Gold deposits in Greece: mineralogy and genetic considerations

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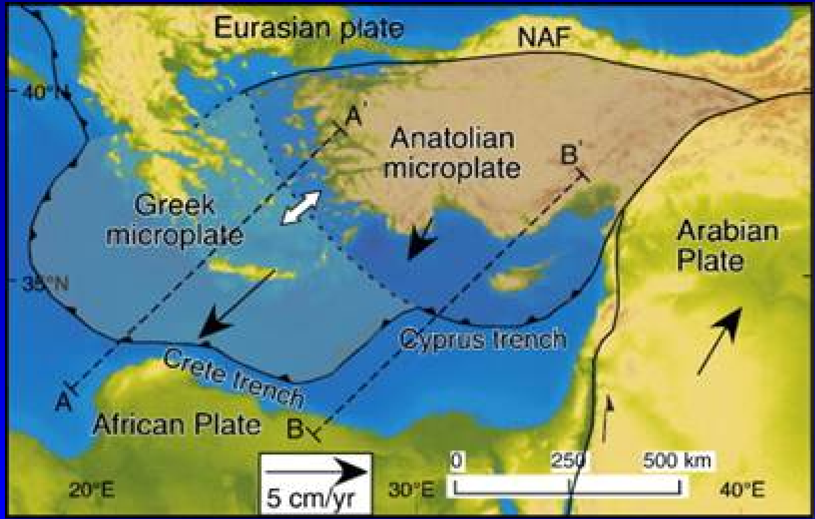
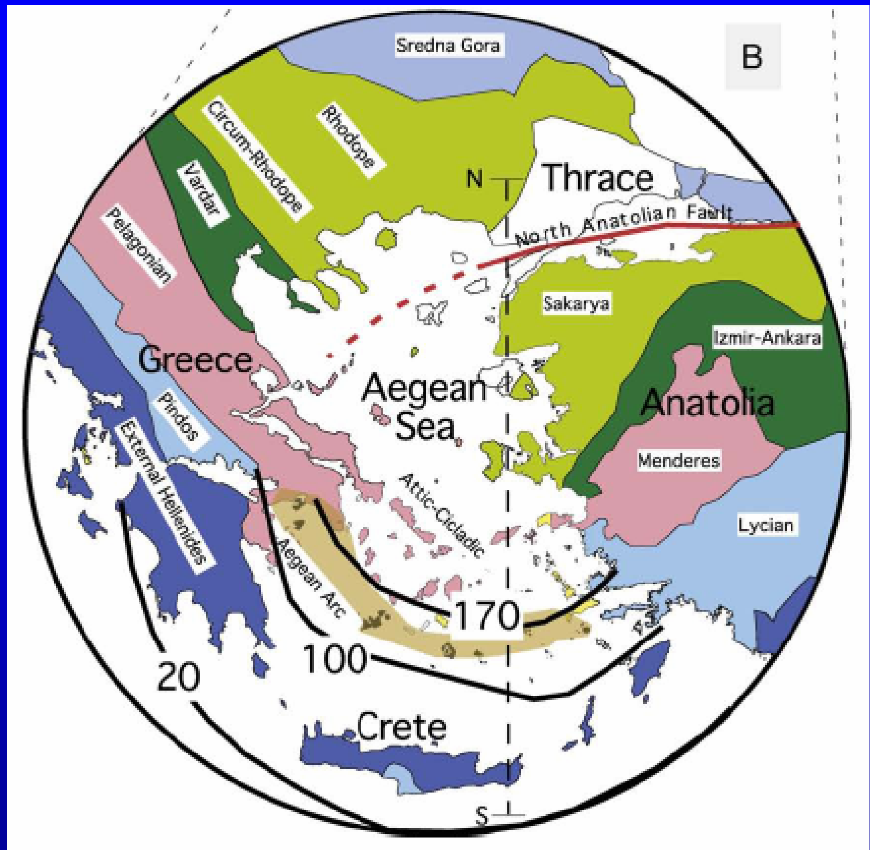
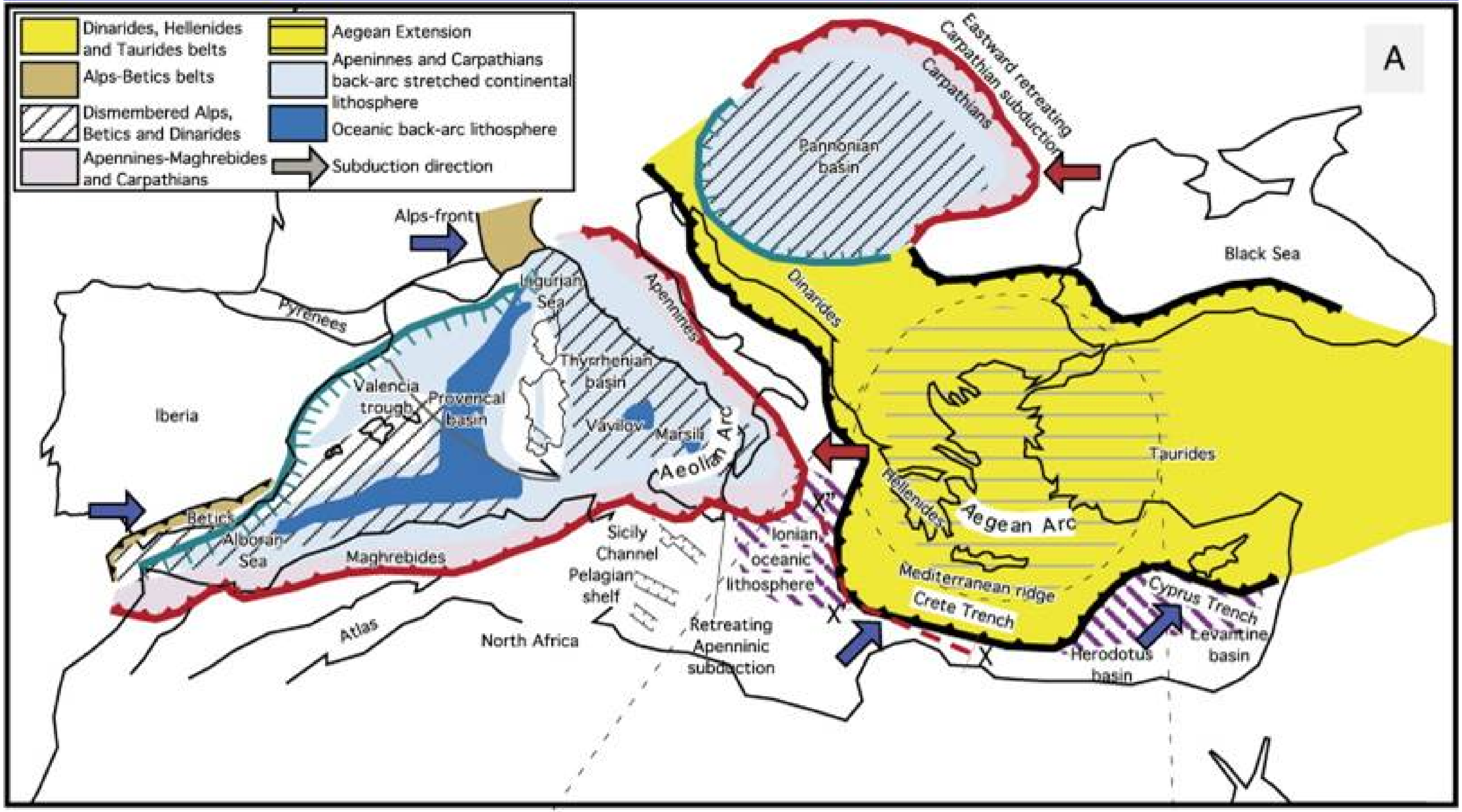




Agostini et al. (2009)

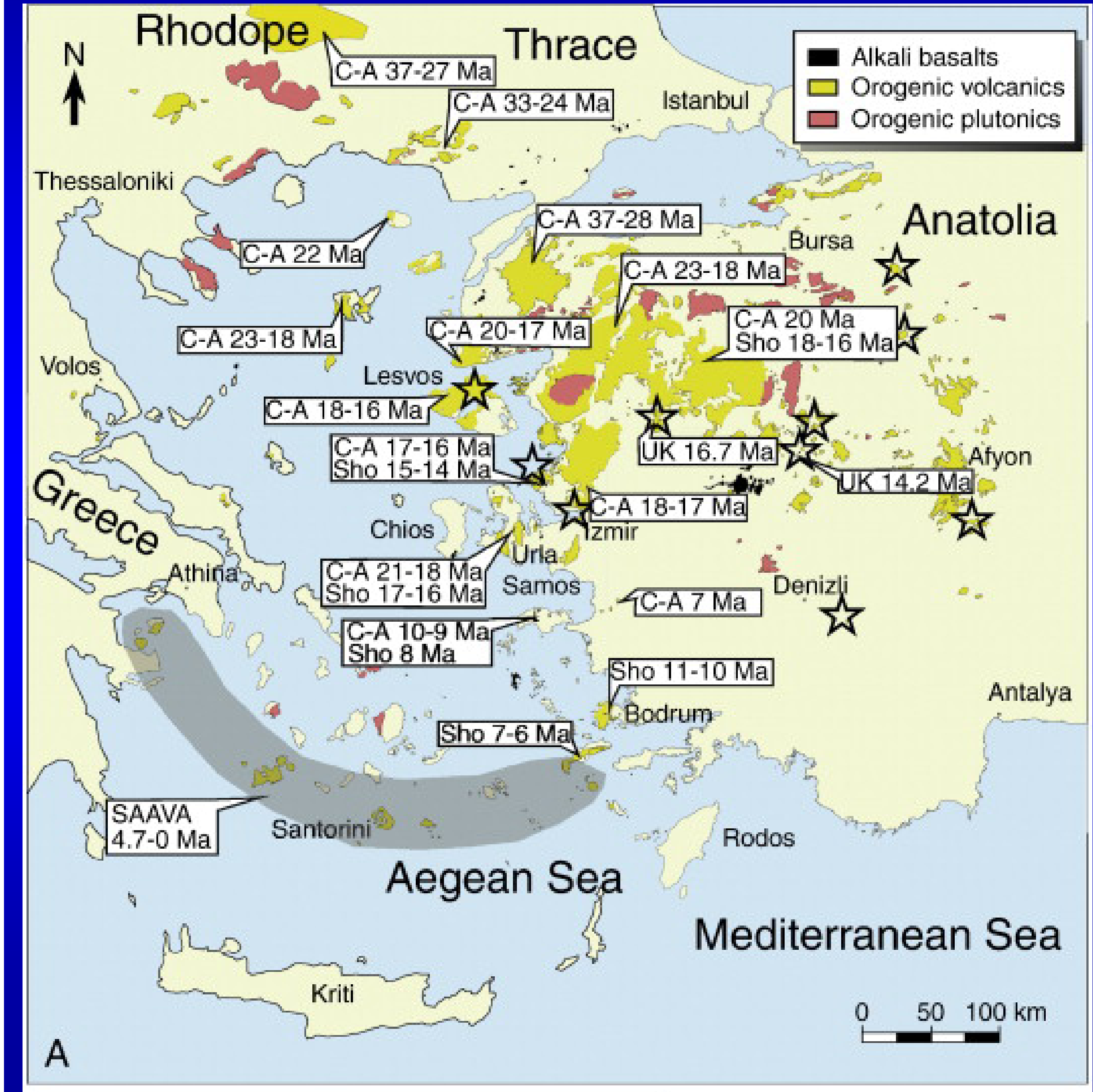
The Hellenides constitute part of the Alpine-Himalayan orogen and formed when Apulia collided with Europe in Late Cretaceous to Tertiary times. After the closure of the Vardar Ocean, shortening and syn-orogenic exhumation of HP-LT rocks occurred during the late Cretaceous-Eocene, before an acceleration of slab retreat changed the subduction regime and caused the collapse of the Hellenic mountain belt and the thinning of the Aegean Sea from the middle Eocene/late Oligocene to the present (Jolivet et al. 2004a, b). During this post-orogenic episode large scale detachments formed which exhumed metamorphic core complexes, in a back-arc setting (Lister et al. 1984; Gautier and Brun 1994a, b). Tertiary to Quaternary magmatism in the Aegean region occurred mostly in a post-collisional setting behind the active Hellenic subduction zone.

Geodynamic framework of the Mediterranean region



Agostini et al. (2009)

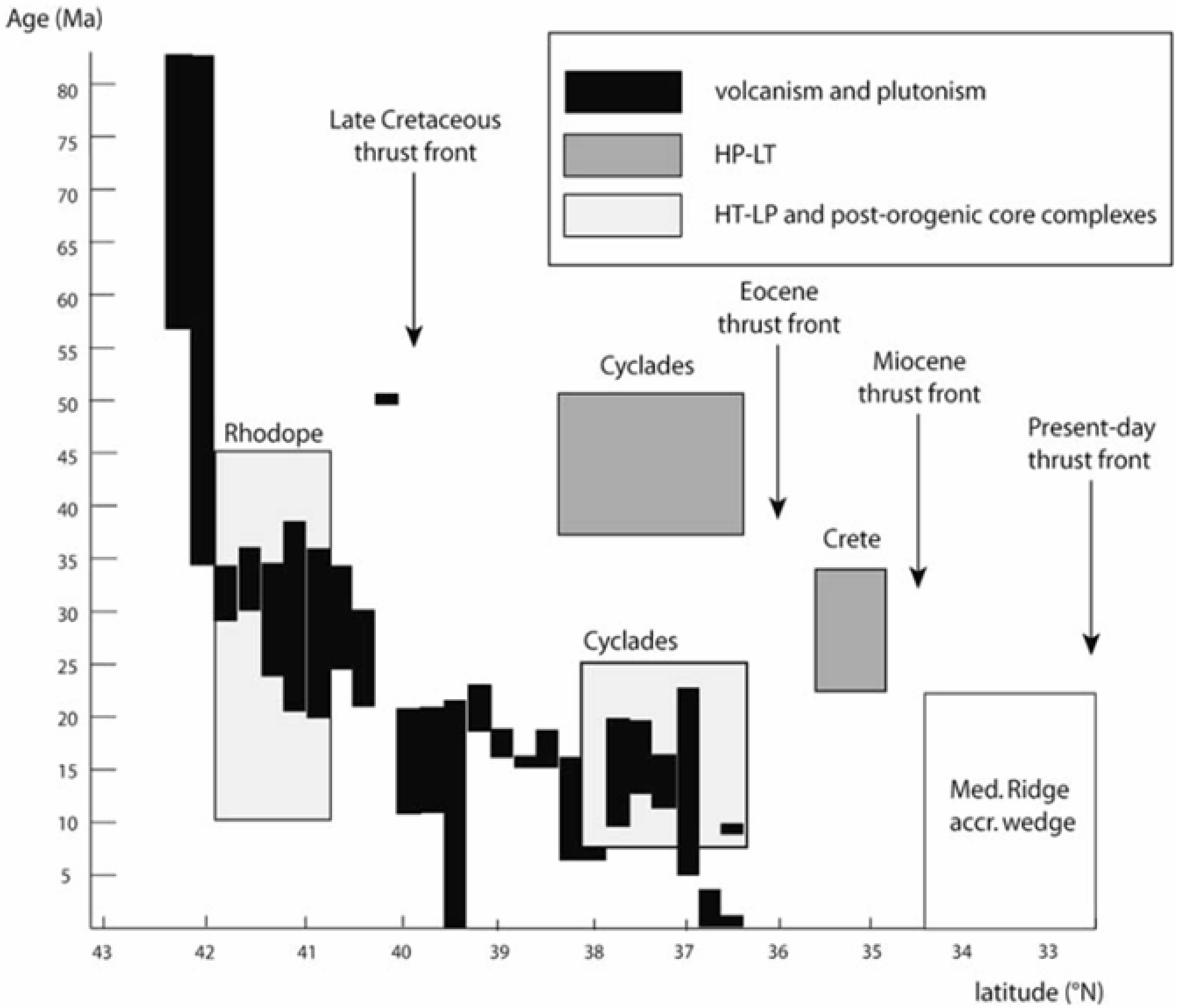
Tertiary volcanism in Greece



Map showing the distribution, age data and petrogenetic affinity for the subduction-related rocks in Aegean–Western Anatolian region. C-A, calc-alkaline; Sho, shoshonitic; U-K, ultra potassic; SAAVA, South Aegean Active Volcanic Arc.

Agostini et al. (2009)

Fig. 6 Latitude versus age diagram of magmatic events in the Aegean region. Data are taken from Fig. 5 and the time range is taken in the grid shown on Fig. 5. The age and position of the main tectono-metamorphic events are also shown (see text for references)

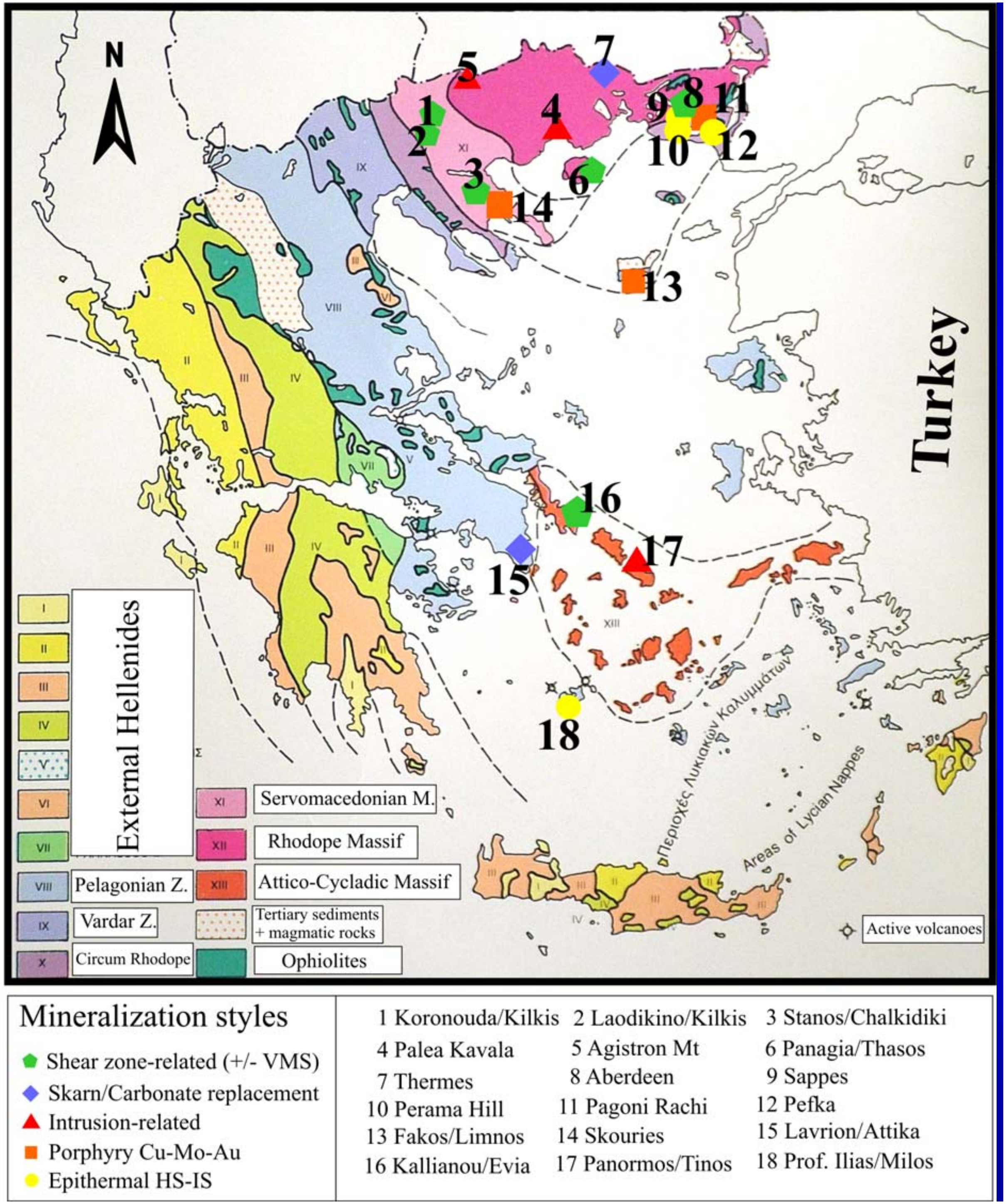


Jolivet & Brun (2010)

Gold mimeralization types

Porphyry-epithermal Cu-Mo-Au-Te
Intrusion-related Mo-W-Au-Ag-Te
Shear zone-related Au-Bi-Te

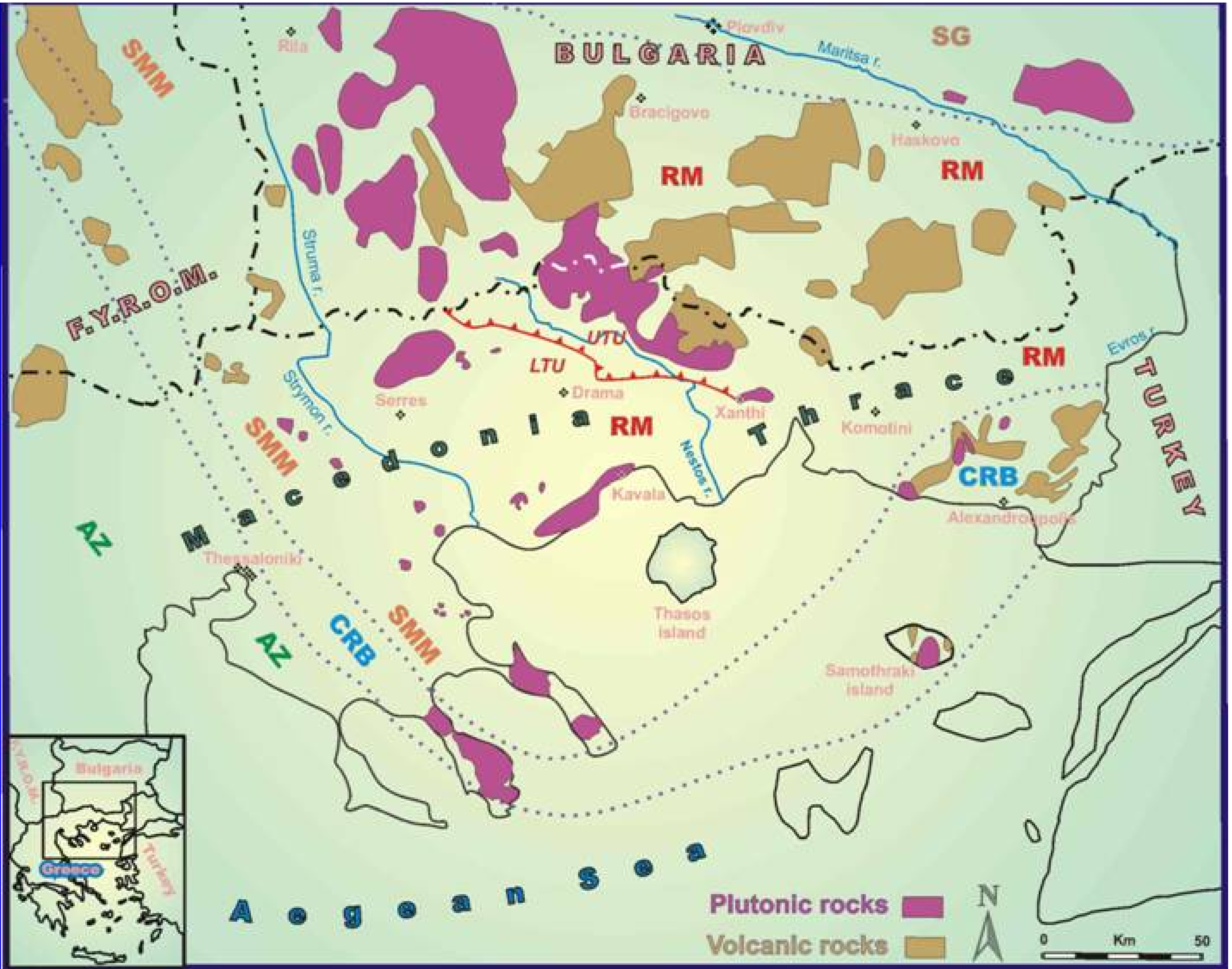
Simplified geologic map of the Hellenides (I.G.M.E. 1983) and location of the gold-bearing mineralization



Porphyry-Epithermal systems

(Oligocene-Miocene)

Oligocene-Miocene magmatic rocks in Southern Balkan peninsula



RM: Rhodope Massif
SMM: Serbomacedonian Massif
CRB: Circum Rhodope Belt
AZ: Axios Zone

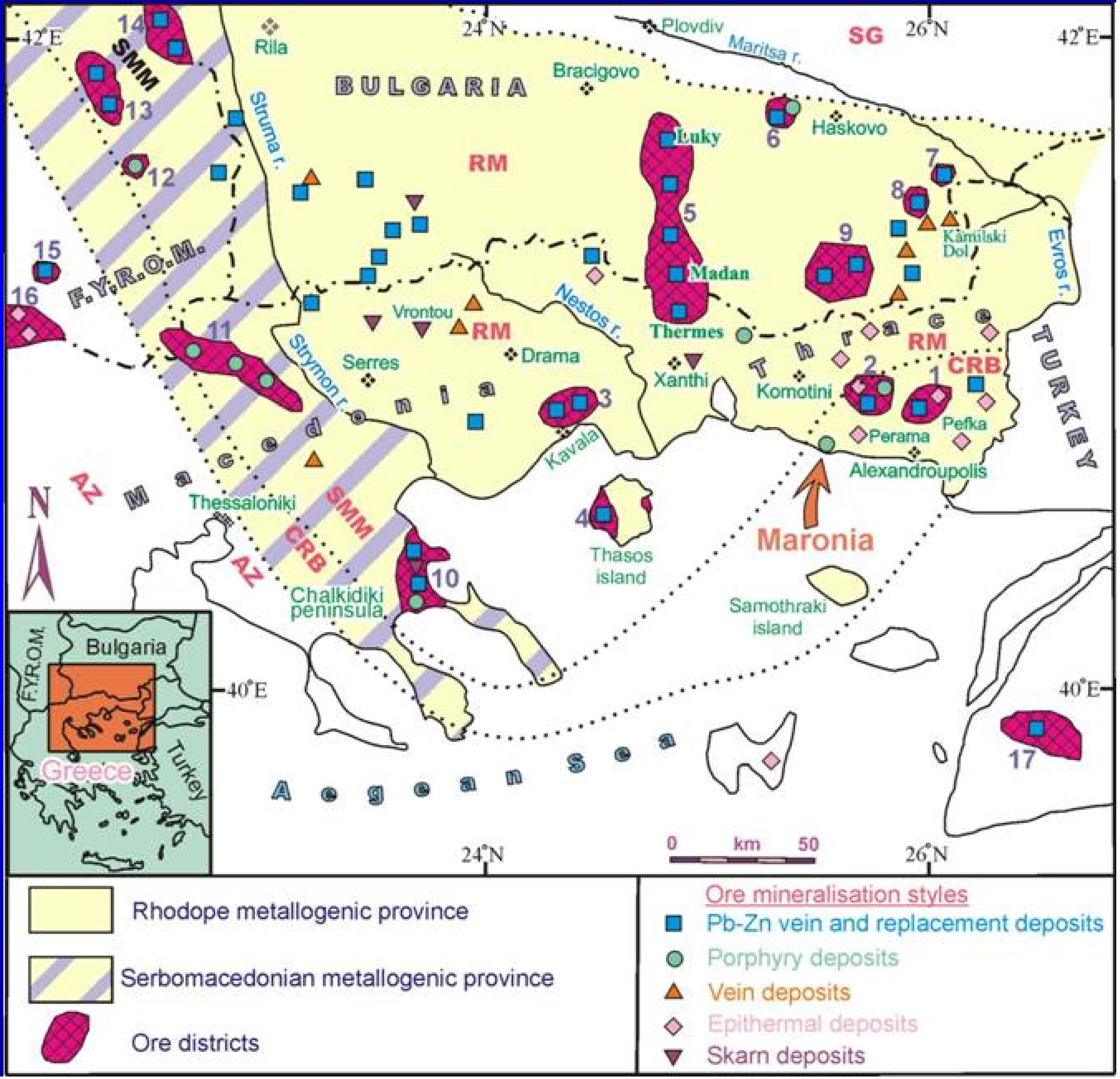
Melfos et al. (2002)

Distribution of the Tertiary ore districts and deposits within the Rhodope and the Serbomacedonian metallogenic provinces in the southern Balkan peninsula.

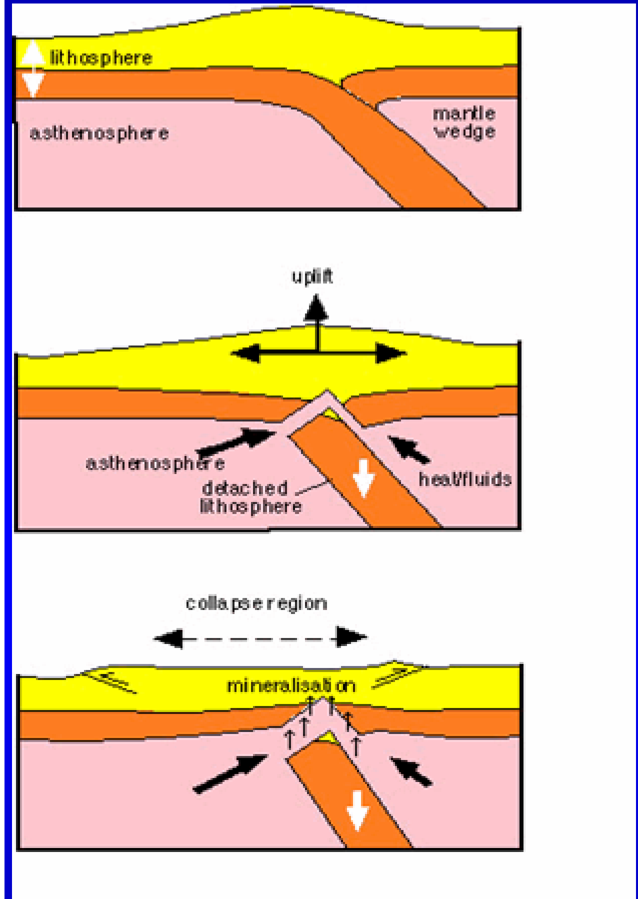
RM=Rhodope Massif
SMM=Serbomacedonian Massif
CRB=Circum Rhodope Belt
AZ=Axios Zone
SG=Srednogorie Zone

1. Esymi
2. Kirki-Sapes
3. Kavala
4. Thasos
5. Thermes-Madan-Luky
6. Spahievo,
7. Lozen
8. Madjarovo
9. Zvezdel
10. Chalkidiki
11. Kilkis (Doirani-Gerakario-Vathi-Pontokerasia)
12. Buchim-Damjan
13. Kratovo-Zletovo
14. Osogovo-Sasa-Toranica
15. Borov Dol, 16. Aridea-Kozuf
17. Balikesir

from Melfos et al. (2002)

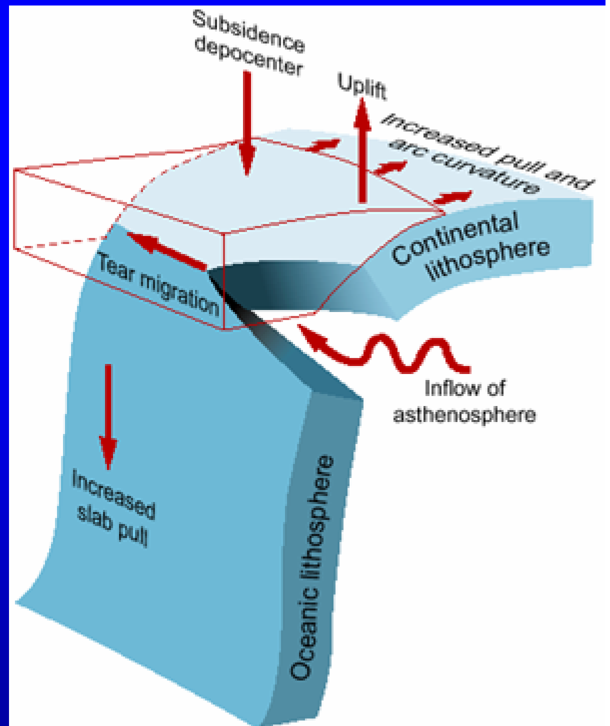


GEODYNAMIC MODEL OF THE PORPHYRY – EPITHERMAL SYSTEMS IN NORTHERN GREECE



The host magmatic rocks were emplaced under subvolcanic conditions in an extensional regime, related to the post-collisional collapse of the Rhodope province.

