**INVESTIGATING LUNAR BOULDERS USING PHOTOGRAMMETRY AND VIRTUAL REALITY**. S. Le Mouélic[1], H. H. Schmitt[2], G. Caravaca[1], Nicolas Mangold[1]. [1]Laboratoire de Planétologie et Géodynamique, CNRS UMR6112, Université de Nantes, France. [2]Dept. of Engineering Physics, University of Wisconsin-Madison, P.O. Box 90730, Albuquerque NM, 87199. [stephane.lemouelic(at)univ-nantes.fr]

**Introduction:** Virtual reality (VR) headsets are available to the general public since 2016. This new immersive technique potentially allows the users to explore 3D reconstructed planetary landscapes, as if they were physically present "on the field". We investigate how the in situ lunar imagery can be used to provide the user the possibility to explore in VR the lunar surface at various human and robotic landing sites.

**The Apollo data set:** During the Apollo missions, 12 astronauts had the opportunity to document the lunar surface, rocks and boulders at 6 different landing sites, using 70-millimeters Hasselblad Cameras equipped with 60-mm and 500-mm focal length lenses. We first focus our efforts on the Apollo 17 landing site, which has been thoroughly sampled by geologist-astronaut Harrisson H. Schmitt. A significant part of the Apollo image collection has been numerized and is now available on public websites. In particular, several relevant images have been taken at stations 6 and 7 during Extra Vehicular Activity 3 (Fig. 1) on boulders rolling down the North Massif [1]. These data sets appear to be suitable for a photogrammetric 3D reconstruction.

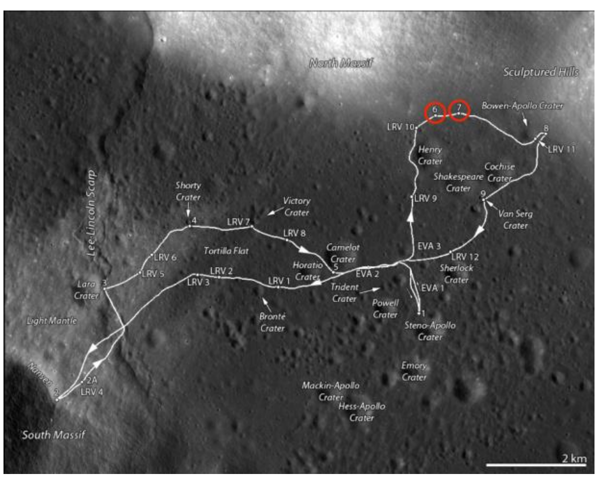


*Figure 1: Apollo 17 traverse map and location of EVA3 stations 6 and 7.*

**Photogrammetry principle:** The Structure-from-Motion photogrammetry principle relies on the identification of tie-points on a set of overlapping images taken from different points of views [e.g. 2]. When a sufficient number of overlapping images of a given scene is available as input, it is possible to compute the position of tie points in a 3D space, together with parameters linked to the camera used to take the pictures. Using a dense point cloud, a 3D mesh can then be reconstructed to provide the shape of the elements constituting the landscape. Individual images are finally mosaicked and wraped over the mesh to provide a final numerical 3D model. Several commercial or freeware softwares can be used to perform all the processing steps. An example of photogrammetric reconstruction on the Apollo 15 site has been shown in [3]

**3D reconstruction of the station 7 boulder:** We used a set of 41 images taken during EVA 3 at station 7 to document what was originally described in situ as a vesicular anorthositic gabbro (images labeled As17-146-22298 to As17-146-22338).

***Figure 2**: Example of images of H. H. Schmitt taking rock samples during EVA 3 station 7 (images labeled As17-146-22335 to As17-146-22338 used as input for the 3D reconstruction of the boulder).*

Fig. 3 shows the photogrammetric project, where the position of the cameras has been automatically retrieved by correlation for each of the 41 frames (blue rectangles). The astronauts documented approximatively half of the boulder. A textured 3D model has been produced from this reconstruction. The inset in Fig. 3 shows a zoom illustrating the level of details that can be achieved in the 3D reconstruction. The mosaicking of the 41 original images has been done using an average of the values on each polygon of the 3D model.

