Hydrothermal Pb-Zn and Cu-Au mineralization in the Kassandra mine district, N Greece: a local mineralization model with regional implications?

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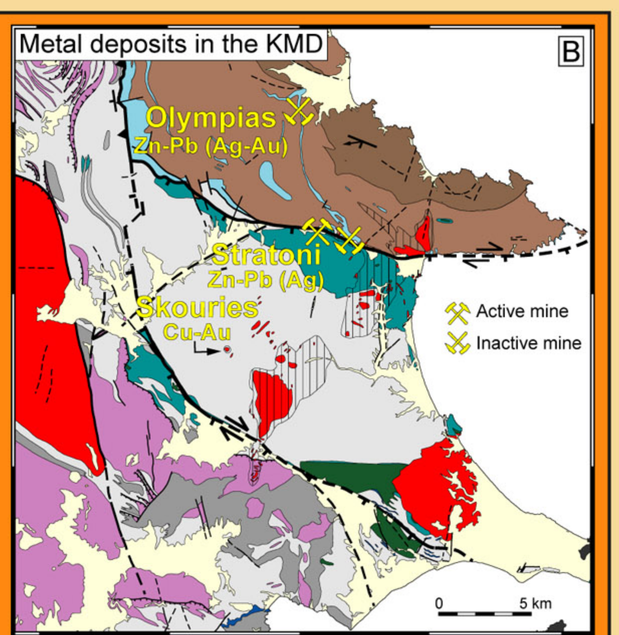
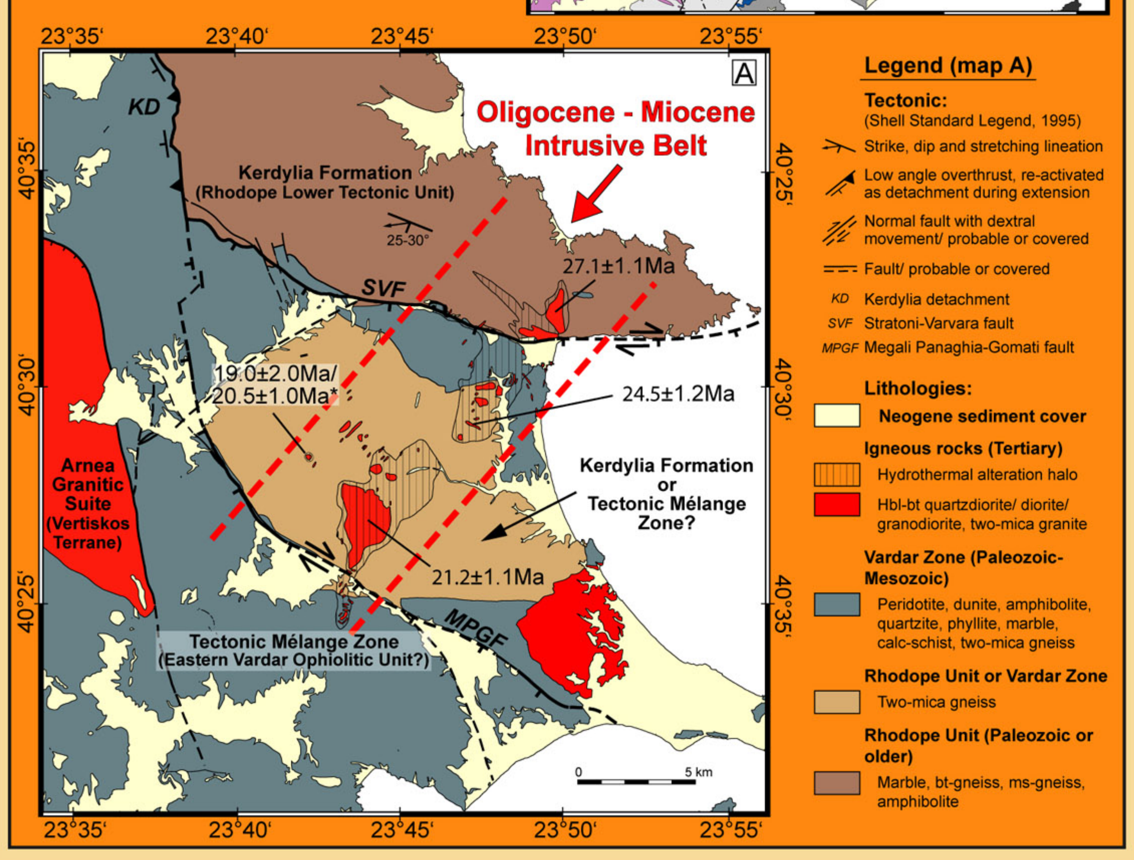
Fig.2: A) Simplified geological map of the Kassandra mine district (KMD) on Chalkidiki in N Greece (on the base of [6]). Radiometric ages: U-Pb zircon & uranothorite fractions and K-Ar whole rock* data [3 and references therein]. Tectono-stratigraphic interpretation after [1] and [5 and references therein].
B) Geological map of the KMD with hydrothermal (-magmatic) base and precious metal deposits of known economic importance (on the base of [6] and [10]).





