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Restoring complex folded geometries in 3D using paleomagnetic vectors; a new tool to validate underground reconstructions

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Three-dimensional reconstructions of the underground involve the integration of discrete and heterogeneous datasets and have significant socio- economic implications. The problem arises when there are limited data to build 3D models or when deformation processes are complex; these reasons inspired the development of restoration methods to validate subsurface reconstructions. The restoration is based on the application of simple geometric (or mechanic) laws that help reduce the uncertainty and increase geomodel accuracy. Apart from mechanical approaches, geometric methods are based on the initial assumption of global conservation of volume during deformation in addition to the paleo-horizontality of the stratigraphic horizons in the undeformed stage.

The problem is that the bedding plane cannot be used as a three-dimensional reference system, because a single vector defines it and additional constraints are required. This is particularly important when dealing with complex structures, such as non-cylindrical structures and the superposition of non-coaxial geometries. In this context, paleomagnetism (known in both the deformed and undeformed stages) can contribute to building a more complete reference system and to reducing the uncertainty in restoration processes. The use of paleomagnetism in restoration tools was suggested in the early 1990's and only a few quantitative map-view applications have been developed since then.

In this contribution, we introduce the two first surface restoration methods that use paleomagnetic vectors as a primary reference. The first one is a simple geometric approach based on the piecewise restoration of a triangulated surface into which paleomagnetic variables can be easily incorporated. It is valid for complexly folded structures. The surface is modelled by a mesh and the method starts from a pin-element. Triangles are laid flat and then fitted together to minimize distances between common vertices and paleomagnetic error. However, this first approach is very sensitive to the density and type of triangulation of the mesh, as well as the location of the pin-element. The second one is based on a parametric approach (gOcad code), whereby a curvilinear coordinate system is computed on the folded surface by numerical optimization. We use paleomagnetic data to define constraints for the computation of this frame, which significantly increases the robustness of the restoration method.

We assess the accuracy of the restoration algorithms using computer and analogue models. We have developed a new methodology to simulate the paleomagnetic vectors in the models and we are able to obtain reliable 3D images of them under a CT scan. These models allow us to set up a known initial undeformed surface (a horizontal horizon and its magnetic reference). We then perform a forward deformation to obtain a controlled deformed surface. Subsequently, we apply a restoration method to that deformed surface, and compare the result from the restored state with the initial undeformed surface. With an ideal restoration method the two states should match perfectly and, therefore, we can quantify the quality of the restoration by measuring the differences between them.

Future work on the method includes the restoration of volumes (now only horizons) and faults (discontinuous deformation). The application to real case studies from the Pyrenean External Sierras, apart from reliable geometric reconstructions of the structures, has to consider the distribution of vectors, which is limited to the surface although it is densely sampled, and the quality, reliability and resolution of real datasets.