MULTI-RING BASINS: WHERE AND HOW TO BEST DETERMINE THEIR STRUCTURE

R. W. K. Potter[1], P. H. Donohue[2], Z. E. Gallegos[3], N. P. Hammond[4], D. A. Kring[5], [1]Impacts and Astromaterials Research Centre, Dept. Earth Science and Engineering, Imperial College London, London, UK, ross.potter04@imperial.ac.uk; [2]University of Notre Dame, Notre Dame, IN, USA, [3]University of New Mexico, Albuquerque, NM, USA, [4]University of California, Santa Cruz, CA, USA, [5]Lunar and Planetary Institute, Houston, TX, USA

Introduction: Multi-ring basins are the largest form of impact structure. They are present throughout the Solar System, with the majority thought to have formed during a Lunar Cataclysm which ended ~3.9 Ga [1]. Models of their structure and formation are based on smaller (complex) craters [*e.g.* 2]; the reliability of this linkage is questionable.

Terrestrial processes such as plate tectonics and erosion have severely eroded possible multi-ring basins on Earth, making it a poor laboratory for their study. Fortunately, Earth's Moon preserves a large number of multi-ring basins. This, coupled with its proximity to Earth, makes the Moon an ideal laboratory for studying and sampling multi-ring basins [3].

A recent NRC report [3] outlined science priorities for the Moon and included the goal (#6b) to determine the structure of lunar multi-ring basins so that they can serve as proxies for multi-ring basins throughout the Solar System. We, thus, initiated a study of the lunar surface to determine where that goal can be met.

Data Collection Techniques: A successful exploration study must sample multi-ring basins in ways that test and discriminate between existing models [*e.g.* 4-6] for their formation. How can this be done? Geological sampling of boulders and outcrops would provide a measure of lithologies, their source regions, and how the rock was transported during the basin-forming event. Seismic surveying could possibly be carried out, depending on the site locality, to infer the subsurface structure. At the same time, quantitative basin data should be collected, if possible, to determine features such as melt sheet thickness and transient crater diameter allowing re-evaluation of scaling laws. Many basins do not have a definitive age; return of rock samples would be vital to help constrain basin ages and, therefore, the timing and length of the LHB.

Methods and Selection Criteria: A total of 53 basins [7-10] were considered in this study and evaluated based on specific criteria and attributes (outlined below) to identify the most suitable sites for determining multi-ring basin structure.

Temporal distribution: Relative age dating suggests all lunar multi-ring basins are older than ~3.8 Ga. Pre-Nectarian basins (~4.5-3.92 Ga) are the oldest and consequently the most degraded due to processes such as viscous relaxation [11] which smooths out their characteristic features. It is therefore desirable to sample 'young' basins (*e.g.* Nectarian and Imbrian-aged) which are (relatively) well-preserved and have maintained their topographic and structural attributes.

Rings: We further limit good study sites to basins that have at least three rings and/or one ring outside the main crater rim (the defining feature of a multi-ring basin).

Certainty: Not all basins are identified as impact structures with the same level of confidence; we examined only those basins of [7] categorized as having a definite impact origin.

Geographical distribution: [12] divided the Moon into three crustal terranes: Procellarum KREEP, Feldspathic Highlands and South Pole-Aitken. Multi-ring basins are distributed over the entire lunar surface

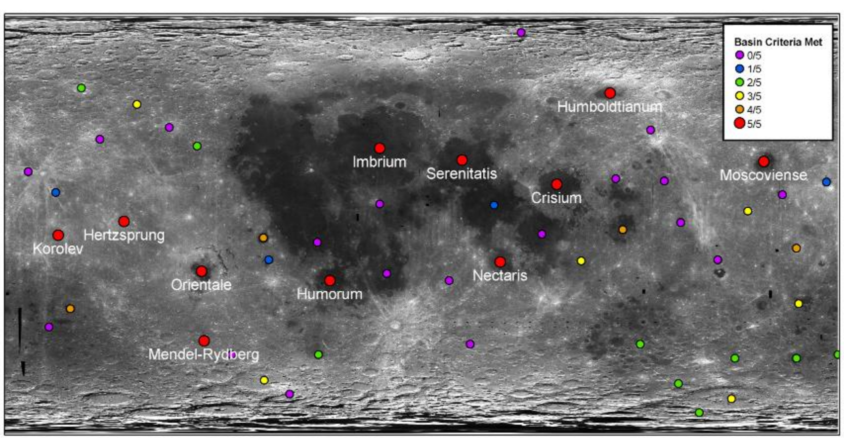
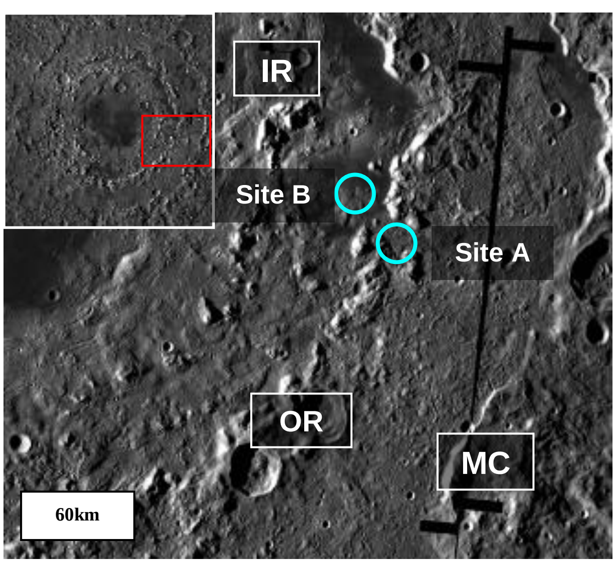


