USING VIRTUAL REALITY TOOLS TO CHARACTERIZE AND MEASURE SEDIMENTARY SERIES IN GALE CRATER: A CASE STUDY.

G. Caravaca[1*], S. Le Mouélic[1], N. Mangold[1], L. Le Deit[1]. [1]UMR CNRS 6112 LPG Laboratoire de Planétologie et Géodynamique, Université de Nantes, France, *gwenael.caravaca@univ-nantes.fr

Introduction: The application of Virtual Reality (VR) to research ends is a recent but growing practice among the community. This technique unlocks previously underrated possibilities to study hardly accessible areas, which is particularly suited for planetary bodies [e.g. 1, 2]. Indeed, a wealth of data (imagery, elevations, mineralogy, etc.) gathered by orbital and ground-based robotic probes can be used to compute 3D models that are readily usable to generate virtual environments, that will in turn be used to address geologic questions. Several solutions to visualize and study such 3D data are currently in development like Pro3D [3] or CosmoScoutVR [4].

Here we have set up an integrated set of measurement tools, specifically designed to replicate a "fieldwork experience" in VR. In this case study, we present such innovative and fully-integrated VR tools. They allow the user to fully take advantage of an immersive virtual environment accurately recreating an area centered around the Kimberley outcrop (Gale crater, Mars), explored by the Mars Science Laboratory rover *Curiosity* in 2014. These tools allows users to perform geological characterization, measurements and observations as if they were physically there (Fig. 1).

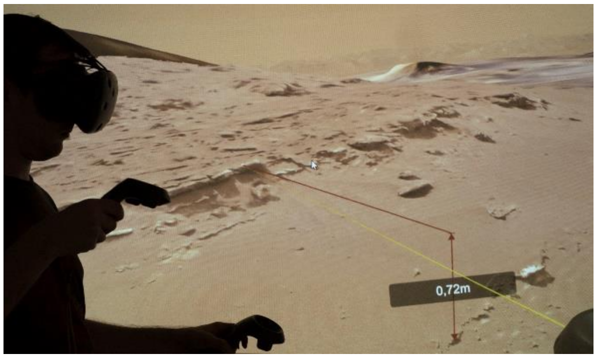

Fig. 1 Illustration of a geologist using Virtual Reality headset and controllers to explore a recreation of the Kimberley outcrop (Gale crater, Mars), and taking measurements using dedicated VR tools.

Entry data and creation of the Virtual Environment: To propose an immersive experience, the virtual environment is generated using a videogame engine [5]. This solution provides a versatile way to integrate, manipulate and interact with large sets of data, those being necessary to recreate an immersive and accurate representation of the actual terrains. This virtual environment is generated from a georeferenced multi-scale set of entry data comprising both orbital-derived and ground-based 3D meshes. Largest-scale orbital models (generated from HiRISE data) are used to visualize the entire study area and to provide a context and background. Closer perspectives are possible using photogrammetric ground-based models (computed from photos taken by the *Curiosity* rover) offering an unprecedented resolution to study at a very fine scale the specificities of the Kimberley outcrop [6].

VR-enabled measurement tools: A set of innovative VR-enabled tools has been designed to provide the users with the possibility to explore and characterize the virtual environment as if they were actually present there. The utilization of these tools tends to replicate various actions and measurements that are classically done on Earth during field campaigns. The user is therefore able to take measurements directly on the virtual terrain using their handhelds controllers to place points on the 3D mesh. These points are used by the VR application to display a wide range of measurements such as distance (either on a fixed axis or freely, Fig. 2a) or angle, but also to calculate strike and dip of a surface using a multi-point best-fit plane (Fig. 2b). Additionally, the use of VR provides enhanced complementary experience to a classical fieldwork. Aside from the fact that the user can go virtually anywhere in the entire virtual environment (including otherwise inaccessible cliffs), we take advantage of the power of this visualization technology to integrate GIS-like features. These functions are used to provide precise position, but also enable advanced features like the ability to quickly and easily switch the basemaps, e.g. from orbital orthoimage to geomorphological map (Fig. 2c), or to reproject actual original photographs taken by the *Curiosity* rover directly onto the 3D terrain (Fig. 2d).

"In situ" measurements at the Kimberley outcrop: These tools are therefore used to reassess the previously studied but still poorly constrained Kimberley Fm., made up of 4 distinct siliciclastic members (Square Top, Dillinger, Mt. Remarkable and Beagle, [e.g. 7]). Using the VR application, we are able to observe and map the contacts between those members from different points of view, and despite the presence of widespread regolith all over the outcrop (yellow lines on Fig. 3). With those new bottom and top limits, we are using our integrated VR tools to perform a serialized measurement of the thickness of the Dillinger member between its lower contact and the reference bed where the Windjana drill hole was performed. These measurements show the presence of a previously unseen but conspicuous lateral variation in the thickness of the Dillinger member, ranging from 55 cm in the northernmost part of the outcrop and up to 85 cm in the southernmost part (green bars on Fig. 3). Going further in the characterization of this interval, we used the best-fit plane tool to compute the strike and dip of the Square Top/Dillinger contact. This led to the characterization of a ~3° dip toward the south, potentially hinting at the presence of a slight paleotopography at the time of deposition.

