Geological modeling on-the-field: Toward a digital field book

Ph.D. thesis
Partnership BRGM-Inria

Ph.D. advisors: Adrien Bousseau, Guillaume Cordonnier (Inria, team GraphDeco), Simon Lopez (BRGM)

Place: Centre Inria d'Université Côte d'Azur

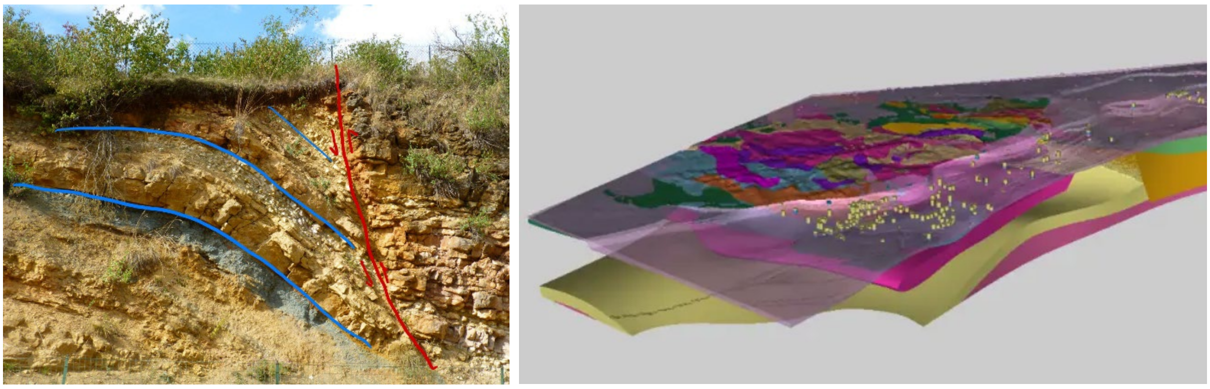

Figure 1. Geologists sketch notes about subsoils onsite (left). These notes are subsequently used to model the subsoil in 3D (right, @BRGM).

Context and motivation

One of the fundamental challenges of geology is to understand the soil, the subsoil and its history, which makes it of great importance to society. Mapping the different types of underground rocks is key to an optimal access to water and natural resources. Knowledge of soils and their chemical composition enables us to ensure the viability of certain plant species, and thus protect biodiversity. Finally, the study of the physics and history of landscapes improves our understanding of risks, enabling us to anticipate and prevent landslides, floods, coastal erosion, etc.

This knowledge is first acquired in the field. Geologists observe the geometry and composition of the subsoil where rock structures outcrop. They record their observations in a field notebook with sketches, annotations, and various notes and measurements (Rudwick, 1976), as illustrated in Figure 1a. This information is subsequently analyzed and used to draw up geological maps, or currently 3D models of the subsoil structure (Figure 1b). Developing geological modeling tools is a specialty of the industrial partner BRGM through the Geomod program (BRGM, 2023).

Challenges and contributions

We propose to unify the two stages of geological mapping – field notes and geological modeling – through a *digital field notebook*. The geologists will sketch on a tablet, a tool close to their habits with the paper notebook (Amorim, 2017), but which also gives them access to the entire geological context of the study area (general or local data from drilling, previous modeling, ...). Therefore, they will be able to immediately propose a new 3D geological model, correct any inaccuracies in previous models, use the available context to refine their interpretation or move the time cursor to evaluate different scenarios in the history of the landscape's evolution.

Finally, developing such a tool will enable us to narrow the gap between the rich corpus of geological visual language, and what is representable by existing modeling tools.

This project presents several challenges, which will lead to as many contributions. Firstly, we need to be able to interactively recast a 2D image of the landscape onto the 3D topography of the terrain, so that the expert's annotations can then be reprojected onto the geological model. Secondly, we need to offer a sketch-based modeling tool that is both fast (enabling instant feedback to the geologist) and geologically consistent – which will be ensured by the use of geometric and mechanical rules combined with geological knowledge. Finally, we will need to couple this model with an interactive simulation tool, enabling users to go back in geological time and study possible past or future evolutions of the subsoil and its resources.

Methodology

- *Axis 1: Registration of a sketch on a DEM*

In the first part of the project, we will register the sketch on the DEM (Digital Elevation Model, or heightfield). The sketch being overlaid on a picture we will explore different techniques for the automatic registration of photographs on a DEM. The problem is to determine the properties of the camera (position on the DEM, orientation) used for the shot.
Assuming that a first approximation is known thanks to the GPS and gyroscope embedded in the tablet, we will use deep learning to refine the parameters (Čadík et al., 2018; Brejcha et al., 2020). We will use different possibilities: learning on a corpus of landscape photography, a differentiable rendering of the DEM (Vicini et al., 2022), or going through an intermediate "latent" representation, as often used in learning, for example, to estimate the pose of 3D objects (Labbé et al., 2022). As this part is critical for the rest of the project, we plan to simplify its execution and increase its accuracy by enabling the geologist to manually annotate correspondences between the photo and the terrain model.

