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INTRODUCTION TO A SPECIAL SECTION
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Special Section:
Science and Exploration of the Moon, Near-Earth Asteroids, and the Moons of Mars

Key Points:
- SSERVI works to advance basic and applied research fundamental to lunar and planetary science and to advance human exploration of the solar system through scientific discovery
- This special collection includes contributions from both SSERVI team members and nonteam members related to science and exploration of the Moon, near-Earth asteroids, and the moons of Mars
- Contributions highlight how remote sensing, laboratory geologic analyses, field work, and medical studies contribute to SSERVI's science and exploration plans

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Introduction to Science and Exploration of the Moon, Near-Earth Asteroids, and Moons of Mars

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Abstract This special collection, sponsored by National Aeronautics and Space Administration's Solar System Exploration Research Virtual Institute, includes contributions relevant to the science and exploration of Moon, near-Earth asteroids, and the moons of Mars. Contributions appear in the *Journal of Geophysical Research—Planets*, *Earth and Space Science*, and *GeoHealth*. Major topics covered by the contributions include, but are not limited to, space weathering, geologic analysis of potential lunar landing sites, field analog investigations, and infrared spectroscopic measurements applied to airless bodies in the solar system.

Plain Language Summary National Aeronautics and Space Administration's Solar System Exploration Research Virtual Institute (SSERVI) promotes the science and exploration of the Moon, near-Earth Asteroids, and the moons of Mars. This special collection includes contributions relevant to this mission by SSERVI team members and the broader science community.

1. Introduction

National Aeronautics and Space Administration (NASA)'s Solar System Exploration Research Virtual Institute (SSERVI) formed in 2013 with nine teams selected for five years of funding starting in early 2014. SSERVI evolved from NASA's Lunar Science Institute and now focuses on furthering the science and exploration of airless solar system bodies that could be near-term human destinations. These include the Moon, near-Earth asteroids, and Phobos and Deimos, the moons of Mars. SSERVI's activities, coordinated by a central office at NASA Ames Research Center, include planning and execution of the annual NASA Exploration Science Forum, sponsoring other meetings and topical sessions, coordinating science education, communication, public engagement, and citizen science activities and facilitating interactions between the funded teams and the broader science and exploration community, largely through the use of virtual collaboration tools.

SSERVI works under the guiding principle that "science enables exploration and exploration enables science." In this spirit, we put out a call for papers focusing on the science and exploration of the Moon, near-Earth asteroids, and the moons of Mars as NASA continues to refine its strategy for the next steps of human exploration of the solar system.

Papers submitted to this special collection include contributions from both SSERVI team members and the broader domestic and international science and exploration community. Contributions span three journals: the *Journal of Geophysical Research—Planets*, *Earth and Space Science*, and *GeoHealth*. The breadth of scope of these contributions demonstrates the presence of a vigorous international research and exploration community.

Contributions to the special collection highlight many research topics that are priorities for SSERVI and the broader airless body science and exploration community. A number of contributions deal with space weathering, a process that occurs in one form or another on every airless body in the solar system. Space weathering is the cumulative effect of solar wind sputtering and implantation, micrometeoroid bombardment, and comminution, among other processes. Space weathering typically results in lower visual albedos, reduced spectral band depths, and changes to spectral slopes, although slope changes vary from body to body (Pieters & Noble, 2016, and references therein). These changes occur as a result of the formation of nanophase opaques, including ^{0}Fe, and amorphous patinas on the rims of mineral grains. This special collection includes contributions that utilize modeling, nanoscale analysis of returned samples, and remote sensing data analysis to shed light on the processes associated with space weathering

Altobelli et al. (2019) and Fiege et al. (2019) utilized a new model to better understand micrometeoroid fluxes on different airless body surfaces and performed microparticle bombardment experiments on meteorite samples. The modeling work suggests that solar system dust populations are too low for bombardment to play a dominant role in space weathering, while the experimental work demonstrates that high-energy micrometeoroid bombardment results in common shock phenomena and resulting changes to infrared spectra of the bombarded samples.

