TRAINING ASTRONAUTS FOR FIELD GEOLOGY: THE ESA PANGAEA TRAINING AND PANGAEA-eXtension TESTING ANALOGUE

F. Sauro[1], M. Massironi[2], Riccardo Pozzobon[2], Harald Hiesinger[3], Nicolas Mangold[4], Jesus Martínez Frias[5], Charles Cockell[6]; L. Bessone[7], [1]Department of Biological, Geological and Environmental Sciences, Italian Institute of Speleology, Bologna University, [2] University of Padua, Dipartimento di Geoscienze, [3] Institut für Planetologie, Westfälische Wilhelms-Universität Münster, [4] Laboratoire Planétologie et Géodynamique de Nantes, CNRS, France, [5] Instituto de Geociencias, IGEO (CSIC-UCM), [6] School of Physics and Astronomy, University of Edinburgh, [7] Directorate of Human and Robotics Exploration, European Space Agency,

Introduction: The need for geological training for astronauts was recognised at the beginning of the Apollo Moon missions in the 1960s [1, 2]. At that time each NASA astronaut went on at least 16 field trips and spent up to 300 hours in the classroom to prepare for each lunar geological mission goal. The Apollo training was based on the principle “You learn by doing and then doing some more”, so repeated learning and practice in many similar environments to the Moon was an important step for the success of the missions. No substitute exists for working in the field to learn the principles of field observation and sampling [1]. Their geological field-training allowed Apollo astronauts to identify, collect and analyse samples on the Moon with efficiency and flexibility.

On future planetary missions astronauts will probably explore, directly or with the remote help of teleoperated rovers, complex environments, rough surfaces, poorly illuminated landscapes, lava tubes and canyon rills, but foremostly, they will be required to help answering more specific scientific questions, resting on the heritage of the past decades on investigation. Training on Earth in places with similar geological features and operational conditions will help the astronauts to identify relevant feature and communicate effectively amongst themselves and the support teams on Earth during geological investigations on planetary bodies. Potential near future missions to the Moon will take into account newly-discovered features such as lava-tube skylights, or extreme environmental settings like sub-polar regions, which were not taken into account during the Apollo missions. But also the future Potential landing sites on Mars will cover a wide range of geological settings from volcanic regions, ice caps, sedimentary basins, deep trenches, craters, etc. Asteroids have a huge variety of features, each target offering distinct peculiarities. The recognition and interpretation of geological structures and processes requires experience, repeated encounters with the subject matter and detailed field studies.

In this preparatory context PANGAEA’s (Planetary ANalogue Geological and Astrobiological Exercise for Astronauts) field training is teaching astronauts decision-making methods and efficient documentation and descriptive techniques rather than wide and purely theoretical knowledge. Also the training is intended to put together a netwoork of european field geologist and geo-microbiologists focused in planetary studies to provide to the astronauts an overview of the potential scientific objectives for future missions.

The first edition of the training took place in September/October 2016 with the participation of a crew of three ESA astronauts while the second edition took place in autumn 2017, with the participation of a crew of 4 amongst ESA astronauts, engineers and mission designers .

Training goals: The PANGAEA course is part of the Basic or Pre-assignment Training of European Astronauts. The training is designed to provide astronauts with introductory but very practical knowledge of Earth and comparative Planetary geology processes and products, to prepare them to become effective partners of planetary scientists and engineer in designing future exploration missions, to impart them solid knowledge of current understanding of the geology of the solar system from leading European scientists. PANGAEA also is the first step in preparing European Astronauts to become effective future planetary explorers during future planetary missions, enabling them and their science advisors on ground to effectively communicate, using a common, yet geologically correct language, aiming at achieving a fast and fruitful decision-making process in selecting scientifically relevant sampling sites.

The course enables Astronauts to attain a basic knowledge about geologic processes and environments on Earth, Moon, Mars and Asteroids, to develop observational and decisional skills in identifying prominent geological features on field, conducting efficient sampling and reporting correctly to the ground, and describing the most important geologic environments that could host extra-terrestrial life.

