

## Appendix D

### Contributions to the Artemis Program (April 2019 – June 2023)

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To assist the March 26, 2019 initiative to land astronauts at the lunar south pole in 2024, the Center for Lunar Science and Exploration (CLSE) generated the following products.

30-day fast-track studies, delivered to the 9<sup>th</sup> floor, A suite, NASA HQ, April 22, 2019

Administrator Bridenstine asked USRA President Jeff Isaacson, who in turn asked CLSE PI David Kring, to provide his Chief Scientist information about lunar surface operations. We provided lunar polar maps (see the section Lunar South Pole Atlas below) and several fast-track study reports:

- **Lunar South Pole Geology: Preparing for a Seventh Landing**, David A. Kring.
- **Preparing for Lunar Surface Science Operations**, David A. Kring.
- **Lunar South Pole Boulders and Boulder Tracks: Implications for Crew and Rover Traverses**, Valentin T. Bickel and David A. Kring.
- **Lander Plume Effects at Outpost on Shackleton Crater Rim**, P. Metzger, D. T. Britt, K. M. Cannon, M. Kinzel, D. Fontes, and D. A. Kring.

Training report, delivered to the 9<sup>th</sup> floor, A suite, NASA HQ, December 22, 2020

In response to Administrator Bridenstine's request of our organization, we provided a full-length report:

- **Training for Lunar Surface Operations**, David A. Kring, Chris A. Looper, Zane A. Ney, and Barbara A. Janoiko, with a foreword by Apollo Flight Director Gerry Griffin, 40 p., LPI Contribution No. 2576.

Replying to rapid-response requests from NASA HQ

NASA Headquarters requested rapid responses to the following topics to help the agency develop its Artemis program.

- Requested Friday, June 18, 2019; Delivered Tuesday, July 2, 2019.  
**Options for a NASA-focused Science Reference Mission to the Lunar South Pole**, David A. Kring, Myriam Lemelin, Chris Looper, Matt Siegler, Essam Heggy, Aaron Paz, Julie Stopar, Venkata Satya Kumar Animireddi, Natasha Barrett, Sarah Boazman, Aleksandra Gawronska, Cosette Gilmour, Samuel Halim, Harish, Kathryn McCanaan, and Jahnvi Shah.

- Requested Thursday, June 27, 2019; Delivered Wednesday, July 10, 2019.  
**Addressing SKGs and Science Support for Human Missions**, David A. Kring, Aaron Paz, and Walter Kiefer.
- Requested Tuesday, May 17, 2022; Delivered Friday, June 3, 2022.  
**Comments Regarding Draft Moon-to-Mars Objectives**, Lisa Gaddis, David Kring, Julie Stopar, Kennda Lynch, Carol Kory, Raj Prabhu, and J. Stephen Herring.

Peer-reviewed journal articles

Thirteen papers were published that are relevant to the Artemis exploration zone within six degrees of the lunar south pole and conditions that astronauts might encounter there. These papers are supplemented by several other papers (listed at the end of the document) that address a sustained global lunar exploration program.

- **Traverses for the ISECG-GER Design Reference Mission for Humans on the Lunar Surface**, *Advances in Space Research* 63, 692–727, 2019, E. J. Allender, C. Orgel, N. V. Almeida, J. Cook, J. J. Ende, O. Kamps, S. Mazrouei, T. J. Slezak, A-J. Soini, and D. A. Kring.
- **Using Boulder Tracks as a Tool to Understand the Bearing Capacity of Permanently Shadowed Regions of the Moon**, *Journal of Geophysical Research – Planets* 125, doi:10/1029/2019JE006157, 2020, H. M. Sargeant, V. T. Bickel, C. I. Honniball, S. N. Martinez, A. Rogaski, S. K. Bell, E. C. Czaplinski, B. E. Farrant, E. M. Harrington, G. D. Tolometti, and D. A. Kring.
- **Lunar South Pole Boulders and Boulder Tracks: Implications for Crew and Rover Traverses**, *Icarus* 348, 113850, 2020, V. Bickel and D. A. Kring.
- **Geologic Context and Potential EVA Targets at the Lunar South Pole**, *Advances in Space Research* 66, 1247–1264, 2020, A.J. Gawronska, N. Barrett, S. J. Boazman, C. M. Gilmour, S. H. Halim, Harish, K. McCanaan, A. V. Satyakumar, J. Shah, H. M. Meyer, and D. A. Kring.
- **Numerical Modeling of the Formation of Shackleton Crater at the Lunar South Pole**, *Icarus* 354, 113992, 2020, S. H. Halim, N. Barrett, S. J. Boazman, A. J. Gawronska, C. M. Gilmour, Harish, K. McCanaan, A. V. Satyakumar, J. Shah, and D. A. Kring.
- **Science-rich Sites for In Situ Resource Utilization Characterization and End-to-end Demonstration Missions**, *Planetary Science Journal* 2:84 (14p.), doi:10.3847/PSJ/abedbb, C. H. van der Bogert, H. Hiesinger, I. Pretto, F. Venditti, A. Lewang, L. Richter, D. Binns, and Ph. Gläser.
- **Framework for Coordinated Efforts in the Exploration of Volatiles in the South Polar Region of the Moon**, *Planetary Science Journal* 2:103 (17p.),

doi:10.3847/PSJ/abf3c5, 2021, M. Lemelin, S. Li, E. Mazarico, M. Siegler, D. A. Kring, and D. A. Paige.

- **Prominent Volcanic Source of Volatiles in the South Polar Region of the Moon**, *Advances in Space Research* 68, 4691–4701, 2021, D. A. Kring, G. Y. Kramer, D. B. J. Bussey, D. M. Hurley, A. M. Stickle, and C. H. van der Bogert.
- **Cryogeomorphic Characterization of Shadowed Regions in the Artemis Exploration Zone**, *Geophysical Research Letters* 49, 10p., e2022GL099530, 2022, V. T. Bickel, B. Moseley, E. Hauber, M. Shirley, J.-P. Williams, and D. A. Kring.
  - Including a 278-page atlas with the physical properties of 44 permanently shadowed regions (PSRs) within the Artemis III candidate landing region ‘Connecting Ridge.’
- **Surface Conditions and Resource Accessibility of Potential Artemis Landing Sites 007 and 011**, *Planetary Science Journal* 3:224, 23p., 2022, N. Kumari, J. Bretzfelder, I. Ganesh, A. Lang, and D. A. Kring.
- **The Distribution and Accessibility of Geologic Targets Near the Lunar South Pole and Candidate Artemis Landing Sites**, *Planetary Science Journal* 3:275, 15 p., 2022, S. J. Boazman, J. Shah, Harish, A. J. Gawronska, S. H. Halim, A. V. Satyakumar, C. M. Gilmour, V. T. Bickel, N. Barrett, and D. A. Kring.
  - Including a database of 86,896 isolated boulders; 3,556 rocky craters; and 7,553 rock exposures around potential Artemis landing sites 001 and 004 in the Artemis III candidate landing region ‘Connecting Ridge.’
- **Elevation Changes and Slope that May Affect EVA Workload Near Potential Artemis Landing Sites**, *IEEE Aerospace Paper No. 2538*, 17 p., 2023, D. A. Kring, V. T. Bickel, C. H. van der Bogert, A. L. Fagan, L. R. Gaddis, H. Hiesinger, J. M. Hurtado, K. H. Joy, M. Lemelin, C. A. Looper, G. R. Osinski, M. Siegler, S. M. Tikoo, and K. Zacny. {Note: This report received the Best Paper Award among 59 contributions in the category of Spacecraft & Launch Vehicle Systems and Technologies.}
- **Buried Ice Deposits in Lunar Polar Cold Traps Were Disrupted by Ballistic Sedimentation**, *J. Geophysical Research – Planets* 128(5), e2022JE007567, 2023, C. J. Tai Udovicic, K. R. Frizzell, G. R. L. Kodikara, M. Kopp, K. M. Luchsinger, A. Madera, M. L. Meier, T. G. Paladino, R. V. Patterson, F. B. Wroblewski, and D. A. Kring.

