**3D geologic model of the shallow subsurface of Chang'E 3 landing site (Sinus Iridum, Moon)**

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**Introduction:** The mission of the PLANMAP project[1] is to foster the production and the publishing of high-quality planetary mapping products, alongside with exploring new and modern approaches for supporting the geological investigation, especially by using three-dimensional geological modelling to study the subsurface of planetary surfaces.

Three-dimensional models serve two main purposes. The first one is to visualize the available data in 3D which allows easy inspection and a full understanding of the geometric arrangement of the data themselves. The second objective is to perform predictions about the placement and the attitude of underground geological structures, namely contacts (either planar or folded) and faults [1]–[3].

Planetary sciences are often characterized by scarcity of data that can be used to constraint such structures, resulting in strong limitations, hence the application of these techniques is poorly documented and explored within the community.

In this work, we provide a highly documented and fully reproducible example of predictive geological modelling applied to the planetary case of the Chang'e 3 GPR data on the Moon.

**Geologic context:** The Chinese CNSA Chang'e 3 mission landed in Sinus Iridum, in the northwestern margin of Mare Imbrium at 44.12°N, 19.51°W (Xiao et al., 2015) on 14th December 2013, on the rim of a 450-meter crater. Analysis of GPR data revealed a multi-layered subsurface characterized by evident reflectors up to 400 m. Deeper layers, resolved by Channel 1 of the GPR system onboard the rover were the object of previous 3D reconstruction [4]. In this work, we analyze and create a geological model of shallower horizons, detected by channel B of the GPR.

**Data and Methods:** The data used for this work are already published [5], hence are freely available within the cited paper. In addition, LROC NAC imagery and DEM[2] were used to constraint the location and elevation of the model.

The data processing is performed only with open source tools to allow complete reproducibility of the results. The python notebooks employed are freely available at https://doi.org/10.5281/zenodo.4055213. Python modules that were used and a detailed description of the methodology can be found in the 6.2 Project Deliverable of the PLANMAP project[3].

The processing comprises the following steps:

- Importing and digitizing Chang'e 3 already-published GPR data, to transform paper's pictures into a numerical representation of the horizons.
- Data merging with existing DEM by assigning elevation to the imported dataset.
- Creation of geometric primitives to generate a visualization of the imported horizons in three dimensions.
- Surfaces fitting and interpolation with planar models, which were chosen in relation to the available geometrical constraints (Figure 1).
- Generation of derived products as thickness and slope maps.
- Prediction of the intersection of the modelled surface in the nearby crater inner slope (Figure 2).

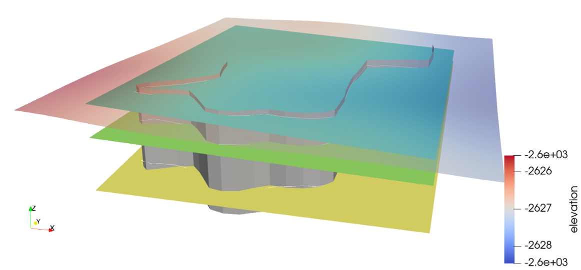


Figure 1. The resulting 3D dataset from the processing of the radargram available in [5]. The radargram is textured as a curved surface corresponding to the rover's traverse.

**Results and Conclusions:** The developed methods allowed a 3D reconstruction of 2B GPR channel by using open source software only. This approach makes the results completely reproducible by anyone without the use of proprietary software.

The developed python notebooks can be used as a teaching and introductory material for learning 3D modelling and are fully documented in PLANMAP's deliverable 6.2[3].

[1] planmap.eu
[2]http://wms.lroc.asu.edu/lroc/view_rdr_product/NAC_DTM_CHANGE3
[3] https://wiki.planmap.eu/display/public/D6.2-public

This work demonstrates the use of 3D modelling to perform prediction on the probable outcropping geometry of observed subsurface layering in the inner SE slope of the nearby crater. Our analysis constitutes a good example of applying 3D modelling in planetary sciences and highlights several important limitations of common planetary cases:

- The availability of real subsurface data is the greatest factor to consider. Indeed just a minor number of instruments onboard exploration rovers/spacecraft are designed to provide information on the subsurface.
- The scarcity of data available for reconstruction must be taken into account by wisely choosing the modelling strategy and the adaptability of modelling functions.
- The limited amount of data and the simple depositional geometries, make it possible to perform the modelling without advanced software, granting complete and detailed control of the reconstruction process.
- The results allowed us to predict the possible outcropping layers within the nearby crater (Figure 2).

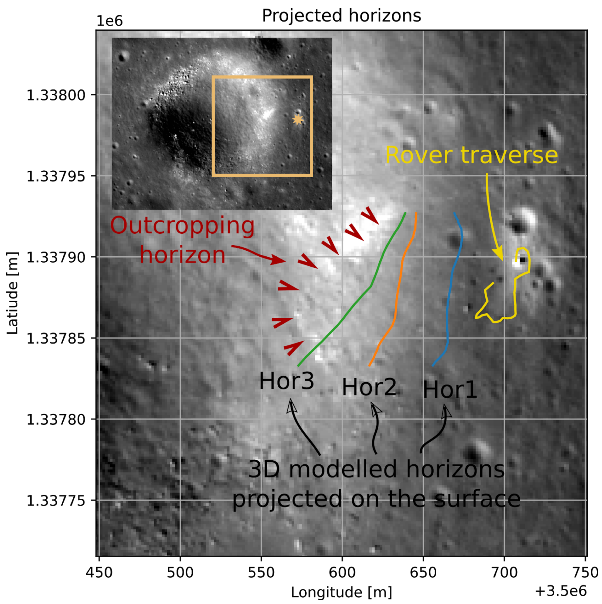


Figure 2. The horizons recognized onto the radargram are fitted with planar surfaces which intersection with a DTM can be shown as a line on the map. Notice that the distance over which this prediction is made, in respect to the dimensions of the rover traverse, is relevant and some imprecision must be expected. Nevertheless, the third and deeper horizon seems to show a good correlation with the highlighted (red arrows) surface features which can represent the exhumed layer and thus show a sounding stratigraphic correlation with the GPR sections

Thanks to 3D geological modelling we demonstrate that at least one of observed horizons can be also identified within the nearby crater, potentially providing a ground-truth constraint to validate the geological model.

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