De Boorder et al. (1998) suggested that the late Cenozoic hydrothermal mineral deposits of the European Alpine belt are related to the emplacement of hot asthenosphere into shallow crustal levels above a detached lithosphere plate.

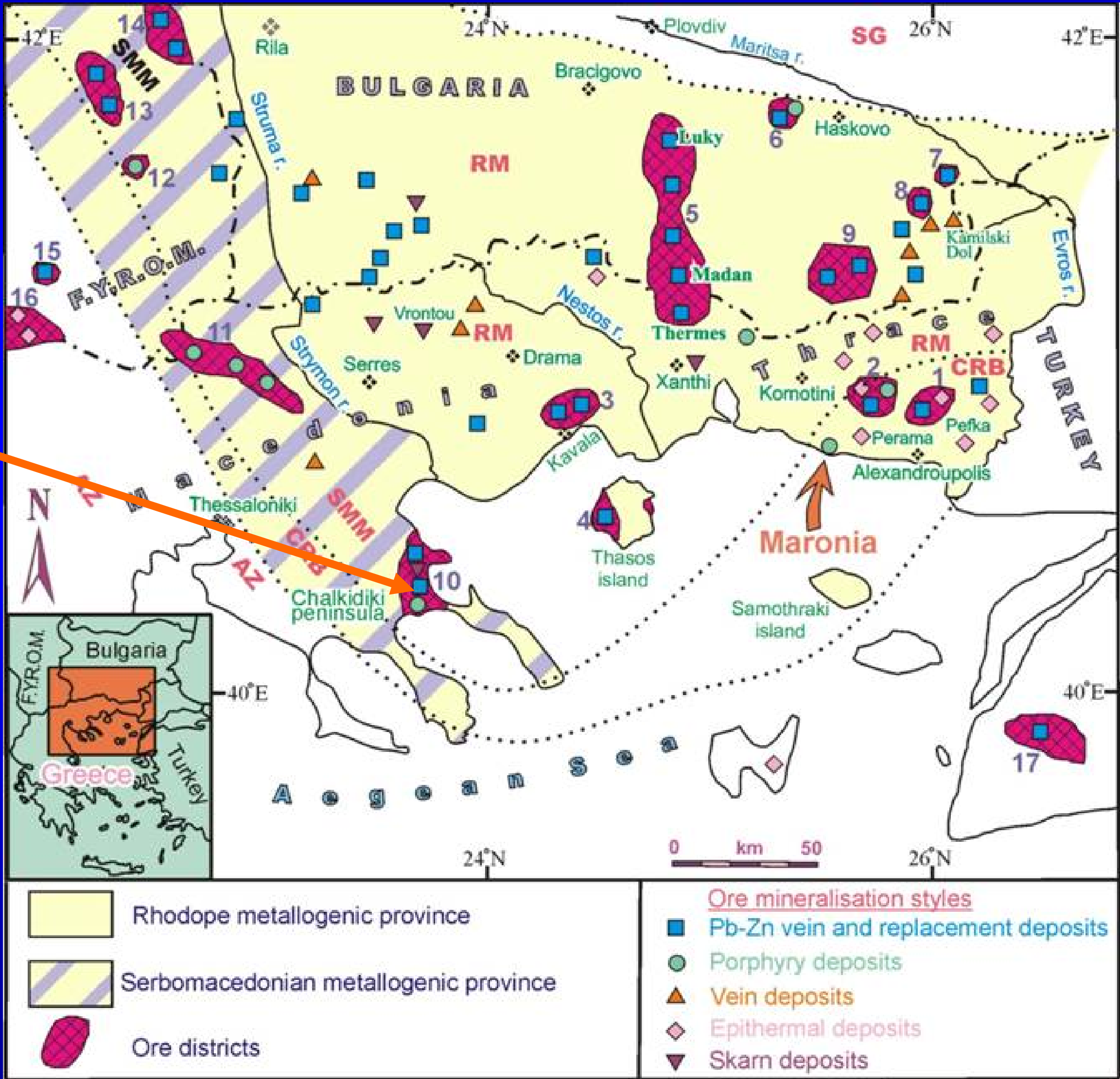


De Boorder et al. (1998)

Such a process may have led to formation of the porphyry Cu-Mo and epithermal Au-Ag systems in western Thrace.

Skouries/Chalkidiki porphyry Cu-Au

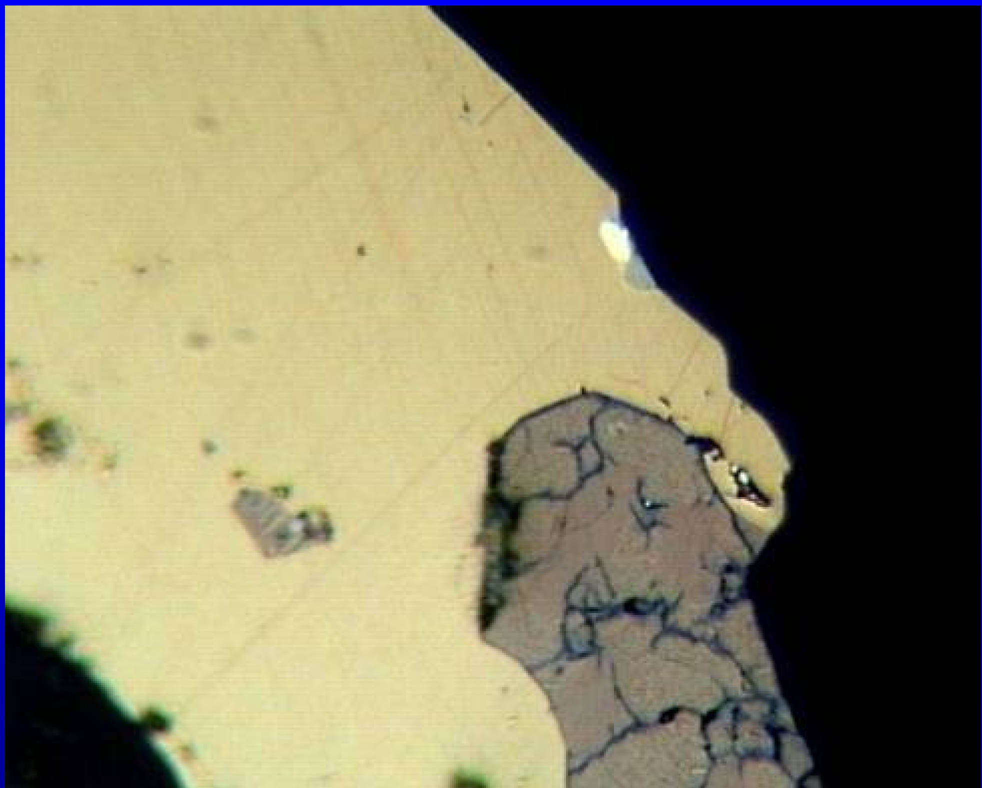
Skouries deposit



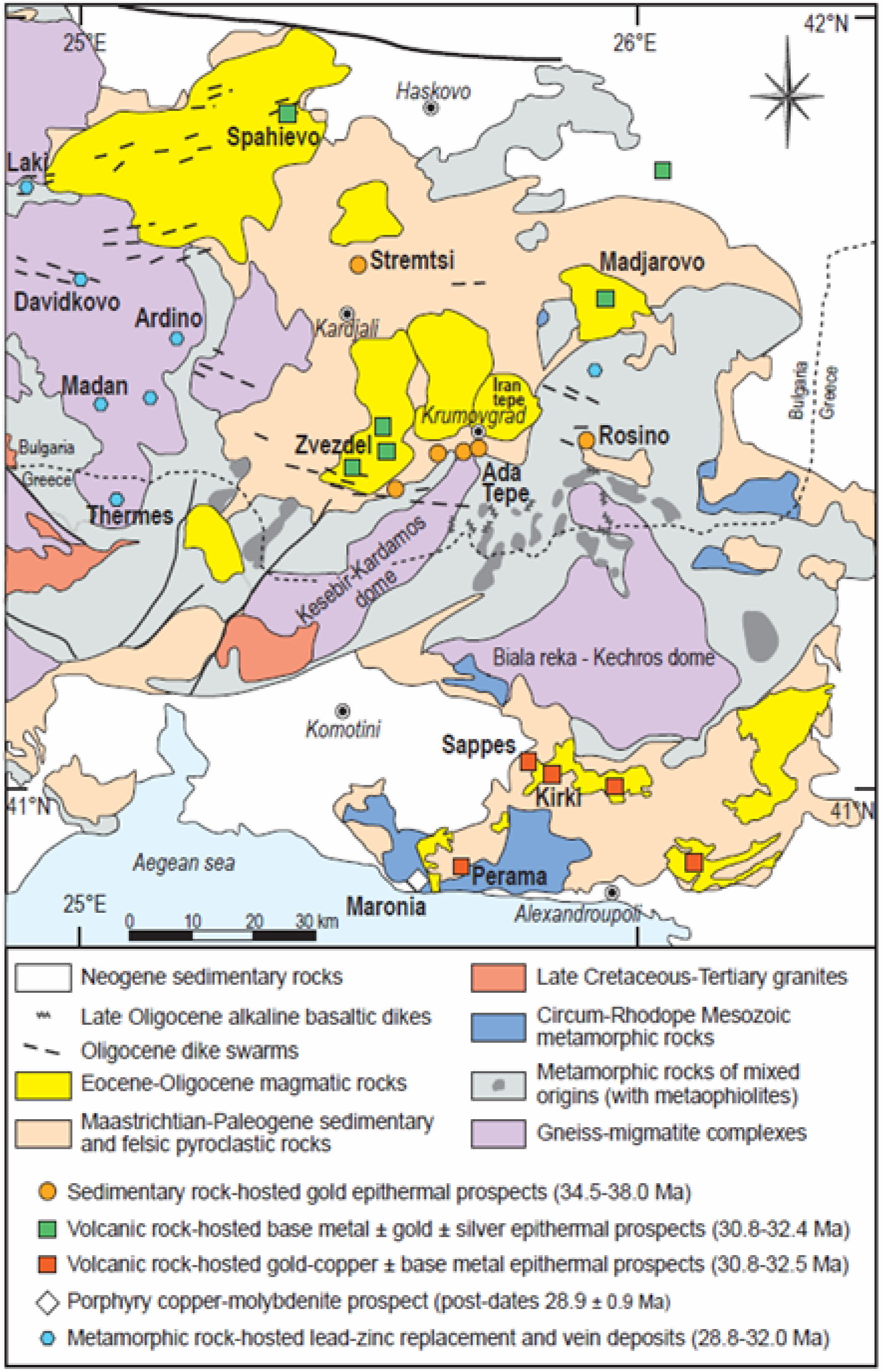
Melfos et al. (2002)

Skouries/Chalkidiki

(porphyry Cu-Au deposit: native gold, hessite, sylvanite, merenskyite in chalcopyrite and bornite**)**

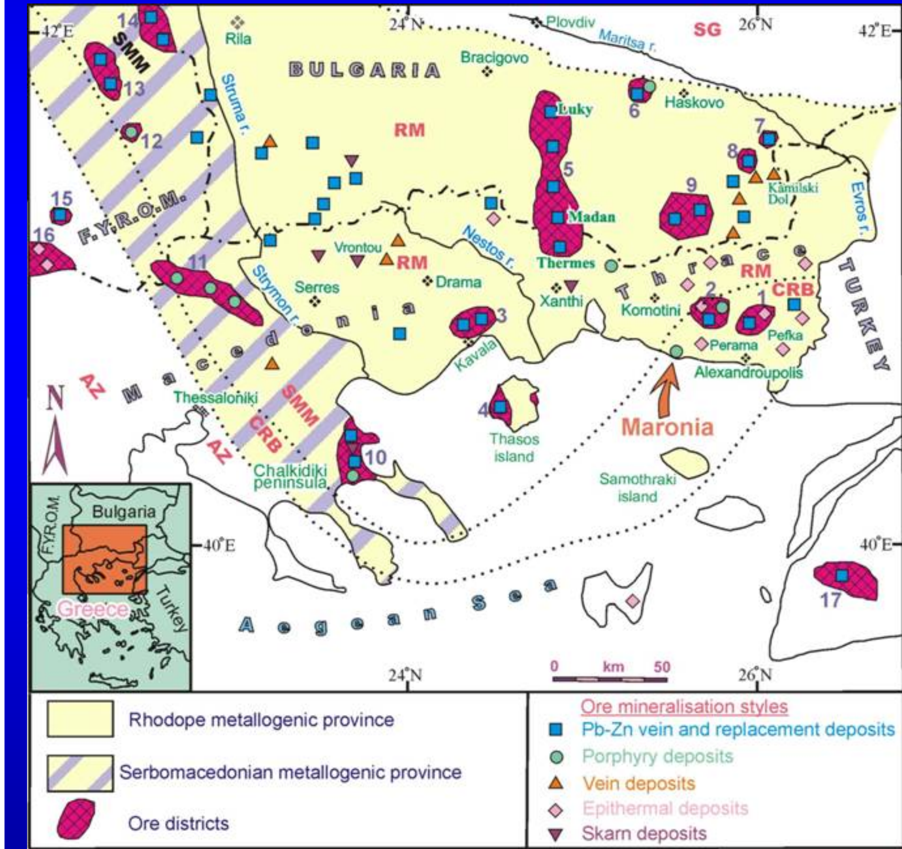


Tarkian et al. 1991

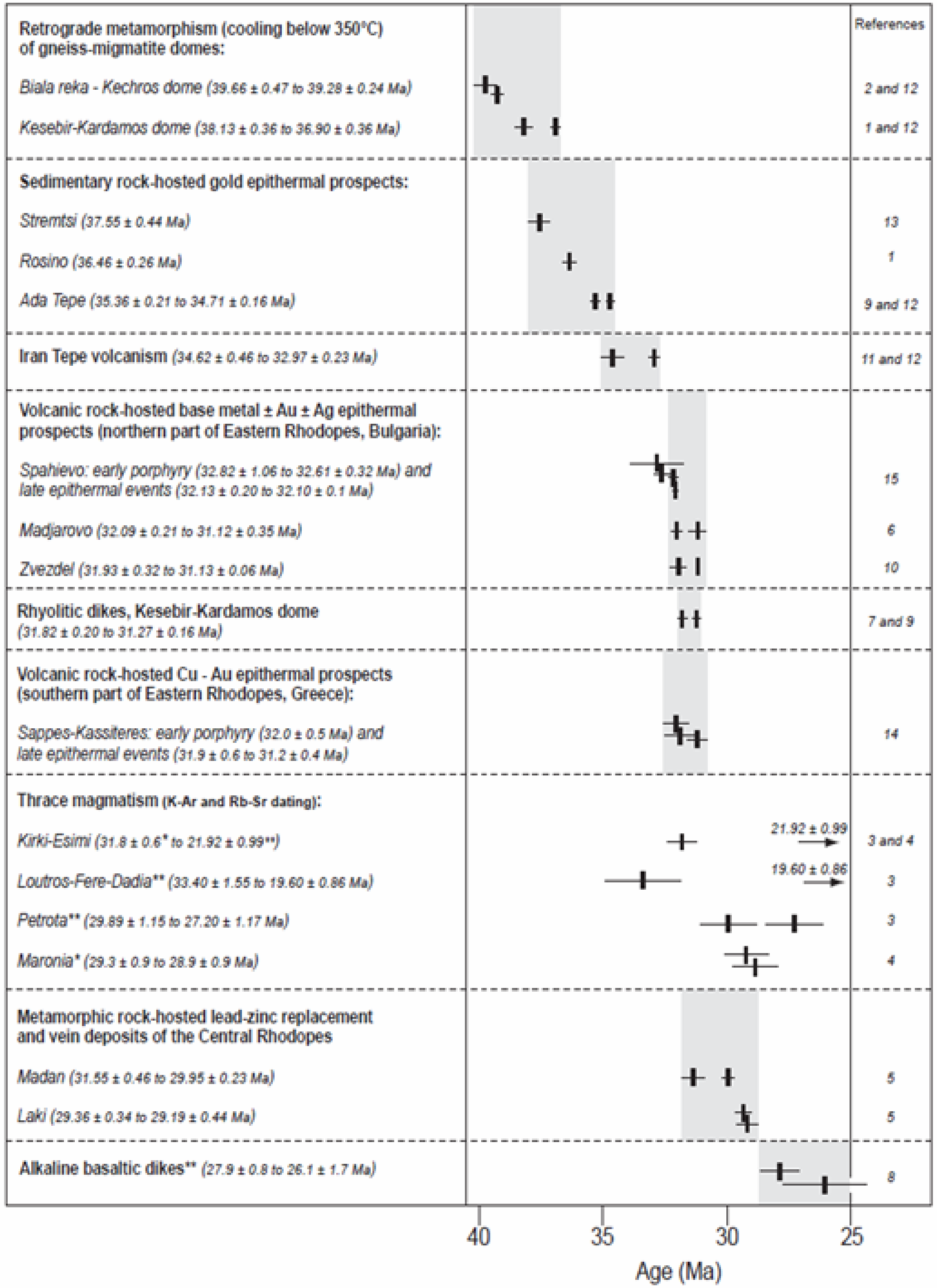


Poprhyry-epithermal systems in western Thrace

Sapes-Kassiteres, Pagoni Rachi-Kirki, Melitena/Komotini, Myli/Esymi, Ktisamta/Maronia, Perama Hill, Mavrokoryfi, Pefka

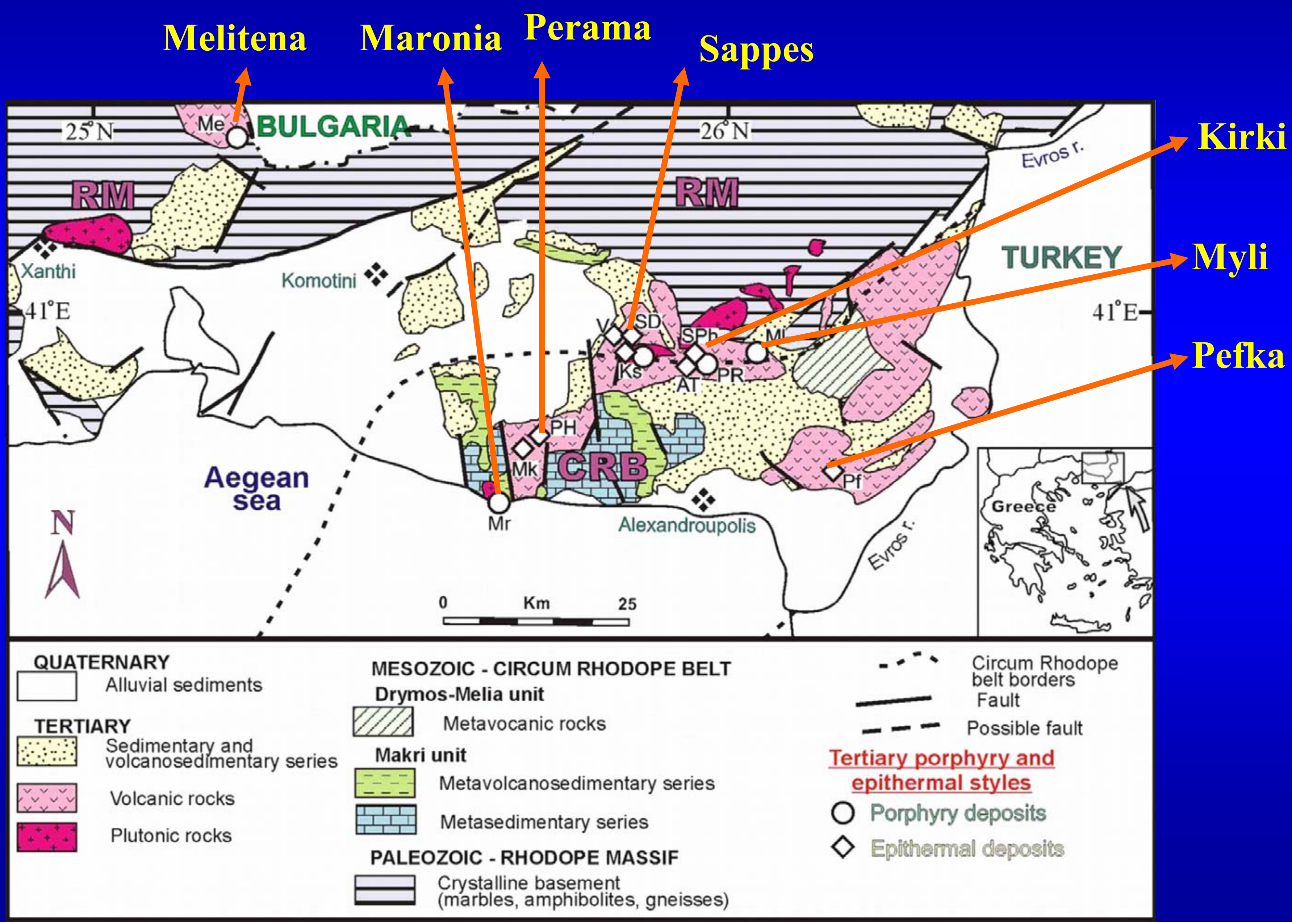


Moritz et al. 2010

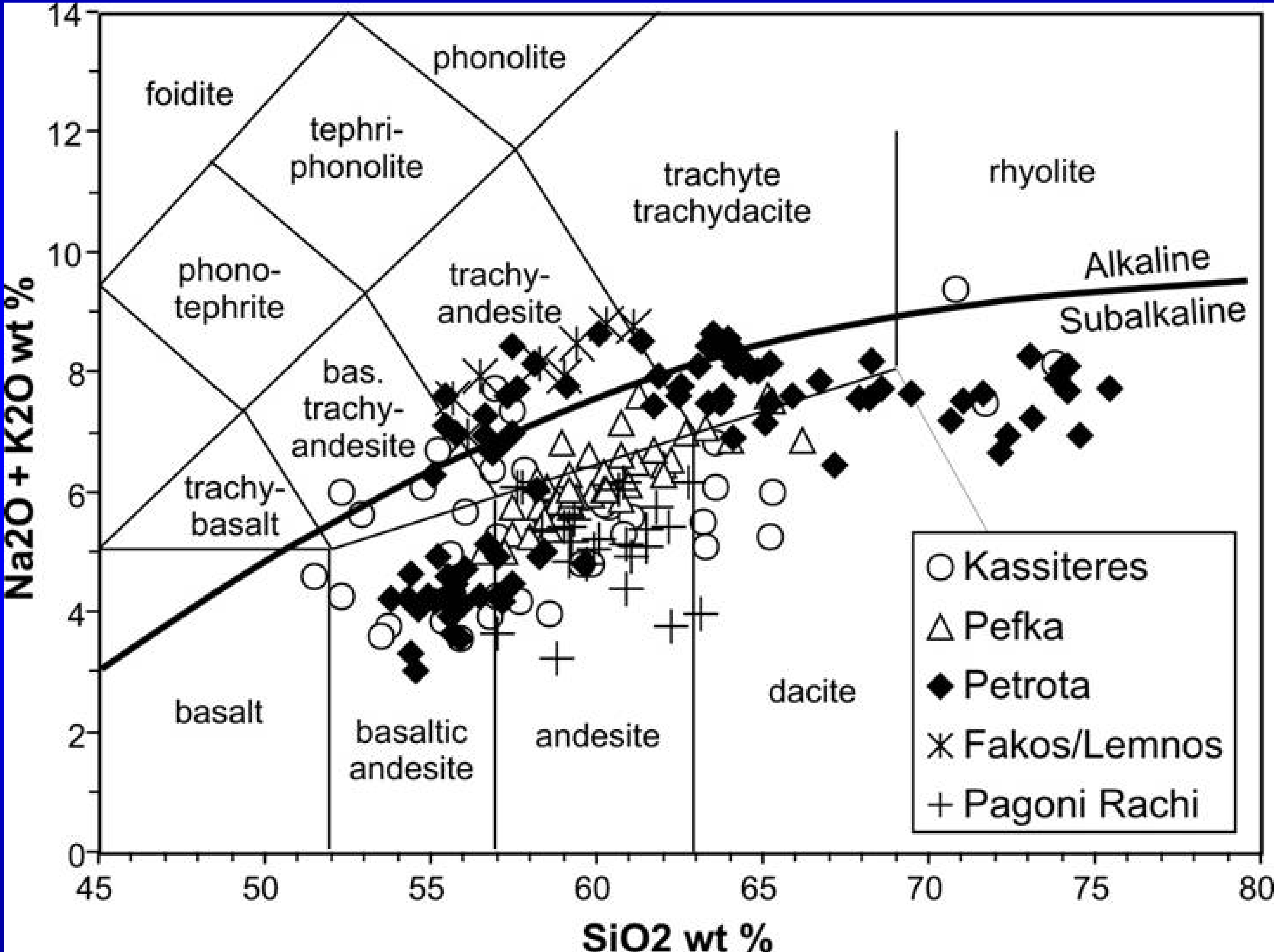


Moritz et al. 2010

Regional Geology



Northeastern Greece: Calc-alkaline to shoshonitic magmatism



Voudouris (2006)

Porphyry Cu-Mo±Au Mineralization

- **Three events of porphyry mineralisation**
  - **The first two ones (32-31Ma) are related to intermediate magmatism (diorite to quartz monzodiorite and dacite porphyry stocks)**
    - **Kassiteres/Sappes, Pagoni Rachi/Kirki, Myli/Esymi,**
  - **The late one (29-?Ma) is related to the acid magmatism (porphyry microgranite, rhyolite porphyry)**
    - **Ktismata/Maronia**

Porphyry Cu-Mo±Au Mineralisations

Deposit	Host intrusion	Alteration	Stockwork, veins	Advanced argillic lithocap
Pagoni Rachi/ Kirki	Dacite porphyry	Qtz-bi-alb/kfd, overprinted by qtz-ser-chl-cc	Qtz-py-cpy-mt-ht-mol, Gal-sph-cpy-tn-tellurides	Present alongside
Kassiteres/ Sappes	Monzodiorite Dacite porphyry	Qtz-bi-alb/kfd overprinted by qtz-ser-cor, qz-dia-alu, qtz-ser-kao-cc	Qtz-py-mol-cpy-mt, Gal-sph-cpy-td/tn-tellurides	Present qtz-cor-dia-alu (above, barren), qtz-alu (alongside, mineralised)
Myli/ Esymi	Dacite porphyry	Qtz-bi-alb/kfd overprinted by qtz-ser-chl-cc	Qtz-py-cpy, Gal-sph-cpy-tn	None known
Ktismata Hill/ Maronia	Microgranite porphyry	Qtz-ser-chl overprinted by qtz-ser-chl-pyr	Qtz-py-cpy-mol, td/tn-cb-fa	Present qtz-pyr (qtz-alu alongside, barren Odontoto)
Melitena	Dacite porphyry	Qtz-ser-pyr-dia	Qtz-mol-py-cpy	Present above (qtz-dia-alu) Barren

Epithermal Au-Ag-Cu Mineralizations in western Thrace

- **Volcanic-hosted (also within sandstones, basement)**
- **Postdate the emplacement of rhyolitic dikes**
- **Three stages of evolution**
  - **Initial stage of acid leaching**
  - **Deposition of HS enargitic ore**
  - **Deposition of IS ore with chalcopyrite-tetrahedrite ss**
  - **Gold as native element and tellurides with both ore assemblages**

Sappes (Viper, St Demetrios, Kassiteres)
Perama (Perama Hill- Mavrokoryfi)
St Philippos/Kirki
Pefka

Epithermal Au-Ag Mineralisations

Location	Deposit Type	Metals	Host rocks	Relation to porphyry systems
Viper	HS-IS veins, breccias	Cu, As, Au, Ag, Te, Bi	Ash tuff, lavas	Alongside Kassiteres
St Demetrios	IS-HS stockworks, breccias	Cu, As, Au, Ag, Te, Bi	Lavas, rhyodacitic Pyroclastics	Alongside Kassiteres, mineralization at depth ?
Kassiteres	IS veins, breccias Also HS veins	Cu, As, Au, Ag, Te	Volcanics, Monzodiorite, Rhyolite	Alongside Kassiteres
Perama Hill	HS disseminations, Veins, breccias	Au, Ag, Cu, As, Sn, Te	Sandstones, Volcanics	Alongside Maronia
Mavrokoryfi	HS breccias	Cu, As, Au, Ag, Te	Andesitic breccias	Alongside Maronia
St. Philipp	HS breccias	Pb, Zn, Ag, Cu, As, Bi, Sn	Sediments, Rhyolite porphyry	Alongside Pagoni Rachi
Pefka	IS-HS veins	Cu, As, Au, Te, Bi, Sn	Volcanics	None known

Melitena

Porphyry Mo-Cu
HS Epithermal Au

Porphyry Mo-Cu deposit in Melitena

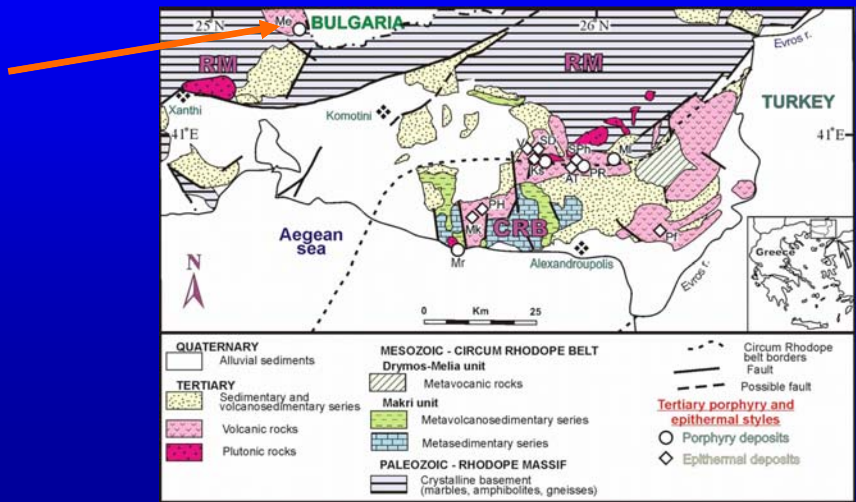
The porphyry Cu-Mo mineralization in Melitena is associated with a Tertiary subvolcanic dacite.

<u>Alteration zone</u>: Sericite, argillic, silicified. A later epithermal event overprints the porphyry type mineralisation

Cu up to 400 ppm, Zn up to 500 ppm, Mo up to 6000 ppm, Au up to 0.3 ppm

The <u>ore mineralization</u> consists of pyrite and molybdenite.

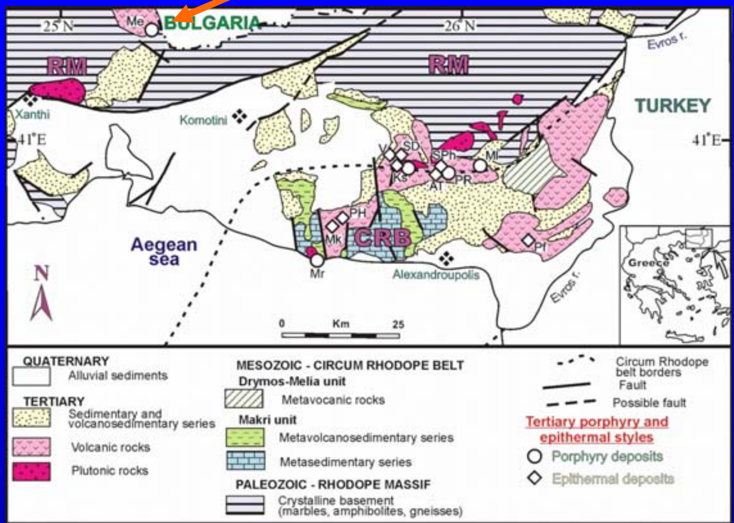
<u>Microthermometric results</u>: homogenisation temperatures from 295° to 363°C and salinities from 2.7 to 3.4 %wt equiv. NaCl.



Melitena: porphyry Mo prospect

Quartz stockworks associated with sericitic and advanced argillic (pyrophyllite, diaspore, APS minerals) alteration of dacite. Silicic alteration on top includes alunite-diaspore.

