ASTRONAUT GEOLOGY TRAINING.

J. E. Bleacher[1], D. B. Eppler[2], B. J. Tewksbury[3], M. A. Helper[4]
[1]NASA Goddard Space Flight Center, Planetary Geodynamics Laboratory, Greenbelt, MD, 20771 (jacob.e.bleacher@nasa.gov)
[2]NASA Johnson Space Center, Exploration Science Office, Houston, TX, [3]Department of Geosciences, Hamilton College, Clinton, NY, [4]Jackson School of Geosciences, The University of Texas at Austin, Austin, TX.

Introduction: The scientific success of the Apollo Missions is a testament to the scientists, engineers and managers who developed the exploration architecture that accomplished their goals. There will be numerous differences between the Apollo Program and HEOMD approaches to surface science during future human exploration of the Solar System. However, many similarities will likely exist. The Apollo Program approach to preparation for science operations included extensive geology training, including over 1000 hours per crew member during the J-Missions [1]. Fielding well trained crew members, particularly for those who do not possess a science background, was considered a major influence on the science success of those missions [1-4]. Although the Apollo geologic training program was discontinued in 1972, Space Shuttle crewmembers received 40-50 hours of limited training in Earth observations prior to their flights [5]. In 2008, it was decided to revamp the geologic training curriculum to include more thorough classroom work and geologic mapping to improve the astronaut's observations skills and understanding of basic geological concepts. The two most recent astronaut candidate classes (2009 and 2013) received this improved geology training, and the Astronaut Office has also involved senior members in short field geology mapping courses and field assistant programs. Here we discuss the current status of astronaut geology training.

Background: Between 2008 and 2010 LEAG and CAPTEM jointly conducted the Lunar Sample Acquisition and Curation Review (LSACR) [6] to assess sample identification, documentation, collection and curation during the Apollo Missions as a basis for recommendations to ensure successful science exploration of the Moon in the future. Among many recommendations the LSACR suggested the development of a geology training program for future human exploration beyond low Earth orbit.

Geology training for the Apollo Program was conducted in an atmosphere of known targets and defined science objectives. The current environment within NASA involves development of hardware to carry humans to a series of possible destinations, with a long range vision of humans at Mars. As such, geology training at this time is primarily focused on basic geologic concepts as a means of enhancing observations and science that might be conducted from the ISS. The goal is not to train astronauts in lunar science or Mars geology, but to begin training the mindset that all astronauts should know the scientific value of, and routinely consider the observations they can make from their unique vantage point. We hope to help develop a Crew Office within which consideration for science operations is the norm for all decision making steps during the development of the human exploration architecture.

Geology Training: Geology training for the astronauts can be generally divided among three main approaches, including: 1) class room teaching and field exercises, 2) a field assistant program, and 3) integrated analog field tests. Classroom and field exercises incorporate an "outcrop to orbit" perspective; whether it be structural geology or volcanology, all topical training integrates orbital observations. The field component of geology training is also integrated with a Crew Office requirement to routinely provide expeditionary training and team building experiences.

***Classroom & Field Exercises*:** Classroom training and field exercises are the primary mechanism for training during astronaut candidacy. The curriculum, as it has evolved between the 2009 and 2013 includes input from > 30 geologists both within and outside of NASA. Classroom training is focused on basic field geology concepts and for the 2013 class involved three weeks of class room activies. Discussion of target specific science was limited and generally presented in a historical context with respect to lunar science associated with the Apollo Program.

The approach to classroom training involves a daily focus on a single geologic discipline. Typically the crew were presented with a perspective of what they can expect to see from ISS, essentially a regional to global perspective from orbit. Lectures and activies become more focused on details within each discipline. The details are not presented as material that is expected to be memorized and retained but in a manner that enables the crew to understand why the observations they can make from ISS are important to scientists on the ground. For example, the crew are trained not to necessarily interpret that a volcano is rhyolitic but to explain that they see a volcano with steep flanks and a dark colored plume that extends nearly 3 volcano diameters to the north. The goal is to train scientific observational skills and an understanding of the value of those observations.

