OROGENIC MINERALIZATIONS – A NEW EXPLORATION TARGET FOR GOLD- POLYMETALLIC ORE DEPOSITS IN GREECE

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A) Accreted terrains, orogenic gold deposits temporally & spatially associated with episodes of crustal growth within developing/growing fore-arc (to back-arc) region of volcanic arc or continental margin. Contemporaneous with/post-date (medium P-T) metamorphism of host rocks (epigenetic)

B) Compressional/transpresssional environments in orogenic gold deposits (Goldfarb et al. 2005).
In order to analyse homogeneous mineralization, a list of 16 most characteristic commodity associations – or deposit types - has been established by ProMine partners.

The ProMine MD database was then queried to extract all deposits of these 16 major types.

As a result, 16 homogeneous deposit populations were obtained, that were processed for potential and predictive mapping.

<table>
<thead>
<tr>
<th>Number</th>
<th>Association Name</th>
<th>Commodity Association</th>
<th>'Type' codes queried in MD database (including 'sons')</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Alkaline &amp; Peralkaline intrusions</td>
<td>Nb, REE, P, (Ta, Zr, Sc, F, U, Fe)</td>
<td>C10, C20</td>
</tr>
<tr>
<td>2</td>
<td>Epithermal</td>
<td>Au, Ag, Sb, Hg, Te, Cu, In</td>
<td>D</td>
</tr>
<tr>
<td>3</td>
<td>Igneous Felsic</td>
<td>Sn, W, Ta, Nb, (Mo, Li, Be, B, In, F)</td>
<td>C40</td>
</tr>
<tr>
<td>4</td>
<td>Igneous Intermediate</td>
<td>Cu, Mo, Au, (Re)</td>
<td>C50</td>
</tr>
<tr>
<td>5</td>
<td>Igneous Replacement</td>
<td>Fe, W, Pb, Zn, Cu, Au</td>
<td>C70</td>
</tr>
<tr>
<td>6</td>
<td>IOCG</td>
<td>Fe, Cu, Au, (P, REE, U, Co)</td>
<td>K</td>
</tr>
<tr>
<td>7</td>
<td>Mafic intrusion</td>
<td>Fe, Ti, V</td>
<td>B30</td>
</tr>
<tr>
<td>8</td>
<td>Mafic or UltraMafic</td>
<td>Ni, Cr, Cu, PGE, (Co, Bi, U, Ag)</td>
<td>B, except B30</td>
</tr>
<tr>
<td>9</td>
<td>Orogenic Gold</td>
<td>Au, (Ag, As, W, Cu, Sb, Bi)</td>
<td>A, plus 'commodity Gold'</td>
</tr>
<tr>
<td>10</td>
<td>Pegmatites</td>
<td>Nb, Ta, Sn, Li, Be, (U, REE)</td>
<td>C60</td>
</tr>
<tr>
<td>11</td>
<td>Carbonate-hosted deposits</td>
<td>Zn, Pb, Ag, Ba</td>
<td>F40</td>
</tr>
<tr>
<td>12</td>
<td>Sandstone- and shale-hosted deposits</td>
<td>Cu, U, Pb, (Ni, Co, Zn, V, PGE, Re)</td>
<td>F20, F30, F60</td>
</tr>
<tr>
<td>13</td>
<td>Sedimentary deposits</td>
<td>Fe, Mn, Ba,K,Na,Sr</td>
<td>F50</td>
</tr>
<tr>
<td>14</td>
<td>VMS</td>
<td>Cu, Zn, Pb, (Ag, Au, Te, Sn, In)</td>
<td>E</td>
</tr>
<tr>
<td>15</td>
<td>Residual deposits</td>
<td>Fe, Al, Ni, Cu, (Mn, Au, P, REE)</td>
<td>H20, H30</td>
</tr>
<tr>
<td>16</td>
<td>Base metals veins</td>
<td>Pb, Zn, Cu, U, (Ba, F)</td>
<td>A, without 'commodity Gold'</td>
</tr>
</tbody>
</table>
Mineral potential mapping - results

1 - Alkaline-peralkaline intrusions
2 - Epithermal and volcanic systems
3 - Igneous felsic
4 - Igneous intermediate
5 - Igneous replacement or skarn
6 - IOCG (Iron Oxide Copper Gold)
7 - Mafic intrusions
8 - Mafic-ultramafic
9 - Orogenic gold
10 - Pegmatites
11 - Carbonate hosted
12 - Sandstone and shale hosted
13 - Sedimentary deposits
14 - VMS (Volcanogenic Massive Sulfides)
15 - Residual deposits
16 - Base metals veins

One map for each commodity association (or deposit type)
Orogenic gold:

Distribution of potential is guided by a single main commodity (Au) and a well constrained type of mineralization. Major districts belong to two groups:

- Paleoproterozoic orogenic deposits related to greenstones in the Fennoscandian shield;

- Hercynian gold-bearing districts related to late Hercynian (~300 Ma) deformation belts (N. Iberian peninsula, French Massif Central, Bohemian Massif).

