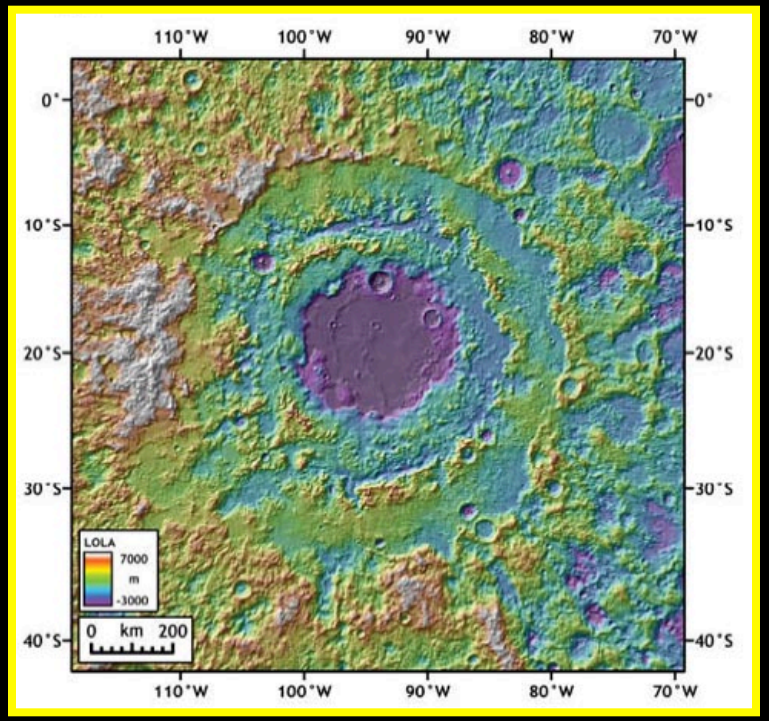
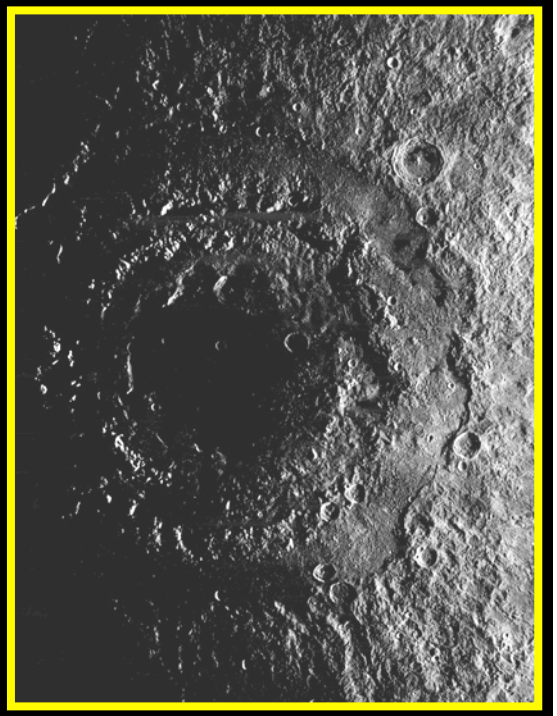
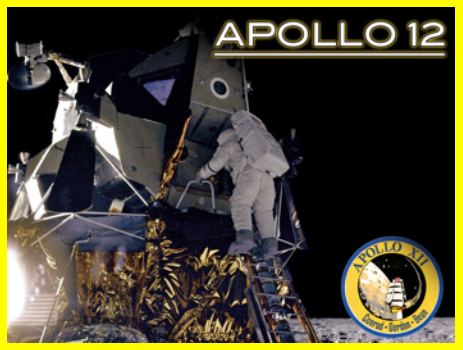
Exploration of Planetary Crusts: A Human/Robotic Exploration Design Reference Campaign to the Orientale Basin

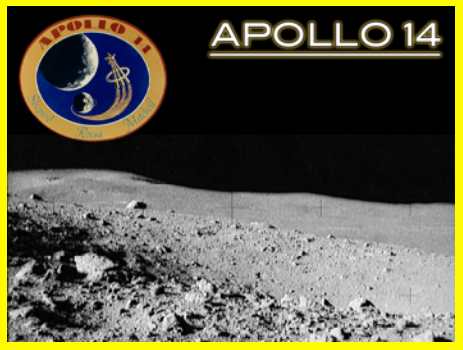


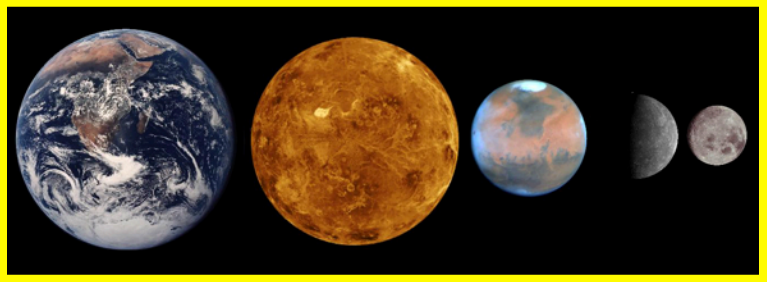


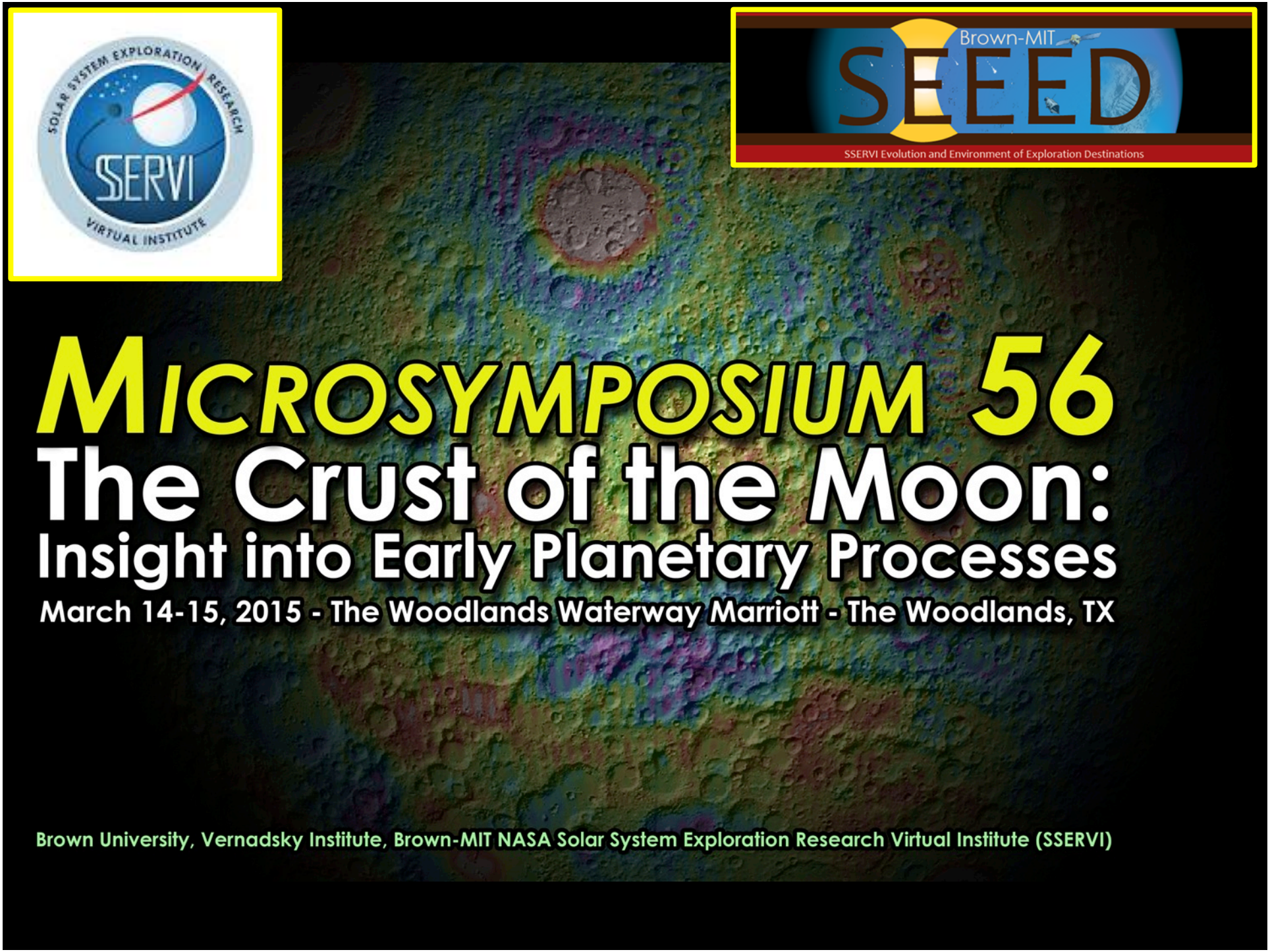
James W. Head, Carle M. Pieters and David R. Scott
Department of Earth, Environmental and Planetary Sciences,
Brown University, Providence, RI 02912 USA

The Moon as a Cornerstone for Solar System Science








SOLAR SYSTEM EXPLORATION RESEARCH
SERVI
VIRTUAL INSTITUTE
Brown-MIT
SEEED
SSERVI Evolution and Environment of Exploration Destinations
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)

Microsymposium 56,
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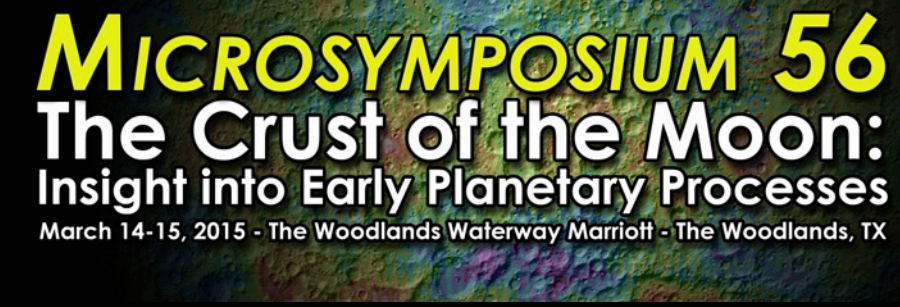

