ANALYSIS OF ORIENTALE BASIN EJECTA AND EVIDENCE FOR MULTISTAGE EMPLACEMENT.

Z. R. Morse[1], G.R. Osinski[1] and L.L.Tornabene[1] [1]Centre for Planetary Science and Exploration/Dept. Earth Sciences, University of Western Ontario. 1151 Richmond Street, London, Ontario, Canada, N6A 5B7

Introduction: Orientale Basin is a multi-ring impact structure centered at (266.5º E, -19.5º N) on the western edge of the nearside of the Moon. It is arguably the best-preserved multi-ring basin in the Solar System [1]. The main crater rings extend approximately 300 km radially from the center of the basin, with ejecta extending an additional 800 km across the lunar surface. With new datasets available from a range of spacecraft, a number of recent studies of Orientale have been conducted; however, they have tended to focus on the central crater and rim uplifts [2, 3]. Our focus is on the ejecta deposits of Orientale with the goal of achieving a better understanding of ejecta emplacement around multi-ring basins.

The structure and facies of Orientale were previously mapped by Moore et al. [1] using images from the Lunar Orbiter IV mission. Their map details the main crater structure with three outer rings; the Inner Rook, Outer Rook, and Cordillera, as well as several distinct facies of distal ejecta. The ejecta region is separated into a concentric facies of close-range ejecta material, a radial facies interpreted to be the result of ballistic ejecta and secondary impacts, and a smooth plains facies that grades out from the radial facies [1].

Methods: High resolution, 100 m per pixel images from the Lunar Reconnaissance Orbiter's Wide Angle Camera (LRO-WAC) [4] were utilized to observe and map the various ejecta facies. While based on the map produced by Moore et al. [1], our work with this new imagery allowed for a refinement of the exact boundaries in this new facies map. Our initial analysis is thus far confined to a relatively narrow wedge of ejecta material in the southwestern region of the basin (Fig. 1). Several areas of interest were identified within, and just beyond the radial facies which show evidence of noticeably different textures within deposits that lie conformably on the radial facies (i.e., the Orientale ballistic ejecta deposits) (Fig. 1).

Using topographic data generated from scans of the lunar surface conducted with the Lunar Orbiter Laser Altimeter (LOLA), a three dimensional digital elevation model was generated to visualize the local topography. The LOLA data was sampled with 5 meter laser spots spaced 25 meters apart to provide a vertical resolution of 10 centimeters per sample point, and a horizontal resolution of 1024 pixels per degree [4]. The LROC WAC images were then overlain on this 3D framework in order to identify any relationship between various morphologies and topography, such as flow patterns of possible impact melt-bearing deposits.

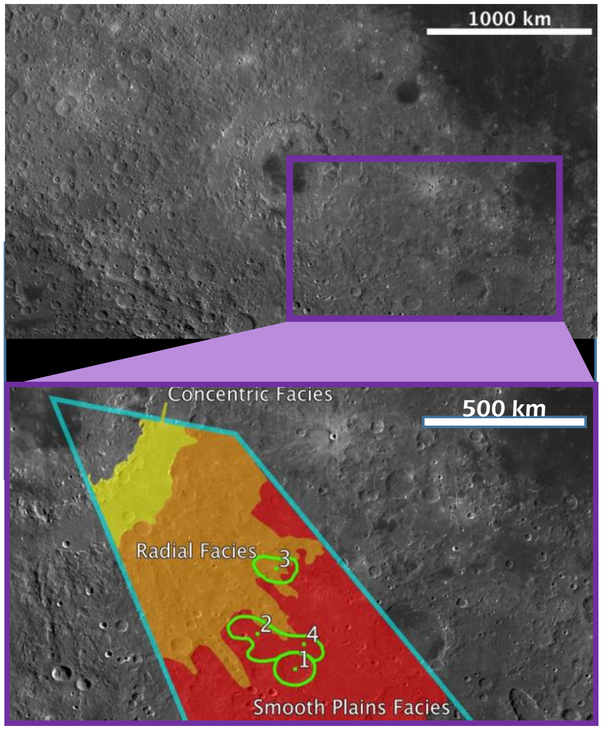

Figure 1. Ejecta facies and areas of interest (LRO WAC base image using JMARS GIS)

All analyses were conducted using the Java Mission and Analysis for Remote Sensing (JMARS) geographic information system provided by Arizona State University [5].

Results and Interpretations: Four features in the radial and smooth plains facies were identified (Table 1) that display distinct linear features consistent with the viscous fluid mass movement of molten rock (Figs. 3 & 4). These features show movement from high to low regions, following topographic lows around high elevation obstacles within their path. This morphology is consistent with the appearance and movement of large scale viscous flow structures within one radius of smaller impact craters [6]. Furthermore all of the identified structures display preferential orientation away from the center of the impact basin.

