Targeted Lunar (Nearside) Sample Return

Important Advances for Technology and Lunar Science

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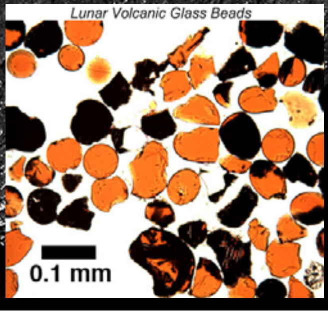
Moon 2020-2030, ESA/ESTEC 14 December 2015

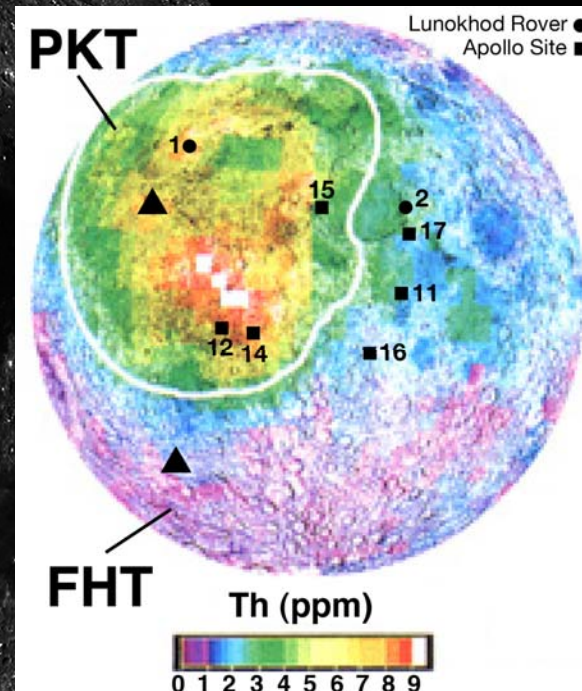


We need more than Apollo & Luna

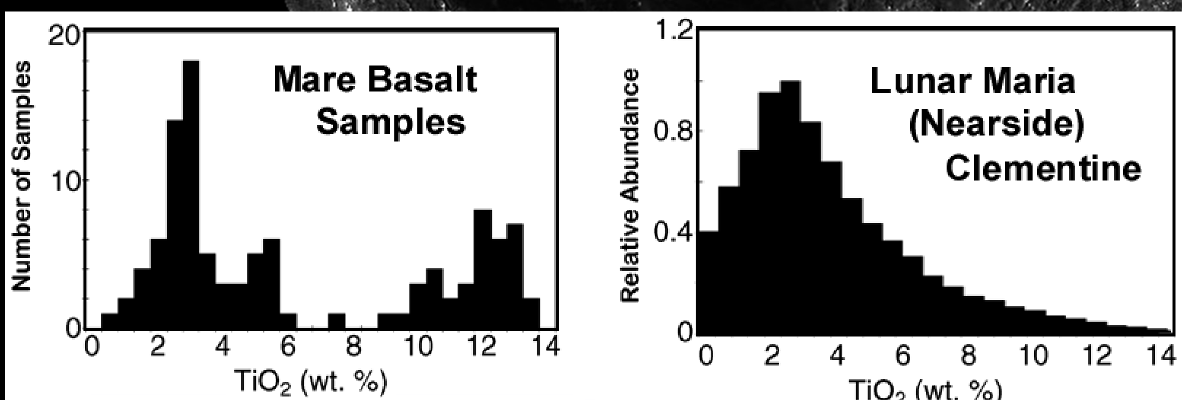
Subsequent missions have shown that the sample return sites were not ideal for exploring the Moon.

- Apollo sites close to terrane boundaries;
- Samples contain PKT signature;
- Apollo sample collection is not representative of the lunar compositional diversity (Clementine/LP and more recent missions) – sample return needed.
- Some lithologies are not present in the sample collection (Chandrayaan-1 & Kaguya missions).

PAN: Ohtake et al. (2009) *Nature* **461**, 236-241
OOS: Pieters et al. (2014) *Amer. Miner.* **99**, 1985-1910

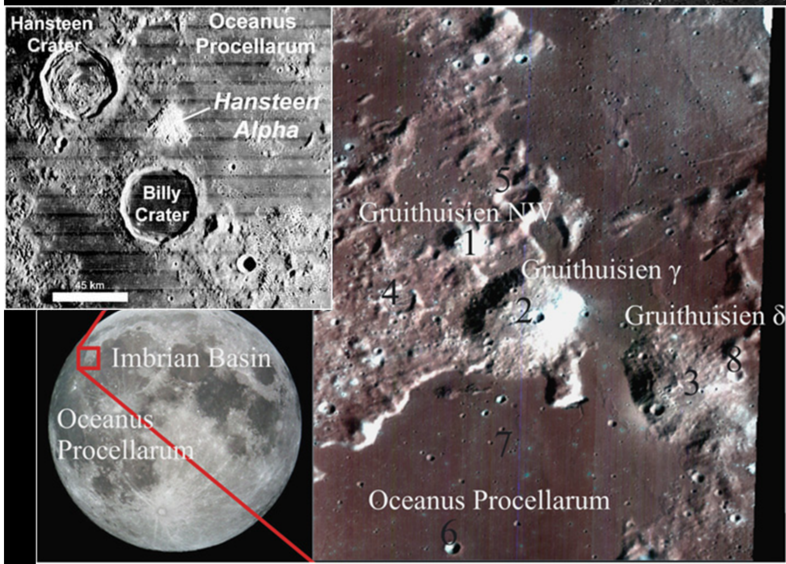


Jolliff et al. (2000) JGR 105, 4197-4126



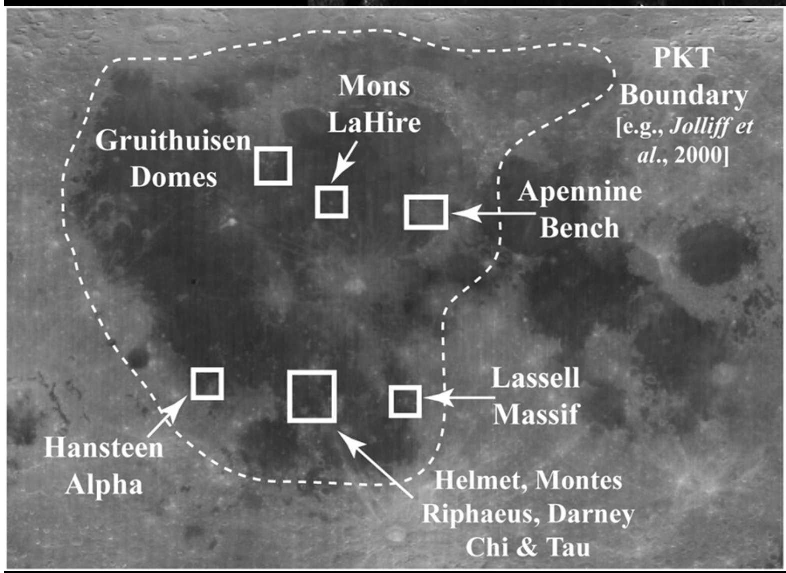
Giguere et al. (2000) *Meteorit. Planet. Sci.* **35**, 193-200

