NEW ESTIMATES OF THE THICKNESS DECAY OF PROXIMAL EJECTA FROM THE ORIENTALE BASIN USING THE LUNAR ORBITER LASER ALTIMETER (LOLA). C. I. Fassett[1], J. W. Head[1], D. E. Smith[2,3], M. T. Zuber[2], G. A. Neumann[3]. [1]Dept. of Geological Sciences, Brown University, Providence, RI 02912, [2]Dept. of Earth, Atmospheric, and Planetary Sciences, Massachusetts Institute of Technology, Cambridge, MA 02139, [3]Solar System Exploration Division, NASA Goddard Space Flight Center, Greenbelt, MD 20771. (Caleb_Fassett@brown.edu)

Introduction: The 930-km diameter Orientale basin is the best preserved and youngest multi-ringed impact basin on the Moon [1-5]. Emplacement of Orientale ejecta was an important surface modification process across a wide region; recent observations [6] of the crater density in the vicinity of the basin show that craters larger than 20 km were removed at a distance of up to ~500 km from main topographic rim of Orientale, the Cordillera Ring (CR). Because of its youth and preservation state, the morphometry and thickness of the ejecta deposit surrounding the basin can be directly assessed using new topographic measurements from the Lunar Orbiter Laser Altimeter (LOLA) [7].

Methods: We use three techniques to measure the thickness of Orientale ejecta. The first of these techniques relies on LOLA to measure the change in relief of pre-Orientale craters. This is similar to the approach used by Moore et al. [8], although with the benefit of far more accurate topography and more measurements (188 craters vs. 70 in [8]). The difference between the observed rim-to-floor relief in these craters and the expected relief in a fresh crater of the same size [9] represents a firm upper limit on the amount of ejecta deposited from Orientale. In general, this is an overestimate of the ejecta thickness, since most craters on the lunar surface experienced pre-Orientale degradation before the basin-forming impact. For this reason, we fit our decay profile to the lower envelope of data at a given radial range to understand the decay of ejecta thickness (Fig. 1a).

A second technique we apply to assess the thickness of ejecta is by finding the smallest crater which survived the Orientale basin-forming impact at a given radial range. Smaller craters are far more common on planetary surfaces than larger craters, and the smallest surviving crater provides information about the scale below which all pre-existing craters were erased. Translating this into a thickness estimate requires an assumption about the ‘pre-weathering’ of the population; we take a range of reasonable values and plot them as a range in Fig. 1b.

Our third approach to estimating the ejecta thickness is direct measurement of ejecta where its topography is possible to infer above a pre-Orientale surface (Fig. 1c). This method is least subject to assumptions, but is only possible at radial distances where the ejecta is relatively thin. These regions are also where ejecta thicknesses appear to be most heterogeneous, and it is not certain that lobes of ejecta at the margin of the deposit is assumed to be representative of the deposit as a whole [as discussed by 10].

Results: We combine these observations by assuming that the ejecta thickness *t* away from the Cordillera Ring can be expressed as a power law of radial range [11], non-dimensionally scaled by the radius of the Cordillera Ring (R_{CR} =465 km):

$$t = T_{CR}(r/R_{CR})^{-B}$$

We then use a nonlinear least squares fit to the data in Fig. 1, equally weighting the three measurement classes. The resulting thickness at the Cordillera Ring is T_{CR}=3500 m (±500), decaying with a power law exponent of B=2.5 (±0.5). The fit is shown as the solid line in Fig. 1; all measurement techniques provide consistent results with this average profile, although variations of a factor of ~2x in thickness exist locally.