Melitena

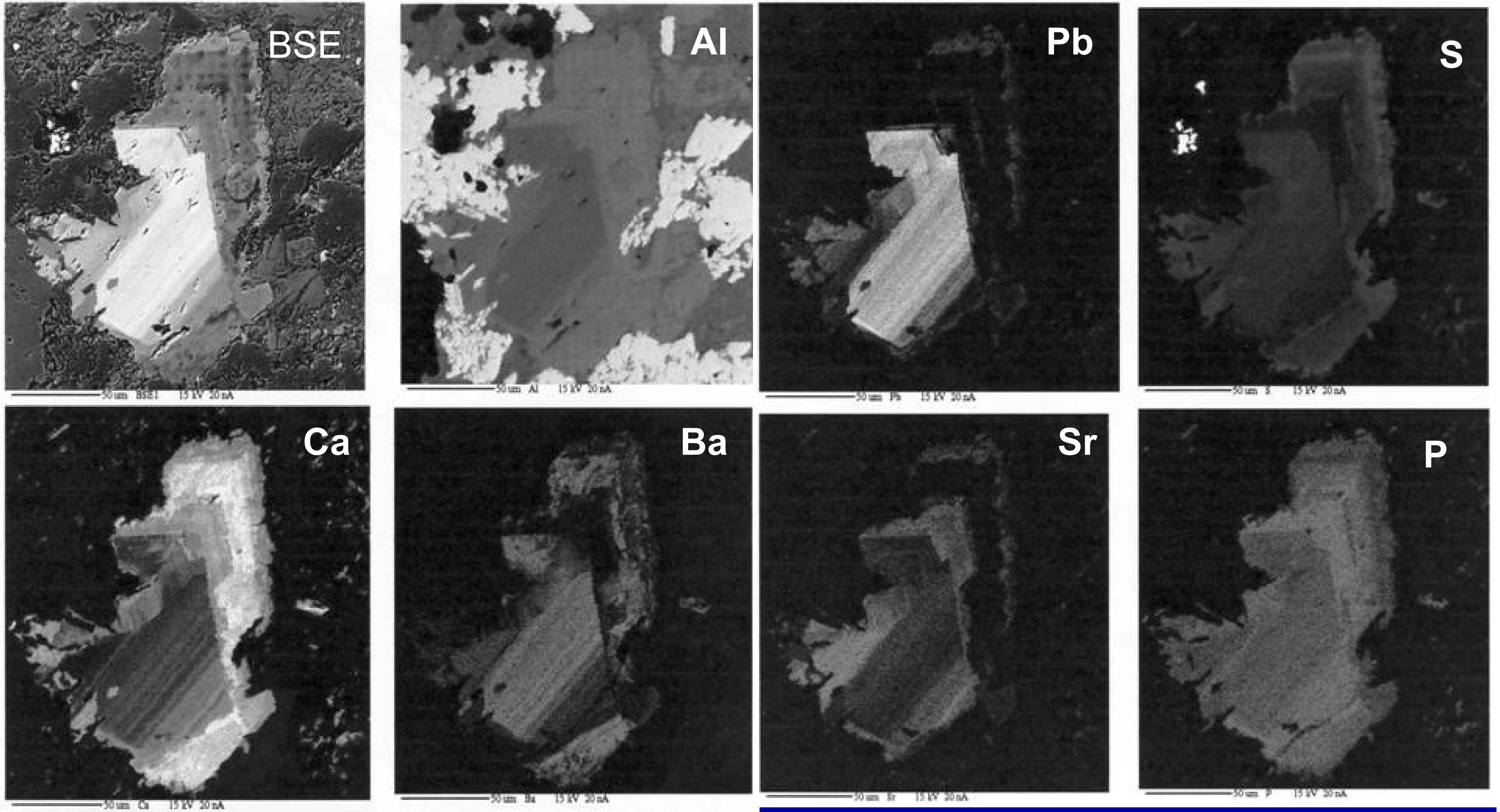


Sericite-pyrophyllite-APS

Quartz-MoS_2

Diaspore-alunite

Element scaning within an APS crystal at Melitena



Core: Ba-rich hinsdalite-woodhouseite-swanbergite → Rim: Ba-rich woodhouseite

Re content in molybdenites

	Melitena		
Wt%	n=49	sd	aver
Re	**0.21-1.74**	**(0.39)**	**0.79**
Mo	57.99-60.20	(0.54)	59.36
Fe	0.00—0.02	(0.01)	0.01
S	38.42-41.85	(0.70)	39.53
			Ator
Re	0.00-0.02	(0.00)	0.01
Mo	0.95-1.02	(0.01)	1.00
Fe	0.00	(0.00)	0.00
S	1.98-2.04	(0.01)	1.99

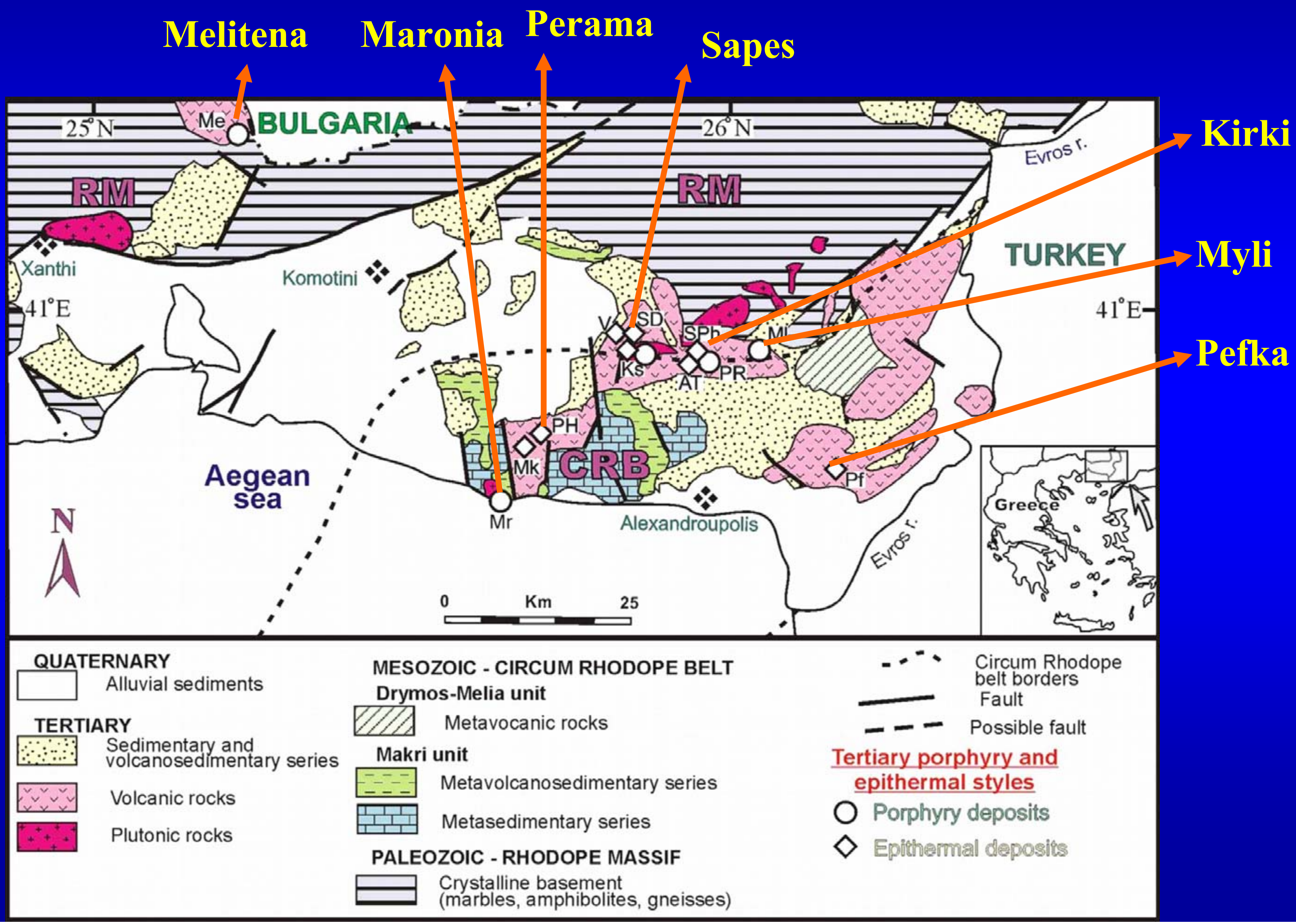
Melfos et al. (2001)

Sapes-Kassiteres

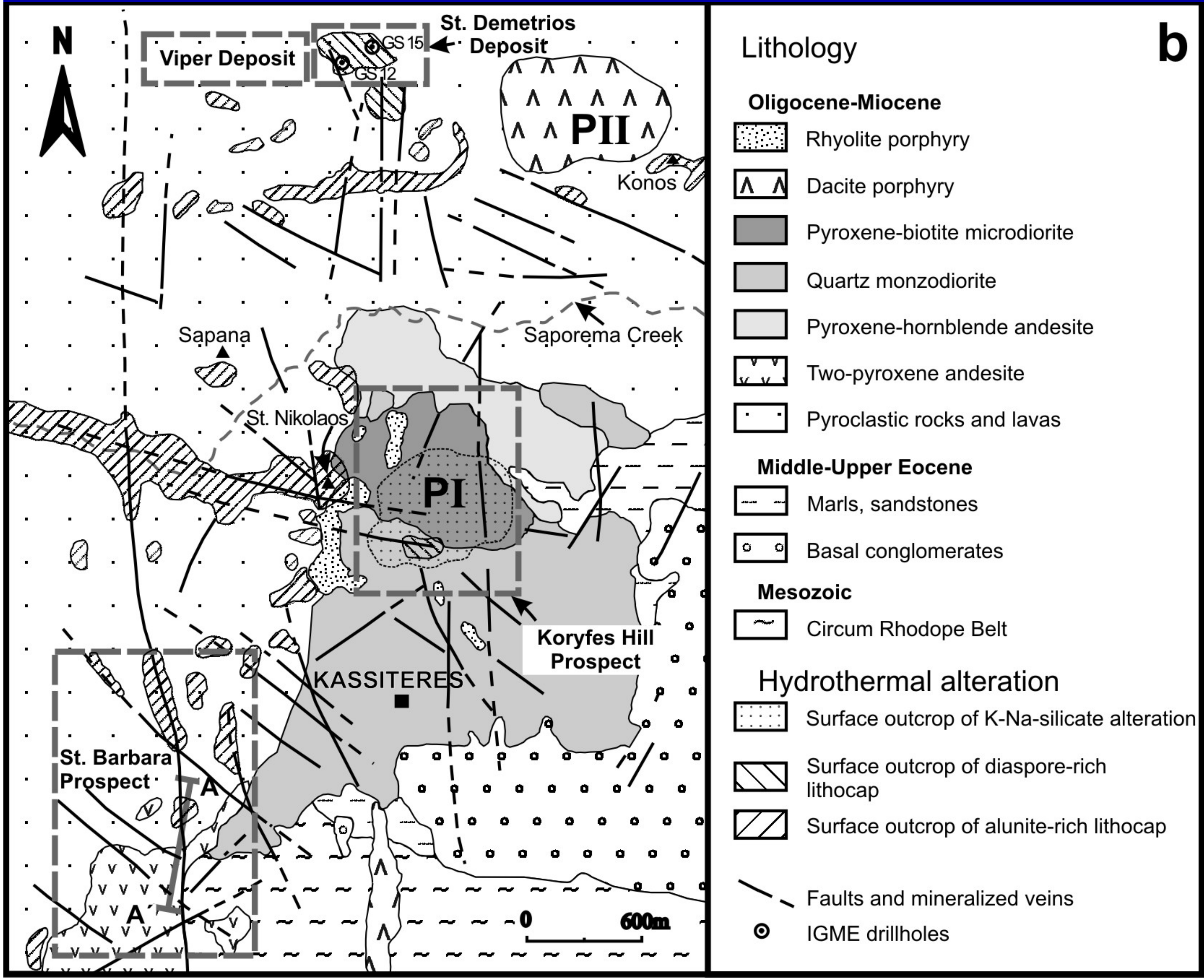
porphyry Mo-Re-Sn-Cu-Au

HS epithermal Au-Ag-Cu-Te

Regional Geology

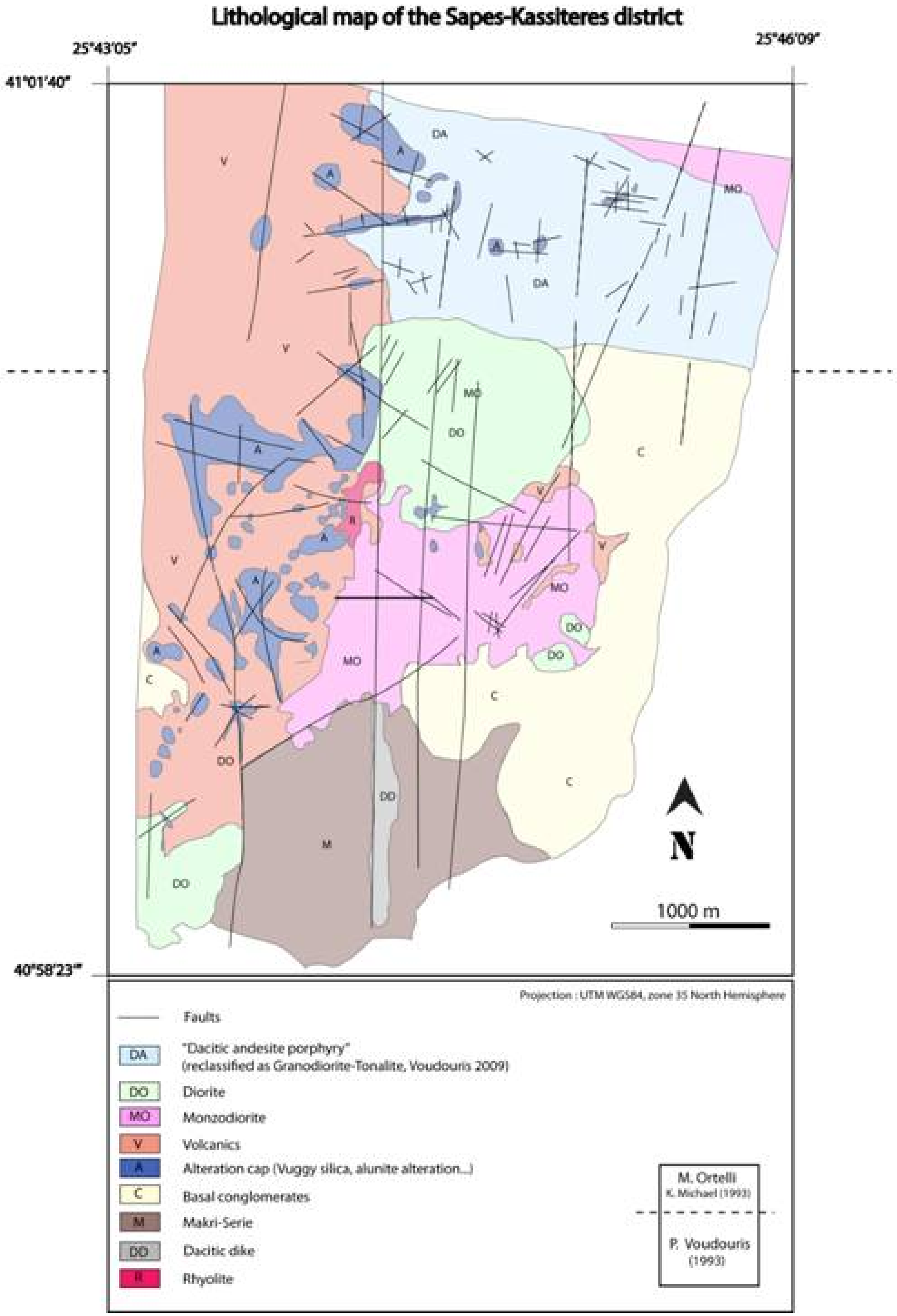


Sapes/Kassiteres

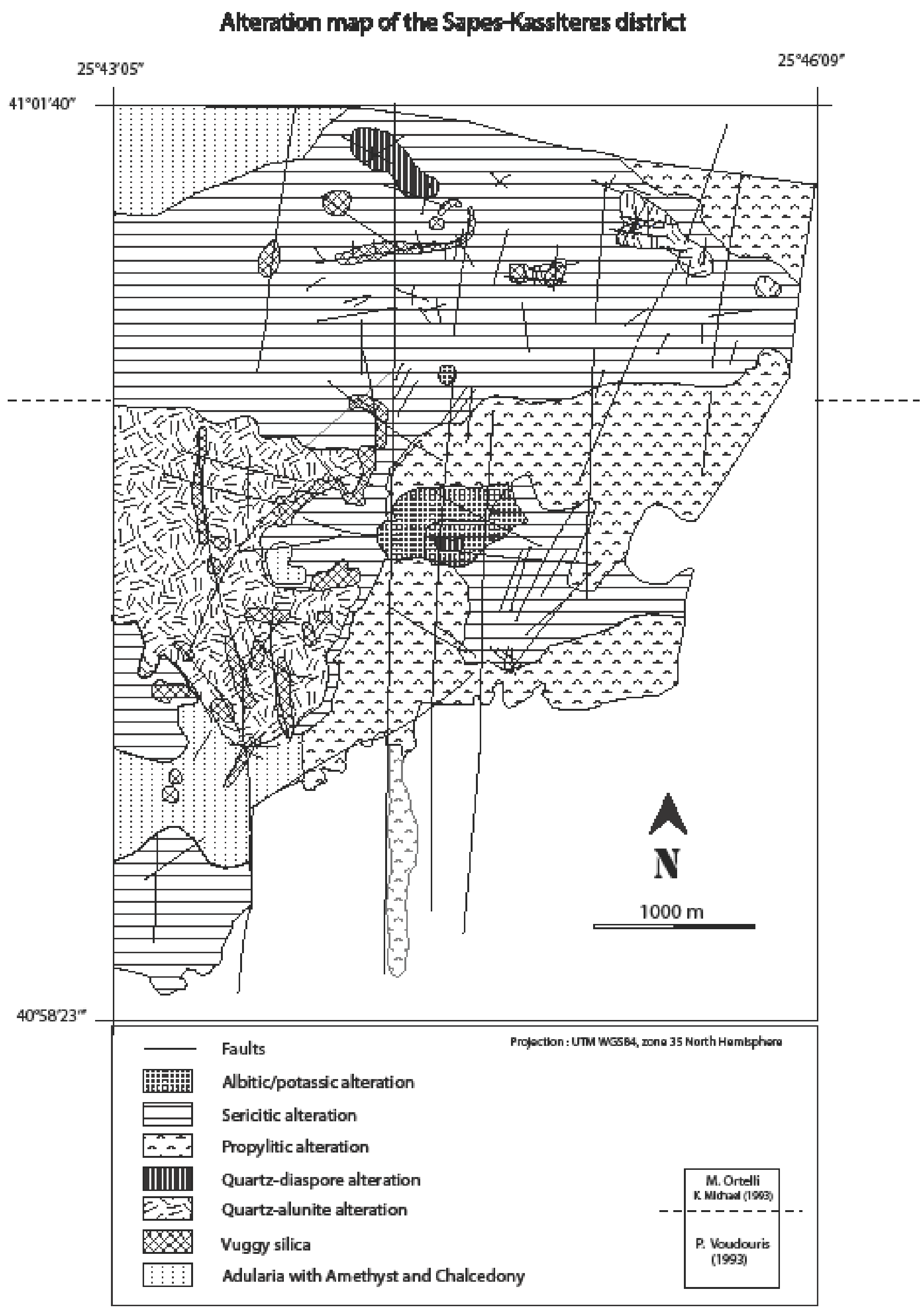


PI, PII: porphyry Cu-Mo mineralization

Voudouris et al. 2006



Ortelli et al. 2009



Ortelli et al. 2009

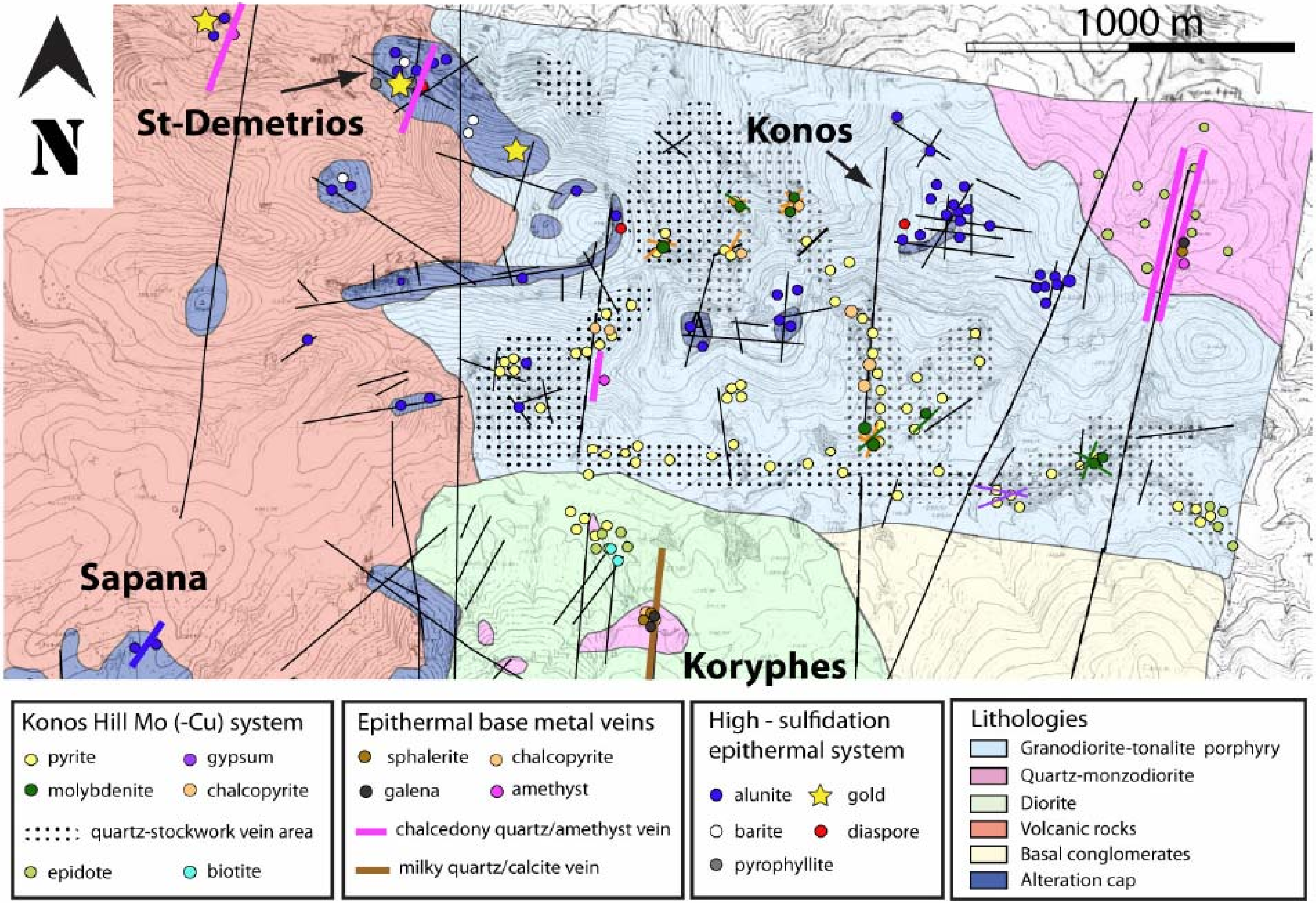


Fig. 3.2 : The Konos/St-Demetrios mineralization systems (see text for discussion).

Ortelli 2009, unpubl. Master thesis, Univ. Geneva

Konos Hill/Sapes (porphyry-epithermal prospect)

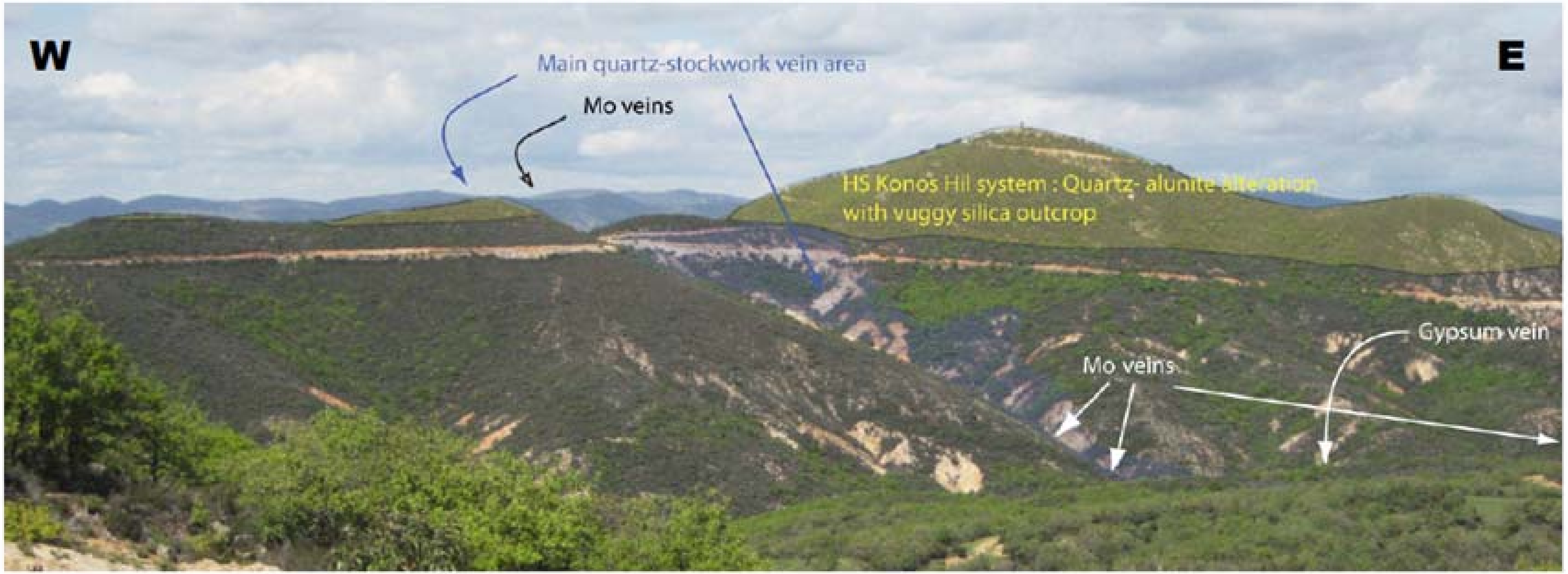


Fig. 3.1 : Landscape with the Konos Hill southern slope. The yellowish shaded area is representing the high-sulfidation system with widespread quartz-alunite alteration with minor vuggy silica restricted along N-S and W-E oriented faults. The blue shade area is representing the main quartz-stockwork vein area, where the best outcrops show molybdenite-pyrite and quartz veins suitable for fluid inclusions analyse (see chapter Fluid inclusions analyses). Curved arrows indicate the northern slope.

Ortelli 2009, unpubl. Master thesis, Univ. Geneva

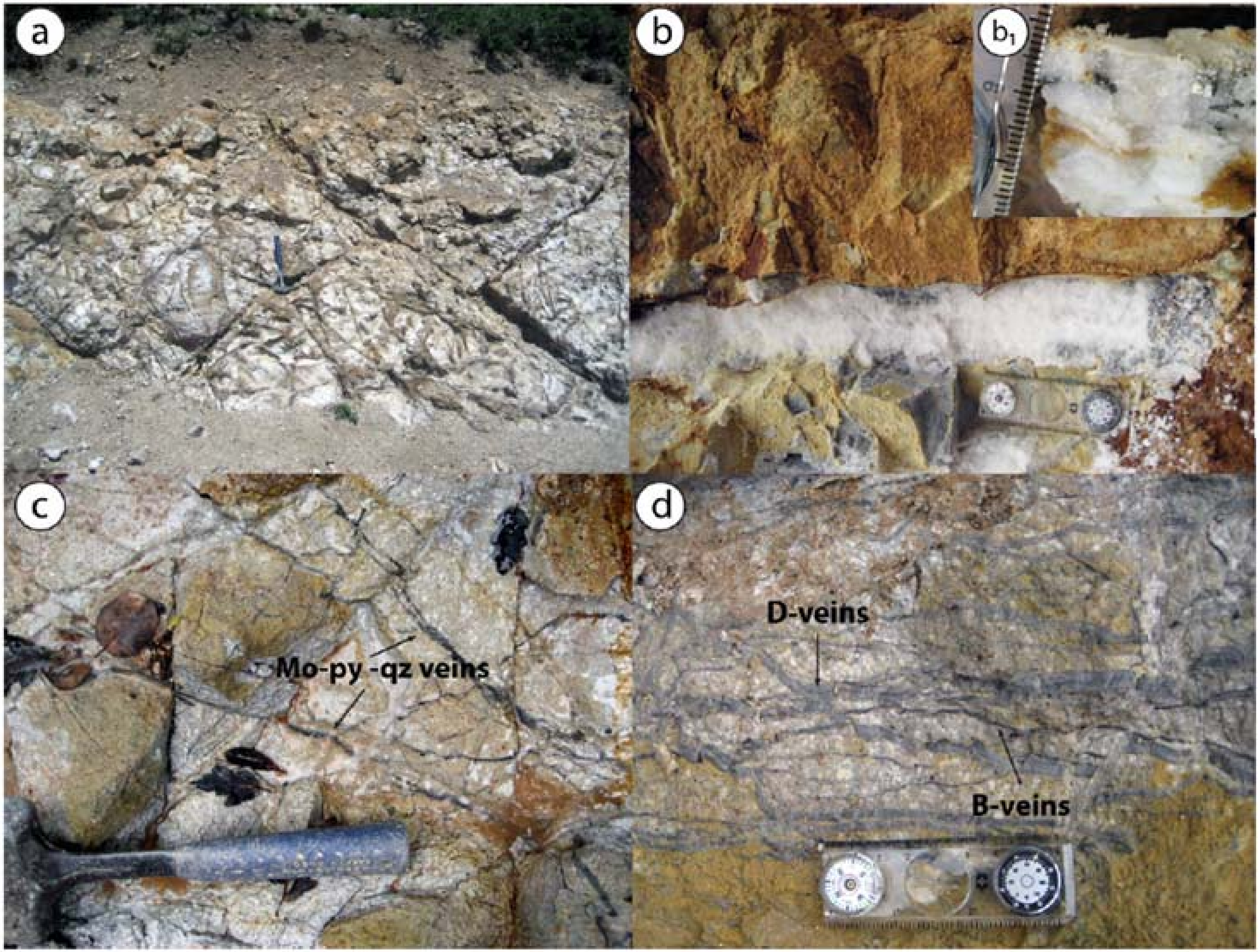
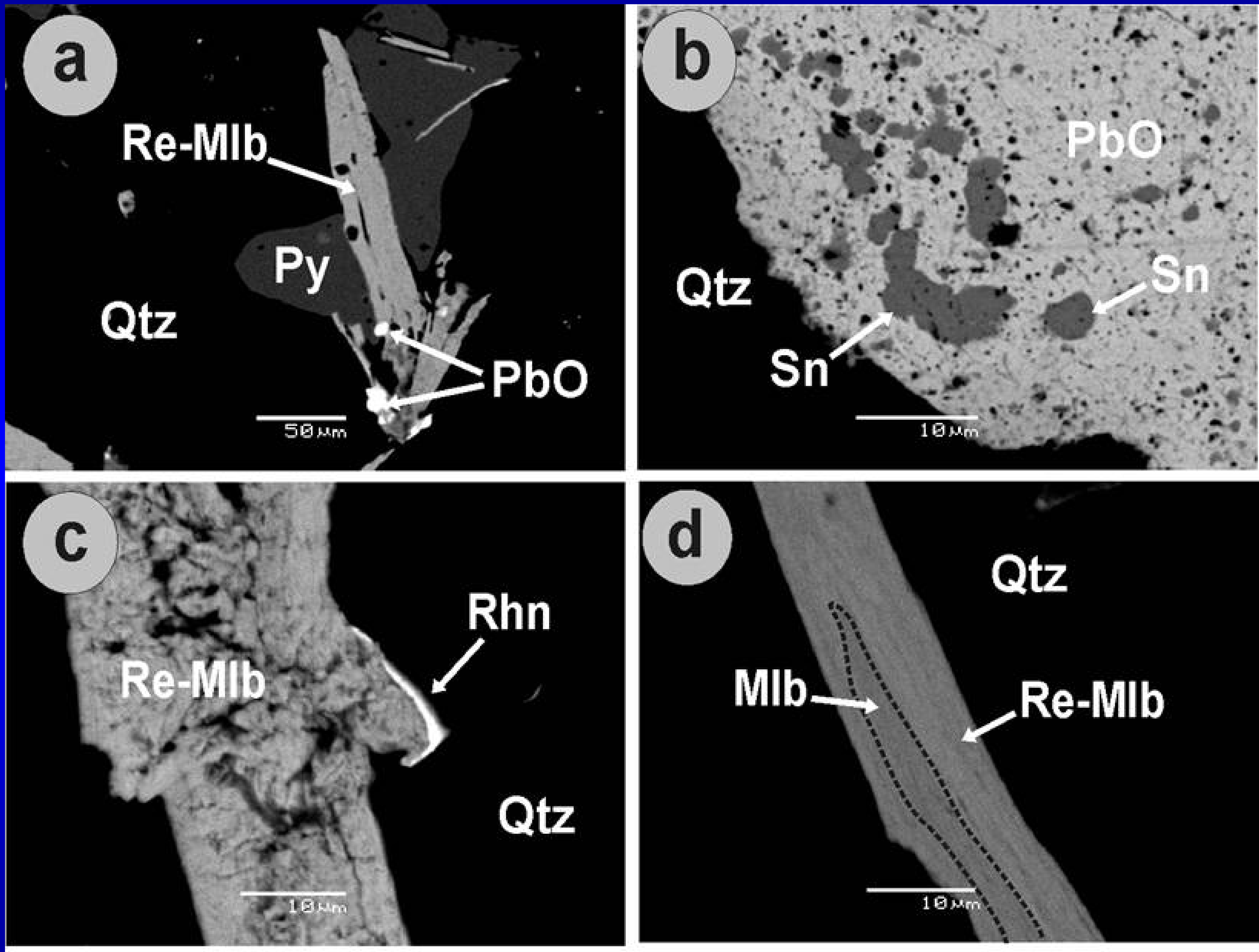


Fig. 3.3 : **a)** Oxydized quartz-vein stockwork outcropping along the road (Fig. 3.1). **b)** Gypsum vein with sulfides in the sericitic altered granodiorite-tonalite. **b_1)** Cubic pyrite crystals in the gypsum veins with chalcopyrite and sphalerite. **c)** Molybenite-quartz-pyrite veins with with dark gray quartz "B"-veins. **d)** Quartz-pyrite-sericite "D"-veins crosscut by dark "B"-veins.