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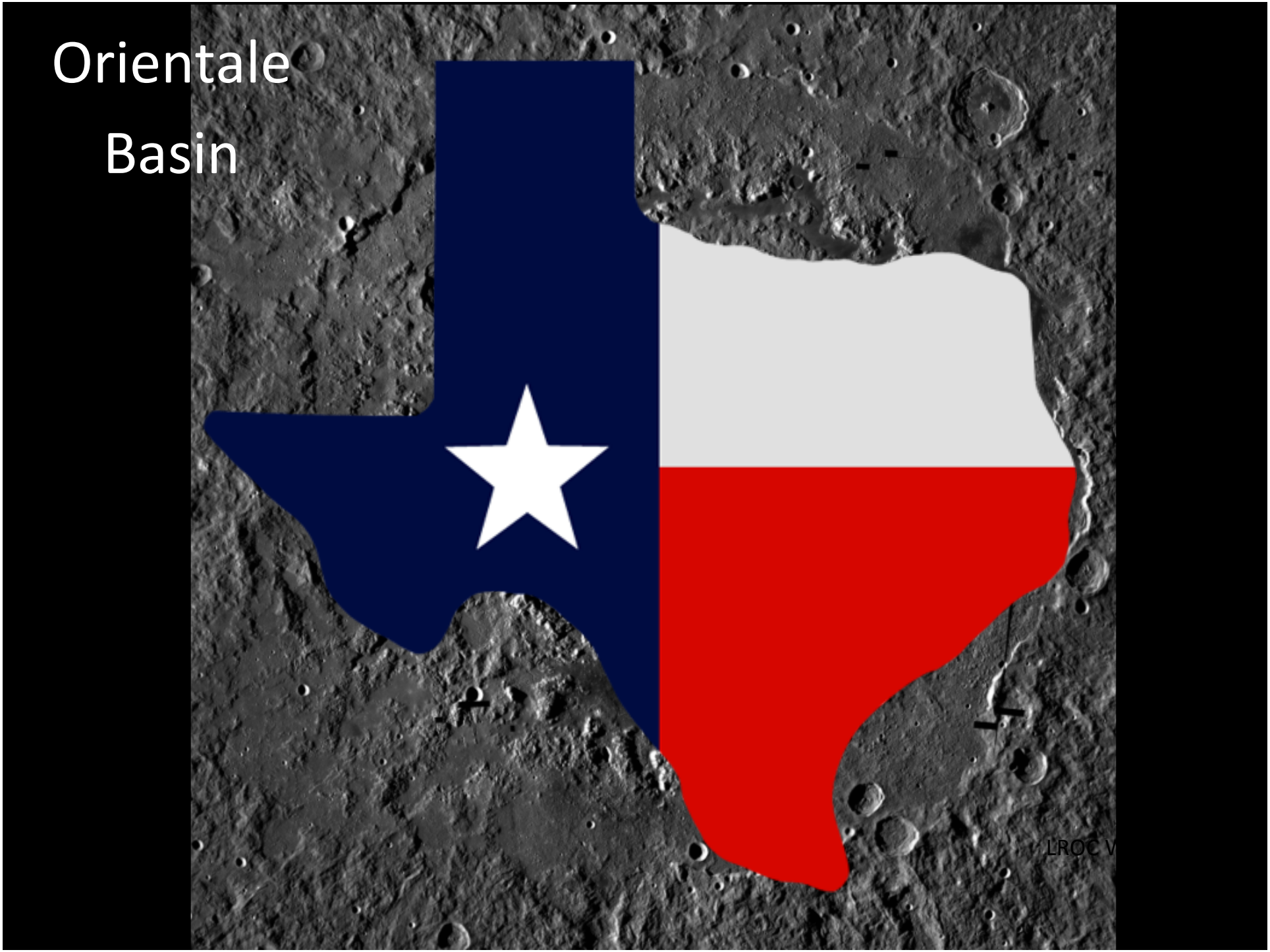
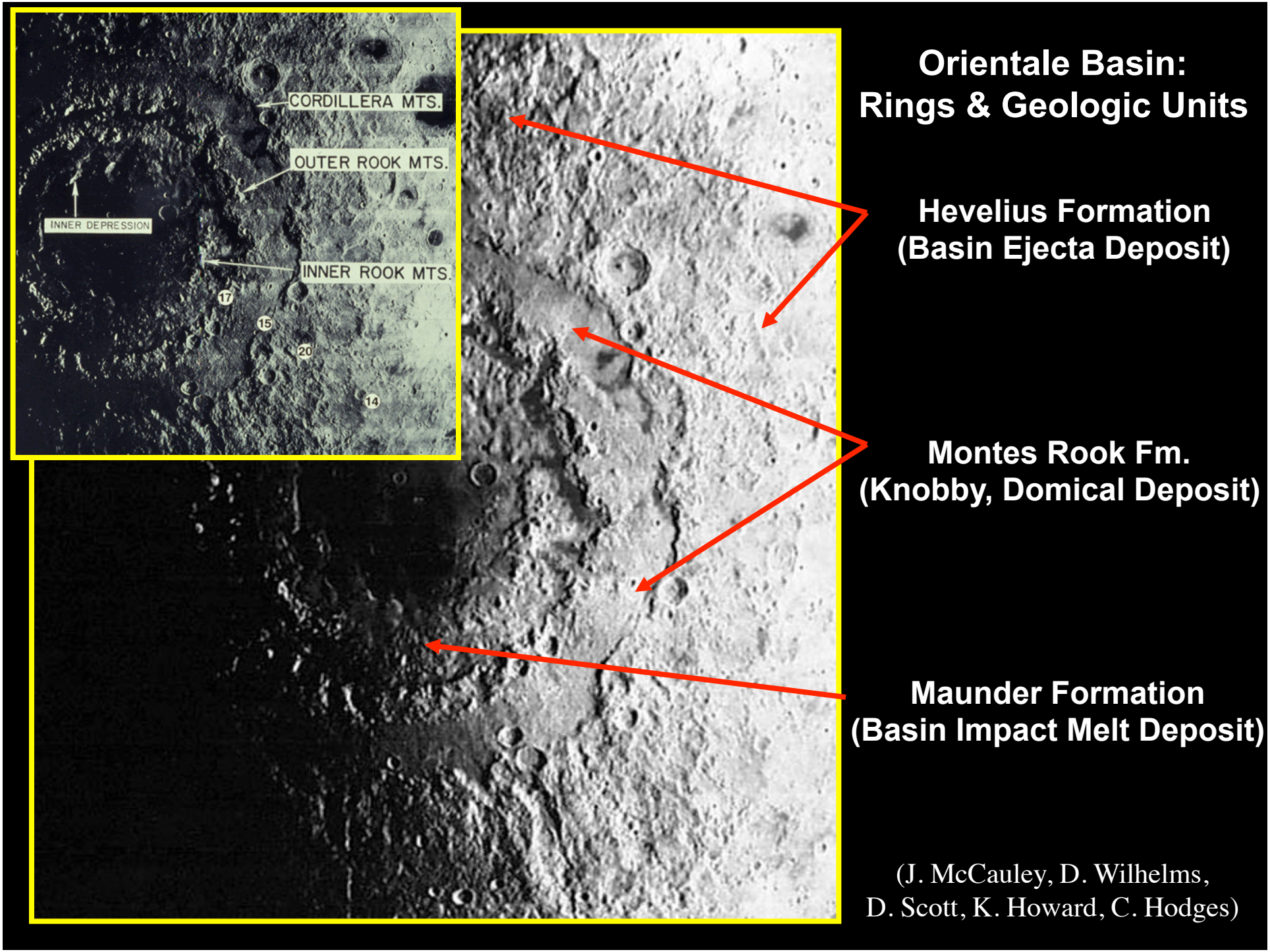

Orientale
Basin
LROC V



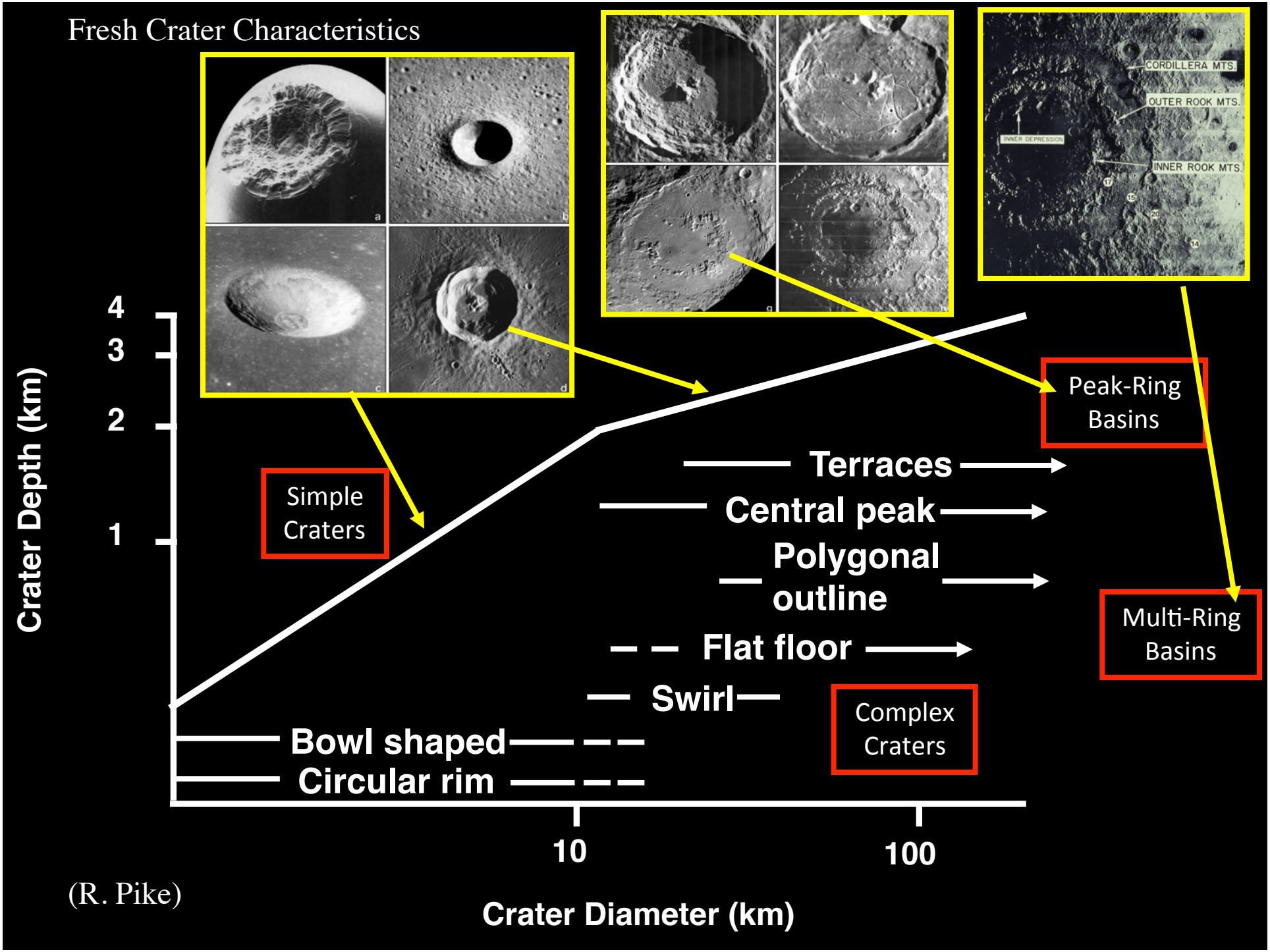
Orientale Basin: Rings & Geologic Units

Hevelius Formation
(Basin Ejecta Deposit)

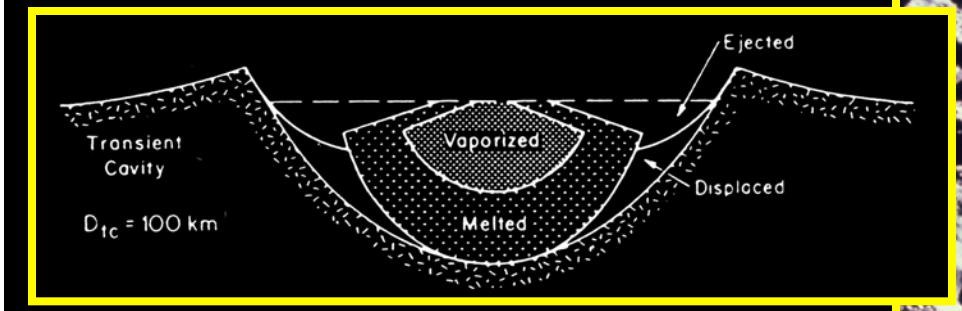
Montes Rook Fm.
(Knobby, Domical Deposit)

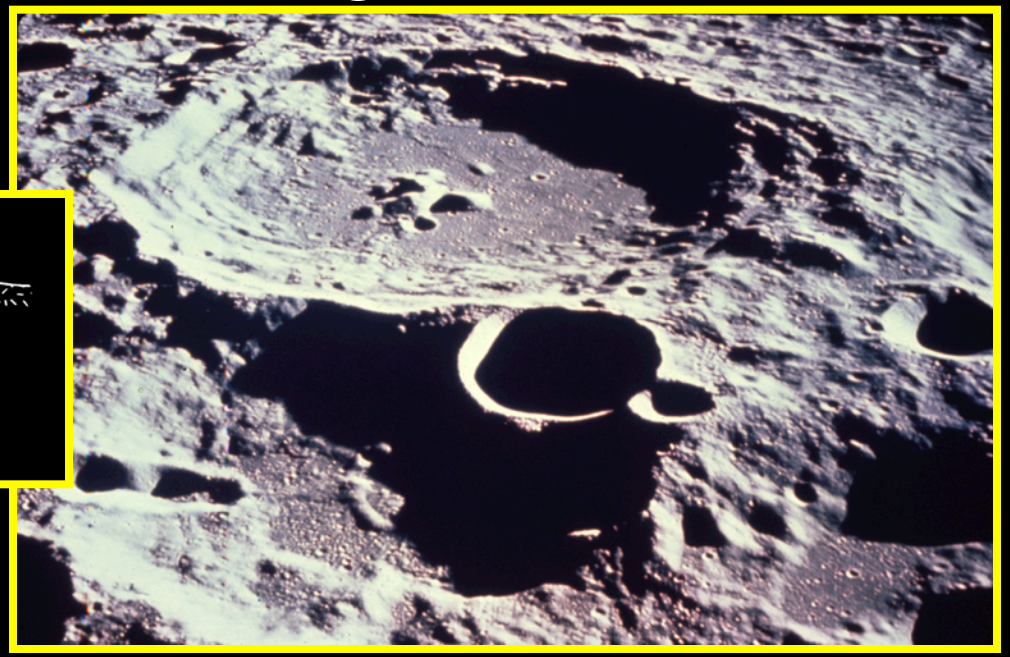
Maunder Formation
(Basin Impact Melt Deposit)