Discussion: *Total Volume of Ejecta*: We can calculate the total volume of ejecta by integration given this power law description of the ejecta thickness. From the Cordillera Ring to one basin diameter from the rim (from r/R_{CR}=1 to 3), this implies an ejecta volume of 4 x 10^6 km^3. Beyond this range, ejecta thicknesses are not constrained by our measurements, although some ejecta is clearly deposited at greater radial range [e.g., 12]. Recognition and direct measurement of basin ejecta becomes increasingly difficult as the deposit thins and the curvature of the Moon becomes important to the thickness profile. The ejecta at the greatest radial range re-impacts with the greatest velocity, which may enhance vertical mixing and combination of Orientale ejecta and local material [13].

If the size of the transient crater is best approximated by the Outer Rook (OR) [e.g., 4], an additional ~2 x 10^6 km^3 of ejecta would have been deposited inside the basin (between the OR and CR) based on the profile we determine. The total volume of ejecta this implies is ~6 x 10^6 km^3, which is of the same order of magnitude as estimates for the volume of the transient cavity; estimates for its size range from 3 x 10^6 km^3 [14] based on gravity data, to 9 x 10^6 km^3, assuming a paraboloid cavity at the Outer Rook, with central depth of 60 km, on the basis of spectroscopic observations that suggest mainly feldspathic crustal material within

Orientale's ejecta and rings [15]. Theory and experiments suggest that the ejecta volume should be less than the transient cavity volume, perhaps by up to a factor of ~2 ([16] gives a factor of ~1.85).

Comparison with Earlier Estimates for Ejecta Decay: Our estimates of the thickness of ejecta (~3.5 km) at the Cordillera Ring agree well with the measurements of Moore et al. [8] from image analysis (their line "D"), and are larger than originally suggested by McGetchin et al. [11] (1.5-2.1 km) on the basis of scaling of smaller terrestrial and lunar craters.

The best-fit decay exponent we find of 2.5 is consistent with B=2.61, used by Petro and Pieters [17] on the basis of scaling arguments by Housen et al. [18]. Formally, our estimate is consistent with the steeper, B=3 decay used by McGetchin et al. [11] as well. However, other functional forms such as a linear decay [19] or a concave-down profile [20] are inconsistent with our data; both would imply ejecta at r/R_{CR} ~1.5 of >2 km, which is inconsistent with the preservation of a D=7.4 km (initial relief ~1750 m) pre-Orientale crater at this radial range.

Conclusion: The ejecta distribution around large basins like Orientale is of interest because ejecta can dominate local stratigraphy, contribute to the lunar megaregolith and become part of our returned sample collection (existing or future). We are currently assessing these factors in light of these measurements, as well as using the observations presented here to better understand the basin formation process itself.

References: [1] Hartmann, W.K., Yale, F.G. (1968), *Comm. LPL, 7*, 131-138. [2] Stuart-Alexander, D., Howard, K., (1970), *Icarus*, *12*, 440-456. [3] Hartmann, W.K., Wood, C.A. (1971), *The Moon, 3*, 3-78. [4] Head, J.W. (1974), *The Moon*, *11*, 327-356. [5] Wilhelms, D.E., (1987), *USGS Prof. Pap.*, 1348, 302 pp. [6] Head, J.W. et al. (2010), *Science, 329*, 1504-1507. [7] Smith, D.E. et al. (2010), *Space Sci. Rev., 150*, 209–241. [8] Moore, H.J. et al. (1974), *Proc. Lunar Sci. Conf. 5th, 1*, 71–100. [9] Pike, R. (1977), in *Impact and Explosion Cratering*, Pergamon Press, 489-509. [10] Head, J.W. et al (1975), *Proc. Lunar Sci. Conf. 6th*, 2805–2829. [11] McGetchin et al. (1973), *Earth Planet. Sci. Lett.*, 20, 226–236. [12] Ghent, R.R. et al. (2008), *Geology, 36*, 343–346. [13] Oberbeck, V.R. et al. (1975), *The Moon*, *13*, 9–26. [14] Wieczorek, M.A., Phillips, R.J (1999), *Icarus, 139*, 246–259. [15] Pieters, C.M. et al. (2009), *LPSC 40*, 2052. [16] Schultz, P.H. et al. (1981), *Proc. Lunar Sci. Conf., 12A*, 181–195. [17] Petro, N.E., Pieters, C.M (2006), *JGR, 111*, E09005. [18] Housen, K.R. et al. (1983), *JGR, 88*, 2485–2499. [19] Short, N.M., Forman, M.L. (1972), *Mod. Geol., 3*, 69–91. [20] Cordell, B.M. (1978), *Mod. Geol.*, *6*, 229–240.

