exploration science resources commerce

Lunar Exploration Analysis Group

Annual Meeting

20-22 October 2015

USRA HQ, Columbia, Maryland

LEAG
LUNAR EXPLORATION ANALYSIS GROUP

exploration science resources commerce

Purpose and Scope

- Integrate the perspectives and interests of the different stakeholders (science, engineering, government, and private sector) to explore common goals of lunar exploration. This meeting is focused around the identification, evaluation, extraction, and use of lunar resources.
- Use the results of recent and ongoing missions to examine the dynamic nature of the Moon and how this could influence future science and exploration missions.
- Provide a forum for community updates and input into the issues that affect lunar science and exploration.

LEAG
LUNAR EXPLORATION ANALYSIS GROUP

exploration science resources commerce

Themes - Lunar Resources

- What resources are most relevant for both near-term and medium-term use within the context of the LER as well as the GER?
- What is(are) the major impediment(s) for developing lunar resources and how can it(they) be overcome?
- What is our current understanding of the location and characteristics of the resources?
- What new observations could LRO make and what new mission(s) would be required to address lunar ISRU questions?
- What knowledge and conditions would enable commercial sector involvement in the extraction, refinement, and utilization of lunar resources?
- What could be the next mission after “Lunar Resurs” (Luna 27, Russia) and Resource Prospector (USA)?

LEAG
LUNAR EXPLORATION ANALYSIS GROUP

exploration science resources commerce

Themes - Lunar Resources

During the resource prospecting phase:

- What are the major questions to be answered?
- What measurements are critical for ISRU, engineering, and science?
- What new technologies are required to make these measurements and answer these questions (i.e., what techniques/technologies are required to extract and process the ore, and store/transport the refined products)?
- What are the best targets for *in-situ* measurements, technical demonstrations, and sample return?

LEAG
LUNAR EXPLORATION ANALYSIS GROUP

exploration science resources commerce

Themes – Dynamic Moon

- What are the implications of new observations for the geologic evolution of the Moon and solar system geology?
- How do current mission results affect the current Decadal Survey and influence our planning for the next?
- How do these new discoveries affect planning for future human missions?
- What future measurements are needed to address unknowns, including strategic knowledge gaps, regarding the Dynamic Moon?
- What new observations could LRO make and what new mission(s) would be required to address?

LEAG
LUNAR EXPLORATION ANALYSIS GROUP

Reconstituted Executive Committee

James Carpenter – ESA rep (European Space Agency)

Ryan Clegg-Watkins – Washington University St. Louis (NGLSE Rep)

Jasper Halekas – ARTEMIS rep (University of Iowa)

Dana Hurley – Lunar Volatiles (Johns Hopkins University Applied Physics Lab)

Kurt Klaus – Boeing & CAB Chair

Sam Lawrence – Vice-Chair (Arizona State University)

Steve Mackwell – Community Liaison (Lunar & Planetary Institute)

Clive R. Neal – Chair (University of Notre Dame)

Noah Petro – LRO Rep and Secretary (NASA-GSFC)

Jeff Plescia – Past Chair (Johns Hopkins University Applied Physics Lab)

Jerry Sanders – ISRU (NASA-JSC)

Ex Officio

Ben Bussey, NASA-HEOMD

Sarah Noble – NASA-SMD

Greg Schmidt (SSERVI)

Commercial Advisory Board (CAB)

Kurt Klaus – Boeing (Chair)

Clive Neal – LEAG Chair

Sam Lawrence – LEAG Vice Chair

Dallas Beinhoff – Boeing

Dale Boucher – NORCAT

Thomas Deidrich – Airbus

Leslie Gertsch – Space Resources Roundtable

Mike Hawes – Lockheed Martin

Jim Keravala – Shackleton Energy

Eric Reiners – Caterpillar

Kevin Peterson – Astrobotic CTO

Bruce Pittman – NASA Ames (Space Portal)

Bob Richards – Moon Express

Kris Zacny – Honeybee Robotics

* Charter currently being drafted

LEAG Activities 2015

- **LEAG Townhalls: LPSC 46 & SSERVI**

- **LEAG-sponsored "networking" session – LPSC 46**

- **New Views of the Moon II**

- Chapter leads identified and being contacted;
- Talk at EPSC last month;
- First workshop scheduled 24-26 May 2016 @ LPI.

LEAG Activities 2015

- **Geological Astronaut Training SAT**

- Recently stood up;
- Not currently part of official astronaut training – ad hoc only;
- Dean Eppler and Jake Bleacher co-chairs.

- **Involvement in the ISECG Global Exploration Roadmap**

- "Humans to the Lunar Surface" part of Science White paper;
- Version 3 currently being revised by the international team;
- The plan: Final version due end of October.

LEAG Activities 2015 (cont.)