Burgess and Stroud (2018) use high resolution scanning transmission electron microscopy to study the amorphous rims associated with space weathered lunar regolith particles. They found evidence for the commonly identified nanoscale metallic Fe inclusions but also more oxidized species. The identification of these phases reveals a gap in our understanding of space weathering processes.

Regardless of the composition of the space weathered rims, the timescales of their formation are another major topic of interest. Poppe et al. (2018) used ARTEMIS data to determine the mean ion flux at the surface of the Moon. These observations, combined with an analysis of laboratory weathering experiments and a Monte Carlo modeling approach, suggest that 100-nm-thick amorphous rims on space weathered grains can form in ~50,000 years, with thicker rims (~400 nm) taking ~3 Myr to form.

At present, the Moon is the most likely destination for future human exploration, and a current target for robotic exploration by the U.S., China, India, Europe, and Israel among others. This special collection includes a number of contributions that provide detailed geological characterizations of the Apollo landing sites, the planned Chang'e 5 landing site near Mons Rümker, and other regions of the Moon using mission data from the Lunar Reconnaissance Orbiter, Kaguya, ARTEMIS, and Chandrayaan-1.

Qian et al. (2018) provide a detailed geologic analysis of the Rümker region in northeast Procellarum, the site of China's upcoming Chang'e 5 sample return mission. They use a variety of orbital remote sensing data sets to identify 14 geologic units in the vicinity of the landing site, including a young (<1.5 Ga) Ti-rich basaltic unit that appears to be unlike anything in the Apollo or Luna sample collections. Return of a sample from this unit could help answer numerous questions about the late stage volcanic history of the Moon. The potential for late stage volcanic activity on the Moon is also addressed by Qiao et al. (2019), who present a detailed geologic study of the Ina shield volcano. Ina was previously suggested to have formed <100 Ma due to a paucity of craters on the shield surface (Braden et al., 2014). Such a young age challenges our understanding of lunar thermal and volcanic history. Qiao et al. (2019) instead argue that late stage activity at the Ina shield resulted in the eruption of a magmatic foam that has poor crater retention properties, resulting in a summit age of 3.5 Gy.

Two additional papers in the special collection conduct studies relevant to the Apollo landing sites. Nagihara et al. (2018) restored large volumes of heat flow experimental data from the Apollo 15 and 17 landing sites. They confirm a previously observed trend of increased temperatures in the lunar regolith at ~1-m depth over time. They hypothesize that surface activities by the astronauts led to a reduced surface albedo, increasing solar heat intake. This study demonstrates that surface exploration activities need to be conducted with care and planning to maximize the science value of future human exploration of the Moon.

The regolith interrogated by astronauts at the Apollo sites was derived primarily by impacts that have occurred over lunar history. Hirabayashi et al. (2018) model impact processes and demonstrate that small simple craters are critical for regolith generation and that ejecta deposited in the transient crater cavities exerts a strong control on regolith distribution. Their model, which also calculates regolith thickness, is consistent with results from the Apollo 15 seismic experiments.

In addition to remote sensing, model-based, or even past in situ geologic characterizations of potential robotic or human landing sites, successful human exploration of the Solar System will require optimized exploration strategies developed through field analog research, which can test science instruments and strategies, concepts of operations, and novel technical approaches in environments relevant to planetary exploration. Three contributions to this special collection describe efforts to develop science and exploration strategies at volcanic analog sites in Idaho, Hawaii, and New Mexico, for future human exploration.

Lunar pyroclastic deposits are among the most potentially interesting targets for future human exploration. Rader et al. (2018) present a field volcanologic study in southern Idaho. They show that the physical characteristics of pyroclastic spatter deposits in the region vary with eruption setting, including the style of eruption, distance to the vent, and properties of local lavas. This work provides important context for potential future human exploration of pyroclastic deposits and could also be used as the basis of detailed remote sensing studies of lunar or terrestrial pyroclastic deposits.