*Invited briefings for agency astronauts and engineers*

- **Lunar South Pole Geology: A 30-minute Introduction**, David A. Kring. JSC Software, Robotics, and Simulation Division (ER) Mountainside Chat, Building 30 (Mission Control Center) Auditorium, May 1, 2019.

- **A Few Notes about Lunar Surface Science Ops**, David A. Kring.  
Lunar Lander Working Group, JSC Building 29 Conference Room, May 2, 2019.
- **Lunar South Pole Geology: Preparing for a Seventh Landing**, David A. Kring.  
JSC Exploration Directorate (EA) Strategy Session, Lunar and Planetary Institute, August 30, 2019.
- **Lunar South Pole Geology: Preparing for a Seventh Landing**, David A. Kring.  
NASA JSC Astronaut Office, September 30, 2019.
- **Brief Introduction to EP-relevant Geology at the Lunar South Pole**, David A. Kring  
JSC Propulsion and Power (EP) All Hands Meeting, Building 30 (Mission Control Center) Auditorium, September 30, 2019.
- **A Geological Perspective of the Lunar South Pole**, David A. Kring.  
JSC Crew & Thermal Systems Division All Hands Meeting, Building 30 (Mission Control Center) Auditorium, October 10, 2019.
- **Science and Commercial Considerations on Exploring the Moon**, panel presentation, NASA Lunar Exploration Forum (a virtual meeting), hosted by John Sharp, Chancellor of the Texas A&M System, and Mark Geyer, Director of the NASA/Johnson Space Center, August 12, 2020. Panel chairs Eileen Stansbery and Brett Denevi; Panelists Karl Hibbitts, Dana Hurley, Brad Jolliff, David Kring, Sam Lawrence, and Clive Neal.
- **Exploring EVA Options in the Impact-cratered Terrain of the Lunar South Polar Region**, David A. Kring.  
JSC Open EVA Research Forum, Virtual Briefing, February 10, 2021.
- **Lunar Surface Training and Operations**, David A. Kring.  
xEVA Operations Team Meeting, Virtual Briefing, March 29, 2021.
- **Potential Refinements of NASA's Moon-to-Mars Objectives**, David A. Kring, Julie Stopar, Raj Prabhu, and J. Stephen Herring.  
Moon-to-Mars Objectives Workshop, Space Center Houston, June 28, 2022.
- **Assessing Geological EVA Conditions in the Vicinity of Potential Artemis Landing Sites 001 and 004**, David A. Kring.  
JSC Open EVA Research Forum, Johnson Space Center, July 27, 2022.

Throughout the period, CLSE has also been responsive to individual agency requests for information: *e.g.*, south polar surface temperatures so that JSC engineers can evaluate thermal loads on surface assets; surface slope assessments of specific regions so that JSC EVA staff can evaluate operational limits; regolith conditions on the rim of Shackleton crater so that JSC ISRU staff can evaluate anchoring technologies; mechanics of meteorite impacts into lunar regolith so that KSC staff can evaluate impact hazards.

### Astronaut training

- CLSE PI Kring led a training activity at Meteor Crater for the new class of astronauts and two senior astronauts, September 19, 2019. The activity was developed with input from Apollo astronauts and an Apollo astronaut trainer, and utilized LPI’s award-winning geological guidebook for Meteor Crater. Some of the astronauts participating in this activity were selected to be part of the Artemis Team.
- CLSE PI Kring updated Houston-based resources that were originally developed with an Apollo astronaut trainer, so that the resources are suitable for training of Artemis astronauts in impact-cratered terrains like that at the lunar south pole (2019-2020).
- CLSE PI Kring identified geologic field sites suitable for training Artemis astronauts in terrains relevant to lunar south polar exploration, many of which he used previously for graduate student and astronaut training, and also explored another potential field site that might be used to supplement Artemis astronaut training (2019-2020).
- CLSE PI Kring led a training activity at Meteor Crater for a new class of astronauts, June 22, 2023. This was a NASA-requested condensed version of an activity Kring developed with input from Apollo astronauts and an Apollo astronaut trainer, and utilized LPI’s award-winning geological guidebook for Meteor Crater.

### Astronaut data products

- CLSE PI Kring provided illustrations showing the scale of the Moon’s Shackleton crater relative to geography of astronaut training sites (2021-2022).
- Responding to a request from the Chief of the Astronaut Office, CLSE PI Kring generated a series of maps of lunar analog landing sites being used by astronauts for training. Maps were delivered December 19, 2022; a second set of maps is in production.
- CLSE PI Kring provided the Artemis II crew a scaled illustration of their crew capsule above the Moon’s South Pole-Aitken basin (2023).

### Space Flight Resource Management (SFRM) Training for Science Operations

- CLSE collaborated with the NASA JSC Flight Operations Directorate (FOD), a JSC EVA specialist, and a JSC Crew Branch specialist to produce a program to train a science operations team that can work in a flight operations environment that supports crew during the Artemis III mission and subsequent Artemis missions.

Two participants in the course then participated in NASA’s JETT3 simulations of Artemis III science operations. A NASA civil servant was asked if the SFRM training helped and responded “Yes, a million percent.”

*Lunar South Pole Atlas, first online edition released May 16, 2019*

Produced with contributions from the CLSE and LPI. The CLSE contributions include:

- **Topographic Contour Map of the Moon's South Pole Ridge**, Kathryn McCanaan, Venkata Satya Kumar Animireddi, Natasha Barrett, Sarah Boazman, Aleksandra Gawronska, Cosette Gilmour, Samuel Halim, Harish, Jahnavi Shah, and David Kring.
- **Slope Map of the Moon's South Pole Ridge**, Kathryn McCanaan, Venkata Satya Kumar Animireddi, Natasha Barrett, Sarah Boazman, Aleksandra Gawronska, Cosette Gilmour, Samuel Halim, Harish, Jahnavi Shah, and David Kring.
- **Slope Map of the Moon's South Pole (85°S to Pole) – Map 1**, Harish, Venkata Satya Kumar Animireddi, Natasha Barrett, Sarah Boazman, Aleksandra Gawronska, Cosette Gilmour, Samuel Halim, Kathryn McCanaan, Jahnavi Shah, and David Kring.
- **Slope Map of the Moon's South Pole (85°S to Pole) – Map 2**, with a modified color scheme for those with color blindness, Harish, Venkata Satya Kumar Animireddi, Natasha Barrett, Sarah Boazman, Aleksandra Gawronska, Cosette Gilmour, Samuel Halim, Kathryn McCanaan, Jahnavi Shah, and David Kring.
- **Slope Map of the Moon's South Pole (85°S to Pole) – Map 3**, reflecting a different slope threshold for lunar operations than Maps 1 & 2, Harish, Venkata Satya Kumar Animireddi, Natasha Barrett, Sarah Boazman, Aleksandra Gawronska, Cosette Gilmour, Samuel Halim, Kathryn McCanaan, Jahnavi Shah, and David Kring.
- **Slope Map between Shackleton and de Gerlache Craters, Lunar South Pole – Map 1**, Harish, Venkata Satya Kumar Animireddi, Natasha Barrett, Sarah Boazman, Aleksandra Gawronska, Cosette Gilmour, Samuel Halim, Kathryn McCanaan, Jahnavi Shah, and David Kring.
- **Slope Map between Shackleton and de Gerlache Craters, Lunar South Pole – Map 2**, with a modified color scheme for those with color blindness, Harish, Venkata Satya Kumar Animireddi, Natasha Barrett, Sarah Boazman, Aleksandra Gawronska, Cosette Gilmour, Samuel Halim, Kathryn McCanaan, Jahnavi Shah, and David Kring.
- **Slope Map between Shackleton and de Gerlache Craters, Lunar South Pole – Map 3**, reflecting a different slope threshold for lunar operations than Maps 1 & 2, Harish, Venkata Satya Kumar Animireddi, Natasha Barrett, Sarah Boazman, Aleksandra Gawronska, Cosette Gilmour, Samuel Halim, Kathryn McCanaan, Jahnavi Shah, and David Kring.
- **Shaded Relief Geological Map of the South Polar Region of the Moon**, E. J. Allender, C. Orgel, N. V. Almeida, J. Cook, J. J. Ende, O. Kamps, S. Mazrouei, T. J. Slezak, A.-J. Soini, and D. A. Kring.

