

Scientific Motivation for Sample Return from South Pole-Aitken Basin

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LROC WAC low-Sun mosaic, central SPA Basin, NASA/GSFC/ASU

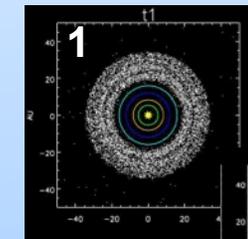
Late Heavy Bombardment: A Key Event in the Early Solar System

- **Late Heavy Bombardment (LHB) proposed in 1974**
 - Based on analysis of samples from large, *late*, near-side basins
 - SPA is the oldest and largest, with >50 basins formed after it
 - Uniquely suited to test the LHB hypothesis
- This “Cataclysm” captivated scientists and public alike
- 2005: “Nice” model – coupled LHB to the orbital dynamics of giant planets
- **Paradigm-shift potential for our understanding of how solar systems work**, hence classified as a high priority NF mission by two Decadal Surveys
 - Importance for Earth, early life, habitability
 - Importance for inner Solar System
 - Understanding of giant planet dynamics
 - Application to early dynamics of extrasolar planets

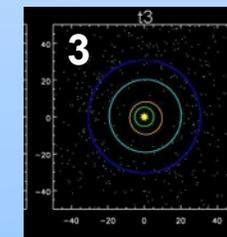
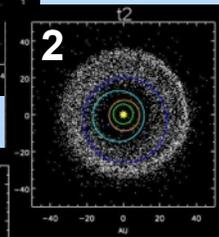
PSRD-Lunar Cataclysm (2001)



Don Davis



Nice model



Gomes et al., 2005, Nature

Lunar record of major early impact bombardment has broad implications for Solar System

Why SPA Basin?

South Pole -
Aitken
Basin

- Largest and oldest clearly recognizable impact basin on the Moon
- SPA anchors the lunar impact chronology.
- SPA formation completely resurfaced a huge area of the Moon and reset ages.

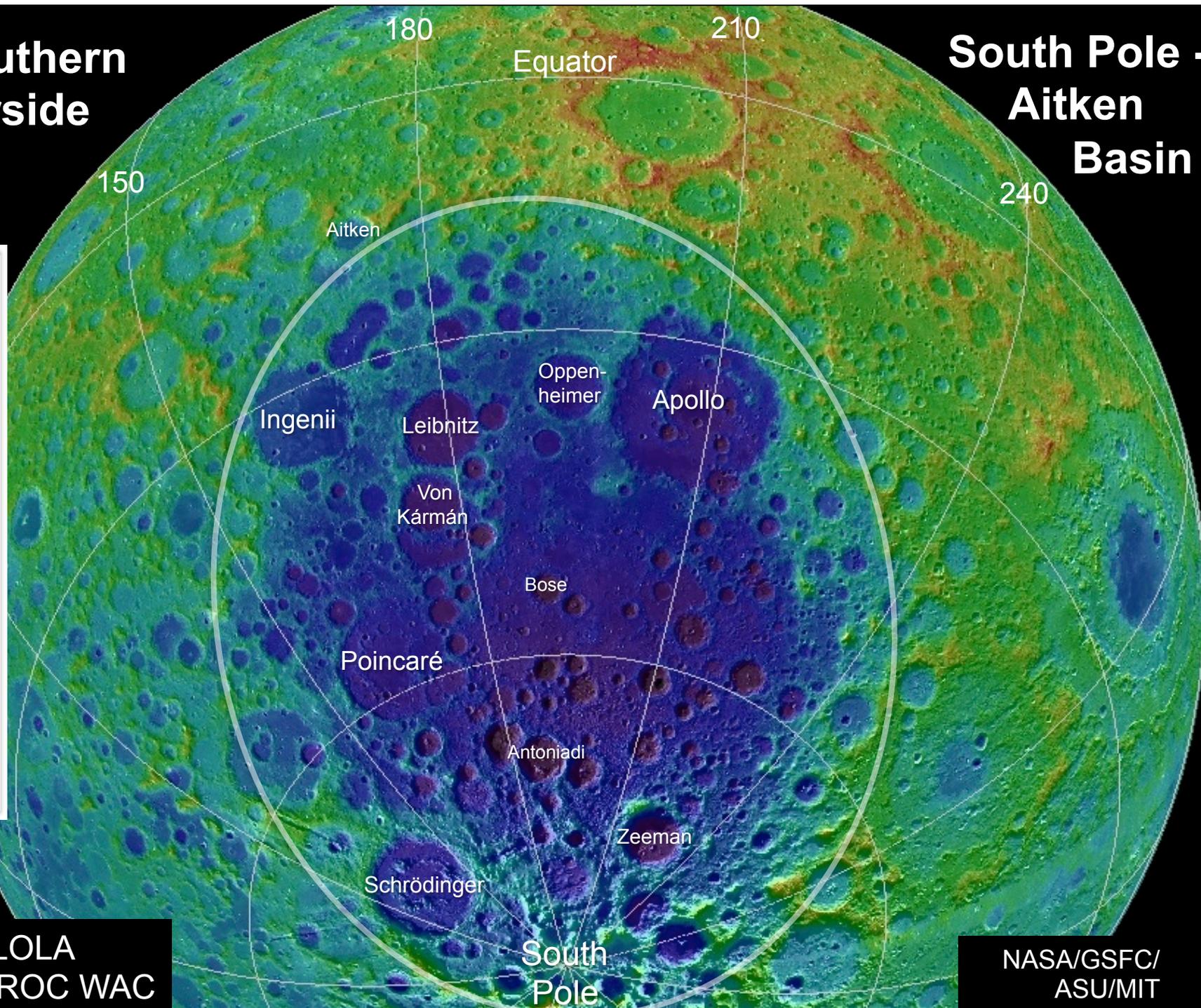
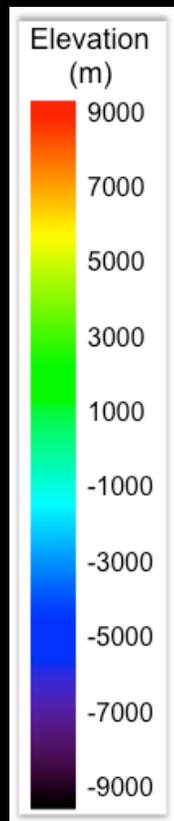
With samples we can determine the age of the basin and the chronology of large impacts within SPA.

