Using 3D/4D modelling tools in exploration for epithermal gold potential areas in Eastern Rhodope zone (Western Thrace, NE Greece)

Arvanitidis N.D., Michael C.
Institute of Geology and Mineral Exploration (IGME), Greece

Christidis C.
National and Kapodistrian University of Athens, Greece

Weihed P.
Luleå University of Technology, Luleå, Sweden

Gaál G.
Geological Survey of Finland, P.O.Box 96, 02151 Espoo, Finland

Royer J.J.
Université de Lorraine, CNRS, Nancy, France

Perantonis G., Bakalis V., Ballas D.
Hellas Gold S.A., Greece

Abstract. 3D/4D modelling tools are gaining ground day to day as advanced exploration technologies in mineral industry. The ability to visualise, interpolate and interpret geological data is a critical time- and money-saving method for mineral explorers. The models can contribute to better understand the geological evolution of mineralizing and ore-forming processes. These models can be key inputs for generating predictive models at different scales.

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 epithermal 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.

Deposit, semi-regional, regional scales 3D models and 4D model were produced to achieve new metallogenetic interpretations and exploration perspectives in Greece.

Keywords. 3D/4D modelling, epithermal gold deposits, exploration tool, gold potential areas.

1 Introduction

Greece’s geology favors a potent and dynamic use of mineral resources. Among the Non-Energy 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 most prospect area for epithermal gold deposits (Perama and Aghios Demetrios deposits) in Greece is the region of western Thrace (Fig. 1):

- 3D geomodel at semi-regional scale across Petrota Tertiary graben and Sappes – Kirki Tertiary basin.
- Regional scale model of Rhodope zone and
- Conceptual 4D model for the metallogenic evolution of epithermal Au deposits in the Tertiary basins of Western Thrace.

For the exploration of epithermal gold potential areas the following geomodels have been constructed:
- 3D geospatial at deposit scale (Perama Hill and Aghios Demetrios).

Figure 1: The study area of the Western Thrace region.

2 Epithermal gold deposits in Thrace

The epithermal gold deposits in the Thrace region are related to the post-collisional extension during late Eocene-Oligocene, forming structurally controlled rift-basins along the southern and eastern margins of the Rhodope zone. These Tertiary basins are characterized by deposition of Early Eocene sediments (molasses, limestones) followed up by late-Eocene – early-Oligocene volcanosedimentary series with calc-alkaline
3. Building of 3D models

Local, semi-regional and regional scales of 3D/4D models were constructed for most of the above mentioned deposits achieving new metallogenetic interpretations and exploration perspectives in relation to the geology, the structural setting, the stratigraphy, the tectonic evolution, the ore bodies geometry, the alteration zones and the ore grades distribution along with further interpretations for across border regional exploration potential.

For the construction of the 3D model were used:
- Aeromagnetic data
- Semi-regional strategic geochemical survey
- Available surface geological and structural data
- Geological cross sections
- Soil geochemical data
- Ground geophysical survey
- Down-hole surveys and drillholes logs providing information on:
  - Wall rock lithology and geochemistry
  - Alteration zones
  - Ore metals distribution (drill hole mineralization intersections)
  - Structural data

3.1 Perama Hill epithermal gold deposit (deposit scale model)

The Perama Hill epithermal gold deposit is located in the eastern part of Petrota graben consisting of subaqueous pyroxene andesitic flows, debris-flows and hyaloclastites, resting on the turbiditic series (Lescuyer et al. 2003). The Perama sandstones which host the gold mineralization are coeval with subaerial felsic eruption in the western part of the graben (pyroclastic flows, accretionary lapilli tuff, quartz porphyry domes and dacite flow; Lescuyer et al. 2003). The metamorphic basement close to the deposit is part of the Circum Rhodope zone (Mesozoic age) and consists of greenschists and calc-schists.

- The mineralizing hydrothermal system was structurally controlled (Fig. 3)
- The rift-fault between the Mesozoic basement and the Petrota graben was possibly the conduit for mineralizing hydrothermal fluids (Fig. 3)
- The sandstones were favouring fluids migration and deposition of gold.
- The deposit is characterized by a vertical pattern of metal distribution zones. The main part of the base metals sulphide mineralization is hosted by volcanic breccias and tuffs at depth.

Figure 3: Major faults at the contact of the Tertiary basin and metamorphic basement rocks (Perama Hill deposit).

3.2 Aghios Demetrios epithermal gold deposit (deposit scale model)

The geological setting comprises strongly altered agglomerate andesitic tuffs, lavas and volcanic breccias. According to the paragenetic distribution of the mineral assemblages four main and two overlapping alteration zones are distinguished in the area (Michael 1988, 1993, 1995, 2005).

- Main alteration zones
  - Silicification zone (hydrothermal eruption vent breccias) (Fig. 4)
  - Advanced argillic zone (subzones of alunite, diaspoare, argillic alteration and pyrophyllite)
  - Propylitic alteration
  - Potassic alteration (southern part of the Tertiary basin)

The hydrothermal eruption vents breccias make favourable structural setting for the gold mineralization at Aghios Demetrios deposit. Younger in age north-eastern faults has caused displacement of the wall rocks (Michael 1993; Bridges et al., 1998; Border et al., 1999; Andrew and Constantinides 2001).