- **Cross-section of Shackleton Crater** (Illustration)  
Note: This illustration makes the point that Shackleton crater is more than three times deeper than the Grand Canyon, which is a description repeated in agency descriptions of the south polar region.
- **Scale of Shackleton Crater – version 1** (Illustration)
- **Scale of Shackleton Crater – version 2** (Illustration)  
Note: NASA Headquarters used a modified version of this illustration for its September 2020 document “Artemis Plan: NASA’s Lunar Exploration Program Overview.”
- **Permanently Shadowed Region** (Illustration)
- **Sweeping Terminator at Lunar Poles** (Illustration)
- **Scale of Lunar South Polar Mountains – version 1** (Illustration)
- **Scale of Lunar South Polar Mountains – version 2** (Illustration)
- **Topography and Permanently Shaded Regions (PSRs) of the Moon’s South Polar Nearside**, map featuring Leibnitz Mountains (*e.g.*, Mons Malapert and Mouten), Julie Stopar and David Kring, 2021.
- **3D View of the Lunar South Pole and Two Potential Artemis Landing Sites**, ETHZ\LPI\Valentin T. Bickel and David A. Kring.
- **Perspective View of the Lunar South Pole, Looking from the Farside to the Nearside of the Moon**, an image produce in ArcScene using Lunar Orbiter Laser Altimeter (LOLA) and illumination data, K. Frizzell, K. Luchsinger, A. Madera, T. Paladino, C. Tai Udovicic, and D. A. Kring.
- **Topographic Map and >1 km-diameter Craters in the Artemis Exploration Zone**, map with the locations of 5,251 impact craters, T. Früh, M. Boyce, A. Camon, S. Halwa, G. Ligeza, and D. A. Kring.

### *Naming Lunar Polar Features*

*The namesakes for the first three features were tremendously accomplished in their fields and also represent the diversity that is being built into the Artemis program. NASA distributed a news story that quoted CLSE PI Kring saying “Apollo demonstrated that lunar exploration can influence the dreams of the nation’s children. I am among those who were motivated. It will be wonderful if the Artemis program generates the same result in an increasingly diverse way.”*

- **Proposed name “Henson” for an impact crater within the Artemis exploration zone**, Jordan Bretzfelder and David A. Kring. The feature is named after Dr. Matthew Henson who in 1909 was the first person in recorded history to reach the Earth’s North Pole, which was a tremendous accomplishment for anyone and more so because of discrimination that impeded the success of black men at that time. NASA Headquarters and the NASA Ames Research Center announced the new name September 20, 2021 after it was approved by the Task Group for Lunar Nomenclature of the International Astronomical Union (IAU).



- **Proposed name “Marvin” for an impact crater within the Artemis exploration zone**, David A. Kring. The feature is named after Dr. Ursula B. Marvin who was an Antarctic polar explorer, one of the original Apollo 11 sample analysts, and co-author of the lunar magma ocean hypothesis. We note that Mark Robinson simultaneously proposed the name Marvin. The name was approved by the IAU Task Group for Lunar Nomenclature October 2021.
- **Proposed name “Stose” for an impact crater within the Artemis exploration zone**, David A. Kring. The feature is named after Dr. Anna Jonas Stose, a pioneering American geologist in the early 20<sup>th</sup> century. The name was approved by the IAU Working Group for Planetary System Nomenclature November 8, 2021.

*Lunar Surface Science contributions in response to agency requests*

- **Differential Distribution of Water Ice and Dry Ice in the Moon’s South Polar Region: Implications for Resource Potential**, D. A. Kring, M. A. Siegler, and D. A. Paige, 2020.
- **Producing Transformative Lunar Science with Geologic Sample Return: A Note about Sample Mass**, D. A. Kring, 2020.
- **Conducting Subsurface Surveys with a Crew Rover to Address Both Scientific and ISRU Objectives**, D. A. Kring and E. Heggy, 2020.
- **A Geologist’s Perspective of Lunar Surface Operations with Small Pressurized Rovers**, D. A. Kring, 2020.
- **Lunar Mobility Strategies, Trade Studies, and Mission Simulations**, D. A. Kring, 2020.

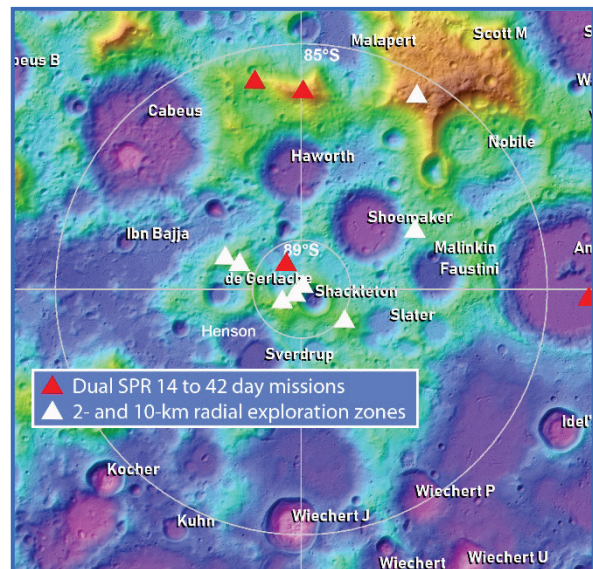


- **Framework for Coordinated Efforts in the Exploration of Volatiles in the South Polar Region of the Moon**, M. Lemelin, S. Li, E. Mazarico, M. Siegler, and D. A. Kring, 2021.
- **Integrated Science and Flight Operations**, D. A. Kring, B. A. Janoiko, C. A. Looper, Z. A. Ney, K. E. Young, D. B. Eppler, and T. G. Graff, 2021.
- **An Exploration Operations System**, D. A. Kring, J. W. Head, H. Hiesinger, and D. H. Needham, 2021.
- **Planning for an Initial Assessment of Volatile-bearing Polar Regolith During Artemis Missions**, D. A. Kring, A. L. Fagan, A. Paz, and M. Lemelin, 2021.
- **Strategy to Generate and Validate a Geospatial Model for the Distribution of Water Ice using Surficial and Orbital Measurements**, M. Lemelin, A. Colaprete, M. Siegler, and D. A. Kring, 2022.
- **Buried Ancient Ice Deposits were likely Dispersed due to Ballistic Sedimentation**, C. J. Tai Udovicic, K. R. Frizzell, G. R. L. Kodikara, M. Kopp, K. M. Luchsinger, A. Madera, M. L. Meier<sup>6</sup>, T. G. Paladino, R. V. Patterson, F. B. Wróblewski, and D. A. Kring, 2022.

*Artemis III Science Definition Team contributions*

Requested Thursday, August 20, 2020; Delivered Tuesday, September 8, 2020.

- **Artemis III EVA Opportunities in the Vicinity of the Lunar South Pole on the Rim of Shackleton Crater**, David A. Kring, Natasha Barrett, Sarah J. Boazman, Aleksandra Gawronska, Cosette M. Gilmour, Samuel H. Halim, Harish, Katie McCanaan, Animireddi V. Satyakumar, and Jahnvi Shah.
- **Artemis III EVA Opportunities along a Ridge Extending from Shackleton Crater towards de Gerlache Crater**, David A. Kring, Natasha Barrett, Sarah J. Boazman, Aleksandra Gawronska, Cosette M. Gilmour, Samuel H. Halim, Harish, Katie McCanaan, Animireddi V. Satyakumar, and Jahnvi Shah.



