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How 3D implicit Geometric Modelling Helps To Understand Geology: The 3DGeoModeller Methodology

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ABSTRACT : 3D geometric modelling is a powerful tool to better understand geology. It allows to check and validate the consistency of the separate 1D or 2D data interpretations. Building a 3D model is also a way to share and communicate a geological view. Futhermore, a consistent 3D geometric model is essential for post-process computations that need an accurate and coherent geometry of geological bodies. An original methodology has been developed in BRGM (French Geological Survey) to interpolate at the same time geological contacts locations and dips of the formations. The model is calculated using an implicit 3D potential field or multi-potential fields, depending on the geological context and complexity. This method is based on a geological pile containing the geological history of the area and the relationships between geological bodies. The geological pile allows automatic computation of intersections and volume reconstruction. By using these tools, the geologist focuses on geological issues and easily tests different interpretations. This methodology has been applied to various geological contexts. The Sapey-Orgère tunnel case-study (Lyon-Turin high-speed train project, Alps) is presented to illustrate the 3D model realization and valorisation.

KEYWORDS : 3D, geological modelling, geometric modelling, potential field, 3DGeoModeller.

1. 3D geometric modelling: A tool for geology

The usefulness of 3D geometric modelling to better understand geology is well established (Houlding, 1994, Wijns et al., 2003, Wu et al., 2005). Modelling consists in the ability of inferring a representation of the reality even where no data are available. This representation can be the final goal of modelling or the geological model can be used to compute simulations to quantify physical processes. In both cases, knowing the geological formation at any place of 3D space is fundamental.

Available tools for 3D modelling are mostly dedicated to petroleum industry by dealing with 3D seismic data. In classical geology issues, available data are sparse and nothing is known between often over sampled locations such as the geological map, cross-sections or bore-holes. Furthermore, the interpolation methods classically used model separate horizons but not intrinsic 3D volumes. Where geology is cylindrical, 2D methods are sufficient to construct horizons honouring cross-sections (Galera et al., 2003) but such approach is restrictive.

Original methods have been developed in BRGM – the French Geological Survey – to answer to the question “How to infer the 3D geometry of geological bodies known by sparse and irregularly located data?” These tools are dedicated to geologists wanting to use the geometric knowledge coming from the geological map, cross-sections and bore-holes to test their geological interpretations by building a 3D model. In that scope, the following work has already been successfully applied to orogenic, basin and mining domains (Courrioux et al., 2001, Genter et al., 2004, Martelet et al., 2004, Maxelon et al., 2005, McInerney et al., 2005).

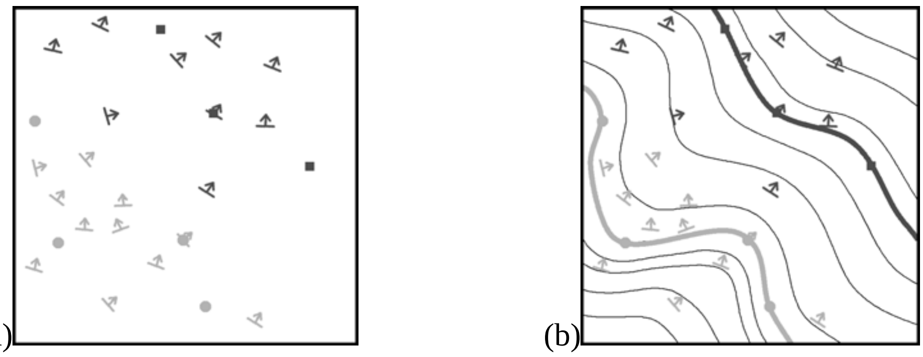
Taking into account both contact locations and orientation data, coherent 3D models are constructed using an implicit scalar method (Lajaunie et al., 1997). It interpolates the data and a geological pile automatically drives the relationships between geological formation, making the model easy to refine and to update.

