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A review on the critical and rare metals distribution throughout the Vertiskos Unit, N. Greece

Stergiou C.L.[(1)], Melfos V. [(1)], and Voudouris P. [(2)]

[1] Department of Mineralogy-Petrology-Economic Geology, Faculty of Geology, Aristotle University of Thessaloniki
[2] Department of Mineralogy-Petrology, Faculty of Geology and Geoenvironment, National and Kapodistrian University of Athens
*Correspondence: christer@geo.auth.gr

Introduction

One of the most crucial factors affecting the operations and the sustainability of the global economy is the undisturbed and steady supply of the high technological industry in critical and rare metals.

This relation is characterized by:

✓ a constant need and unrest to meet the **industrial production supply demands**,
✓ the **growing technological needs** of the societies of the advanced and advancing countries,
✓ the reshape of the traditional trading networks under **unstable political and economic environment**,
✓ a raging **concern on the ethics** of critical and rare metals exploitation,
✓ an effort to support the supply demand with **domestic production** trying to achieve a certain level of **self-sufficiency,**
✓ several **research projects** on the critical and rare metals **exploration and exploitation potentials,**
✓ the **development of breakthrough** technological applications such as the exploitation of **industrial by-products (e.g. red mud)** and the **recycling of e-wastes.**

The **European Union (EU)** since 2008 has steadily support several **EU funded research projects** on the domestic exploration and the economic geology of all mineral resources as they are summarized at **PERC code**.

Critical metals → according to the **EU Growth Commission** are characterized the following: antimony **(Sb)**, beryllium **(Be)**, bismuth **(Bi)**, cobalt **(Co)**, gallium **(Ga)**, germanium **(Ge)**, hafnium **(Hf)**, indium **(In)**, niobium **(Nb)**, scandium **(Sc)**, tungsten **(W)**, tantalium **(Ta)**, the Heavy Rare Earth Elements **(HREEs)**, the Light Rare Earth Elements **(LREEs)**, and the Platinum Group Metals **(PGMs)**.

Rare metals → rare natural occurrence in technically and economically exploitable worthy concentrations and high monetary acquisition cost → rhodium **(Rd)**, platinum **(Pt)**, palladium **(Pl)**, iridium **(Ir)**, osmium **(Os)**, rhenium **(Re)**, ruthenium **(Ru)**, germanium **(Ge)**, beryllium **(Be)**, gallium **(Ga)**, indium **(In)**, tellurium **(Te)**, mercury **(Hg)**, bismuth **(Bi)**, gold **(Au)**, and silver **(Ag)**.

The critical and rare metals definition is mainly derived from: **the technological, economic, dependency, and supply risk impact** that they have on the modern high technological industry **and not from the natural occurrence of these metals.**

They are used in the manufacture of: *diodes, infrared detectors, semiconductors, batteries, low friction metals, paints, ceramics, flame retardants, resistant super alloys, magnets, catalysts, liquid crystal displays, photovoltaic systems, wind turbines, flat panel displays, and hybrid and electric vehicles. Military industry* → **strategic metals** → jet fighter engines, space-based satellites.

Geological and Metallogenic Overview

Geological Setting

In northern Greece the **Oligocene-Miocene Serbo-Macedonian metallogenic belt (SMMB)**, along with the adjacent Rhodope metallogenic province, host the majority of the ore bearing intrusions and intrusion-related ore deposits of Greece (Figure 1).

The **Vertiskos Unit** build up the largest part of the complex tectono-magmatic terrain which hosts the SMMB (Figure 1).

Eocene-Oligocene detachment and supra-detachment faults favored the magmatic and hydrothermal fluid circulation. **Oligocene-Miocene**, shear zones and normal and strike-slip faults further enhanced this circulation.

Metal endowment *(Figure2a,b,c)*

✓ Northern part of the **Kilkis ore district** → porphyry ore deposits.
✓ Southern part of the **Kilkis ore district** → intrusion related ore mineralization.
✓ NE Chalkidiki → **Kassandra mining district** → Carbonate replacement ore mineralization types characterize the northern part of the district, while the southern part hosts mainly porphyry ore deposits.