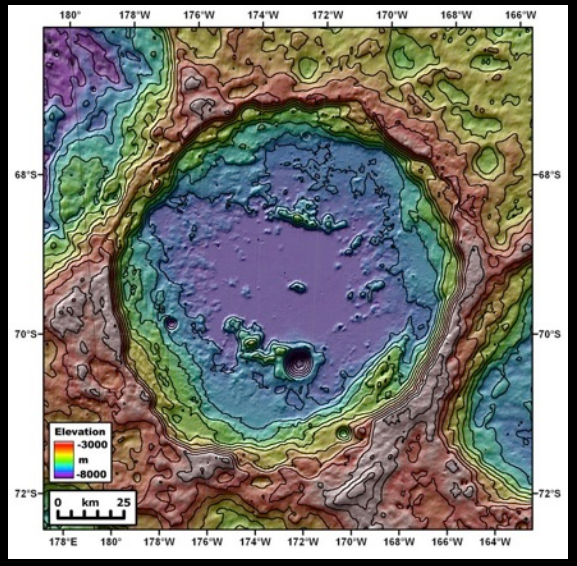
(J. McCauley, D. Wilhelms,
D. Scott, K. Howard, C. Hodges)

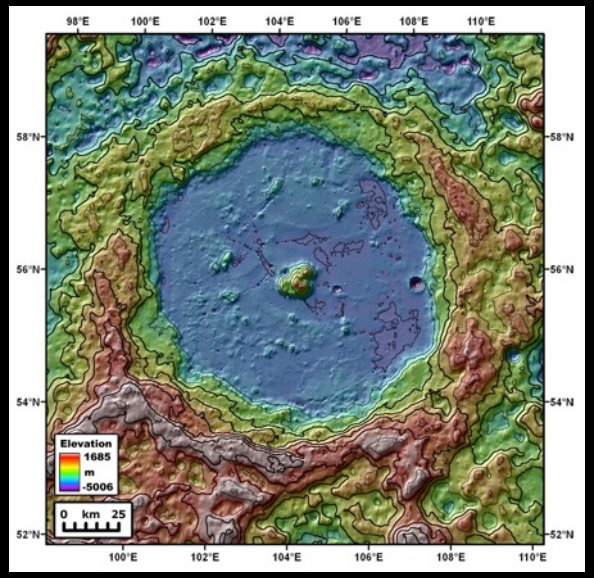

Fresh Crater Characteristics
CORDILLERA MTS.
OUTER ROOK MTS.
INNER DEPRESSION
INNER ROOK MTS.
Crater Depth (km)
4
3
2
1
Simple Craters
Peak-Ring Basins
Terraces
Central peak
Polygonal outline
Flat floor
Swirl
Multi-Ring Basins
Complex Craters
Bowl shaped
Circular rim
10
100
Crater Diameter (km)
(R. Pike)

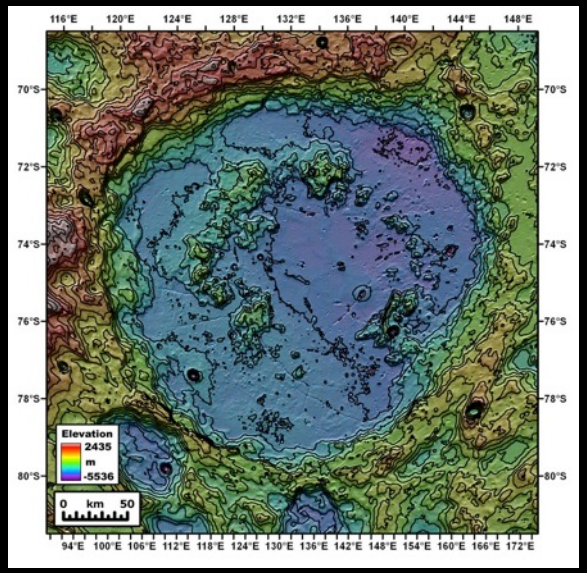
Orientale: Laboratory for study of impact cratering processes
Complex crater to multi-ring basin scale

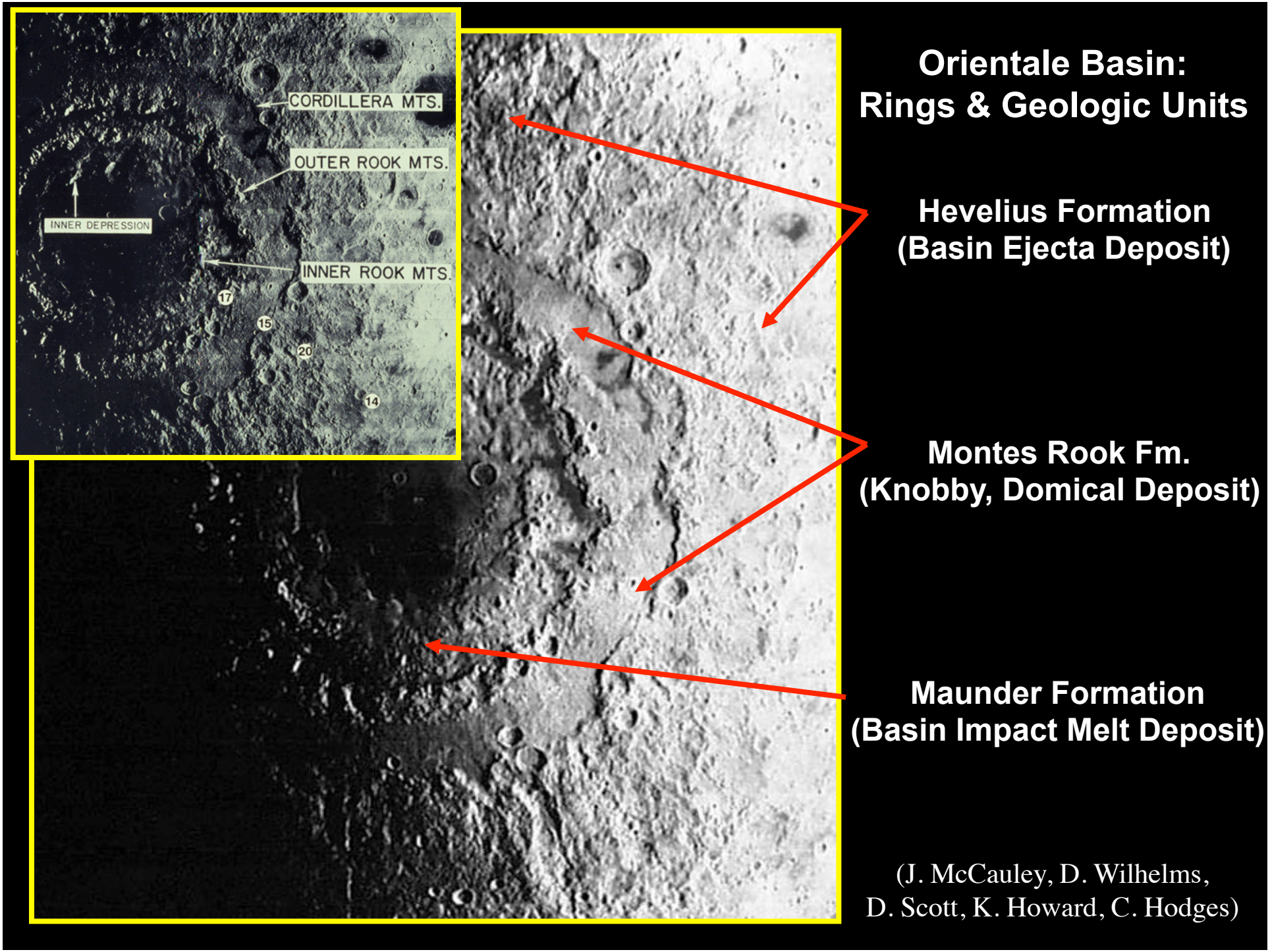












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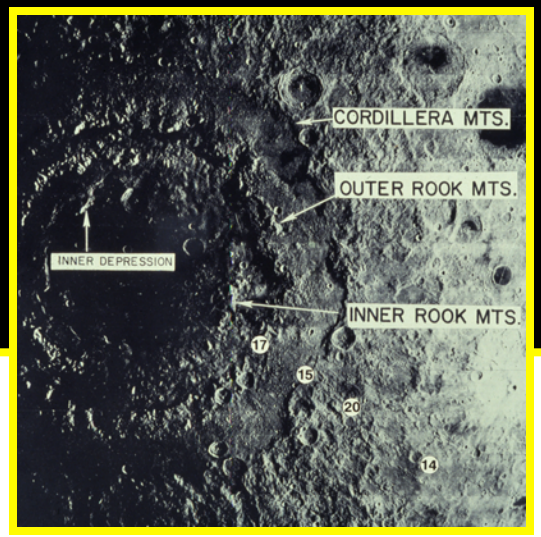
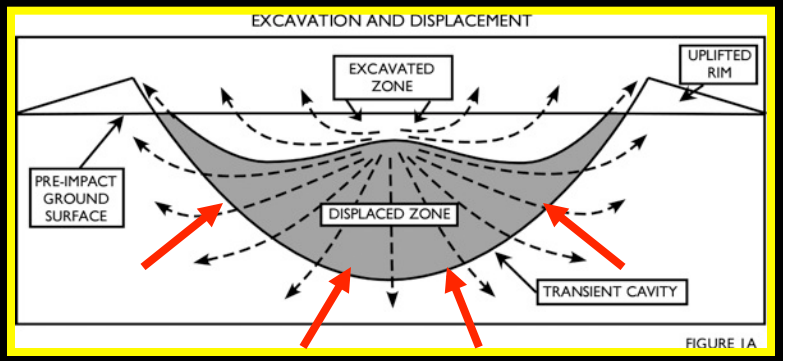
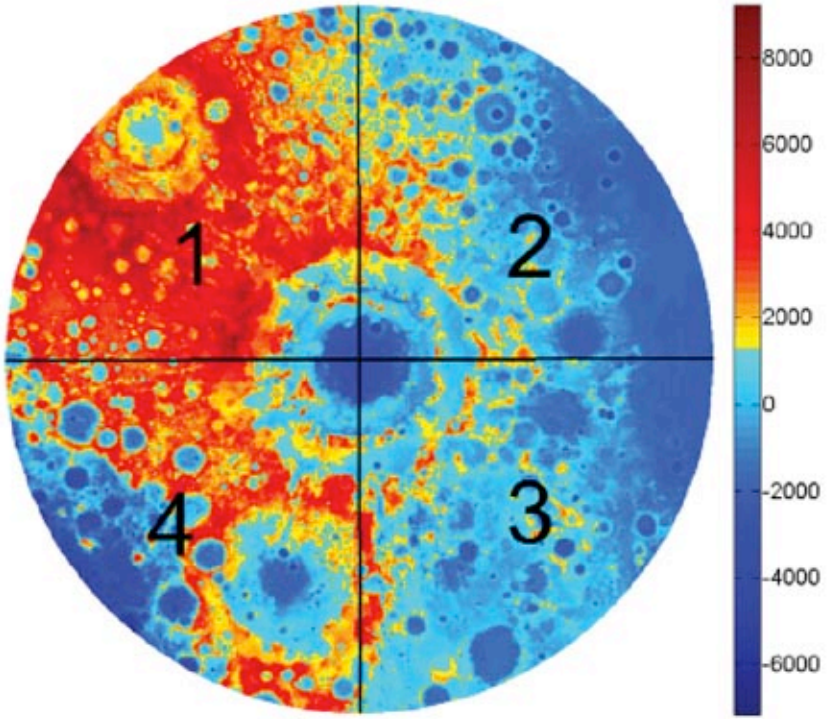
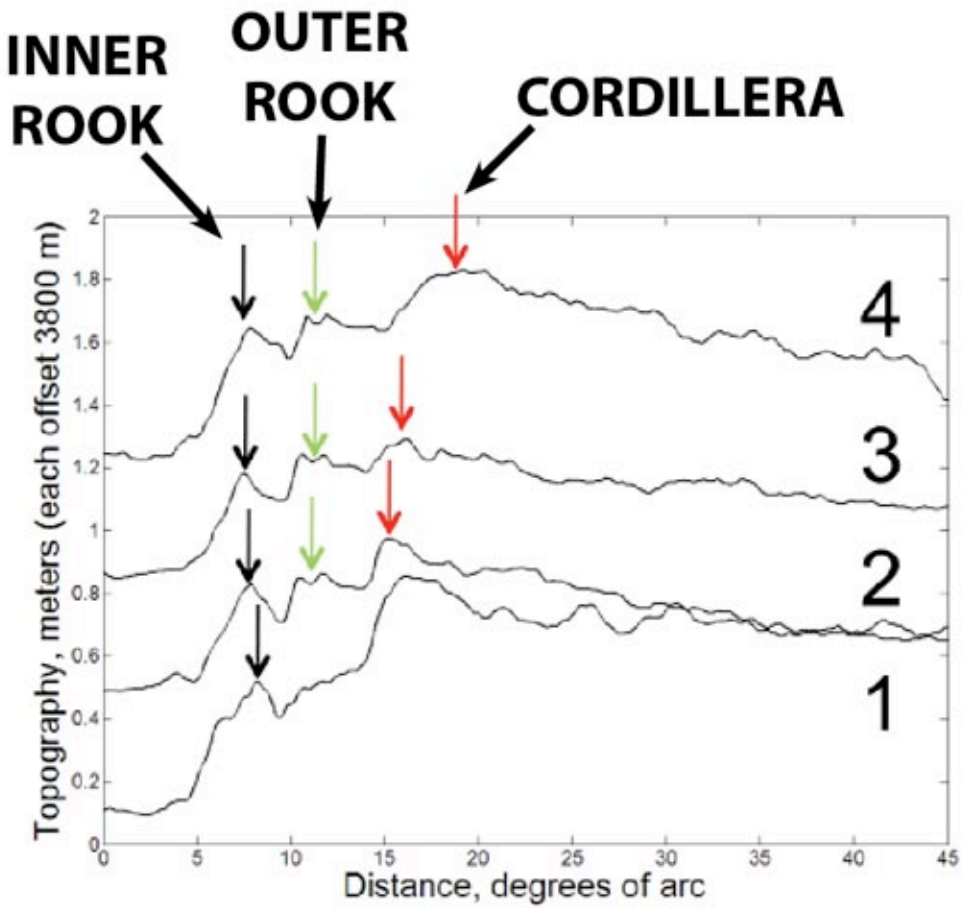
Origin of Impact Basin Rings:



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







(D. Smith, M. Zuber, G. Neumann et al.)

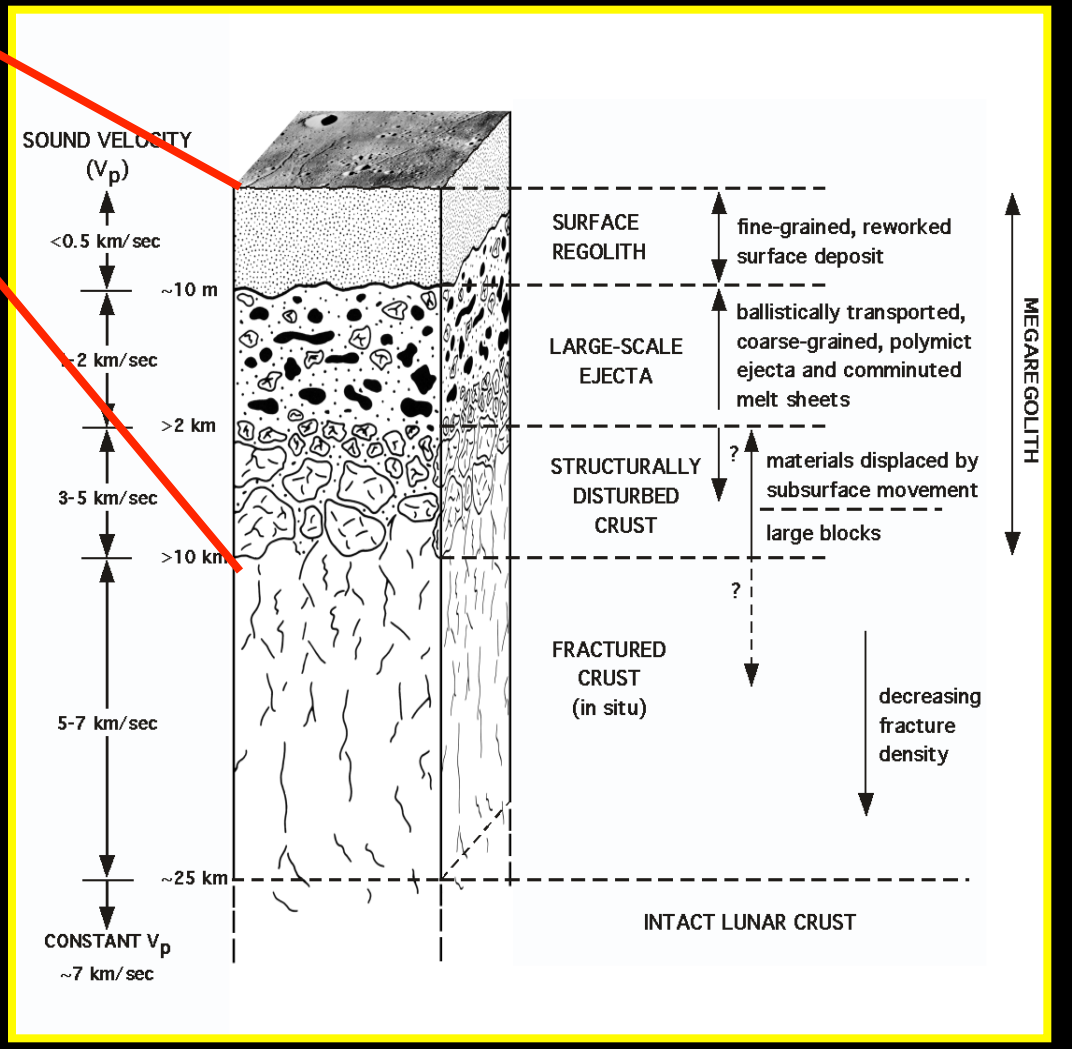
Structure and Composition of the Lunar Crust: The Magma Ocean Model

"New Views of the Moon" (2006)

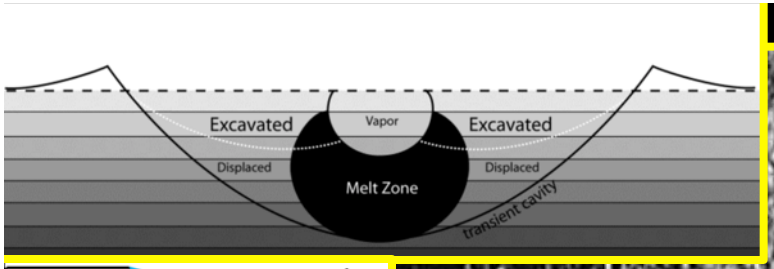
Megaregolith
(~10 km thick)

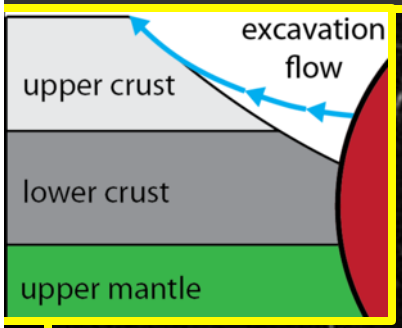
Upper Anorthositic Crust
(~15 km thick)

Lower Noritic Crust
(~25 km thick)

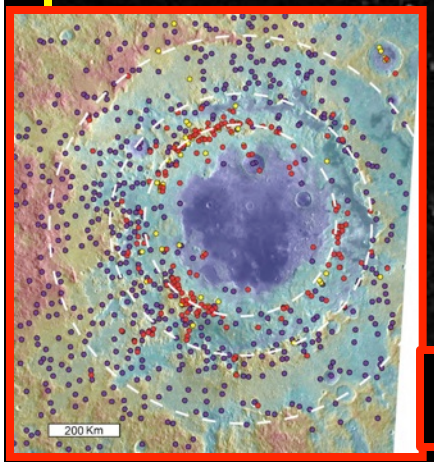


- Crust averages ~50 ±16 km thick.
- Upper and lower crust about equal.
- Upper crust heavily modified in the upper ~10 km by impact processes.





Moon Mineralogy Mapper (M3)



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

Orientale Basin: Rings & Geologic Units

Hevelius Formation
(Basin Ejecta Deposit)
Feldspathic breccias; homogeneous, well-mixed.

Cordillera Mountains:
Feldspathic breccias;
unweathered.

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

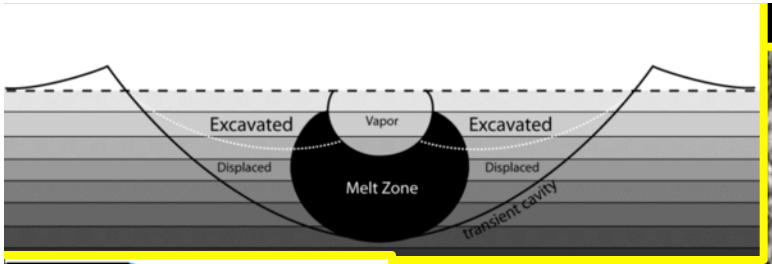
Outer Rook Mountains:
Norites, noritic anorthosite
and anorthosite; more crystalline
blocks.

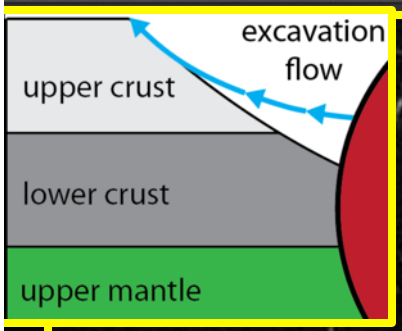
Inner Rook Mountains:
Massifs are crystalline anorthosite;
discrete peaks and clusters of peaks.

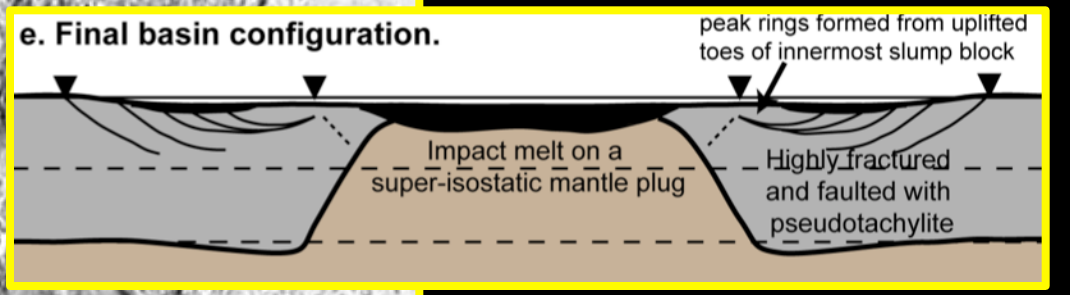
Maunder Formation
(Basin Impact Melt Deposit)

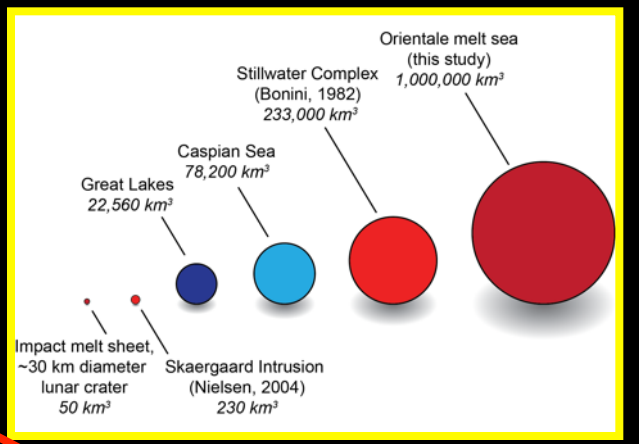
(Pieters et al., 2009, 2011;
Head et al., 2010, 2012; Cheek et al., 2012)

