Exploration of Planetary Crusts: A Human/Robotic Exploration Design Reference Campaign to the Lunar Orientale Basin.
James Head[1], Carle Pieters[1], David Scott[1], Brandon Johnson[1], Ross Potter[1], Jeffrey Hoffman[2], Bernard Foing[3], Lev Zelenyi[4], Igor Mitrofanov[4], Mikhail Marov[5], Alexander Basilevsky[5], Mikhail Ivanov[5], Ralf Jaumann[6], Long Xiao[7], Junichi Haruyama[8], Makiko Ohtake[8], P. Senthil Kumar[9], Oded Aharonson[10]. [1]Brown University, Providence, RI USA; [2]MIT, Cambridge, MA USA: [3]ESA ESTEC, Noordwijk, The Netherlands; [4]Institute for Space Research, RAS, Moscow, Russia; [5]Vernadsky Institute, RAS, Moscow, Russia; [6]DLR Institute of Planetary Research, Berlin, Germany; [7]China University of Geosciences, Wuhan, Hubei, China; [8]ISAS, JAXA, Sagamihara, Japan; [9]CSIR-NGRI, Hyderabad, India; [10]Weizmann Institute, Rehovot, Israel.

By the year 2050 we need to be working on fundamental scientific problems in an integrated fashion, utilizing a broad strategy for the systematic exploration of the solar system using wide ranges of technology and accomplishing our fundamental goals through international cooperation. For example, Microsymposium 56, "The Crust of the Moon: Insights Into Early Planetary Processes", (http://www.planetary.brown.edu/html_pages/micro56.htm) identified a series of outstanding problems for future international human/robotic exploration of the Moon centered on: 1. Crustal geometry/physical structure; 2. Crustal Chemistry/mineralogy/petrology; 3. Exogenic crustal modification by impacts; 4. Chronology of crustal formation/evolution. Furthermore, the nature of mantle uplift and the possibility of sampling mantle in the uplifted material as well as determining the nature of basin impact melt processes (differentiated or undifferentiated) is critically important. Direct dating of impact melt and placing Orientale in the firm context of lunar chronology is also achievable.

In response we are formulating a human/robotic exploration design reference campaign to the 930 km Orientale impact basin (1,2), the most well preserved basin on the Moon, that provides insight into all aspects of these fundamental questions. Our design reference mission is a model for the exploration of the planets in the 2050 time frame, and combines robotic exploration geophysics traverses operated radially from the basin interior, together with human exploration missions to the key sites that will provide data to address these questions. We outline six human exploration mission landing site targets using the HALO Mission Architecture concept and capabilities: 1) Base of the Cordillera ring/Montes Rook Formation; 2) Base of the Outer Rook ring/Lacus Veris maria; 3) Inner Rook peak-ring massifs/Maunder Formation impact melt rough facies 1; 4) Maunder Formation impact melt sheet smooth facies; 5) Central melt sheet craters/Mare Orientale/Kopff crater; and 6) Maunder crater interior/ejecta. Our strategy for human/robotic exploration optimization centers on six themes and is totally flexible to the important new results of significant discoveries that will be made in the next few decades:

I) Precursor (What do we need to know before we send humans?);
II) Context (What are the robotic mission requirements for final landing site selection and regional context for landing site results?);
III) Infrastructure/Operations (What specific robotic capabilities are required to optimize human scientific exploration performance?);
IV) Interpolation (How do we use robotic missions to interpolate between human traverses?);
V) Extrapolation (How do we use robotic missions to extrapolate beyond the human exploration radius?);
VI) Progeny (What targeted robotic successor missions might be sent to the region to follow up on discoveries during exploration and from post-campaign analysis?).

We use the targeted human exploration sites to illustrate how human exploration, complemented and assisted by robotic exploration, can provide insights into early planetary processes by exploring and characterizing the crust of the Moon. Our architecture provides insight into human/robotic exploration strategies for other lunar regions and other destinations on other planetary bodies.

This international design reference mission approach will assist in identifying the key technologies, including laboratory, remote sensing and in situ that will be necessary to accomplish these fundamental and broad scientific goals in the 2050 time frame. It will also serve to form the partnerships and identify the opportunities and obstacles to international synergism. Human-Robotic partnerships in science and engineering synergism (SES), such as that exemplified by the

NASA Solar System Exploration Virtual Institute (SSERVI), are absolutely essential to formulating and achieving these goals.

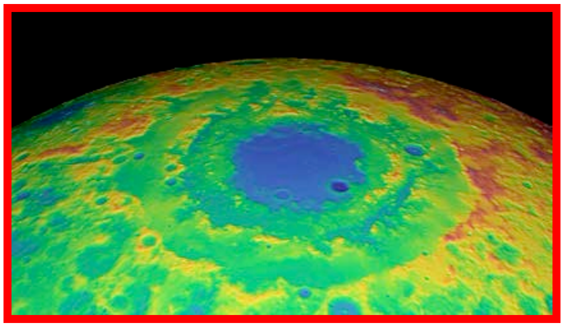

Fig. 1. Perspective view of the topography of the Orientale Basin. LRO LOLA data.