Structure and locations: PANGAEA is organised in three main tsessions: 1)Earth and Lunar Geology, 2) Sedimentary processes on Earth and Mars, and preparatory field activities, 3) Volcanism and practical geologic self-directed traverses, with a focus on planetary protection and geomicrobiology

The first session is organized at the premises of the European Astronaut Center, with a field traverse at the

Ries Crater (as a Lunar Analogue). The second session is held in the Permo-Triassic terrigenous sequence of the Italian Dolomites (as a Mars Analogue for sedimentary features). The third session is located in the Lanzarote Geopark in Spain (Mars and Lunar analogue for volcanism).

While the first two sessions are mainly focused on understanding planetary geology and acquiring the basic knowledge and methodology of field geology, the third phase in Lanzarote is dedicated to real geologic traverses. These self directed traverses are focusing on the application of the flexecution method and on understanding how different operational settings, analitic instrumentation, decision support tools and supporting technologies influence the process. Flexecution is the standard concept of operation for terrestrial field geologists and should serve as the model for how planetary field geology is performed: during the traverse the crew have the freedom to make real-time adaptations to the planned tasks based on their field observations, re-prioritization of science objectives, and unanticipated discoveries. Future crews will surely require a higher autonomy in the field, which clearly highlights the need for them to achieve increased decision-making capacity with limited support from geologic experts or the ground team, albeit supported by advanced knowledge support systems.

Applications to robotic and human lunar missions: In view of potential missions to the Moon, PANGAEA is a fundamental training and testing step to improve astronaut skills in understanding geologic targets and overcoming operational issues.

In future lunar missions astronauts could be involved in field geological activities even without necessarily being on the lunar surface. This is the case expecially of robotic and rovers tele-operated by astronauts from a lunar outpost around the Moon with negligible time delay, like the DSG (Deep Space Gateway),. In view of potential precursor sampling return mission to the Moon (e.g. HERACLES), astronauts will have a fundamental role in the overall success of geological documentation and sampling activities. Rovers and robotic arms would be maneuvered following a flexecution approach where the skills and the gologic understading of the operator can have a real impact in the choice of the samples.

Obviously these requirements will be even more important during human missions to the surface, where EVA activities could last longer and become even more effective than those of the Apollo missions.

An analogue for testing field geology operations and tools: In addition to the astronaut field geology training purposes, one week after the last training session, in November 2017, ESA has decided to offer the PANGAEA framework to internal actors, partner agencies, and external investigators as an analogue test campaign (called PANGAEA-eXtension) focused on testing technologies and operational concepts for field geology and exploration. Two main objectives have been driving the choice of experiments for the campaign: testing of technologies and operations for geological and geo-microbiological sampling, and testing of technologies for exploration, mapping, navigation and communication in low lighting conditions, lava tubes and rough terrain. Both these objectives are within the general aim to acquire knowledge on how to develop exploration and field geology strategies for planetary missions, with a specific focus on lunar settings. 15 experiments have been proposed by 11 different research institutions and companies, involving 4 different space agencies, allowing to develop a testing program with an ambitious set of inter-related goals, with outcomes applicable either or both to human and robotic exploration. Operational concepts for geological sampling during spacewalks have been compared while testing new analytical and mechanical instruments supporting sample collection in realistic environmental and situational conditions. A series of technological applications have been used to achieve navigability and geologic information on the testing sites through 3D scanning and drone photogrammetry. In lava tube environments microbiological sampling has been combined with in-situ portable DNA sequencing of cave microbiota, remote sensing and 3D mapping, and testing underground communication instruments. Geophysical technologies have been used to identify underground voids and to characterize the geologic substrate.

All these tests and experiments have been performed with the participation of European astronauts and the assistance of ESA operation and training experts with the aim of evaluating potential applications and developments for future missions and astronaut trainings.

Conclusions: Even if the next lunar surface missions are foreseen in a timeframe of 10 to 20 years, the definition of effective geological sampling, curation and documentation will require a continuous and synergetic programme of preparation and field testing. PANGAEA represents one of the fundamental reference training and testing programmes, preparing for and leading to an effective and collaborative human and robotic scientifically sound exploration of the solar system.

[1] Lofgren G. E., Horz F. Eppler D. (2011) *Geological Society of America Special Papers*, *483*, 33-48.
[2] Schmitt H. H., Snoke A. W., Helper M. A., Hurtado J. M., Hodges K. V., Rice J. W. (2011) *Geological Society of America Special Papers*, *483*, 1-15.