2. Interpolation method using implicit 3D potential field

Geologists build maps and cross-sections to describe the geometry of their field. These interpretations are often based on data coming from field observations, boreholes and seismic profiles. 3D modelling needs to use these 1D and 2D data and interpretations but to construct the 3D model one needs to fill the gaps between the data. The major feature of this original interpolation method is that the 3D geological space is described through a potential field formulation in which geological boundaries are iso-potential surfaces and their dips are represented by the gradients of the potential.

The potential field method leads to an interpolation available in the whole 3D space of the area. It considers the limits between geological bodies as isopotential surfaces. This method needs the position of the interfaces between geological bodies to be known at some place i.e. the ones given by boreholes, map and sections. It also requires orientation vectors that represent the tangential plane of isopotential surfaces and their polarity, in a geological language these are azimuths, dips and polarities of the geological structures commonly measured in the field. Dip measurements are not necessarily located on the geological interfaces. They can represent stratifications or foliations related to the contacts. Fig.1 shows this principle in 2 dimensions. When the potential field is calculated, the potential value is known for every point at 3D space. A range of potential values defines a geological body. On one hand, 3D points associated to the limits values belong to the interfaces. On the other hand, 3D points corresponding to values within the range are contained in the body.

This geostatistical interpolation allows to build 3D model of sub-parallel geological interfaces. Nevertheless, generalisation to more complex geometry has been achieved.

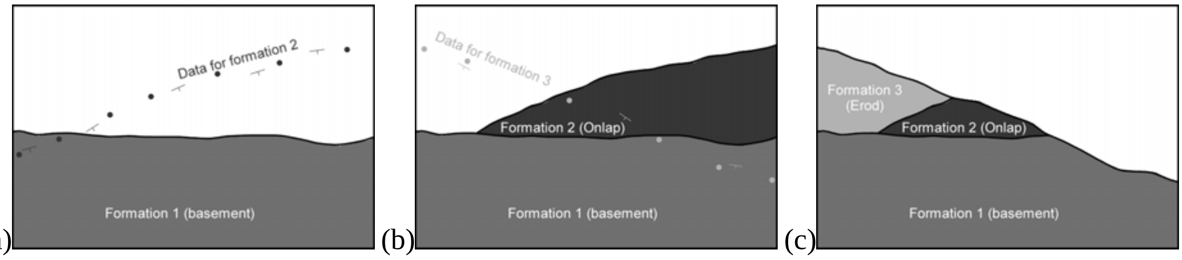


(a) (b)

Fig. 1. Principle in 2-Dimensions of the geostatistical interpolation using the potential field method. (a) A geological body observed by the locations of its contacts (squares points for one side, circles points for the other side) and dip measurements. (b) The geological body modelled by potential field method. Thick curves represent its limits. Thin curves represent foliations trajectories inside and outside the body. The isovalues honour both interface points and foliation vectors.

3. Generalisation of the interpolation method with multiple potentials

According to their definition, iso-surfaces coming from a single potential field can not be secant or have common points. Two adjacent interfaces contained in a given potential have a sub-parallel behaviour (Fig.1b). Except in some sedimentary cases, a geological body is not present all over the studied area, it often settles and stops on (Onlap relation) or erodes (Erod relation) another. These relations are achieved by associating each step of the geological history to a potential field. Each potential field has a behaviour parameter (Erod or Onlap) which controls its relation with older geological bodies i.e. potential fields already interpolated (Fig.2).



(a) (b) (c)

Fig. 2. Multipotential fields allow Onlap and Erod relations between interfaces. (a) Interpolated formation 1 (basement). Data for potential field of formation 2 in black. (b) Formation 2 interpolated with Onlap relation. Data for potential field of formation 3 in light grey. (c) Formation 3 interpolated with Erod relation.

