A MODEL FOR THE ORIGIN OF THE DARK RING AT ORIENTALE BASIN. S.M. Baloga[1], L.S. Glaze[1], and P. D. Spudis[2], [1]Proxemy Research (14300 Gallant Fox Lane, Suite 225, Bowie, MD 20715; steve@proxemy.com,) [2]Johns Hopkins University Applied Physics Laboratory (Laurel, MD).

Introduction: We have investigated some plausible formation mechanisms for the dark ring at Orientale on the Moon. Figure 1 shows an image of the dark ring derived from Clementine data. The diameter of this deposit is approximately 175 km [1]. One possible formative mechanism based on Lunar Orbiter imaging is that this feature was produced by an annular set of volcanic vents associated with a pre-Orientale structure [2]. Subsequent analysis of Galileo images supported the notion of multiple local pyroclastic events by the reactivation of zones of weakness [3]. An alternative possibility is that the dark ring is a pyroclastic deposit from a single, central vent eruption [1]. The potential source is an elongate feature roughly near the center of the ring. The appearance of the dark annular deposit does in fact resemble Promethean style Io deposits (with colors reversed) and comparable physics is indeed suggested.

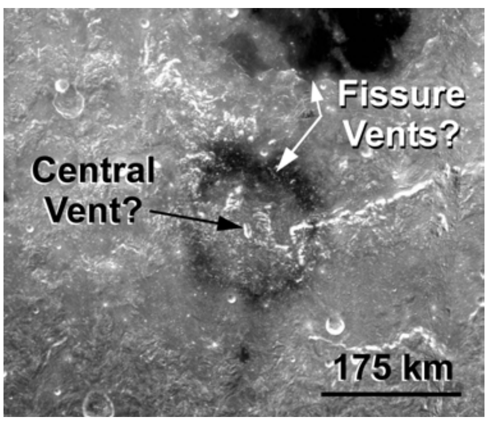

Figure 1. Dark ring SW of Orientale Basin.

The location of the central vent analyzed by Head et al. [1] can be seen in Figure 1. However, based on detailed examination of the annulus, there are many features around the annulus that could indeed be putative fissures. Due to the irregularity and asymmetry of the dark ring, we consider the distributed source hypothesis just as viable as the single central vent concept, in spite of its resemblance to the Prometheus deposit of Io.

Approach: At issue is whether such a deposit could be formed by a single central vent source or a more widely distributed set of vents. These alternatives have significantly different implications about the nature of volcanism and the subsurface. Based on the similarity to Io of both the deposit and low atmospheric density environment, we have used a stochastic-ballistic emplacement model to explore alternative formation mechanisms for the Orientale deposit. The stochastic-ballistic model has been used for many years to address the deposition of volcanic plume products on Io (e.g., Prometheus) and the bright conforming deposits around lava flows that have been called "auras" [4, 5, 6, 7]. This approach relates the areal density of 'airfall' deposits (e.g., as measured by brightness) to the physics of eruption or source conditions. Such source conditions include the distribution of energies, mass fluxes, ejection angles and so forth. This model divides a plume into two regions, a 'stochastic region' near the vent where many types of random effects influence the motion of plume effluents, and an outer region where transport of particles follows ballistic trajectories. Because the physical processes of ejection are very complicated, probability distributions are used as boundary conditions to the ballistic regime. In practice, we work backward from areal brightness distributions to the distributions of energies, momenta, and ejection angles at the source.

The stochastic-ballistic theory can be applied to a single point source, or to extended sources such as lava flow auras on Io, or potential distributed vents at Orientale. In principal, the extension of the stochastic-ballistic model to extended sources seems straightforward. One simply treats each pixel that could be the source of volatiles as a miniature plume, then sums all the contributions as shown in Figure 2. However, two major difficulties must be overcome to obtain a reliable way of doing this summation.

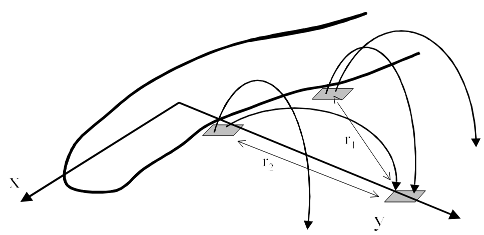

Figure 2. Stochastic-ballistic deposit from two typical pixels along an extended source.

First, the applications to volcanic plumes [4] uses a 'differential' formulation that produces mathematical artifacts called 'singularities' where the areal density becomes infinite and non-physical. This problem is overcome with a 'cumulative probability' formulation that uses integrals instead of differentials to remove these artificial singularities. The analytic reformulation accommodates arbitrary distributions of energies, momenta and ejection angles.

The second issue concerns the algorithm for performing the summation of contributions to each pixel. The problem is that cylindrically symmetric source distributions of different intensities, orientations, and distances must be combined into an arbitrarily oriented square pixel. The possibilities for numerical computation errors are large.

