3D presentation of spatial geological data: Examples from Crete

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Emmanouil Manoutsoglou
Technical University of Crete

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E. Manutsoglu
Department of Mineral Resources Engineering, Technical University of Crete, Hania, Greece

E. Spyridonos
Department of Dynamic, Tectonic and Applied Geology, National and Kapodistrian University of Athens, Greece

ABSTRACT

The method of digital 3D modeling is demonstrated using three examples of geological interest, on the island of Crete. The geological map of the Samaria gorge is revised, after transferring the existing geological map and new field data to a 3D model. The 3D pattern of tectonic lineaments of the Imbros gorge is extracted and the orthophoto maps of the Kourtaliotiko Gorge are overlain on the DTM of the region.

1. INTRODUCTION

General and thematic cartography, constitutes the basic tool for the earth science specialists. While, however, the object of study -the Earth- is three-dimensional, the maps have been developed on a two dimensional media, the paper. In the last years, the development of digital computer technology and virtual reality techniques opened new fields for processing and presenting spatial earth-related data, by constructing three-dimensional digital models. Such models can form the core of information system with widest applications, for research as well as for practical applications.

Most of the data needed for geological mapping are of geometrical type (strike, dip), and they are collected by field observations and measurements. For the geometrical simulation of geological phenomena, the conceptual geological model is implemented into a three dimensional digital geometrical model. The primary data collection at the field follows the principles of the geological mapping. These data, supplemented by all other data available for the region under study, are transferred to the virtual digital space by applying simple geometrical rules.

Three-dimensional geological models provide the possibility to present specialized scientific knowledge in a understandable way, to groups of users with different scientific background, but can also stir the interest of the public.

In this work we demonstrate three applications of the 3D digital modeling approach of geological phenomena: a) geological mapping, b) 3D patterns of tectonic lineaments for tectonic analysis and c) verification of an existing geological map by overlaying of orhtophotomaps on a digital terrain model.

2. METHODOLOGY

Computerized three-dimensional geological modeling evolved in the mining community in the late sixties. The availability of computers allowed geologists to build digital representations of the deposit geometry and the spatial distribution of ore grades. The interactive CAD environment (Goebl, 1992) soon became the platform to build up packages incorporating geometrical modeling, property modeling, mine design and groundwater modeling. A comprehensive overview of the capabilities of state-of-the-art systems is provided in (Houlding, 1994). The addition of visualizing software to the suite of design tools allows geologists to animate their models or inspect them by means of virtual flying-through.

In our case studies the integrated geo-scientific software package SURPAC2000 by

Surpac Software International Pty. Ltd. (SSI) of Perth, Western Australia (1995) has been used. It offers 3D-CAD modeling techniques and GIS functionality. This package uses real-world co-ordinates, which enabled us to combine different kinds of data such as maps of different scales, photomaps, field data and geological sections.

3. GEOLOGICAL SETTING

The island of Crete is located north of the Hellenic trench. The geological framework consists largely of nappes of contrasting lithologies and metamorphism that were stacked southwards during an Oligocene to early Miocene N-S compression. Most of the whole nappe stack of continental Greece is recognized in Crete. It has however a reduced thickness and more important shortening. The nappes are stacked from top to bottom, *i.e.* from the most internal to external units in the following order: Asterousia nappe, Miamou nappe, Arvi nappe, Pindos-Ethia nappe, Tripolitza nappe, Phyllite nappe and Trypali nappe. The Plattenkalk Group represents the lowermost known tectonic unit beneath the nappe pile of Crete and their formation has been involved in the tectonometamorphic process during the Oligocene-Miocene (Manutsoglu *et al.*, 1999).

4. CASE STUDIES

4.1 Modeling of the Samaria Gorge

Within the study area (Fig. 1), the Plattenkalk Group forms an E-NE/W-SW striking, northeasterly dipping anticline. The amplitude of this large-scale structure exceeds 1000 m. Its half wavelength is about 6000 m. Rocks of the Trypali nappe, where the doline of the Omalos plane lies, tectonically overlay most parts of its northwestern limp. The core of the anticline is built up of stromatolithic dolomites and calcitic marbles, which occur from 700 m to an altitude of more than 1000 m. This area is the strongest exhumed part of the whole island. The transition between the carbonatic and the siliciclastic rocks of the 'Gigilos beds' is marked by a sharp, brittle tectonic contact, which can be traced over several kilometers both in the field and from satellite imagery. The southern limp of this anticline is cut by a number of gorges with several kilometres length (*e.g.* the gorges of Samaria, Klados, Ag. Irini) (Manutsoglu *et al.*, 1999, 2001). The formation of this large-scale structure is reflected by a great number of mesoscopic structures. The main directions of those inter-formations defined the scattered allocation of the aquifers.

After a detailed research concerning the stratigraphic and the tectonic evolution of the geological formations of the Southwestern part of Crete (mainly the Plattenkalk Unit), a geometrical digital 3D model was set up for Samaria gorge (Fig. 2).