Let's call the chronological succession of the formations and their relationships the geological pile. Concerning Fig.2, each geological formation defines one potential field. The corresponding geological pile is, from the bottom to the top (i.e. from the first deposition to the last) : Formation 1 (Onlap), Formation 2 (Onlap), Formation 3 (Erod). As soon as the geological pile is defined, it contains the geological history, i.e. a geological knowledge independent of the data. Then, intersections between geological bodies are automatically governed by the geological pile. By using this tool, geologist focuses on geological interpretation without managing intersections purposes.
The methodology described above has been applied to various geological case-studies in different geological contexts such as basin, orogenic or urban geology. A software, the 3DGeoModeller has been developed in order to build 3D geometric models from maps, cross-sections, boreholes, etc. This software, providing a convivial Graphic User Interface, is used by geologists to test and refine their interpretations and finally to construct their 3D models. Import/export facilities allows to load data and to use 3D models for post-processes.

4. The Sapey-Orgère tunnel (Lyon-Turin high-speed train project, Alps)

The Lyon-Turin high-speed train railroad project will cross the Alps along a 60 km long tunnel. The main difficulty for the tunneller is to assess the geological formation that will be encountered. A 6 x 10 x 4 km 3D geometric model has been built in the Sapey-Orgère area, the most complex part of the tunnel line (Fig.3). 3D volumes of each geological body have been modelled using the structural map, interpreted drill holes and positions and dip measurements data acquired during complementary field works. Data have been interpolated the by the potential fields method. The model is represented using a marching-cube algorithm. As the geological formations are known at any place of the 3D geometric model, any section can be easily derived. Typical sections along the tunnel line have been constructed to quantify the location of geological bodies (Fig.3a). Their position along the tunnel is strongly related to the main fold axis of the zone. The uncertainties on the geological interpretation along the tunnel line have been estimated by varying the dips of the folded structures (Fig.3b).

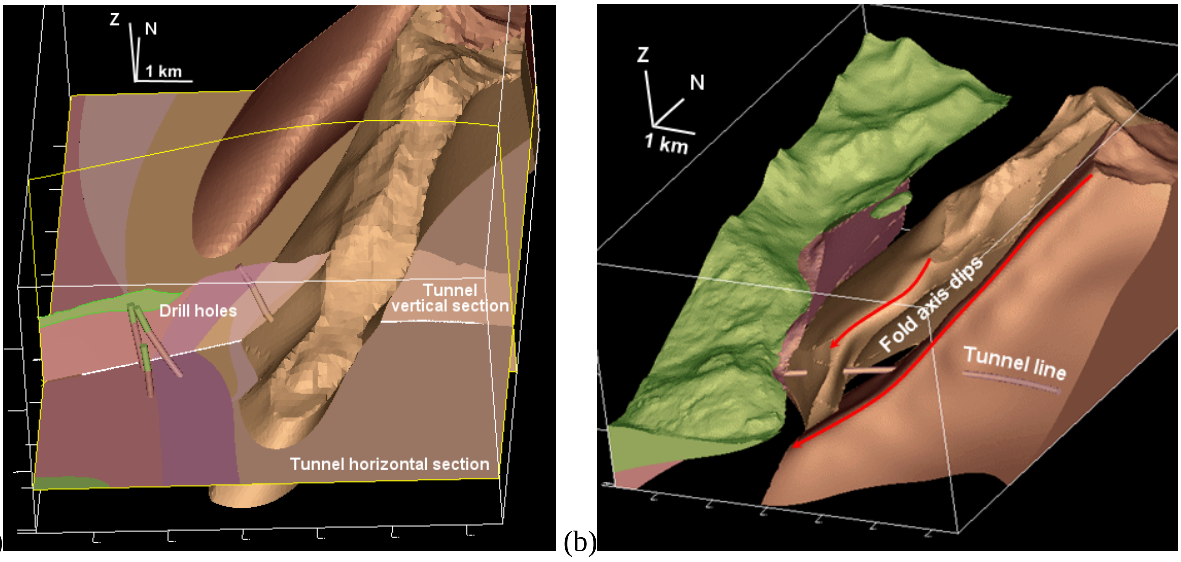
(a) (b)


Fig. 3. 3D Model of the Sapey-Orgère zone (Alps). (a) View from South. Plane and curved sections along the tunnel are derived from the model. (b) View from S-E. Uncertainties along the tunnel are inferred by changing the interpretation of fold axis dips.

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