

# NAC Workshop

Science Associated with the Lunar Exploration Architecture

## Report Overview: Scientific Context for the Exploration of the Moon

*Space Studies Board,  
National Research Council*

Carlé M. Pieters (Vice Chair)

George A. Paulikas (Chair)

# The Context

## Vision for Space Exploration

- The Moon is the first waypoint for human exploration in NASA's VSE.
- Robotic missions that will precede and support human exploration of the Moon offer opportunities to accomplish important scientific investigations about the Moon and the solar system beyond.
- The current NRC/NAS study is intended to meet the near term needs for science guidance for the lunar component of the VSE.



# The Request



From: Mary Cleave, NASA Associate Administrator for Science [SMD]

To: Lennard Fisk, Chair of Space Studies Board of NRC/NAS

## Primary Tasks

- Identify a prioritized set of scientific goals that can be addressed in the near term (~2006-2018) by robotic lunar missions and in the mid term (~2018-2023) by astronauts on the Moon.
- Suggest which of the identified scientific goals are amenable to orbital measurements, in situ study, or terrestrial analysis via the return of lunar samples to the Earth.

## Secondary Tasks

- Comment on those areas where there is a synergistic overlap between measurements addressing scientific goals and measurements required to ensure human survival or resource utilization.
- Collect and characterize possible scientific goals that might be addressed on or from the Moon in the long term (i.e., after ~2023) and deserve further study.

# Committee and Staff

- George A. Paulikas, The Aerospace Corporation (retired), Chair
- Carlé M. Pieters, Brown University, Vice Chair
- William B. Banerdt, Jet Propulsion Laboratory
- James L. Burch, Southwest Research Institute
- Andrew Chaikin, Arlington, Vermont
- Barbara Cohen, University of New Mexico
- Michael Duke, Colorado School of Mines (retired)
- Harald Hiesinger, University of Muenster
- Noel W. Hinners, Lockheed Martin Astronautics (retired)
- Ayanna M. Howard, Georgia Institute of Technology
- David J. Lawrence, Los Alamos National Laboratory
- Daniel F. Lester, McDonald Observatory
- Paul G. Lucey, University of Hawaii
- Stefanie Tompkins, Science Applications International Corporation
- Francisco Valero, University of California-San Diego
- John V. Valley, University of Wisconsin
- Charles D. Walker, Boeing (ret) and former Astronaut Payload Specialist
- Neville J. Woolf, University of Arizona

David H. Smith, Robert L. Riemer, Rodney Howard, and Stephanie Bednarek, NRC staff

# Committee Schedule

- Meeting 1 June 20-22, 2006  
National Academies' Keck Center, Washington, D.C.
- Meeting 2 August 2-4, 2006  
National Academies' Beckman Center, Irvine, California
- Interim Report to NASA September 15, 2006
- Meeting 3 25-27 October, 2006  
Santa Fe, New Mexico
- Meeting 4 13-15 February, 2007  
Colorado
- Final Report to NASA by May, 2007



## Lunar Science Committee Outreach in 2006

Date	Event	Location	Presentation Type	Presenters
24-27 July	ILEWG-8	Beijing, China	Oral Presentation	David Smith
18-22 September	Europlanet	Berlin, Germany	Oral Presentation	Harald Hiesinger
25 September	NAC/PSS	Boulder, Colorado	Oral Presentation	George Paulikas, Carle Pieters
3-4 October	LROC Team Meeting	Phoenix, Arizona	Conference Call	Harald Hiesinger
8-13 October	DPS	Pasadena, California	Poster Paper	David H. Smith, George Paulikas
11 October	CSSP	Washington, D.C.	Conference Call	George Paulikas, Carle Pieters
12 October	DPS	Pasadena, California	Press Conference; forum	George Paulikas, Carle Pieters, Bruce Banerdt
31 October-2 November	Space Resources Roundtable 8	Golden, Colorado	Oral Presentation	Michael Duke
29 November	CAA	Irvine, California	Oral Presentation	George Paulikas, Carle Pieters
28-30 November	<i>STScI Astrophysics Enabled by Return to the Moon</i>	Baltimore, Maryland	Oral Presentation	Daniel Lester
4-6 December	<i>AIAA 2<sup>nd</sup> Space Exploration Workshop</i>	Houston, Texas	Panel Discussion	Noel Hinners
4 December	COMPLEX	Irvine, California	Oral Presentation	George Paulikas, Carle Pieters
11-15 December	AGU	San Francisco, California	Panel Discussion, Oral Presentation and Display	Carle Pieters