Orientale Impact Melt Sea





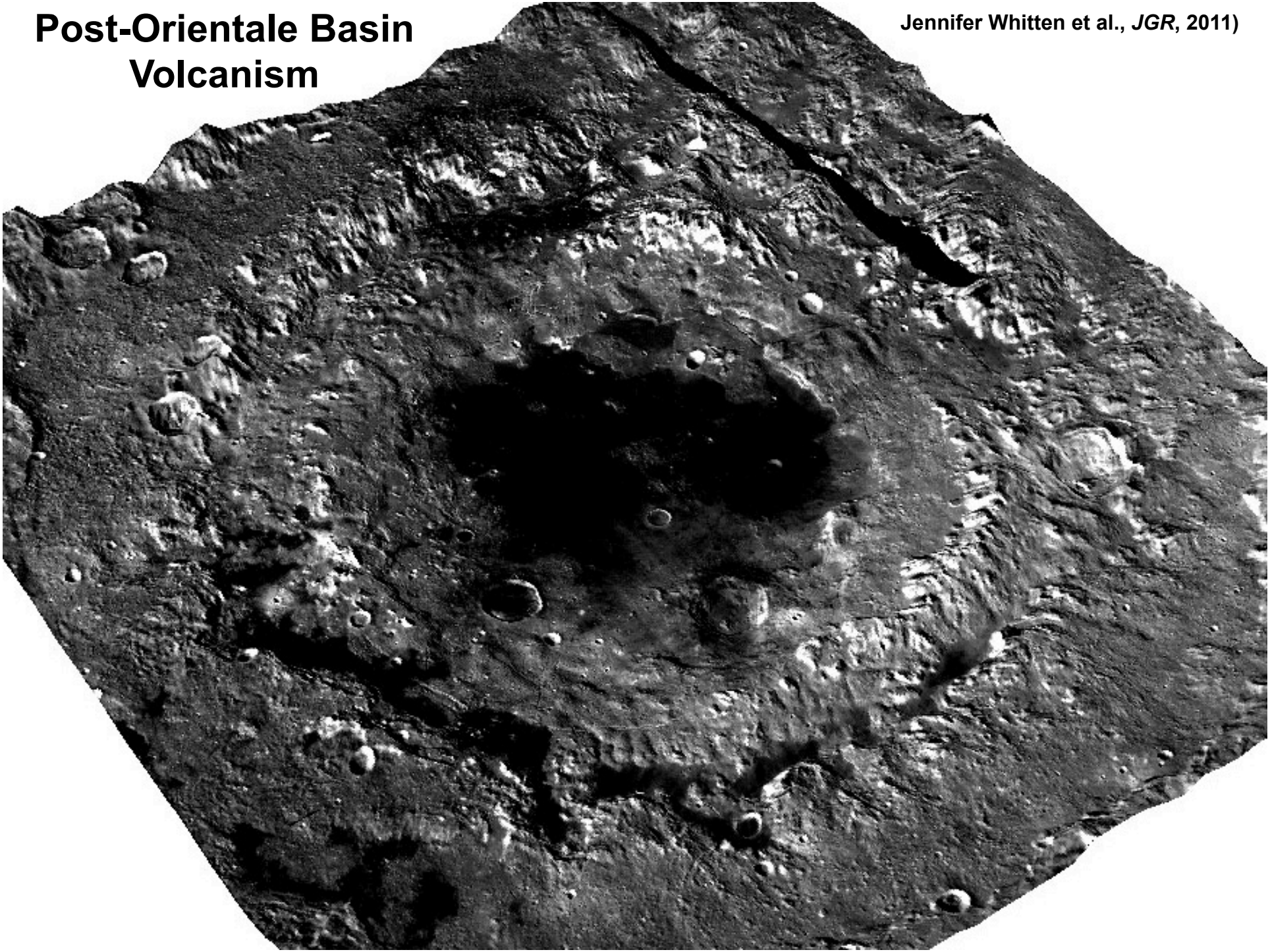




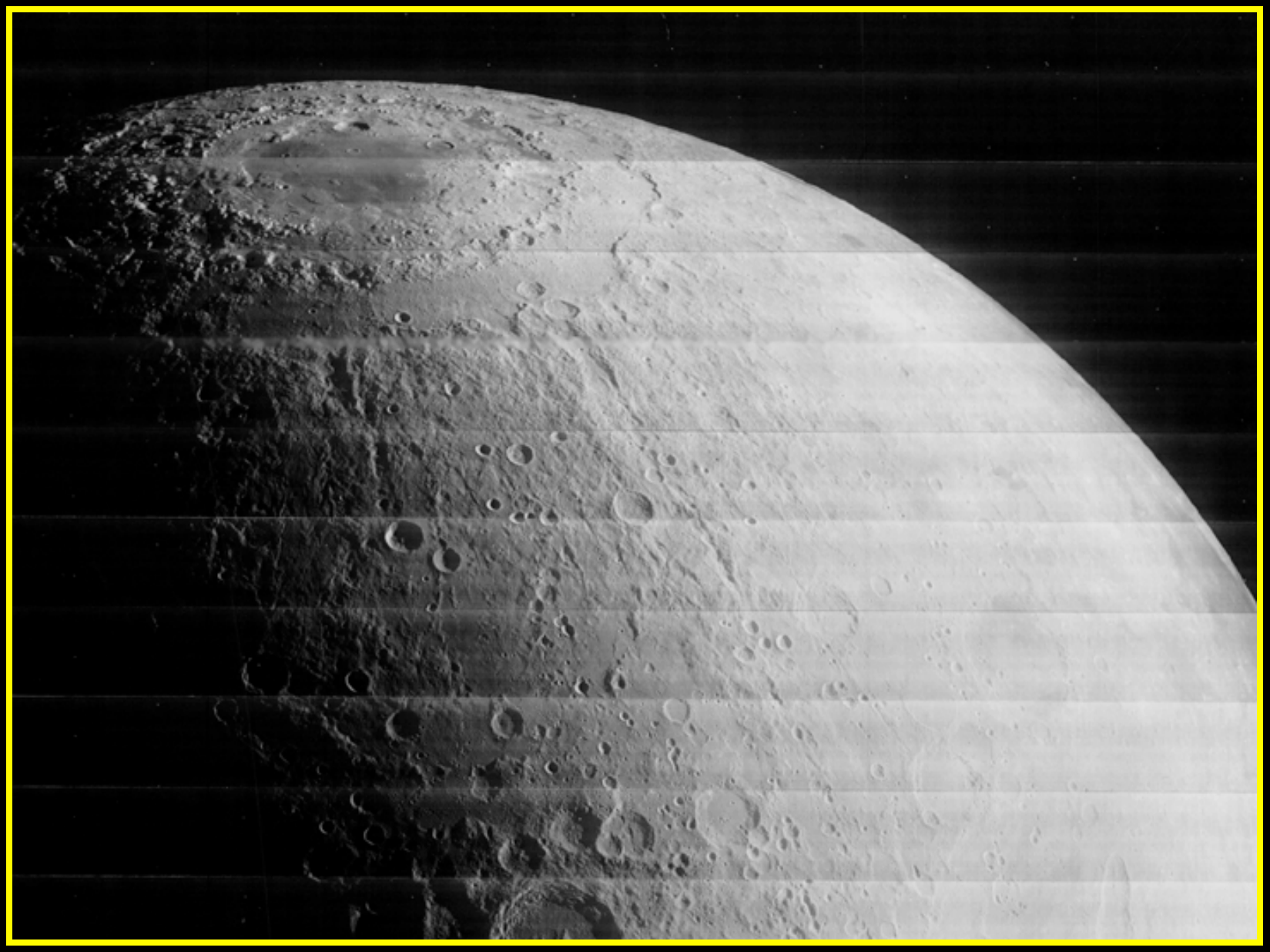
Maunder Formation (Basin Impact Melt Deposit)

(Wilson and Head, 2010; Vaughan et al, 2011, 2012)

Post-Orientale Basin Volcanism



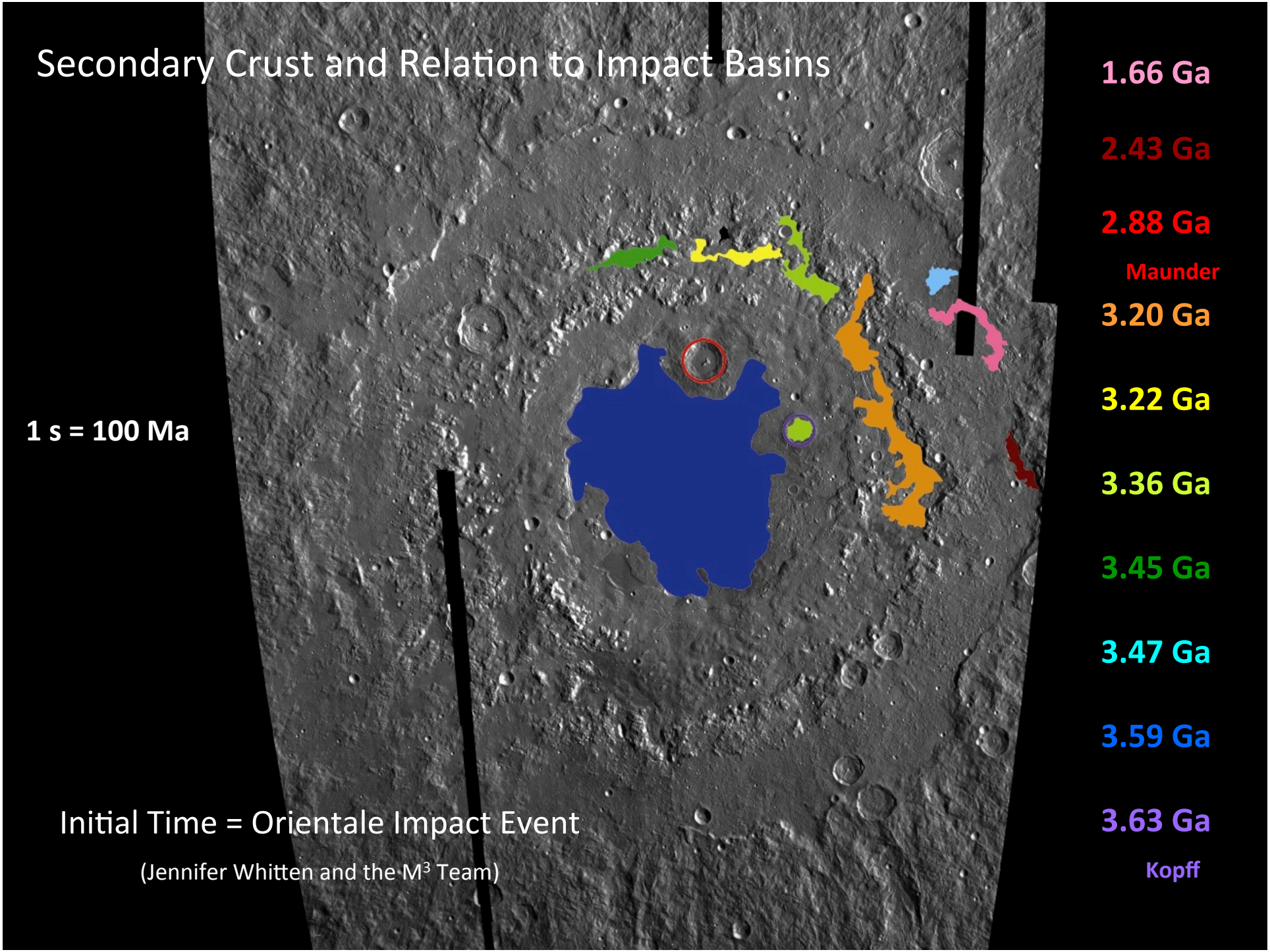
Jennifer Whitten et al., *JGR*, 2011)