- **ESA Topical Team response to the V-SAT Report**
- Substantial agreement with V-SAT findings, with some differences and changes of emphasis;
- V-SAT membership currently working with the Topical Team.

- **Presentation to National Academies Space Studies Board**
- "The Scientific and Exploration Benefits of Human Lunar Exploration";
  - 4 November 2015, UC Irvine.

- **Re-vamping the LEAG website:**
- "Science nuggets" page initiated;
- Community asked to supply nuggets;
- On going project.

http://www.lpi.usra.edu/leag/science_nuggets/

Science Nuggets

Lunar Science & Exploration Highlights

Missions to the Moon this century

MISSION	Agency	Launch Date	End Date
SMART-1	ESA	27 Sept. 2003	3 Sept. 2006
Kaguya (SELENE)	JAXA	14 Sept. 2007	10 June 2009
Chang' E-1	CNSA	24 Oct. 2009	1 Mar. 2010
Chandrayaan-1	ISRO	22 Oct. 2008	31 Aug. 2009
Lunar Reconnaissance Orbiter (LRO)	NASA	17 June 2009	STILL ACTIVE
LCROSS	NASA	17 June 2009	9 Oct. 2009
ARTEMIS	NASA	20 July 2009*	STILL ACTIVE
Chang' E-2	CNSA	1 Oct. 2010	8 June 2011**
GRAIL	NASA	10 Sept. 2011	17 Dec. 2011
LADEE	NASA	6 Sept. 2013	17 Apr. 2014
Chang' E-3	CNSA	1 Dec. 2013	STILL ACTIVE

* Actual launch date = 17 Feb. 2007 as part of the THEMIS mission. Date represents the start of operations once the three satellite arrived at the Moon.

** End of lunar operations and departed lunar orbit.

http://www.lpi.usra.edu/leag/science_nuggets/

- Moon's Greatest Hits Since 2000 (large file with all science nuggets)
- Anhydrous Moon
- Ash flow caldera discovered
- Global maps and datasets
- Highlands composition
- Impact melts
- LADEE Science Highlights
- Lunar core
- Lunar laser ranging
- Lunar Magma Ocean
- Lunar pits
- Lunar swirls
- Lunar terranes
- New lunar lithologies
- New measurement techniques
- Organic matter in lunar samples
- Procellarum Basin
- Recent lunar tectonism
- Recent volcanic activity
- Regolith properties
- SPA impact
- Volatiles - Endogenous
- Volatiles - Surface

Mission-specific science results:

- ARTEMIS
- LRO
  - LRO-Camera
  - LRO-Diviner
  - LRO-LAMP
  - LRO-CRaTER
  - LRO-LEND
  - LRO-LOLA
  - LRO-MiniRF

