,500 m/s) and angles (25°-90°). The trajectories of ejecta were resolved into horizontal and vertical velocity vectors with the V_r term included for various latitudes. The addition of rotational velocity causes particles erupted on the east side of a vent to travel farther, where V_r is positive, while those erupted on the west side, where V_r is negative, travel less far than in a static reference frame. When applied through a 360° azimuth range, the modelled ejecta are deposited as a circular blanket which is offset to the east from where it would have landed in a *static* frame of reference. The ground location of the vent after a flight time=t is simply V_r(t) to the east of its original position. With this approach, one can determine the ground positions of both the vent and its ejecta at the end of a ballistic flight. The vent and the ejecta blanket will then be positioned with an offset geometric relationship. If the vent position is considered as one foci of an elipse located on the east-west axis of the ejecta blanket, its position with relation to the ejecta can be expressed as an eccentricity. An eccentricity of 1 indicates a vent located at the center of the circular ejecta blanket, while an eccentricity of 0 indicates a vent located on the perimeter of its ejecta and a negative eccentricity indicates a vent which has completely rotated out from under its own ejecta. Figure 2 illustrates the effect of varying the ejection angles and velocities used as input for the model. Eccentricity values for -13° latitude are shown. At higher latitudes the graph functions will shift upwards in value towards 1 (increasing symmetry). This graph indicates that almost all volcanic eruptions with ejection angles between 75°-90° should produce offset vent/ejecta patterns. None of the modeled eruption conditions produced a negative eccentricity. Such eccentricity curves may be useful for constraining eruption conditions of lunar pyroclastic vents. The eccentricity of several dark-halo craters in Alphonsus was measured to average 0.66. These craters are located near latitude -13° and have dark-halos with radii ranging from 3 to 5 kilometers. When the 0.66 value is superimposed on an eccentricity graph (the horizontal line in figure 2) for this latitude, the points where the line cuts the calculated curves represents the upper and lower bounds for the eruption angles and velocities which could have produced such a geometric relationship. By calculating the ballistic limits for this latitude and comparing them to the observed ejecta radii, one can arrive at a unique value of ejection angle and velocity (although the .66 eccentricity line also cuts the graph at 1,000 m/s, such a velocity would produce a deposit tens of kilometers in radius which is not the case here). Thus, a 75° eruption angle with a velocity of 90 m/s would produce an Alphonsus dark-halo crater with a radius of 3.5 kilometers. Using a different approach, Head and Wilson (1) estimated volatile contents and predicted eruption velocities of 80 m/s for the Alphonsus dark-halo craters, a figure in close agreement with the 90 m/s value predicted by eccentricity modeling.

The Moon undoubtedly rotates and as such this velocity vector must be imparted to any erupted particles. By including this vector in ballistic equations of lunar trajectories it is seen that virtually all non-polar ejecta will be affected to a greater or lesser degree. The offset arising from near-equator eruptions is so large that asymmetry of ejecta to vents is required in every case. A symmetric vent/ejecta pattern near the equator may in fact be indicitive of an asymmetric eruption. Such rotational offsets should be observable on any rotating planet which simultaneously lacks an atmosphere and hosts volcanism.

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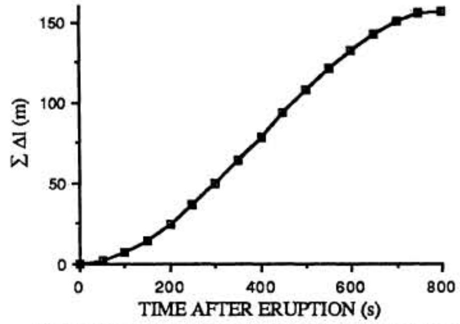

Figure 1: Difference in horizontal distance traveled by vent and ejecta (see text).

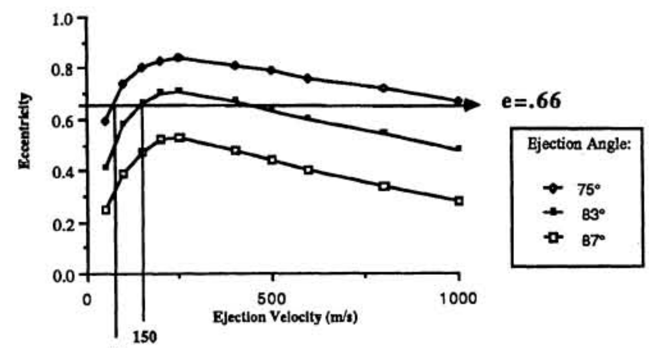

Figure 2: Eccentricity curves for -13° latitude. The horizontal line represents the measured eccentricities of four Alphonsus dark-halo craters.