Non-Mare Silicic Magmatism



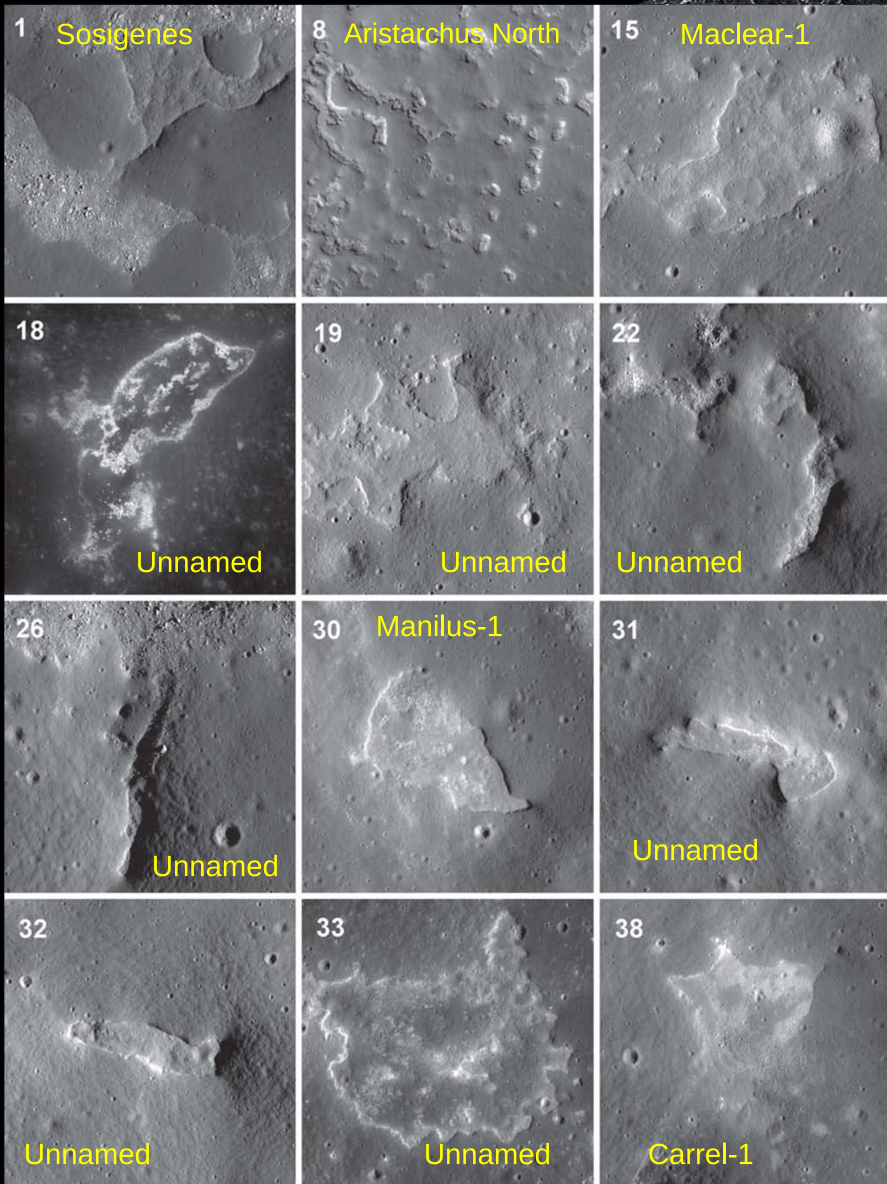
Gruithuisen Domes
Hansteen Alpha

Enhanced Th;
Explosive volcanism;
Christensen frequency (CF) value derived from DIVINER data indicates silica-rich lithologies.

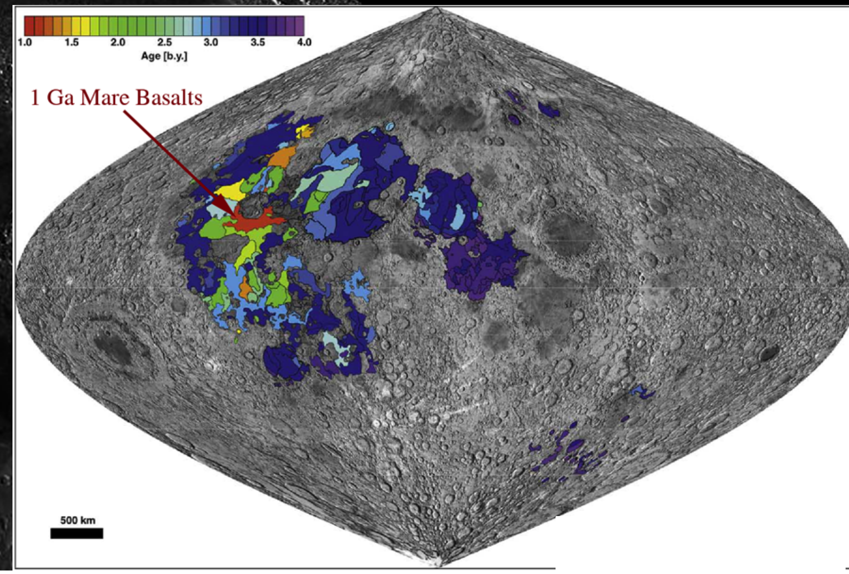


Kusuma et al. (2012) *Planet. Space Sci*. **67**, 46-56.
Hagerty et al. (2006) *J. Geophys. Res*. **111**, E06002, doi:10.1029/2005JE002592.
Lawrence et al. (2005) *Geophys. Res. Lett*. **32**, L07201, doi:10.1029/2004GL022022
Hawke et al. (2003) *J. Geophys. Res*. **108** (E7), 5069, doi: 10.1029/2002JE002013.

Recent Volcanic Activity



"Recent" volcanic eruptions ~ 1 Ga.



Hiesinger et al. (2003) JGR 108, (doi: 10.1029/2002JE001985)

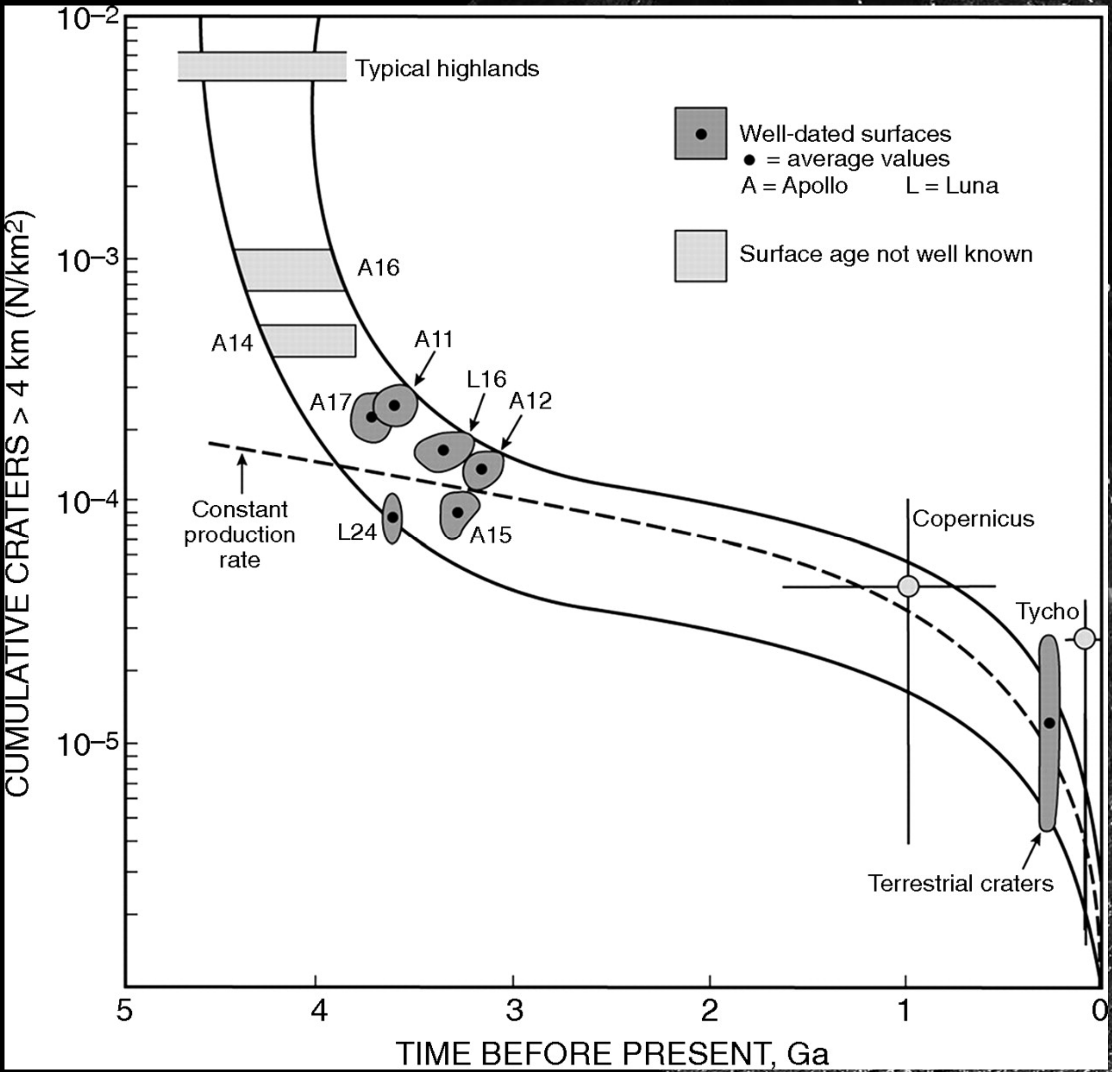
Ina depression in Lacus Felicitatis

Schultz et al. (2006) *Nature,* v. 444**, p. 184-186.**

"IMPs" (Irregular Mare Patches) <100 Ma.

