3D RECONSTRUCTION OF LUNAR ROCK SAMPLES FROM THE APOLLO 17 MISSION. S. Le Mouélic[1], L. Macquet[1], H. H. Schmitt[2], N. Mangold[1], G. Caravaca[3], B. Seignovert[1,4], and E. Le Menn[1], [1]LPG, CNRS UMR6112, Univ. Nantes, France. [2]Dept of Engineering Physics, Univ. Wisconsin-Madison, P.O. Box 90730, Albuquerque, NM 87199, USA. [3]IRAP, UMR 5277 CNRS, UPS, CNES, Toulouse, France. [4]OSUNA, Nantes, France

Introduction: The Apollo 17 manned mission landed in the Taurus Littrow valley on the Moon in December 1972. The geology of this site was thoroughly investigated during extra vehicular activities performed during three days spent at the surface [1, 2]. A total of 111 kg of well-documented rock and soil samples were collected and brought back to Earth. Among several waypoints of interest, astronauts spent more than one hour to investigate five large boulder fragments at Station 6, lying at the base of the North Massif. Schmitt et al.'s [2] analysis indicates that original single boulder originated in Crisium-age melt breccia ejecta overlain by Serenitatis-age melt breccia ejecta. Earlier photogeologic interpretations had suggested that the North Massif was largely Serenitatis in age [3, 4]. In a previous study [5], we used scanned photographs taken *in situ* with astronaut's Hasselblad film cameras to reconstruct a 3D model of each of the boulders using Structure-from-Motion photogrammetry techniques. In addition to the 3D reconstruction of the boulders themselves reported in [5], we have now reconstructed in 3D several rock samples hammered from the boulders, using archived photographs from the Lunar Receiving Lab facility in Houston.

Photogrammetric Reconstruction of Lunar Samples: Several stereoscopic photographic pairs were systematically acquired several decades ago for a significant number of the samples brought back to Earth.

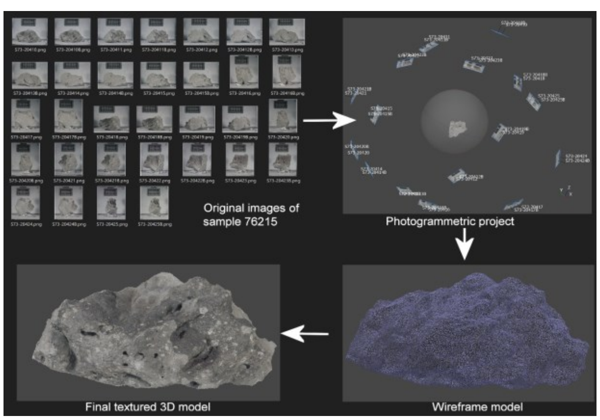

Fig. 1: Main steps of the 3D reconstruction process for sample 76215. Photos of the sample (upper left) are imported into a photogrammetric software (upper right). The automated correlation between overlapping images is used to produce a 3D mesh (lower right). A final draping texture is computed using a mosaic of the original photos (lower left).

When a sufficient number of viewpoints have been acquired, this potentially allows a complete photogrammetric 3D reconstruction of the rocks from these archived scaned images. For our study, we used original photographs available on the LPI website as input. We were able to compute a detailed textured 3D model of sample 76315 (a micropoikilitic impact melt breccia), sample 76215 (a vesicular micropoikilitic impact melt breccia that included part of the wall of a large vesicle), and sample 76015 (another vesicular micropoikilitic impact melt breccia), all collected at Station 6. The full 3D reconstruction process is illustrated in Fig 1 for sample 76215.

Visualization of the 3D Models of the Samples: We have posted the 3D models of these lunar rock samples, together with models of the boulders they were taken from, on the Sketchfab web platform (https://sketchfab.com/LPG-3D) to allow their visual inspection (Fig. 2).

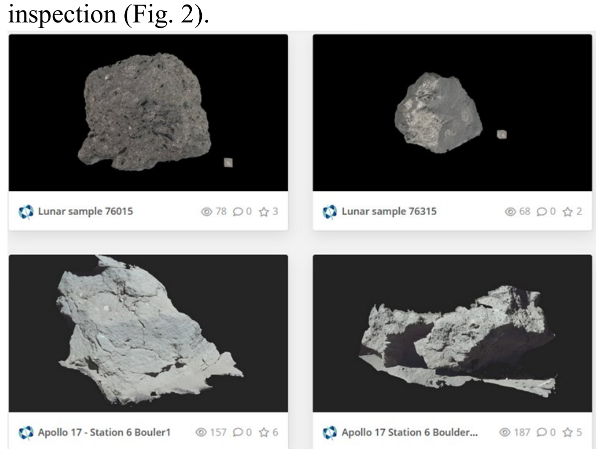

Fig. 2: Examples of the 3D models of lunar boulders of Station 6 and corresponding lunar rock samples on the sketchfab web plateform.

These 3D numerical reproduction have a strong potential value for conservation as the actual rock samples have been broken into multiple pieces after being photographed. They can therefore be thought as a kind of historical heritage of the original rocks, which do not exist anymore in their original form. A true scale copy of the shape of these original rocks can be produced using a 3D-Printer (Fig. 3). They can also be viewed using augmented reality, with a cellphone or a tablet (using the Sketchfab app), or even manipulated in virtual reality using a VR headset (Fig. 3).

