THE ESA PANGAEA-X TESTING CAMPAIGN IN THE CORONA LAVA TUBE (LANZAROTE, SPAIN) AS AN ANALOGUE FOR LUNAR CAVES EXPLORATION

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Introduction: On future planetary missions astronauts will probably explore complex environments such as lava tubes, canyon rills and rough surfaces. Training and technological testing on Earth in places with similar geological features and operational conditions will help the astronauts to perform better their tasks and to maintain a high situational awareness between themselves and the ground support during geological investigations in our Solar System. Potential near future missions to the Moon will take into account features such as lava-tube skylights, or extreme environmental settings like sub-polar regions, which were not taken into account during the Apollo missions. In this preparatory context ESA has included in the PANGAEA geological field training for astronauts [1] a traverse in the lava tube of La Corona in the volcanic island of Lanzarote, one of the best analogue for planetary lava tubes in Europe [2, 3]. This traverse is focused on teaching to the astronauts how to recognize specific lava tube morphologies, secondary mineralizations and potential spots for geomicrobiological research. Three editions of the training have been held in 2016, 2017 and 2018 with the participation of a total of 5 ESA astronauts, 1 Cosmonaut, engineers and mission designers. In addition to the astronaut field geology training purposes, one week after the training session, in November 2017 and 2018, ESA has decided to offer the PANGAEA framework to internal actors, partner agencies, and external investigators as an analogue test campaign (called PANGAEA-X), focussed on testing technologies and operational concepts for field geology and exploration. One of the main objectives identified for the 2017 campaign was testing of technologies for geo-microbiological sampling, exploration, mapping, navigation and communication in the Corona Lava Tube and other volcanic cavities of Lanzarote (Tinguaton volcanic gayser vents), as an analogue to planetary caves exploration.

PANGAEA-X 2017 planetary cave-oriented objectives: The PANGAEA 2017 eXtension campaign took place from 20th to 24th November 2017. For the 5 days of field trials, interrelated activities were combined to create more valuable tests and operational scenarios. The first two days were dedicated to tests of surface geological sampling and analytical instrumentation and operations, with human-robotics interaction, taking into account mobility constraints of lunar surface sorties. The last three days took place in subterranean environments and were focussed mainly on lava tube exploration and mapping. The following research projects linked to planetary caves have been implemented:

Augmented field Geology and Geophysics for Planetary Analogues (AGPA): a project of the Jacobs University Bremen and DLR with multiple experiments related to planetary geology investigation approaches and analytical tools. The AGPA team tested a geoelectric system searching subsurface features (cavities, lava tubes, Fig. 1), an innovative LIDAR mapping system inside of the lava tube, and a passive seismometer to study the subsurface. Drone photogrammetry was used for documenting and for 3D high-resolution reconstruction of the Tinguatón vents testing site.

Pegasus backpack (PEGASUS LEICA): Leica Geosystems (France) tested a combined SLAM/LIDAR systems embedded in a portable backpack for real-time mapping of lava tubes and rough terrains [4].

Environment Modelling and Navigation for Robotic Space-Exploration (ENTERN): lead by the German Research Centre for Artificial Intelligence (DFKI), this research project focused on testing a rover system for exploration of rough terrain in lava tubes (Fig. 2); the rover ASGUARD was tested both autonomously and in tele-operation mode to evaluate critical constrains of the environment and efficiency of the different settings.

Microbiological Sampling Sequence (MICSS) and DNA extraction (DNAX), with the support of the Mobile Procedure Viewer (MOBIPV): the "Instituto de Recursos Naturales y Agrobiología de Sevilla" and the NASA's Johnson Space Center provided specific instrumentation and procedures to perform microbiologic sampling and in situ DNA extraction and sequencing in a lava tube. The experiment was performed by an ESA astronaut within an operational relevant scenario, taking into account sampling protocols to avoid cross contamination, and with the support of the ESA mobIPV procedure viewer.

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

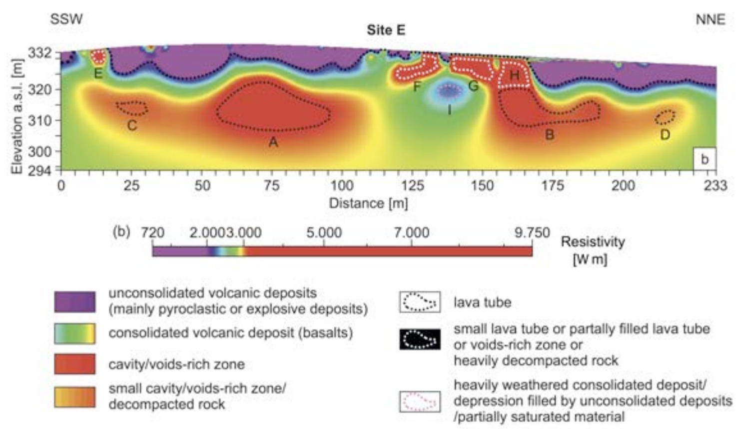

Fig. 1. Example of results of the AGPA geoelctric experiment showing the section of the Corona Lava Tube (A) and of another uknown tube about one hundred meters to the NNE.

Fig. 2. ESA astronaut Matthias Maurer driving a rover of the ENTERN experiment in the Corona Lava Tube.

missions and astronaut trainings. All experiments were documented with detailed reports and the results and data obtained by the different teams were presented at the European Geoscience Conference in March 2018. All participants deemed the campaign a really useful platform for validating concepts and instrumentation, mainly thanks to the integration in realistic operational scenarios and to the combination of field geology with surface and subsurface human and robotics operations

Results: All the different experiments have provided important data and lessons learned. As an example the stationary and mobile lidar mapping by LEICA, AGPA has provided, with the support of the company VIGEA, the longest centimetric resolution 3D model of a lava tube achieved so far (6.5 km), including high resolution models of the collapses through drone photogrammetry[4]. The MICSS experiment, performed by the ESA astronaut Matthias Maurer has shown the possibility of obtaining in situ an impressive amounts of data on the microbial diversity caracterizing the cave, with important implications for fast decision making in sampling protocols [5]. The AGPA geoelectric experiment has demonstrated the ability to identify a lava tube according to the 3D models, and also to discover additional parallel conduits not accessible to humans [6]. The ENTERN project has been able to test tele-operated and authonomous navigation of a rover in a lava tube environment, allowing to better define the robotic, communication and navigation approaches to lava tube exploration .

Conclusions: the synergies created by the PANGAEA-X campaign have demonstrated to be extremely useful for ESA in the framework of future human and precursor planetary missions since it allows testing and validation of complex operational concepts and testing of exploration technologies, scientitic methods and instrumentation. In addition, it fosters the exchange between research institutes, instrument developers and operational experts and thus boosts synergetically the use of novel portable analytical instrumentation and spin-in of new technologies and research into operations. Last but not least it provides a continuously increasingly relevant operational growth and novel scenarios for future ESA CAVES and PANGAEA training events.

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