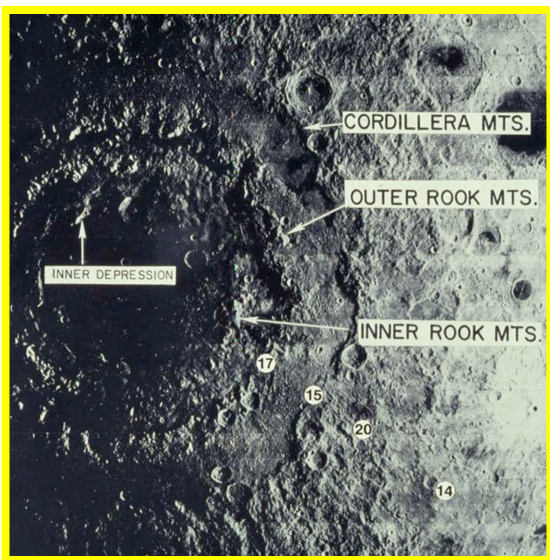

Fig. 2. The Orientale Basin from Lunar Orbiter, showing the rings and the Apollo and Luna equivalent landing site locations for the Orientale Basin.

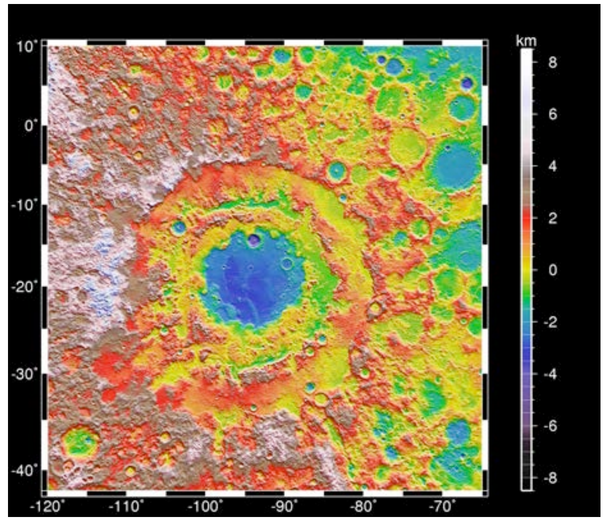

Fig. 3. LRO LOLA Topography of the Orientale Basin.

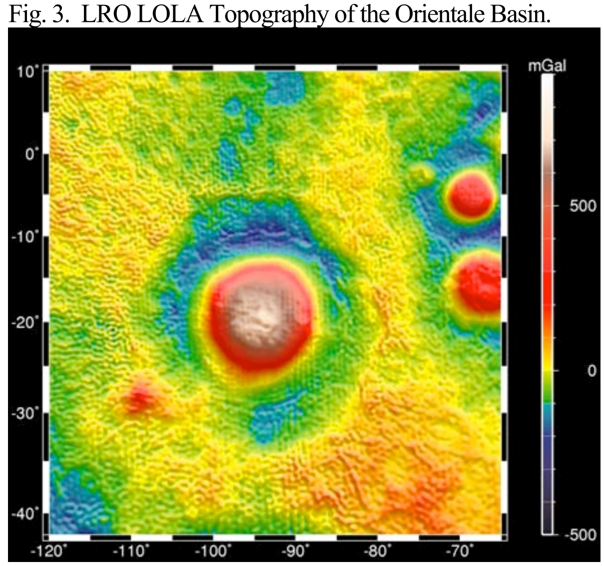

Fig. 4. GRAIL Bouguer gravity map of Orientale Basin.

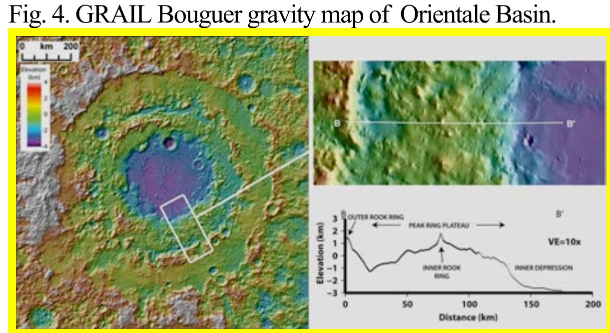

Fig. 5. Exploration Region of Interest 3 (ROI-3) for the origin of Inner Rock Mountains and Maunder Formation impact melt.

References: (1) Zuber, Maria T. et al, (2016) Gravity field of the Orientale basin from the Gravity Recovery and Interior Laboratory Mission. *Science*, 354, 438-441DOI: 10.1126/ science.aag0519. (2) Johnson, B. et al. (2016) Formation of the Orientale multiring basin, *Science*, 354, 441-444, DOI: 10.1126/science.aag0518.