Ortelli 2009, unpubl. Master thesis, Univ. Geneva

Sapes porphyry-Mo prospect: Re-rich molybdenite, rheniite, native Sn



Voudouris et al. (2010a)

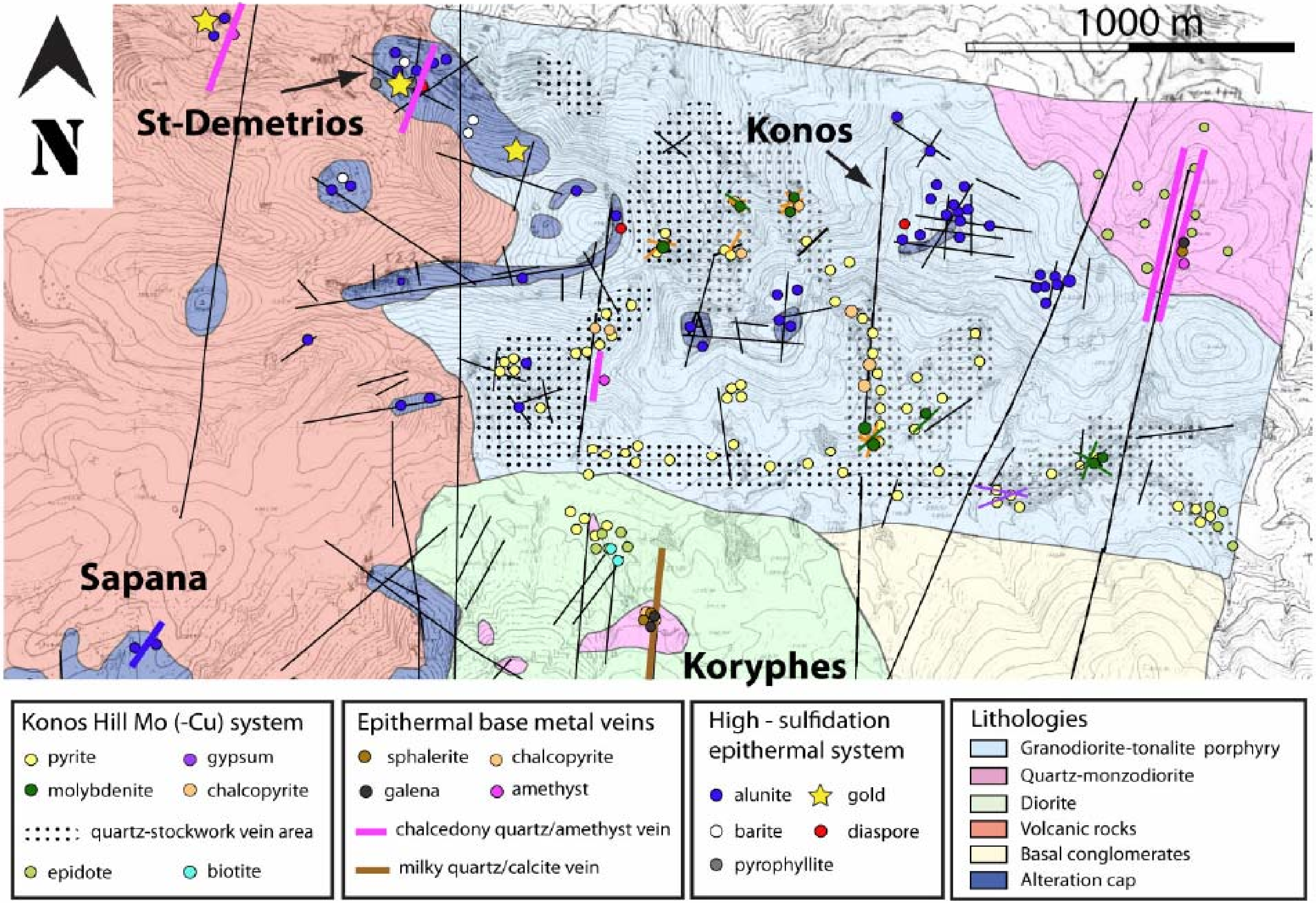
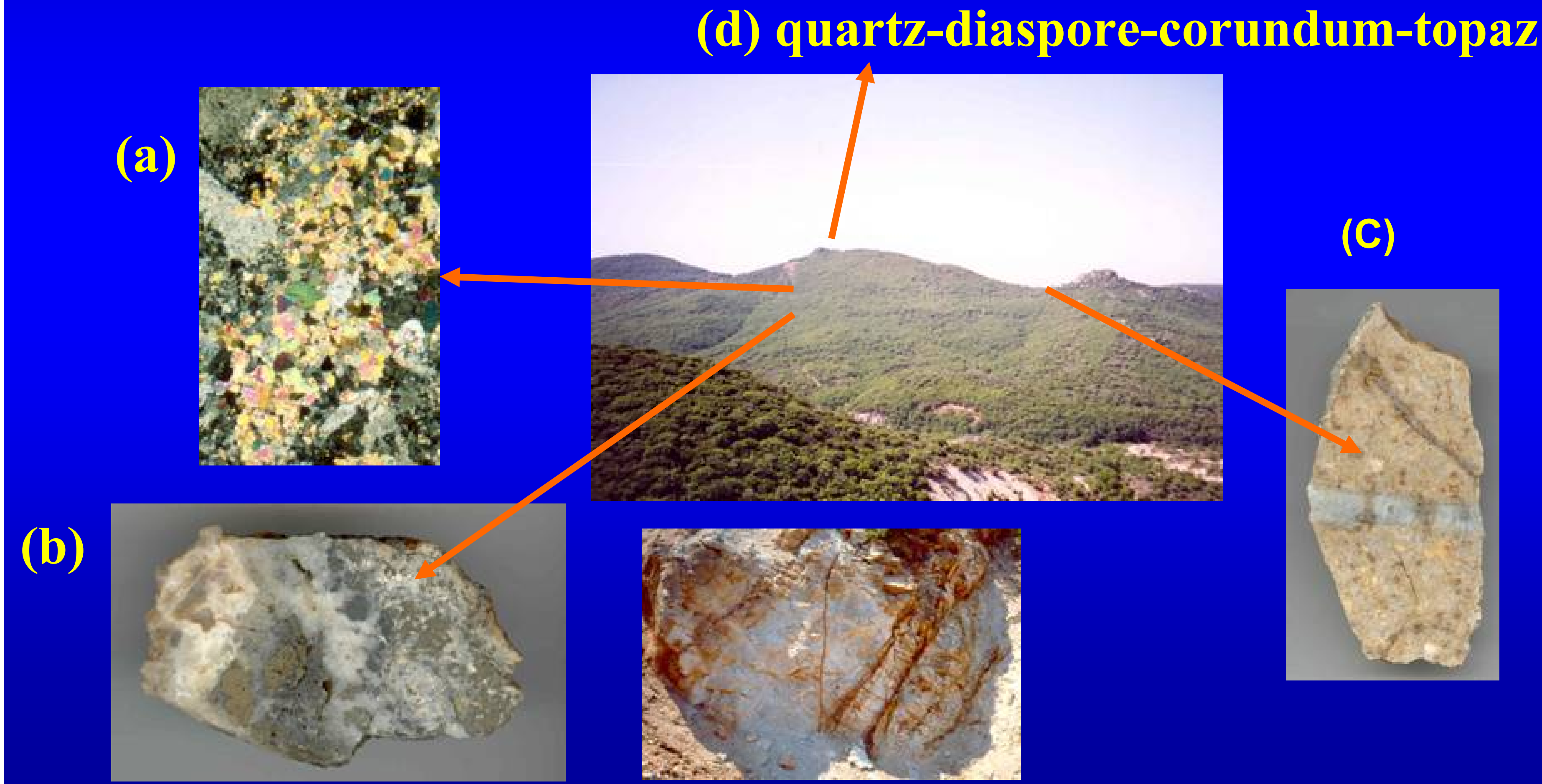


Fig. 3.2 : The Konos/St-Demetrios mineralization systems (see text for discussion).

Ortelli 2009, unpubl. Master thesis, Univ. Geneva

Koryphes porphyry-Cu prospect

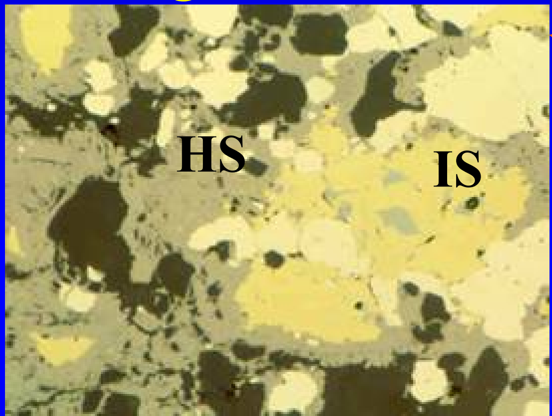
K-silicate alteration (a) overpinted by IS polymetallic veins (b) with sericitic alteration. Late-stage veins postdate intrusion of rhyolite dikes (c). Barren lithocap (d) present

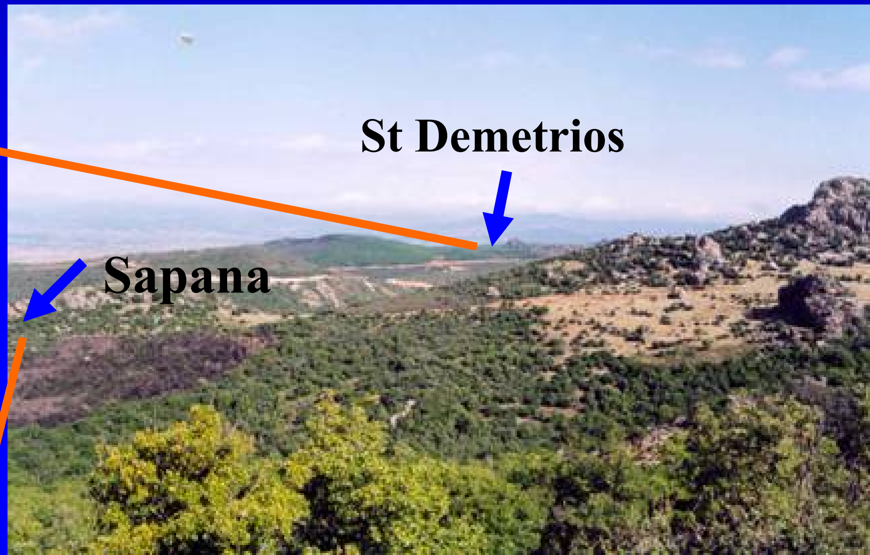


St Demetrios deposit – Sapana prospect

From IS towards HS mineralisation?. Introduction of precious metals (Gold and Au-Ag-tellurides) with both assemblages

Enargitic ore

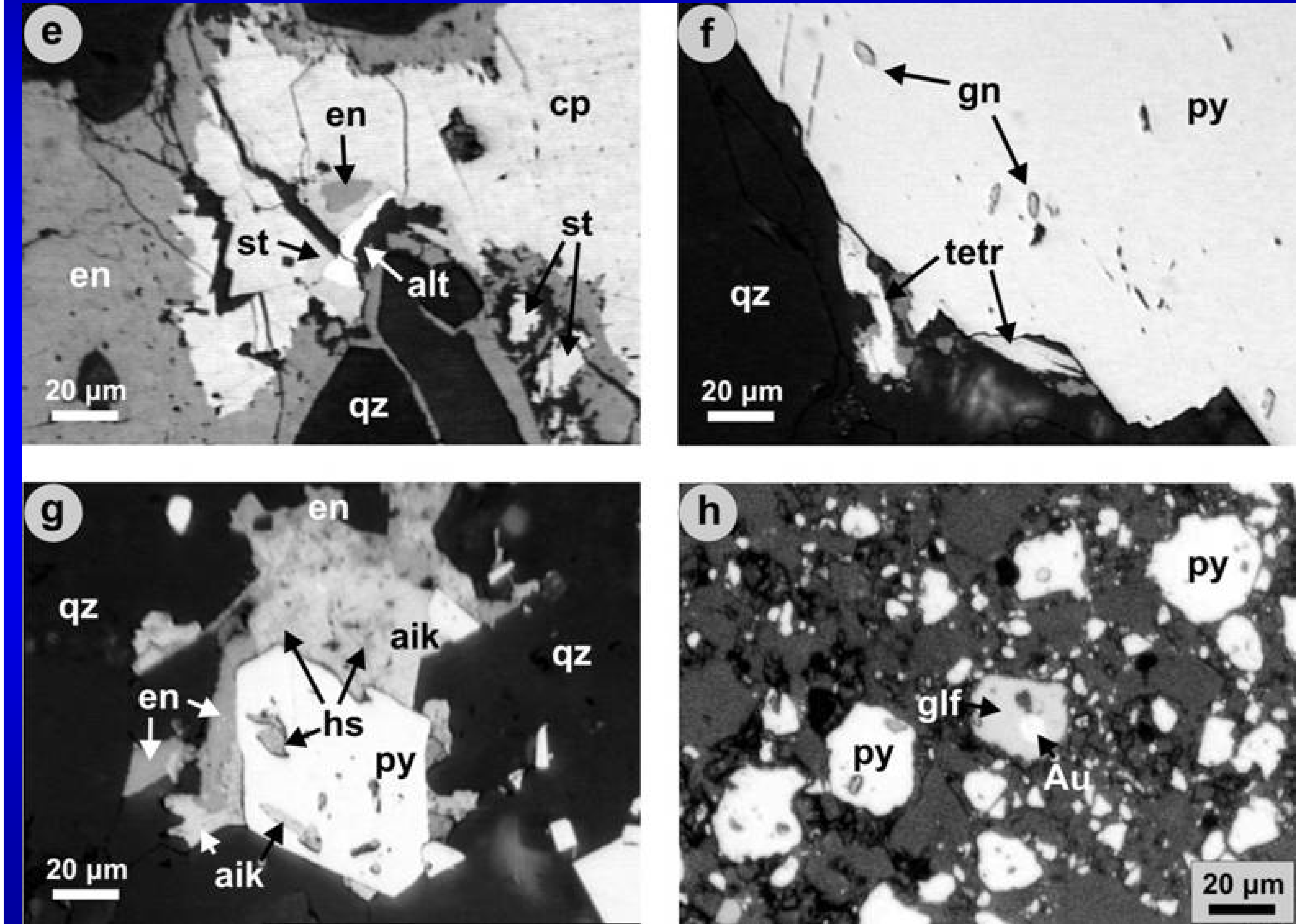




Native gold

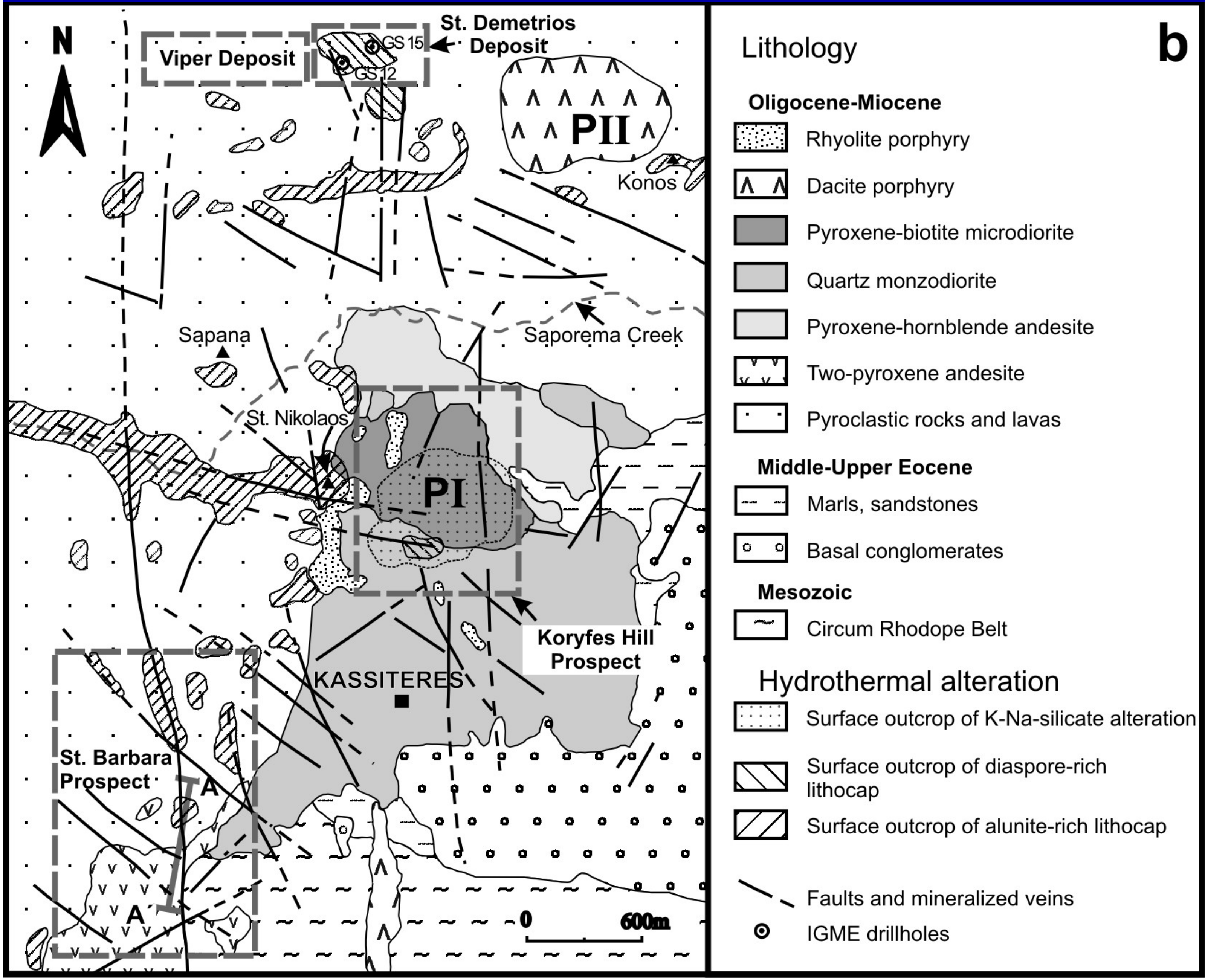
Alunitic alteration and alunite veining accompanies enargitic ore

St Demetrios: hessite, stützite, goldfieldite, tetradymite, native gold, aikinite



Voudouris et al. (2006)

Sapes/Kassiteres



PI, PII: porphyry Cu-Mo mineralization

Voudouris et al. 2006

Kassiteres – St Barbara prospect

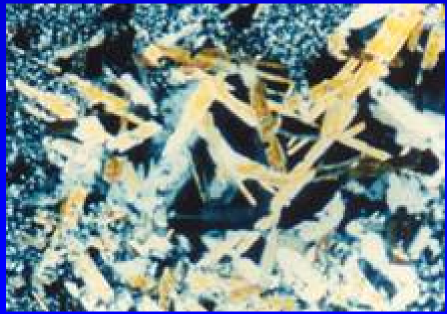
Precious metal veins developed below silicic and advanced argillic alteration: Early IS quartz-carbonate veins with Au-Ag tellurides are overprinted by late IS quartz veins with base metals

Advanced argillic alteration

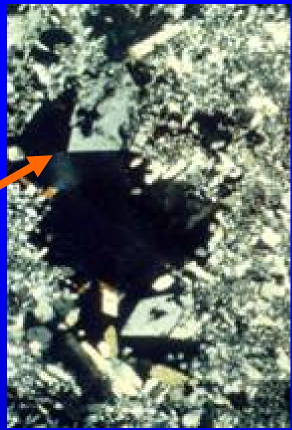
quartz veins

K-feldspar alteration

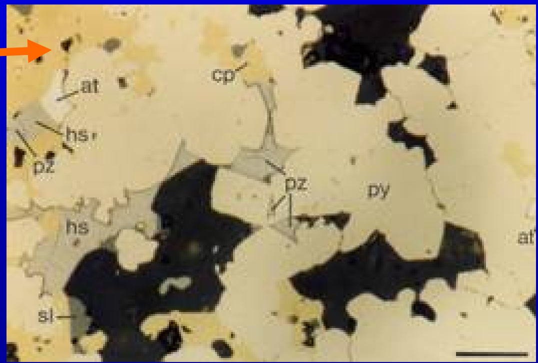
Quartz-cc-veins, Au-Ag-tellurides



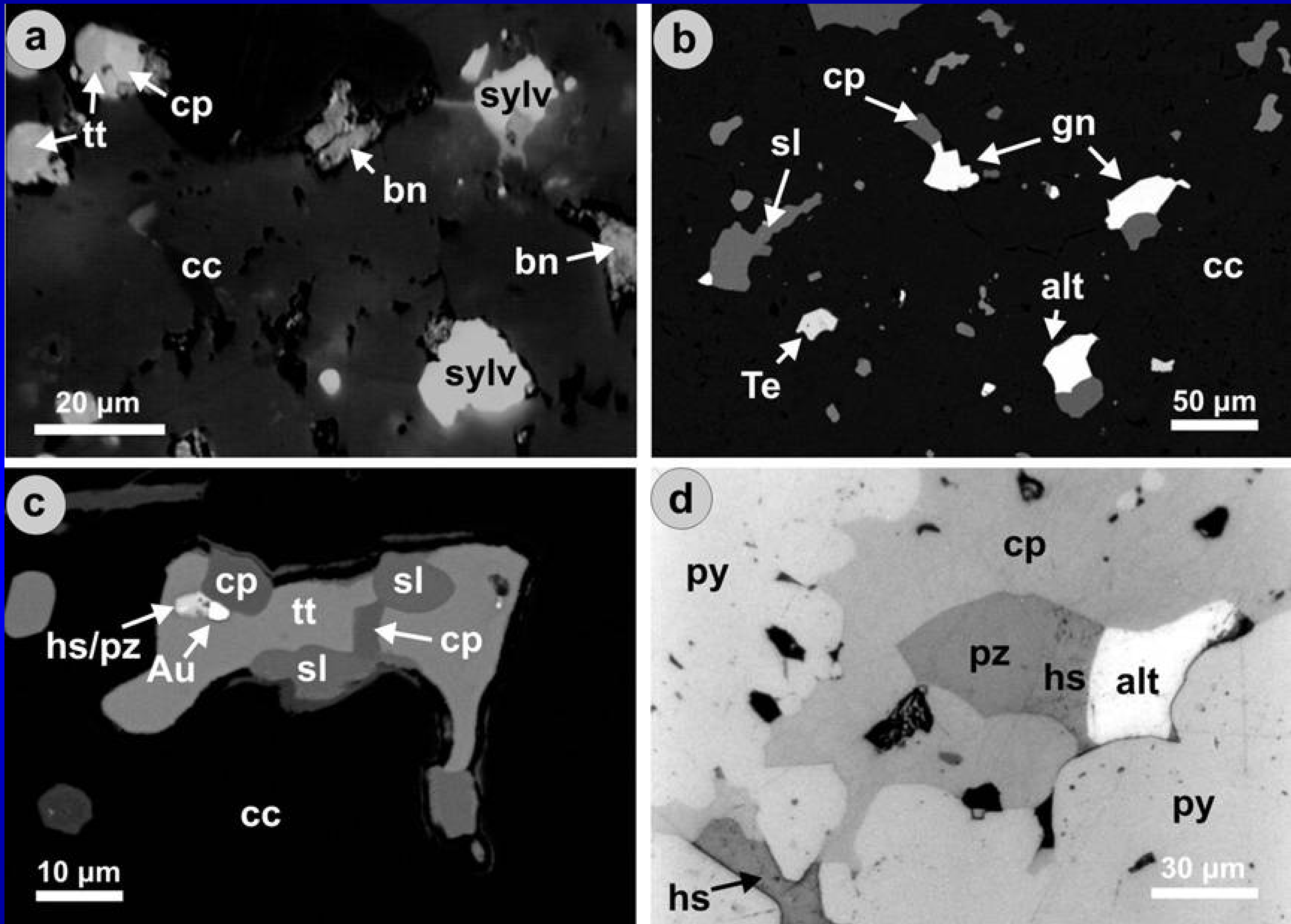
Alunite



Adularia

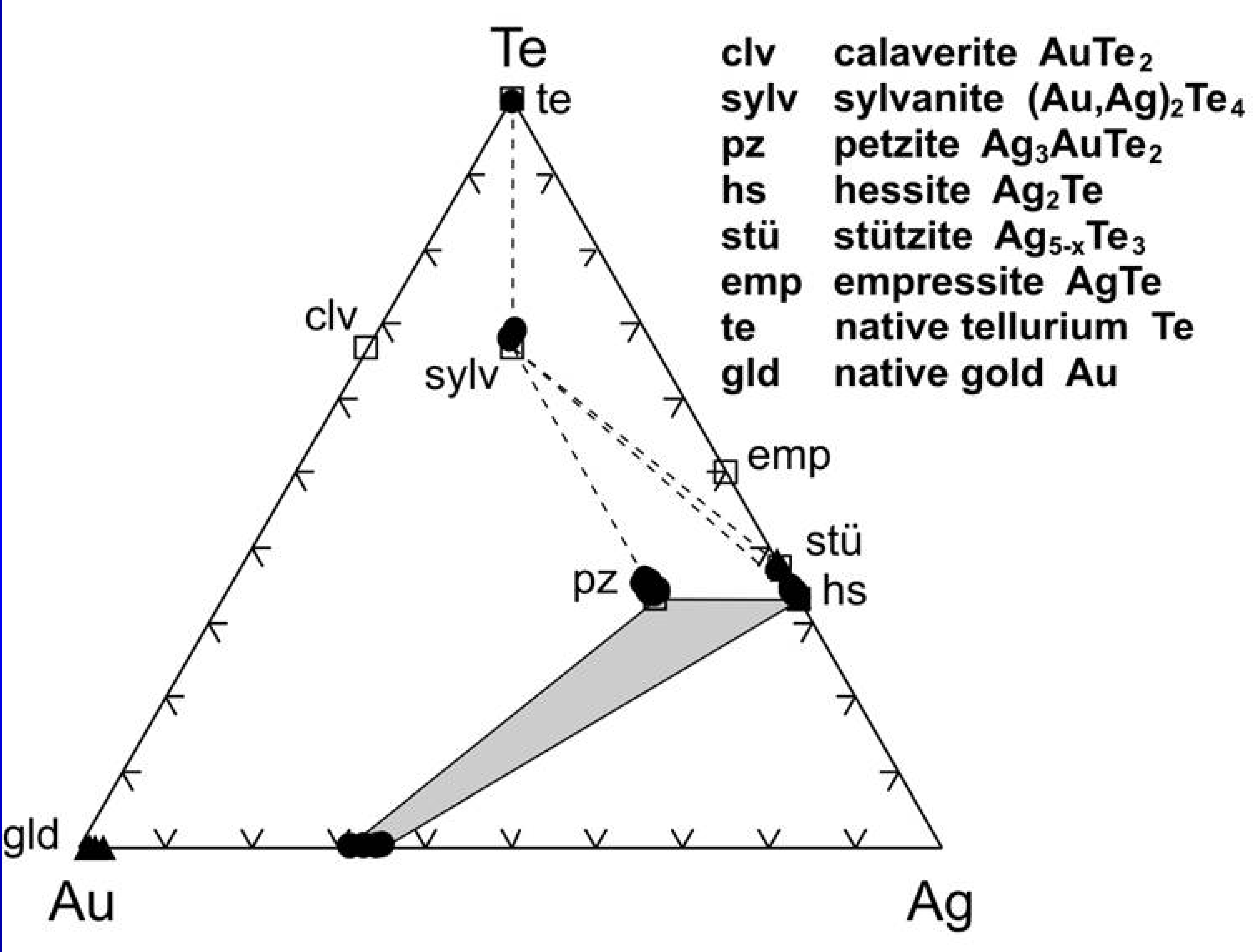


St Barbara: hessite, petzite, sylvanite, electrum, native Te



Voudouris et al. (2006)

Kassiteres-St Demetrios/Sappes



Voudouris et al. (2006)