1. Project objectives, geological framework

Economic mineral deposits of magmatic-hydrothermal origin are unevenly distributed in metallogenic belts across SE Europe (fig. 1). An understanding of the geological and ore genetic controls on the distribution of mineral deposits in metallogenic belts is a key to locating further reserves and potential economic deposits. This project adresses the **spatial and temporal distribution of hydrothermal ore deposits** in the south Balkan region and is focussed on the **Kassandra mine district (KMD) in N Greece** (fig. 1 and 2). This district forms the SE segment of an economically important, polymetallic belt developed throughout SE Europe [4; fig. 1]. Base and precious metal mineralisation is believed to be related to Tertiary (Oligocene-Miocene) magmatism in the metamorphic hinterland of the Hellenic orogen [3, 4]. However, despite available data, an overarching **district model** in the context of the geodynamic evolution **is distinctly lacking**. The KMD has not been seriously studied for nearly 20 years. Quantifying (1) the genetic link between hydrothermal mineralisation and regional magmatism and (2) the role of ophiolites in the mineralisation process will have important applications in future exploration strategies.

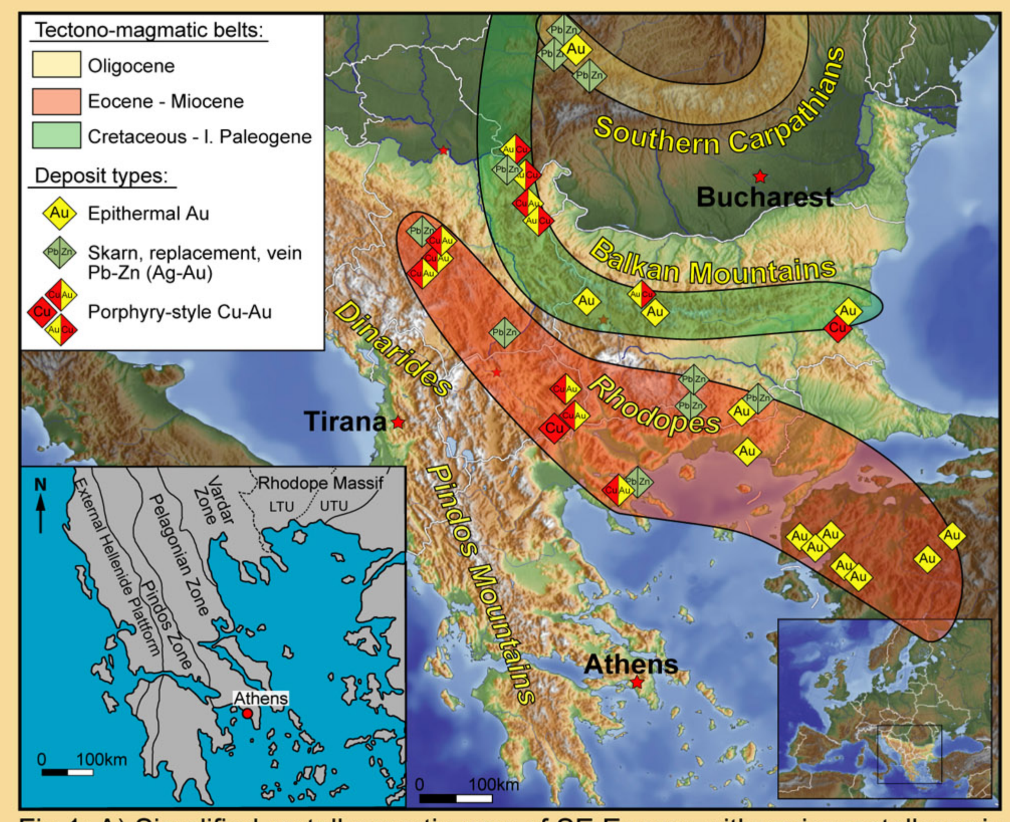


Fig.1: A) Simplified metallogenetic map of SE Europe with major metallogenic belts (modified after [4], [7] and [10]; basemap: Wikimedia Commons, 2008). B) Tectono-stratigraphic units of the Hellenic orogen (modified after [5]).

The ***KMD*** is an ***ideal study area*** for developing **local mineralisation models** of different, spatially related, hydrothermal deposit types of known economic importance, making it one of Europes's largest precious metal resources:

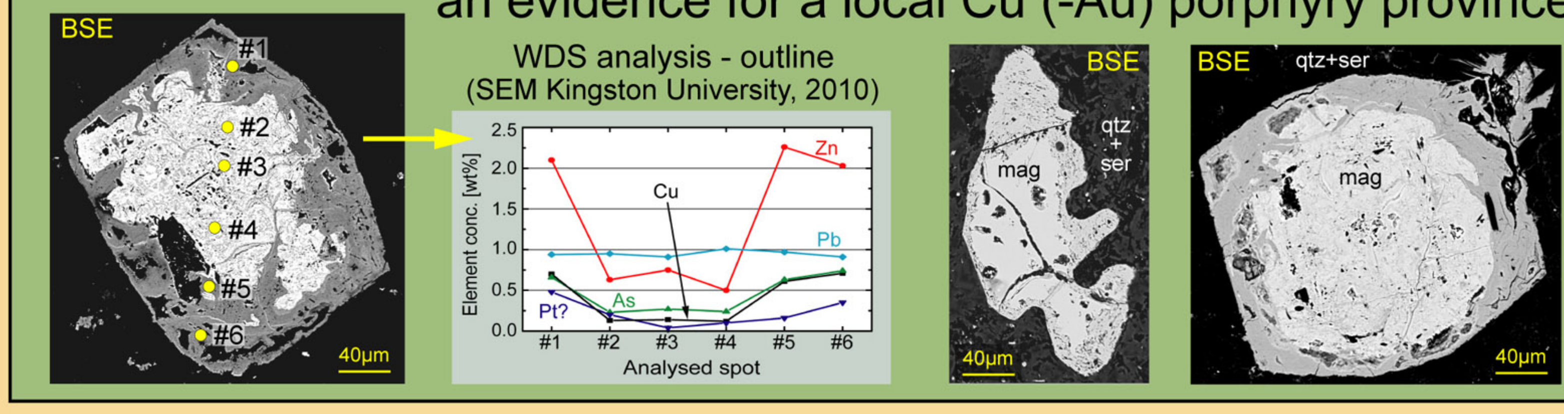
(1) Olympias and Stratoni; Pb-Zn (Au-Ag) carbonate-hosted massive sulphide replacement deposits,

(2) Skouries; a Cu-Au porphyry deposit [3, 8].

