Exploration of Planetary Crusts: A Human/Robotic Exploration Design Reference Campaign to the Orientale Basin

James W. Head, Carle M. Pieters and David R. Scott
Department of Earth, Environmental and Planetary Sciences, Brown University, Providence, RI 02912 USA
The Moon as a Cornerstone for Solar System Science
MICROSYMPOSIUM 56
The Crust of the Moon: Insight into Early Planetary Processes
March 14-15, 2015 - The Woodlands Waterway Marriott - The Woodlands, TX

Brown University, Vernadsky Institute, Brown-MIT NASA Solar System Exploration Research Virtual Institute (SSERVI)
These questions centered on the following five themes:

1. Crustal geometry and physical structure;
2. Crustal chemistry, mineralogy and petrology;
3. External crustal modification: The impact record;
4. Chronology of crustal formation and evolution: The lunar paradigm; and
5. What are the major outstanding problems and how do we resolve them?
Orientale Basin
Orientale Basin: Rings & Geologic Units

Hevelius Formation (Basin Ejecta Deposit)

Montes Rook Fm. (Knobby, Domical Deposits)

Maunder Formation (Basin Impact Melt Deposit)

(J. McCauley, D. Wilhelms, D. Scott, K. Howard, C. Hodges)
Fresh Crater Characteristics

Crater Depth (km)

Crater Diameter (km)

Simple Craters

Complex Craters

Peak-Ring Basins

Multi-Ring Basins

Bowl shaped

Circular rim

Terraces

Central peak

Polygonal outline

Flat floor

Swirl

(R. Pike)
Orientale: Laboratory for study of impact cratering processes
Complex crater to multi-ring basin scale
Orientale Basin:
Rings & Geologic Units

Hevelius Formation
(Basin Ejecta Deposit)

Montes Rook Fm.
(Knobby, Domical Deposit)

Maunder Formation
(Basin Impact Melt Deposit)

(J. McCauley, D. Wilhelms,
D. Scott, K. Howard, C. Hodges)
Origin of Impact Basin Rings:

-Which basin ring Most closely corresponds to the transient cavity rim crest?

(D. Smith, M. Zuber, G. Neumann et al.)
Structure and Composition of the Lunar Crust: The Magma Ocean Model

“New Views of the Moon” (2006)

Megaregolith (~10 km thick)

Upper Anorthositic Crust (~15 km thick)

Lower Noritic Crust (~25 km thick)

- Crust averages ~50 ±16 km thick.
- Upper and lower crust about equal.
- Upper crust heavily modified in the upper ~10 km by impact processes.
Hevelius Formation (Basin Ejecta Deposit)
Feldspathic breccias; homogeneous, well-mixed.

Montes Rook Fm. (Knobby, Domical Deposit)
Feldspathic breccias; some anorthosite blocks.

Maunder Formation (Basin Impact Melt Deposit)

---

Cordillera Mountains:
Feldspathic breccias; unweathered.

Outer Rook Mountains:
Norites, noritic anorthosite and anorthosite; more crystalline blocks.

Inner Rook Mountains:
Massifs are crystalline anorthosite; discrete peaks and clusters of peaks.

Maunder Formation (Basin Impact Melt Deposit)

Red Dots (Inner Rook Mountains):
Materials >~98% plagioclase (Cheek et al., 2012)

(Orientale Basin: Rings & Geologic Units)

(Pieters et al., 2009, 2011; Head et al., 2010, 2012; Cheek et al., 2012)
Maunder Formation
(Basin Impact Melt Deposit)

Orientale
Impact Melt Sea

(Wilson and Head, 2010; Vaughan et al, 2011, 2012)
Initial Time = Orientale Impact Event

(Jennifer Whitten and the M³ Team)
Secondary Crust and Relation to Impact Basins

Initial Time = Orientale Impact Event
(Jennifer Whitten and the M³ Team)
Orientale: Comparison to Nearside Mare Ages

Span of ages of volcanism similar to lunar nearside

Modified from Hiesinger et al., 2011

(Jennifer Whitten et al, JGR, 2011)
• These questions centered on the following five themes:
  • 1. Crustal geometry and physical structure;
  • 2. Crustal chemistry, mineralogy and petrology;
  • 3. External crustal modification: The impact record;
  • 4. Chronology of crustal formation and evolution: The lunar paradigm; and
  • 5. What are the major outstanding problems and how do we resolve them?
Strategy for Human/Robotic Exploration Optimization

• I) **Precursor**: (What do we need to know before we send humans?);

• II) **Context**: (What are the robotic mission requirements to provide final landing site selection and regional context for the landing site results?);

• III) **Infrastructure/Operations**: (What specific robotic capabilities are required to optimize human exploration 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 specific targeted robotic successor missions might be sent to the region to follow up on specific discoveries during exploration and from post-campaign analysis?).
Brown-MIT Science and Engineering Synergism

Determine Science Requirements:
- Full lunar access: Poles, NS/FS.
- Longer stay times: 7-14 days.
- More payload to/from Moon.
- More mobility on Moon.
- More flexibility with robots.
- Human-Robotic Partnerships.

Optimize Engineering for Science:
- KISS: Keep It Simple, Stupid.
- Start with what works: Luna/Apollo!!
- Use 40 years of technology advance.

Train the next generation:
- Develop bottom-up approach.
- Scientists and engineers work together.
- Work toward a legacy: Lasting results.

Science and Engineering Synergism: SES!
Staging the Landing Vehicle

LOID Separation

LOID Powered Descent

LL Powered Descent

Landing Site

Ballistic Trajectory

LOID Impact Distance

LL = Lunar Lander
LOID = Lunar Orbit Insertion & Descent Stage
Six Human Exploration Mission Landing Site Targets: HALO Mission Architecture Concept and Capabilities

• a) Base of Cordillera ring/Montes Rook Formation;
• b) Base of the Outer Rook ring/Lacus Veris maria;
• c) Inner Rook peak-ring massifs/crenulated Maunder Formation impact melt facies;
• d) The Maunder Formation impact melt sheet smooth facies;
• e) Central melt sheet craters/Mare Orientale/Kopff crater;
• f) Maunder crater interior and ejecta.
Six Human Exploration Mission Landing Site Targets: HALO Mission Architecture Concept and Capabilities

- a) Base of Cordillera ring/Montes Rook Formation;
- b) Base of the Outer Rook ring/Lacus Veris maria;
- c) Inner Rook peak-ring massifs/crenulated Maunder Formation impact melt facies;
- d) The Maunder Formation impact melt sheet smooth facies;
- e) Central melt sheet craters/Mare Orientale/Kopff crater;
- f) Maunder crater interior and ejecta.
Origin of the Inner Rook Mountains/Impact Melt Sheet

Red Dots (Inner Rook Mountains):
Materials >~98% plagioclase
(Cheek et al., 2012)
Lunar Orientale Basin: Past and Future Exploration
MICROSYMPOSIUM 56
The Crust of the Moon:
Insight into Early Planetary Processes
March 14-15, 2015 - The Woodlands Waterway Marriott - The Woodlands, TX

Brown University, Vernadsky Institute, Brown-MIT NASA Solar System Exploration Research Virtual Institute (SSERVI)