By taking into consideration the most modern exploration techniques **the northern part is a greenfield area, especially in respect to the critical and rare metals occurrences.**

In recent years,
✓ several authors have highlighted **the critical and rare metals potential** of selected Oligocene-Miocene ore bearing intrusions deposits in the Vertiskos Unit.
✓ **the distribution and the relation of these metals with the ore minerals, the magmatic rocks, the regional tectonics and the hydrothermal alterations need a more thorough investigation (Table 1)**

Oligocene-Miocene ore mineralization types

- Porphyry type
- Epithermal type
- Skarn/Carbonate replacement
- Intrusion related; Shear-zone hosted & metamorphic-hosted quartz vein types
- Residual oxides Mn, Fe
- Major cities, lakes and rivers

Figure 2. The spatial distribution of the ore mineralization types across the Vertiskos Unit and the adjacent Kerdylion Unit in northern Greece.

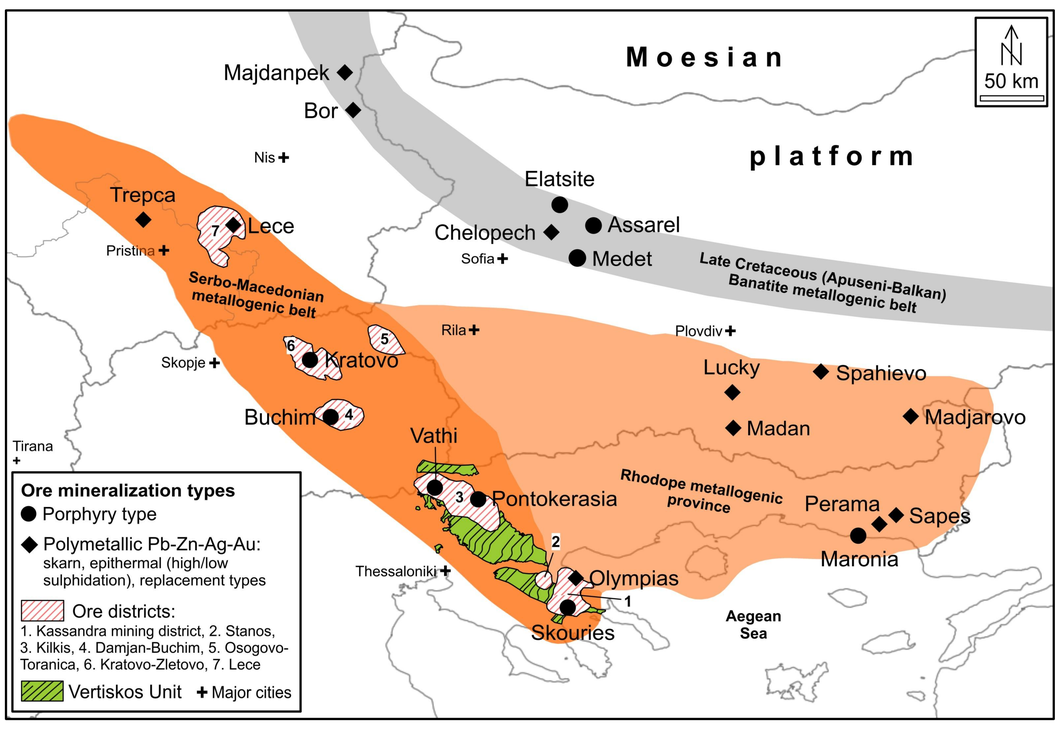

Figure 1. Schematic map showing the spatial development of the SMMB and the Rhodope metallogenic province across the SE Balkan Peninsula. The major ore districts of the SMMB are highlighted.