# Lunar Science Committee Outreach in 2007

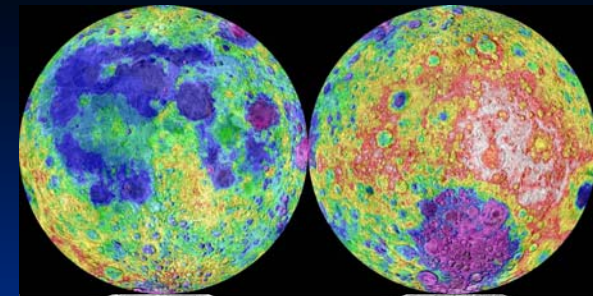
Date	Event	Location	Presentation Type	Presenters
5-10 January	AAS	Seattle, Washington	Display	n/a
19 February	COEL	Washington, D.C.	Conference Call	George Paulikas, Carle Pieters
21-23 February	ISU	Strasbourg, France	Oral Presentation	Harald Hiesinger
26 February-2 March	NAC Lunar Science Workshop	Tempe, Arizona	Oral Presentation	Carle Pieters
12-16 March	LPSC???	Houston, Texas	Forum	Carle Pieters
15-20 April	EGU	Vienna, Austria	Oral Presentation	Harald Hiesinger

In the context of a Balanced Program

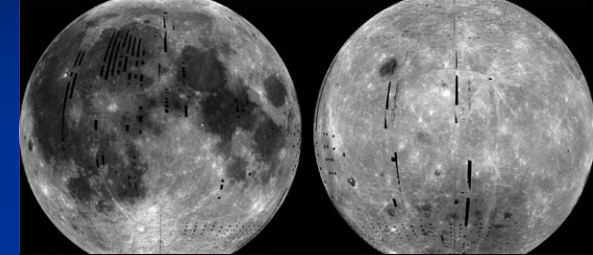
# Why the Moon?

- The Moon is a *witness* to 4.5 billion years of solar system history.
- The Moon presents a record of planetary geologic processes in the purest form
  - Early crust evolution
  - Differentiation
  - Impact craters
  - Volcanic processes
  - Regolith processes and early Sun
- The Moon provides accessible unique environments
  - Polar regions
  - Exosphere (atmosphere)
  - Stable Platform