Images = 450 m across **Braden S.E. et al. (2014) *Nature Geoscience,* v. 7, p. 787-791.**

Cratering Chronology



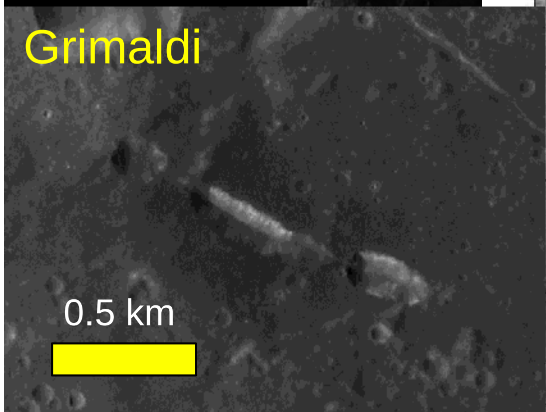
Constraining crater chronology.

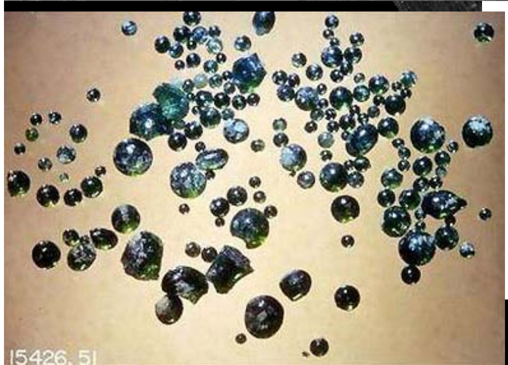
Important for Solar System Science.