During classroom training each crew memberconstructs a preliminary geologic map of the field exercise area, a volcanic region of about 140 km^2, from remote sensing data . Most days are concluded with a new look at their map based on the geologic discipline of the day. In other words, each day ends by revisiting and revising the map on the basis of the geologic lessons that day. The end result is a well constructed remote sensing map from which they develop field-testable hypotheses and plan their field activities.

Shortly after completion of classroom training the crew are taken into the field. Although the primary objectives are geological, living and working outdoors also provides opportunities for expeditionary training. With preselected field targets and their prelimary maps in hand, crew member pairs and a field geologist conduct geologic mapping, sample characterization and collection, and data collection with a range of geologic instruments. A geologic map and cross section that integrate both remote sensing and field observations are the final team products of these efforts. Results are later compared with published interpretation(s) for the site. Upon requests from the Crew Office, a similar approach has been adopted for senior members who joined the Astronaut Corp prior to the 2009 class. Field training exercises for this purpose have been conducted several times in the last few years with the intent of providing a baseline level of geologic training and experience for the entire Crew Office.

***Field Assistants*:** Classroom training and field exercises provide a large group with a basic level of geologic knowledge. However, basic field exercises can lack a sense of "doing new science". To address this the field assistant program was developed. In this program geology trainers inform the Crew Office of opportunites for astronauts to take part in current research projects. As field assistants the crew members are given an opportunity to experience the reality of testing multiple working hypotheses and dealing with the real-life difficulties of doing so. The participants are exposed to situations where field geologists disagree while discussing their observations in the field. This provides the field assistants with a realistic view of how geologists communicate and present their observations and testable hypotheses. The emphasis complements the goals of the classroom/field activities in which training observational capabilities is the goal.

We consistently find the field assistant program to benefit the geologists as well. Astronauts often approach field science from well outside the geologist's "box" of thinking. By challenge the team's conventional thinking the assistants help push the research in new directions. Because many of these projects are related to planetary analogs, the astronauts who participate are also given a chance to gain relevant planetary science knowledge, which they typically present to the Crew Office through briefings. Perhaps the best testament to the quality of the students in the training is the recognition that astronauts have often made observations that the professionals have missed.

***Integrated Analog Field Tests*:** NASA and ESA conduct a range of integrated analog field tests such as the *NASA Extreme Environment Mission Operations* (NEEMO) or ESA's *Cooperative Adventure for Valuing and Exercising human behaviour and performance Skills* (CAVES), among many others. These field tests provide opportunites to assess various aspects of human exploration including hardware, operations, environments, duration, and science. The Crew Office often provides personnel to support these tests, which opens opportunities for the science community to provide scientific content and training to the participants. For instance, when active, NASA's *Desert Research And Technology Studies* (Desert RATS) focuses on conducting basic geology as influenced by current NASA hardware and operations concepts. Thus, crew members are routinely provided with basic field geology backgrounds to enable them to evaluate how the hardware and operations hindered or enhanced their ability to provide geologic observations.

Conclusions: Field geology training was a fundamental aspect of the success of the Apollo Program. Astroanauts of the Shuttle Program era received roughly one week of training related to orbital observations of the Earth. LEAG and CAPTEM recently recommended an increase in this training and the development of a official geology training program to ensure the science success of future human exploration programs. Geology training that was developed and implemented within NASA for the 2009 and 2013 astronaut classes, included NASA personnel, US and State Geological Surveys and participants from academia. This effort builds upon the Apollo geology training, is reestablishing the links between NASA and professional geologists ouside of NASA, and has exposed several early career participants to the institutional Apollo knowledge base that is now retired or might be retired over the next decade. The goals of the training program are to develop a Crew Office with a healthy understanding of how science fits within human exploration of the Solar System and to put in place and provide experience for the next generation of astronaut geology trainers.

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