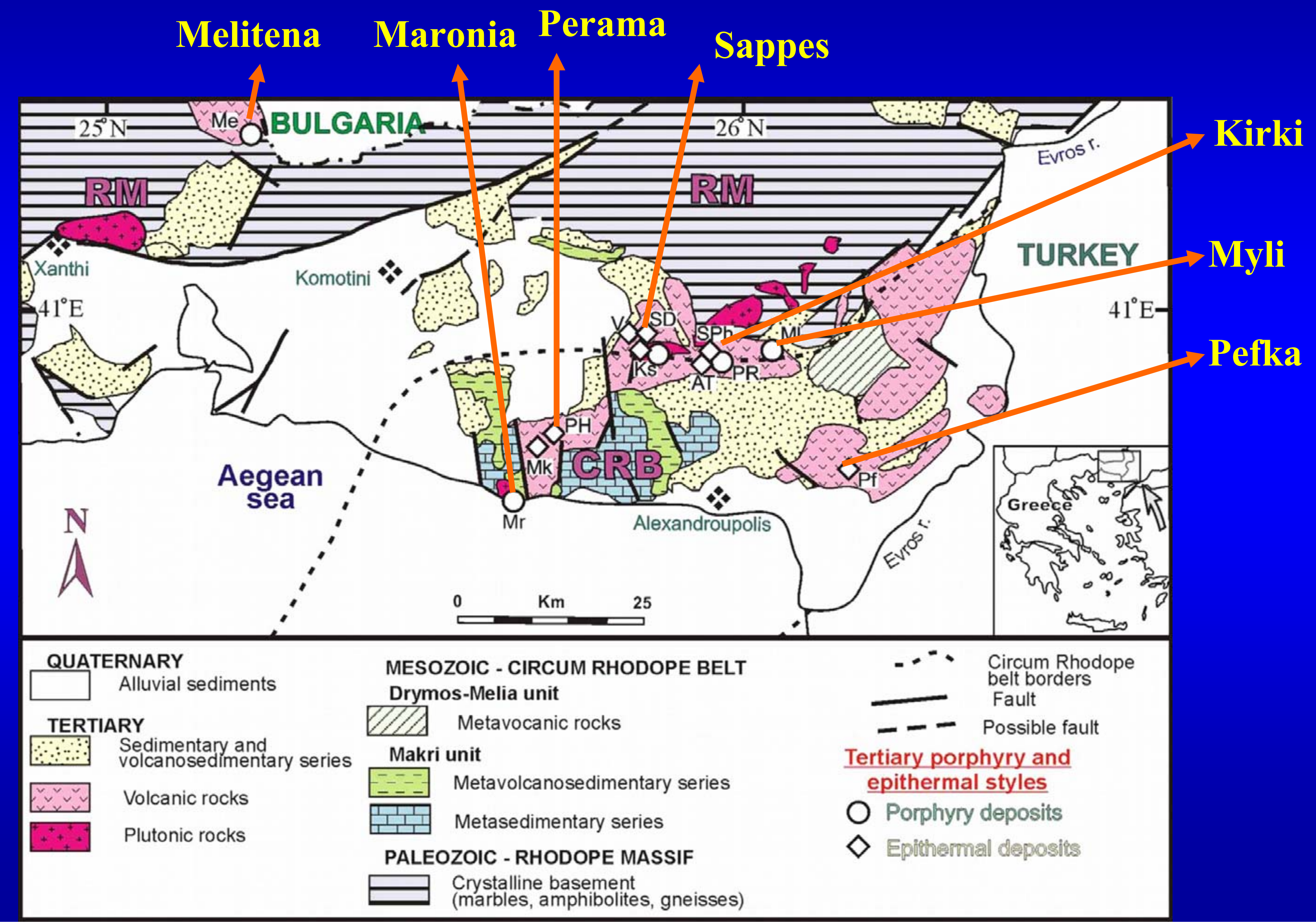
Pagoni Rachi

porphyry Mo-Re-Sn-Au-Te

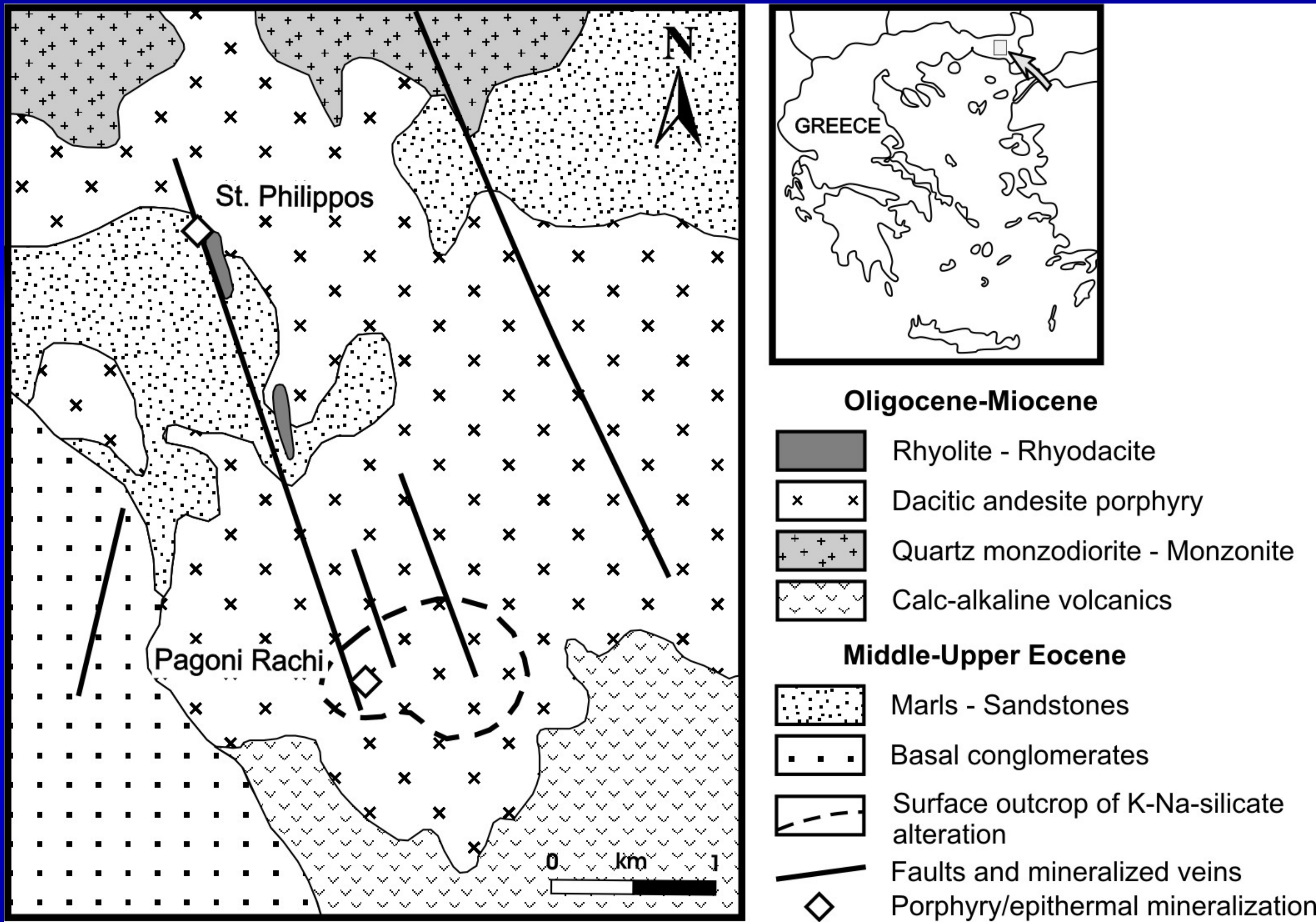
St Philippos

HS epithermal Cu-Pb-Ag-Sn

Regional Geology

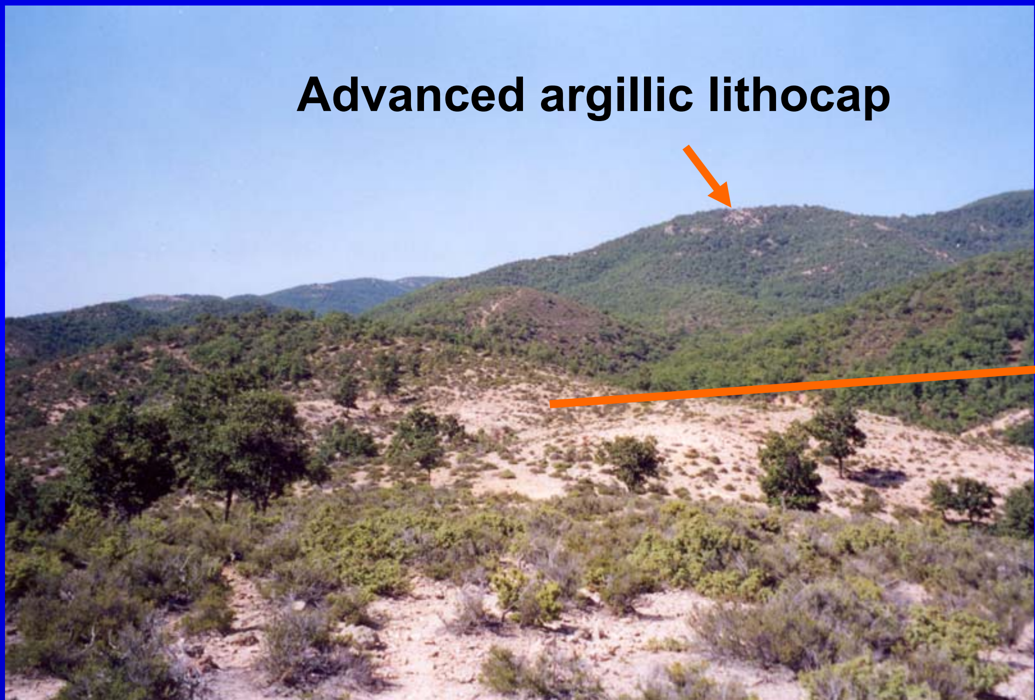


Regional Geology



Voudouris et al. (2009a)

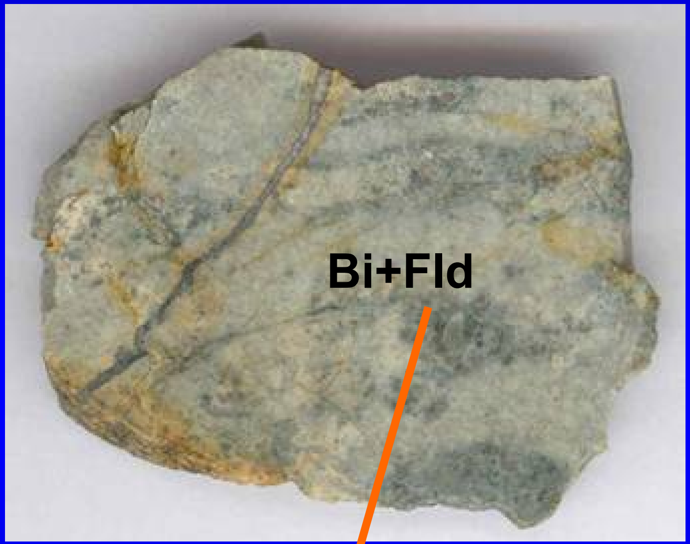
High-sulfidation lithocaps distal to Na-K-Ca-silicate alteration and quartz stockwork (1 x 1 km^2)

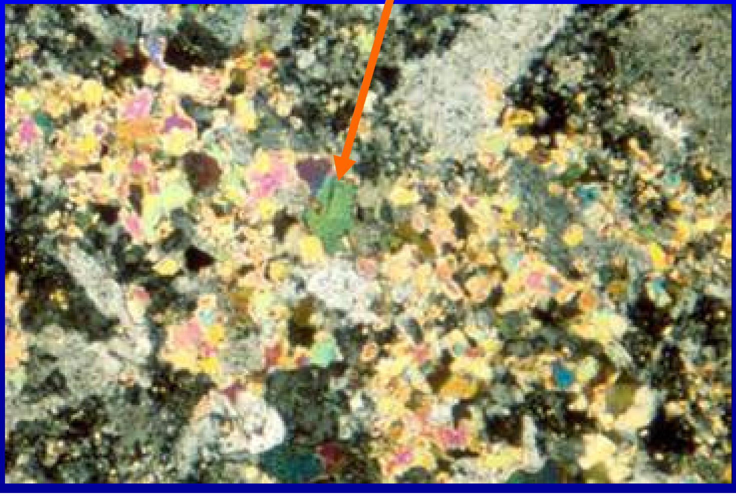


Oxidized quartz stockwork

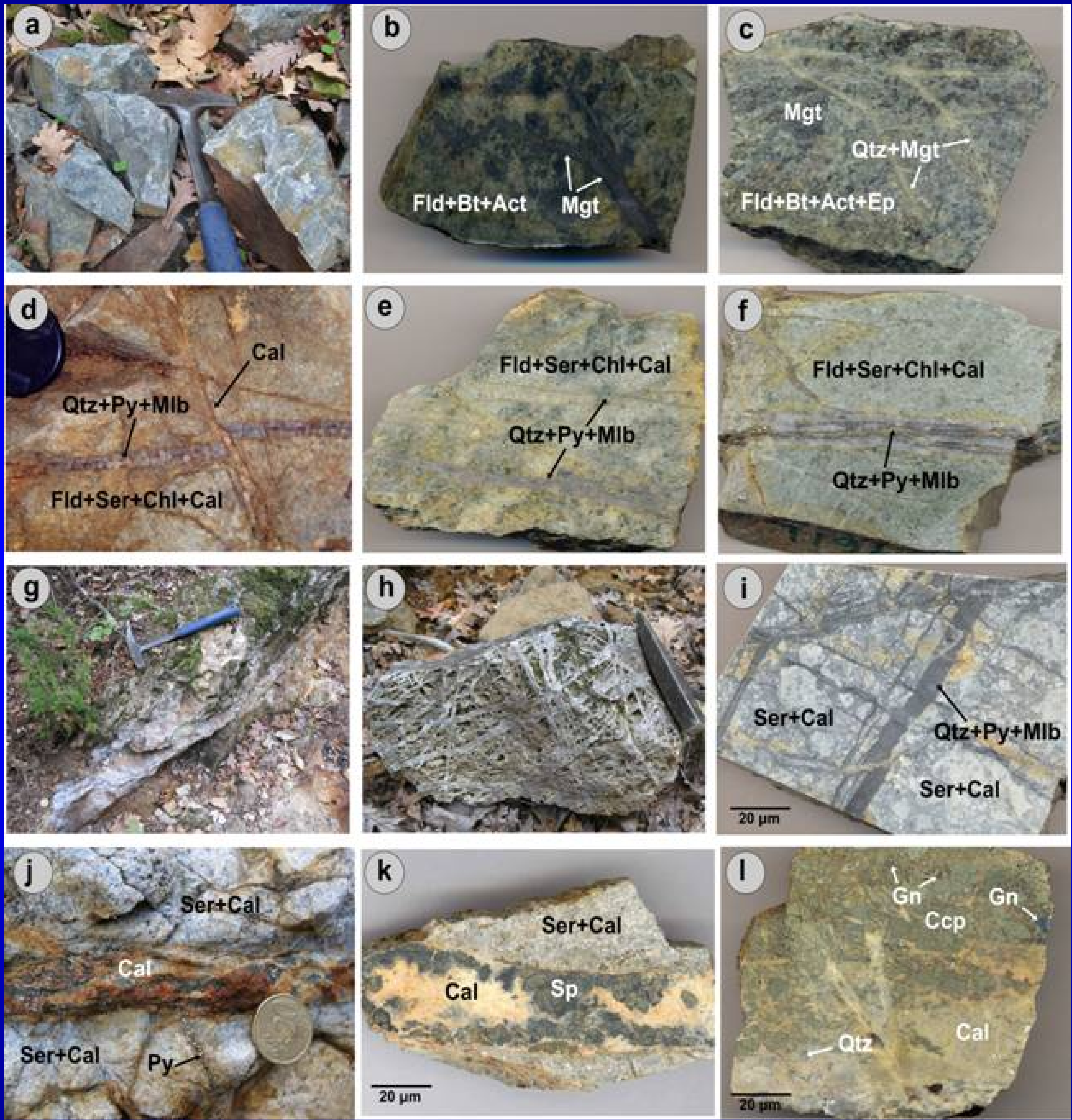
Early quartz veins related to Na-K-Ca-silicate alteration. Late carbonate-quartz-sericite veins.

Early veins (A- and M-types) related to Na-Ca-K-silicate alteration and mt+py+cpy+bn+Au mineralization





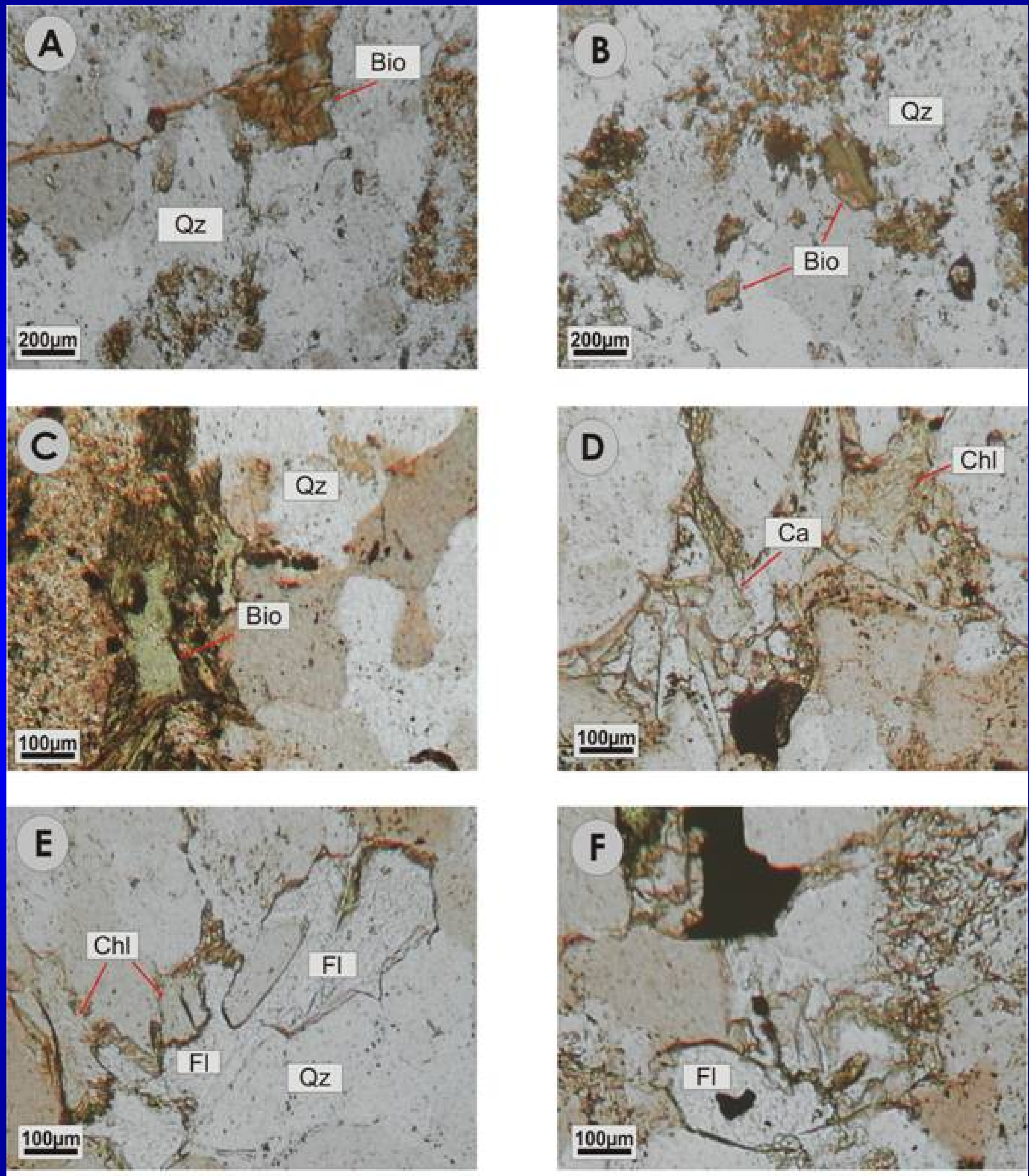
Quartz ± feldspar ± chlorite ± sericite ± calcite veinlets with pyrite-molybdenite ± chalcopyrite



Voudouris et al. (2009a)

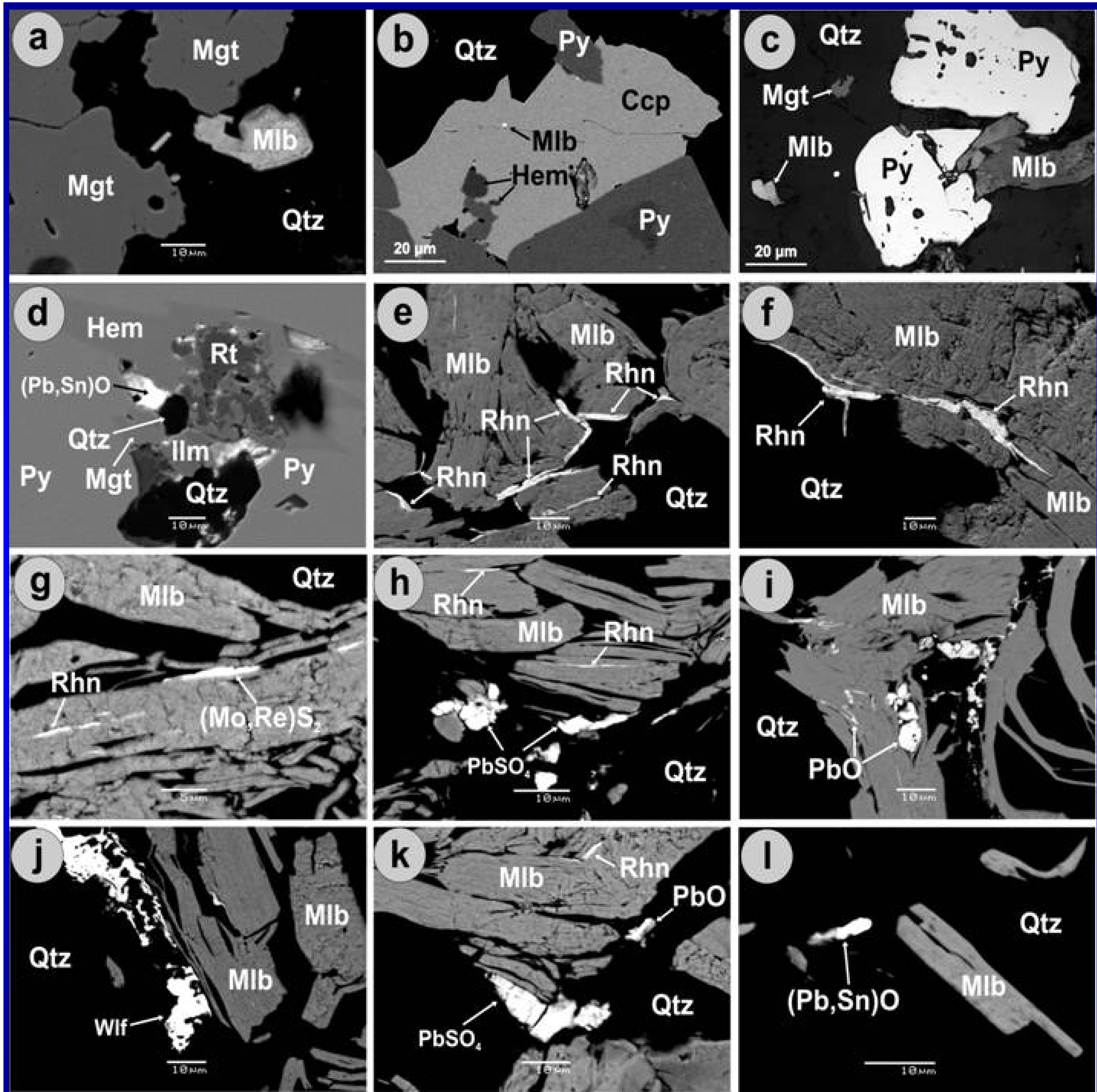
Vein mineralogy

Fluorite (Fl) in the Quartz-Molybdenite-Rheniiite veins



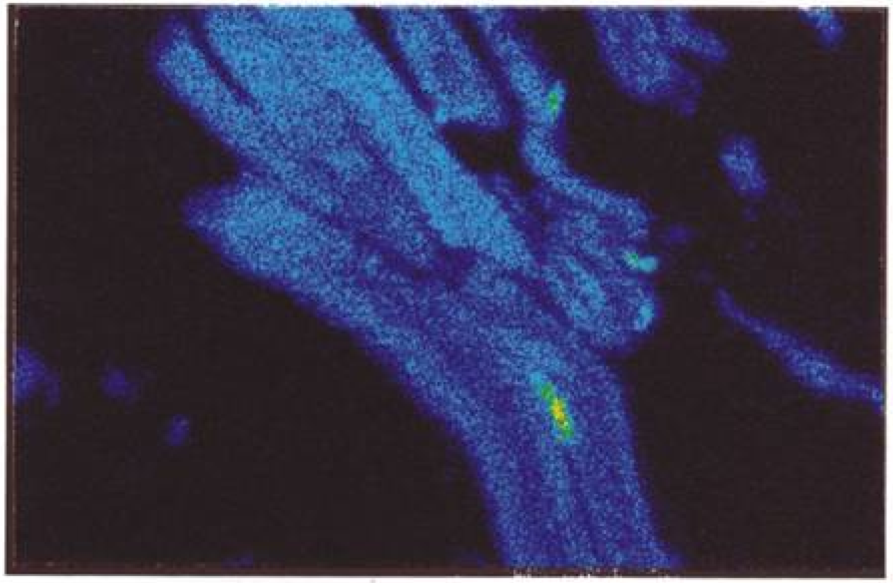
Voudouris et al. (2010b)

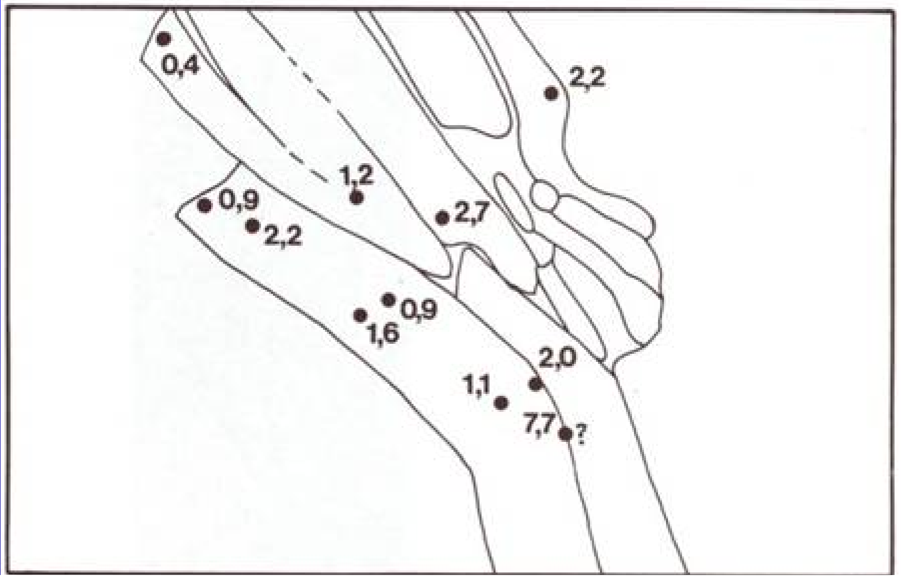
Ore mineralogy

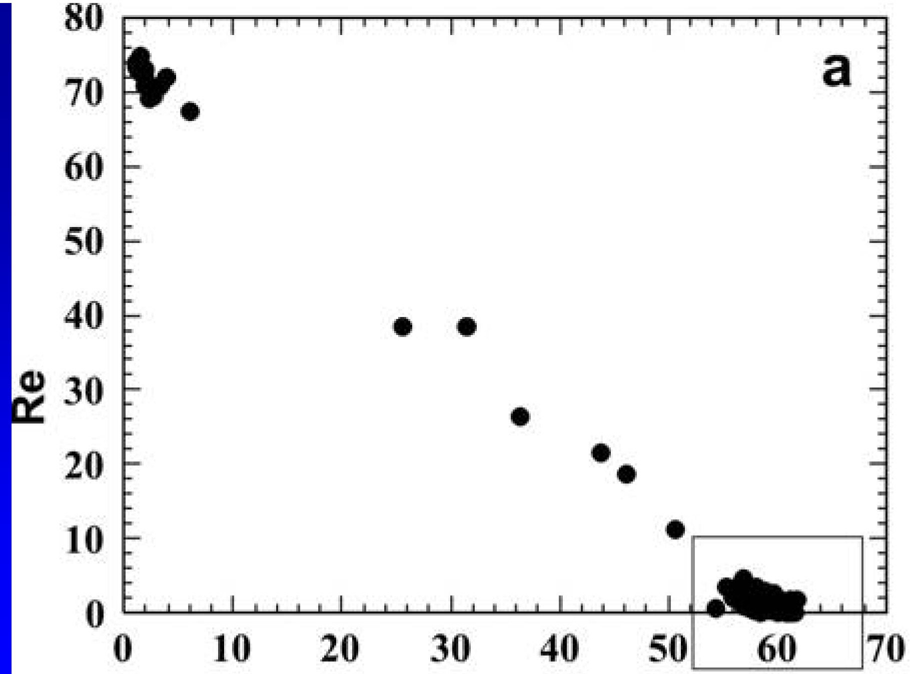


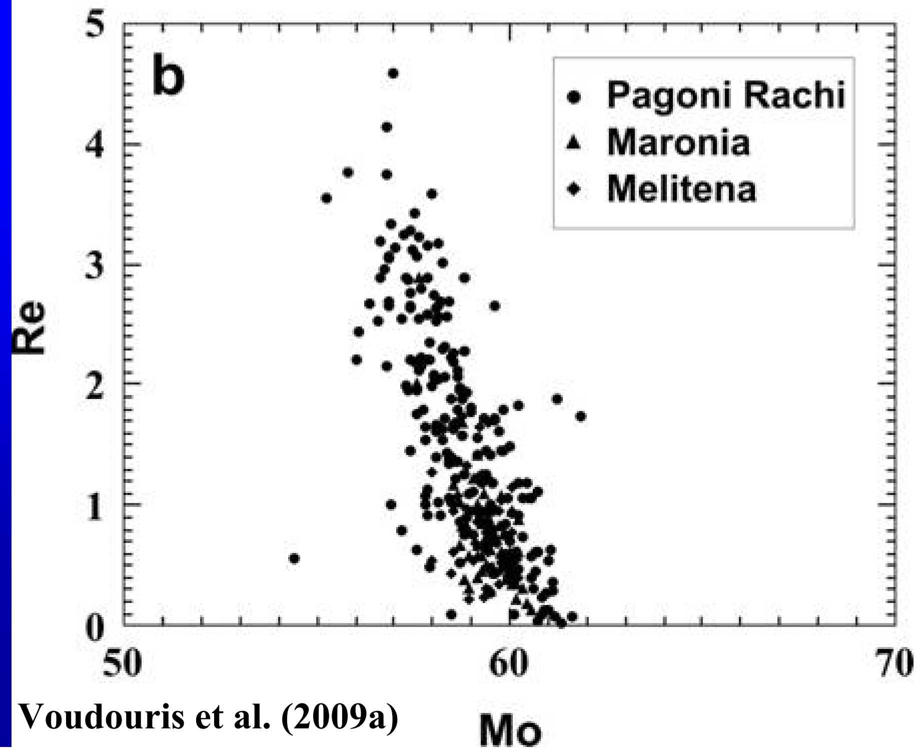
Voudouris et al. (2009a)