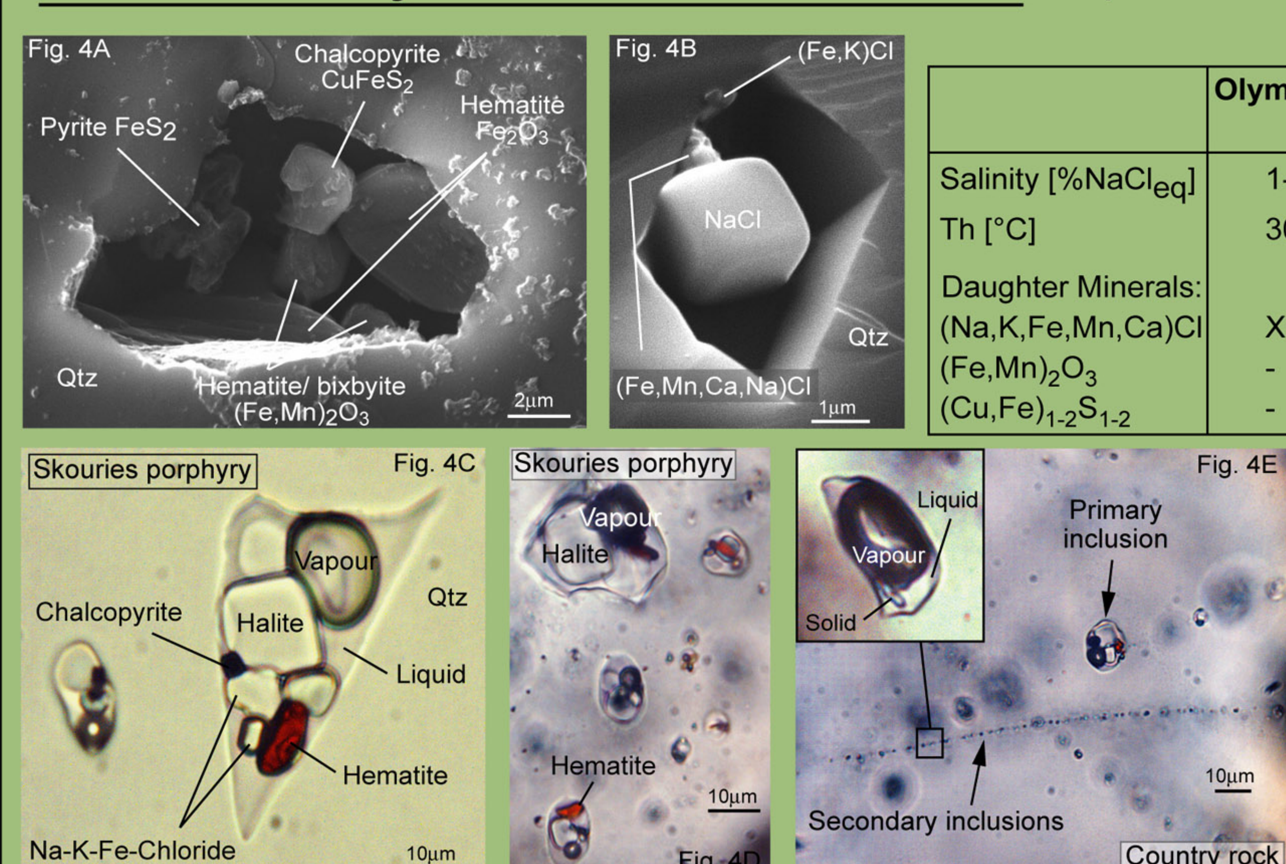
2. Nature of mineralisation and work to date

	Skouries	Olympias and Stratoni	
Deposit type	Cu-Au porphyry	Carbonate-hosted replacement deposits	
Host rock	Porphyritic syenite, biotite-gneiss	(Rhodochrositic) marble	
Country rock	Paleozoic gneiss basement = Kerdylia Formation (see fig. 2B)		
Mineralisation type	Syn-, post-magmatic alteration (Stockwork, veins, disseminations)	Fault-controlled metasomatism (Massive bands ± veins, disseminations)	
Formation age	19.0±2.0Ma/ 20.5±1.0Ma	Eocene-Miocene?	
Geodynamic setting	Post-collisional extensional regime (metamorphic hinterland of Hellenic orogen)		
	Hangingwall of Stratoni-Varvara fault	Footwall of Stratoni-Varvara fault	
Interpretation	Emplacement in regional intrusive belt (dilatational jog faults?)	Genetic linkage to core complex formation and subduction-related magmatism?	
Major ore minerals	Native Au+Cu; electrum	Sphalerite ZnS	
	Chalcopyrite $CuFeS_2$	Galena PbS	
	Bornite Cu_5FeS_4	As-pyrite FeAsS	
	Cuprite Cu_2O	Pyrite FeS_2	
	Malachite $Cu_3[(OH),(CO)_3]_2$	Chalcopyrite $CuFeS_2$ (just in Stratoni)	
Reserves (p&p, [6]):		Olympias	Stratoni
Cu [Mt]	0.8	-	-
Zn [Mt]	-	0.7	0.2
Pb [Mt]	-	0.5	0.1
Au [Moz]	3.9	3.6	-
Ag [Moz]	-	52.0	10.0

Zoned magnetites in a dioritic subvolcanite in the vicinity of Skouries: an evidence for a local Cu (-Au) porphyry province?