This problem with numerical computations was overcome by developing a new algorithm that sums cylindrically symmetric functions with finite radii that may only partially cover an arbitrarily oriented square pixel in the deposit. It can be shown that this algorithm converges to exact analytic results when the resolution of images becomes perfect. We believe that this algorithm will have much wider applications than the problem we present here because such a binning problem occurs in numerous remote sensing applications. In addition, the errors for various configurations, orientations, and total pixels can be readily estimated by using prescribed test cases.

Orientale Example: Using the Clementine data shown in Figure 1, we have interpreted the degree of darkness to be a direct measure of the areal concentration of particles. We can then construct brightness transects from each potential source through the dark deposit. To compare the competing hypotheses, we have compared predicted areal concentrations to surface brightnesses for (1) a single, central, elongated vent, and (2) multiple sources around the annulus. We can then determine what kinds of energy and angular distributions are consistent with the observed Clementine brightness transects.

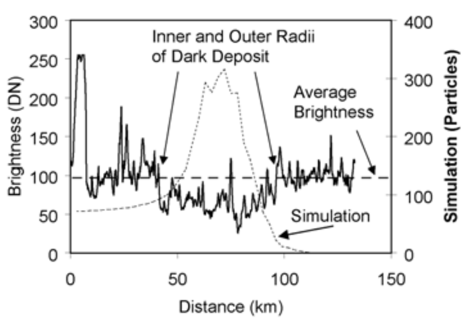

Figure 3. Typical radial brightness transect and transect for simulated deposit in Fig. 4.

As an example, here we show simulations for a single central vent. Figure 3 shows a typical brightness transect from a single central vent (x = 0) radially outward to a distance of approximately 140 km. Based on several such transects, the ring has an average width of approximately 43 km, centered a distance of 87 km from the central source. The average brightness in the region surrounding the annular feature is also shown (horizontal dashed line).

There are no solutions of the stochastic-ballistic model that are consistent with the Orientale deposit for an eruption at a single ejection velocity, regardless of variations in the ejection angles. However, in nature, the velocities have some distribution. If we allow the ejection speeds to have a Gaussian distribution with a small relative standard deviation (as was done in [4]), the stochastic-ballistic approach produces an annular high density deposit.

Figure 4 shows a simulation where we have chosen an average velocity resulting in a maximum radial travel distance of 105 km. The normal distribution of particle speeds has a relative standard deviation of 7%, and the maximum ejection angle of the cone at the source is 45°. The black scale bar represents the average annular radius. The white scale bar is 43 km in length, the average width of the Orientale ring.

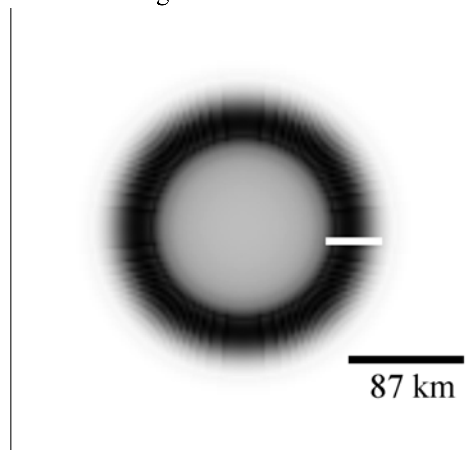

Figure 4. Single central vent simulation.

Figure 3 compares a radial transect across the simulated deposit in Figure 4 to the typical Clementine transect. The scale bar on the right side of Figure 3 indicates the number of particles that would land in a 15 x 15 Clementine pixel grid, for every million particles ejected.

The important thing to note from the comparison in Figure 3 is that the maximum particle concentration occurs at about the same radial distance as the middle of the dark ring, and the width of the simulated ring is analogous to the actual annulus.

Taken as a whole, the single point central vent scenario seems to produce a pyroclastic deposit that is consistent with the observed dark ring at Orientale. Small discrepancies between the simulation and the actual ring may be explained by asymmetry in the ejection cone or post-emplacement gardening of the regolith. This supports the hypothesis put forward by [1]. We are currently investigating what other conditions give equally plausible results.

References: [1] Head, JW et al., 2002, *JGR, 10.1029/2000JE001438* [2] Schultz, PH and PD Spudis, 1979, *LPSC X*, 2899-2918 [3] Greeley R. et al., 1993, *JGR, 98*, 17,183-17,205 [4] Glaze, LS and SM Baloga, 2000, *JGR, 105,* 17,579-17,588 [5] Baloga, SM and LS Glaze, 2001, *LPSC XXXII*, #1306 [6] Baloga, SM, et al., 1982, *Bull Am Astr Soc, 14*, 735 [7] Baloga, SM et al., 1983, *LPSC XIV*, 35-36.