Summary: The growing use of VR to explore and characterize planetary surfaces is a giant leap toward a better and finer comprehension of their geological features. To that extent, dedicated VR-enabled tools integrated within virtual environments generated using both large-scale orbital and small-scale, high-resolution, ground-derived data, is key to provide an immersive "virtual fieldwork" experience. Using these tools, one is capable to perform geological measurements with unprecedented accuracy and with the ability to freely observe the structures from any point of view, without deformation, which is usually prevented on a traditional computer screen. VR therefore allows us to propose accurate measurements of planetary outcrops, leading to the better understanding of the sedimentary processes.

Acknowledgments: EU H2020 PlanMap project and VR2Planets.

References: [1] McGreevy (1993) in *Virtual Reality*, 163-197. [2] Le Mouélic et al. (2020) *Remote Sensing*, 12(11), 1900. [3] Barnes et al. (2018) *Earth Space*, 5(7), 285-307. [4] Schneegans et al. (2020), Zenodo, http://doi.org/10.5281/zenodo.4288287. [5] Mat et al. (2014), *IOP Conf. Series: Earth and Env. Science* 20, 012037. [6] Caravaca, G. et al. (2020) *Planet Space Sci.*, 182, 104808 [7] Le Deit et al. (2016) *J. Geophys. Res. Planets*, 121, 784-804.

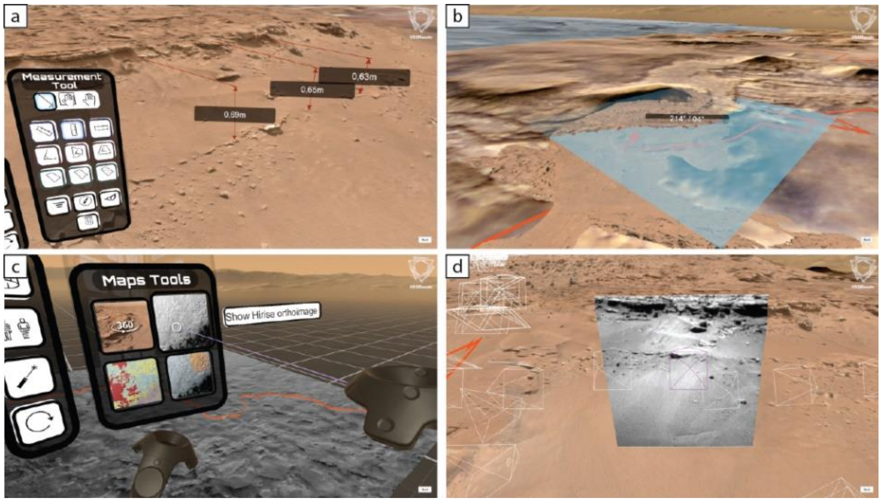

Fig. 2 Illustration of several VR-enabled tools usable in the virtual environment on the Kimberley outcrop. a) Distance measurement; b) Best-fit plane computed using several point to calculate the strike and dip of a given surface; c) GIS-like feature allowing to quickly switch between several basemaps (e.g. geomorphologic map, orthoimage); d) Actual Navcam image taken by *Curiosity* reprojected onto the 3D terrain of the virtual environment.

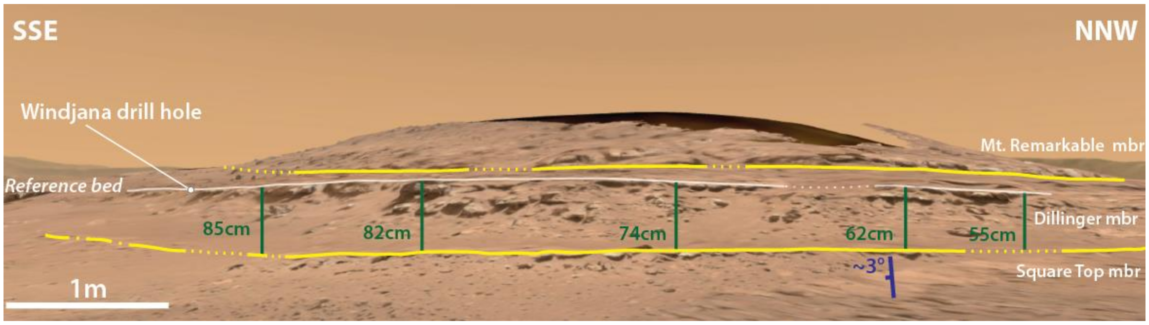

Fig. 3 VR interpreted view of the Kimberley outcrop, highlighting the newly mapped contacts between the Square Top, Dillinger and Mt. Remarkable members (yellow lines, dashed lines denotating a hidden part). Main thickness measurements of the Dillinger member are expressed by green bars, highlighting a lateral variation in thickness of the member. The observed southward dip of the Square Top/Dillinger contact is shown in blue.