Additional more scattered deposits can be found in other Hercynian (Salsigne) or Caledonian (Great Britain and Norway) domains and the Balkan-Carpathian region.
Orogenic gold deposits are a distinctive type of mineral deposits that has been the source for substantial world gold production.

- The globally youngest – dated orogenic gold lodes are the very widespread vein systems of the Alpine – Carpathian orogen which are associated with Europe / Africa collision during the Palaeogene.
- The Alpine – Carpathian orogen underwent thrusting, nappe emplacement and high temperature metamorphism in the latest Eocene, followed by Oligocene vein formation.
- The best studied orogenic gold deposits in the Alpine – Carpathian orogen are the deposits of the Monte Rosa province in northwestern Italy, the orogenic gold veins in the Austrian Alps and the Late Miocene veining occurred in the Swiss Alps at about 10 Ma.
Subduction-related magmatism

- Increased rate of subduction
- Collision with African crust
- ProMine
Major Au mineral zones in Greece

- Sredna Gora Zone
- Serbo-Macedonian Zone
- Rhodope Zone

Late Cretaceous Magmatic Activity

Tertiary Magmatic Activity

Porphyry Cu & Epithermal Au Metallogenetic Zone

Epithermal Au & Porphyry Cu-Mo Metallogenetic Zone
Orogenic gold deposits
- are present in various metamorphic terrains displaying various types of mineralization.
- show strong structural control of the ore forming processes and potential deposition takes place near large scale compressional structures (thrust shear faults).
- their controlling structures are mainly related to major faults and associated brittle deformation characterized by silicified fracture zones, ductile shear zones and breccias, and foliated zones.

Three styles of orogenic gold-base metal mineralizations have been defined in relation and association with
- low-grade metamorphic rocks.
- overthusted serpentinites.
- high-grade metamorphic terrains.
Adding a new Au target
Komaros area

Structural setting

- The mineralization in eastern Rhodope zone is associated with thrusting and hosted by brecciated greenschists and calc–schists (Circum Rhodope belt). The thrust follows the contact between greenschists and calcschists.

- The structural pattern observed in the area is interpreted to have formed under north–south compressional conditions.
Mineralization in folds and veins.

Mineralization occurs in quartz veins and folds (en–echelon folds, convergent and conjugate folds). Au, Ag, Cu, Pb, Zn, As is the characteristic geochemical association.

Albite, carbonate minerals, chlorite, sericite, epidote and barite are common gangue minerals.
Oxidized ore as matrix of brecciated material

Ore mineralogy and grades

- The mineralization is characterized by oxidation of base metal sulphide ore minerals. Gold occurs as native gold in quartz veins and as inclusions in iron oxides. The oxidized ore hosts gold from 1 to 49 g/t and the average grade is 6.3 g/t. Galena and sphalerite are the residual primary minerals in oxidized ore.

- The oxidized ore consists of smithsonite, cerussite, malachite, azurite, hematite, jarosite and gold. The proximal gangue mineral assemblages consist of albite, carbonate minerals, chlorite, sericite and epidote, minerals typical for orogenic gold mineralization.
OG in high metamorphic terrains

- This is well developed in western Rhodope zone.
- The deposits are normally controlled by second order structures near the compressional thrust fault between Serbomacedonian and Rhodope zones.
- The common characteristic of these mineralizations is mainly the Fe-rich oxide mineral gossaneous concentrations.
- The host rocks are varying with marbles and schists to be the most common ones.
Structural setting

- Two main compressional deformation events (D1, D2) were recognized in crystalline units of the western Rhodope zone. (D1), of Eocene-Oligocene age (50-23 Ma), created a system of NE-SW trending folds and associated reverse faults. (D2), of Miocene age (18-23 Ma), is accompanied by the Kavala granodiorite intrusive (19-22 Ma).