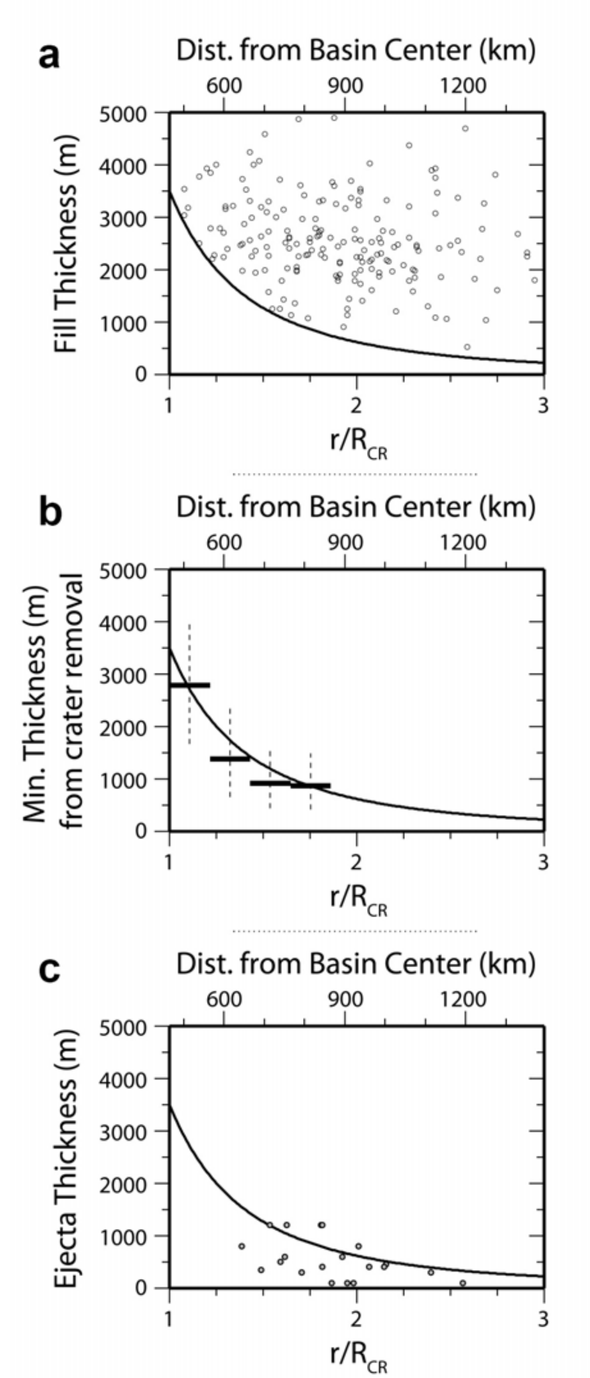

Fig. 1. (a) Radial distribution of fill within craters near Orientale based on their diminished relief, compared to fresh craters of the same size [9]. The lower envelope on the data is relied upon for fitting since most craters were likely to be somewhat degraded before the Orientale event. (b) Estimates for the thickness of ejecta on the basis of the smallest craters at various ranges. (c) Direct measurement of ejecta thickness where it is possible to infer the pre-ejecta surface. In (a)-(c), the primary x-axis is normalized by the Cordillera rim radius (R_{CR}=465 km). The black model fit to all data in (a)-(c) has ejecta thicknesses $T=3500(r/R_{CR})^{-2.5}$.