LRO Wide
Angle Camera

NASA/GSFC/
Arizona State Univ.

**Southern
Farside**

**South Pole -
Aitken
Basin**



**LRO LOLA
and LROC WAC**

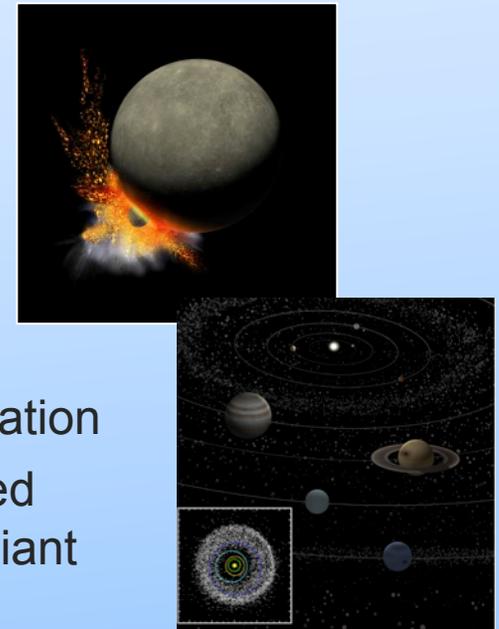
**NASA/GSFC/
ASU/MIT**

SPA Science

- **Early Solar System chronology**
 - establish age of early Solar System events
 - test dynamical models
- **Lunar history:**
 - magmatic history, impact bombardment, volcanism
- **Crustal structure:** lower crust, upper mantle
 - SPA impact melt "sea" – differentiated?
- **Giant impact processes**
 - depth of excavation, impact-melt production and differentiation
- **Basaltic Volcanism:**
 - ages, compositions, mantle heterogeneity
 - test nearside – farside dichotomy

