Space Studies Board

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	STScI *Astrophysics Enabled by Return to the Moon*	Baltimore, Maryland	Oral Presentation	Daniel Lester
4-6 December	AIAA *2nd Space Exploration Workshop*	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

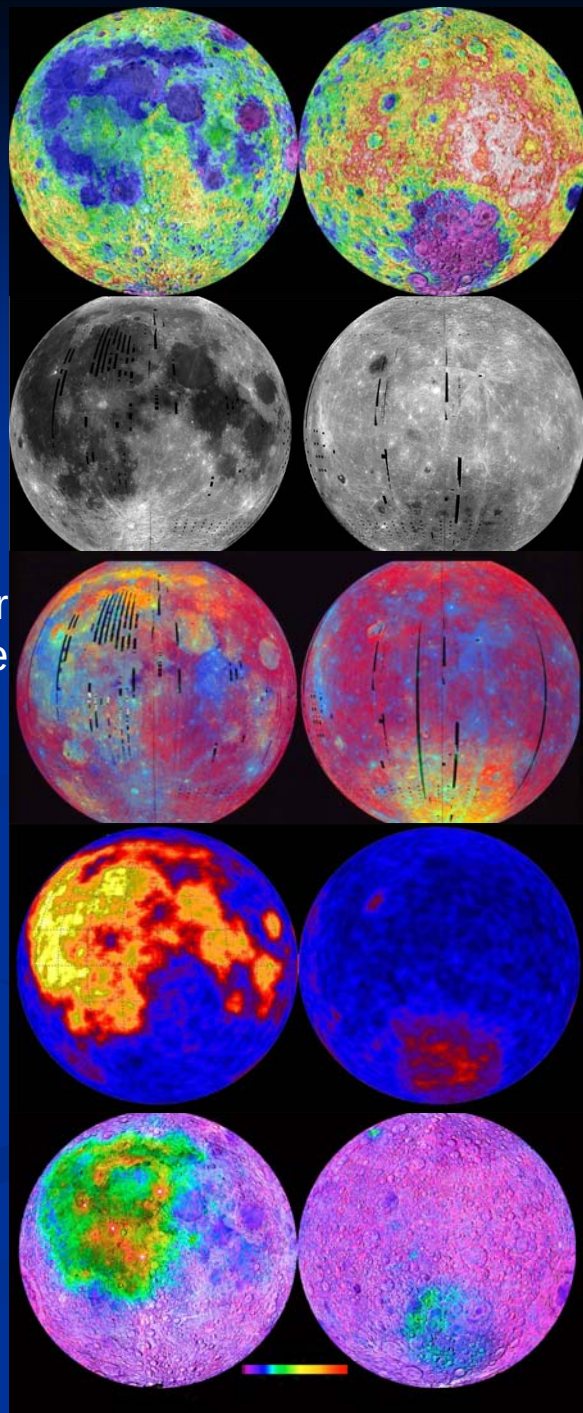
Topography

Albedo

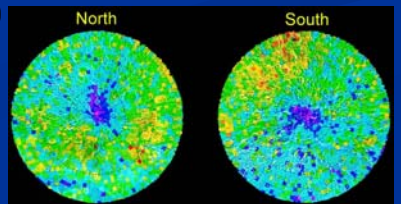
Color Composite

Iron

Thorium



Polar H

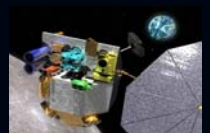


International Lunar Exploration

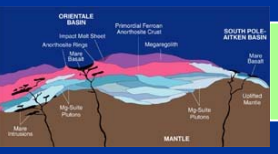
	SMART-1 [ESA]	**SELENE [JAXA]**	**Chang'E [CNSA]**	**Chandrayaan1 [ISRO]**	**LRO [NASA]**
Launch	2003	2007	2007	2008	2008
Orbit	400 x 4000 km polar	100 km polar circular	200 km polar circular	100 km polar circular	50 km polar circular
Objectives	Technology demonstration; investigate poles; Sept 2006 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 **LCROSS**

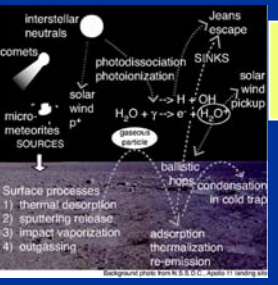






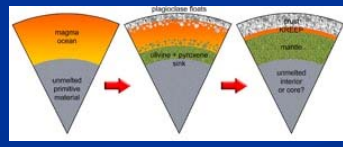
Overarching Science Themes

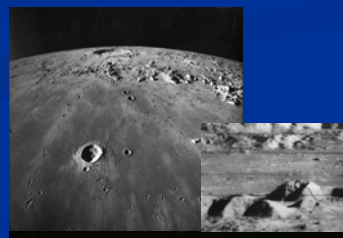




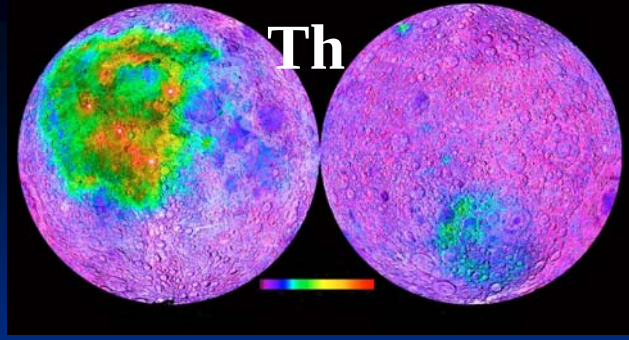
Lunar Science

- Early Earth/Moon System
- Terrestrial Planet Differentiation
- Solar System Impact Record
- Lunar Environment