The geological model was set up in a number of successive steps: Initially, a DTM (Digital Terrain Model) was set up to describe the topography of Samaria gorge. All geological boundaries were digitized and then overlaid onto the topography DTM to obtain the proper elevations. Finally, bedding planes were incorporated into the model.

After fieldwork, new geological data were collected and the new revised geological map was conducted (Fig. 2).

All existing data (from literature and field work) were used for the construction of the 3-D geological model of the revised geological structure of the area, as shown in Figures 2 and 3. This model is the first digitized geological database on the geological formations of Crete. The model could be enriched by future research data, since by its nature it is a dynamic expanding system.

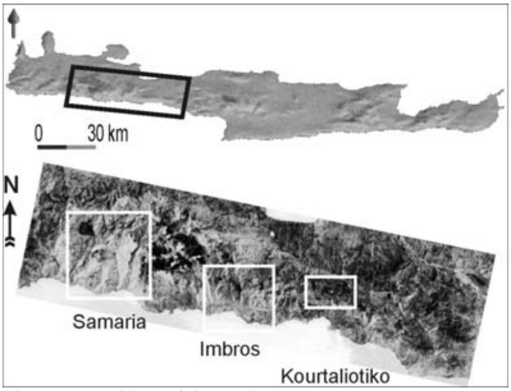

Figure 1: Position of the study area.

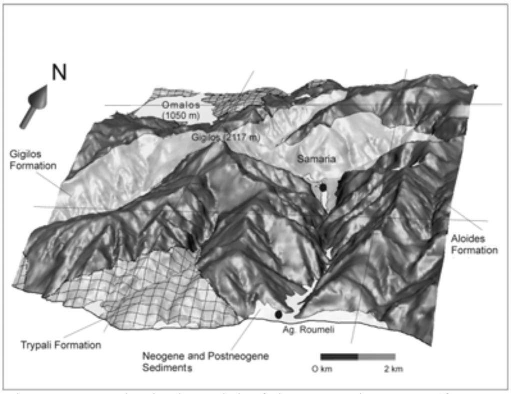

Figure 2: Geological model of the Samaria gorge (from Manutsoglu *et al.*, 1999, 2001).

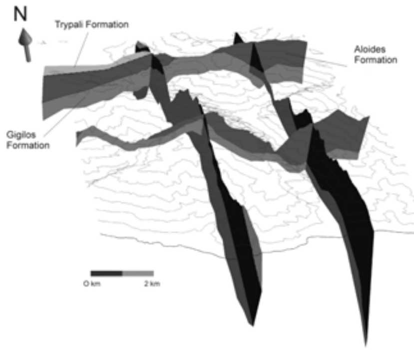

Figure 3: 3D sections through the geological model of Samaria gorge (from Manutsoglu *et al.*, 1999, 2001).

4.2 Modeling of the tectonic fabrics of the Imbros Gorge

The same procedure as with the Samaria region was followed for the Imbros Gorge. The resulting model can be seen on Figure 4. The aim for the study of this region however was not the revision of the geological map, but the detailed tectonic analysis.

The three dimensional representation of the fault pattern (Fig. 5) allows, in combination with the field data, a better discrimination of fault generations.

4.3 Modeling the Kourtaliotiko Gorge

In our first case study, the Samaria Gorge, the aim of modeling was to combine newly acquired field data with the existing geological map, which was published back in 1960 and

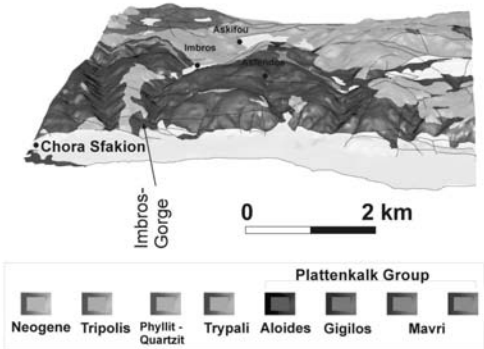

Figure 4: Geological model of the Imbros Gorge.

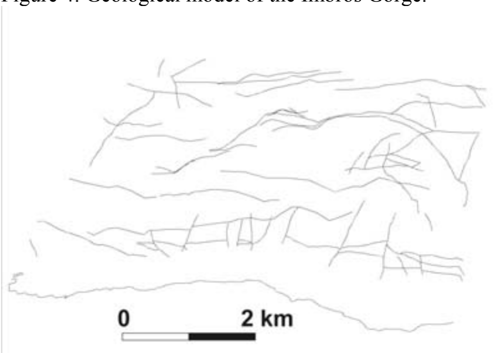

Figure 5: 3D fault pattern of the Imbros Gorge.

there was a need to be revised. In the case of the Kourtaliotiko Gorge, the existing map is a newer one. The aim of modeling was to set up a preliminary geological model, based on the geological map and the photomaps, in order to plan the detailed fieldwork.