2a Preliminary fluid inclusion results: vapour-rich and hypersaline inclusions are most common



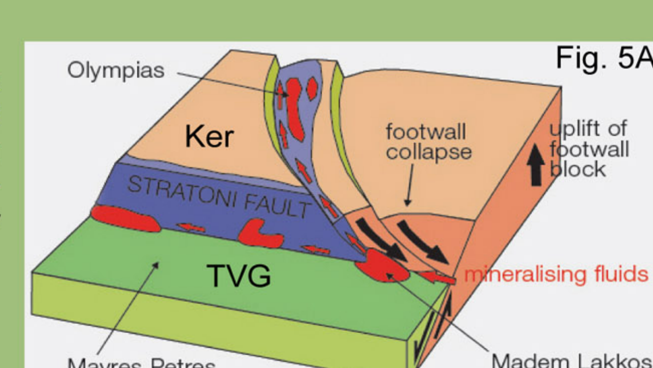
	Olympias [8,9]	Stratoni [8]	Skouries	
			Porphyry [3]	Country rock
Salinity [$\%NaCl_{eq}$]	1-32	50-65	50-65	≥50
Th [°C]	300-400	450-500	450-500	380-430
Daughter Minerals:				
(Na,K,Fe,Mn,Ca)Cl	X	X	X	X
$(Fe,Mn)_2O_3$	-	-	-	X
$(Cu,Fe)_{1-2}S_{1-2}$	-	-	-	X

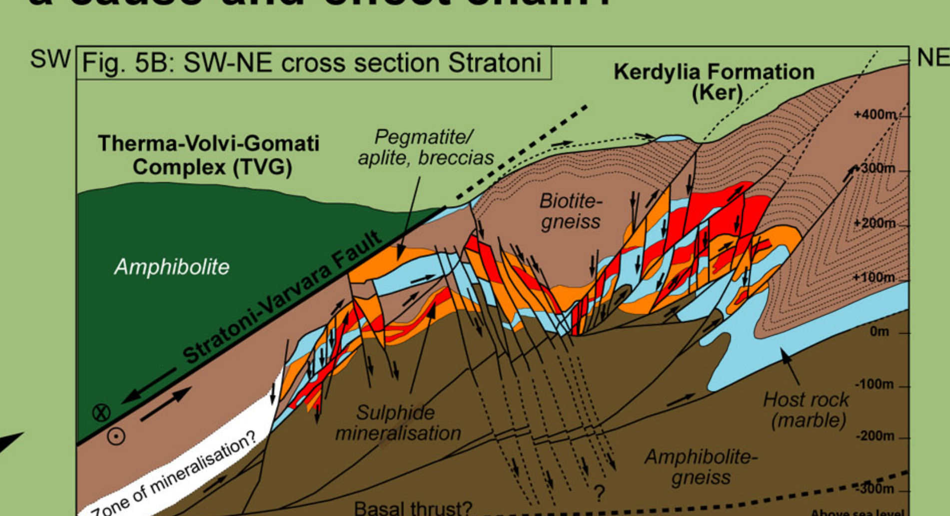
Fig.4A-E: Fluid inclusions in ore-related quartz veins in (fig.4C and 4D) and around the Skouries porphyry deposit (fig.4A + 4B, 4E).
(A-B) SEM pictures of opened fluid inclusions from quartz veins that are cross-cutting the country rocks in 1km distance from the Skouries deposit. Chlorides, sulphides and oxides are the daughter minerals (SEM Kingston University).
(C-E) Transmitted light pictures of multi-solid, hypersaline inclusion in the porphyry and in country rocks (same wafer as in A-B). Inset of fig. 4E shows a secondary gas-rich inclusion in the country rocks.