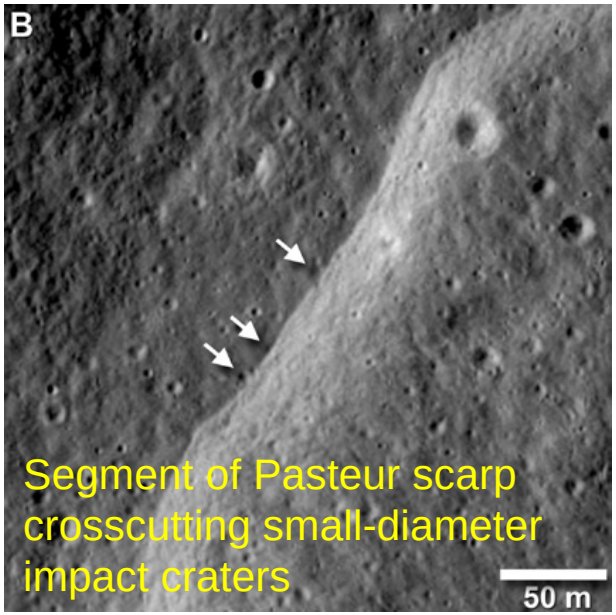
Submit a nugget:
neal.1@nd.edu

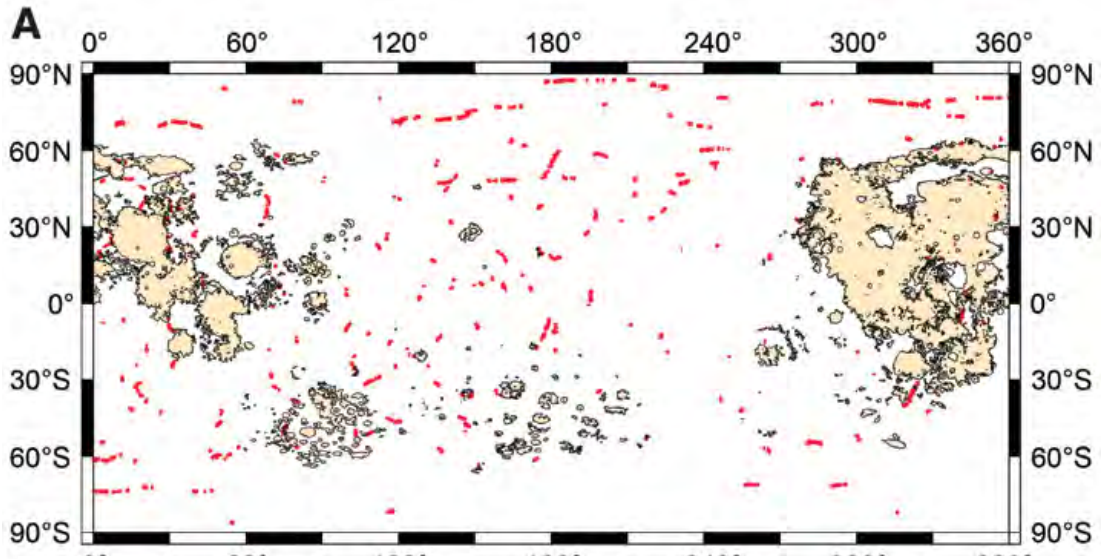
Science Nugget Examples

Global thrust faulting on the Moon and the influence of tidal stresses

Thomas R. Watters, Mark S. Robinson, Geoffrey C. Collins, Maria E. Banks, Katie Daud, Nathan R. Williams, and Michelle M. Selvans (2015) *Geology* **43**, 851-854.

- LROC images – 3200 lobate thrust fault scarps on the Moon.
- Estimated to be <50 Ma and maybe actively forming today.
- Non-random distribution consistent with late-stage global contraction.
- Present-day tidal stresses potentially activate these thrust faults.
- Possibly produce the enigmatic shallow moonquakes recorded by Apollo, some of which had body wave magnitudes ≥5.



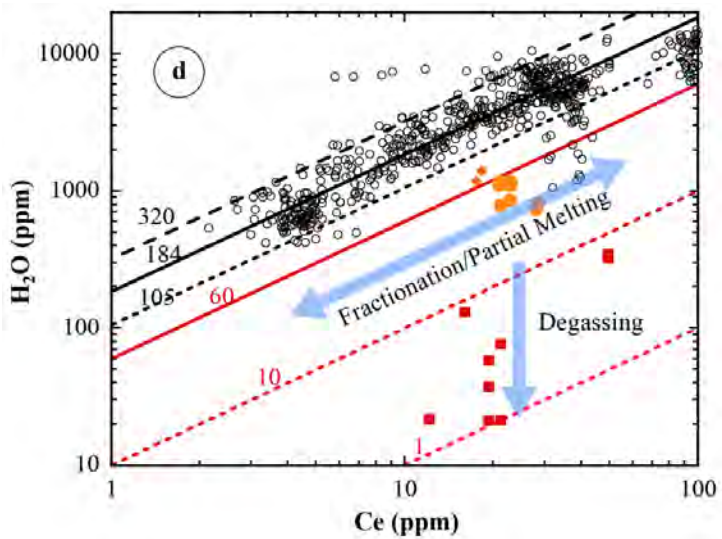


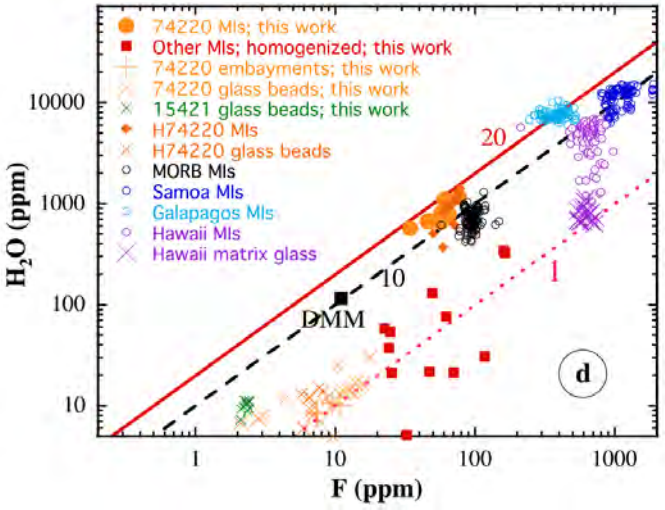
Map of digitized locations of lobate scarps on the Moon

Water, fluorine, and sulfur concentrations in the lunar mantle

Yang Chen, Youxue Zhang, Yang Liu, Yunbin Guan, John Eiler, Edward M. Stolper
(2015) *Earth & Planetary Science Letters* **427**, 37-46

- Analysis of volatiles in melt inclusions in 74220, 15421, 10020, 12008, 15016.
- Results by Hauri et al. (2011) for 74220 are not anomalous.
- Approximate constancy of volatile depletion in the Moon relative to the Earth explained by assuming that both acquired volatiles from a similar source or by a similar mechanism, but the earth was more efficient in acquiring the volatiles.
- The H_2O, F and S concentrations in the primitive lunar mantle source to be similar to or slightly lower than those in terrestrial MORB mantle.