Early Solar System Impact Chronology

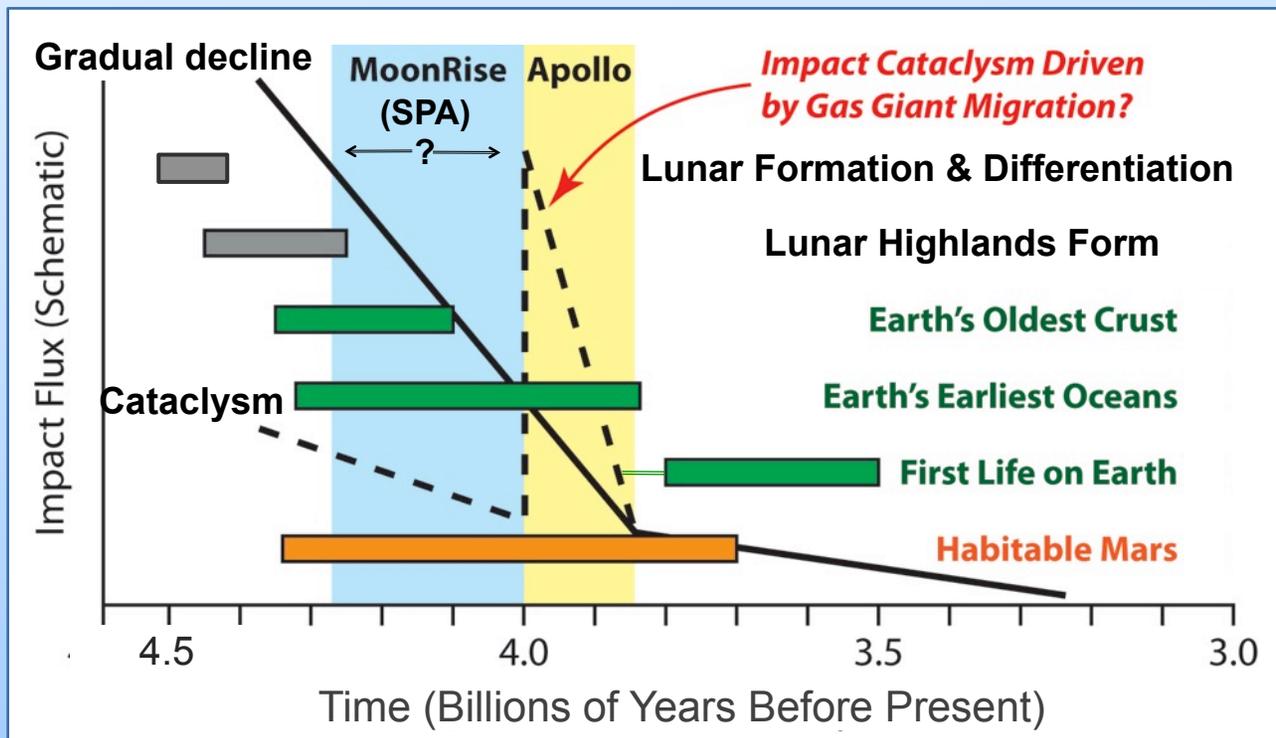
- **Large impact chronology** recorded in SPA is important for the following reasons:
 - Spans range from SPA formation to formation of Schrödinger, second youngest of the lunar impact basins, and beyond
 - Determined outside the Apollo/Luna sampling zone, which is dominated by Imbrium
 - Fundamental to testing key early Solar System dynamics models
 - ★ Nice and Grand Tack models for giant planet migration
 - ★ Hypothesis that pre-Nectarian impacts were related to sweep-up of late accretional or Moon-forming giant impact debris (Bottke et al., 2014)



SPA large impact chronology provides a record of heavy bombardment of the Moon independent of the nearside record, which is dominated by Imbrium.

SPA as a Window into the Early Solar System Environment

- MoonRise science builds on chronology and chemistry from Apollo, but..
 - the cataclysm test cannot be done solely with Apollo samples; **SPA samples are required.**