High Re-content in molybdenite
Rheniite



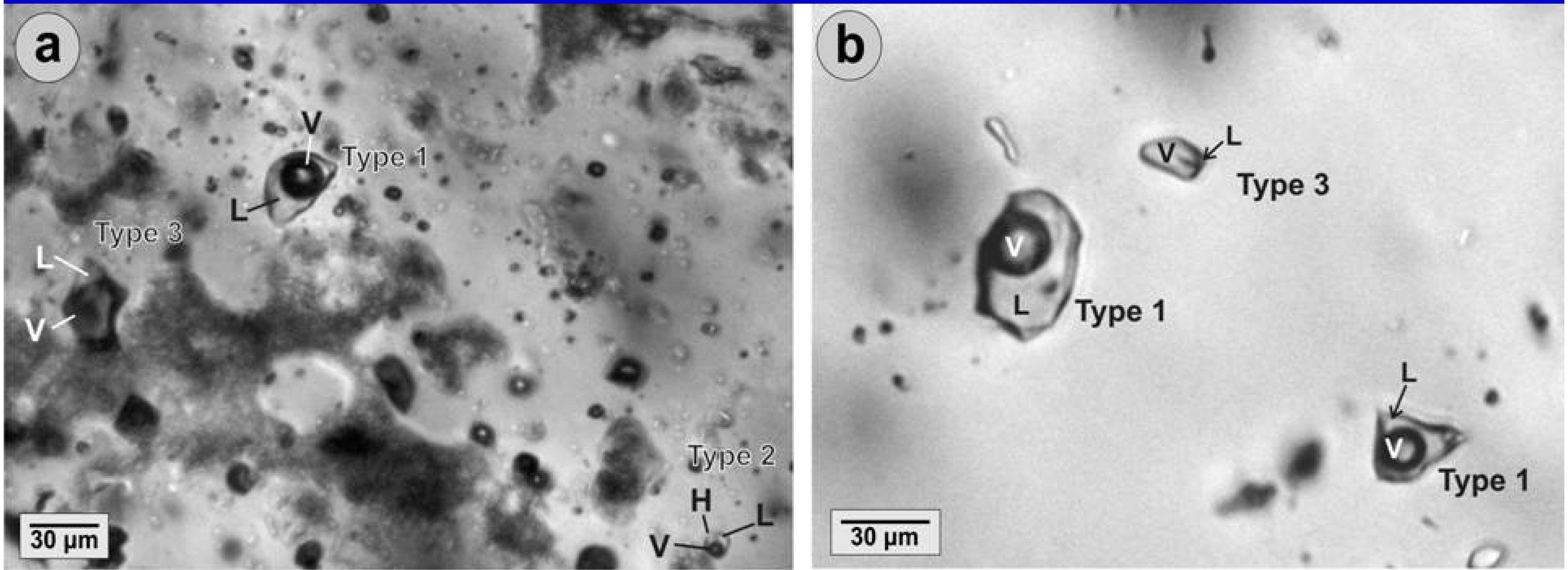




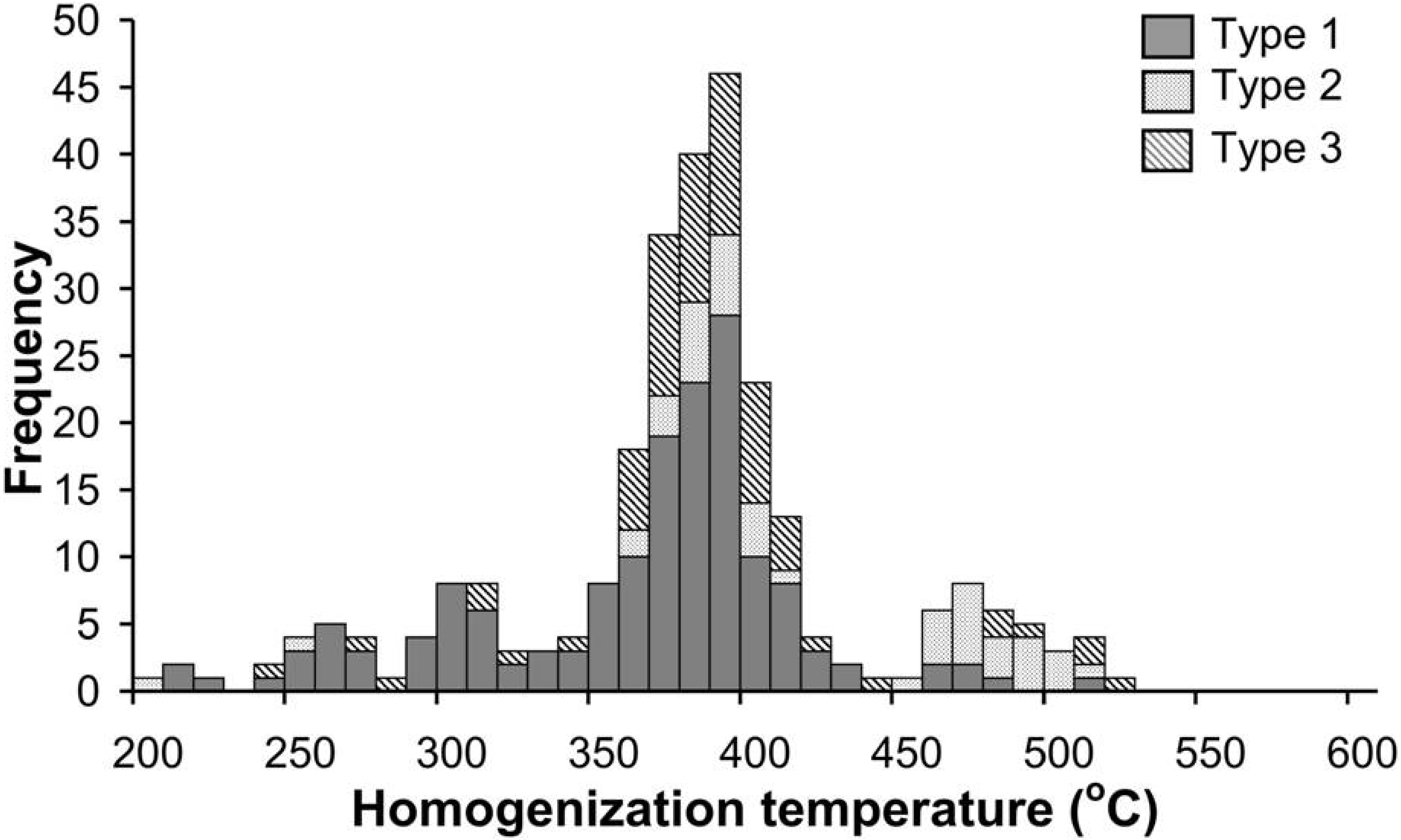


Voudouris et al. (2009a)

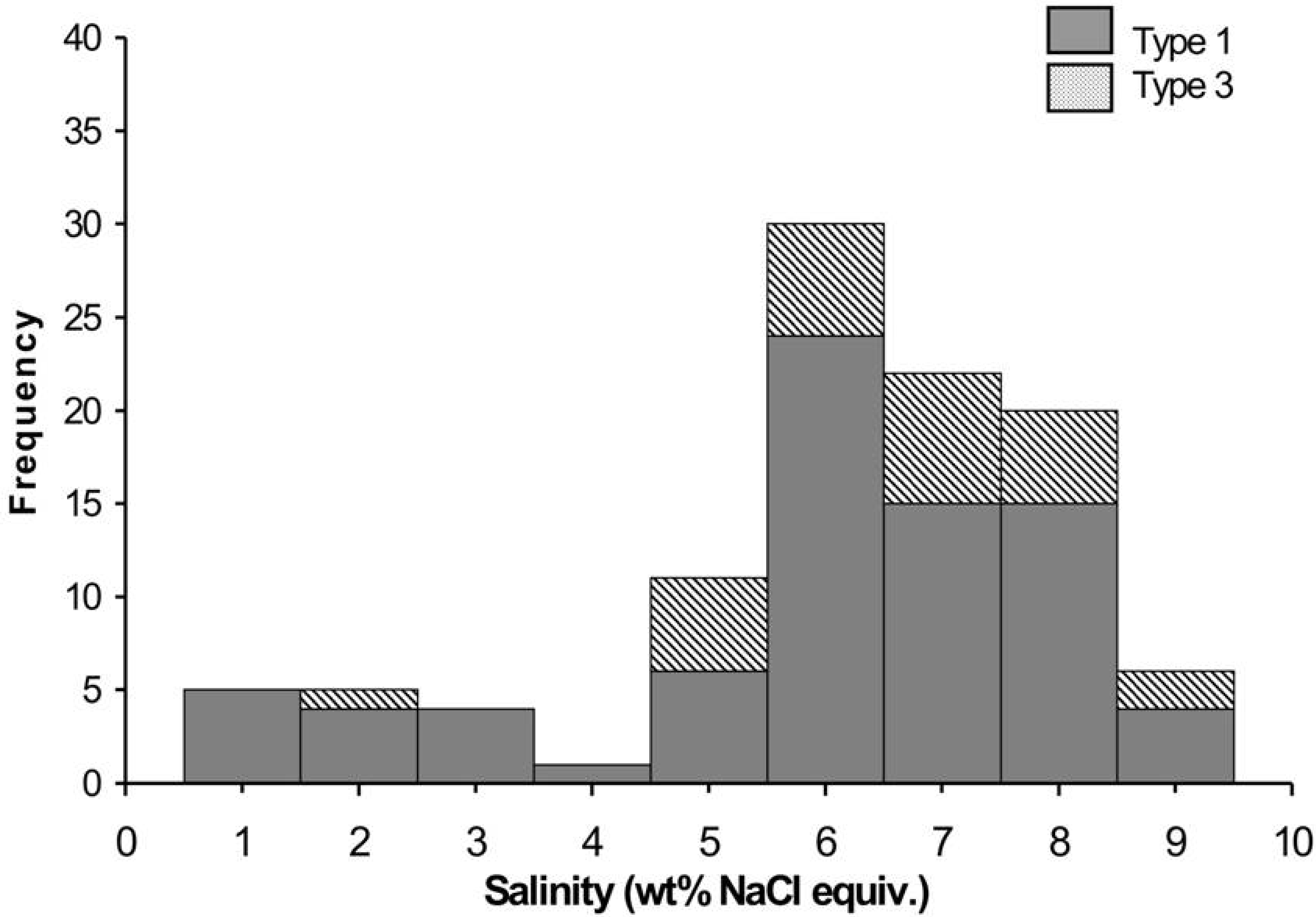
Fluid inclusion results



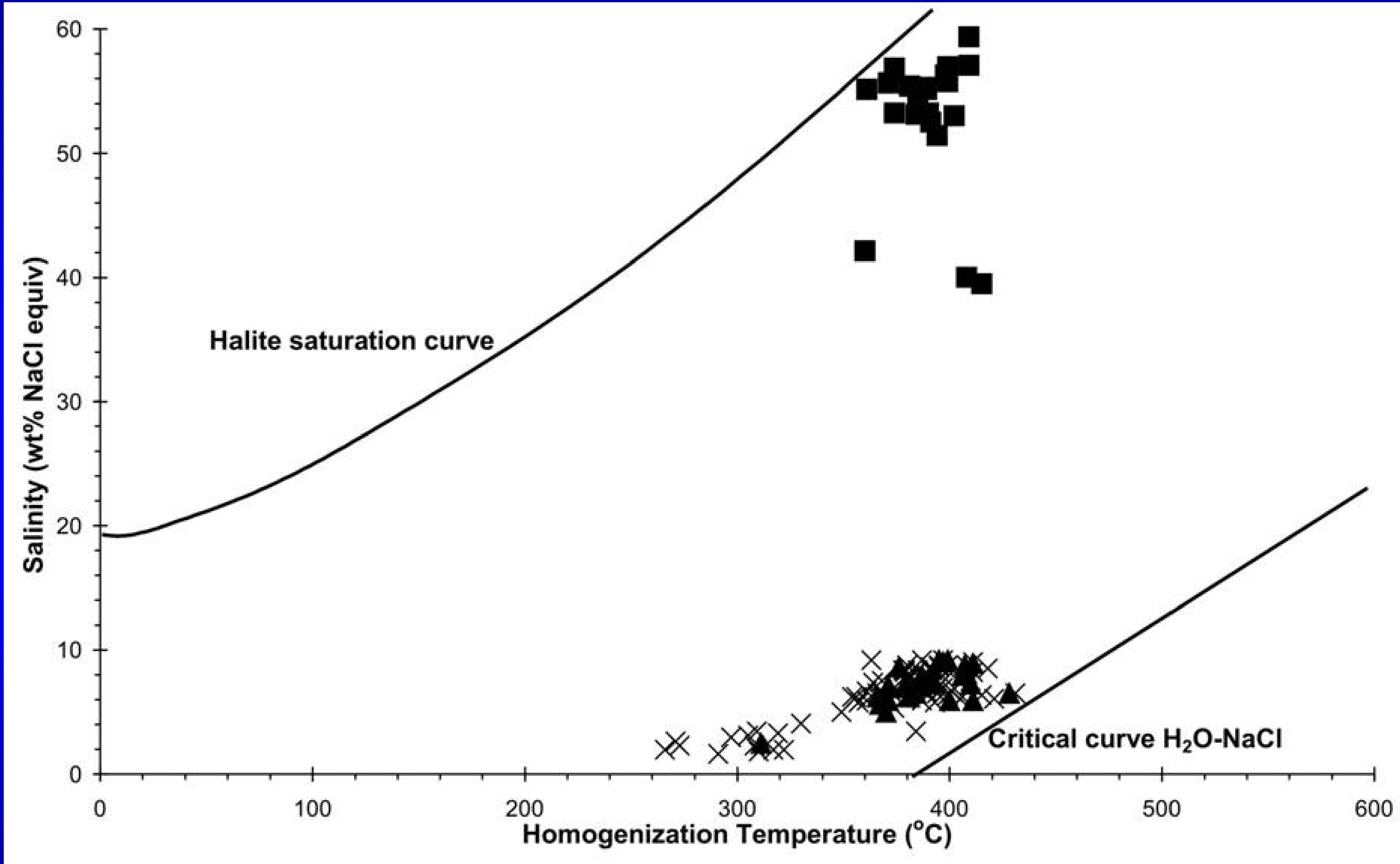
Voudouris et al. (2009a)



Voudouris et al. (2009a)

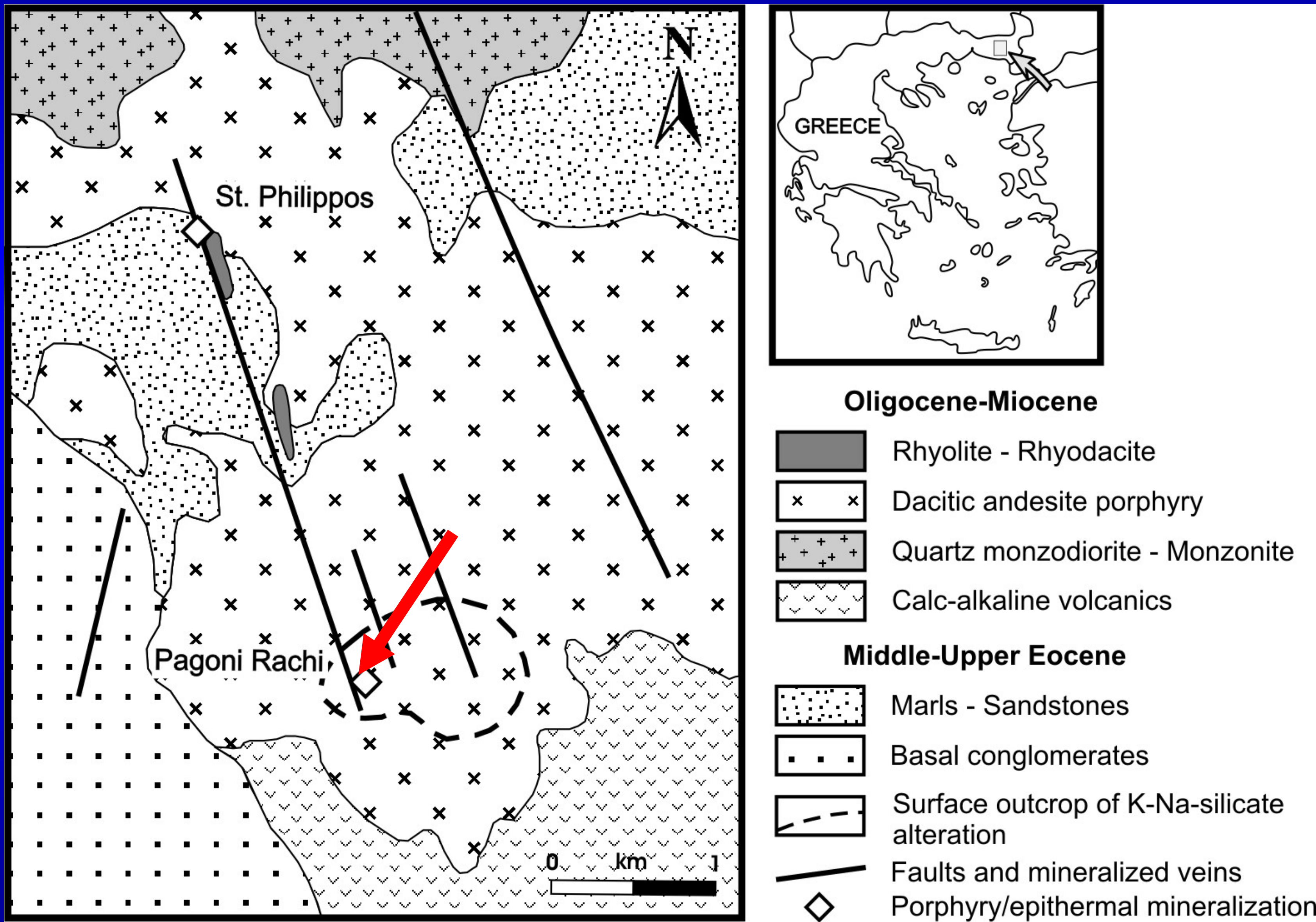


Voudouris et al. (2009a)

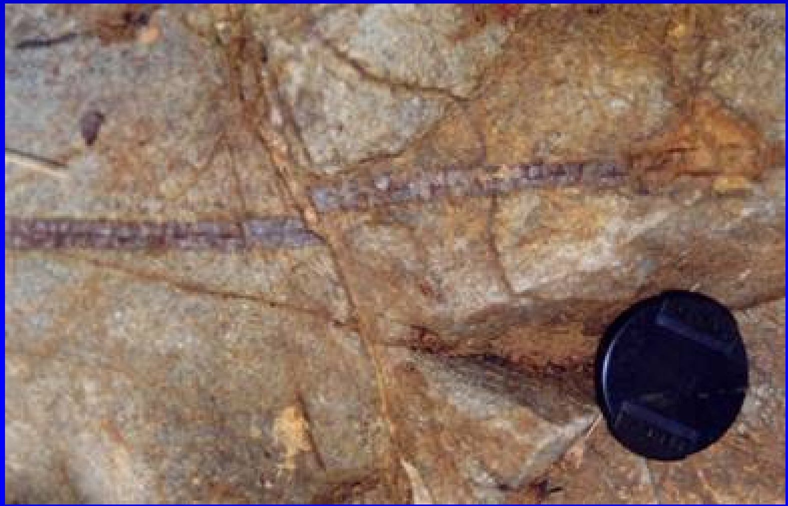


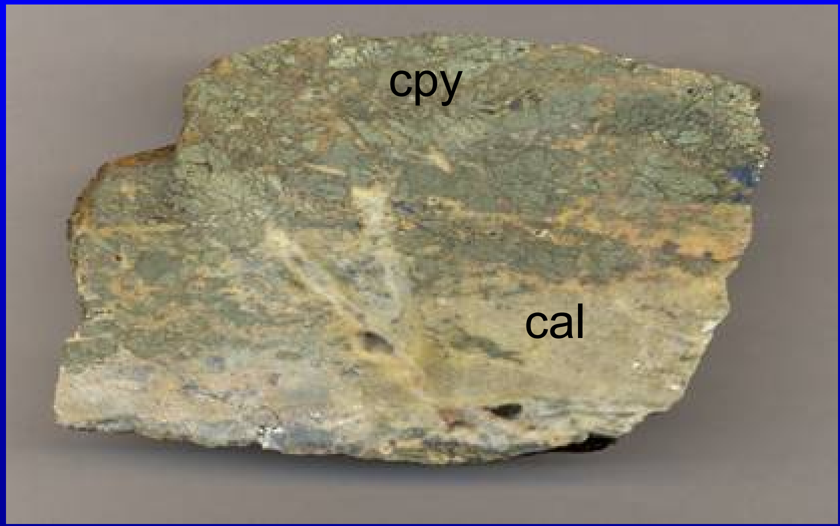
Voudouris et al. (2009a)

Late carbonate-quartz Au-Ag-Te rich veins

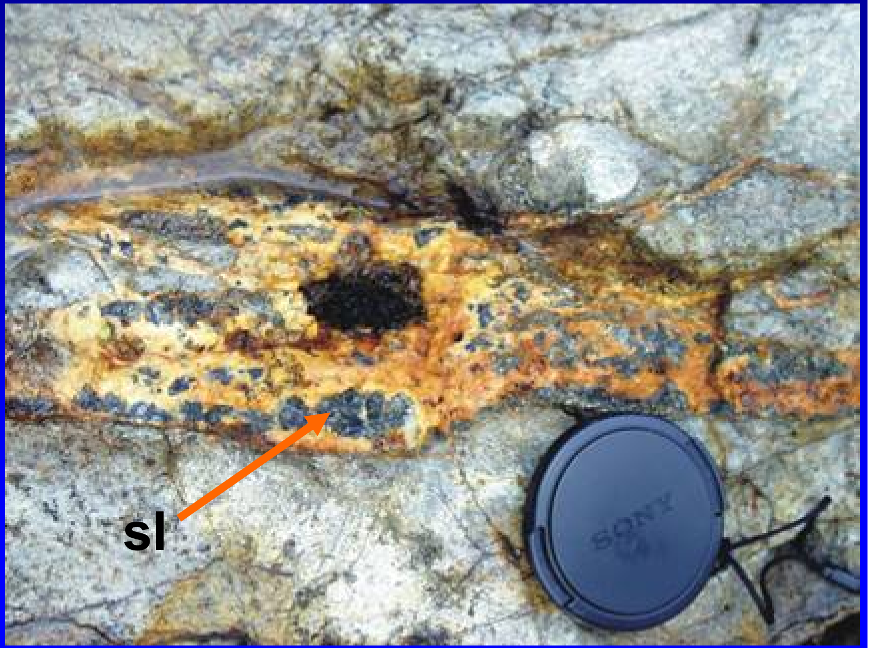


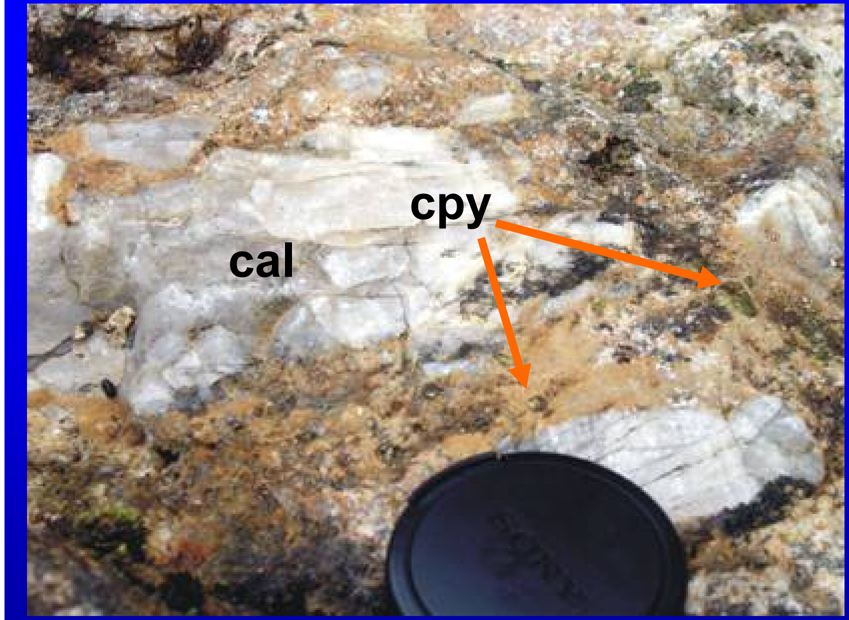
Early veins are overpinted by carbonate-quartz-sericite polymetallic veins with sericite-carbonate alteration. py→sl→gn+cpy+tn/td+hs+pz+Au+Bi-sulfosalts



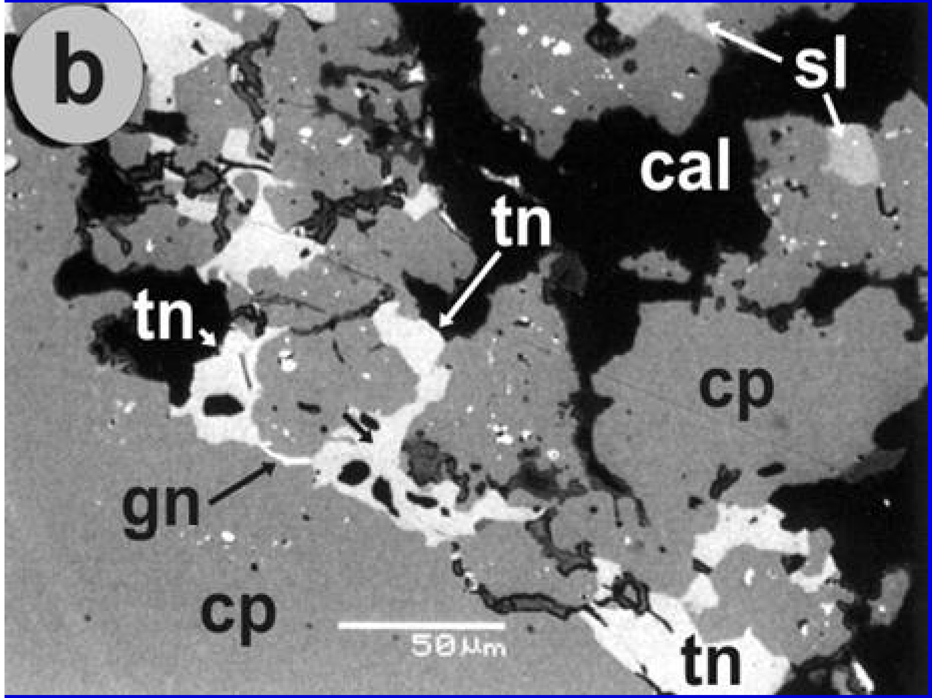


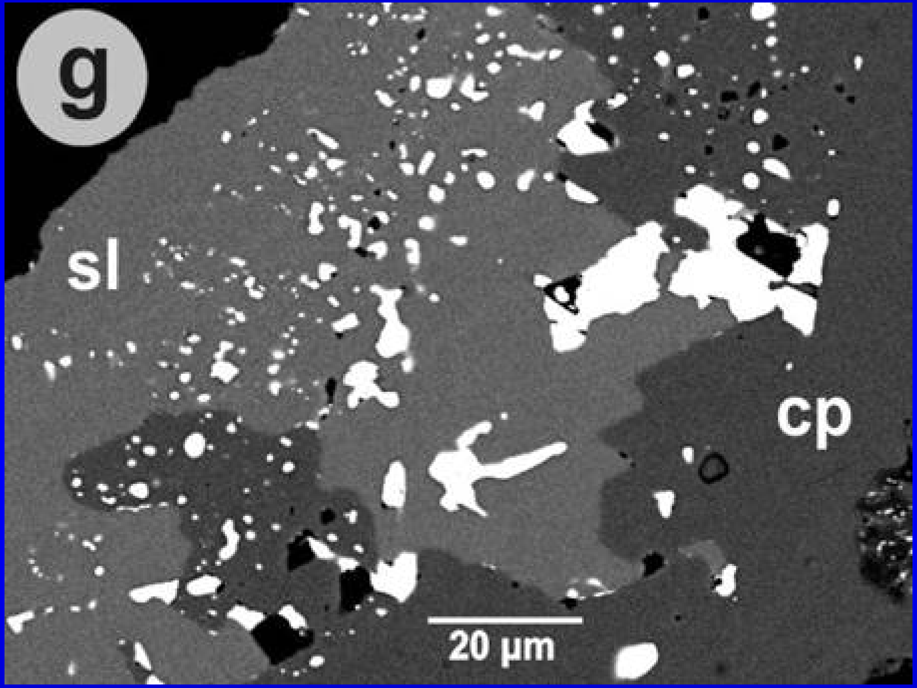
Carbonate-quartz-sericite veins: Deposition of Bi-sulfosalts and Ag-Au-tellurides at 265° to 290 °C, with salinities of ~ 3.0 wt % NaCl equiv.





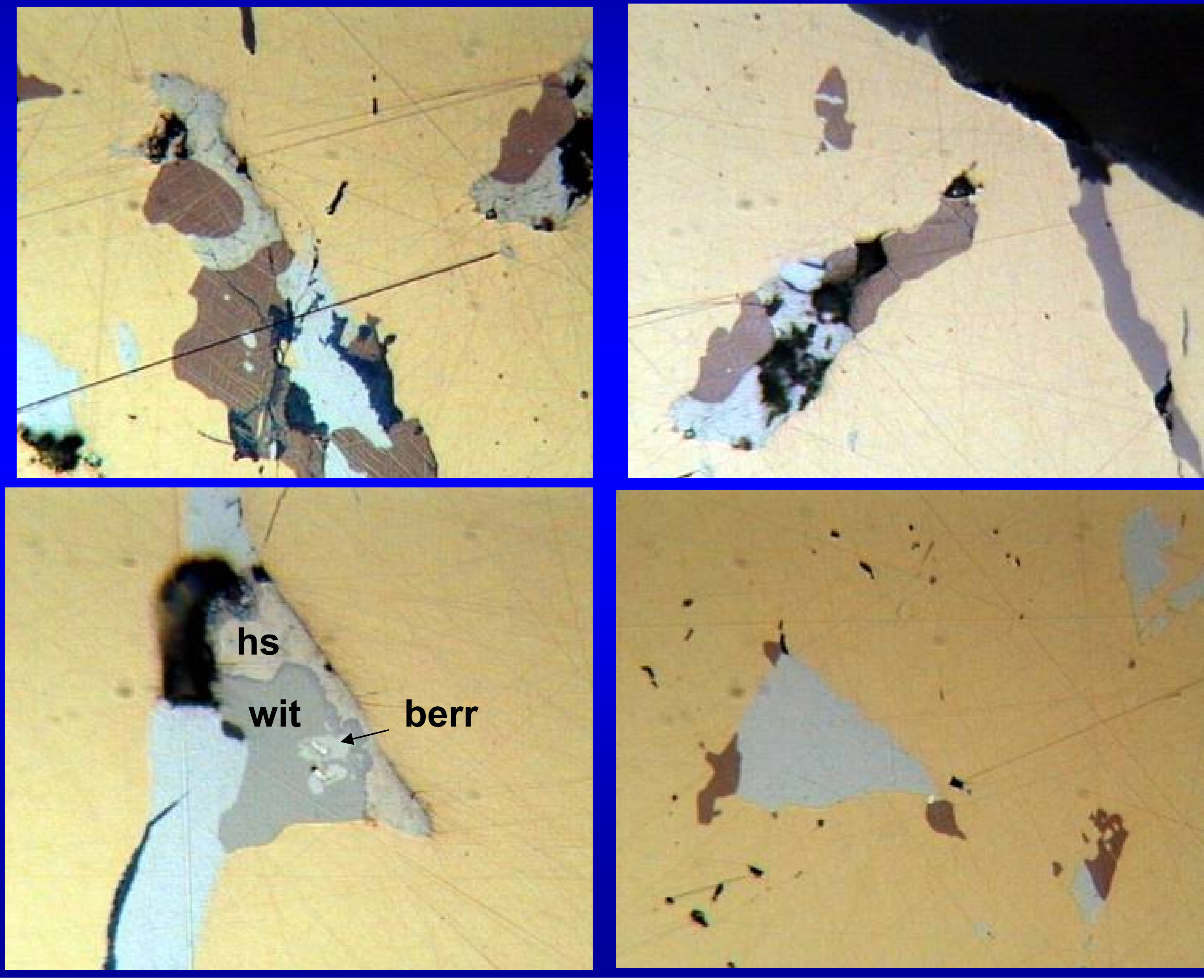
Carbonate-quartz-sericite veins: Intermediate sulfidation ore assemblage





Bi-sulfosalts and tellurides associated with sphalerite, chalcopyrite, galena and tennantite/tetrahedrite

Pagoni Rachi: wittichenite, a berryite-similar sulfosalt, hessite, bornite and galena in carbonate-quartz-sericite veins



