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Marion Massé, François Civet

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Using Virtual Reality to replicate “*in situ*” field work on Mars

Caravaca, G.^{1,*}; Le Mouélic, S.¹, Mangold, N.¹, Le Deit, L.¹, Massé, M.¹ & Civet, F.²

¹ UMR 6112 Laboratoire de Planétologie et Géodynamique, Université de Nantes, Université d'Angers,

2 Rue de la Houssinière, 44300 Nantes, France

² VR2Planets, 44322 Nantes, France

* gwenael.caravaca@univ-nantes.fr

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Planetary Geology, the study of planetary surfaces and morphologies of the planets and moons of the solar system, relies on data gathered by robotic probes (orbiters, landers, rovers) sent throughout the system. These data are returned to Earth for analysis and interpretation of the geological properties of the different planetary bodies. However, only one of these planetary bodies has been visited by humankind until now, Earth's Moon (Luna), by 6 manned missions of the Apollo program. This means that exploration and understanding of the other bodies rely on remote data, whose characterization might sometime be tricky, particularly due to the lack of “in-person” approach.

To try and overcome these problematics, the growing use of 3D reconstructions and their integration within Virtual Reality (VR) environments is enabling us to visualize and experience with unprecedented accuracy the geological data returned by probes. This is notably the case with the sedimentary record of the planet Mars, as 3D shape and spatial distribution of the sedimentary structures observed there by the rovers of different missions have critical importance to understand the past environments associated with stable liquid water at the surface.

In this work, we focus on the geological characterization of the Kimberley outcrop in Gale crater, Mars. This outcrop was traversed by the *Curiosity* rover of the Mars Science Laboratory mission in 2014. While a detrital record deposited in a fluvial environment is understood for this outcrop, its stratigraphic relationships within this series and with its immediate to local surroundings are still poorly constrained, highlighting the need for a finer characterization of the sedimentary record.

As part of the European Horizon 2020 project PlanMap, we developed an integrated VR application dedicated to the geological characterization of the Kimberley outcrop on Mars (CARAVACA *et al.*, 2020a). The VR environment (Fig. 1) is based on regional high resolution orbital data and a local photogrammetric Digital Outcrop Model made from *Curiosity* data (CARAVACA *et al.*, 2020b).

The VR application allows to freely roam around the reconstructed outcrop and its vicinity within a ~3x3 km area, observable at various scales (real scale, Fig. 2a; regional scale, Fig. 2b). It features a complete set of measurement tools (with accuracy at the mm-scale) including distance (Fig. 2a), angles and strike/dip (Fig. 2b) measurements. The application also allows to switch basemaps between greyscale and colour orthoimages, geomorphological map, or a 360 panorama (Fig. 2c) in a GIS-like manner to access various information. Finally, the user has also the ability to reproject actual images taken by the various cameras onboard the rover on the 3D mesh from their exact point of view (Fig. 2d).

These VR tools represent first steps toward a complete “field-trip” to a remote and otherwise inaccessible Martian geological outcrop, in order to explore and characterize its sedimentary record in an accurate and efficient way.