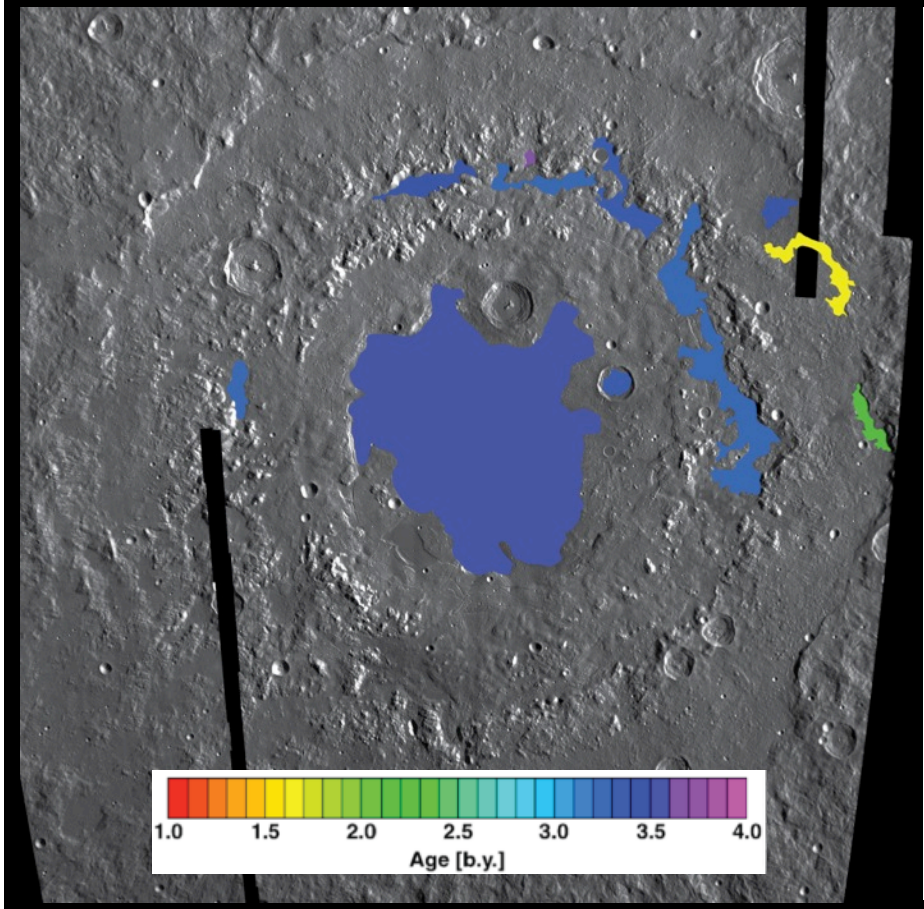
Initial Time = Orientale Impact Event

(Jennifer Whitten and the M^3 Team)

1 second = 100 Ma


Secondary Crust and Relation to Impact Basins
1 s = 100 Ma
Initial Time = Orientale Impact Event
(Jennifer Whitten and the M3 Team)
1.66 Ga
2.43 Ga
2.88 Ga
Maunder
3.20 Ga
3.22 Ga
3.36 Ga
3.45 Ga
3.47 Ga
3.59 Ga
3.63 Ga
Kopff

Orientale: Comparison to Nearside Mare Ages



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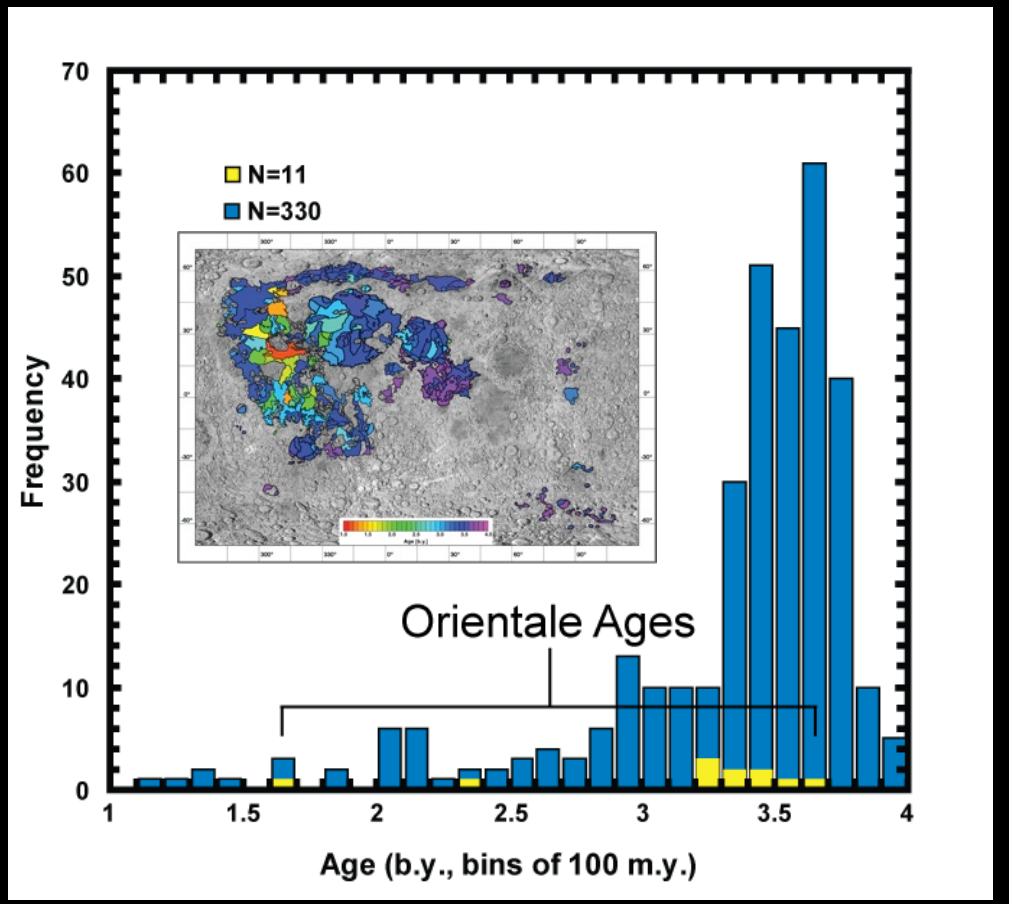
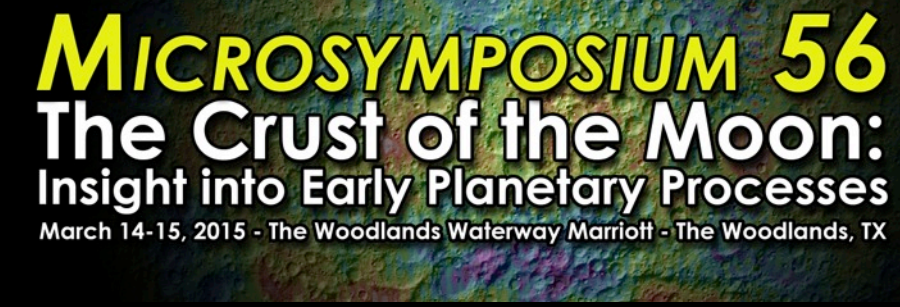


Modified from *Hiesinger et al., 2011*

Span of ages of volcanism similar to lunar nearside

Microsymposium 56,
"The Crust of the Moon: Insights Into Early Planetary Processes"



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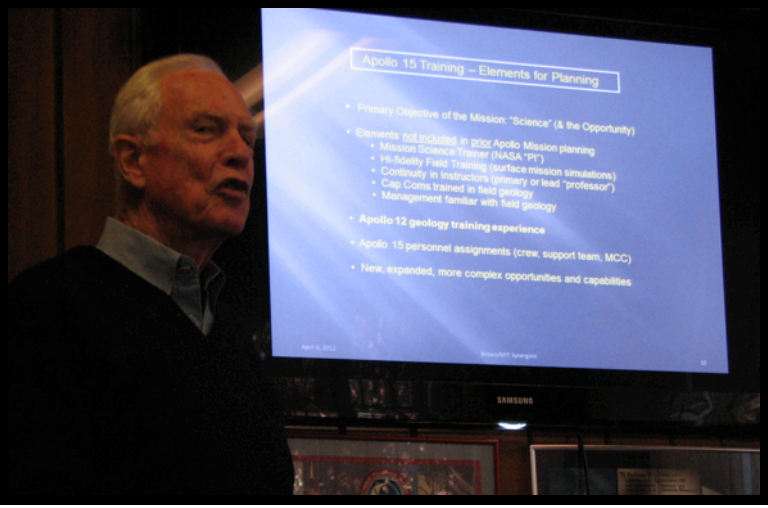
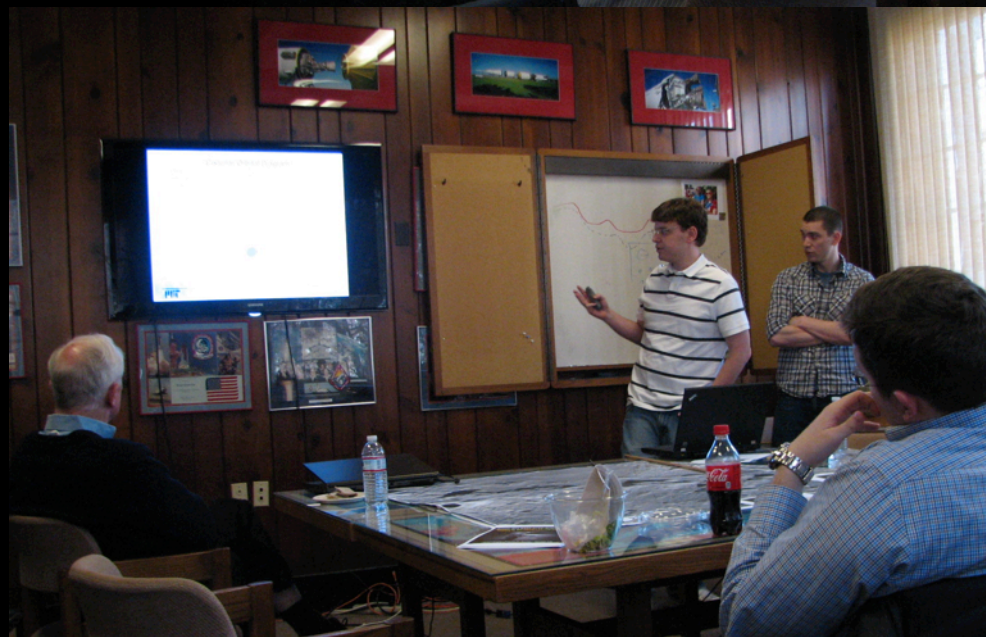
  - 4. Chronology of crustal formation and evolution: The lunar paradigm; and
  - 5. What are the major outstanding problems and how do we resolve them?

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





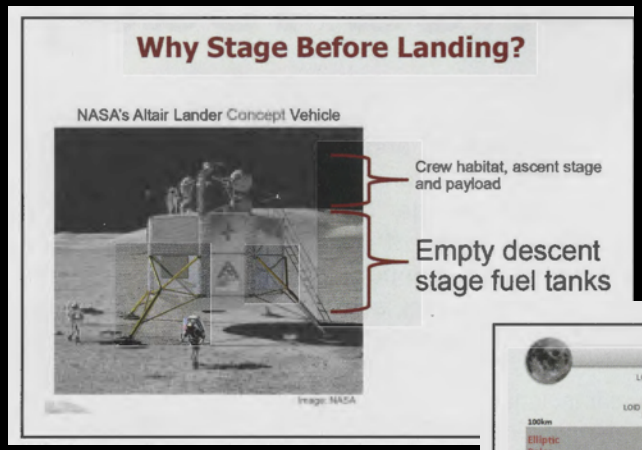
Resuming Human Exploration of the Moon: What Approach? What Architecture? Science and Engineering Synergism

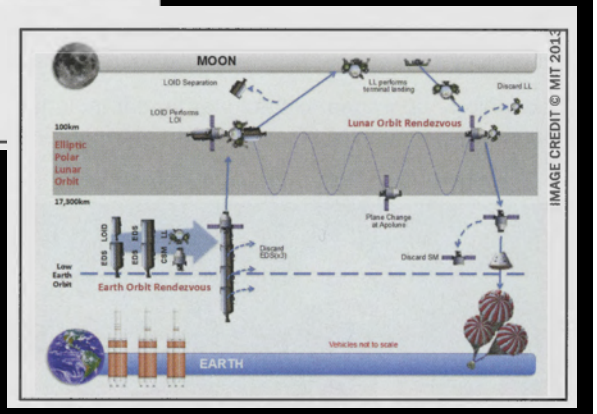
Determine Science Requirements:
-Full lunar access: Poles, NS/FS.
-Longer stay times: 7-14 days.
-More payload to/from Moon.
-More mobility on Moon.
-More flexibility with robots.
-Human-Robotic Partnerships.

