Using 3D/4D modelling tools in exploration for porphyry and manto-polymetallic potential areas in Eastern Chalkidiki peninsula, N. Greece

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Abstract. The challenge of mineral exploration is to approach new exploration targets. 3D and 4D modelling are the new exploration tools that can help the mineral explorers to visualise, interpolate and interpret geological data are a critical time- and money-saving method. In NE Greece, where most of the potential resources and feasible deposits are hosted, polymetallic-gold mineralizations occur in a wide range of genetic types comprising magmatic, hypothermal/ mesothermal manto-type, orogenic, epithermal and supergene mineralization types.

The genetic link between porphyry copper and large polymetallic manto style sulphide deposits can be incorporated into regional exploration strategies in a complex metamorphic terrain of schists, gneisses and marbles of Palaeozoic age, whereas the epithermal type deposits were emplaced within a broad volcanic belt of Oligocene-Miocene age, which developed first in Bulgaria and then moved south through northern Greece to the region of Thrace.

The following geomodels have been constructed:
- 3D geomodels at deposit scale in Olympias, Mavres Petres, Skouries.
- 3D geomodels at semi-regional scale at North-Eastern Chalkidiki peninsula (Arvanitidis et al. 2012) and
- regional scale model of the Hellenic-Balkan belt.

Keywords. Mineral belt, 3D/4D modelling, manto-polymetallic deposits, exploration tool, potential areas.

1 Introduction

Greece’s geology favors a potent and dynamic use of mineral resources. Among the Non-Energy Metallic Minerals commodities, base and precious metals, in particular zinc, lead, copper gold, and silver are becoming an increasingly important and rapidly growing target of the mining industry. In NE Greece, where most of the potential resources and feasible deposits are hosted, polymetallic-gold mineralizations occur in a wide range of genetic types. The mineralization potential is consisted of magmatic porphyry copper type deposits, hypothermal/ mesothermal manto-type polymetallic sulphides and epithermal gold systems (Arvanitidis 2010).

The Eastern Chalkidiki peninsula in northern Greece with polymetallic replacement deposits (Olympias, Madem Lakkos, Mavres Petres) and porphyry copper deposit (Skouries) is the study area (Fig. 1).

![Figure 1. The study area of Eastern Chalkidiki peninsula.](image)

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2 Geology of Eastern Chalkidiki peninsula (Serbomacedonian zone)

The Serbomacedonian zone is a complex metamorphic terrain of schists, gneisses and marbles that are often mineralized and intruded by Variscan granitic rocks. It trends NW, is some 500 km long, and is host to numerous deposits, including Olympias and Stratoni manto-type polymetallic deposits, and Skouries and Pontokerasia, porphyry copper in Greece, Sasa and
Zletovo Pb – Zn deposits, and Bucim porphyry copper in the Former Yugoslav Republic of Macedonia, as well as the Lece polymetallic deposit in Serbia – Montenegro.

The Serbomacedonian zone consists of two major lithostratigraphic units of Paleozoic age, known as the Kerdylia and Vertiskos formations. The Olympias, Madem Lakkos and Mavres Petres belong geotectonically to the Kerdylia formation whereas the Skouries porphyry-copper-gold deposit to the Vertiskos one.

The Serbomacedonian zone incorporated into Kerdylia and Vertiskos formations (Fig. 2).

Figure 2. Geological map of Eastern Chalkidiki peninsula.

The contact between the Kerdylia and Vertiskos formations is partly gradational, but largely deformed and displaced by the major Stratoni-Varvara fault zone.

3. Building of 3D models

Local, semi-regional and regional scales of 3D/4D models were applied in most of the above mentioned deposit types and areas achieving new metallogenic interpretations and exploration perspectives in relation to the geology, the structural setting, the stratigraphy, the tectonic evolution, the ore bodies geometry, the alteration zones, the ore grades distribution and the genetic links between the spatially related porphyry and manto systems, based on airborne geophysics, along with further interpretations for across border regional exploration and prospecting potential.

Information and data used for 3D modelling, included:

- Wallrock lithology and geochemistry
- Alteration zones
- Ore metals distribution (drill hole mineralization intersections)
- Structural data

3.1 Olympias manto-type polymetallic deposit (deposit scale model)

The Olympias deposit is a polymetallic (Pb, Zn, Ag, Au) massive sulphide replacement ore body hosted by Kerdylia marbles. The mineralization is emplaced in deep-seated fault zones and their intersections with marble beds giving place to replacement and formation of lateral stratabound mantos, very often deposited at the contact zone between marbles and overlying gneisses (Kalogeropoulos et al., 1989; Arvanitidis, 1993).

Two main deposits have been identified, the West and East deposits.

The 3D model created shows the structure of the deposit and the fault-controlled setting of the ore-bodies, as well as the stratabound replacement mantos on behalf and inside the marbles (Fig. 3). A deeper-seated extension of the west ore body is indicated and makes a potential target to further underground surveys and exploration drilling.