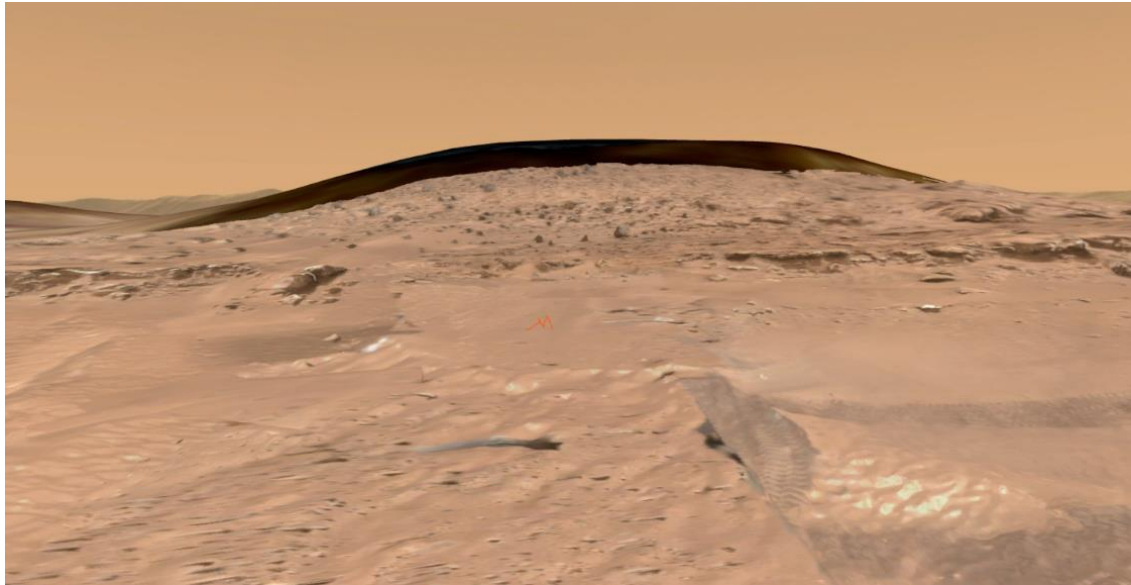


Figure 1: View of the VR environment toward the Kimberley outcrop (Gale crater, Mars), reconstructed from regional orbital data and a photogrammetric Digital Outcrop Model based on Curiosity rover images (visible on Sketchfab at: <https://skfb.ly/6RXJD>).

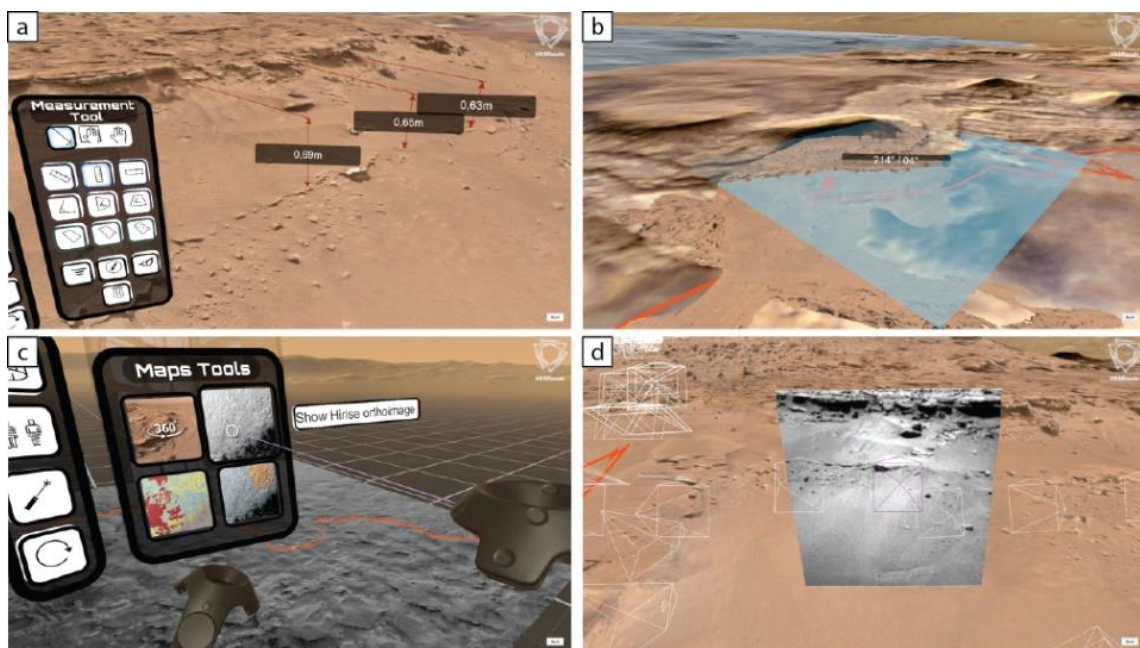


Figure 2. In-application views of the various measurement tools. a) Example of vertical distance measurements. b) Strike and dip measurement using the best-fit plane computation tool. c) Map selection tool, with greyscale and colour orthoimages, geomorphological map and 360 panorama. d) Example of actual Navcam image taken by the rover Curiosity reprojected on the 3D DOM from its original point of view.

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