Enhancing science backroom situational awareness: lessons learned during astronaut geological training. F. Sauro[1,2,3], L. Turchi[1], S.J. Payler[1,4], R. Pozzobon[5], M. Massironi[5], L. Bessone[1], [1]European Space Agency (European Astronaut Centre, Linder Hoehe, 51147 Köln, Germany) [2] Department of Biological, Geological and Environmental Sciences, Italian Institute of Speleology - Bologna University, [3]Miles Beyond Srl, [4]Agenzia Spaziale Italiana, Rome, Italy, [5] University of Padua, Dipartimento di Geoscienze – Padova.

Introduction: During the next phase of lunar exploration, astronauts on EVA will collect geological samples from the surface of the Moon for return to Earth. As outlined in the recently released Artemis III Science Definition Team report [1], this new generation of lunar explorers will require geological field science training, such as that currently offered by ESA's PANGAEA course. During these courses, astronauts will train to identify and properly document geological samples and features. Although this field training in terrestrial analogue environments will be crucial to the missions success (as Apollo astronaut testimony suggests [2]), the expertise available on the ground through the science backroom will always be significantly greater than that present within the crew on the Moon. The science backroom will therefore be required to input on tasks such as locating areas of interest, deploying instrumentation and selecting samples. As coordinating these time critical tasks across vast distances with many additional considerations is complex, it is very important to ensure that this collaboration is efficient. Therefore, in order for ground based science teams to effectively participate in any of these tasks, they must have situational awareness of the remote science work being performed. This requires a range of information associated to the field activities be provided in real-time from space to ground.

During the PANGAEA training and PANGAEA-X testing campaigns, we developed a training environment that includes methods for enabling the astronauts and the scientists to speak the same scientific operational language when working together on field science problems. In addition we have developed and tested a data information exchange system called the Electronic FieldBook that allows the two entities to share observations. This abstract discusses the lessons learned during the PANGAEA training so far, and how they could be applied to advance the scientific outcomes of future lunar surface activities.

Defining a scientific operational language: During the first editions of the PANGAEA training, it was realized one of the main problems presented to the science support and field teams was the capability of both to quickly and accurately understand the geological information being provided from the field and the scientific instructions from the support teams. In general, astronauts use a specific operational language that can limit their ability to properly describe geological features or unexpected discoveries, and the scientists often use specialised terminology that is not always intuitive for the crew. A significant lesson learned from the PANGAEA training is that the best field geology training approach requires the alignment of all entities involved (crew, scientists, communicator) in terms of terminology and descriptive strategies. In order to overcome this problem, it is clear that field geological training for future missions will requires the mutual involvement of the crew, science backroom and CAPCOM, to develop a common glossary and descriptive approach. Additionally, it is also clear that a preliminary shared definition of scientific expectations from traverse sampling and documentation is helpful in resolving problems in advance. To address these issues within its own training exercises, PANGAEA has already developed a standardised terminology glossary and an operational description flow for geological outcrops and samples.

The importance of backroom situational awareness: The types of visual information and data required to assess the lunar landscape is the same that field scientists typically gather on Earth when recording and assessing terrestrial geological environments. This means that high quality images, videos, analytical tool measurements, notes, and other information from the field are all essential for the backroom science team to provide effective support to space. However, during PANGAEA it was observed that this information is difficult to properly assess when received out of context. It is therefore crucially important that this information is structured in a way that all entities involved have access to the correct metadata regarding sampling and outcrops to align their perceptions. For example, every single element of information must be closely associated to location and orientation data in order for the ground teams to maintain their situational awareness. The science teams must be able to easily understand the provenance and context of a particular image, note, or measurement, in order to make an effective assessment. This outcome is also underlined in recommendation 6.3.7.1b of the Artemis III Science Definition Team report [1].

In order to meet these requirements, any system overseeing information transfer from the astronaut on the Moon to ground, must heavily focus on incorporating GIS features, such as multilayer maps, to keep the ground teams aware of traverses, crew and asset positions relative to scientifically interesting areas during exploratory EVAs. These systems must also be able to view this information through different methods to suit their needs, such as adding hyperspectral overlays to maps to understand local mineralogy. All this must be available in near real-time and propagated to all entities involved.