Gradual decline: older age for SPA, no support for gas giant migration

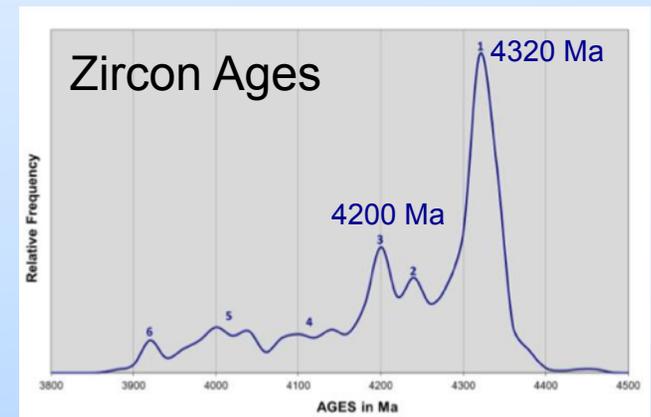
Cataclysm: younger age for SPA, support for gas giant migration

To understand early Solar System environments, we must acquire new samples from the most ancient of lunar impact basins: South Pole-Aitken basin.

Lunar Geologic History

- **Magmatic History**

- Are SPA rocks related to Mg suite rocks or one of the granulite suites?
- What are the igneous rock clasts in SPA impact breccias?
- Was SPA formation related to one of the igneous rock age spikes recorded in lunar samples? (*Grange et al.*; *Gaffney, Borg et al.*)



Grange et al., 2013

- **Impact Bombardment**

- Early bombardment chronology anchored by age of SPA resurfacing.

- **Volcanism**

- What are the basalt compositions and ages in SPA?

Was SPA a trigger for major near-side magmatic activity?

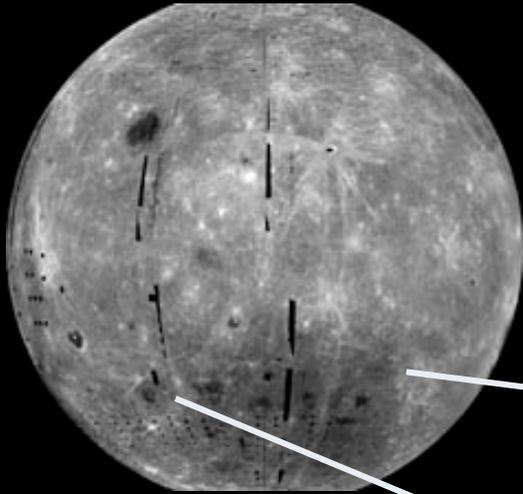
Schultz & Crawford 2015;
Kring et al., 2015)

Crustal Structure

- **Crustal density is high and porosity relatively low for SPA interior**
 - Why? What is exposed: mantle or lower crust?
- **Lower crust**
 - What are the lower crustal components?
 - Is the lower crust excavated by SPA mafic or feldspathic?
 - Distinguish using mineral assemblages and mineral compositions.
- **Differentiated Impact Melt**
 - Does the present-day SPA "crust" represent differentiated impact melt? (Vaughan and Head, 2013; Hurwitz and Kring, 2014)
 - What are the rock compositions and textures?

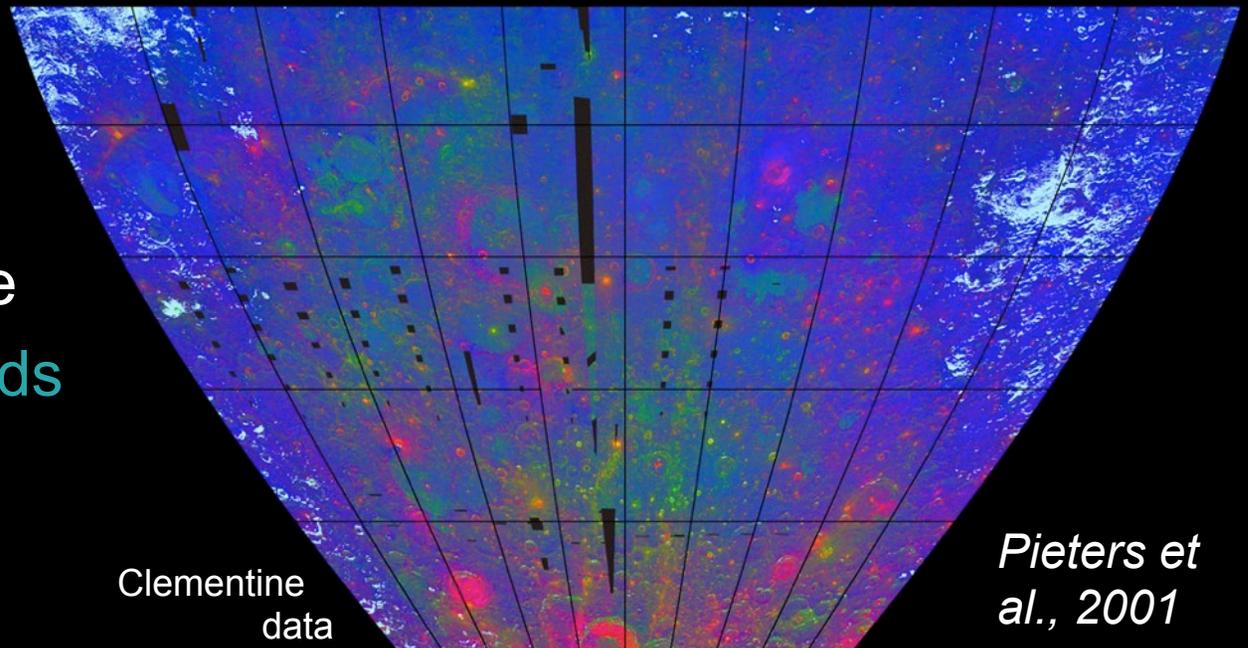
Samples are needed to answer these questions

