CHARACTERISTICS OF VOLCANIC DEPOSITS ASSOCIATED WITH THE ORIENTALE BASIN FROM CHANDRAYAAN-1 MOON MINERALOGY MAPPER (M3) DATA: THE ORIENTALE DARK RING.

J. Head[1], C. Pieters[1], J. Mustard[1], M. Staid[2], L. Taylor[3], T. McCord[4], P. Isaacson[1], R. Klima[1], J. Nettles[1], J. Whitten[1], and the M3 Team. [1]Brown Univ., Providence RI 02912; [2]PSI, Tucson AZ; [3]Univ. Tenn., Knoxville TN 37996; [4]BFC, Winthrop, WA; (james_head@brown.edu).

Introduction and Background: Mare volcanic deposits provide evidence for the nature, magnitude and composition of mantle melting as a function of space and time [1] and commonly occur in the interiors of impact multi-ringed basins; mare genetic relationships to these basins is debated [2-3]. Most lunar multi-ringed impact basins have been filled with mare deposits to a substantial degree [4-7], but the ~930 km diameter Orientale basin, the youngest and most well preserved multi-ringed basin on the Moon, displays a remarkably fresh and very sparsely flooded basin interior [9-11]. Orientale provides a background template on which to analyze and assess: 1) the location, nature, characteristics and distribution of volcanic vents, 2) the location, mineralogic characteristics and affinities of the volcanic deposits, 3) the temporal relationships of the deposits with the age of the impact basin itself, and 4) the volume and relationship of mare basalt volcanism to the formation and evolution of impact basins. We use a mosaic of images at ~155 m/pxl (2.9 μm; reflected light and thermal emission) and spectra from the Moon Mineralogy Mapper (M3) experiment [12] flown onboard Chandrayaan-1 to define and characterize the array of volcanic features and their settings, building on numerous previous studies of volcanism in the Orientale region. Deposits of volcanic origin associated with the Orientale basin have six main modes of occurrence: 1) Mare Orientale itself, occurring in the central part of the basin, covering 47,000 km^2, and estimated to be ~1 km thick [9]; 2) Lacus Veris and Lacus Autumni, consisting of small lava ponds arranged in arcuate bands in the northeast part of the basin at the base of the Outer Rook and Cordillera Mountains respectively [13]; 3) the dark ring to the south of Orientale [14-16]; 4) cryptomaria in regions generally distal to the Orientale basin ejecta deposit (the Hevelius Formation and adjacent smooth plains) [17-20], 5) mare deposits on the floors of post-Orientale impact craters such as Schlüter [13], and 6) post-Orientale deposits that lap onto distal basin deposits and that often occur in the vicinity of cryptomaria [5,19]. In this study we focus on the nature of the dark ring located in the southern interior of the Orientale basin (Fig. 1).

The Low-Albedo Ring: The low-albedo ring in the south-southwest portion of the Orientale basin was originally discovered in Zond data [21-24] and interpreted to be a mare region [21,24]; subsequently it was interpreted as a series of vents associated with a 175 km diameter, inner ring of a 350 km diameter pre-Orientale basin by Schultz and Spudis [25]. In Galileo data, the dark ring has a moderate albedo and 1 μm absorption, suggesting that it is a pyroclastic deposit contaminated with older underlying Orientale basin material [18], described as favoring the interpretation of an ancient basin with associated pyroclastic vents. Pieters et al. [26] showed that the ring deposit is slightly brighter than nearside mantling deposits, has a very weak 1 μm absorption band and a relatively high UV/VIS ratio, but lower than nearside black sphere deposits. This opened the possibility of two interpretations: 1) contamination by highland material of ilmenite-rich dark mantling material such as the black beads sampled at Apollo 17 [18], or 2) the weak 1 μm band could indicate that the deposits are not homogeneous glass, but are in a crystallized form [31]. In contrast to the buried basin interpretation, later analyses of Clementine data [32-33] revealed the presence of a centrally located linear depression (Fig. 2-3) that has been interpreted as a vent for an Io-like volcanic eruption that formed a plume to create a top-down deposited pyroclastic ring dark mantle deposit (DMD) [28]. Clementine multispectral data [27] suggested that the DMD has a glass band absorption and a steep slope in the UVVIS, indicating the presence of volcanic glasses and an affinity to the Aristarchus Plateau and Alphonsus DMD; the vent walls are characterized by a noritic signature. Head et al. [28] used these data to outline a model of dike emplacement to shallow levels, degassing to produce magmatic foam, and eruption of the foam into a symmetrical spray of pyroclasts ~40 km high, producing the ~154 km-wide dark pyroclastic ring; the predicted velocities and rapid cooling times are consistent with a glassy nature of the deposit in the Clementine data [27].

Interpretations from M3 Data: The new M3 data permit us to assess further the nature of the features and deposits and the proposed models for their origin [21-29]. Especially useful is the M3 image mosaic (~155 m/pxl, 2.9 μm reflected light and thermal emission, and Sun elevation angle intermediate between Clementine and LO).