- **Artemis III EVA Opportunities on the Rim of de Gerlache Crater**, David A. Kring, Jordan M. Bretzelder, Indujaa Ganesh, Nandita Kumari, Antonio Lang, and Matthew A. Siegler.
- **Alternative Artemis III EVA Opportunities near de Gerlache Crater**, David A. Kring, Jordan M. Bretzelder, Indujaa Ganesh, Nandita Kumari, Antonio Lang, and Matthew A. Siegler.
- **Artemis III EVA Opportunities on the Lunar Farside near Shackleton Crater**, David A. Kring, Jordan M. Bretzelder, Indujaa Ganesh, Nandita Kumari, and Antonio Lang.
- **Preparing for Artemis III EVA Science Operations**, David A. Kring.
- **Artemis III EVA Opportunities on Malapert and Leibnitz  $\beta$  Massifs**, David A. Kring, John E. Gruener, and Dean B. Eppler.
- **A Multi-Purpose Landing Site Near Crater Idel'son**, H. Hiesinger, C. H. van der Bogert, M. Massironi, F. Sauro, R. Pozzobon, S. J. Payler, L. Bessone, N. Mangold, and others.
- **Global Heat Flux Predictions for Landing Sites: Polar Advantages**, M. A. Siegler, S. Nagihara, M. Grott, S. Smrekar, J. Feng, R. Weber, P. Hayne, D. Paige, and C. Neal.
- **Lunar Heat Flow: Global Predictions and Reduced Heat Flux**, Matthew Siegler, Seiichi Nagihara, Matthias Grott, Paul Warren, David Paige, Walter Kiefer, Suzanne Smrekar, and Mark Wieczorek.
- **Science Case for Microwave Wavelength Measurements**, Matthew Siegler, Jianqing Feng, and co-signers.
- **Ground Truth: Testing Theories for the Distribution of Lunar Volatiles**, Matthew Siegler, Norbet Schorghofer, Paul Hayne, David Paige, Pierre Williams, Erwan Mazarico, and Michael Barker.
- **Probing the Geomechanical Properties of the South Polar (Pen-)Umbral Regolith**, V. T. Bickel, W. D. Carrier III, and co-signers.
- **The Importance of Measuring Heat Flux Near the Lunar South Pole**, Walter S. Kiefer, Seiichi Nagihara, Matthias Grott, Matthew Siegler, and Kris Zacny.
- **Seismology on Artemis III: Exploration and Science Goals**, P. Lognonné, N. Schmerr, and others, including P. Senthil Kumar.

*Artemis Contamination and Research Integrity (CaRI) contribution*

Rapid Response Requested Thursday, June 17, 2021; Delivered Wednesday, June 23, 2021.

- **Artemis Crew Core Sample of Potentially Volatile-bearing (Icy) Regolith**, David A. Kring.

*Artemis Contamination and Research Integrity (CaRI) contribution*

Addendum; September 16, 2021.

- **Stable Trench Depths of 3 Meters Are Possible in Lunar Regolith**, David A. Kring.

*Short-format study results*

- **Lunar South Pole Geology: Preparing for a Seventh Landing & Lunar Surface Science Operations**, David A. Kring, NASA Exploration Science Forum, July 23, 2019.
- **Differential Distribution of Water Ice and Dry Ice in the Moon's South Polar Region: Implications for Resource Potential**, David A. Kring, Matthew A. Siegler, and David A. Paige, Lunar and Planetary Science Conference, March 2020.
- **Exploring the Consequences of Ballistic Sedimentation on Potential Polar Ice Deposits on the Moon**, David A. Kring, European Lunar Symposium, May 14, 2020.
- **Potential Water and Dry Ice Distribution in the Lunar South Polar Region**, D. A. Kring, M. A. Siegler, and D. A. Paige, NASA Exploration Science Forum, July 10, 2020.
- **Geologic and Exploration Training for Lunar Surface Operations**, D. A. Kring, NASA Exploration Science Forum & European Lunar Symposium, July, 2021.
- **Testing Estimated Polar Regolith Physical Properties with In Situ Geotechnical Measurements between the South Pole and Potential Artemis Landing Site 001**, David A. Kring and Valentin T. Bickel, European Lunar Symposium, May 26, 2022.
- **Geomorphic Characterization of Shadowed Regions on the Shackleton-Henson Connecting Ridge**, V.T. Bickel, B. Moseley, E. Hauber, M. Shirley, J.-P. Williams, and D.A. Kring, NASA Exploration Science Forum, July 2022.
- **Assessing Landing and EVA Options in the Vicinity of Potential Artemis Landing Site 001**, D. A. Kring, V. T. Bickel, A. L. Fagan, L. Gaddis, H. Hiesinger, J. M. Hurtado, T. Huning, M. Lemelin, C. A. Looper, G. R. Osinski, S. M. Tikoo, and C. H. van der Bogert, NASA Exploration Science Forum, July 2022.
- **Visibility Opportunities on the Shackleton-Henson Connecting Ridge from the SpaceX Artemis III Human Landing System**, E. Peña-Asensio, P. Tripathi, J.

Sutherland, K. Mason, A. Goodwin, V. T. Bickel, and D. A. Kring, Lunar and Planetary Science Conference, March 2023.

- **Modeled EVA Traverses into Permanently Shadowed Regions near Schackleton Crater Rim & Connecting Ridge**, P. Tripathi, A. Goodwin, E. Peña-Asensio, J. Sutherland, K. Mason, V. T. Bickel, and D. A. Kring, Lunar and Planetary Science Conference, March 2023.
- **Determining Ages of Rocks Accessible within the Artemis Exploration Zone**, R. V. Patterson, T. J. Lapen, D. A. Kring, M. Lemelin, and M. L. Meier, Lunar and Planetary Science Conference, March 2023.
- **Volatile Abundance of Paired Lunar Troctolites and the Early Lunar Crust**, T. J. Barrett, K. L. Robinson, K. Nagashima, G. R. Huss, J. W. Boyce, and D. A. Kring, Lunar and Planetary Science Conference, March 2023.
- **Impact Melting, Excavation, and Redeposition of Crustal Components within the Artemis Exploration Zone**, D. A. Kring, Lunar and Planetary Science Conference, March 2023.

#### Lunar Science and Exploration (LSE) information portal

The LPI and CLSE designed, several years ago, an online portal that collates public domain information about the Moon. It is designed to be the ‘go to’ place for the Moon. To help support the growing Artemis community, we:

- Continued to update the LSE portal with new content throughout 2019-present.
- Provided a week-long electronic introduction to the LSE system that reached more than 800 members of the lunar community, 2020.
- Produced a summary of reports about lunar dust properties and potential dust hazards that are available in the LSE portal. Many of the ‘unknowns’ identified in recent dust forums were, instead, ‘knowns’ that could be found in the LSE portal, 2021.
- In the “Computational Tools” section, we produced a “Lunar Season Calculator” to aid mission planning in the lunar polar regions. Although the lunar subsolar latitude variation is small compared to that of Earth, it has significant effects on the illumination conditions on the surface and, therefore, has important implications for the proper timing of exploration activities.

#### Classroom illustrations

Several illustrations were added to our online Library of Classroom Illustrations

- **Volatiles in the Cabeus Crater Permanently Shadowed Region (PSR)**

- **Cabeus Crater Ice versus Apollo Regolith Solar Wind**
- **Cabeus Crater Ice versus Volcanic Volatile Deposits (version 1)**
- **Cabeus Crater Ice versus Volcanic Volatile Deposits (version 2)**
- **Cabeus Crater Water versus Surface Detected Water**
- **Ingredients for Lunch in the Lunar Regolith**
- **Lunar South Polar Summer**
- **Lunar South Polar Regolith Thermal Profile 0 to 1 Meter Depth**
- **Lunar Regolith Thermal Profile Daily Swing 0 to 20 Centimeters Depth**
- **Lunar Surface Hydrogen Abundances**

*Educational products*

We began a series of printed products that help students and the public understand the Artemis program.