SPA Mineralogy



- Near lack of anorthosite
→ was upper crust removed?
- Abundance of norite, dearth of olivine
→ lower crust? Impact-melt breccia?
→ upper layer of differentiated melt sea?

Soils
Anorthosite
Basalt ponds
Norite
Mafic-rich



Pieters et al., 2001

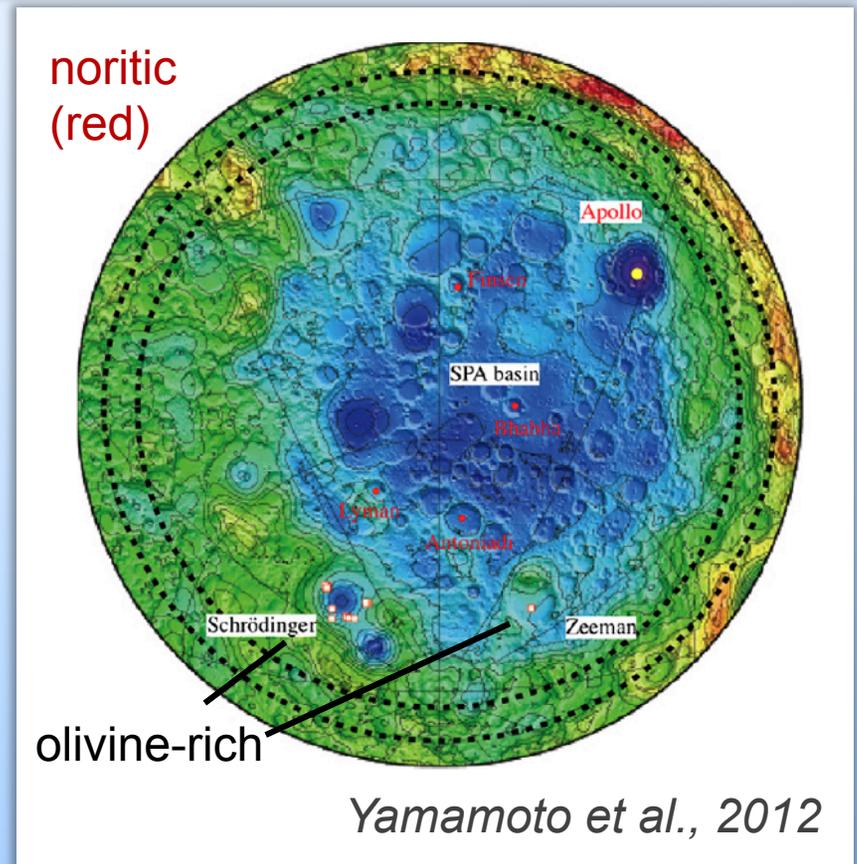
SPA Mafic Mineralogy

- **Central Peaks**

- **Alder:** anorthosite¹; Ol-noritic gabbro²
- **Antoniadi:** Ol-norite²
- **Bhabha:** norite; Ol-noritic gabbro²
- **Bose:** Ol-gabbroic norite²
- **Finsen:** gabbroic norite²
- **Fizeau:** gabbroic norite²
- **Lemaître S.:** Ol-norite²
- **Maksutov:** Ol-gabbroic norite²
- **Stoney:** Ol-noritic gabbro²
- **Zeeman:** Ol-rich³

