LUNAR FLOOR-FRACTURED CRATERS: CLASSIFICATION, DISTRIBUTION AND IMPLICATIONS FOR MAGMATISM AND SHALLOW CRUSTAL STRUCTURE. L. M. Jozwiak[1], J. W. Head[1], G. A. Neumann[2], M. T. Zuber[3], and D. E. Smith[3]. [1]Department of Geological Sciences, Brown University, Providence, RI 02912 (lauren_jozwiak@brown.edu). [2]Solar System Exploration Division, NASA Goddard Space Flight Center, Greenbelt, MD 20771. [3]Department of Earth, Atmospheric, and Planetary Sciences, MIT, Cambridge, MA 02139.

Introduction: Floor-fractured craters (FFCs) are a class of lunar craters defined by their distinctly shallow, often platelike floors, and combinations of radial, concentric, and polygonal floor-fractures; a variety of other interior features are often observed, such as moats, ridges, small dark-haloed pits, and patches of mare material. They were first classified by Schultz [1] , who recognized eight overall types of floor-fractured crater. These eight subtypes have widely differing appearences, a factor that could provide insight into formation mechanisms (different manifestations of the same mechanism, or indicators of varying formation mechanisms).

Two formation mechanisms for FFCs were initially proposed: 1) magmatic intrusion [1], in which magma rising toward the surface in dikes encountered low-density breccia lenses beneath crater floors and spread laterally to form sills, raising and fractuiring the crater floor. 2) viscous relaxation [2], in which the properties of the crust permitted viscous flow in the vicinity of the crater, causing long-wavelength relaxation of the topography and uplift and fracturing of the crater floor.

Critical to distinguishing between these two end-member hypotheses and identifying others is a quantative assessment of the topography of FFCs and knowledge of their regional and local settings. The purpose of this study is to use newly available Lunar Reconnaissance Orbiter (LRO) Lunar Orbiter Laser Altimeter (LOLA) altimeter and Lunar Reconnaissance Orbiter Camera (LROC) image data to provide an updated global catalog of the locations, classes, morphometric and morphologic characteristcs of all lunar floor-fractured craters. We use the excellent 8-class system initially described in Schultz [1] as a starting point for classification and the enhanced LOLA/LROC data sets to examine and categorize all FFCs; we found evidence for a new FFC class, discernably different from the previously existing types. Our approach, and the global categorization of all FFCs, permits the spatial distribution of each FFC-subtype to be plotted and assessed allowing for further investigation into FFC formation mechanisms. Upon completion, the data set will be made available on our web site at http://www.planetary.brown.edu/html_pages/data.htm.

Methods: LOLA topography and LROC-WAC images were analyzed in ArcGIS. Using Schultz [1] as an initial reference, several exemplary craters from each type were analyzed for overall group characteristics, and to establish the breadth of characteristics that encompass a specific subtype. The initial global map of FFC distribution [1] served to demonstrate the proximity of FFCs to the lunar maria and to show their global distribution, but did not distinguish the location of FFC-subtypes or provide a global database. We thus undertook a global survey of the LROC Wide-Angle Camera (WAC) data base to identify those FFCs in [1] and to locate the presence of any additional FFCs. Using the enhanced classification characteristics of this analysis, all lunar FFCs were assigned a category, and their location, diameter, and name were recorded, generating the global catalogue of all observerd FFCs (Fig. 1). From this catalogue, distribution maps for the individual types of FFCs were made, allowing trends in location to be observed (Fig. 4-5). These trends were then compared to the characteristics of each type for insights into modes of formation.