- **Potential Artemis III Landing Regions – Exploring the Unexplored, an 8” diameter card featuring candidate Artemis III landing regions (front) and bilingual text (English and Spanish) that describes attributes of the lunar south polar region (back).**
- **Potential Artemis III Landing Regions – Exploring the Unexplored, revision 1 with new geographic names in the south polar region, 2023.**

*Public presentations and university colloquia*

- **From First Steps to Next Steps: Celebrating Apollo 11 and the Future of Lunar Exploration**, David A. Kring, Houston Museum of Natural Science, Glassell Gallery, July 20, 2019. The presentation was followed by a performance of “Apollo” by the musical quintet WindSync.
- **Future Lunar Exploration**, David A. Kring, The Lunar and Planetary Institute, July 20, 2019.
- **Lunar Geology: Past, Present, and Future**, a panel presentation on the U.S.S. Hornet (the Apollo 11 recovery vessel) in an event organized by NASA SSERVI and NASA HQ,

July 24, 2019. Panelists Harrison Schmitt, David Kring, Jen Heldmann, and Ariel Deutsch.

- **Lunar South Pole Geology**, David A. Kring, Rice University Professional Masters Space Studies Seminar, Moody Center for the Arts, October 22, 2019.
- **JFK’s Moonshot Mandate and the Future of Lunar Exploration**, a panel presentation at Florida Tech University, co-sponsored by USRA, November 6, 2019. Panelists Andrew Aldrin, Saida Caballero-Nieves, David Kring, Shawn Quinn, and Winston Scott.
- **Lunar Prospecting with Robotics**, a panel presentation organized by NASA HQ’s Steve Clarke for SpaceCom, November 20, 2019. Panelists Kristen Bennett, David Kring, and Kris Zacny.
- **Introduction to Lunar Geology with Notes about Those Issues Affecting ISRU**, David A. Kring, presented to an ISRU class at the University of Central Florida and distributed nationally via the SSERVI network, January 20, 2020.
- **Lunar South Pole: Preparing for a Seventh Landing**, David A. Kring, Houston Spaceport Frontier Lecture, hosted by the Rice Space Institute, Rice University, January 23, 2020.
- **Lunar South Pole – Preparing for a Seventh Landing**, David A. Kring, for the NASA Alumni League. This was a virtual seminar with a nationally distributed audience, September 3, 2020.
- **10 Minute Introduction to Exploration of the Lunar South Pole**, David A. Kring, for NASA TV on International Observe the Moon Night, September 26, 2020.
- **Covering ground on the Moon – Using Crew Rovers and Tele-operated Assets**, David A. Kring, presented (virtually) to the School of Earth and Space Exploration, Arizona State University, January 22, 2021.
- **Apollo 14 EVA Traverses and Implications for Artemis III EVA**, David A. Kring. Remarks made as part of the Fernbank Science Center’s “Apollo 14: 50 Years Later” anniversary event in Atlanta using virtual meeting technology, February 5, 2021. Nearly 650 households participated.
- **Integrated Science and Flight Operations with Note about Required Training**, David A. Kring, presented (virtually) to LPI Science Staff, April 19, 2021.
- **Forward! To the Moon**. A panel presentation at the Houston Museum of Natural Science, March 29, 2022, organized by Jack Burns (U. Colorado Boulder). Panelists Tony Beyers (Lockheed Martin Deputy Orion Program Manager), Woody Hoburg (NASA astronaut), and David Kring.

- **The Artemis Exploration Zone at the Lunar South Pole**, David A. Kring, a public lecture presented at Lowell Observatory, Flagstaff, Arizona, December 15, 2022.
- **Exploring Landing Site and EVA Options in the Artemis Exploration Zone**, David A. Kring, presented at the USGS Astrogeology Center, Flagstaff, Arizona, December 21, 2022.
- **Exploring the Artemis Exploration Zone**, David A. Kring, presented (virtually) at the Institut für Planetologie, Westfälische Wilhelms-Universität, Münster, Germany, 5 April 2023.
- **Artemis Lunar Exploration**, David A. Kring, keynote address at the Spring Symposium of the Geophysical Society of Houston, Cullen Hall of Gems and Minerals, Houston Museum of Natural Science, April 19, 2023.
- **What Might Artemis Astronauts Encounter at the Lunar South Pole?**, David A. Kring, Cosmic Explorations Speaker Series, Lunar and Planetary Institute, Houston, Texas, June 8, 2023.
- **A Lunar Perspective on Impact Cratering of Earth**, David A. Kring, Distinguished Lecture Series, Houston Museum of Natural Science, June 30, 2023.
- **Astrogeology of the Artemis Exploration Zone**, David A. Kring, Johnson Space Center Astronomy Club, July 14, 2023.

### **Additional Lunar Science Contributions, 2019-present**

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#### *Peer-reviewed journal articles*

Eight additional lunar science papers were published, including one that examines the trafficability in an important ISRU terrain and another that examines a source of volatiles on the Moon. The highlight, however, is the discovery of a rock fragment in an Apollo 14 sample that may be the oldest known rock from Earth.

- **Terrestrial-like Zircon in a Clast from an Apollo 14 Breccia**, *Earth and Planetary Science Letters* 510, 173–185, 2019, J. J. Bellucci, A. A. Nemchin, M. Grange, K. L. Robinson, G. Collins, M. Whitehouse, J. F. Snape, M. D. Norman, and D. A. Kring.
- **Evidence for Multiple 4.0 – 3.7 Ga Impact Events within the Apollo 16 Collection**, *Meteoritics and Planetary Science* 54, 675–698, 2019, T. Niihara, S. P. Beard, T. D. Swindle, L. A. Schaffer, H. Miyamoto, and D. A. Kring.
- **Analysis of Lunar Boulder Tracks: Implications for Trafficability of Pyroclastic Deposits**, *J. Geophysical Research – Planets* 124, 1296–1314, 2019, V. T. Bickel, C. I.

Honniball, S. N. Martinez, A. Rogaski, H. M. Sargeant, S. K. Bell, E. C. Czaplinski, B. E. Farrant, E. M. Harrington, G. D. Tolometti, and D. A. Kring.

- **The Isotopic Composition of Volatiles in the Unique Bench Crater Carbonaceous Chondrite Impactor Found in the Apollo 12 Regolith**, *Earth and Planetary Science Letters* 540, 12p., 116265, doi:10.1016/j.epsl.2020.116265, 2020, K. H. Joy, R. Tartese, S. Messenger, M. E. Zolensky, Y. Marrocchi, D. R. Frank, and D. A. Kring.
- **Timing of Geological Events in the Lunar Highlands Recorded in Shocked Zircon-bearing Clasts from Apollo 16**, *Royal Society Open Science* 7, 21p., 200236, doi:10.1098/rsos.200236, 2020, K. H. Joy, J. F. Snape, A. A. Nemchin, R. Tartèse, D. M. Martin, M. J. Whitehouse, V. Vishnyakov, J. F. Pernet-Fisher, and D. A. Kring.
- **The Lunar Surface as a Recorder of Astrophysical Processes**, *Philosophical Transactions of the Royal Society A* 379, 20190562, doi:10.1098/rsta/2019/0562, 2020, I. A. Crawford, K. H. Joy, J. H. Pasckert, and H. Hiesinger.
- **Astronomy from the Moon: The Next Decades**, *Philosophical Transactions of the Royal Society A* 379, 20190560, doi:10.1098/rsta.2019.0560, 2020, J. Silk, I. Crawford, M. Elvis, and J. Zarnecki.
- **Human-assisted Sample Return Mission at the Schrödinger Basin, Lunar Farside, Using a New Geologic Map and Rover Traverses**, *Planetary Science Journal* 2:51 (23p.), doi:10.3847/PSJ/abdb34., 2021, E. C. Czaplinski, E. M. Harrington, S. K. Bell, G. D. Tolometti, B. E. Farrant, V. T. Bickel, C. I. Honniball, S. N. Martinez, A. Rogaski, H. M. Sargeant, and D. A. Kring.
- **Deciphering the Origin(s) of H and Cl in Apollo 15 quartz monzodiorites: Evidence of multiple processes and reservoirs**, *Geochimica et Cosmochimica Acta*, in press, T. J. Barrett, K. L. Robinson, J. J. Barnes, G. J. Taylor, K. Nagashima, G. R. Huss, I. A. Franchi, M. Anand, and D. A. Kring.