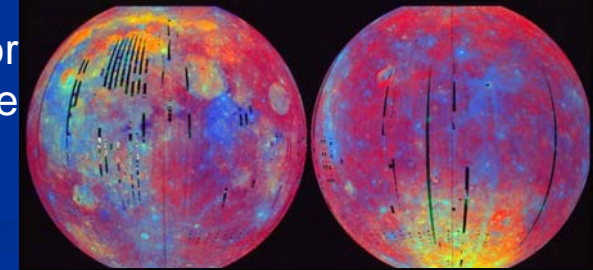
Topography



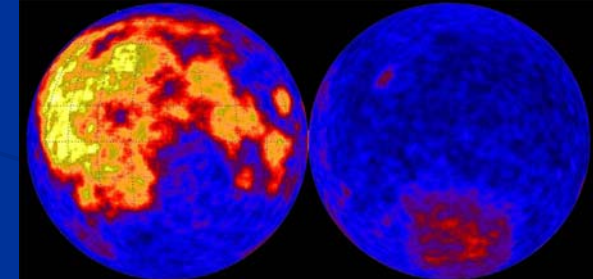
Albedo



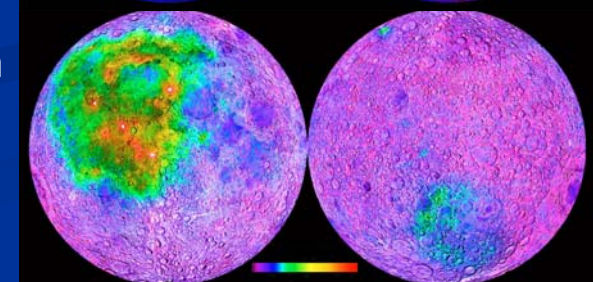
Color Composite



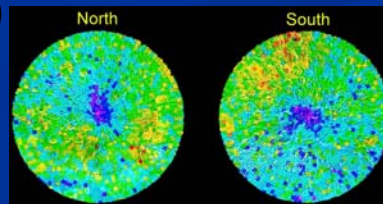
Iron



Thorium

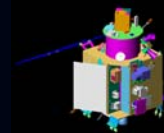
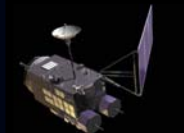


Polar H



# International Lunar Exploration

	<b>SMART-1 [ESA]</b>	<b>SELENE [JAXA]</b>	<b>Chang'E [CNSA]</b>	<b>Chandrayaan1 [ISRO]</b>	<b>LRO [NASA]</b>
Launch	2003	2007	2007	2008	2008
Orbit	400 x 4000 km polar	100 km polar circular	200 km polar circular	100 km polar circular	50 km polar circular
Objectives	Technology demonstration; investigate poles; Sept 2006 impact ending	Study lunar origin and evolution; develop technology for future lunar exploration	Surface structure, topography, composition; particle environment	Simultaneous composition and terrain mapping; demonstrate impact probe	Improve geodetic net; evaluate polar areas; study radiation environment
Payload	AMIE, CIXS, SIR, plasma experiments	TC, MI, SP, relay satellites, X-ray, g-ray; laser altimeter; radar sounder, magnetometer, plasma imager	4-band micro-wave, IIM, X-ray, gamma-ray, WA stereo, energetic ions, laser altimeter	TMC, HySI, LLRI, HEX, Impact probe + C1XS, SARA, SIR2, miniSAR, M3, RADOM	LOLA, LROC, LAMP, LEND, CRaTER, Radiometer <b>LCROSS</b>



# Overarching Science Themes

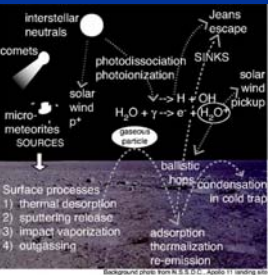
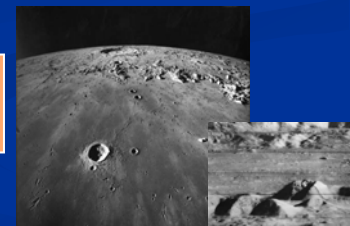
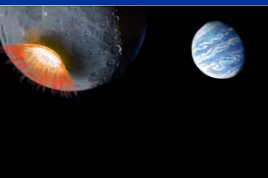
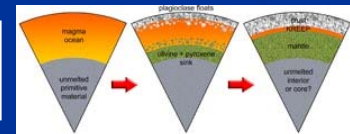
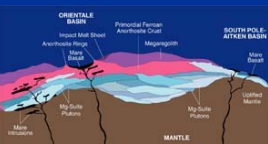
## Lunar Science