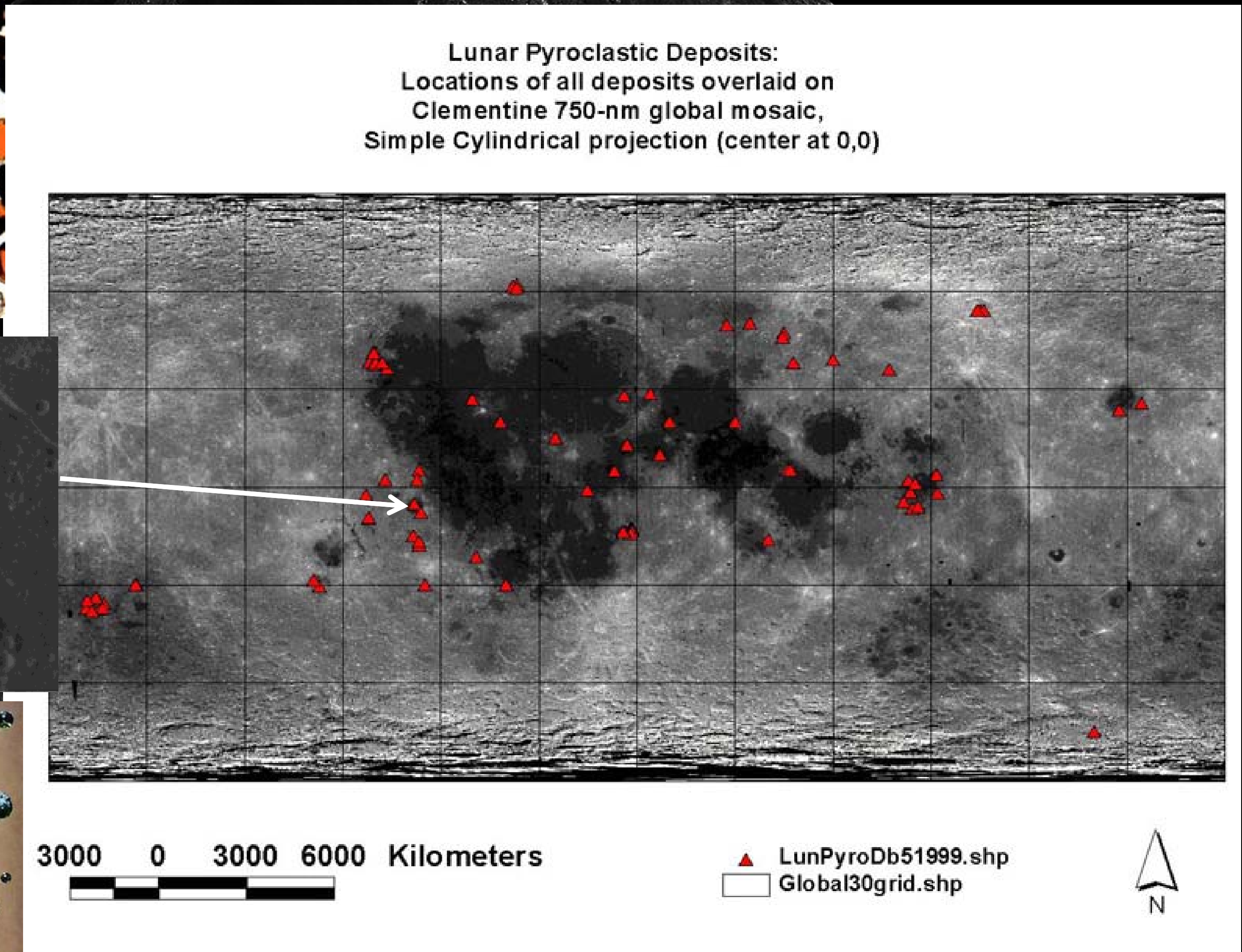
Barlow (2010) GSA Bull. 122, 644-657

Pyroclastic Deposits

http://astrogeology.usgs.gov/geology/moon-pyroclastic-volcanism-project

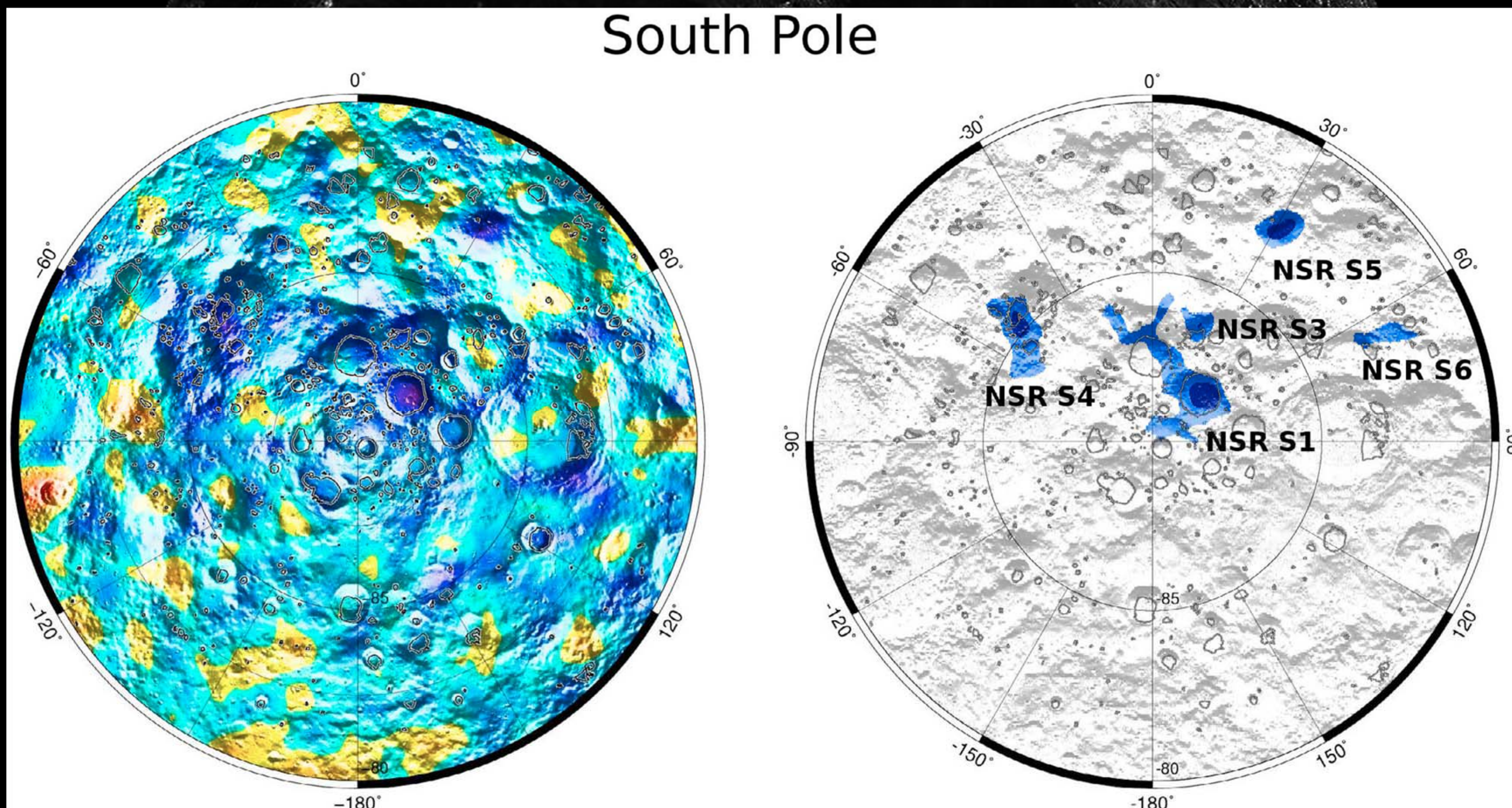






Ice Permafrost Around PSRs

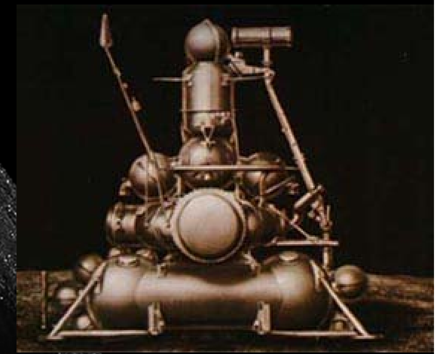
Neutron Suppression Regions (NSRs)are found in both permanently shadowed and illuminated areas, and they are not coincident with Permanently Shadowed Regions (PSRs). Possible with nearside sample return?



Mitrofanov et al. (2012) *J. Geophys. Res.* **117** E00H27, doi:10.1029/2011JE003956.

Why Humans on the Moon?

Sample Return - Robotic



Mission	Country	Date Returned	Mass (kg)
Luna 16	USSR	24 Sept. 1970	0.10
Luna 20	USSR	25 Feb. 1971	0.03
Luna 24	USSR	22 Aug. 1976	0.17
Total			**0.30**

Sample Return - Human

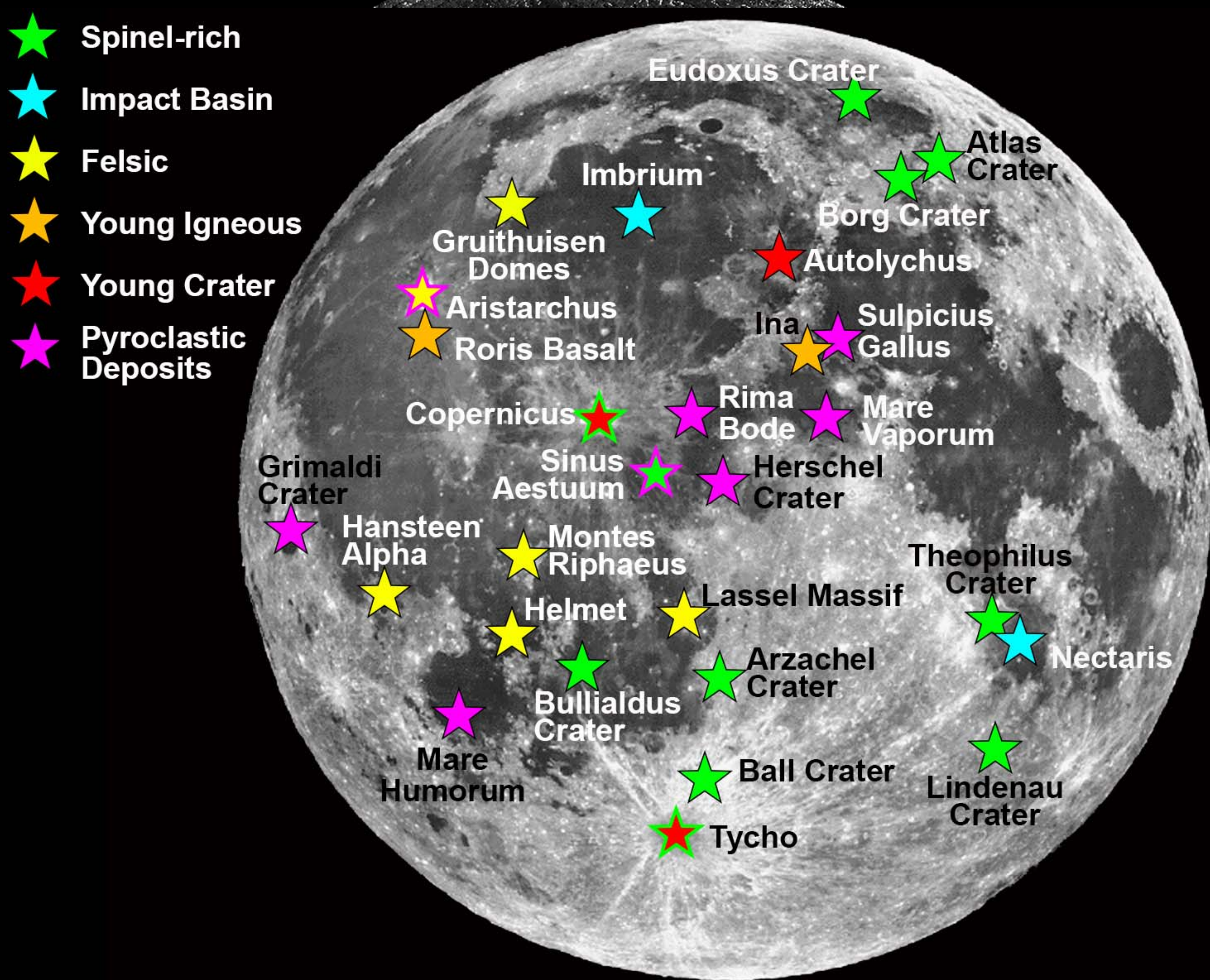
Mission	Country	Date Returned	Mass (kg)
Apollo 11	USA	24 July 1969	21.6
Apollo 12	USA	24 Nov. 1969	34.3
Apollo 14	USA	9 Feb. 1971	42.3
Apollo 15	USA	7 Aug, 1971	77.3
Apollo 16	USA	27 Apr. 1972	95.7
Apollo 17	USA	19 Dec. 1971	110.5
Total			**381.7**

Future Sample Return Missions

Sample Return:

- New lithologies
- South Pole-Aitken Basin impact melt (“Moonrise”)
- Other younger (e.g., Copernicus, Tycho) impact craters
- Multi-ring basins (Nectaris, Imbrium, and Orientale)
- Young volcanic features (e.g., the Ina Structure)
- Felsic domes (Gruithuisen Domes, Hansteen-Alpha, Compton-Belkovich);
- Large pyroclastic deposits;
- Cryogenic sample return.

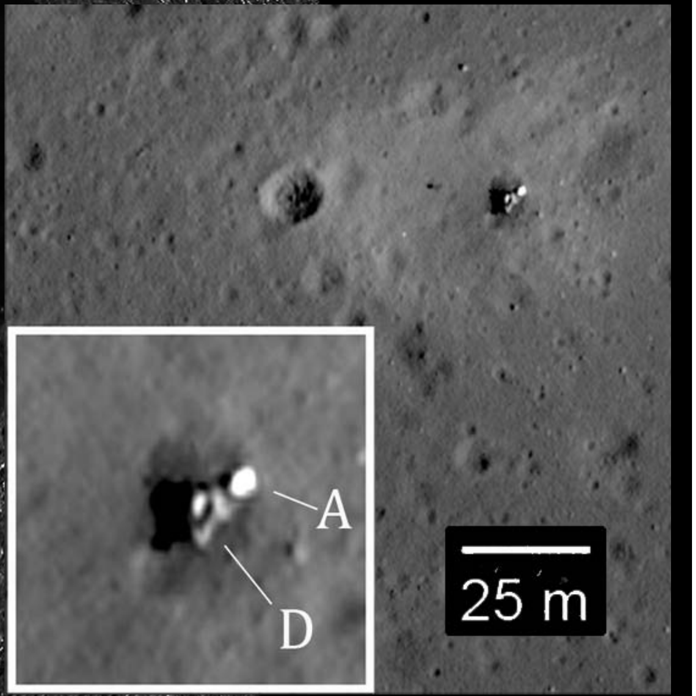
Targeted Sample Return



Previous Robotic Sample Return from the Moon was not Easy!