Critical and Rare Metals throughout the Vertiskos Unit

The **Skouries Cu-Au porphyry deposit** → measured and indicated resources of 289.3 Mt grading 0.58 g/t Au and 0.43% Cu. **Pt and Pd: 45 to 490 ppb and up to 3300 ppb** respectively.

Table 1. Characteristics of selected critical and rare metal bearing ore mineralization occurrences from the Vertiskos Unit.

Deposit name	Ore & mining districts	Commodities	Mineralization type	Deposit style	Critical & rare metals
Vathi	Kilkis	Cu, Au, Ag, Fe, Mo, U	Porphyry	Sub-alk Cu-Au	**W, Ga, Te, Bi, La, Ce, Nd, Gd, Au, Ag**
Gerakario	Kilkis	Cu, Au	Porphyry	Sub-alk Cu-Au	**Sb**
Skouries	Kassandra	Cu, Au, Mo	Porphyry	Sub-alk Cu-Au	**Pd, Pt,Ru,Te, Bi**
Stanos	Stanos	Cu, Au, Ag, Bi, Te	Intrusion related		**Au,Ag,Bi,Te**
Laodikino	Kilkis	Cu, Au, Fe, As, Zn, Pb, Te, Co, Ni, Sb, Bi	Intrusion related	Shear-zone hosted & Meta-morphic -hosted quartz vein	**Au, Te, Co, Sb, Bi**
Rizana	Kilkis	Sb, W	Intrusion related		**Sb, W**
Stephania	Kilkis	Cu, Ag, Au, Bi, Te, Co, Ni, As	Intrusion related		**Ag, Au, Bi, Te, Co**
Koronouda	Kilkis	Cu, Au, Ag, Zn, Pb, Fe, As, Ni, Co, Sb, Te, Bi	Intrusion related		**Au, Ag, Co, Sb, Te, Bi**

✓ The **Vathi Cu-Au-Mo-U porphyry deposit** → indicated resources of 15 Mt grading 0.8 g/t Au and 0.3 % Cu. **Critical and rare metals con**tents include up to: **6.996 ppm Au, 4.2 ppm Ag, 200 ppm W, 24.5 ppm Ga, 0.81 ppm In, 3 ppm Te, 22.06 ppm Bi, 500 ppm La, 715 ppm Ce, 211 ppm Nd, 13.67 ppm Gd.**
✓ The **Rizana Sb-bearing shear-zone hosted deposit** → indicated reserves of 0.05 Mt grading 30%–35% Sb. **Wolframite** is also found within the ore assemblage.
✓ The **Gerakario Cu-Au porphyry deposit** → probable reserves indicate 28 Mt of ore with 0.9 g/t Au and 0.4% Cu. No data exist for the Sb reserves. Stibinte hosted in peripheral quartz veins.
✓ The **Stanos, Laodikino, Stephania and Koronouda ore mineralization** are hosted within **shear zones and/or metamorphic quartz veins crosscutting gneisses**. Although their mineralogical assemblages resemble those of other shear-zone hosted deposits worldwide, they do not belong to the orogenic gold type of ore deposits. The regional metallogenic models, the salinity of the hydrothermal fluids, as well as the enrichment they share in common in chalcophile elements (e.g. Au, Bi, Te, Co), **suggest that their genesis is related to buried magmatic intrusions.**
✓ Several other minor ore mineralizations enriched in Sb, Au, Ag, Bi, Co, Ni **(e.g. Philadelphio, Nea Madytos, Kolchiko)** → general **lack of information on their spatial morphological characteristics and their reserves.**

Conclusions

❖ The **critical and rare metals** are integral and the most significant components of the modern high technological industry. This is demonstrated by their numerous uses in industrial manufacturing.
❖ **Complex geotectonic and magmatic processes** characterize the **Tertiary metallogenic processes at the Vertiskos Unit in northern Greece.** These processes inherited a **significant metal enrichment in base and precious, as well as in critical and rare metals.**
❖ This creates a future economic potential, and **adds to the sustainability of the present and future exploration and exploitation projects in Northern Greece.**

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