Early Earth/Moon System

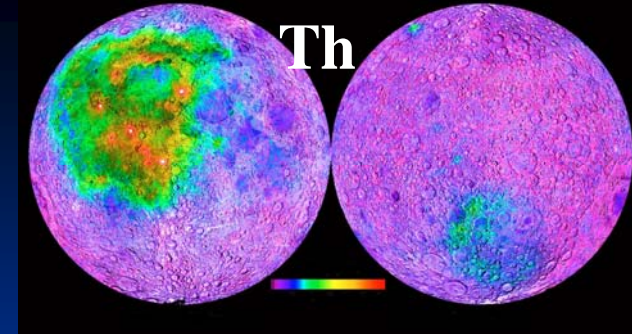
Terrestrial Planet Differentiation

Solar System Impact Record

Lunar Environment



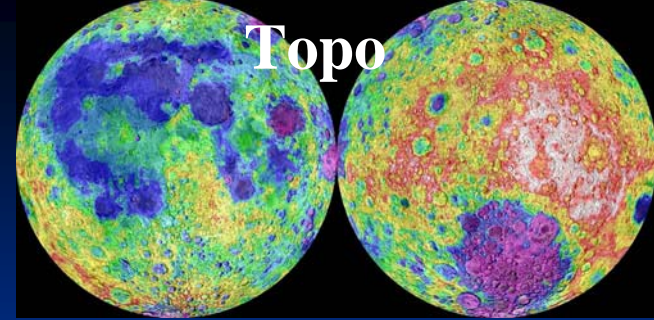
# Science Concepts



1. The **bombardment history of the inner Solar System** is uniquely revealed on the Moon
2. The structure and composition of the lunar **interior** provides fundamental information on the evolution of a differentiated body
3. Key planetary processes are manifested in the diversity of lunar **crustal rocks**.
4. The lunar poles are special environments that may bear witness to the **volatile flux** over the latter part of solar system history.
5. Lunar **volcanism** provides a window into the thermal and compositional evolution of the Moon.
6. The Moon is an accessible laboratory for studying the **impact process** on planetary scales
7. The Moon is a natural laboratory for **regolith processes** and weathering on anhydrous airless bodies.
8. Processes involved with the **atmosphere and dust environment** of the Moon are accessible for scientific study only while the environment remains in a pristine state.

# Science Priorities

## in the Context of Lunar Exploration



### 1. Fundamental Solar System Science

- Characterize and date the **impact flux** (early and recent) of the inner solar system.
- Determine the **internal structure** and composition of a differentiated planetary body.
- Determine the compositional diversity (lateral and vertical) of the **ancient crust** formed by a differentiated planetary body.
- Characterize the **volatile compounds** of polar regions on an airless body and determine their importance for the history of volatiles in the solar system.

### 2. Planetary Processes

- Determine the time scales and compositional and physical diversity of **volcanic processes**.
  - Characterize the **cratering process** on a scale relevant to planets.
  - Constrain processes involved in **regolith evolution** and decipher ancient environments from regolith samples.
  - Understand processes involved with the **atmosphere (exosphere)** of airless bodies in the inner solar system.
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- Determine the utility of the Moon for astrophysics observations and as a platform for observations of Earth and solar-terrestrial processes.