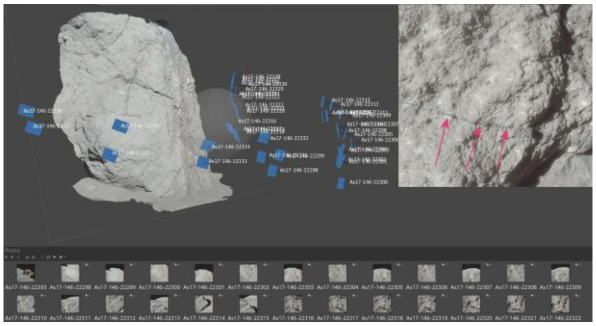

***Figure 3**: Photogrammetric project showing the location of the 41 Apollo images surrounding the reconstructed textured 3D model of the station 7 boulder. The inset shows a zoom of the 3D model, with arrows pointing to a 3-5cm dike.*

The full 3D model is displayed in Fig. 4, together with a character showing the scaling in VR. The scaling can be refined using a known reference such as the gnomon or the geologic hammer, when available in the original images. This step can prove to be problematic when no known reference is available on the scene. For those equipped with a VR headset, a version of the 3D model can be directly seen online in VR at this address : https://skfb.ly/6NpGR. It allows in particular to investigate in details the morphology of the boulder.

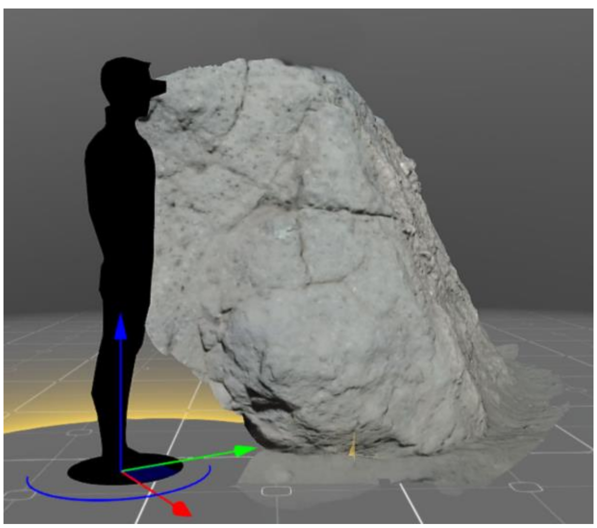

***Figure 4**: Any user equipped with a virtual reality headset can stand in front of the 3D reconstructed station 7 boulder and investigate it in details in virtual reality.*

The 3-5 cm dikes which are intruding noritic breccia in this boulder comprising angular minerals and lithic clasts appear readily in VR. These dikes were probably generated by vapour-fluidized comminuted materials and lithified by condensing silicate vapours and/or by subsequent shock welding [4].

**Scientific interest of the virtual reality reconstruction:** One of the main interests of the VR reconstruction is to give a real sense of scales and shapes, without the deformations induced by reprojections on a conventional computer screen. The surface of the Moon lacks of atmospheric scattering (inducing distance effects on Earth) and known features such as trees, roads, or any known reference that could help the brain to figure out the distances, and therefore the size (and real shape) of lanscapes elements. This problem is easily overcomed by VR. In addition, the photogrammetric reconstruction in VR allows a very user friendly synthetic visualization and manipulation of the scientific content of a whole set of images.

**Conclusion and future work:** We have reconstructed in 3D and integrated in virtual reality the boulder explored by Apollo 17 astronauts during their EVA3 at Station 7. The same exercice will be done at station 6. Whereas most of recent photogrammetric projects are carried out with images taken from digital cameras, it is noteworthy to mention that the reconstruction process can still work with Apollo images, thanks to the quality and homogeneity of the scans of the original films. The rendering in the virtual world can eventually be merged with LRO orbital imagery and in situ 360° panoramas to provide the general context. A particular care has to be taken to handle the lighting conditions in the virtual world to provide a realistic experience. A normal map can also be computed to render the micro relief on the boulder without overloading the processor.

The photogrammetry technique can also eventually be applied to descent images when available to compute a local high resolution digital elevation model and to retrieve the descent spacecraft trajectory [5]. Several tests show that a similar local reconstruction can also be done on the Chinese Change'3 site using the Yutu rover imagery. We show a preliminary example online at this address : https://skfb.ly/6HVD6

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**Bibliography**: [1] Schmitt, H. H., et al., Icarus, 298, 2-33, 2017. [2] Westoby M.J. et al., 'Structure-from-Motion'photogrammetry: A low-cost, effective tool for geoscience applications. Geomorphology 179, 300-314, 2012. [3] Manheim M. et al., vol. 12, EPSC2018-996, 2018. [4] Hudgins, J. A. and Spray J. G, 37th LPSC, Houston, 2006. [5] Binet et al., 50th LPSC, abstract # 2132, 2019.