For this study, four maps of Geographic Service of Army of scale 1:5000 were used (map sheet numbers 9522^7, 9532^1, 9522^8 and 9532^2, dimensions of each sheet are 3'x1.5'. These topographic maps were digitized and transferred to the National Geodetic System (E.G.S.A. 87). Finally, a DTM of the topography was produced.

The corresponding orthophotomaps that were used (code maps: 540-894, 540-891, 544-894, 544-891) were supplied by the topographic service of the Ministry of Agriculture. These maps were produced in the framework of the *Completed System of Management and Control (O.S.D.E.) of the rural and veterinary regions of Greece*. Shooting of the photomaps took place in 1998 and they refer to the National Geodetic

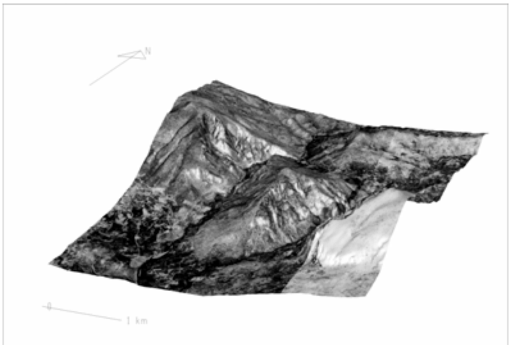

Figure 6: The orthophotomaps superimposed on the Digital Terrain Model (from Archontakis *et al.*, in press).

System (E.G.S.A. 87) with Traverse Merkator projection (TM '87).

The orthophotomap is produced by processing successive air photographs of a region so that the central projection of the photograph is transformed to the map projection. In this procedure, the relative coordinates of the photomap pixels are associated to the absolute coordinates of a geodetic reference system.

On the next step, the orthophotomaps were superimposed on the DTM (Fig. 6) to produce a realistic visualization of the research area. The next step was to digitize the existing geological map and than to project the digitized map on the topography DTM (Fig. 7). A study of the two visualizations reveals the regions where further fieldwork is necessary.

5. CONCLUSIONS – PROSPECTS

The methodology presented in this work speeds up the production of backgrounds for the set-up of 3-Dimensional geological models by combining existing topographic and geological maps and photomaps.

The method of 3 Dimensional Digital Geological Modeling presents some important advantages compared to the classic, static type of presentation (e.g. the paper geological map):

- the researcher is supported in the production of a logically consistence model. Errors and antinomies become obvious during the geometrical simulation process and they can be corrected.
- Interpretation errors, concerning the classic geological map are extensively limited, because the field and literature data are transferred to the digital model with bigger precision.

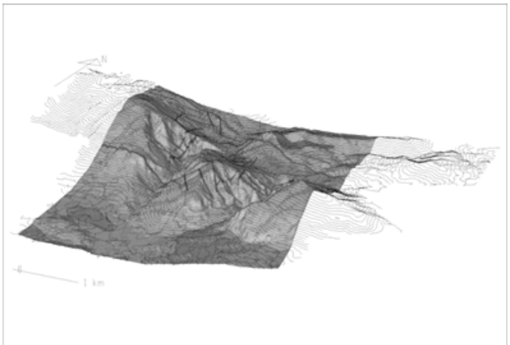

Figure 7: Superposition of the geological map on the digital topography model (geological map SELLIA sheet).

- Also the modeler is obliged to articulate and finally implement his own interpretation of the data with greater precision and clarity.
- The 3D digital geological model can produce every desirable geological section, where the classical geological map is accompanied by only one or two section. The production of the sections from the model is automated (the user has only to specify the direction), and the produced sections are unique. In contrary, the construction of a geological section from a map requires a lot of work and great experience from the researcher. This is the step where the most interpretation errors occur.
- It makes possible the quantification of geological information (Volumes, strata thickness). It is easy to extract different types of information from the model, like underground maps, strata thickness maps, 3D fault patterns and 3D intersection lines etc.
- It is possible, with relatively small effort, to combine many types of data: maps of different scales and thematic content, drillhole data, remote sensing data and GPS information.
- The analytic capabilities of the method are only limited by the resolution of the data used.
- The production of maps is greatly accelerated.
- The dynamic nature of digital models allows

the fast integration of new data to the model. As soon as new knowledge is available, the model can be revised and be accessible to other researchers.

- The production of special thematic maps for different applications and specialized users is easy.

The wider application of the 3D digital modeling approach is still held back by the great amount of data needed, as well as by the lack of available digital background (e.g. digitized topographic maps).

However, in the last years the power of available computer systems (hardware and software) grows rapidly, while the needed base data (photomaps and topographic maps) become more and more available in digital form.

The method presented in this paper speeds up the production and maintenance of geological maps. The 3D digital geological model is regarded as an alternative to the classical geological map, and constitutes a dynamic information system, which supports research work and information exchange between geologists as well as other scientific specialties.

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