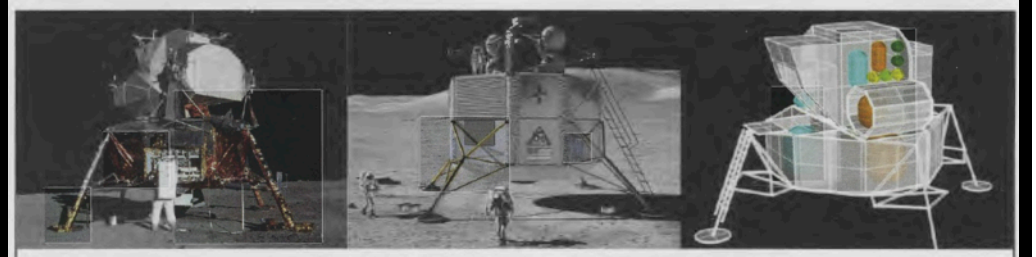
Optimize Engineering for Science:
-KISS: Keep It Simple, Stupid.
-Start with what works: Luna/Apollo!!
-Use 40 years of technology advance.

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

Science and Engineering Synergism:
SES!



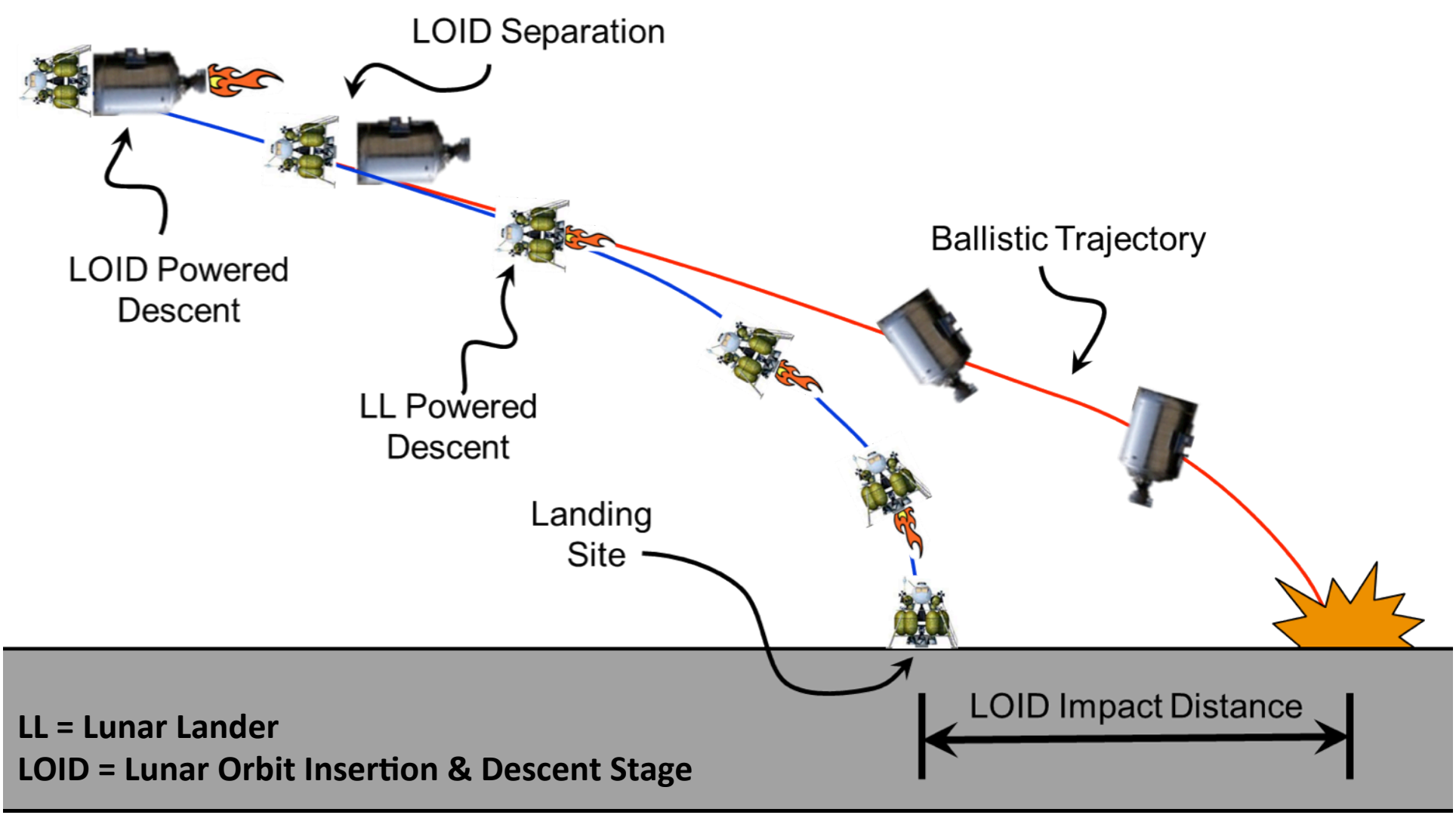




LANDING VEHICLE COMPARISON

	Apollo LM	Altair (Constellation)	HALOs/Lunar Lander
Payload Mass	500 kg	2700 kg	2300 kg/1200 kg
Sample Return Mass	100 kg	100 kg	350 kg/700 kg
Crew to Surface	2	4	3/3
Surface Days	3	7	7/14

Staging the Landing Vehicle



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.

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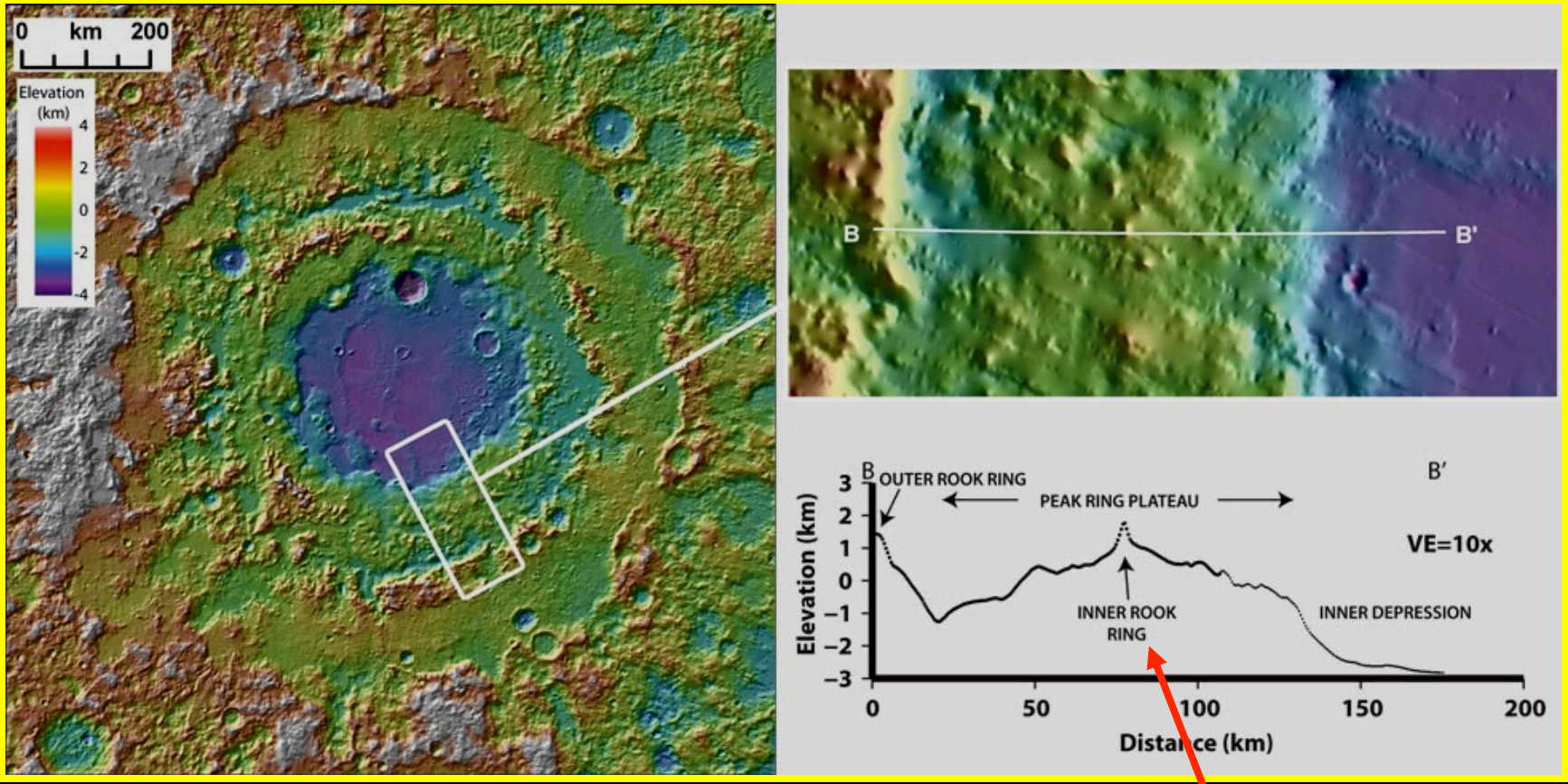
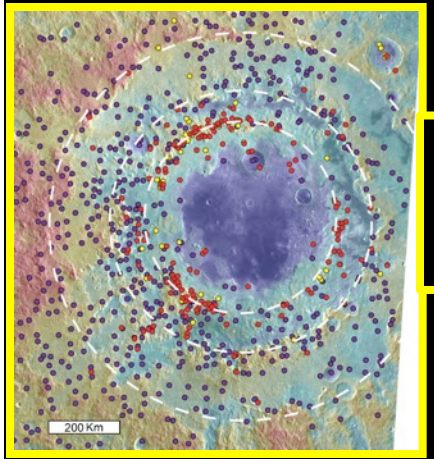
Origin of the Inner Rook Mountains/Impact Melt Sheet





