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The ESA PANGAEA programme: training astronauts in field science

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Abstract. PANGAEA (Planetary ANalogue Geological and Astrobiological Exercise for Astronauts) is a field training course designed by the European Space Agency (ESA) that, since 2016, has imparted to ESA and NASA astronauts, and Roscosmos cosmonauts the basic theoretical and practical knowledge of geology and astrobiology and trained them in the field. Hence developing independent field skills, including working with a remotely located science team, is a key part of the training. For this reason, classroom and field lessons are tightly interwoven so that the concepts introduced in the classroom are shown in the field soon afterwards. The primary field sites selected for the course are the Permo-Triassic sedimentary sequences in the Italian Dolomites, analogue to the Martian alluvial plains ones, the impact geological environment of the Ries Crater, Germany, a comprehensive suite of volcanic emplacements and deposits in Lanzarote, Spain, and the anorthosite outcrops, analogue to lunar highlands rocks, in Lofoten, Norway. Each site is used as a base to deliver the main learning sessions, respectively: 1) Earth geology, rock recognition and sedimentology on Earth and Mars, 2) Lunar geology and impact cratering, 3) volcanism on Earth, Moon, and Mars, and astrobiology 4) intrusive rocks and lunar primordial crustal evolution. The four sessions are designed to increase the trainees' autonomy in the field up to autonomously executed geological traverses including sampling activities. Whilst PANGAEA's primary focus is astronaut training, where appropriate, technologies being developed for future missions are used to evaluate their performances in analogue field envi-ronments and to train the astronauts in using technologies that might support future missions.

Introduction

In 2016 some of the authors proposed to ESA the first field course for astronauts in geological and astrobiological planetary exploration named PANGAEA (Planetary ANalogue Geological and Astrobiological Exercise for Astronauts). This was possible thanks to the far-sightedness of prof.

Debei which immediately understood the potential of a course like PANGAEA for future human exploration of the Moon and Mars and made available all the needed facilities of the University of Padua to carry out the first edition which was attended by the ESA astronauts Luca Parmitano, Pedro Duque and Matthias Maurer. Other 4 editions of the training have been implemented since 2016, with a sixth one foreseen in 2023. In total, 10 astronauts from ESA, NASA and Roscosmos and additional 5 non-astronaut trainees including space engineers, EVA and operation specialists have attended the course. In this work we will summarise the course strategy, structure and lessons learned, but for a more detailed description the reader is referred to Sauro et al. [1] .

Goals and structure

The course forms part of the basic and pre-assignment training for European astronauts, and is open to trainees from other agencies. Significant focus is given to skills relevant to future field exploration, such as practical geological and geobiological field training, execution of self directed traverses in the field, ability to provide clear scientific descriptions of geological landscapes and features, and efficient documentation of sampling sites. For this reason, although minor portions of the course are taught in classrooms, most of the activities are in analogue geological environments, as done in the seventies during the preparation for the Apollo missions [1, 2]. PANGAEA course integrates both geology and astrobiology (including planetary protection) enabling overlapping concepts and ideas to be explored thoroughly. Trainees also have the opportunity to practice conducting field science under the additional constraints imposed by realistic spaceflight operational conditions.

Teaching in analogue sites

The primary field sites selected for the course are Permo-Triassic terrigenous sequences in the Italian Dolomites, impact lithologies in the Ries Crater, Germany, a comprehensive suite of volcanic deposits in Lanzarote, Spain and the Flakstadøy intrusive complex in the Lofoten archipelago, Norway. Each is used as a base to deliver the main learning sessions, respectively; 1) Earth geology, rock recognition and sedimentology on Earth and Mars, 2) Lunar geology and impact cratering, and 3) volcanism on Earth, Moon and Mars, execution of geological traverses, and sampling techniques and 4) Anorthosite and Mg-Suite intrusive complexes and lunar highlands. Classroom lessons are conducted at these field sites using local facilities often provided by Geoparks (e.g. Bletterbach Geopark in Italy, Ries Geopark in Germany and Lanzarote Geopark in Canary Islands). For the field work component, trainees are initially shown the basics of field geology and astrobiology during the first two sessions. In the third session they begin a process of becoming independent field scientists conducting geological traverses with realistic scientific goals, such as determine the contact relationship between geological units and the relative timing of events, recognise stratigraphic and tectonic structures, and sample rocks representative of the location or affected by different alteration processes (e.g. hydrothermal alteration). Trainees are initially accompanied by their instructors, but the coaching is progressively reduced until the field crew is supported by a remote science team, simulating a science back room in mission control.

Fig. 1. *a) Self directed traverse in Lanzarote by ESA astronaut Alexander Gerst and NASA astronaut Stephanie Wilson. b) ESA astronaut Samantha Cristoforetti acquiring a microbilogical sample in a lava tube in Lanzarote. c) ESA astronaut Matthias Maurer sampling an anorthositic block in Lofoten.; d) NASA astronaut Kathleen Rubins observing at a sample in Ries.*

Lessons learned

Astronauts tend to be practically minded, and long theoretical lessons do not provide them with the best opportunity to learn. For this reason each theoretical lesson must be always coupled with field activities and firmly connected to examples on how the specific knowledge can be applied in the future missions. Dissociating lessons from these goals can lead trainees to lose interest and eventually question the point of the learning. For this reason the classroom has been conducted in facilities close to the field sites so that classroom lessons and field trips often occur on the same day.

Typically, field trips used for academic teaching involve visiting locations to learn more about a particular environment in context. For training astronauts, these types of field trips are still important, however bringing in some elements of planetary surface exploration and in field scientific research realism is pivotal to sustain trainees motivation and knowledge retention. PANGAEA achieves these objectives performing increasingly autonomous traverses through geological landscapes with predefined science goals and remotely located science teams. This contextualises the knowledge trainees gained through the regular field trips in a planetary exploration setting and promote the trainee's independence forcing a flexible execution in the field. Adding to the traverses real scientific objectives, defined with the local experts, with potential for

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further science advancements and publications, is also a very important motivational factor fostering the engagement of the trainees.

The course is also very enriching for the scientists involved who had to learn about operational constraints and simplify the communication to be the most effective as possible.

When available, traverses should include technological capabilities relevant to planetary exploration. Although the exact set of capabilities for EVAs on the lunar or Martian surface are yet to be designed and built, the core concepts of scientific data collection, documentation, and communication can still be effectively demonstrated by using Commercial off-the-shelf (COTS) hardware, prototypes and low TRL (technology readiness level) instruments to emulate the capabilities that should be available to astronauts conducting geological exploration on the Moon or Mars. This includes ways to collect images, notes, spectra, and other scientific data [e.g. 3]. Incorporating such systems into the training was found to be a highly effective way to allow astronauts to understand the types of information required for performing effective science during planetary surface exploration with remotely located science teams. Overall, it allowed them to appreciate the importance of quality data collection for enabling scientific interpretation.

Conclusion

The time constraints and areal extent of lunar surface exploration will be extended significantly during future Artemis missions thanks to the technological advancements made since the Apollo era. It is therefore particularly important to train astronauts to self-directed field work and efficient communication with ground based science teams. Astronauts that will be not specifically launched to the Moon or Mars, will be in any case likely involved in the planning, preparation and implementation of such missions. Training key personnel in geology and astrobiology in terrestrial field analogues as in the ESA-PANGAEA course will be essential to the success of such expensive and high-risk endeavours

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