Soviet Union is the only country to successfully return samples from another planetary surface, but….

Luna 15	13 July 1969	Failed (crashed)
Luna 16	12 Sept. 1970	Succeeded
Luna 18	2 Sept. 1971	Failed (crashed)
Luna 20	14 Feb. 1972	Succeeded
Luna 23	28 Oct. 1974	Failed (damaged)
Luna 24	14 Aug. 1976	Succeeded



The Luna 23 vehicle (descent stage, ascent stage and Earth-return capsule) landed at an unexpected speed and fell on its side.

http://lroc.sese.asu.edu/news/uploads/luna23_figure.png

Future Sample Return Missions

Technology Development:

- Landers and sample return vehicles.
- Cryogenic sampling, transport, and curation.
- Rover development to survive the lunar day/night temperature swings, sample identification, collection, and storage (including cryogenic capabilities).
- Development of a Moon Assent Vehicle to return the samples.
- These developments would have feed forward implications for Mars sample return or SR from other destinations.

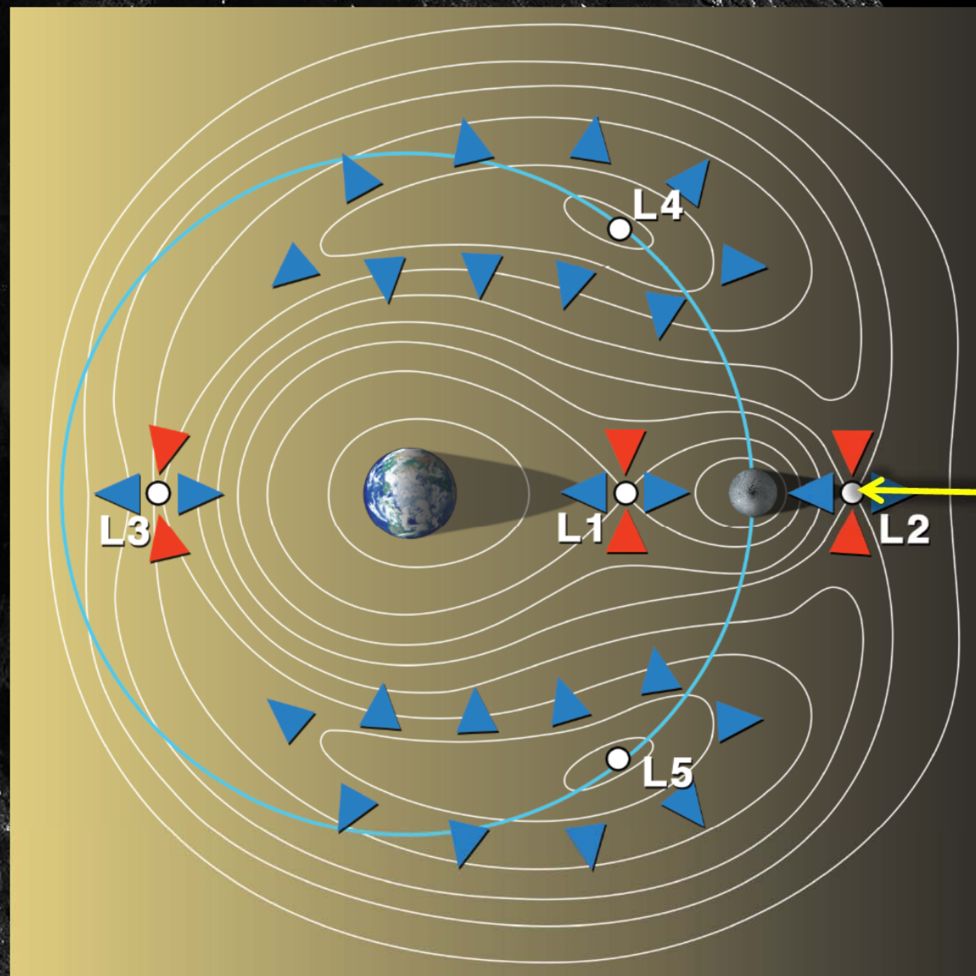
Benefits of Early Lunar Robotic Sample Return

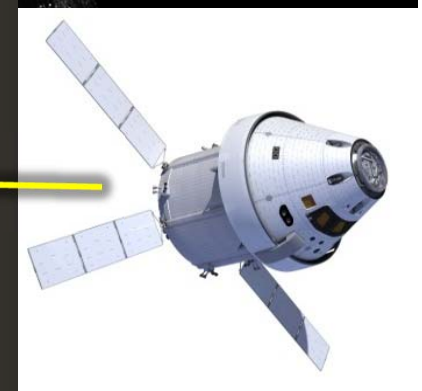
- Would enable science and exploration, as well as human-robotic synergies.
- Availability of an orbiting/L2 habitat could facilitate targeted robotic sampling of the lunar farside without much com-delay, and facilitate exploration of the farside without the need for a relay satellite.
- Sampling rovers could be sent ahead of human missions to undertake teleoperated sampling and reconnaissance of specific sites then rendezvous with the astronauts who would investigate important sites further and return the samples.
- Alternatively, the sample return could be purely robotic, re-establishing the capability that was last successful in 1976 (Luna 24).

Questions or Coffee?

Orion Crew Vehicle at Earth-Moon L2 can teleoperate rover on Farside

- E-M L2 is 60,000 km above farside. Minimal station-keeping to orbit about L2.
- This mission is much less expensive than Apollo-style missions since no lunar lander is required.
- Mission is affordable with NASA's current & notional outyear budgets.
- Timetable for first crewed mission(s) is early 2020's.