Analysis: Image and topography data were compared to the predicted features that would be caused by various formation mechanisms (e.g., [1,2]) (Figs. 2-3). For example, viscous relaxation is predicted to cause a shallowing of crater floors (Fig. 2), and general subduing of topography, especially long-wavelength topography, as a result of higher thermal gradients [2,3,4]. Half-space models [3,4] of viscous relaxation modification of crater walls are unable to reproduce moat features seen in the two largest FFC classes (3 and 4). For the amount of shallowing observed in FFCs, these models also predict a noticeable degradation in the height of the crater rim crest; however, one of the characteristics of FFCs is a rim-crest height comparable to that of an unmodified crater of the same size (Fig. 3). LOLA topographic profiles of FFC floors show a mostly level floor, unaffected by regional slopes; although viscous relaxation would not depend on regional topography, it would be likely to reflect it, whereas laccolith formation would be likely to erase regional topography on the crater floor, and produce a relatively level plane above the intrusion.

Depending on the size of the underlying intrusion, laccolith formation would also have a distinct effect on crater floor morphology. Large scale (thick) intrusions, or ones that intrude very shallowly below the overlying crater floor produce enough force to cause a piston-like uplift in the crater floor. This can be best seen in the flat floored, large Class 1 FFCs (Fig. 1), and also the Class 3 FFCs (Fig. 4) which are located within the mare and along the mare edges. As the intrusions become smaller (thinner), or deeper below the overlying crater, they cause varying amounts of flexure in the overlying crust, with the resulting floor fractures being predominantly concentric. This manifestation can be observed in the morphology of Classes 2 and 4, with their often-convex floors, and well-developed concentric fractures. From the distribution maps (Figs. 1, 4, 5), one can see an evolution in crater type as one moves away from the mare and into the highlands, from flat-floored, occasionally mare-flooded Class 3 craters at the edge (Fig. 4), to the much smaller and more irregular Class 4 FFCs in the lunar highlands (Fig. 5).

Theoretical magma overpressures were calculated for representative craters in each class using the method of [5]. To a first order, the pressures calculated from the models are feasible [see also 6], and of the proper magnitude to allow for dike propagation within the lunar crust without actually breaching the crust [7]. More significantly, they correspond logically to the observed characteristics of the intrusion. For example, very shallow, plate-floored type 3 FFCs are primarily along the immediate edges of the mare (Fig. 4) and have theoretical intrusion overpressures great enough to cause piston like uplift of the overlying floor. Whereas the smaller, more amorphous, often convex type 4a FFCs are located away from the mare edges (Fig. 5) and have lower magma overpressures which would cause the overlying thicker crust to flex, but not fracture into piston-like uplift. Thus this study supports and enhances the theory of FFC formation as a result of subsurface magmatic intrusion and laccolith formation [1].

Impact Melt Related FFCs: This study introduces a new class of FFC, Class 4c, which despite sharing the V-shaped moat of all Class 4 FFCs, does not appear morphologically similar to other types of FFC. Many of these craters are located in a row, and could be modified secondaries from nearby craters and basins. Indeed, we interpret these 10-20 km craters to have been filled with impact melt which subsequently cooled and cracked, thus causing their resemblance to other classes of FFC, perhaps similar to some of the small distributed melt ponds on the Moon [8].

References: [1] P. Schultz (1976) *The Moon* 15, 241; [2] Z. Danes (1965) *Astrogeologic Studies, Annu. Prog. Rep. A,* 81; [3] A. Dombard and J. Gillis (2001) *JGR* 106, 27901; [4] J. Hall et al. (1981) *JGR* 86, 9537; [5] A. Johnson and D. Pollard (1973) *Tectonophysics* 18, 261; [6] R. Wichman and P. Schultz (1995) *JGR* 100, 3233; [7] J. Head and L. Wilson (1992) *G&CA* 55, 2155; [8] M.S. Robinson (2011) *LPSC XLII*, 2511.

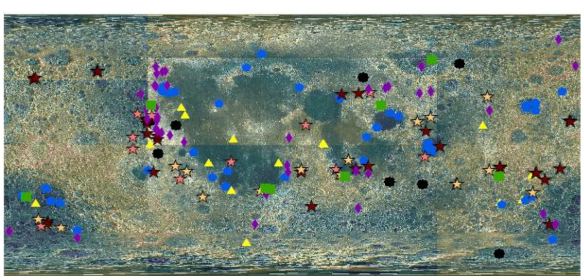

Fig. 1. Global distribution of FFCs (equal area projection). Class 1-Black circles. Class 2- yellow triangles. Class 3-Blue hexagons. Class 4- Stars (4a-red, 4b-salmon, 4c-peach). Class 5- Purple Diamonds. Class 6- Green Squares.