- Numerous papers:

- Pieters et al., 2001, JGR-P
- Lucey 2004, GRL
- Lucey et al., 2005, LPSC
- ¹Ohtake et al., 2009, Science
- ²Cahill et al., 2009, JGR-P

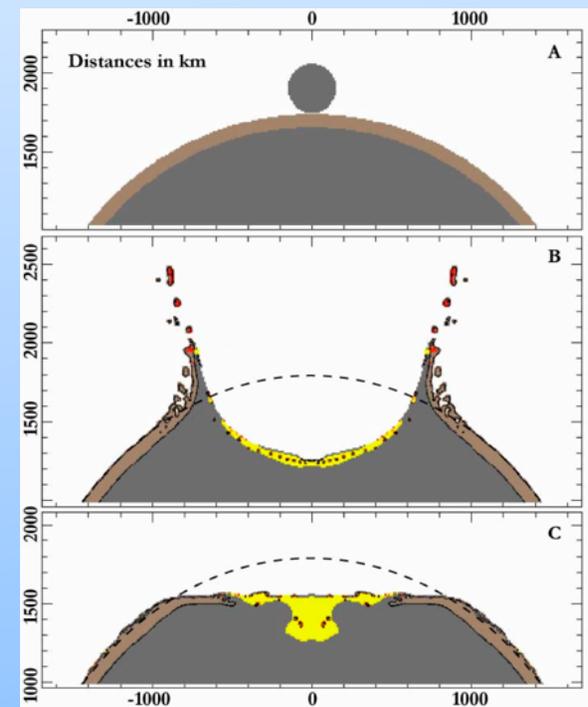
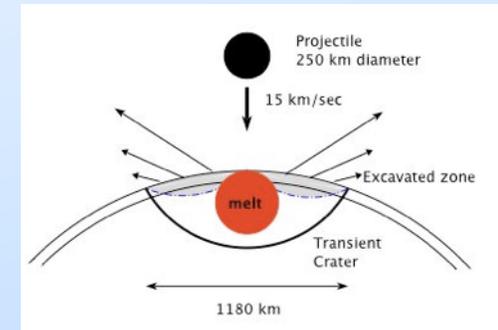


- ³Yamamoto et al., 2012, Icarus
- Donaldson Hanna et al. 2012, JGR-P, LPSC
- Kramer et al. 2013, Icarus
- Moriarty et al. 2013, JGR-P
- Donaldson Hanna et al. 2014, JGR-P

Giant Impact Processes

- Depth of excavation?
- Obliquity of impact?
- Impact melt sea depth?
- SPA ejecta and thickening of northern farside highlands?
- Lower crust and upper mantle components?
- Impactor debris?