Science backroom-crew exchange flow: In order for the backroom decisions to be most effective, it is important that supporting scientists are also able to interact with the crew to make decisions. Much like during Apollo, radio voice communications remain the primary method of communication during EVAs [3], and science teams supporting real-time operations will be integrated into the voice loop mission structure in some way. However, voice communication can be high inefficient for conveying information related to field science, particularly when transferred across multiple teams. Therefore, in order to maintain effective crew/science backroom coordination and context, it is also important for the science team and crew to be able to annotate images or data, and add additional information like notes, and transmit it to the crew as required. This must happen in a transparent fashion so that all teams involved are able to factor in science decisions to operational planning.

Systems to enhance backroom situational awareness: During the early PANGAEA astronaut training and PANGAEA-X campaigns, the lack of ability to transfer integrated geolocalised data collected by the astronauts to the supporting science team in real-time was seen as an essential tool missing for the remote science team to support geological traverses. This led to the development of the Electronic FieldBook (EFB) system [4]. The EFB is designed to support field mission operations, scientific data gathering and direct interaction with mission control and science support teams through automatic data transmission. The system provides a structured way to collect data during geological traverses, where astronauts can interact with a number of sensors, collect data and/or samples, and take notes (Fig. 1). This is all then automatically associated to specific sites or samples, and transferred to support teams who can interact with the content to provide feedback directly to the field teams.

Through the development and testing of the EFB at PANGAEA, it has become clear that the information system coordinating between the crew and the science backroom for exploring the Moon should include the following capabilities:

- Display of pre-defined traverses, geological stops and sampling sites, with retrieval of associated reference and real time information.
- Marking of geological stops, sampling sites, and interesting areas on the map.
- Positioning of all field elements in 2D and 3D maps.
- Collection and storage of geo-located relevant geological/scientific information and data analysis.
- Simultaneous multiple crews data acquisition.
- Interface with external scientific instruments like microscopes or analytical tools.
- On-site decision support thanks to embed of custom machine learning models for mineral recognition.
- Access to reference and support material (e.g. scientific databases, manuals).

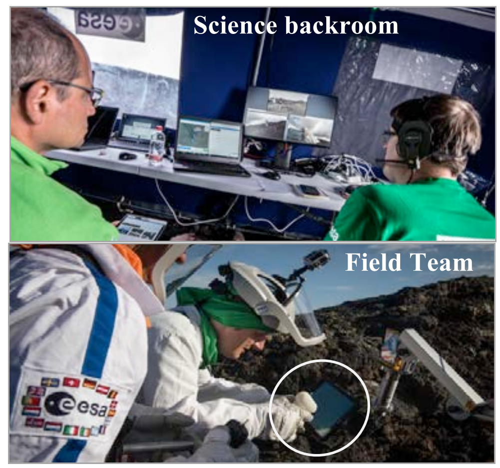

Fig. 1. EFB in use during a geological traverse. Top: The science backroom team using the EFB to maintain situational awareness over a traverse. Bottom: Field teams using EFB tablets and instruments (circled)

Conclusions: During the preparation for the next phase of lunar exploration, all actors involved in future surface EVAs (crew, science backroom, CAPCOM) should be involved in the training of astronauts for field geology. This includes during simulations of geological traverses, in order to develop a common language and alignment on science objectives [5]. In addition, the PANGAEA programme demonstrated need for intuitive methods and electronic tools like the EFB tool suite that allow science teams and astronauts to work collaboratively on geological problems to ensure the best science decisions are made, and that these decisions are understood by all parties.

References: [1] Artemis III Science Definition Team Report, 2020, NASA. [2] Schmitt, H. H., A. et al.. *Geological Society of America Special Papers* 483 (2011): 1-15. [3] Coan D. Exploration EVA System Concept of Operations Summary for Artemis Phase 1 Lunar Surface Mission, 2020. [4] Turchi L. et al *Planetary Space Science*. [5] ISECG – Global Exploration Roadmap, 2020.