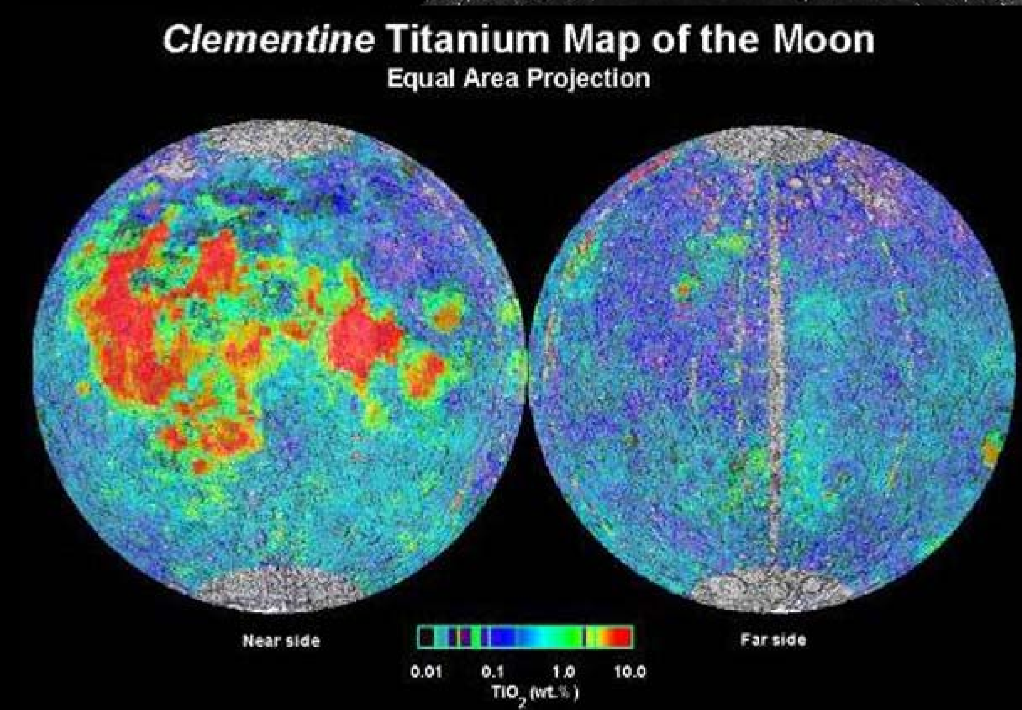


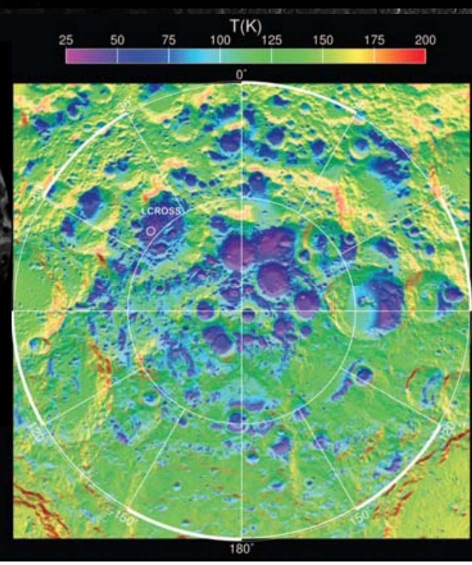


Waypoint Mission Concept

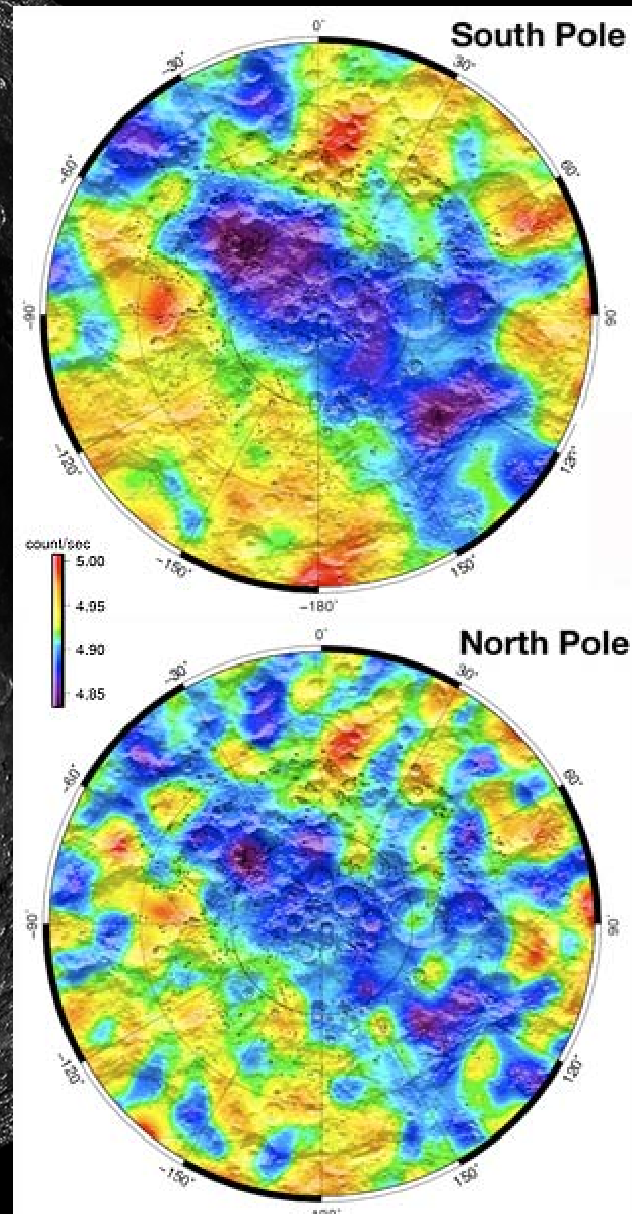
Burns *et al.* 2013, *Advances in Space Research*, 52, 306.

Resource Prospecting



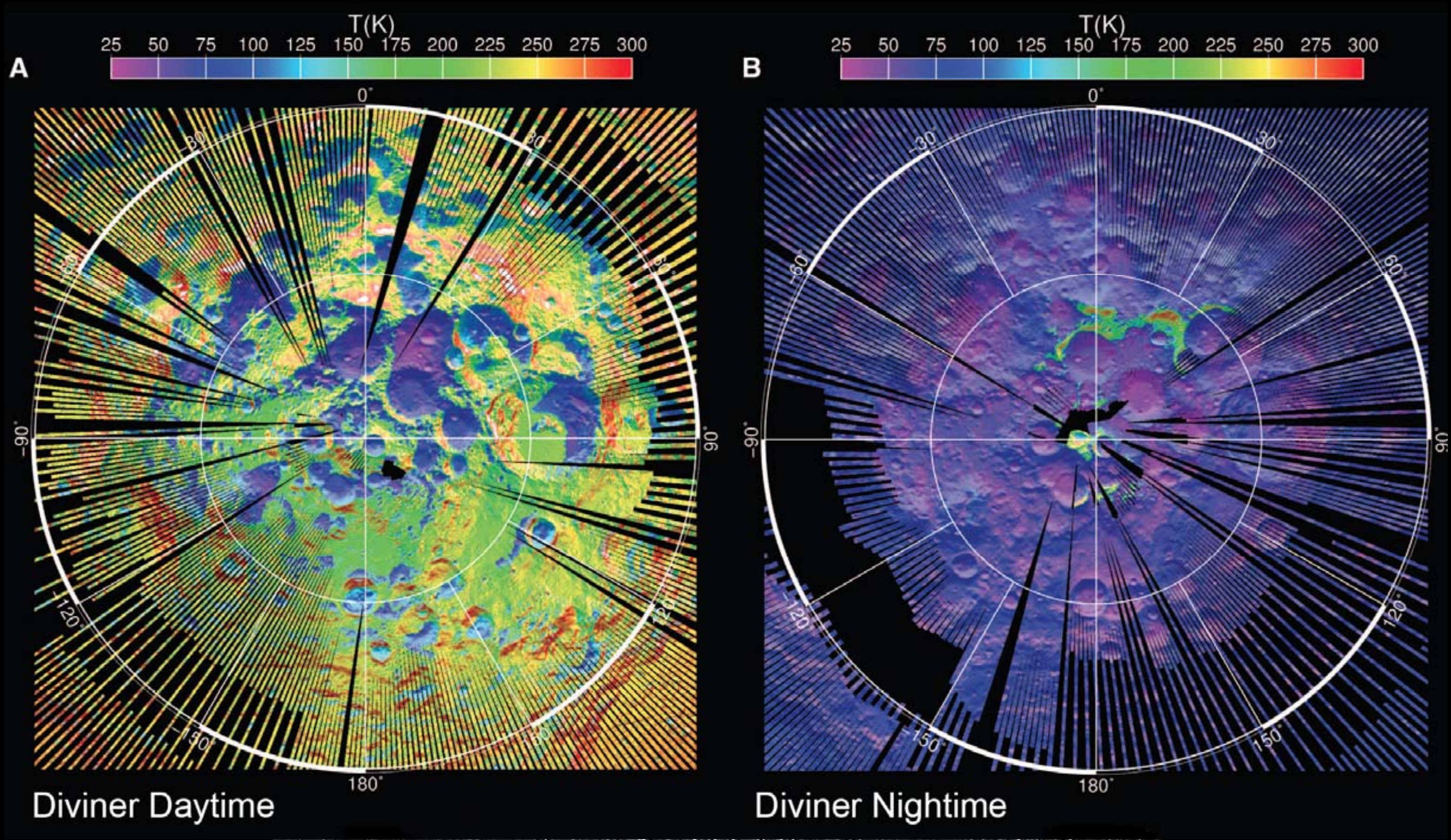


Permanently Shadowed Regions (PSRs; cold traps)



Resource Prospecting

Permanently Shadowed Regions (PSRs).