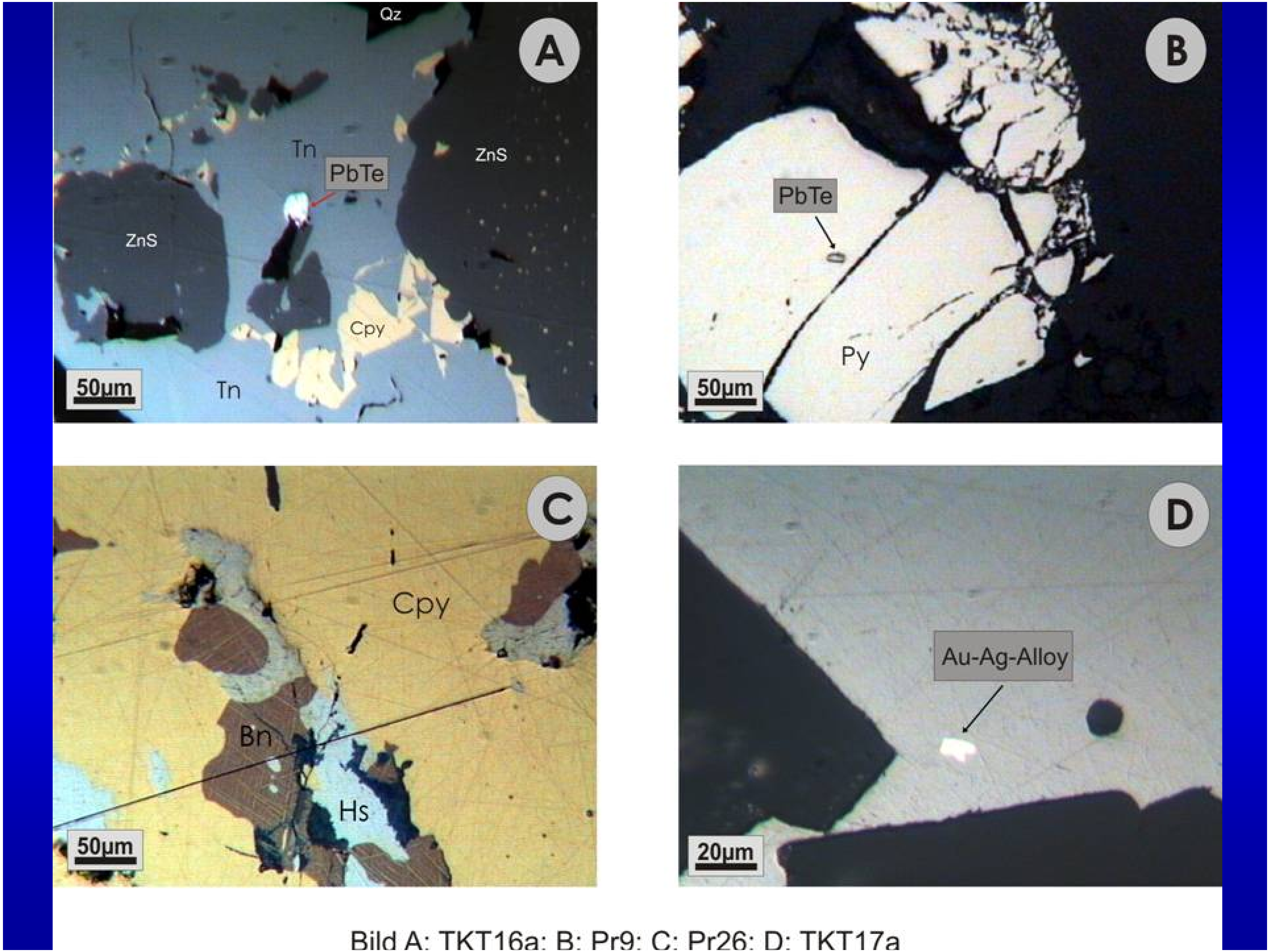
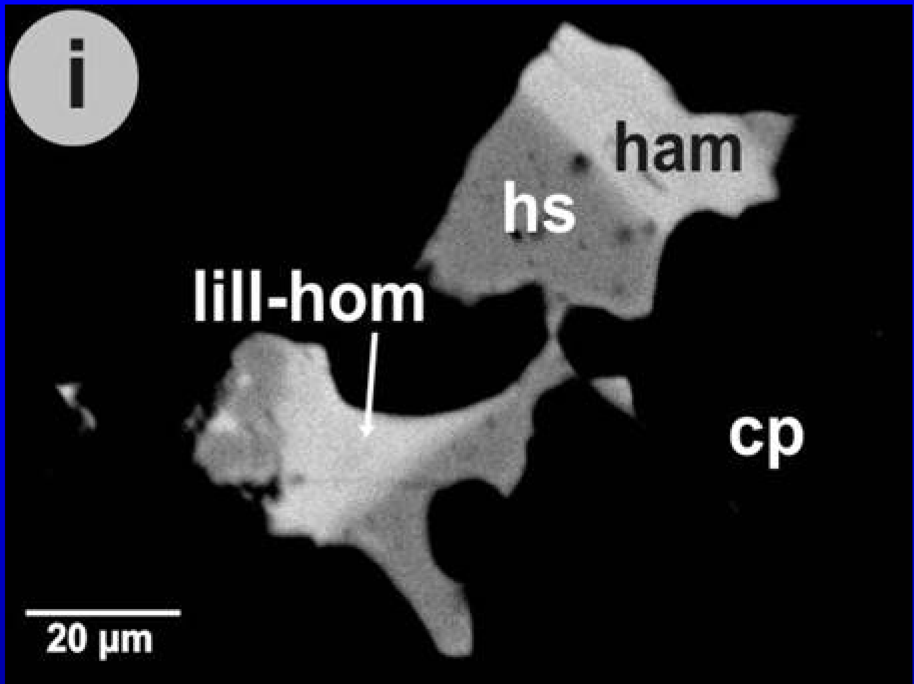


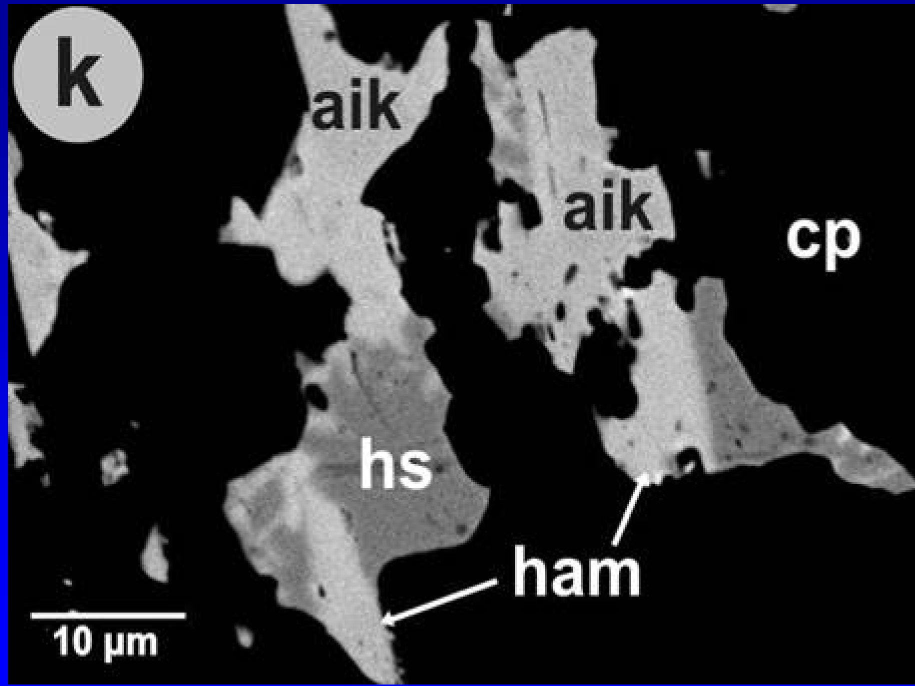
Bild A: TKT16a; B: Pr9; C: Pr26; D: TKT17a

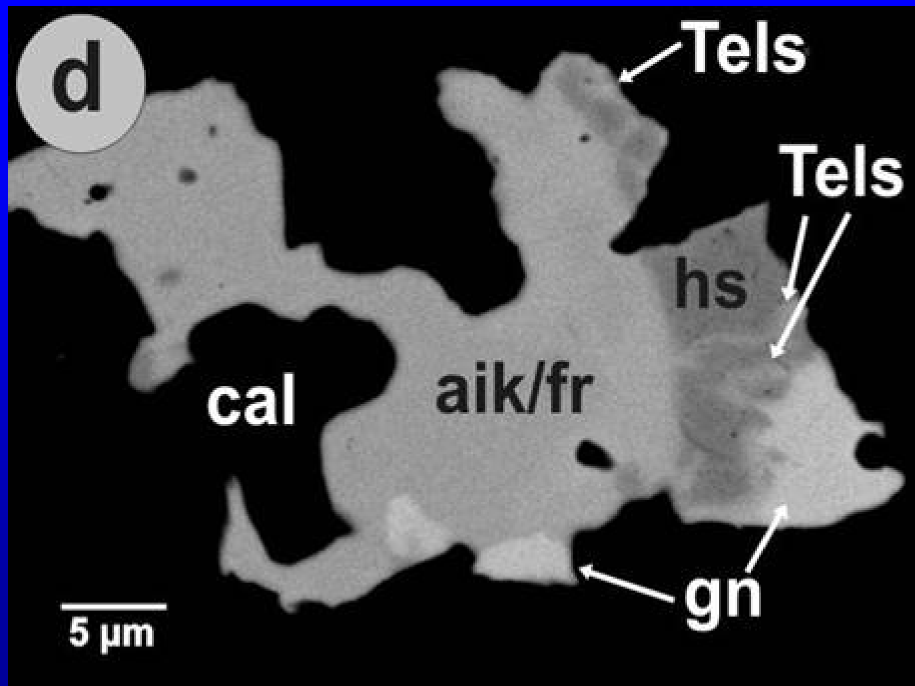
Bismuth sulfosalts

Tetradymite

Hessite

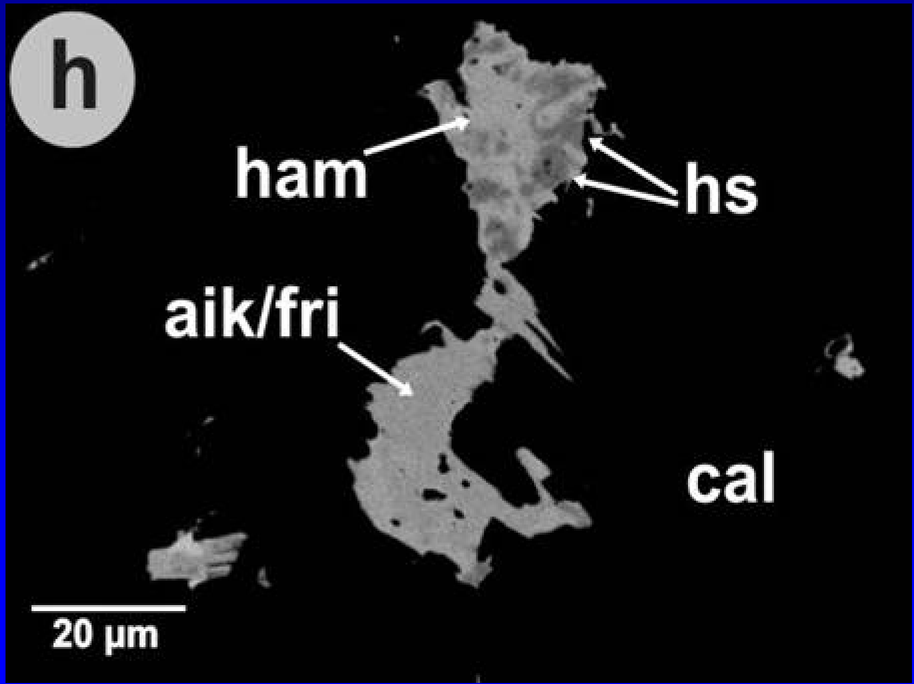


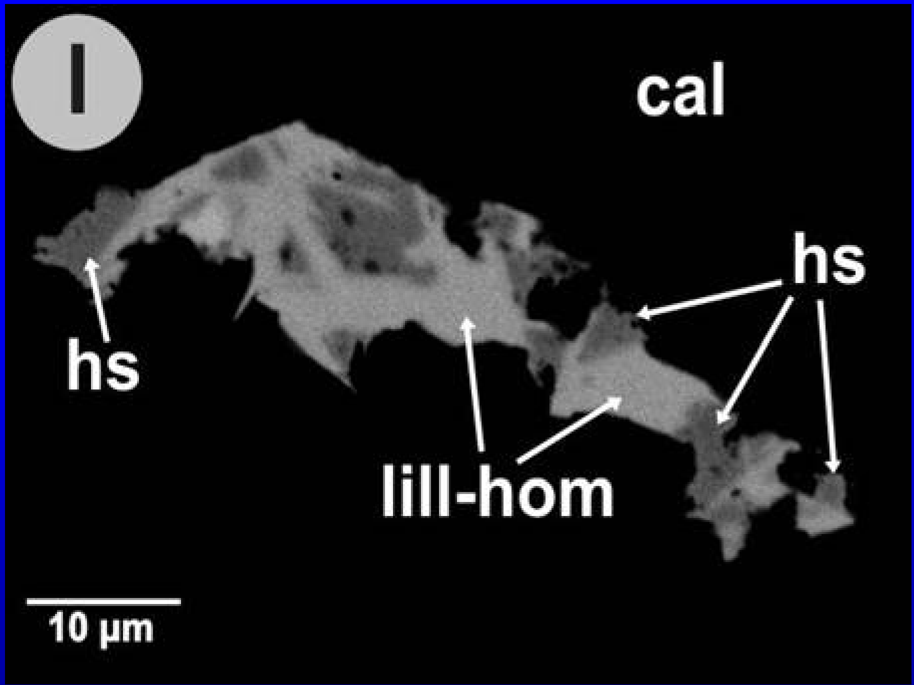


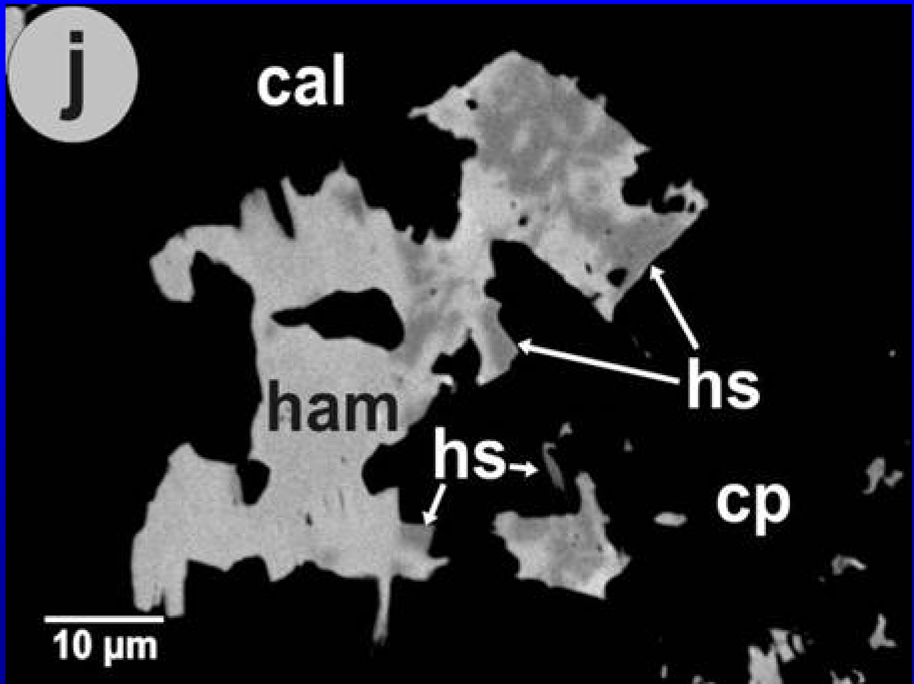


Bismuth sulfosalts

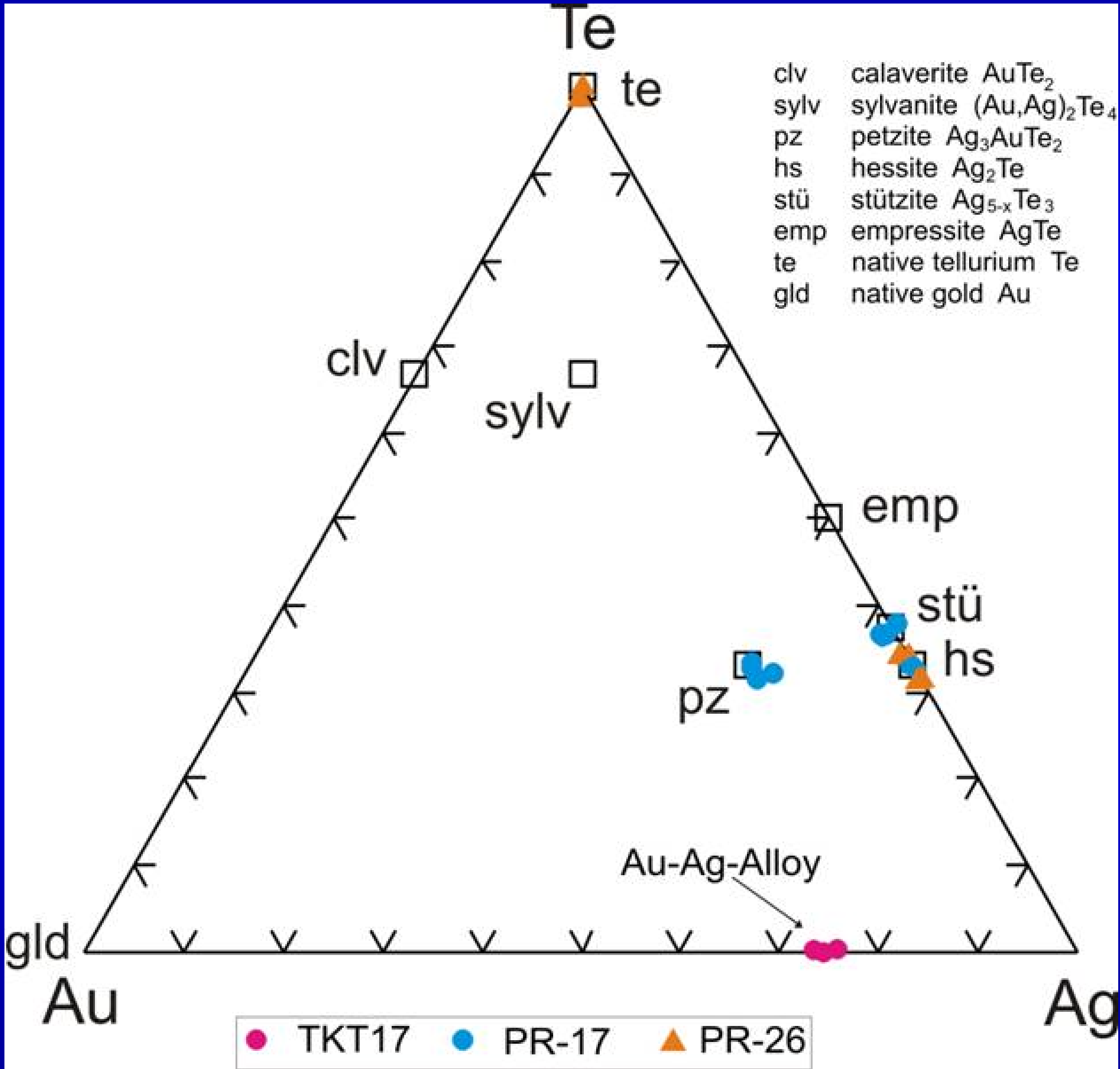
Hessite





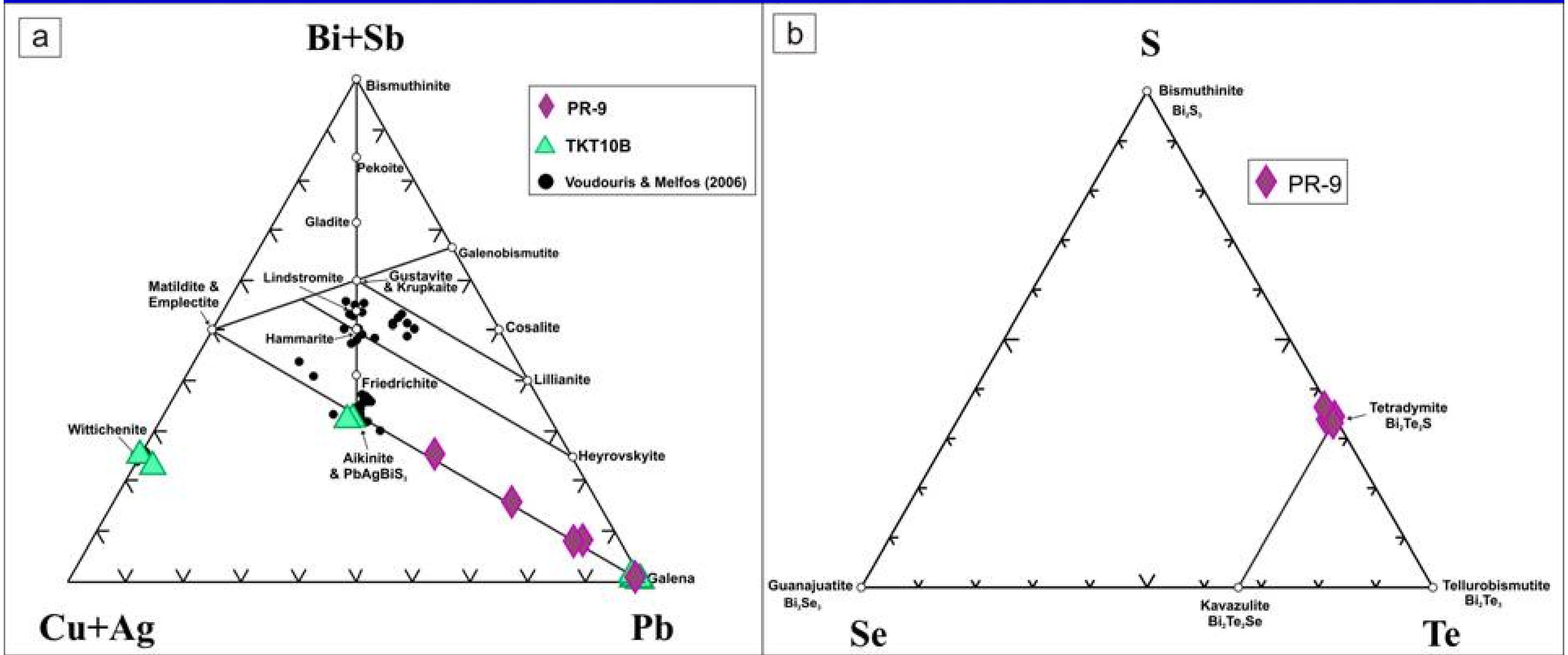


Ag-Au tellurides (Pagoni Rachi)



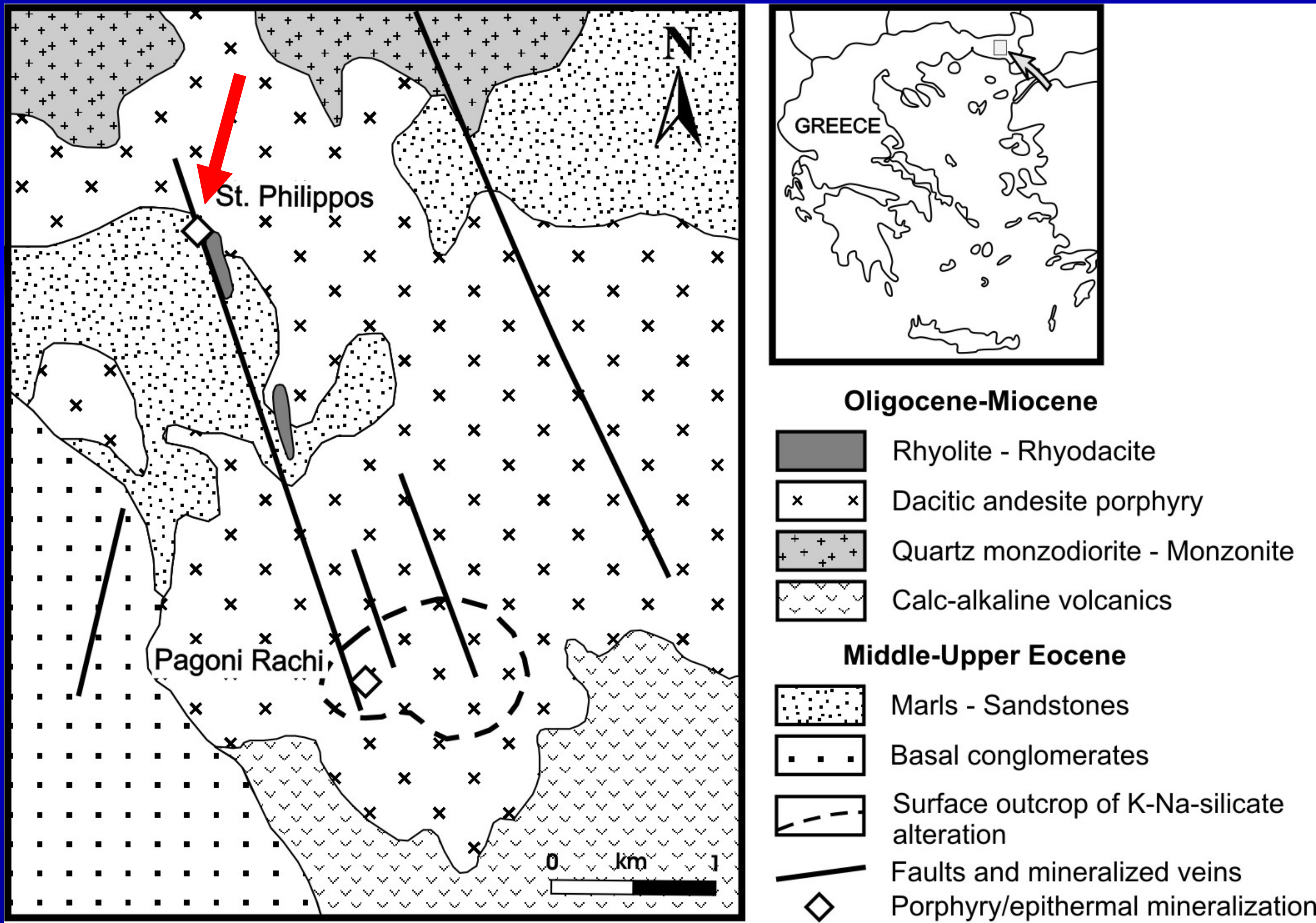
Voudouris et al. (2010b)

Bi-sulfosalts and Bi-tellurides (Pagoni Rachi)



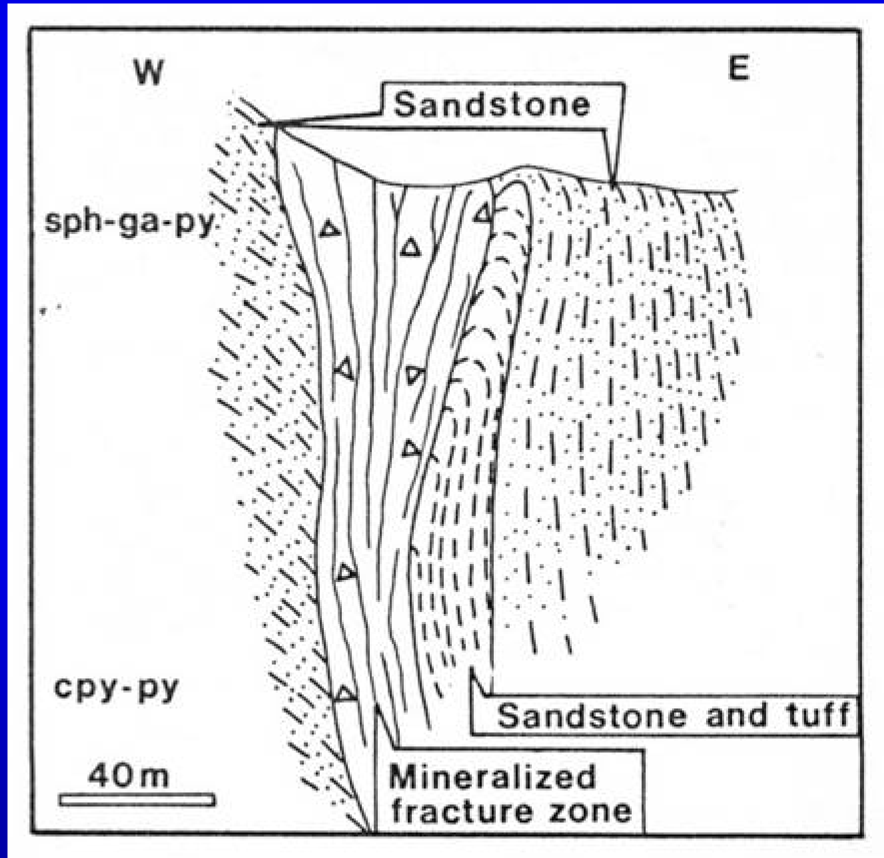
Voudouris et al. (2010b)

St Philippos deposit: Regional Geology



St. Philippos polymetallic HS-IS deposit. alongside the Pagoni Rachi porphyry Cu-Mo prospect. Massive sulfide vein ore assemblage.

Open pit



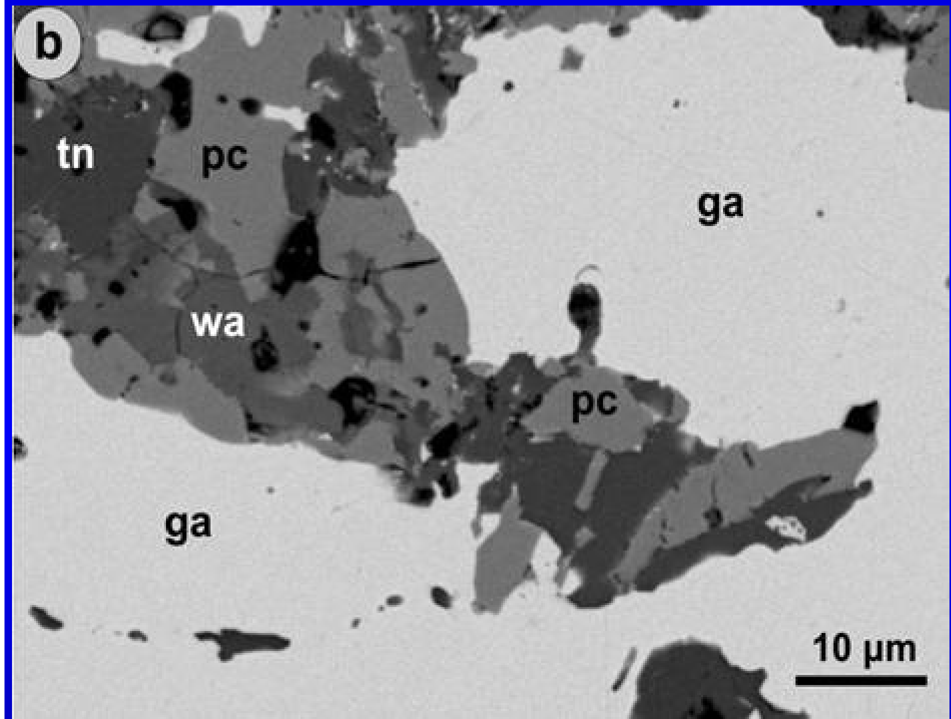
Michael et al. (1989a)

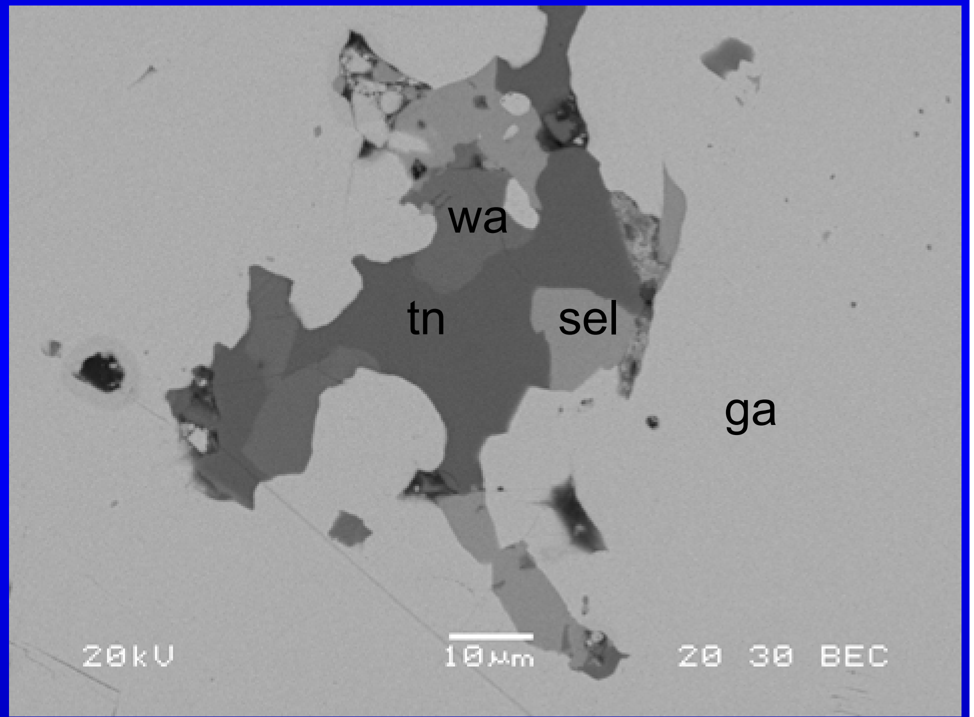
St. Philippos deposit

Rhyolite porphyry

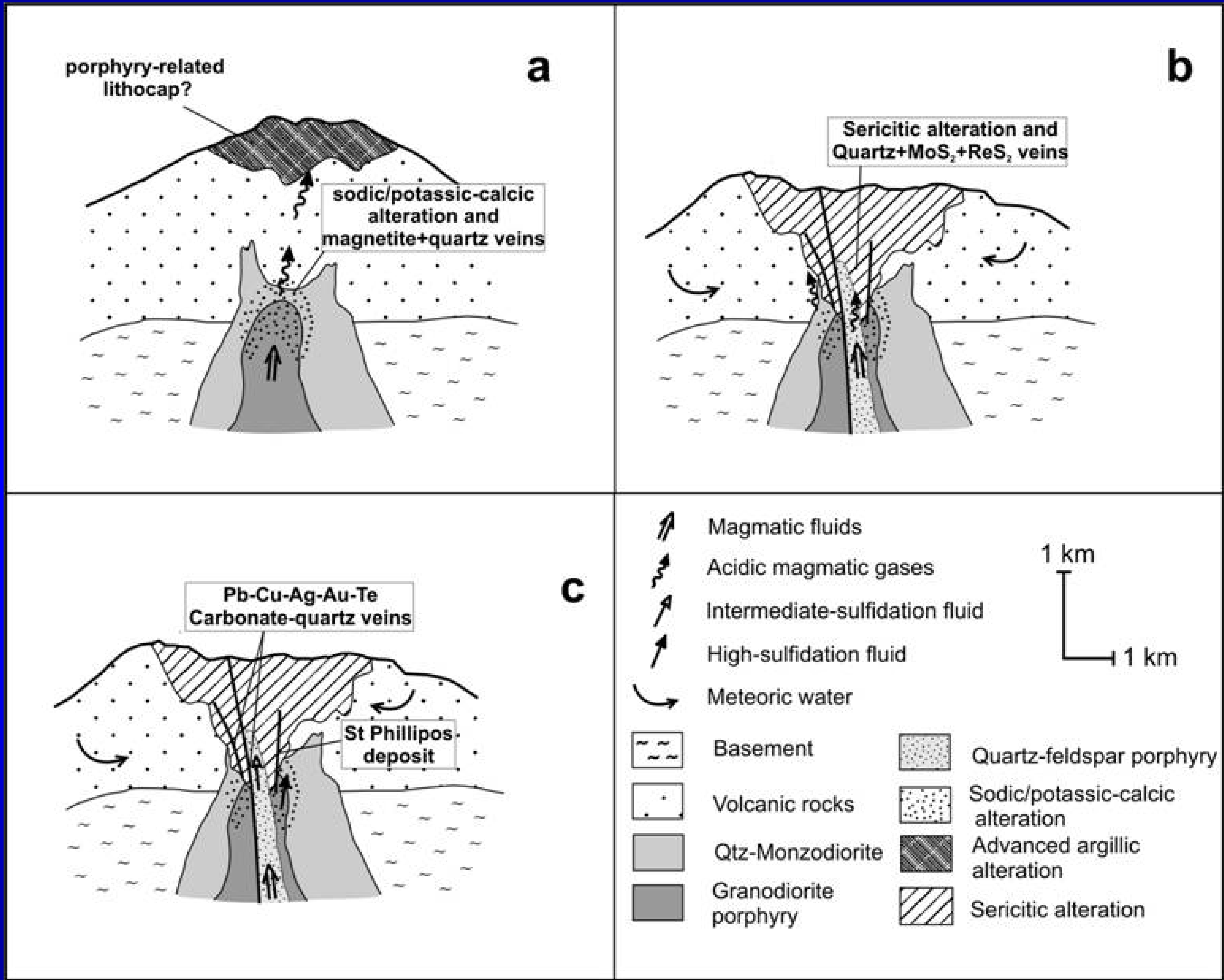
St Philippos deposit

Ag-sulfosalts in IS ore assemblage (tennantite+galena).