### **Training Lunar Community Leaders & Agency Staff**

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A key CLSE objective is to train a workforce with the talent needed to assist the nation with a comprehensive lunar exploration science program, both from within academia and NASA. A summary of training activities is attached as an appendix. Former CLSE team members assisting the Artemis program in leadership positions include:

- Prof. Amy Fagan, tenured university professor and current LEAG Chair.
  - Former CLSE graduate student, Lunar Exploration Science intern, and postdoc.
- Dr. Debra Needham, Program Scientist, SMD, Exploration Science Strategy and Integration Office, NASA HQ.
  - Former CLSE postdoc and Deputy Team Leader.



- Dr. Amanda Nahm, Program Officer, SMD, PSD, Research and Analysis Group, NASA HQ; currently managing a SSERVI review.
  - Former CLSE postdoc.
- Dr. Shoshana Wieder, Program Officer, SMD, PSD, Research and Analysis Group, NASA HQ; currently leading the Lunar Data Analysis Program and the Korea Pathfinder Lunar Orbiter Participating Scientist Program.
  - Former CLSE Lunar Exploration intern.

In addition, talent was drawn from our science team:

- Dr. Jake Bleacher, Chief Exploration Scientist, HEOMD, NASA HQ.
  - Former CLSE Co-I.
- Dr. Dave Draper, Deputy Chief Scientist, NASA HQ.
  - Former CLSE Co-I and JSC liaison.

### **Addendum: Historical Summary of CLSE Training**

A key CLSE objective is to train a workforce with the talent needed to assist the nation with a comprehensive lunar exploration science program.

### **Postdoctoral Researchers (Past and Present)**

Dr. Thomas Barrett (*USRA-LPI*)  
 Dr. Jeremy Bellucci (*Swedish Museum of Natural History*)  
 Dr. Katherine Bermingham (*University of Maryland*) – then to Rutgers University  
 Dr. Timmons Erickson (*USRA-LPI*) - then to the NASA Johnson Space Center  
 Dr. Amy L. Fagan (*USRA-LPI*) – then to Western Carolina University  
 Dr. Marion Grange (*Curtin University of Technology, Western Australia*)  
 Dr. Juliane Gross (*USRA-LPI*) – then to the American Museum of Natural History  
 Dr. Debra Hurwitz (*USRA-LPI*) – then to the NASA Goddard Space Flight Institute  
 Dr. Katherine Joy (*USRA-LPI*) – then to the University of Manchester, United Kingdom  
 Dr. Georgiana Kramer (*USRA-LPI*) – then a Visiting Scientist at the LPI  
 Dr. Katherine Kretke (*Southwest Research Institute and USRA-LPI*)  
 Dr. Véronique Le Roux (*Rice University*) – then to the Woods Hole Oceanographic Institution  
 Dr. Simone Marchi (*USRA-LPI and Southwest Research Institute (SwRI)*) – then to SwRI  
 Dr. Amanda Nahm (*USRA-LPI*) – then to the University of Texas, El Paso  
 Dr. Takafumi Niihara (*USRA-LPI*) – then to the University of Tokyo  
 Dr. Teemu Öhman (*USRA-LPI*) – then to the Arctic Planetary Science Institute, Finland  
 Dr. Ross Potter (*USRA-LPI*) – then to Brown University  
 Dr. Tabb C. Prissel (*USRA-LPI and NASA JSC*)  
 Dr. Katharine Robinson (*USRA-LPI*) – then to the University of Wisconsin, Madison  
 Dr. Martin Schmieder (*USRA-LPI*) – then to HNU Neu-Ulm University, Germany  
 Dr. Barry Shaulis (*USRA-LPI*) – then to the University of Arkansas

Dr. Joshua Snape (*Swedish Museum of Natural History*)  
Dr. Axel Wittmann (*USRA-LPI*) – then to Washington University

### **Graduate Student Researchers (Past and Present)**

Donald Barker (*University of Houston*)  
Sky Beard (*University of Arizona*)  
Steve Braun (*University of Houston*)  
David Burney (*University of Notre Dame*)  
Jesse Davenport (*University of Notre Dame*)  
Patrick Donohue (*University of Notre Dame*)  
Amy Fagan (*University of Notre Dame*)  
Miriam Galenas (*University of Maryland*)  
Connor Hilton (*University of Maryland*)  
Patrick Lowe (*University of Notre Dame*)  
Katie O’Sullivan (*University of Notre Dame*)  
Ruby Patterson (*University of Houston*)  
Ross Potter (*USRA-LPI*)  
Sarah Roberts (*University of Notre Dame*)  
Katherine Robinson (*University of Hawaii*)  
Barry Shaulis (*University of Houston*)  
Sam Simmons (*University of Houston*)  
Kellen Springer (*University of Houston*)  
Fiona Thiessen (*Swedish Museum of Natural History*)  
Emily Worsham (*University of Maryland*)

### **Lunar Exploration Student Interns**

#### **2008 Program**

Tomas Kohout (*University of Helsinki*)  
Anna Losiak (*Michigan State University*)  
Katie O’Sullivan (*University of Notre Dame*)  
Kevin Thaisen (*University of Tennessee*)  
Shoshana Weider (*University College London*)

#### **2009 Program**

Daniel Eldridge (*University of Colorado, Boulder*)  
Megan Ennis (*University of Tennessee*)  
Amy Fagan (*University of Notre Dame*)  
Jarmo Korteniemi (*University of Oulu, Finland & University of Münster, Germany*)  
Trevelyn Anne Lough (*University of Buffalo*)  
James Pogue (*University of California, Santa Cruz*)  
Simon Porter (*Arizona State University*)  
Kaitlin Singer (*North Carolina State University & University of Tennessee*)  
Joshua Snape (*University College London*)  
Lesley Werblin (*Mount Holyoke College*)

### **2010 Program**

Jean-Francois Blanchette-Guertin (*University of British Columbia*)

Patrick Donohue (*University of Notre Dame*)

Jessica Flahaut (*ENS Lyon*)

Zachary Gallegos (*University of New Mexico*)

Noah Hammond (*University of California, Santa Cruz*)

Christine Jilly (*University of Hawaii at Manoa*)

Ross Potter (*Imperial College London*)

Priyanka Sharma (*University of Arizona*)

Audrey Souchon (*University of Paul Sabatier Toulouse III*)

### **2011 Program**

David Blair (*Purdue University*)

Sarah Crites (*University of Hawai'i*)

Myriam Lemelin (*Université de Sherbrooke*)

Daniela Nowka (*Freie Universität Berlin*)

Agata Przepiorka (*Space Research Centre of the Polish Academy of Sciences*)

Stephanie Quintana (*Colorado School of Mines*)

Carolyn Roberts (*SUNY at Buffalo*)

Kirby Runyon (*Temple University*)

Claudia Santiago (*University of Texas-El Paso*)

Tiziana Trabucchi (*University of New Brunswick*)

### **2012 Program**

Jessica Barnes (*Open University*)

Renee French (*Northwestern University*)

Joshua Garber (*University of California, Davis*)

Wil Poole (*University College London*)

Phillipa Holly Smith (*Open University*)

Yunsheng Tian (*University of Toronto*)