Figure 1: The spatial distribution of lunar multi-ring basins. Basins are colored by the number of criteria met for determining basin structure. Criteria used were: age, certainty, and rings (divided into number ($\geq$ 3), presence of peak ring and presence of outer ring). Named basins are the highest priority for sampling.

and, as a consequence, were produced within these differing crustal terranes. Thus, an exploration program that samples and compares basins in different terranes would produce the most insights.

Results: A total of 11 basins were found to satisfy these criteria (Fig. 1). Of these 11 basins, Orientale (930 km diameter) is the highest priority site for study due to its relatively young age, number of rings, and well-preserved structure. Other basins (particularly those indicated in red in Fig. 1) could be visited, though fewer attributes would be available for study.

Case Study: To illustrate how a mission to Orientale could enhance our understanding of multi-ring basins, we examine a potential landing site at the Outer Rook Ring within the Orientale Basin (Fig. 2). This location has been chosen because the Outer Rook Ring is, depending on the model, believed to represent the main crater rim [4] or peak ring [13]. Two sites are highlighted: Site A is located within a gap in the Outer Rook Ring. Here, sampling of the northern or southern flank of the ring massif could be undertaken. The gradient of the northern slope is 18°, easily within the capabilities of a lunar rover, which would allow the sampling of outcrops and boulders on the top and at the base of the massif. Structure and composition can, therefore, be inferred and used to test existing models for multi-ring basins. Site B is located inside the Outer Rook, and provides access to smaller massifs within an area containing an elevated Fe content. This could represent lower crustal material [14]; sampling this material, as well as that in the smaller massifs, could define the excavation depth. Studies at these two sites would, therefore, help to define the nature of the Outer Rook Ring, as well as the structural features of multi-ring basins.



Limitations: Based on current mission architecture [15], crew are limited to a 10 km exploration radius. This means only one main basin feature, *e.g.* one ring structure, could be sampled in a single mission. Multi-rover mission scenarios with much longer driving distances are being explored and if this radius was increased to a minimum of 35 km, then two ring structures can be sampled at Orientale.

Summary: To address science goal 6b of [3], 11 multi-ring basins are suitable mission targets. Of these, Orientale Basin is the highest priority due to its preservation, age, and number of attributes available for discrimination amongst hypotheses. A successful mission would entail sampling and geologic mapping of lithologies and any faults, but might be augmented by seismic surveying. Current mission architecture limits the distance and, therefore, the number of sites which can be visited during a single mission to a multi-ring basin, nevertheless vital field data can be collected at single sites if well-designed like those in Fig. 2.

Acknowledgements: This work was part of the 2010 LPI Lunar Exploration Summer Intern Program supported by the NLSI Center for Lunar Science and Exploration. We thank LPI staff for their help and support.

References: [1] Tera, F. et al (1974) *EPSL*, 22, 1-21 [2] Cintala, M. J. & Grieve, R. A. F. (1998) *MAPS*, 33, 889-912 [3] NRC (2007) *The Scientific Context for the Exploration of the Moon*, National Academies Press, Washington, D. C. [4] Head, J. W. (1974) *The Moon*, 11, 327-356 [5] Brittan, J. et al (1999) In: *GSA Spec. Pap*. 339, 269-280 [6] Head, J. W. (2010) *GRL*, 37, L02203 [7] Wilhelms, D.E. (1987) *The Geological History of the Moon*, U.S. Government Printing Office, Washington, D. C. [8] Pike, R. J. and Spudis, P. D. (1987) *Earth, Moon, and Planets*, 39, 129-194 [9] Spudis, P. D. (1993) *The Geology of Multi-Ring Basins*, Cambridge University Press, Cambridge [10] Cook, A. C. et al (2000) *LPSC XXXI*, #1978 [11] Hikida, H. & Wieczorek, M. A. (2007) *Icarus*, 192, 150-166 [12] Jolliff, B. L. et al (2000) *JGR*, 105, 4197-4216 [13] Hodges, C. A. & Wilhelms, D. E. (1978) *Icarus*, 34, 294-323 [14] Head, J. W. et al (1993) *JGR*, 98, 17149-17181 [15] Kring, D. A. (2010) Pers. Comm., July 2010

Figure 2 (left): Two example sampling localities (turquoise circles, 10 km exploration radii) in the vicinity of Orientale's Outer Ring. Site A is located in a gap between the Outer ring (OR), site B is located between the Inner (IR) and Outer Rook rings. MC = Montes Cordillera. The two sites are approximately 20 km apart (Base image: LROC WAC mosaic of Orientale Basin. Geometry Test, 6 June 2010, Arizona State University).