Based on the 3D modelling approach of the two epithermal deposits the following can be concluded:
- The ore forms a flat lying body trending NW and dipping N-NE (Fig. 5)
- The N-NE part of the area is of a high potential for gold exploration
- The ore body is approximately 550 m long and 100-160 m wide (Fig. 5)
- A NE trending fault zone intersects and separates the ore body (Figs. 4, 5). This fault zone has also caused displacement of the wall rock alteration zones.
- Gold mineralization is mainly associated with hydrothermal eruption vent breccias (Fig. 4).
Figure 4: Hydrothermal alteration zones and main faults of the Aghios Demetrios epithermal gold deposit.

Figure 5: Structural setting of the Aghios Demetrios gold and base metal ore bodies.
- Base metals mineralization is developed at deeper levels (Fig. 5).
- The deposit is characterized by vertical zonal pattern of the ore metals and alteration zones distribution (Fig. 5).
- The advanced argillic zone is widespread (Alunite, diasporo, kaolinite, pyrophyllite; Fig. 4).
- The mineralizing hydrothermal system was structurally controlled related with deep structures.

3.3 Semi-regional 3D modelling across Thracian epithermal gold deposits

A geological reconstruction of the area in semi-regional scale has been created using cross sections (Fig. 6), aeromagnetic data, rift basin structures (Fig. 7) and the 3D models developed at deposit scale. Fifteen geological cross sections were set up across the Petrota and Sappes-Kirki Tertiary basins (Fig. 6).

Figure 6: 3D geological map and geological sections across the epithermal gold deposits areas in Thrace.

Figure 7: Rift-basins structures of Petrota graben and Sappes-Kirki Tertiary basin.

3.4 Regional 3D model of Rhodope zone

Using 3D models, metallogenetic data and mineral districts in Rhodope zone from the both sides area of Greece and Bulgaria, it can be outlined a perspective province for epithermal gold and copper-molybdenum deposits (Fig. 8).

The epithermal gold deposits in both sides developed at contact (graben structures) between Tertiary rocks and metamorphic basement.

The hydrothermal breccia is the favorite site for gold deposition. Gold mineralization is mainly connected with hydrothermal eruption vent breccias and fissure vent systems.

Figure 8: 3D model that depicts the epithermal perspective province in Rhodope zone.

The lithologically favorite sites for epithermal gold deposition are tuffs, breccias, volcanics of intermediate composition, sedimentary rocks, shoshonitic rocks, acid volcanic and metamorphic rocks.

The high-sulphidation and low-sulphidation epithermal gold systems in Greece and Bulgaria respectively are potential for new discoveries.

The Cu-Mo occurrences and the potassium hydrothermal alteration that found in many areas, indicate that the porphyry copper type of mineralization is also a perspective target.

It is suggested that the hydrothermal system is created by intrusions basing on spatial relationship between granitoids and epithermal systems. Sulfur isotopes results indicate that the fluids were predominantly magmatic (values ~0‰).

4. Conceptual 4D model of epithermal Au deposits in Tertiary basins of Western Thrace

For the construction of the 4D model of epithermal
metallogenetic evolution in western Thrace have been used: i) Geological evolution throughout the Rhodope zone, ii) Main deformation process, iii) Geochronology of the formations, iv) Magmatic activity (volcanic and emplacement of granitoids and shallow porphyry intrusives), v) Hydrothermal alteration study, vi) Fluid inclusion study and vii) Stable isotopes geochemistry.

Acid sulphate fluids escaped from the magmatic source (granitoid intrusives and porphyry stocks; Fig. 9) causing acid leaching, creation of silica supersaturation solutions and precipitation of massive chalcedonic silica (impermeable horizon) at the base of water table. Convecting fluids have trapped beneath the impermeable horizon and a hot overpressured aquifer is formed. The increased pressure was led to a hydrothermal explosion with a formation of hydrothermal breccias and precipitation of gold and base metals (Michael 2005).

The hydrothermal breccia is favorite site for gold deposition. Gold mineralization is mainly connected with hydrothermal eruption vent breccias and fissure vent systems.

The 4D models proofed to be very useful tools for improving the knowledge of the ore deposition and conduct a successful mineral exploration in order to determine new potential areas.

**Summary and conclusions**

The use of a 3D geomodel method has an increasingly important role in integrating and analyzing geoscientific information to make it easier to present and understand, and to develop more efficient exploration tools.

In the Greek study areas, the 3D models not only contributes to ore feasibility evaluation, which is a key factor in mining industry, but also enables better understanding of the mineralizing processes that led to the ore formation, and to assist the exploration of new deposits as well as the expansion of known.

In general the 3D model of Aghios Demetrios provides the geometry and orientation of the ore body, the pattern metals distribution zones, the role of later faults in displacing the ore body and the reserves verification of the deposit. In the Perama Hill epithermal gold deposit, the 3D model shows the development of mineralization zones, as well as the structural and lithological control of ore deposition.

A geological reconstruction of the epithermal deposits in Thrace region, at semi-regional scale, shows that N-NE (Perama Hill) and N-S (Aghios Demetrios) trending structures seems to have been the conduit of hydrothermal fluids and the fissure vent systems. These faults correspond to deep structures forming the rift/graben Tertiary basins.

The research leading to these results has received funding from the European Community’s Seventh Framework Programme ([FP7/2007-2013] [FP7/2007-2011]) under the grant agreement nº 228559. This publication reflects only the author’s view, excepting the Community for any liability.

**References**


Arvanitidis N (1993) Regional ore geologic studies setting controls and distribution of Metallic ore deposit types in the Serbo-Macedonian and Western Rhodope zone. I.G.M.E. technical report


Michael C (1993) Geology and Geochemistry of the epithermal gold deposit in Konos area. Xanthi. IGME. 1-75 (In Greek)

