**ESA PANGAEA - TRAINING ASTRONAUTS IN FIELD GEOLOGY FOR RETURNING TO THE MOON.**

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**Introduction:** Future Moon missions will require astronauts to perform science-focused surface exploration in complex geological environments. Although astronauts currently participate in EVAs and science experiments in low Earth orbit (LEO), scientific exploration of a planetary surface during EVAs has not been carried out since the Apollo missions. Consequently, astronaut corps have received limited field geology training in the last forty years. Moreover, many astronauts and mission developers participating in the planning of future missions to planetary bodies have limited knowledge of the scientific disciplines underpinning them. Field geology and astrobiology will be the focus of exploration on the Moon and Mars, meaning that for these individuals to effectively contribute to the preparatory and execution phases of these missions, varied levels of training in such disciplines is required. PANGAEA (Planetary ANalogue Geological and Astrobiological Exercise for Astronauts) is a geological and astrobiological field training course organized by ESA. Since 2016, four editions of the course have trained astronauts from three different space agencies, including members of the Artemis team.

***Fig. 1.*** *NASA Artemis astronaut Kate Rubins examines an outcrop during PANGAEA training.*

**Goals and structure:** The course forms part of the basic and/or pre-assignment training for European astronauts, and is open to trainees from other agencies. Whilst PANGAEA intends to impart core theoretical and practical knowledge of geology and geobiology to the trainees, significant focus is given to skills in areas relevant to future missions, such as decision-making, clear scientific descriptions and efficient documentation. For this reason, although portions of the course are taught in classrooms, significant focus is given to developing field skills in analogue geological environments, as was done for the Apollo missions [1, 2]. Trainees also have the opportunity to practice conducting field science under the additional constraints imposed by realistic spaceflight operational conditions.

A significant strength of the PANGAEA course is that it integrates both geology and astrobiology training into its field work. Both disciplines inform each other, and teaching them together enables overlapping concepts and ideas to be explored thoroughly.

**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 igneous petrology in the anorthosite massifs of Lofoten, 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, 3) volcanism on Earth, Moon and Mars, 4) Lunar highlands and crustal evolution. The last two are also focused on practical learning on execution of geological traverses and sampling techniques.

***Fig. 2.*** *Science support team examining scientific data taken by astronauts in the field.*

Classroom lessons are conducted at these field sites using local facilities. For the field work component, trainees are initially shown the basics of field geology during the first two sessions. In the third session they begin a process of becoming independent field scientists. This is enabled by having trainees conduct 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 that were exposed to high temperature fluids. Initially trainees are accompanied by their instructors to help them achieve these goals, but this support is progressively reduced until they are only supported by a remote science team through voice communications.

**Integrated testing for exploration beyond LEO:** Whilst PANGAEA's primary focus is training, where appropriate and complementary, technologies being developed for future missions are used and tested by the trainees during geological traverses. This provides an opportunity to examine the performance of new equipment and software in analogue field environments, whilst also providing trainees with experience using technology that might support future missions. For example, trainee's use the Electronic Fieldbook (EFB) system to collect scientific data. This is a suite of hardware, software and networking tools being developed at the European Astronaut Center (EAC) to support scientific fieldwork in the context of astronaut analogue field training and future missions beyond LEO.


***Fig. 3.*** *Astronaut, Matthias Maurer, using the EFB during a mock EVA to transfer data back to the science team for analysis.*

The logistical framework established by the training course also provided the opportunity for establishing a more extensive technological testing separate from the core training focus. This resulted in the creation of the PANGAEA-X (PANGAEA-eXtension) campaign, which focuses on testing technologies and operational concepts with applications to future Moon and Mars missions. To date, this has involved three campaigns in 2017, 2018 and 2021, with a host of research institutions and ESA projects utilising the Lanzarote analogue for testing. This has included examining EVA science operations in preparation for lunar activities, and developing a geological test scenario for testing a tele-operated rover.

**Conclusion:** Preparations for human missions back to the Moon have already started, especially in the view of the Artemis programme. Improvements to surface mobility and extended surface exploration times enabled by the technological advancements made since Apollo, mean the time for scientific exploration will be extended significantly. It is therefore more important than ever to have astronauts capable of acting as independent field scientists, who can also understand and communicate efficiently with ground-based science teams. These astronauts will also be heavily involved in the planning, preparation and implementation of such missions, meaning even if they do not actually travel to the Moon or Mars, proficiency in geology and astrobiology will help them perform in many roles. In order to get the best return from these expensive and high-risk endeavours, training key personnel in the scientific disciplines driving these missions will be essential to their success. Utilising terrestrial analogues will ensure the best training.

**References:** [1] Lofgren G. E. *et al*. (2011) Geological Society of America Special Papers, 483, 33-48. [2] Schmitt H. H (2011) Geological Society of America Special Papers, 483, 1-1