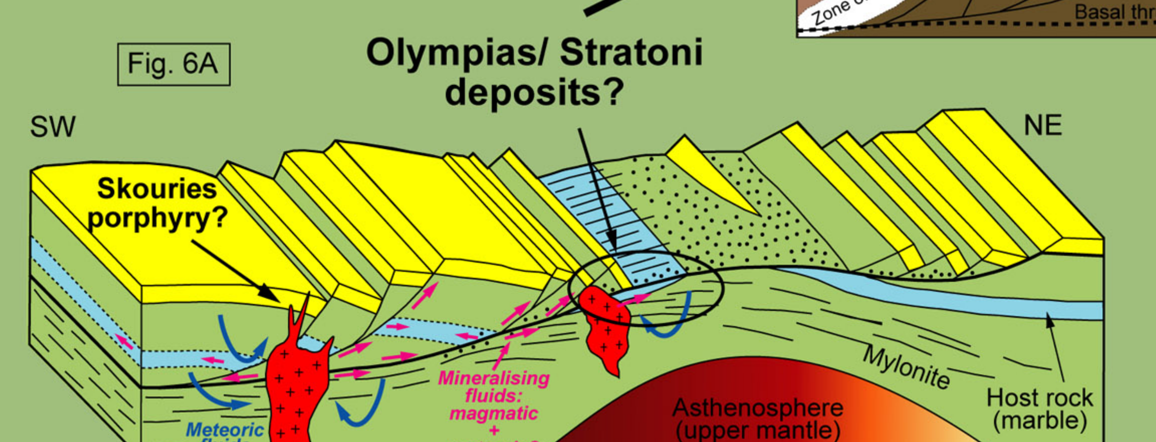
2b Preliminary genetic mineralisation model for the Kassandra mine district:

hydrothermal mineralisation related to metamorphic core complex formation and associated magmatism... ➔ **a cause-and-effect chain?**

Fig. 5A and B: Cross sections through the Stratoni and Olympias mineralisation zone: hydrothermal mineralisation model (modified after [2] and [10]).







The Southern Rhodope core complex: geodynamic setting and driving force for mineralisations in the study area?

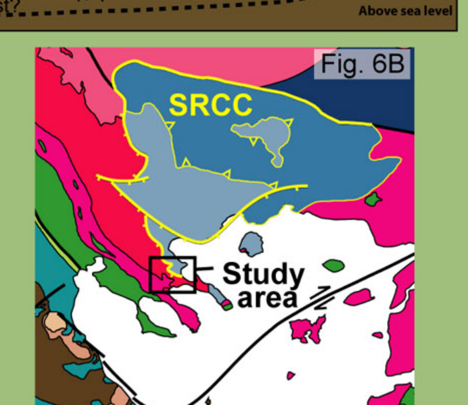


Fig.6A -B: Simplified cross section across the Southern Rhodope core complex (SRCC; A) and geological map showing the SRCC adjacent to the study area (B).

3. Conclusions and future work

First results of own and literature work reveal...

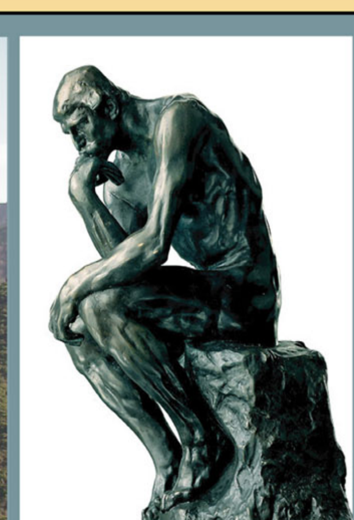
- a reasonable understanding of the geological setting
- a probable linkage tectonic-magmatism-mineralisation
- a distinctive (magmatic?) fluid inclusion assemblage

Future work will comprises...

- geochemistry (stable and radiogenic isotopes, trace elements)
- geochronology (U-Pb, Ar-Ar, Re-Os)
- fluid and melt inclusion studies (host rocks vs. country rocks)

... to...

➔ identify mineralisation phases related to geodynamic phases
➔ determine the evaluation of involved magmatic systems
➔ determine the origin of metals and fluids
➔ evaluate the metal partitioning mechanisms between magma and fluids (magmatic, meteoric)



Χαλεπά τά καλά
(Good things are difficult)
Plutarch

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