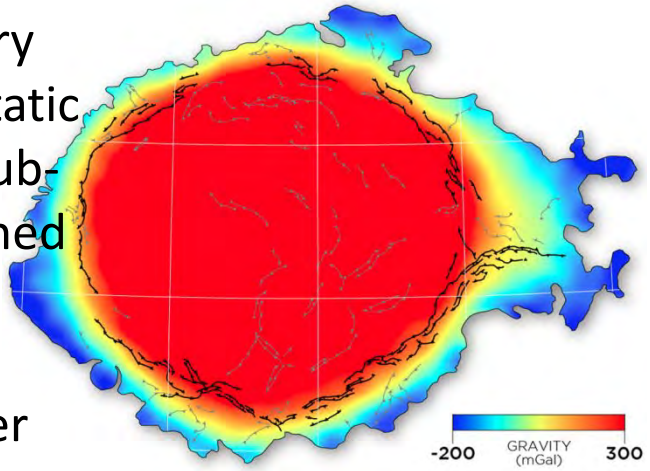


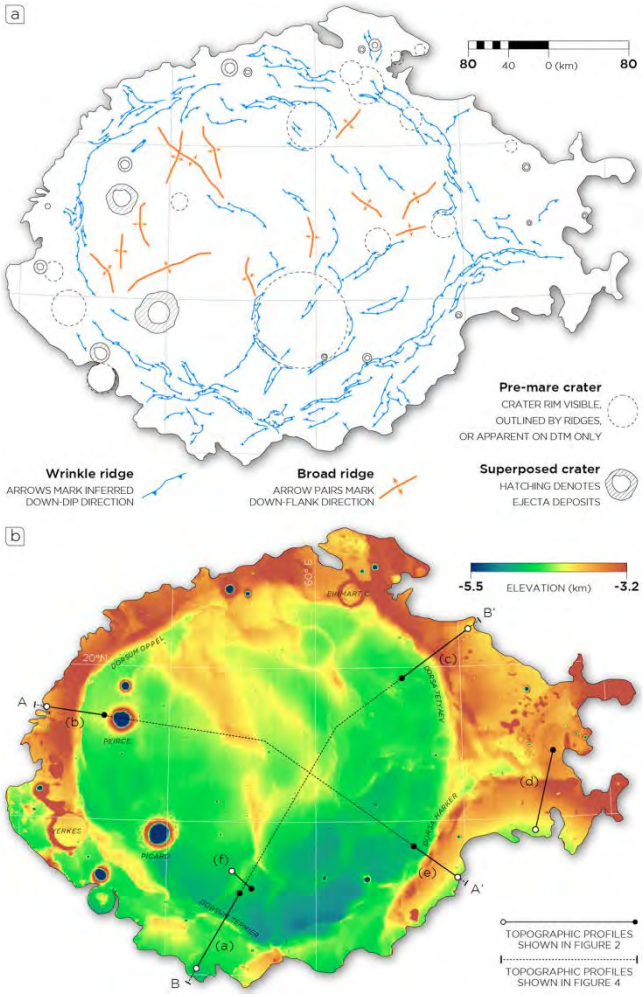
Deep-seated thrust faults bound the Mare Crisium lunar mascon

Paul K. Byrne, Christian Klimczak, Patrick J. McGovern, Erwan Mazarico, Peter B. James, Gregory A. Neumann, Maria T. Zuber, Sean C. Solomon (2015) *Earth & Planetary Science Letters* **427**, 183-190.

GRAIL data, LROC WAC DTM, and finite element modeling show that the deep-seated thrusts may have been localized by the boundary between the super-isostatic mantle material and a sub-isostatic collar of thickened crust that resulted from basin formation and modification shortly after impact. Other mascons formed in a similar manner.

GRAIL free-air gravity anomaly map (to degree and order 320) for the interior of Mare Crisium.





Tectonic landforms and physiography of Mare Crisium. (**a**) Structural map of the basin interior. (**b**) Color-coded elevation map of the mare deposits.

Future Activities

- Workshop on the Nature of the Lunar Mantle
- International Lunar Workshop wrapped in to NVM II
- Technology Roadmap development – more at this meeting
- LEAG Townhall at LPSC 47
- NGLSE-LEAG networking “meet-and-greet” session at LPSC 47
- NVM-II Workshop 24-26 May 2016
- Send suggestions to anyone on the Ex Comm.