Figure 3: 3D visualization of the Olympias ore deposit.

3.2 Madem Lakkos and Mavres Petres polymetallic replacement deposits (deposit scale model)

Madem Lakkos and Mavres Petres are, like Olympias massive, stratabound lead-zinc-silver carbonate replacement deposits hosted by Kerdylia formation marbles and developed, when spatially (in time and space) intersected by cross-cutting fault zones. The geological setting comprises also the major Stratoni-Varvara thrust fault bringing tectonically in contact Kerdylia marble interbedded, biotite gneiss and Vertiskos amphibolite.

The Mavres Petres ore body was 3D modelled (Fig. 5), with respect to intersecting fault zones (Figs. 4, 5), the overall geological setting and the compositional distribution of metal grades.

Setting up the complete 3D geological model of the Mavres Petres ore deposit all available data and sources of information were compared and integrated (Fig. 5).
During the creation of the model, a considerable amount of knowledge concerning the mineralization area and the ore body was specifically updated; some new N-S striking and cross-cutting fault structures were interpreted, but further investigations are required to determine their metallogenetic relationship to any of the mineralization processes (Penet 2010).

3.3 Skouries porphyry copper-gold deposit (deposit scale model)

The Skouries ore deposit is part of the NW trending Serbomacedonian porphyry copper belt extending through FYROM to Serbia and Romania. The Skouries porphyry intrusion consists of a series of rhyodacitic, dioritic to andesitic dykes and stocks emplaced into Vertiskos amphibolitic basement rocks in association with ultrabasic lithologies. It forms a pipe-like, mineralized subvolcanic body (Frei 1995). The deposit is characterized by more or less concentric potassic, propylitic, phyllic and argillic alteration zones, affecting mostly the host schists (Frei R 1995; Kalogeropoulos et al 1991).

Based on existing data and the work carried out by Penet (2010), it was possible to identify and map the major brittle deformation features, in terms of faults and related fracture zones, and using digital interpretations of the topography to better model and locate the main lineaments controlling and defining the porphyry intrusive corridor (Fig. 6). Three mainly NE striking directions of faulting were identified (Fig. 6).

The Skouries 3D models are becoming efficient exploration tools to target and locate new potential porphyry copper – gold mineralizations in the area.

3.4 Semi-regional 3D modelling of North-Eastern Chalkidiki

The local deposit scale 3D models were integrated and co-interpreted along with the regional scale geological knowledge to provide semi-regional 3D modelling of the metallogenetic evolution. For the region of North-Eastern Chalkidiki peninsula the previously presented deposit scale 3D models were evaluated along with regional scale data on: i) Geological setting, ii) Structural characteristics, iii) Geophysical measurements.

The creation of the 3D geological map was further elaborated by fifteen geological sections across the area, for better understand the 3rd dimension.

By integrating structural, geological and the geophysical data it was possible to 3D model the intrusive bodies and the basement rocks of the area considering also the perspective of the crossborder geotectonic zones e.g. Carpathian-Balkan belt. In this respect, figure 7 shows the semi-regional geological setting of Vertiskos and Kedyllia formations, composing the Paleozoic Serbomacedonian zone, in tectonic contact with Mesozoic Circum Rhodope Belt.

4. Conceptual 4D modelling in polymetallic manto and porphyry type systems of Eastern Chalkidiki peninsula

The geological information used to analyze the geological history in order to create the 4D model of Eastern Chalkidiki peninsula included: Geochronology...
of formations, main deformation process and orientation/dip analysis, geological evolution of Kerdyllia and Vertikos formation, and hydrothermal alteration, fluid inclusion, stable isotopes studies.

Figure 8: Screenshots from the 4d model that depicts the main stages of the development of polymetallic replacement deposits.

4D models were incorporated into local exploration as they proved to be significance to identify new potential mineralization targets.

Summary and conclusions

In the study areas, the 3D models not only contribute to ore feasibility evaluation but also enable better understanding of the mineralizing processes.

The Mavres Petres mine 3D modelling revealed a series of parallel faults, vertical to the main Stratoni-Varvara fault, and established a reliable tool for exploration of new ore potential areas at depth and along the westward extension of the main fault structure, in the area of Piavitsa.

In the semi-regional scale 3D modelling of NE Chalkidiki peninsula, the interaction between faults and magmatic intrusions was very much obvious. In addition the geological sections across the area indicated the types of mineralization processes taken place.

The 3D models are very useful tools for improving the knowledge of the ore deposition and conduct an efficient and successful mineral exploration for locating deep-seated mineralizations. Given the multi-disciplinarity of the existing data and the advanced IT capabilities it is realistic to further develop 3D into 4D models when the time parameter is combined and added. This will secure even more and make the exploration efficiency more sustainable to determine additional potential areas and discover new exploitable deposits with the same or different resource characteristics.

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