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3D modeling using geognostic data: The case of the low valley of Foglia river (Italy)

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Abstract

In specific geological contexts, such as alluvial environments, the lithology is highly heterogeneous and laterally variable. As a result, a large number of lithological data are collected (generally random and under sampled) for stratigraphic reconstruction.

The integrated management of geo-lithologic data causes major methodological problems, because data obtained from geognostic investigations have to be normalized and correlated. Data are often affected by their degree of precision, a detail depending on the investigation technique and on the geologist's interpretation.

This paper presents a methodological approach to organizing, integrating, and interpolating subsoil, mechanical (boreholes, penetration tests), and geophysical (seismic profiles, resistivity sounding) investigations for the construction of a three-dimensional geological model supported by geographical information systems and geostatistics.

A practical application concerning the lower Foglia river alluvial deposits (Northern Marche, Italy) was carried out to investigate the geometry of these sedimentary bodies.

This integrated approach offers many advantages for the understanding and in-depth visualization of the geometry of the deposits. Moreover, it allows for the acquisition of qualitative and quantitative information about hydrogeological settings, which is useful for water resources exploitation and protection.

The achieved goals are the design of a data management workflow for geo-lithological data, the construction of a three-dimensional geological model of the lower Foglia river alluvial plain, a comparison between the geological sections obtained from the model and those made in a traditional manual fashion, and, in addition, new stratigraphic and hydrogeological considerations about the study area.

Keywords: Multi-source data validation; Data management workflow; GIS; Geostatistics; 3D geological modeling

1. Introduction

The main research purpose of this project is the development of methodologies and techniques for geological data processing in order to obtain new information. The resulting data processing techniques and methodologies are highly strategic and can provide very useful information for reconstructing the stratigraphic context and the sedimentological setting of the target area.

In the past, geological data were represented only on paper maps or using sections. Today, relational data base management system (RDMS), geographic

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information system (GIS), and three-dimensional (3D) modeling are the most common tools applied to store, elaborate, query, analyze, and implement geological data.

Each of these tools has a limit. The main RDMS limit is that the processed results are output as a dataset only, useful for a statistical and analytical approach, but without geographic information or spatial relations. The distinctive features of a geological GIS are

- visualization of which geognostic data fulfill the conditions required (e.g. which boreholes have substrata deeper than 35 m, which investigation points present a gravel thickness greater than 5 m, etc.);
- elaboration of spatial analysis or 2.5D views using specific tools.

Such elaborations, despite being useful and interesting, do not provide new information about the deposit structure. It is very difficult to imagine the deposit assessment, lateral distribution and continuity, thickness and eteropic contacts using contour maps and geological sections, particularly if we are studying a specific geological context such as alluvial plains.

For a more integrated approach towards a realistic geological representation, digital models were developed over the last years. 3D models can represent geological structures more accurately (Jones, 1989). Recently developed programs offer different approaches for data implementation, allowing the user to collect more information. The introduction of 3D models considerably increases our ability to analyze the deposit assessment and to obtain new and detailed spatially reconstructed stratigraphic information.

Requicha (1980) identified six schemes to define methods representing rigid solids. Three of these schemes apply to the construction of geometric primitives, and the remaining three fit the construction of geological models (Jones, 1989).

D'Agnese et al. (1997) present two main schemes for 3D spatial representations similar to Requicha's, but more detailed: the volume or "voxel" representation methods (evolution of 2D raster representation, or grid) and the 3D surface representation methods (equivalent to a vector-based GIS approach). Voxel techniques provide opportunities for continuously displaying varying phenomena (Turner, 2000) and they are largely diffused in GIS products. However, voxel representation requires a very large data storage capacity; in fact, a volume represented by 100 rows by 100 columns by 100 layers requires 1,000,000 voxels. 3D surface representation methods incorporate simple polygon meshes and linear interpolations to define surfaces and geological features (boundary representation methods, Mallet 1988, 1991; Houlding, 1991) and are less widely used in commercial GIS products.

A 3D model can be built using two different approaches.

The first approach is based on "solid modeling", a tool for constructing 3D models of geological structures (Bak and Mill, 1989; Bayer and Dooley, 1990; de Kemp, 2000; De Donatis et al., 2002; Fisher and Wales, 1990; Galera et al., 2003; Gjoystdal et al., 1985; Jones and Wright, 1993; Tanner et al., 2003). The most popular method used in building the solid model is defined by representing the outer surface of the solid ("boundary representation") by a collection of individual faces. The second approach to build a 3D model is based on "geostatistical modeling" (Poeter and Mckenna, 1995; Nathanail and Rosenbaum, 1998; Wingle et al., 1999; Marinoni, 2003; Regli et al., 2004). 3D geostatistical analysis uses volume representation methods (voxels). The 3D interpolation randomly converts sampled data to volume data. It must be noticed that the interpolation methods are not physical modeling tools, for they do not have direct correlations with real-world physical processes.

We present an integrated approach with these tools to elaborate lithologic data derived from subsoil investigations, showing step by step the data management workflow designed to collect data, integrate different data qualities, store them in a geodatabase, and construct a 3D geological model applying geostatistics. The reconstruction of alluvial deposits of the lower Foglia river valley is presented as an application of this method.

2. Geological setting

The Foglia river lower alluvial plain (Fig. 1) is situated within the Municipality of Pesaro (Italy). Three orders of terraces beyond the present alluvial deposits can be identified. The topographically higher terrace (T2) is visible only in some reduced and isolated edges on the left side of the river. The T3 terrace is primarily preserved on the right-hand side and it is laterally in contact with wide detrital fans. The T4 terrace was a floodplain before the construction of the embankment that begins about