### **2013 Program**

Natalie Curran (*The University of Manchester*)

Jasmeet Dhaliwal (*University of California, San Diego*)

Amber Gullikson (*Northern Arizona University*)

Mark Leader (*University of Texas, Austin*)

Nicola Potts (*The Open University*)

Rushal Rege (*Columbia University*)

### **Exploration Science Student Interns**

#### **2015 Program**

Shelby Bottoms (*University of Colorado, Boulder*)

Abigail Calzada-Diaz (*Birkbeck College, University of London*)

Mark Leader (*University of Texas, Austin*)

Dayl Martin (*University of Manchester*)

Francesca McDonald (*University of Manchester*)  
Sean O'Hara (*University of Illinois at Chicago*)  
Sarinya Paisarnsombat (*University of New Brunswick*)  
Edgar Steenstra (*Vrije Universiteit Amsterdam*)  
Christian Venturino (*University at Buffalo*)

### **2016 Program**

Elyse Allender (*University of Cincinnati*)  
Natasha Almeida (*Birkbeck College London*)  
John Cook (*University of Houston*)  
Jessica Ende (*University of Tennessee*)  
Oscar Kamps (*Utrecht University*)  
Sara Mazrouei-Seidani (*University of Toronto*)  
Csilla Orgel (*Freie Universität Berlin*)  
Thomas Slezak (*Brigham Young University*)  
Assi-Johanna Soini (*University of Helsinki*)

### **2018 Program**

Samantha Bell (*University of Manchester, UK*)  
Valentin Bickel (*Max Planck Institute, Germany*)  
Ellen Czaplinski (*University of Arkansas, USA*)  
Benjamin Farrant (*University of Manchester, UK*)  
Elise Harrington (*University of Western Ontario, Canada*)  
Casey Honniball (*University of Hawai'i, USA*)  
Sabrina Martinez (*Tulane University, USA*)  
Alexander Rogaski (*South Dakota School of Mines & Technology, USA*)  
Hannah Sargeant (*The Open University, UK*)  
Gavin Tolometti (*University of Western Ontario, Canada*)

### **2019 Program**

Venkata Satya Kumar Animireddi (*Andhra University, India*)  
Natasha Barrett (*University of Alberta, Canada*)  
Sarah Boazman (*University College London, UK*)  
Aleksandra Gawronska (*Miami University, USA*)  
Cosette Gilmour (*York University, Canada*)  
Samuel Halim (*University of London, UK*)  
Harish (*Physical Research Laboratory, India*)  
Kathryn McCanaan (*University of Manchester, UK*)  
Jahnvi Shah (*University of Western Ontario, Canada*)

### **2020 Program**

Jordan Bretzfelder (*University of California, Los Angeles*)  
Indujaa Ganesh (*University of Arizona*)  
Nandita Kumari (*Stony Brook University*)  
Antonio Lang (*University of Buffalo*)

### **2021 Program**

Katelyn Frizzell (*Rutgers University*)  
Megan Kopp (*Boston College*)  
Gayantha Loku Kodikara (*University of Wisconsin-Milwaukee*)  
Kristen Luchsinger (*New Mexico State University*)  
Alissa Madera (*Rutgers University*)  
McKayla Meier (*University of Idaho*)  
Tyler Paladino (*Idaho State University*)  
Ruby Patterson (*University of Houston*)  
Christian Tai Udovicic (*Northern Arizona University*)  
Frank Wroblewski (*University of Idaho*)

### **2022 Program**

Arthur Goodwin (*University of Manchester*)  
Kashauna Mason (*Texas A&M*)  
Eloy Peña-Asensio (*Autonomous University of Barcelona*)  
Jennifer Sutherland (*Intitut Laue-Langevin, TU Berlin*)  
Prateek Tripathi (*Indian Institute of Technology, Roorkee*)

### **2023 Program**

Matilda Boyce (*University of Western Australia*)  
Alex Camon (*Université de Sherbrooke*)  
Thomas Früh (*Westfälische Wilhelms-Universität Münster*)  
Stephanie Halwa (*University of Manchester*)  
Gabriela Ligeza (*University of Basel*)

### **Undergraduate Student Researchers**

Adeene Denton (*Rice University*)  
Charis Hall (*University of Houston*)  
Robert Hoffmann (*Rice University*)  
Lillian Schaffer (*University of Houston*)  
Laura Seifert (*University of Arizona*)  
Sam Simmons (*University of Houston*)

### **Field Training and Research Program at Meteor Crater**

#### **2010 Student Participants**

Jeffrey Balcerski (*Case Western Reserve University*)  
David Blair (*Purdue University*)  
Matthew Chojnacki (*University of Tennessee*)  
Patrick Donohue (*University of Notre Dame*)  
Sarah Drummond (*University of Tennessee-Knoxville*)  
Joshua Garber (*University of California-Davis*)  
Michelle Hopkins (*University of Colorado-Boulder*)

Matthew Huber (*University of Vienna*)  
Steven Jaret (*Harvard University*)  
Anna Losiak (*University of Vienna*)  
Analisa Maier (*University of Colorado*)  
Julie Mitchell (*University of Houston-Clear Lake*)  
Lissa Ong (*University of Arizona*)  
Lillian Ostrach (*Arizona State University*)  
Katie O’Sullivan (*University of Notre Dame*)  
Ross Potter (*Imperial College London*)  
Stuart Robbins (*University of Colorado-Boulder*)  
Bhairavi Shankar (*University of Western Ontario*)  
Erin Shea (*Massachusetts Institute of Technology*)  
Kelsi Singer (*Washington University*)  
Michael Sori (*Massachusetts Institute of Technology*)  
Sebastian Sturm (*Westfälische Wilhelms-Universität Münster*)  
Malte Willmes (*Westfälische Wilhelms-Universität Münster*)  
Michael Zanetti (*Washington University*)

### **2011 Student Participants**

Shoshanna Cole (*Cornell University*)  
Kathleen Craft (*Virginia Tech University*)  
Sarah Crites (*University of Hawaii*)  
Tenielle Gaither (*Northern Arizona University*)  
Christine Jilly (*University of Hawaii*)  
Myriam Lemelin (*Université de Sherbrooke*)  
Margaret Rosenberg (*California Institute of Technology*)  
Laura Seward (*University of Central Florida*)  
Eugenie Song (*University of Washington*)  
Joshua Snape (*University College London*)  
Matthieu Talpe (*Massachusetts Institute of Technology*)  
Kevin Thaisen (*University of Tennessee*)  
Michael Veto (*Arizona State University*)  
Matthew Wielicki (*University of California Los Angeles*)  
Felicity Williams (*Open University*)  
Emily Worsham (*University of Maryland*)

### **2014 Student Participants**

Corwin Atwood-Stone (*University of Arizona*)  
Aaron Boyd (*Arizona State University*)  
Jessie Brown (*University of New Brunswick*)  
Laura Corley (*University of Hawaii at Manoa*)  
Natalie Curran (*University of Manchester*)  
Connor Davis (*Western University*)  
Katrina Korman (*Temple University*)

Aviva Maine (*Northern Arizona University*)  
Francesca McDonald (*University of Manchester*)  
Stephanie Montalvo Delgado (*University of Puerto Rico at Mayaguez*)  
Raquel Nuno (*Arizona State University*)  
Seda Oezdemir (*University of Vienna*)  
Kathryn Rathbun (*University of Iowa*)  
Nisa Rhodes (*University of Texas at El Paso*)  
Hannah Susorney (*Johns Hopkins University*)  
David Weiss (*Brown University*)