Feature Descriptions. Feature 1 appears to be a counterclockwise curving flow down a slope, into a shallow impact crater named Inghirami (291º E, -48º N) (Fig. 3). The constituent material of this feature mostly covers the floor of this older crater, filling a circular area with a diameter of approximately 71 km. Feature 2 is a larger curved feature situated along a shallow slope along the outer extent of the radial facies

Feature	Coordinates	Avg. Length	Avg. Width	Slope
1	(290.8° E, -48.5° N)	71km	71km	4.20°
2	(287.1° E, -43.9° N)	27km	120km	2.50°
3	(289.4° E, -37.5° N)	212km	32km	3.62°
4	(292.2° E, -45.2° N)	78km	42km	1.37°

Table 1. Feature Details

(Fig. 4). This feature has an average length of 27 km from high to low topography, and follows the slope for some distance, giving it a width of about 120 km. Features 3 and 4 are more linear, showing flow down shallow slopes away from the center of the impact basin. Feature 3 is approximately 212 km long. It is 20 km wide near the source and increases in width to about 44 km toward the bottom. This feature appears to split several times as it moves around high topographic obstacles. Feature 4 has a length of about 78 km and an average width of 42 km.

Discussion and Conclusions: These features display textures and a morphology that are not consistent with the hummocky appearance of ballistic ejecta or the rough secondary impact craters extending form Orientale in the radial facies. It is also clear that there are no nearby volcanic vents or lava tubes, eliminating the possible subsurface origin of these features [7]. Furthermore the distance over which these features are spread, combined with their large scale and preferential orientation away from the center of the basin, makes it unlikely that they could have been generated in any impact event other than the one that formed Orientale Basin.

The shallow slopes over which these features extend [Table 1] also point to past molten flow as the source of their texture. Other mechanisms of large-scale material movement such as slumping or dry mass wasting could only be triggered on significantly steeper slopes [8].

We therefore suggest that these four features are the solidified remains of impact melt flows that originated from the center of the basin. These deposits are seen to overlie hummocky deposits interpreted as ballistic ejecta, which, by default, requires emplacement after the initial emplacement of the ballistic ejecta. This is consistent with the emplacement of melt-rich ejecta from the crater cavity during the modification stage of crater formation and suggests that the multi-stage ejecta emplacement model proposed by Osinski et al. [8] and applied to complex craters may hold for large basin-sized events as well.

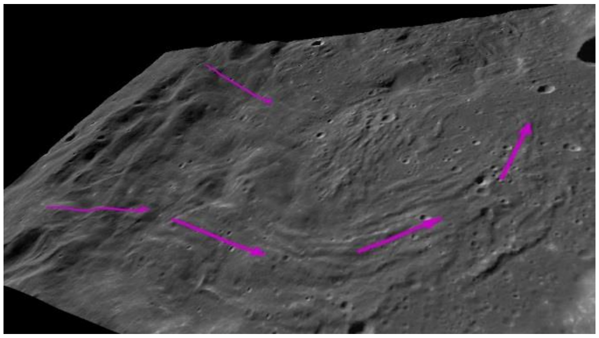

Figure 2. Flow patterns observed in feature 1

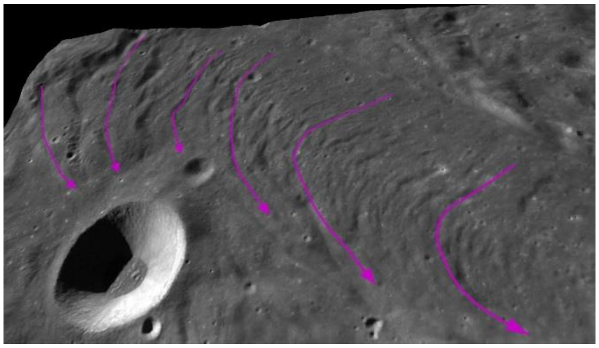

Figure 3. Flow patterns observed in feature 2

Further mapping with LRO-WAC and an investigation of the study area will be undertaken using LRO's Narrow Angle Camera images for a more detailed analysis of the features. The study area will also be expanded to include some features in the southern extent of the basin ejecta. Our initial results show evidence of ponded melt deposits that may be connected by flow channels through the radial and concentric facies to the main impact structure.

References: [1] Moore H. J. et al. (1974) *5th Lunar Conference, 1, 71–100.* [2] Vaughan et al. (2013) *Icarus, 223, 749-765.* [3] Head et al. LPSC 41, 1030, 2010. [4] Chin G. et al. (2007) *Space Sci Rev,* 129, 391–419. [5] Christensen, P.R. et al. JMARS – A Planetary GIS. [6] Hawke and Head (1977) *Impact and Explosion Cratering*, 815–841. [7] Head et al. LPSC 41, 1032, 2010. [8] Varnes (1978) Transportation Research Board Special Report, 176, 11-33. [9] Osinski et al. (2011) *Earth and Planetary Science Letters, 310, 167–181.*