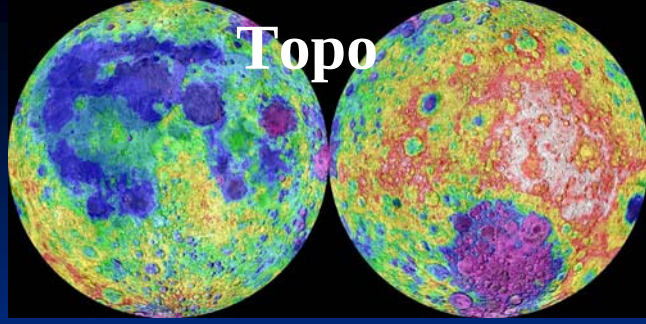
Science Concepts



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 maniested 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.

- Determine the utility of the Moon for astrophysics observations and as a platform for observations of Earth and solar-terrestrial processes.

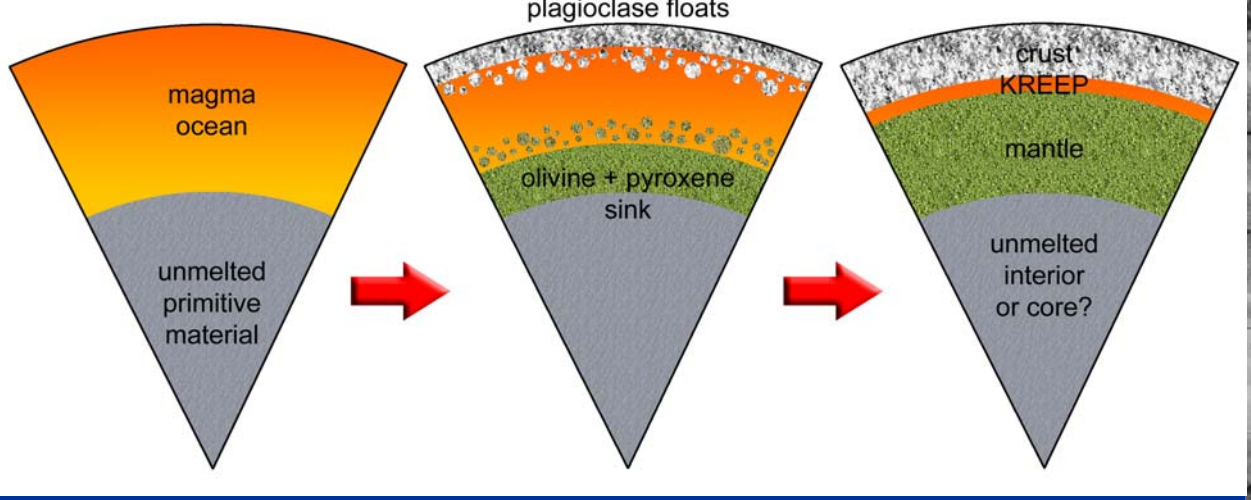
Additional Findings, Priorities and Near-term Recommendations

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

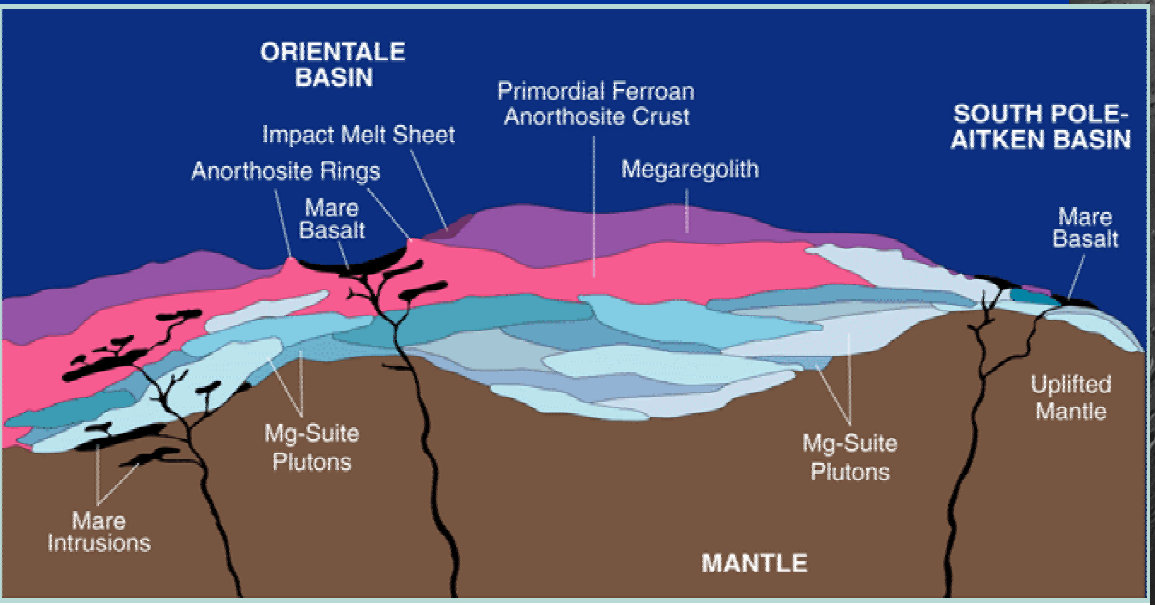
- Enabling Activities are Critical in the near-term. Make a strategic commitment to stimulate lunar research and engage the broad scientific community.
  - Lunar Fundamental Research Program
  - Lunar Data Analysis Program
  - Lunar Technology Development Program
- Establish strong ties with International 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.