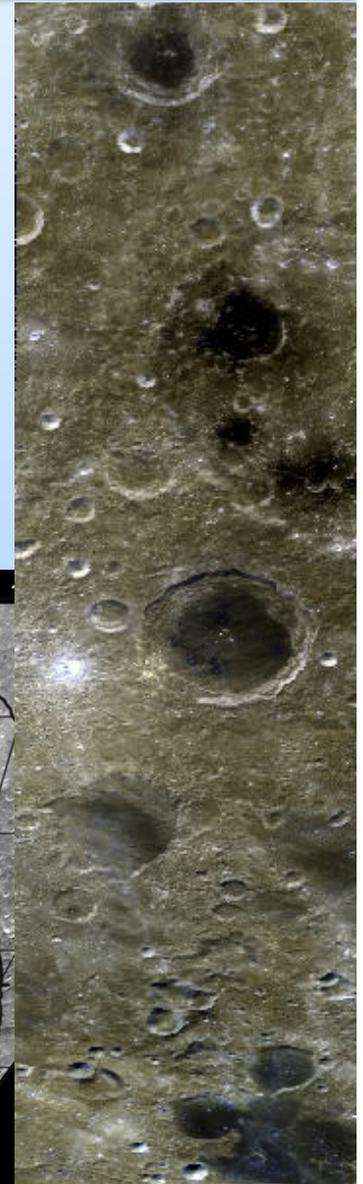
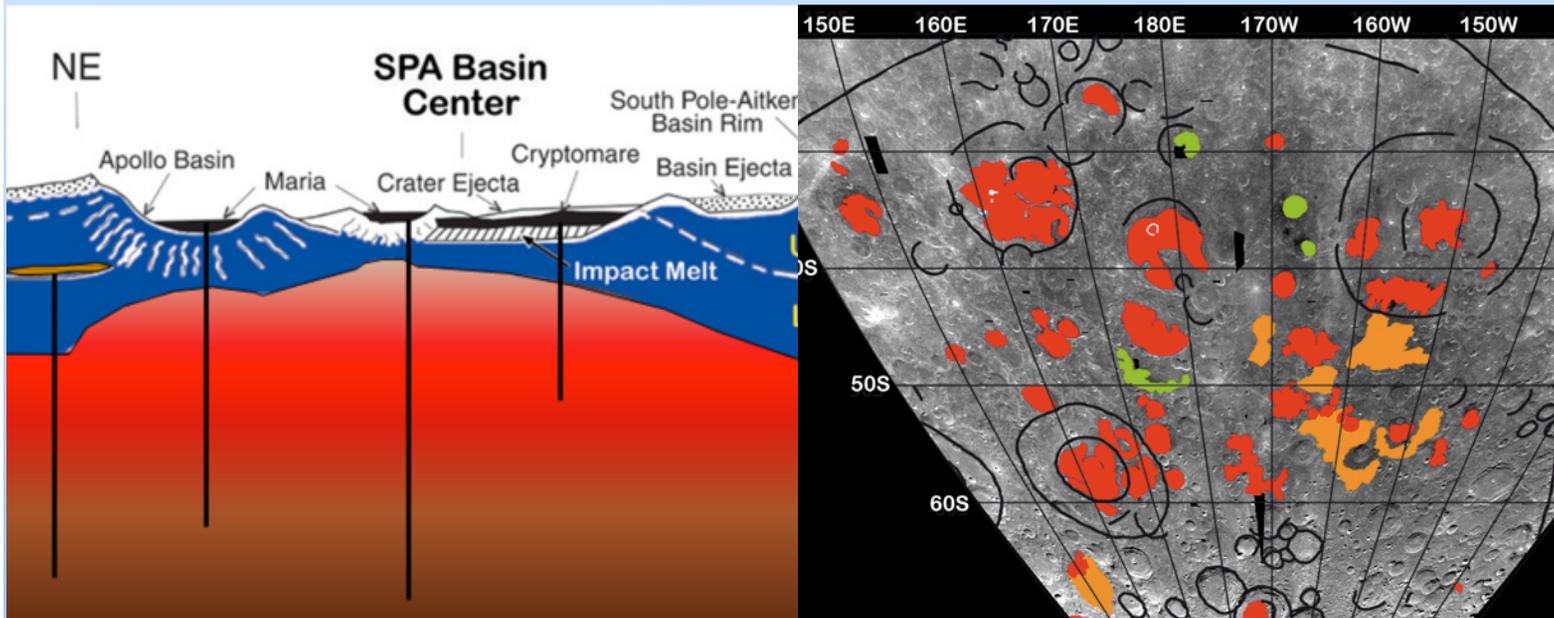
What is the origin of the farside highlands vs. nearside lowlands dichotomy?



From J. Melosh and G. Collins

Volcanism in SPA

- Chronology and Composition of Basaltic Volcanism
 - sampling sub-SPA mantle and testing models for origin and differentiation of the Moon
 - timing and thermal evolution
 - mare vs. cryptomare and ages



Conclusions, SPA Science

- **Chronology**
 - need samples from known location far from nearside "Apollo zone"
 - determine SPA chronology (SPA and younger craters within SPA)
- **Lunar history, Magma Ocean Differentiation, Volcanism**
 - need samples from known location far from nearside "Apollo zone"
- **Giant impact processes**
 - Asymmetry, depths of excavation, impact-melt differentiation...
- ***Level of scientific inquiry requires sample return.***
 - *Recent and current mission datasets frame the science and enable exploration in ways not previously possible.*