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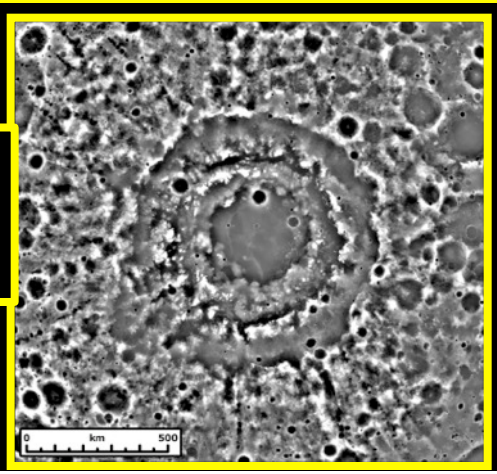
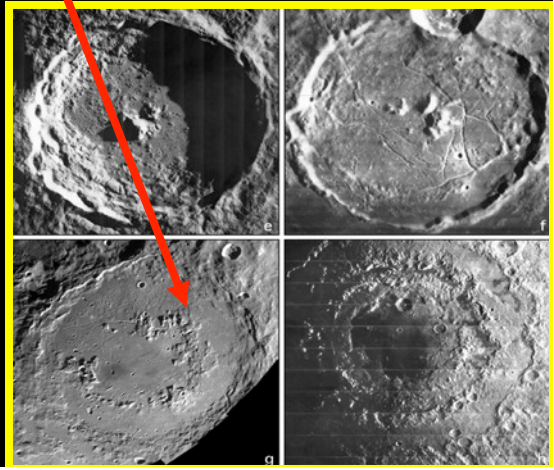
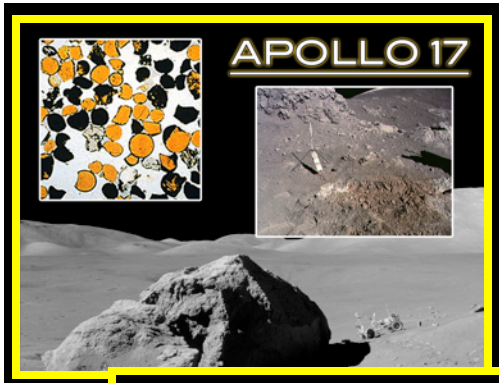
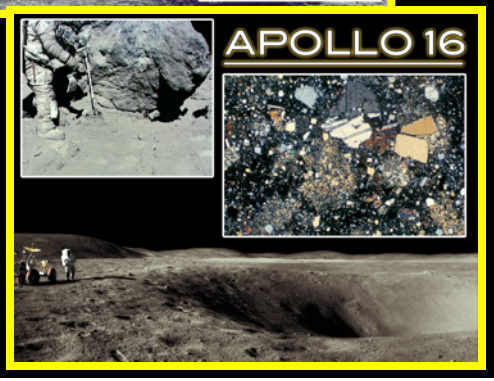
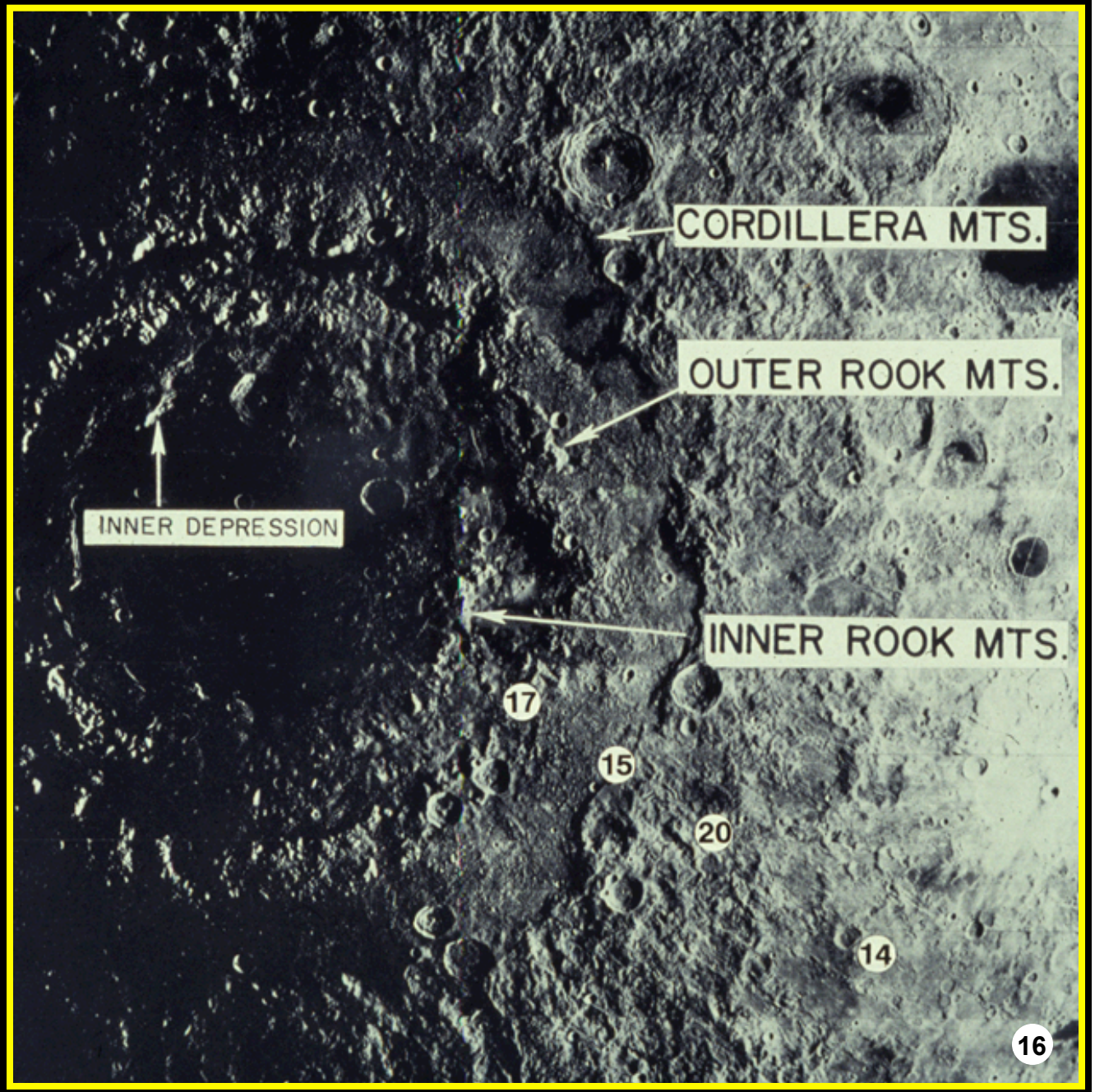


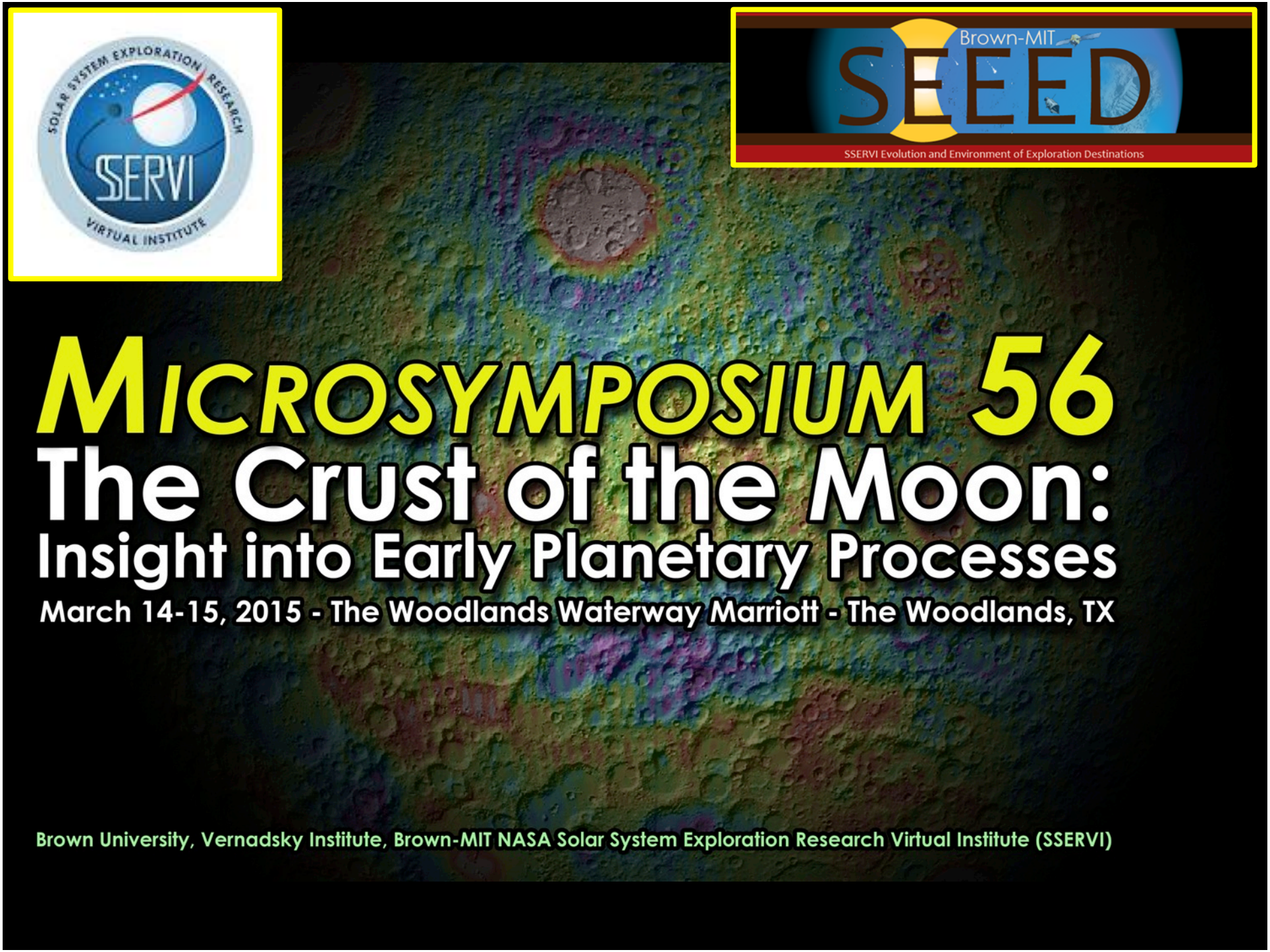
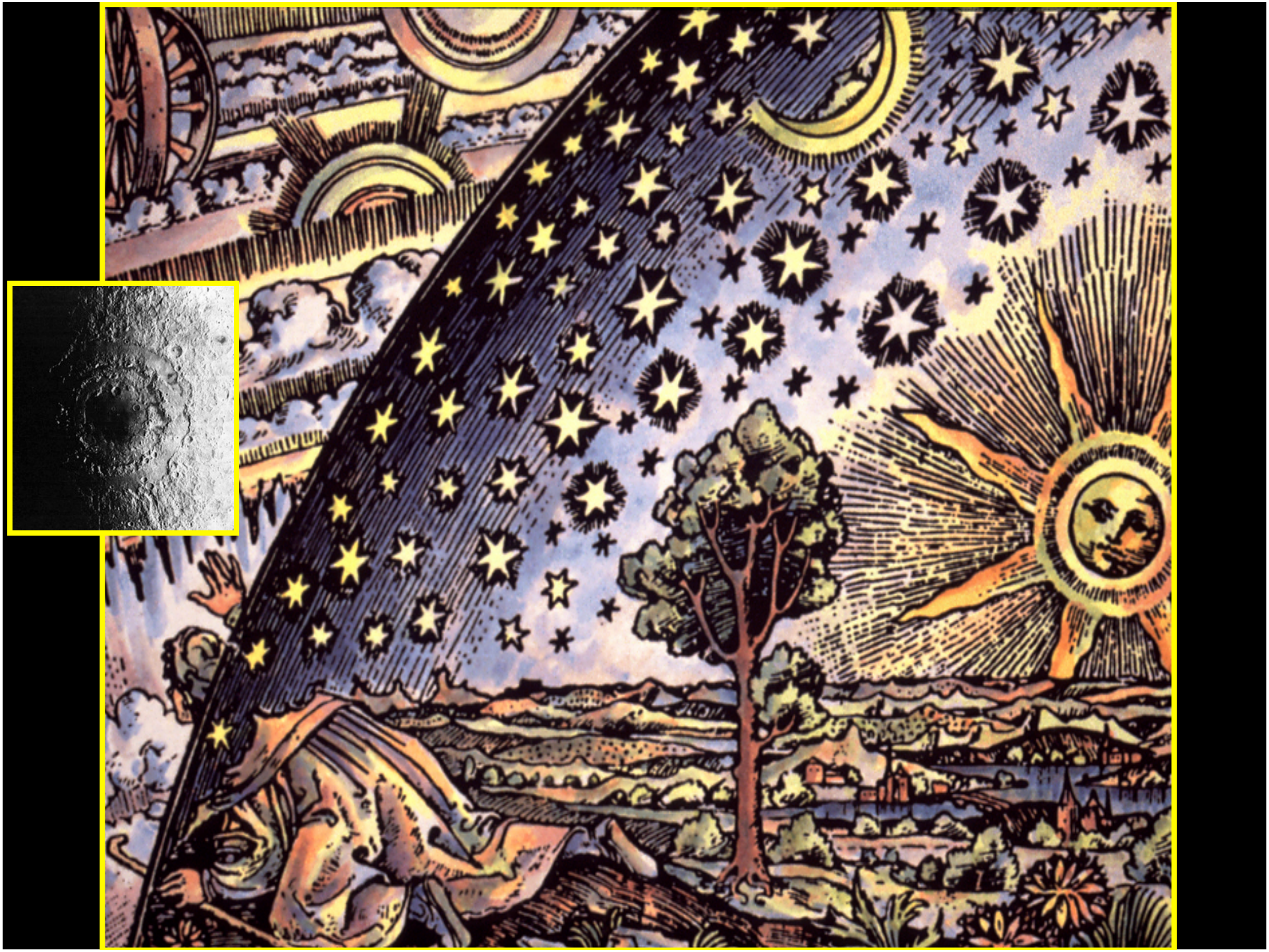


Lunar Orientale Basin: Past and Future Exploration





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