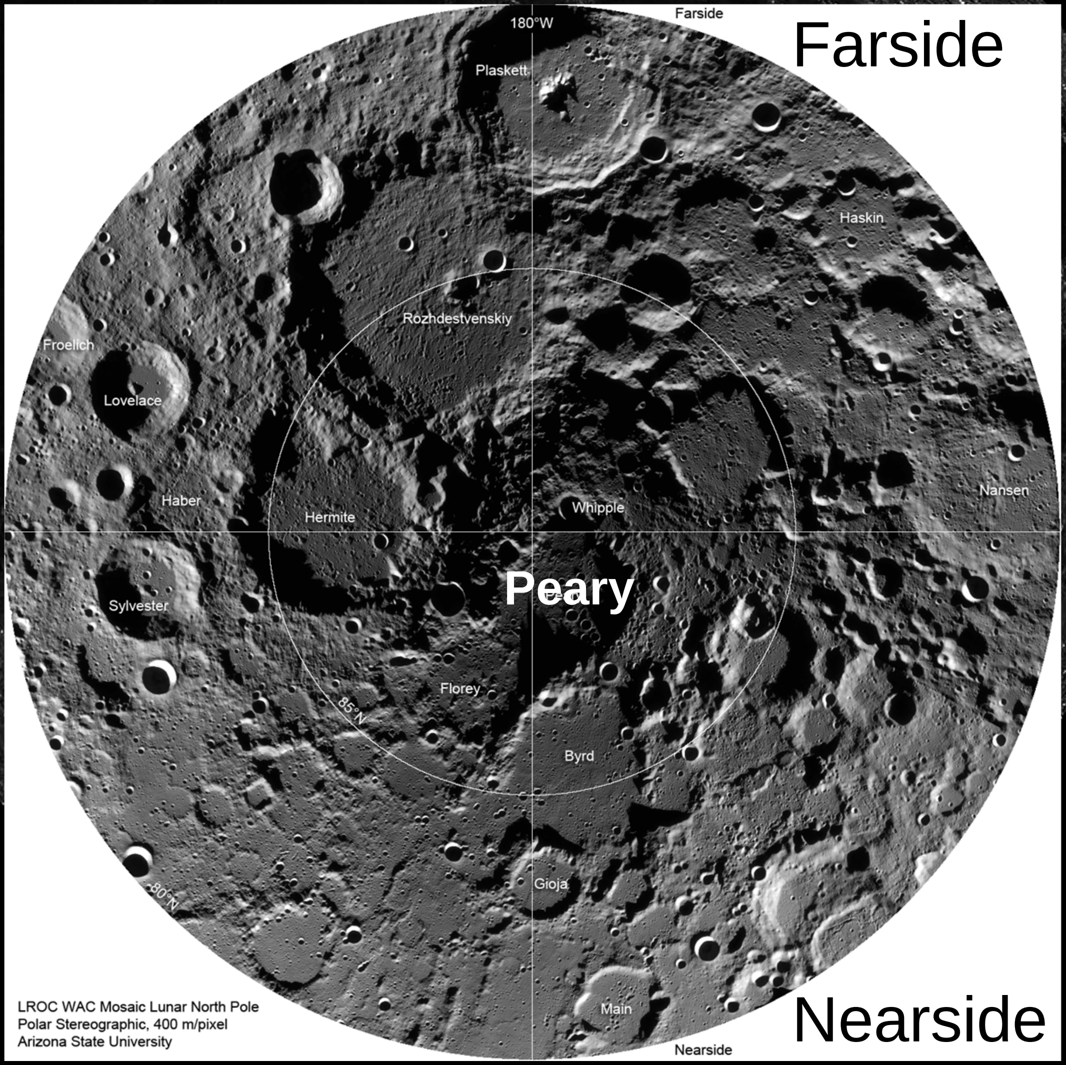
What is the size of the volatile deposits in PSRs? What form are they in?

Engineering challenge: low temperatures (25K).

Resource Prospecting

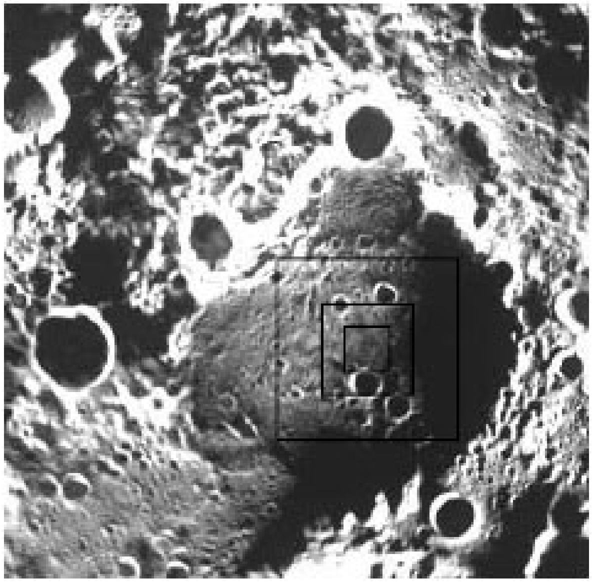
Permanently Shadowed Regions (PSRs).

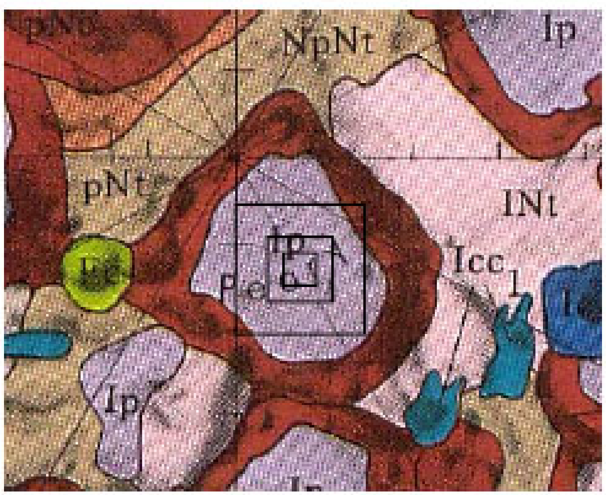
Peary Crater – North Pole



Resource Prospecting

Peary Crater





(Clementine uvvis color ratio image not available)

Location (longitude, latitude): 30.00, 88.50

Scientific Rationale:
Polar volatiles
Impact process

Resource Potential:
Highlands regolith
Enhanced hydrogen in permanently shadowed polar craters (water ice?)

Operational Perspective:
Highlands terrain
Polar location
Areas of permanent shadow

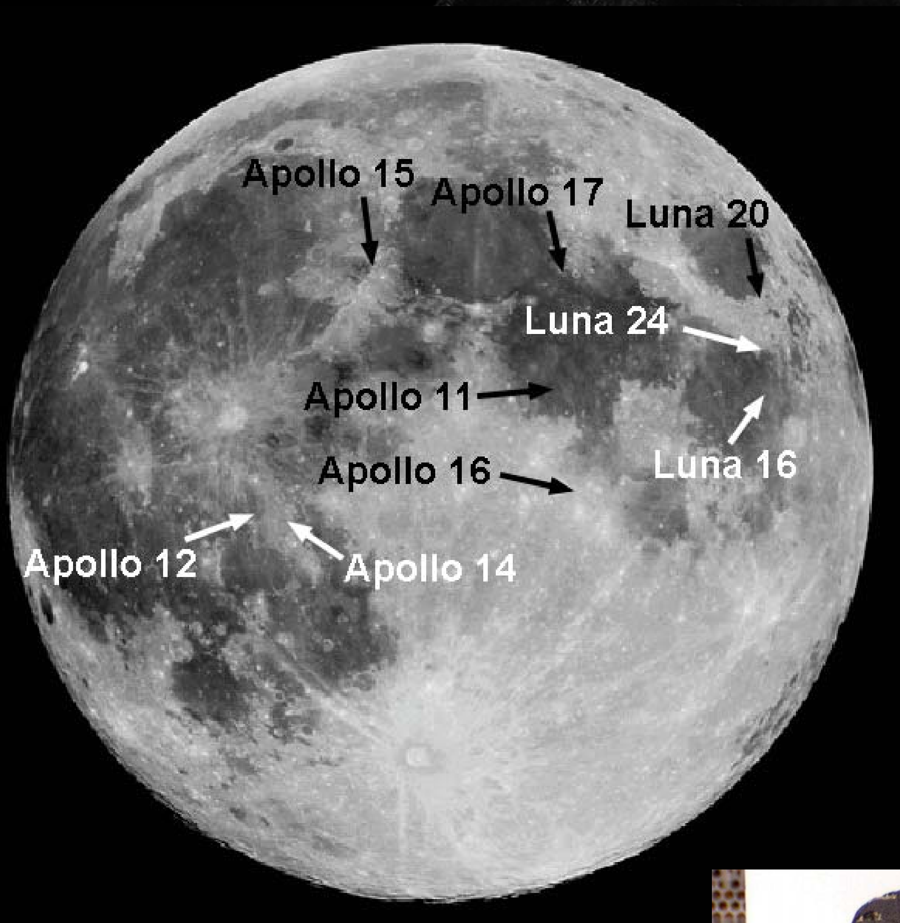
NASA References:
Exploration Systems Architecture Study (2005)
Geoscience and a Lunar Base (1990)

Missions to the Moon this Century

Mission	Launch Date	End Date
Clementine	*25 Jan. 1994*	*5 May 1994*
Lunar Propsector	*7 Jan. 1998*	*31 July 1999*
SMART-1	27 Sept. 2003	3 Sept. 2006
Kaguya (SELENE)	14 Sept. 2007	10 June 2009
Chang'e 1	24 Oct. 2009	1 Mar. 2009
Channdrayaan-1	22 Oct. 2008	31 Aug. 2009
LRO	17 June 2009	STILL ACTIVE
LCROSS	17 June 2009	9 Oct. 2009
ARTEMIS	20 July 2009*	STILL ACTIVE
Chang'e 2	1 Oct. 2010	April 2012
GRAIL	10 Sept. 2011	1 Jan. 2012
LADEE	6 Sept. 2013	17 Apr. 2014
Chang'e 3	1 Dec. 2013	STILL ACTIVE

* Actual launch date = 17 Feb. 2007 as part of THEMIS mission. Date represents start of operations once three satellites were moved to the Moon

Current Sample Return Collections



<5% of lunar surface explored.