Character of the Dark Ring: M3 image data (Fig. 2) show no evidence for specific vents in the zone that is characterized by the dark ring (compare Fig. 1a, c and 2). The dark ring material seen in the Clementine and Zond data (Fig. 1a, c) appears to be uniformly draped over the underlying topography and no evidence is seen in the lower sun-illumination M3 data for ponding or flooding that might be associated with extrusive lava flows. No evidence for Aristarchus Plateau-like sinuous riles, Alphonsus-like dark-halo craters, or Hadley Rille-like linear depressions are seen in the ring itself. Craters in and adjacent to the dark ring (e.g., at 12:30 and 6:30 o'clock) appear to be impact craters that postdate the ring pear to be impact craters that postdate the ring and penetrate through the ring into underlying Orientale basin deposits (Fig. 2).

Nature of the Elongate Depression: M3 image data reveal the nature of the elongate depression in the center of the DMD (Fig. 2) and show exposed rocky material in the western wall; M3 spectra are consistent with the materials in the vent wall being noritic in nature, similar to the nearby massifs in the Outer Rook ring [30]. No morphologic evidence is seen for thick deposits of pyroclastics subduing topography on the rim of the elongate depression, nor spectral evidence of significant pyroclastics there; this is consistent with a model of an explosive venting of foam at the top of a dike and formation of an Io-like umbrella-shaped eruption plume, where accumulation dominates in a ring [28]. LOLA data [31] indicate a depth of at least 2.8 km for the elongate depression, supporting a volcanic, rather than impact origin for the crater.

Spectral Characteristics of the Deposit and Elongate Depression: Preliminary analysis of M3 spectra of the DMD confirm a pyroclastic origin but show that some of the deposits are more similar to Apollo 17 crystallized beads rather than glasses, as interpreted from Clementine data [27].

Conclusions: The new M3 data are consistent with an Io-like eruption plume model for the Orientale DMD [33] but show that Apollo 17-like crystallized beads may be more important than previously thought. Origin of the DMD from a central vent negates the requirement for a series of vents associated with a 175 km diameter, inner ring of a 350 km diameter pre-Orientale basin [30]; analysis of M3 images does not reveal specific morphologic evidence for the presence of pre-Orientale basin rings in these positions [30, Fig. 1; 34, Fig. 2] extending inside the Outer Rook Mountains.

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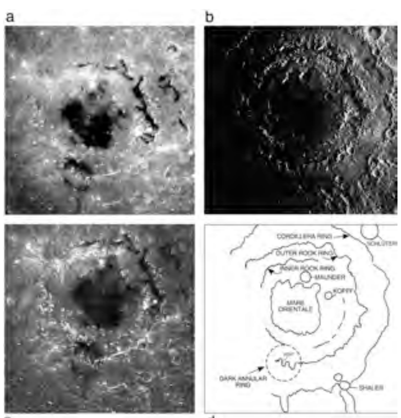

Fig.1. Orientale basin showing location of dark ring: a. Zond 8 (image 8-306); b. Lunar Orbiter (LO IV-187M); c. Clementine 750 nm mosaic; d. Sketch map showing the main characteristics of the basin and vent/ring location. (From [28]).

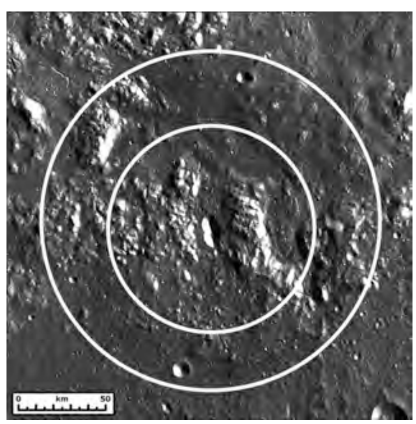

Fig. 2. Elongate depression nested in massifs of the Outer Rook (OR) Mountain ring; tow rings (60 km and ~100 km radius) enclose the dark ring seen in Fig. 1a, c). North of the massif ring the surface texture is characterized predominantly by the corrugated facies of the Maunder Formation [9-11] interpreted as impact melt lying inside the Orientale crater. South of the OR lies the domical facies (Montes Rook Formation) interpreted to be Orientale ejecta deformed during the inward collapse of the Orientale rim crest [9]. The elongated depression is interpreted to be the central vent for the dark ring deposit (Fig. 1).

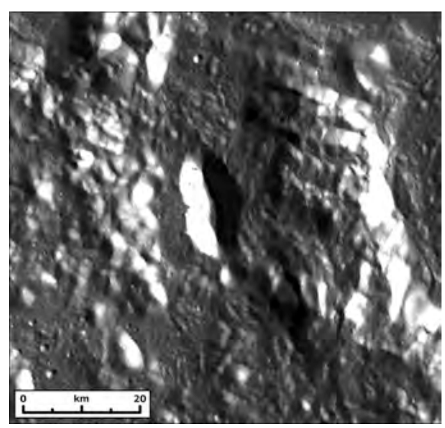

Fig. 3. Details of the interior and immediate surroundings of the elongate depression in M3 data. Exposures of noritic material are seen in the western wall of the inner depression. Little evidence is seen for extensive rim deposits, consistent with the style of explosive eruption envisioned in [28].