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GROUNDWORK
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Geologic training for America's astronauts

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ABSTRACT

NASA astronauts are smart, highly motivated, intensely curious, and intellectually fearless. As pilots, scientists, and engineers, they have outstanding observational and reasoning skills. Very few, however, have any prior background in geology. The purpose of this article is to inform the geologic community about what we are doing to provide useful geologic training for current and future NASA astronauts who will spend many months observing Earth from orbit on the International Space Station and who will be involved in such activities as suit and tool testing, field operations, mission planning, and future off-planet exploration.

THE CONTEXT

NASA currently selects a new astronaut candidate class every four years, and each astronaut class undergoes 18 months of training before graduating to join the Astronaut Corps. The training is intense and focuses primarily on the International Space Station (ISS)—basic spaceflight operations, ISS systems, spacewalks, robotic arm operations, Russian language, human life sciences, and flight certification in T-38 jets. Geologic training is currently limited to four weeks. In that short amount of time, astronaut candidates must have an effective initial training experience in Earth observations, as well as learn about past, present, and future planetary missions to prepare them for public outreach obligations and future lunar and planetary exploration destinations.

In 2008, the authors introduced a new geologic training program built on geologic training that began with the *Apollo* missions. Each crewmember of *Apollo* 15, 16, and 17 received over 550 hours of geologic training in mission-relevant field locations (Amsbury, 1989; Evans et al., 2011; Lofgren et al., 2011; Phinney, 2015), and the success of a mentored approach to field training has shaped our current curriculum. After *Apollo*, classroom training focused on Earth observations from orbit (Amsbury, 1989; Evans et al., 2011). Field training remained an important, though much more limited, part of astronaut training (Bauer et al., 2000; Muehlberger, 2004; Dickerson, 2004), and Shuttle-era field training provided important background and context for our curriculum. The integrated approach to astronaut geologic training currently involves two weeks of classroom training followed by five days in the field. In addition, astronauts also receive a week of classroom training focused on NASA planetary missions, including the successes of *Apollo* and the motivation for human exploration of the Moon, Mars, and asteroids.

DESIGNING EFFECTIVE GEOLOGIC TRAINING

NASA's current mission is ISS-focused, and Earth is the first planet that current astronauts will see from a spacecraft. Geologic training must prepare astronauts to recognize geologic features and events, and to interpret, document, and report what they see from orbit to geologists on the ground. They also need to understand how remotely sensed data augment visual observations and relate to features that can be observed in the field.

In order to meet a NASA requirement to make the training ISS-focused, we have taken an "orbit to outcrop" approach. Astronauts gain first-hand experience both in interpreting what can be seen from orbit and in making field observations and interpretations that provide critical constraints on what can be interpreted from orbital images alone. ISS crewmembers have responded enthusiastically to requests to photograph specific targets for use in training their fellow astronauts. Consequently, we can base our training around recently acquired images from the ISS of rock units, structures, and surface features that astronauts will interpret in the field.

Our biggest challenge was how to provide effective training for geological novices in a period of time that is presently constrained by astronaut schedules to two weeks in the classroom followed by one week in the field. Our approach is to focus the entire training on a narrowly defined field problem, use the classroom training to prepare astronauts effectively for tackling that field problem, and challenge them with a field experience that gives them personal practice in making informed observations, collecting data, and interpreting geologic processes and histories at a field site with geologic features that are important in both a terrestrial and planetary context.

The field site around which we have based the training is located in the northern Rio Grande Rift in New Mexico, USA. We chose the site in part for the variety of features that can be interpreted both in the field and in orbital imagery and in part for analogs of basaltic volcanism and faulting on other planets. During the pre-field classroom sessions, astronauts use a variety of remotely sensed data, including ISS photos, to construct a

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Figure 1. Astronauts Andrew Morgan and Christina Hammock Koch working a field geologic mapping problem along the Rio Grande Gorge in the Rio Grande del Norte National Monument, Questa, New Mexico, USA. NASA photograph jsc2014e069405 by Lauren Harnett.

preliminary geologic map of the field area, adding new observations and interpretations as they learn about topics in the classroom. Fieldwork includes three days of geologic mapping and one day of geophysical surveys to add subsurface data. We group the astronauts into small groups (in 2013, four per group, with two geologist instructor-mentors), and each group combines their individual preliminary maps into a consensus solution to the geology of the field area. On the final day in the field, each astronaut team presents a geologic map, cross section, and geologic interpretation.

Throughout the training, we underscore that the purpose is to develop astronauts' abilities to infer processes from products, to recognize significant relationships and events on Earth's surface, and to document and describe those events in a way that allows Earth-bound scientists to understand and visualize them. Both in the classroom and in the field, we emphasize the relationships among outcrop, local, regional, and global patterns. In short, the training is designed to give them an effective experience in doing what geologists do and tying that to what they will see from the ISS.

FIELD TRAINING—INTEGRATING GEOLOGY AND FLIGHT OPERATIONS

Life on the ISS involves both management of daily operations and integration of new crewmembers into an experienced crew that has been aboard ISS for several months. In order to improve crew integration skills, NASA emphasizes crew resource-management training. We conduct our fieldwork from a semi-primitive camp on the edge of the Rio Grande Gorge, and teams of astronauts assist in cooking duties as well as engage in camp activities, managed by a senior astronaut, to focus on the crew management skills needed for ISS. This part of the training purposely stresses the astronauts—long days are common during spaceflight, with multiple priorities demanding attention and challenging each crewmember's time management as well as interpersonal skills. Conducting a field geologic investigation while managing camp activities has proven valuable for teaching both geology and spaceflight management skills.

THE FUTURE

Our team is currently looking forward to training the 2017 astronaut candidate class. We will also continue to offer short geologic field experiences for NASA engineers and managers and provide additional preflight training as requested by astronauts who have been selected for ISS missions and want a deeper understanding of the geology they will see on orbit. We are also expanding "post-graduate" training opportunities to accommodate a strong crew interest in geology, which we have seen continue after their basic geology training. We feel that this is a good indicator that Earth and planetary science is alive and well in NASA's Astronaut Corps. That interest and experience will be critical for developing crew operations for future planetary exploration missions.

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