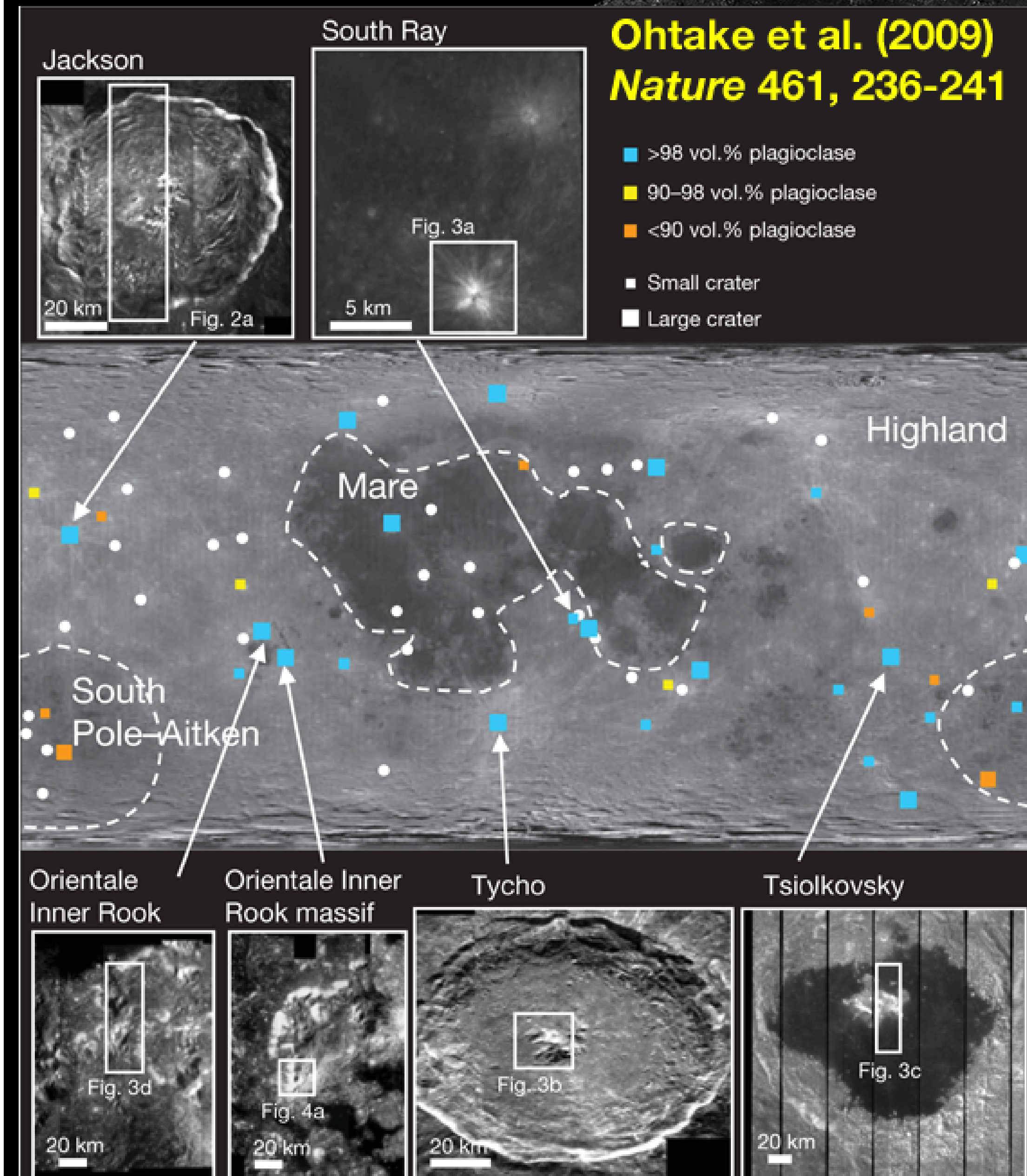
Apollo samples not representative.

Lunar renaissance since the 1990s has demonstrated the presence of unsampled lithologies and changed our understanding of the Moon.

Need targeted sample return as part of the next stage of lunar exploration.

Lunar Meteorites

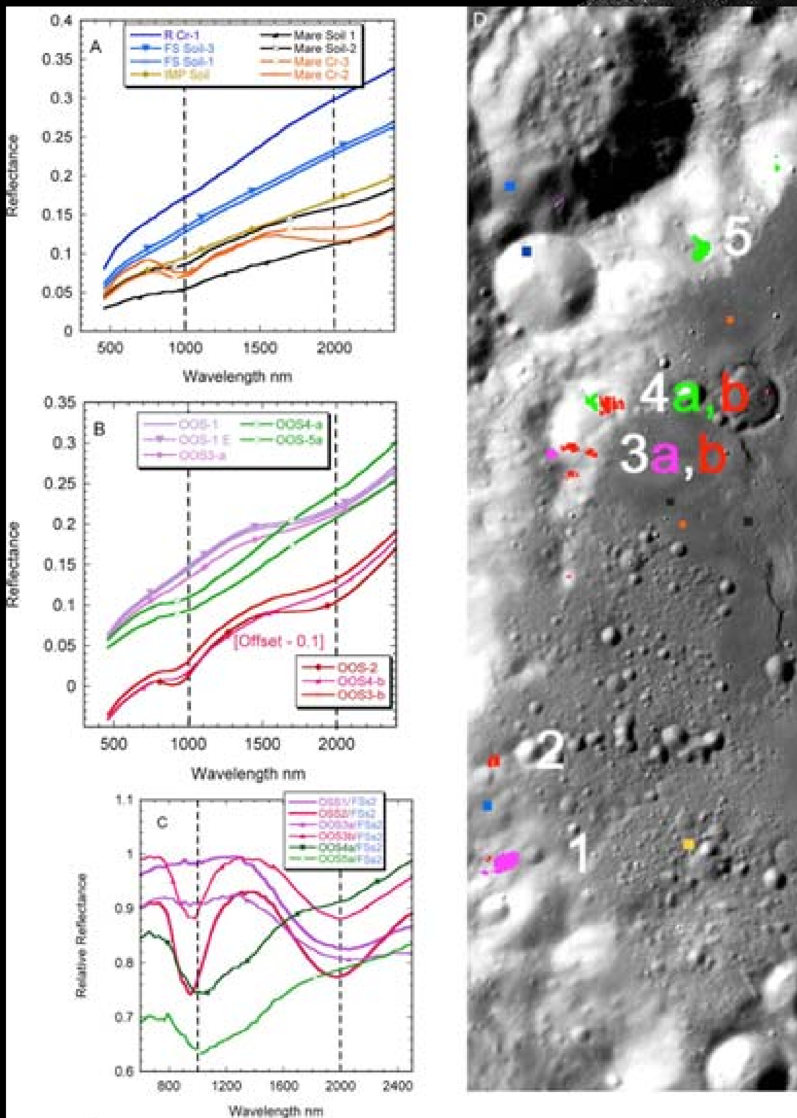
New Lunar Lithologies



Rock Types not represented in the sample collection.

Pure Anorthosite: Kaguya (SELENE)

New Lunar Lithologies



Rock Types not represented in the sample collection.

Olivine, Orthopyroxene, and Mg-Spinel-rich lithologies (OOS)

Chandrayaan-: M3

Pieters et al. (2011) *JGR*, **116**, E00G08; Pieters et al. (2014) *American Min*. **99**, 1895-1910

Why Humans on the Moon?

Opportunity (Mars) ~40.5 km……………………………11+ Years
Lunokhod 2 (Moon) ~37 km………………………………~4 mos.

Apollo 17 LRV (Moon) 35.74 km……………………….3 Days
Apollo 15 LRV (Moon) 27.8 km………………………..3 Days
Apollo 16 LRV (Moon) 27.1 km………………………..3 Days