Ito et al. (2018) and Young et al. (2018) present results from field analog work at the Kilauea December 1974 lava flow in Hawai'i and the Potrillo Volcanic Field in New Mexico. Among the goals of the field teams associated with these studies was to test the incorporation of field portable instrumentation into geologic field work, as might be conducted on the Moon. Ito et al. (2018) demonstrate the use of field portable infrared (~8–13 μm) imaging and spectroscopy in field settings. They show that the incorporation of infrared analysis capability provides substantial added value in field campaigns and suggest that the technique and instruments should be further developed for human missions to the Moon or other bodies. Young et al. (2018) take a broader approach to examining the role of field portable instrumentation in planetary field work. They describe the activities of crews of geologists and astronauts engaging in simulated extravehicular activities at the Kiluea and Potrillo sites. They used the detailed timeline data for exploration and scientific measurements generated by this work to map onto extravehicular activity timelines used for NASA analog mission work. They note that development of both hardware and software must be prioritized to reduce the time that astronauts would spend making and/or interpreting scientific measurements.

Finally, the use of spectroscopy at ultraviolet through midinfrared wavelengths to study airless bodies is another major theme of this special collection. Contributions include laboratory, modeling, and remote sensing studies that use spectroscopy to better interpret the compositions, physical properties, and volatile contents of the Moon, Phobos, and asteroids.

Laboratory spectroscopic studies provide the basis for qualitative and quantitative interpretation of remote sensing data. Kiddell et al. (2018) present visible/near-infrared (IR; ~500-2500 nm) spectra of dust-coated carbonaceous chondrite slabs. They observe a range of changes to the spectral albedo, slopes, and absorption bands that correlate with particle size and sample preparation. These results can be used to help interpret the sampleability of carbonaceous chondrite asteroids and other spectrally similar minor bodies.

Similarly, Shirley and Glotch (2019) present the thermal IR (~2000–200 cm^{-1}; 5-50 μm) emission spectra of a range of common silicates and oxides acquired under simulated lunar environment conditions. They show that systematic changes to the spectra occur as a function of particle size, although in a way that is substantially different from variations in a terrestrial atmosphere. This and similar studies provide the bases for remote thermal IR spectral analyses of airless bodies. For example, Glotch et al. (2018) used thermal-IR spectra of minerals, rock powders, and the Tagish Lake carbonaceous chondrite meteorite acquired under simulated Phobos conditions to show that thermal IR spectra of Phobos acquired by the Mars Global Surveyor Thermal Emission Spectrometer are most consistent with a basaltic regolith, perhaps with a phyllosilicate component. Interestingly, the thermal IR spectral characteristics of Phobos are quite distinct from those of Tagish Lake or other carbonaceous chondrites measured under environmentally appropriate conditions by Donaldson Hanna et al. (2019). Glotch et al. (2018) suggest that these results support an impact, rather than an asteroid capture origin for Phobos.

Two studies utilize telescopic spectral measurements of asteroids to address fundamental aspects of their compositions. Burbine et al. (2018) used visible/near-IR spectra of pyroxene-rich basaltic achondrites to determine the mineralogies of a number of V-type asteroids that are spectrally similar to (4) Vesta. They show that most of these asteroids have compositions similar to eucrites or diogenites, which are known to originate from (4) Vesta.

The hydration state of asteroids is a topic of substantial interest, due to the common correlation of hydrated minerals with the presence of primitive organic matter in meteorites, and the potential of volatiles as fuel sources for scientific and, potentially, commercial missions. Using a number of estimates based on observed asteroid populations and models of the near-Earth object population, Rivkin and DeMeo (2019) estimate that there are ~300 ± 150 near-Earth objects > 100 m in diameter or larger that, based on fuel consumption for a round trip mission, are more accessible than the surface of the Moon.

Taken together, the 23 papers contributed to this special collection are a representative, though by no means complete, cross section of the science and exploration topics of interest to SSERVI and the broader international community. SSERVI will continue its efforts to foster United States and international science and exploration collaborations that will support future human and robotic exploration of the Moon, near-Earth asteroids, and the moons of Mars.

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