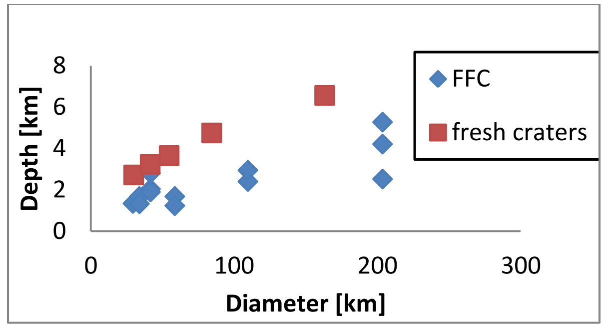

Fig. 2. Depth v. Diameter relationship for FFCs plotted the same relationship for fresh craters of comparable diameter. Note the distinctly shallower trend followed by the FFCs.

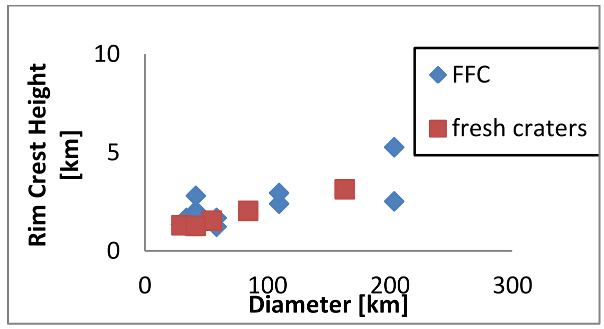

Fig. 3. Rim Crest Height v. Diameter for Floor Fractured Craters and for fresh craters of comparable diameter; they follow the same trend, implying the formation mechanism altered only the crater floor and not the overall crater shape.

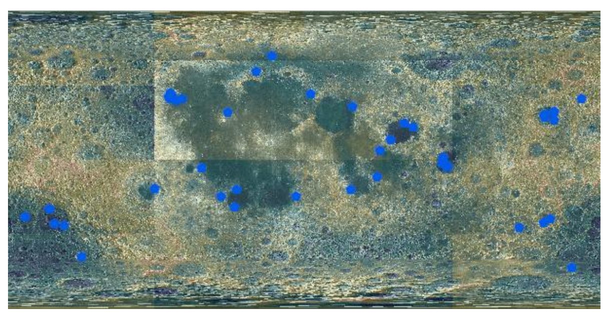

Fig. 4. Distribution of Class 3 FFCs. These cluster at maria edges, have extremely flat floors, wide moat-like features, and diameters ~30-60 km; type example, Gassendi.

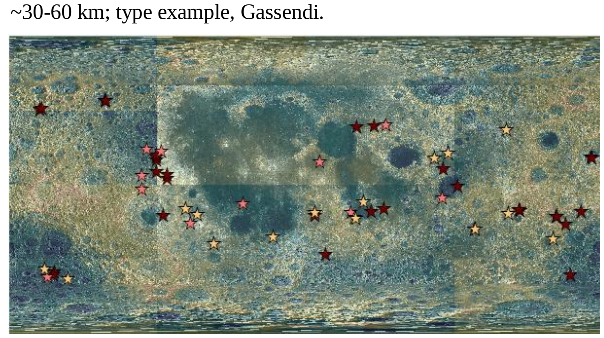

Fig. 5. Distribution of Class 4 (types a,b, and c) FFCs. Note distance from mare edges, especialy the crater cluster W of Oceanus Procellarum. Class 4 are small (average ~10-30 km); all share a pronounced V-shaped moat; examples Bohnenberger (4a) and Gaudibert (4b).