EVOLVING FLOWFIELDS FROM THE IMBRIUM AND ORIENTALE IMPACTS. P. H. Schultz[1] and S. Papamarcos[2], [1]Department of Geological Sciences, Brown University, Providence, RI 02912 (peter_schultz@brown.edu), [2]Department of Geological Sciences, University of Oregon, Eugene, OR 97403

Introduction: Early-time coupling comprises a greater fraction of crater growth as crater dimensions increase, impact angles decrease, and gravity increases [1]. A large basin formed by an oblique impact may have a transient diameter only a few projectile diameters across with the early stages of energy/momentum transfer covering more than half of crater growth, analogous to strength-controlled impacts in laboratory experiments [2]. Consequently, signatures of the early stages of coupling are expressed by the evolving stages of ejecta emplacement (direction and arrival time). Here we compare the proximal and distal ejecta grooves around the Imbrium and Orientale impact basins in order to document the evolving stages of excavation. These results are compared with similar expressions on Mars and Mercury.

Background: Secondary craters are typically modeled as produced by ejecta striking the surface at a nominal angle of 45°. Oblique trajectories, however, result in much lower ejection angles downrange and higher angles uprange [3]. As a result, downrange secondary cratering should produce scouring or secondary craters breached downrange. When projected back, such secondaries should reveal their provenance within the impact basin. In laboratory experiments, early time (higher speed ejecta) can be traced back to near the point of first contact, whereas late-time (lower speed) ejecta originate closer to the crater center [2]. Consequently, for large basins produced by an oblique trajectory, there could be an analogous pattern for their ejecta as a function of distance and direction. The Orientale and Imbrium impact basins provide test cases. The higher gravity and larger size of both Mars and Mercury allows further testing the hypothesis.

Approach: Ejecta grooves were mapped as a function of distance and azimuth around the Orientale and Imbrium basins over the entire Moon. Ejecta grooves were defined as elongated secondaries, segmented secondaries, or breached secondaries. Equally important were downrange lineations extending from these features, which indicate retained momentum after impact. As previously demonstrated [4,5], closely spaced impacts can create elongated craters with breaches and septa. Consequently, this study focused only on basin secondaries and lineations retaining a clear signature of a trajectory. Source images came from earth-based telescopes, Lunar Orbiter, Apollo (Hasselblad, Metric, and Panoramic camera), Zond, and Clementine missions. These multiple views allowed examining features with differing solar illuminations (angle and direction) and resolutions. End points for each lineation or groove were included in a GIS mapping coordinates and mapped in a variety of projections in order to identify evolving directions.

Geologic mapping of ejecta facies first provided clear evidence for the oblique trajectory (NE to SW) for the Orientale impact basin [6, 7]. Asymmetries in the distribution of massifs and a mascon offset from the geometric center were also consistent with this trajectory [9]. For Imbrium, an elongated inner massif ring and predominance of the Sculpture to the southeast are consistent with an oblique NW-SE trajectory [8, 9]. Consequently, working trajectories were used for reference for uprange/downrange and bilateral symmetry for both basins. Each mapped groove was extended as a great circle back to the each basin. The intersection between each groove extension and the adopted basin trajectory axis then defined the degree of offset between the launch position and the geometric center of the basin. Although a given secondary could have been launched from near the final basin rim, some are not radial to the basin and require an offset source (Fig. 1).

Similarly, groove extension intersected orthogonal great circles positioned at different distances uprange from the basin center (Fig.2). This strategy places limits on the position of the first contact by the basin-forming object. The different groove sets were then examined as a function of azimuth around and distance from each basin. Other large craters and basins on the Moon (as well as Mars and Mercury) exhibit similar evidence for the evolving source regions for primary ejecta. Just as uprange ejecta can be used to characterize the evolving flow field for oblique impacts [10,11], downrange ejecta grooves establish limits on the first point of contact.