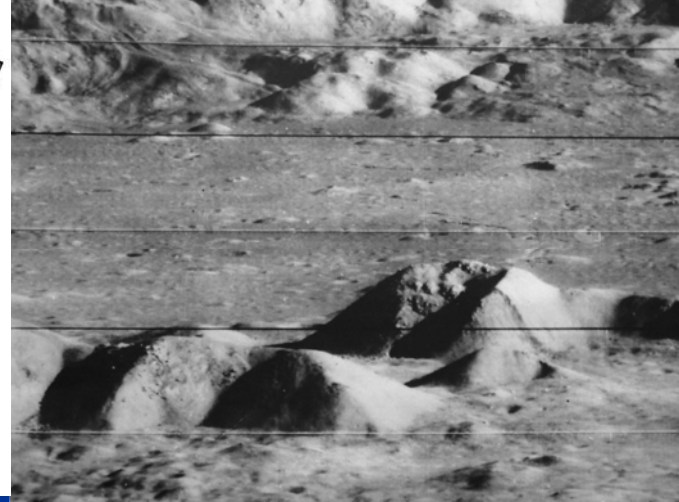
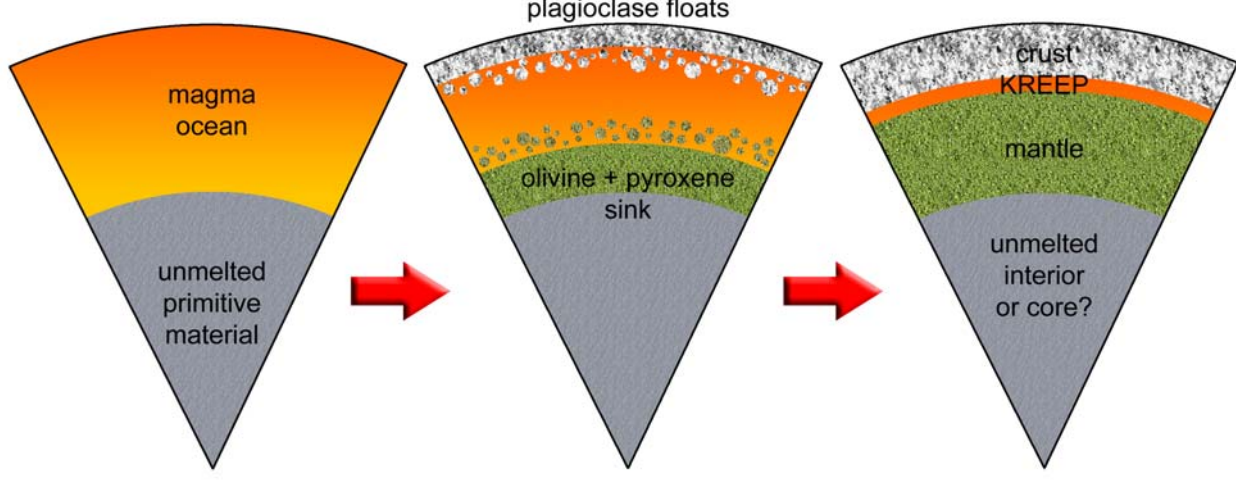
# Additional Findings, Priorities and Near-term Recommendations

PRINCIPAL FINDING: Lunar activities apply to ***broad*** scientific and exploration concerns

