Mission Strategies for Determining the Vertical Extent and Structure of the Lunar Megaregolith. J.-F.
Blanchette-Guertin[1], C. E. Jilly[2], J. Flahaut[3], A.L. Souchon[4,5], P. Sharma[6] and D. A. Kring[7]. [1]Department of Earth
and Ocean Sciences, University of British Columbia, Vancouver BC V6T 1Z4, Canada (jguertin@eos.ubc.ca),
[2]Hawaii Institute of Geophysics & Planetology, University of Hawai'i at Manoa, Honolulu, HI 96822, [3]Laboratoire
des Sciences de la Terre, UMR CNRS 5570, École Normale Supérieure de Lyon/ Université Claude Bernard, 2 rue
Raphaël Dubois, 696222 Villeurbanne Cedex, France, [4]DTP/IRAP, Observatoire Midi-Pyrénées (OMP), CNRS
(Toulouse, France), [5]Observatoire Midi-Pyrénées (OMP), Université Paul Sabatier (UPS) (Toulouse, France),
[6]Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ 85721. [7]Lunar and Planetary Institute, 3600
Bay Area Boulevard, Houston, TX 77058.

Introduction: The 2007 NRC *Scientific Context for the Exploration of the Moon* [1] outlines the main science concepts to be addressed by future lunar exploration missions. Concept 3 aims at unraveling the main planetary processes that shaped the Moon by investigating the diversity of lunar crustal rocks. Assessing the vertical extent and structure of the lunar megaregolith (MR) is one of five scientific goals in Concept 3. The MR is the product of more than 4.5 Gy of surface impacts and studying it could yield invaluable information about its causes as well as its effects on the Moon's evolution. This work proposes several methods to provide ground truth to the MR thickness models, and suggests a few locations on the Moon's surface where they could be implemented.

Motivation: A more thorough understanding of the thickness and structure of the lunar MR is critical for various reasons: **(i)** It can provide information about the Moon's bombardment history; **(ii)** It will allow a better understanding of MR formation and evolution on other terrestrial bodies and on the early Earth; **(iii)** It will provide means to better analyze the current (and potentially, future) seismic data and, in turn, provide a better understanding of the subsurface structure of the Moon; **(iv)** It will provide important constraints on the thermal evolution of the Moon.

Background: The lunar MR is thought to be the product of the short-lived Late Heavy Bombardment (LHB) [2]. The large impacts responsible for the formation of the lunar basins would have excavated, mixed and fractured the lunar surface to a depth of several kilometers. This would have resulted in a highly fragmented layer composed of basin ejecta and structurally disturbed crust over a fractured crust (see Figure 1). The subsequent, smaller meteoroid impacts (post-LHB) would have pulverized and mixed the very top layer of the crust (the regolith), but would have had a negligible effect on the overall structure of the MR [2,3].

The first evidence of a highly fractured surface layer comes from the seismic data collected during the Apollo Passive Seismic Experiment (1969-1977).

The data showed intense scattering, represented in the very long-lived seismic coda, that is uncharacteristic of coherent crystalline rock in the upper 2-3 km, and especially in the upper 100 m or so [4].

All currently available estimates on the global thickness of the MR layer are based either on models of cratering processes (*e.g.*, [1,5-7]) or on orbital or Earth-based radar and photometry data (*e.g.*, [8,9]). Current estimates range from 1-2 km for nearside mare to 5-10 km for the highlands.

Target Site Requirements: Two landing site requirements were identified in order to achieve this science goal. We need to target sites that will allow for *in situ* visual and/or geophysical measurement of the extent and structure of the MR. We also need to target enough sites to collect measurements from the three main regions of the Moon (nearside mare, highlands, South Pole-Aitken Basin), as they are thought to have different MR thicknesses.

Methodology and Partial Results: Three different methods to characterize the MR have been identified.

Geological mapping of the walls or peak rings of the youngest multi-ring basins: Multi-ring basins are the largest structures on the Moon. The mechanisms of basin formation, as well as their final lateral and vertical structures are poorly understood. However, analysis of seismic and gravity data from the Chicxulub crater on Earth (best terrestrial multi-ring basin analog) suggests that peak rings are produced by the collapse of central peaks [10]. Also, spectral analysis of two rings within Orientale, the youngest lunar basin, suggests they are composed of anorthosite from the crust [11]. The topography of those rings suggests that 1.5 to 4 km depth in that crust may be exposed in those rings [12], potentially revealing the transition between the MR and the undisturbed underlying crust. It is suggested that a geological map of the youngest basins' (Orientale and Schrödinger) walls and peak rings could be a potentially useful way to determine the thickness and structure of the MR (see [13]).