Results: The global distribution of grooves and elongated secondaries from the Orientale basin are consistent with prior studies for its trajectory from the northeast toward the southwest [7, 8]. The longest grooves/chains extend downrange into the South-Pole-Aitkin Basin and to either side of the trajectory axis (northwest of Imbrium and across the western Southern Highlands). Distal grooves/chains extending back to the trajectory axis intersect uprange of the center of the Orientale basin. This sets a minimum diameter for the Orientale transient crater. The number of downrange secondaries intersecting the set orthogonal lines placed at different distances uprange rapidly decreases beyond the Cordillera scarp. Secondaries closer to the basin (within a basin radius of the rim) typically intersect the trajectory axis close to the basin center (well within the Inner Rooke Mountains). Important exceptions include long rimmed grooves breaching the Cordillera scarp and clearly not radial to the basin center. Their extensions indicate an ejection position uprange from the basin center. Later arriving ejecta deposits with clearly preserved radial flow textures extend outward from the basin rim and superpose these grooves.

Very similar patterns emerge for the distribution of secondaries/grooves from the Imbrium basin. Downrange chains/grooves form parallel sets that never cross the assumed trajectory axis, except far from the basin (Fig. 1). In other words, they appear to form parallel sets. Distal uprange chains/grooves also converge uprange from the basin center (near Sinus Iridum). Uprange secondaries are generally more circular, with breached rims away from the basin. This is consistent with higher ejection angles. Distant sets occur northeast of Crisium and northwest of Procellarum (Fig. 1). Close to Imbrium, crisscrossing grooves and secondaries occur: one set pointing uprange; the other radial to the Imbrium center.

Implications: The systematic pattern of elongated secondaries and grooves reveals an evolving source regions for ejecta launched from the basin. The most distal sets converge uprange from the basin center. Some near-rim grooves originating uprange were subsequently buried by later (and radial) ejecta deposits. It is proposed that these nonradial sets originated near the region of contact between the impactor and the Moon. Parallel groove sets provide a constraint on the maximum diameter of the impacting object. For Imbrium, this diameter is about 275km (Fig.2).

Based on comparisons with laboratory experiments, intense scouring by impactor fragments also occurred downrange, *prior to* late-stage excavation. In other words, the bodies responsible for both Imbrium and Orientale created downrange depressions prior to main-stage excavation. For Orientale, this is expressed as an elongated scallop downrange. For Imbrium, such downrange scouring may have produced the depression occupied by Mare Vaporum, rather than an adjacent Nectarian basin. Ejecta-produced scours cross the Imbrium rim (Apennines) and also can be identified on the interior collapsed rim (Apennine bench).

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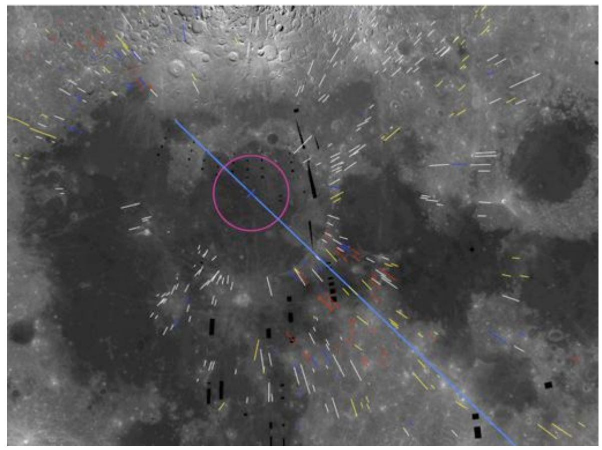

Figure 1: Sets of secondary grooves and elongated craters associated with the Imbrium basin. Blue line indicates proposed trajectory axis. Purple circle corresponds to 300km radius. Colors indicate convergence along the trajectory axis: white near radial; yellow downrange; blue uprange; red = sub-parallel to trajectory axis.

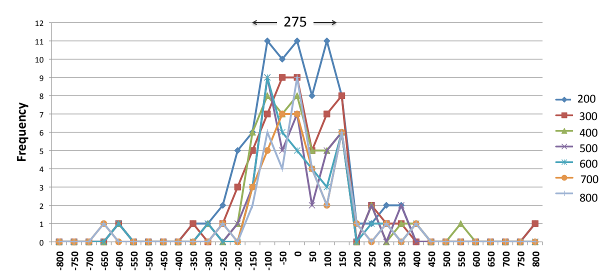

Figure 2: Proposed diameter of Imbrium impactor based on secondary grooves and elongated craters (Fig. 2) whose extensions intersect orthogonal lines positioned at different distances (200km to 800km) from basin center (shown) along trajectory axis.