- The deposits are normally controlled by second order structures near the compressional thrust fault between Serbomacedonian and Rhodope zones.
West Rhodope mineralizations

- The mineralizations in western Rhodope zone are located in the Pangeon, Palea Kavala, Symvolon and Angistron.
- Mineralization in Palea Kavala is a combination of subhorizontal thrust shear zone and subvertical fault. The intersection of these structures has provided a location favoring dissolution and replacement of the marble. Large auriferous pods have been developed.
- Mineralization at Symvolon is controlled by thrust which occurs along the contact between the upper marble horizon and lower schist or gneiss zone.

In Angistron the mineralization has low volume and is associated with a zone of hydrothermal alteration several hundred of meters wide. The alteration is also related to a series of subvertical vein systems.
OG in high metamorphic terrains

- Au – Sb polymetallic mineralization in Kalindiri area.

Structural setting and mineralogy
- formed under the influence of the major regional north – south compressional environment. Thrust faults trending eastward are very important structures for the area.
- Au - Sb – polymetallic mineralization is normally controlled by second order structures near the compressional thrust faults. The NW, NNW trending shear zones are the most important controlling structures. The thickness of the fault zones is up to five meters and the zones are strongly brecciated.
- found in silicified marbles along the thrust fault contact between carbonate rocks and metamorphic basement rocks

Disseminated free gold occurs in a quartz matrix. Gold (5-23μ) also occurs within Fe – hydroxides.

- Intensive alteration zones associated with faults (normal and thrust faults) in marbles characterized by quartz, dolomite, calcite kaolinite, ankerite, garnierite, jasperoids.
The homogenization temperatures (Th) clearly indicate hydrothermal fluids typical for orogenic gold mineralizations and deposits. For example:

- The Sb mineralization in Kalindiri area ranges from 294° to 330° and the salinity is 0.2 – 7 wt% NaCl equiv. The homogenization temperatures suggest also that the mineralization took place during the gradual decrease of fluid temperature from 330° to 118°. Gold mineralization was deposited between 118° and 268°C. The coexistence of vapor rich and liquid rich inclusions is may be an evidence of boiling.

- The Au – bearing veins of Palia Kavala and Pangeon areas indicate that mineralization took place between 216 and 440° (low salinity, H₂O- CO₂ rich fluids), conditions similar to orogenic environment of deposition.

- The large quantities of CO₂ and H₂O-rich fluids were released during greenschists to lower amphibolites facies of metamorphism in the Rhodope zone.
Stable isotopes (O,C) analyses of calcite

The oxygen isotopes analyses of calcite veins from Palea Kavala and Pangeon with average $\delta^{18}$O values 22.01 and 28.72 per mill respectively, support the metamorphic origin (+15 to +35 per mill) of the fluids.

<table>
<thead>
<tr>
<th>Area</th>
<th>$\delta^{18}$O (smow) (Range)</th>
<th>Mean value</th>
<th>Num. of samples</th>
<th>$\delta^{13}$C (PDB)</th>
<th>Num. of samples</th>
<th>Source of data</th>
</tr>
</thead>
</table>
Gold and base metal mineralizations occur throughout the Rhodope zone in northern Greece at a range of spatial scales and geological environments. Orogenic gold deposits in Greece are present in various metamorphic terrains displaying variable types of mineralization. The main geological characteristics include:

• Deformed and variably metamorphosed host rocks
• Strong structural control of the ore forming processes and potential deposition taking place within/near large/small scale compressional structures (thrust faults)
• The emplacement of granitoid stocks involves increase in heat flow and fluid circulation in response to fracturing.
Conclusions

• The fluid inclusion data, the stable isotopes values and some geological data define a geochemical environment indicating orogenic gold mineralization setting.
• The mesothermal conditions of deposition, the low salinity, the CO$_2$-H$_2$O rich fluids, the high oxygen values are characteristic for orogenic type of mineralization.
• The emplacement of the Kavala granitoid took place 19-22 Ma) and coincides with the second (D2) compressional deformation event (18-23 Ma). This may indicate, the orogenic gold veins occurring in the western Rhodope zone belongs to Miocene. Absolute dating of the above orogenic mineralizations is still open to further investigation. The detailed knowledge of the orogenic mineralizations and processes of deposition can help to define potentially mineralized areas within regions of Rhodope and Serbomacedonin zones.
• This is the first documentation of orogenic mineralizations which become a new exploration target for gold-polymetallic ore deposits in Greece.
OROGENIC GOLD PREDICTIVITY

Derived from mineral deposit density, weighted by deposit class
Thank you for your attention