Investigation of the central peaks/walls of young and fresh complex craters that have a large estimated stratigraphic uplift compared to the estimated MR thickness: The central uplift of complex craters is composed of material that comes from deep below the center of the crater [14,15]. The magnitude of the structural uplift (SU) can be estimated using the empirical relation derived in [14]. As seen in Figure 1, it is unlikely that a well-preserved base of the MR will be visible in the central peak or in the crater walls. The central peak rarely rises more than a few hundred meters above the crater floor, which is not enough to expose the entire MR layer. Also, the slumped crater walls will show repeated sections of the upper part of the MR and not necessarily all the way down to the basal contact between the MR and the undisturbed crust. However, by targeting deep craters for which the SU is greater than the estimated MR thickness, it should be possible to investigate and characterize the structure and composition of deeper levels of the MR. This would yield valuable information that can be used along other measurements (*e.g.*, seismic data) to better characterize the MR layer as a whole. Note that the interpretation of central peak features will need to be deconvolved from the inherent faulting that occurs in central uplifts. Some craters that satisfy this requirement are Copernicus (SU ~16km *vs.* ~1-2km MR thickness) and Langrenus (~25km *vs.* ~1-2km), both in the near side mare region, Tycho (~18km *vs.* ~5-10km) and Vavilov (~17km *vs.* ~5-10km), both in the highlands.

Installation of a seismometer network on the lunar surface: It is suggested to install a global network of new generation seismometers in order to get precise measurements of the absolute thickness of the MR layer at various locations on the Moon. No specific seismometer location is necessary for the scope of this assessment, but it is recommended to install seismometers over at least the three main geochemical regions of the Moon: the nearside mare region, the highlands, and the South Pole-Aitken Basin.

Conclusions: An assessment of the vertical extent and structure of the lunar MR might not be classified as one of the "Highest-Priority Science Goals" in the 2007 NRC report. However, all landing sites suggested for higher priority science goals [see 16, 17] are amenable to one or more of the methods suggested above. As such, characterization of the MR could be attempted at most landing sites of future lunar missions.

References: [1] NRC (2007) The Scientific Context for Exploration of the Moon: Final report. [2] Hartmann W.K. (1973), *Icarus*, 18(4), 634-636. [3] Head J.W. (1976) , 7th Lunar Science Conference, 3, 2913-2929. [4] Latham G. et al. (1972), 3rd LPSC, 3, 2519-2526. [5] Short N.M. and M.L Forman (1972), *Modern Geology*, 3(2), 69-91. [6] McGetchin T.R. et al. (1973), *EPSL*, 20(2), 226-236. [7] Petro N.E. and C.M. Pieters (2008), *MPS*, 43(9), 1517-1529. [8] Thompson T.W. et al. (2009), *Geology*, 37(7) 655-658. [9] Shkuratov Y.G. and N.V. Bondarenko (2001), *Icarus*, 149(2), 329-338. [10] Morgan J.V. et al. (2000), *EPSL*, 183(3), 347-354. [11] Bussey D.B.J. and P.D. Spudis (2000), *JGR*, 105(E2), 4235-4243. [12] Head J. W. (1974), *The Moon*, 11, 327-356. [13] Souchon A.L. et al. (2010), *this meeting*. [14] Cintala M.J. and R.A.F. Grieve (1998), *MPS*, 33(4), 889-912. [15] Sharma P. et al. (2010), *this meeting.* [16] Flahaut J. et al. (2010), *this meeting*. [17] Jilly C. et al. (2010), *this meeting*. [18] Hörz et al. (1991), *The Lunar Sourcebook*, 62-120.
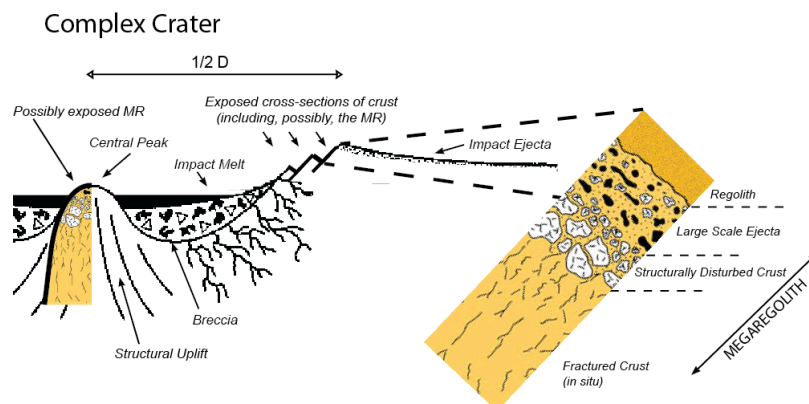
Complex Crater

Figure 1: Schematic of a complex crater structure and potential locations of MR exposure. Well-preserved complex craters could expose deeper MR layers in the crater walls, depending on the depth of exposed wall material. The MR could also be visible in the central peak, depending on the magnitude of the structural uplift and on the amount of exposed material. D is the diameter of the crater. Modified from [18].