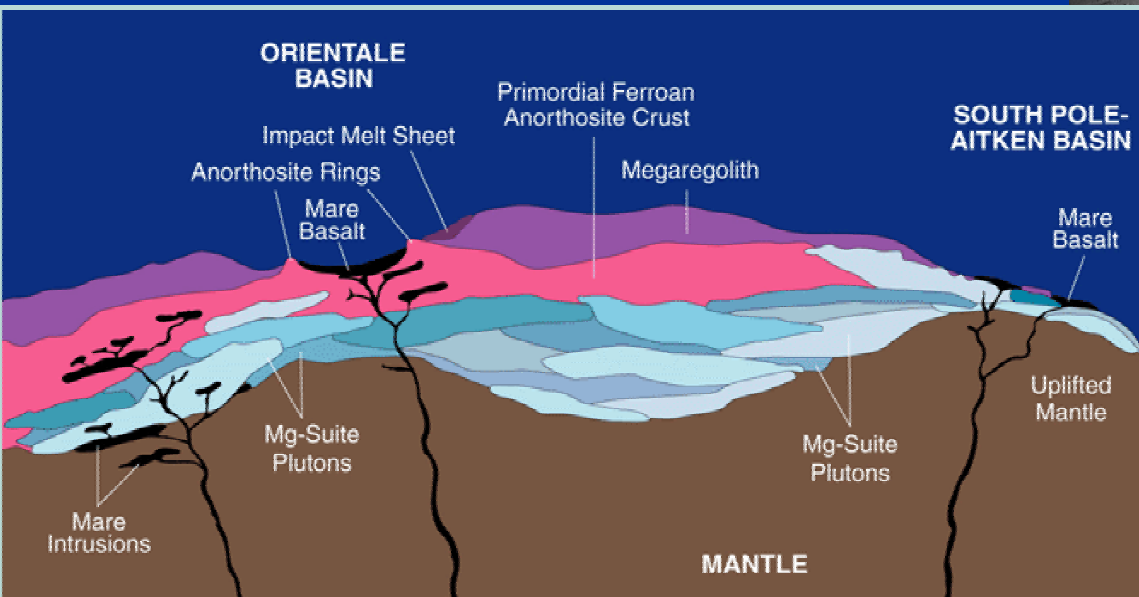
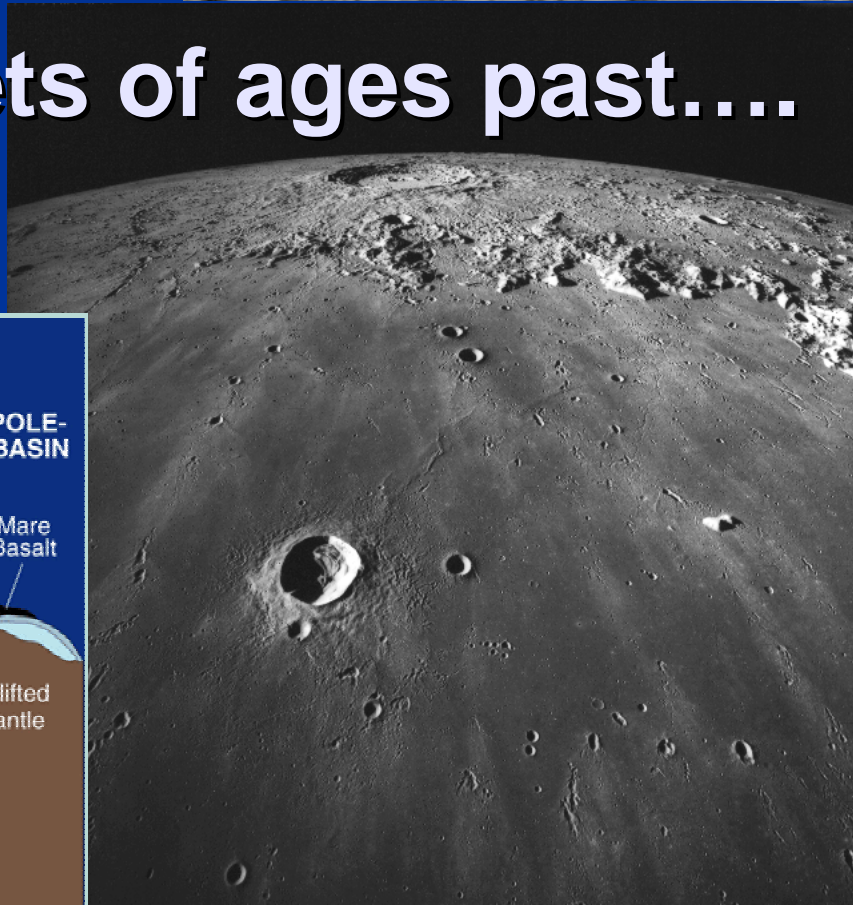
- Enabling Activities are Critical in the near-term. Make a strategic commitment to **stimulate lunar research** and engage the broad scientific community.
  - Lunar Fundamental Research Program
  - Lunar Data Analysis Program
  - Lunar Technology Development Program
- Establish strong ties with **International Lunar Programs**.
- Explore the **South Pole-Aitken Basin**.
- Maximize the diversity of **Lunar Samples**.
- Proceed with lunar surface mission development and **Site Selection Process** with full input of the science community.

# Related Findings and Recommendations

- Optimize the **partnership** between NASA's Exploration Systems Mission and Science Mission Directorates.
- Identify and develop **lunar-specific** advanced technology and instrumentation.
- Plan principal investigator and **curatorial facilities** for new lunar samples.
- Optimize astronaut lunar field investigations —an **integrated human/robotic** approach.



# The Moon holds secrets of ages past....



(Graphic by Nancy Hulbirt for PSRD based on a concept by Paul Spudis, APL.)



The Moon as seen  
from the Earth ~4.2  
Gyr ago.

The Earth as seen  
from the Moon ~15  
years from now.