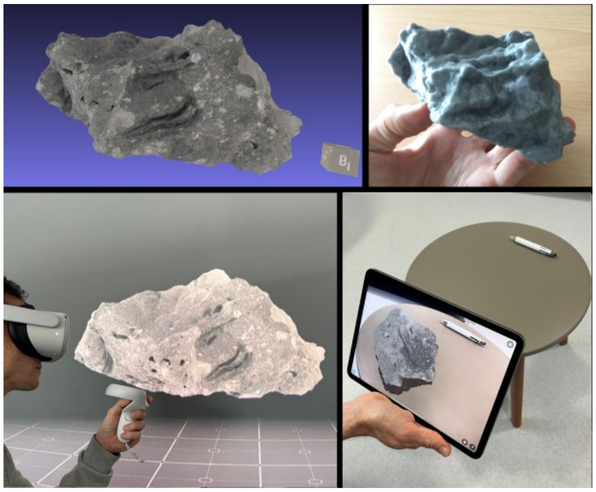

Fig. 3: 3D numerical model of the lunar sample 76215 (upper left) compared with its 3D print at 1:1 scale (upper right). The 3D numerical model can also be investigated either in virtual reality (lower left) or in augmented reality with a tablet or cellphone (lower right)

Complementarity with Previous 3D work on the Boulders

In a previous study [5], we reconstructed in 3D the three main boulders constituting Station 6 using Apollo images. We have refined these 3D models using a set of additional photographs, in particular the ones constituting two 360° panoramas. This allowed to better constrain the respective sizes and orientations of the boulders with respect to each other. A 3D perspective view of the photogrammetric project is shown in Fig. 4.

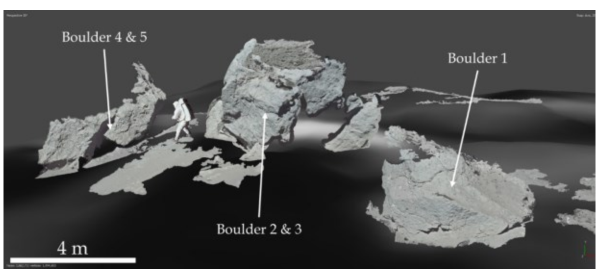

Fig. 4: Perspective view of the 3D photogrammetric reconstruction of Station 6 outcrop, made from 172 Apollo images. An astronaut has been added for scale.

Integration into Virtual Reality and Scientific Analysis: The 3D models theoretically offer the possibility to replace the rock samples in their original position and orientation directly on the 3D models of the boulders themselves (Fig. 5). It allows to retrieve the original orientation of the sample, to investigate for example the characteristics of coatings. On sample 76015, which was loose and in place on Boulder 5, at least three different places show various degree of patina formation, which can be correlated with the original position of the sample with respect to different levels of exposure to micro-meteors. The upper sky-facing side is the most affected by space weathering effects, with a well-developed patina. On its lower edge, a less altered face appears to be protected by a crevice. A similar, continous variation in patina thickness is present on the vesicle wall on 76215. Analysis is continuing relative to the variations of patina thickness versus length of exposure, as there are suggestions that Boulders 4 and 5 were broken off Boulder 2 after the parent boulder rolled into place ~20 million years ago.

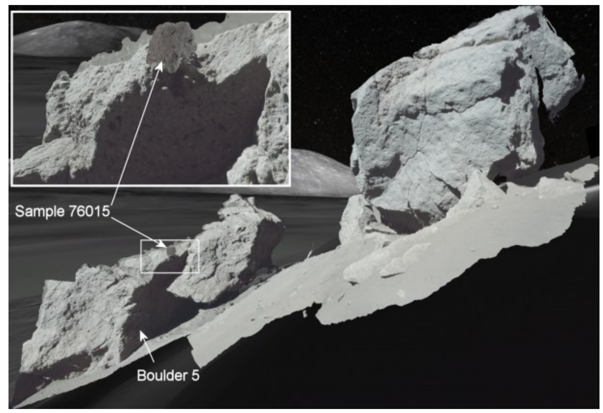

Fig. 5: Virtual reality simulation of station 6 integrating 3D models of boulders, rock samples and orbital imagery for the context. Sample 76015 has been placed at its original location in the virtual environment, according to images taken before and after being removed. The scene can be visited in Virtual Reality on the SteamVR workshop.

Conclusion and Future Work: We have carried out a photogrammetric 3D reconstruction of Station 6 boulders and three corresponding lunar rock samples using a set of original scanned Apollo and Lunar Facility Lab film photography. The three reconstructed lunar rock samples do not physically exist anymore in their original form, as they have been sawed in multiple pieces for analysis. Their numerical 3D reconstruction from archived images allows again their visual investigation as bulk rocks, and their in place study on the boulders in a virtual reality environment.

Such techniques could be useful in the context of the forthcoming Artemis landing missions, provided that astronauts and robotic explorer acquire relevant set of images (i.e. enough overlapping images taken from different viewpoints).

References: [1] Wolfe, E.W. et al., U.S. Geol. Surv. Prof. Pap. 1981, 1080, 225–280, 1981. [2] Schmitt, H.H. et al., Icarus, 298, 2–33, 2017. [3] Spudis, P. D., and G. Ryder, LPSC 12th, 133–148, 1981. [4] Hurwitz and Kring, EPSL, 436, 64–70, 2016. [5] Le Mouélic, S. et al., Remote Sensing, 12 (11), 2020.