- *Axis 2: From sketch to 3D model*

In the second part, we will use the geologist's sketches and annotations to establish and refine a geological 3D model of the subsurface. We will propose a suitable data structure, based on a combination of implicit surfaces that are particularly effective for modeling objects made of a superposition of different layers (Buffet *et al.*, 2019). At the level of outcrop zones documented by the geologist, it will be easy to use sketches and annotations to parameterize these layers. On the other hand, interpolation between the visible parts and the pre-established parts of the geological model (Renaudeau, 2019, Pizzella *et al.*, 2021) will lead us to propose new techniques based on geometric constraints (e.g., surface developability (Fondevilla *et al.*, 2017)), physical constraints (incompressibility, rigidity...) or temporal constraints (geological events, erosion, deposition, faults... (Cordonnier *et al.*, 2017)). We will also use deep learning tools (Hillier *et al.*, 2021) to speed up geometric calculations.

- *Axis 3: Geological simulation*

Finally, the third part of this thesis will focus on adding a temporal axis to the subsurface reconstruction process, to enable the geologist to test the compatibility of his interpretation with several possible pasts. One solution would be to develop a complete simulator of the various geological events, but such an approach is often very costly in terms of computing time and resources, which is incompatible with the embedded and interactive purpose of the digital field notebook. Instead, we will develop a method based on a geometric approximation of the physical constraints established in part 2, which would enable the geologist to navigate efficiently through the geological periods (Garcia *et al.* 2018) and test different interpretations or parameters.

Validation and impact

The subsequent steps of the project will be validated, first locally on simplified use cases and synthetic landscapes. This will greatly reduce the development cycle during the prototyping period. The demonstrator will then be validated in the field, with expert geologists, in some of the region's massifs.

As the field notebook has no digital equivalent, the proposed tool would profoundly change the practice of geology in the field (confrontation of available data and knowledge directly with field observations, and reduction of interpretation bias in the field). If trials are conclusive, it could rapidly be adopted by the whole community.

References

Amorim, R.M., 2017. 3D Geological Modeling from Concept Sketches and Annotations. University of Calgary.

Buffet T., Rohmer D., Barthe L., Boissieux L., Cani M.-P., 2019 Implicit Untangling: A Robust Solution for Modeling Layered Clothing. ACM Transactions on Graphics, 2019, Proc. ACM SIGGRAPH, 38 (4), Article No. 120:1-12.

Brejcha, J., Lukáč, M., Hold-Geoffroy, Y., Wang, O., Čadík, M., 2020. LandscapeAR: Large Scale Outdoor Augmented Reality by Matching Photographs with Terrain Models Using Learned Descriptors, in: Vedaldi, A., Bischof, H., Brox, T., Frahm, J.-M. (Eds.), Computer Vision – ECCV 2020, Lecture Notes in Computer Science. Springer International Publishing, Cham, pp. 295–312.

BRGM, 2023. GeoModeller : the 3D geological modelling software, https://www.brgm.fr/en/software/geomodeller-3d-geological-modelling-software

Čadík, M., Sýkora, D., Lee, S., 2018. Automated outdoor depth-map generation and alignment. Comput. Graph. 74, 109–118

Fondevilla, A., Bousseau, A., Rohmer, D., Hahmann, S., Cani, M.-P., 2017. Patterns from Photograph: Reverse-Engineering Developable Products. In Computers & Graphics.

Garcia M., Cani M.-P., Ronfard R., Gout C., Perrenoud C., 2018, Automatic Generation of Geological Stories from a Single Sketch, Expressive '18 - The Joint Symposium on Computational Aesthetics and Sketch Based Interfaces and Modeling and Non-Photorealistic Animation and Rendering

Hillier, M., Wellmann, F., Brodaric, B., Kemp, E. de, Schetselaar, E., 2021. Three-Dimensional Structural Geological Modeling Using Graph Neural Networks. Math. Geosci.

Labbé Y., Manuelli L., Mousavian A., TyreeA., Birchfield S., Tremblay J., Carpentier J., Aubry M., Fox D., Sivic J, MegaPose: 6D Pose Estimation of Novel Objects via Render & Compare, CoRL 2022.

Pizzella, L., Alais, R., Lopez, S., Freulon, X., Rivoirard, J., 2021. Taking Better Advantage of Fold Axis Data to Characterize Anisotropy of Complex Folded Structures in the Implicit Modeling Framework. Math. Geosci.

Renaudeau, J., 2019. Continuous formulation of implicit structural modeling discretized with mesh reduction methods. Université de Lorraine.

Vicini D., Speierer S., Jakob W. 2022. Differentiable Signed Distance Function Rendering. In Transactions on Graphics (Proceedings of SIGGRAPH) 41(4). 125:1–125:18.

Yuan X., Braun J., Guerit L., Rouby R., Cordonnier G. A new efficient method to solve the stream power law model taking into account sediment deposition. Journal of Geophysical Research: Earth Surface, 2019, 124 (6), pp.1346-1365.