## **2016 Student Participants**

Samuele Boschi (*Lund University*)  
Christy Caudill (*University of Western Ontario*)  
Mitali Chandnani (*University of Alaska Fairbanks*)  
Nicholas DiFrancesco (*Stony Brook University*)  
Shannon Hibbard (*Temple University*)  
Kynan Hughson (*University of California Los Angeles*)  
Mallory Kinczyk (*North Carolina State University*)  
Audrey Martin (*University of Tennessee*)  
Ellinor Martin (*Lund University*)  
Mélissa Martinot (*Vrije Universiteit Amsterdam*)  
Cameron McCarty (*University of Tennessee*)  
Kathryn Powell (*Washington University*)  
Adam Sarafian (*Massachusetts Institute of Technology*)  
Douglas Schaub (*Stony Brook University*)  
Katherine Shirley (*Stony Brook University*)

## **2018 Student Participants**

Lauren Angotti (*Case Western Reserve University*)  
Michael Bouchard (*Washington University in St. Louis*)  
Benjamin Byron (*University of Texas at San Antonio*)  
Neeraja Chinchalkar (*Auburn University*)  
Sietze De Graaff (*Vrije Universiteit Brussel*)  
Thomas Déhais (*Vrije Universiteit Brussel*)  
Lori Glaspie (*Northern Arizona University*)  
Joshua Hedgepeth (*University of Western Ontario*)  
Madison Hughes (*Washington University in St. Louis*)  
Pim Kaskes (*Vrije Universiteit Brussel*)  
Jane MacArthur (*University of Leicester*)  
Maree McGregor (*University of New Brunswick*)  
Catherine Ross (*University of Texas at Austin*)  
Kaitlyn Stacey (*University of Texas at Dallas*)  
Stephanie Suarez (*University of Houston*)  
Christina Verhagen (*Rutgers University*)

## **Short Course and Field School at the Sudbury Impact Structure (Coordinated with the Canadian Lunar Research Network)**

### **2012 Student and Postdoctoral Participants**

Katherine Armstrong (*Portland State University*)  
Marlene Bamberg (*University of Potsdam*)  
Chloe Beddingfield (*University of Tennessee*)  
Tenielle Gaither (*Northern Arizona University*)  
Miriam Sharp (*University of Maryland*)  
David Baker (*Brown University*)  
Matthew Huber (*University of Vienna*)  
Debra Hurwitz (*USRA-LPI*)  
Steve Jaret (*Stony Brook University*)  
Georgiana Kramer (*USRA-LPI*)  
Yutaro Kuriyama (*University of Tokyo*)  
Michael Lucas (*University of Tennessee*)  
Cameron Mercer (*Arizona State University*)  
Christopher Mount (*Northern Arizona University*)  
Catherine Neish (*NASA Goddard*)  
Lillian Ostrach (*Arizona State University*)  
Ross Potter (*USRA-LPI*)  
Andrew Ryan (*Arizona State University*)  
Nicholas Swartz (*Temple University*)  
Olivia Thomson (*University of Puerto Rico*)  
Michael Veto (*Arizona State University*)  
Matthew Wielicki (*UCLA*)  
Shawn Wright (*Auburn University*)  
Michael Zanetti (*Washington University*)

Plus another 8 Canadian student participants, for a total class size of 32.

### **2013 Student and Postdoctoral Participants**

Nadja Drabon (*Stanford University*)  
Amy Fagan (*USRA-LPI*)  
Jenna Fleck (*Johns Hopkins University*)  
Neva Fowler-Gerace (*University of Toronto*)  
Alexandria Gaucher-Loksts (*University of Ottawa*)  
Audrey Horne (*University of North Carolina at Chapel Hill*)  
Jane MacArthur (*University College London*)  
Aviva Maine (*Northern Arizona University*)  
Samantha Peel (*University of Tennessee-Knoxville*)  
Jessica Pickett (*Queen's University*)  
Sarah Roberts (*University of Notre Dame*)  
Lauren Schurmeier (*University of Illinois at Chicago*)



Jennifer Scully (*University of California Los Angeles*)  
Joshua Snape (*The Open University*)  
Vivian Sun (*Brown University*)  
Kevin Thaisen (*University of Minnesota-Duluth*)  
David Trang (*University of Hawaii at Manoa*)  
Nathan Williams (*Arizona State University*)

Plus another 13 Canadian student participants, for a total class size of 31.

### **2017 Student and Postdoctoral Participants**

Michael Bouchard (*Washington University in St. Louis*)  
Sietze Jan de Graaff (*Vrije Universiteit Brussel*)  
Leticia De Marchi (*Auburn University*)  
Scott Eckley (*The University of Texas at Austin*)  
Sierra Ferguson (*Arizona State University*)  
John Gemperline (*University of Colorado, Boulder*)  
Madison Hughes (*Washington University in St. Louis*)  
Carol Hundal (*Wellesley College*)  
Pim Kaskes (*Vrije Universiteit Brussel*)  
Ari Hirsh Dickman Koepfel (*The City College of New York*)  
Katrina Korman (*Temple University*)  
Margaret Landis (*University of Arizona*)  
Ebberly MacLagan (*University of Alberta*)  
Xiaochen Mao (*Washington University in St. Louis*)  
Martin Schmieder (*USRA-LPI*)  
Kaitlyn Stacey (*University of Texas at Dallas*)  
Jesse Tarnas (*Brown University*)

Plus another 14 Canadian student participants, for a total class size of 31.

### **Field Training and Research Program at the Zuni-Bandera Volcanic Field**

#### **2015 Student Participants**

Jessica Ende (*University of Tennessee*)  
Keenan Golder (*University of Tennessee*)  
Jane MacArthur (*University of Leicester*)  
Ryan Nickerson (*Washington University*)  
Kirby Runyon (*Johns Hopkins University*)  
Nicole Thomas (*University of New Mexico*)

## **Field Training and Research Program in the San Francisco Volcanic Field**

### **2022 Student and Postdoctoral Participants**

Thomas Barrett (*USRA-LPI*)  
Megan Borel (*University of Florida*)  
Nandita Kumari (*Stony Brook University*)  
Rudi Lien (*University of Oregon*)  
Kaushik Pradhan (*University of Texas, El Paso*)  
Eleni Ravanis (*University of Hawaii at Manoa*)  
Sourabh Shubham (*University of Maryland*)  
Divyareshimi Thottungal Ravy (*University of Manchester*)

### **Extravehicular Activity (EVA) Exercises at Meteor Crater**

### **2021 Student and Postdoctoral Participants**

Jordan Bretzfelder (*University of California, Los Angeles*)  
Frédéric Diotte (*University of Sherbrooke, Canada*)  
Krystyna Doran (*Rutgers University*)  
Katelyn Frizzell (*Rutgers University*)  
Thomas Früh (*University of Münster, Germany*)  
Aleksandra Gawronska (*Miami University, Ohio*)  
Cosette Gilmour (*York University, Canada*)  
Elise Michelle Harrington (*University of Oslo*)  
Elisha Jhoti (*University of California, Los Angeles*)  
Stefano Lannini Lelarge (*University of Pisa, Italy*)  
Alissa Madera (*Rutgers University*)  
Maree McGregor (*University of New Brunswick, Canada*)  
Aaron Morrison (*University of Missouri*)  
Tyler Paladino (*Idaho State University*)  
Ruby Patterson (*University of Houston*)  
Leah Sacks (*University of Western Ontario, Canada*)  
Jahnvi Shah (*University of Western Ontario, Canada*)  
Tara Sweeney (*University of Texas, El Paso*)  
Bennett Wilson (*York University, Canada*)  
Bidgong Zhang (*University of California, Los Angeles*)

### **Space Flight Resource Management Training for Science Operations**

Dr. Cherie Achilles (*University of Maryland & NASA Goddard Space Flight Center*)  
Dr. Barbara A. Cohen (*NASA Goddard Space Flight Center*)  
Ms. Angela Garcia (*NASA Johnson Space Center*)  
Dr. Casey Honniball (*NASA Goddard Space Flight Center*)  
Prof. José Hurtado (*University of Texas – El Paso*)

Dr. Zachary R. Morse (*Howard University and NASA Goddard Space Flight Center*)  
Dr. Kirby Runyon (*Johns Hopkins APL*)