Hypothetical model for Pagoni Rachi – St Philippos deposits



Voudouris et al. (2009a)

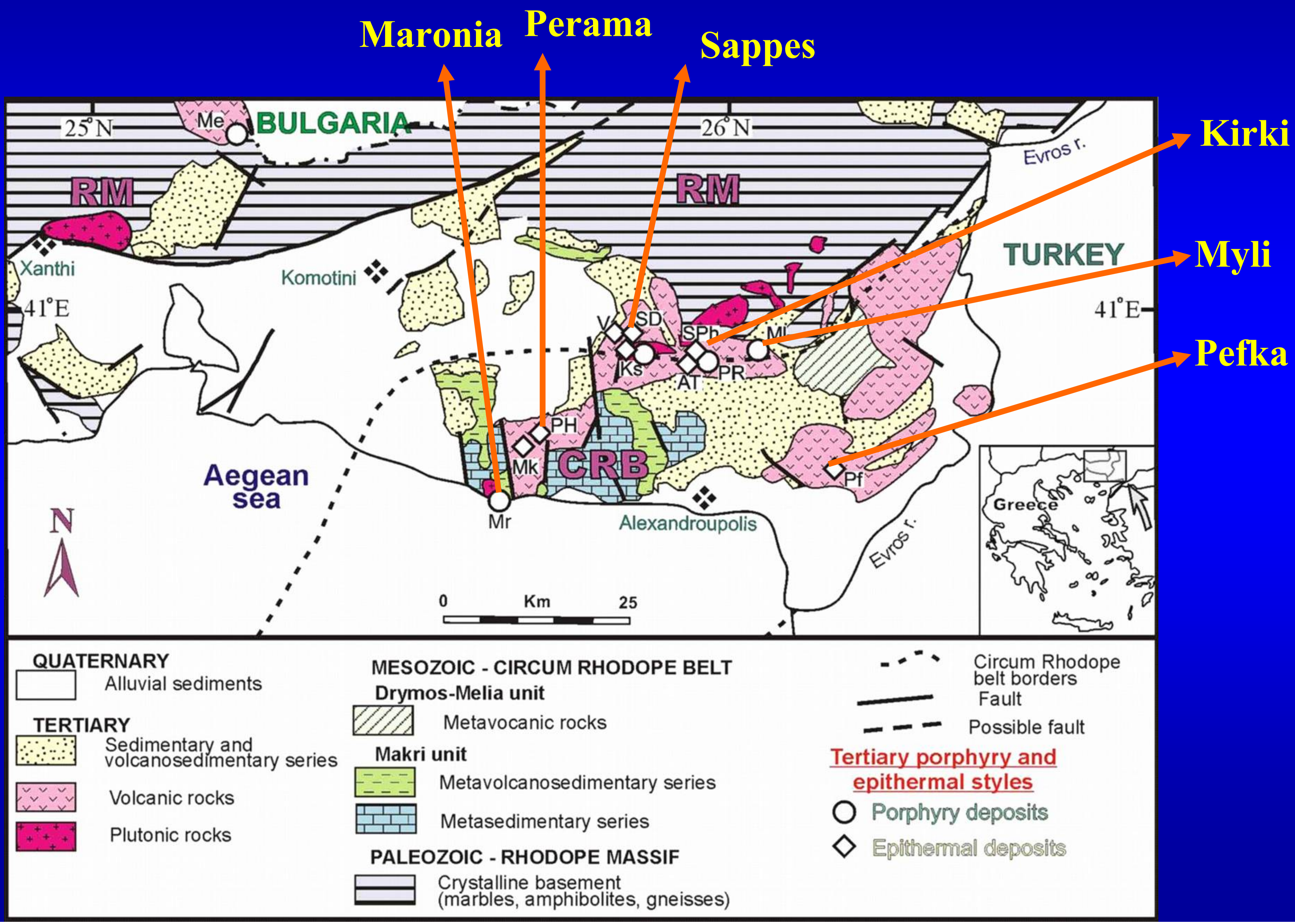
Maronia

Porphyry Cu-Mo-Au

Perama Hill-Mavrokoryfi

HS epithermal Au-Ag-Cu-Te

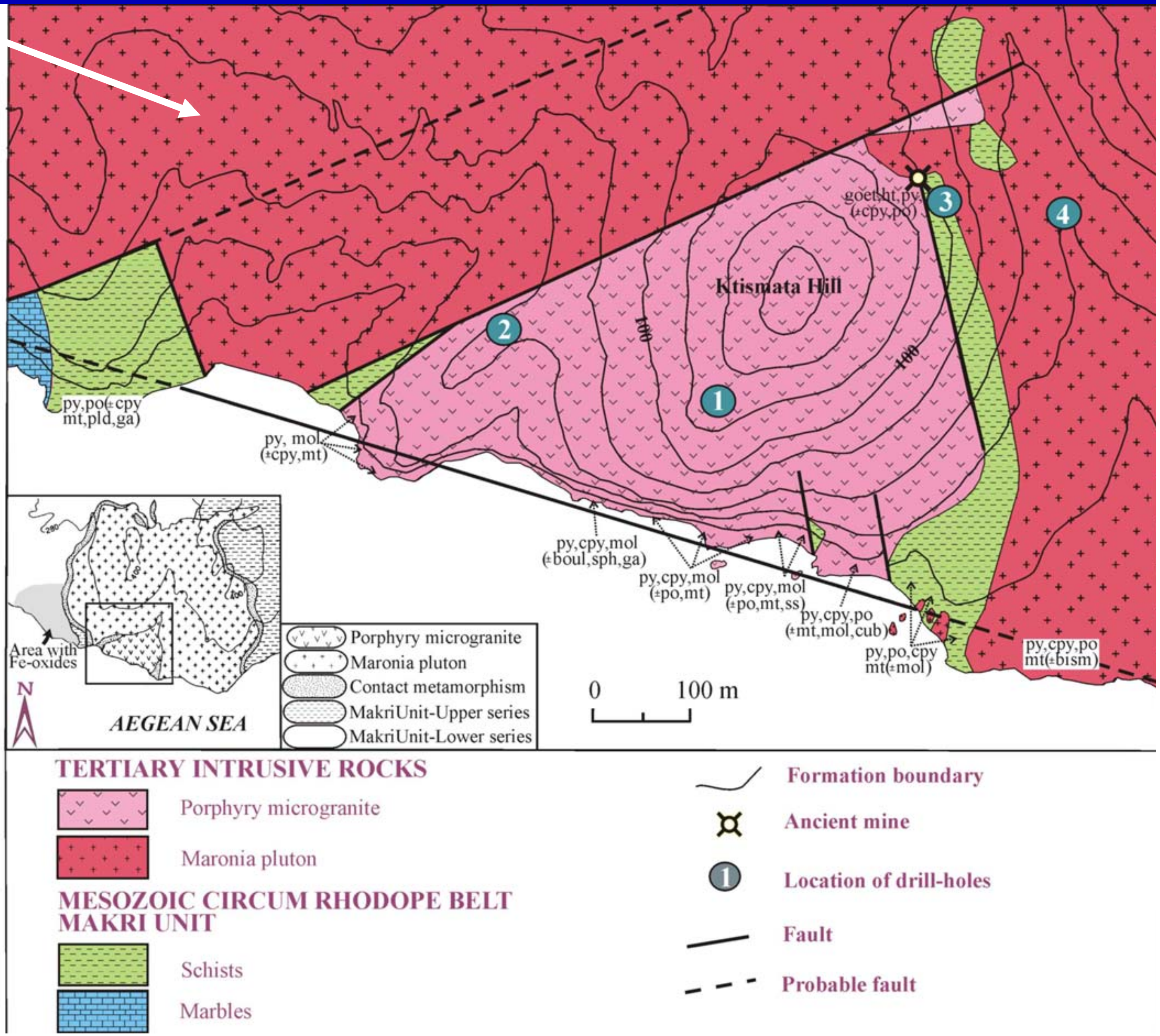
Northeastern Greece: Regional Geology



Co-Ni-Pt mineralization related to the Maronia pluton

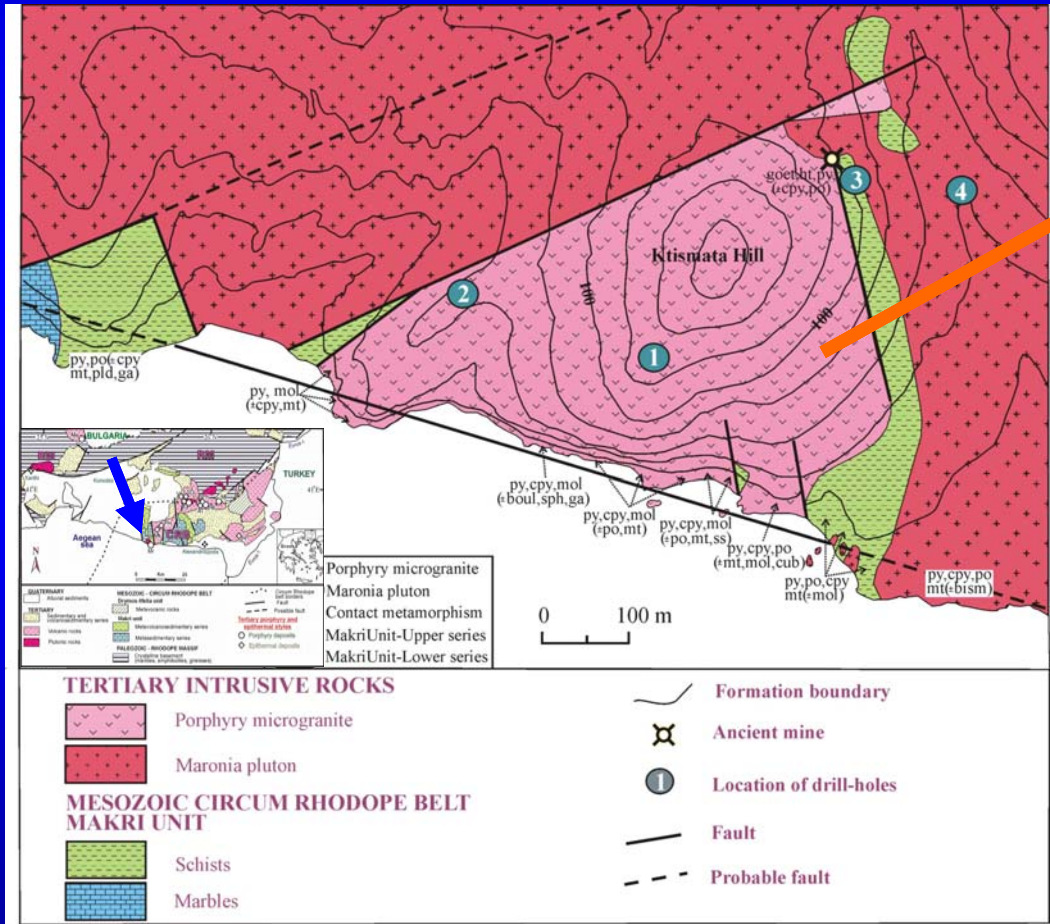
Melfos et al. (2002)

Geological sketch map showing the geology of the Maronia porphyry Cu-Mo mineralisation



Maronia area

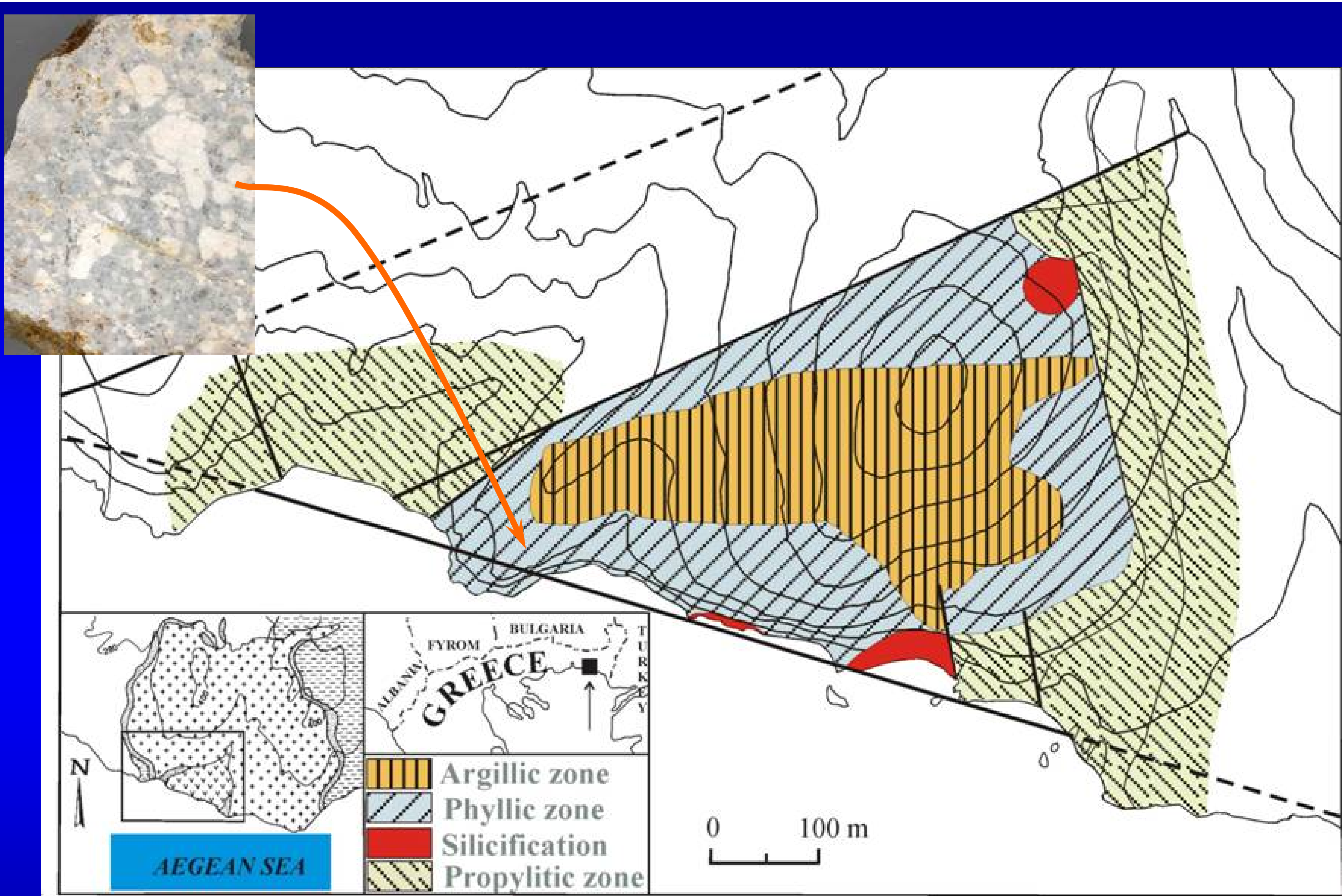
Ktismata Hill Cu-Mo-Au deposit related to a porphyry microgranite penetrating the Maronia pluton



The microgranite represents subvolcanic equivalent to the rhyolitic dikes

Melfos et al. (2002)

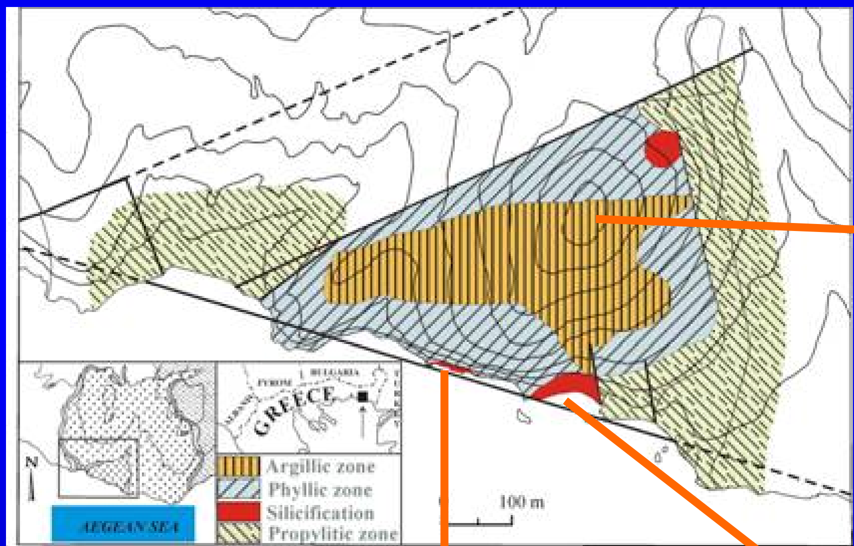
Porphyry microgranite



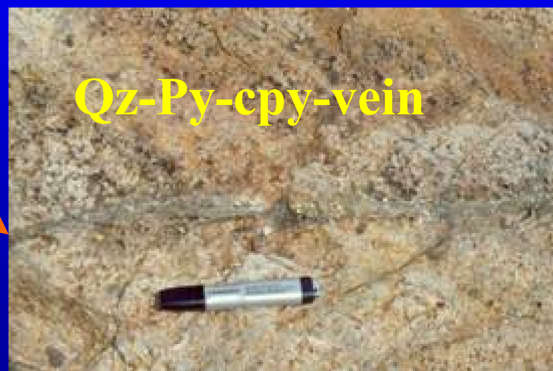
Sketch map of hydrothermal alteration zoning of the Maronia porphyry type deposit. Phyllic, silicified, argillic and propylitic zones are illustrated (Melfos et al. 2002)

Ktismata Hill Cu-Mo-Au deposit

K-silicate alteration absent. Cu-Mo ore related to sericitic (±pyrophyllite) alteration and intense silicification. Several stages of quartz veining: Early porphyry-style veins with Cu-Mo-Au mineralisation succeeded by HS ore assemblages.



Sphalerite-galena



Ore minerals of the Maronia porphyry Cu-Mo deposit:

pyrite, chalcopyrite, pyrrhotite, molybdenite and magnetite

minor Cu-Pb-(Sb+As) sulphosalts: tennantite, tetrahedrite, zinkenite, chalcostibite, famatinite, bournonite, boulangerite and meneghinite

trace amounts of cubanite, pentlandite, sphalerite, galena and bismuthinite

---

Molybdenite

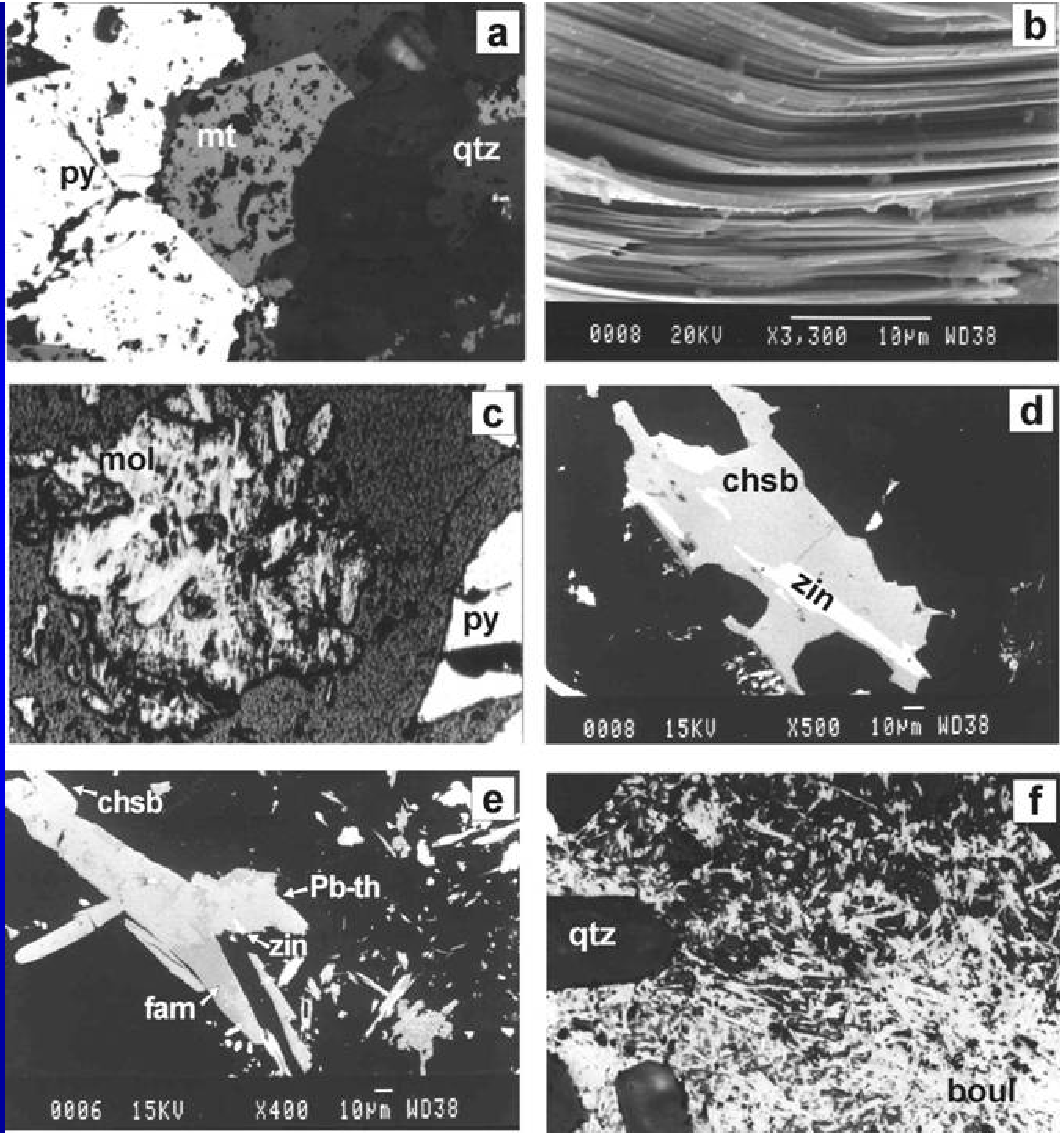
X-ray diffraction analyses: mixed $2H_1$ and 3R polytypes

microprobe analyses: 0.12 to 2.88 wt% Re

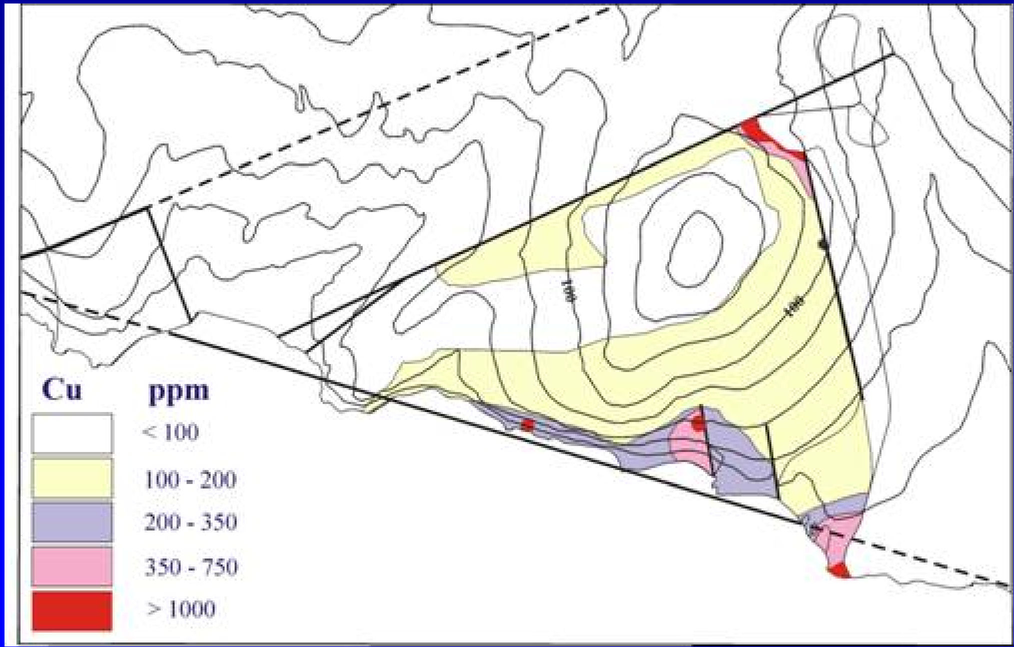
average chemical formula $Re_{0.01}Mo_{0.99}S_{2.00}$

Melfos et al. (2002)

Ore mineral associations from the Maronia Cu-Mo porphyry-type mineralisation

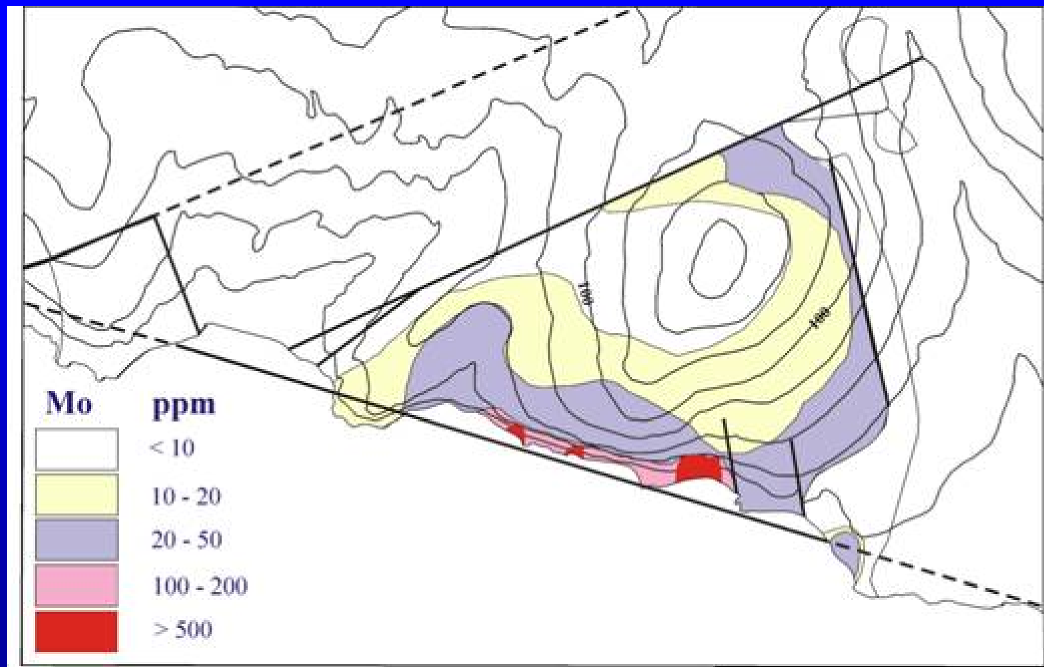


Melfos et al. (2002)



Distribution of copper (Cu) and molybdenum (Mo) within the Maronia porphyry type deposit. The element distribution corresponds to the zones enriched in chalcopyrite and molybdenite, respectively.

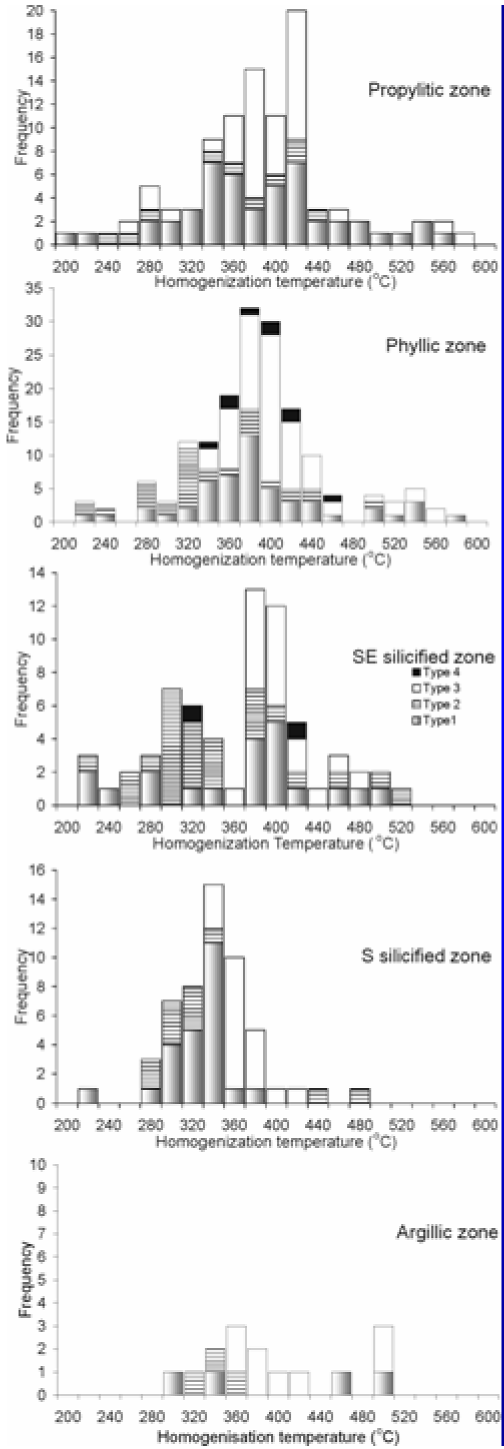
Surface samples of altered rock contain as much as 7,600 ppm Mo, 5,460 ppm Cu and 1 ppm Au.

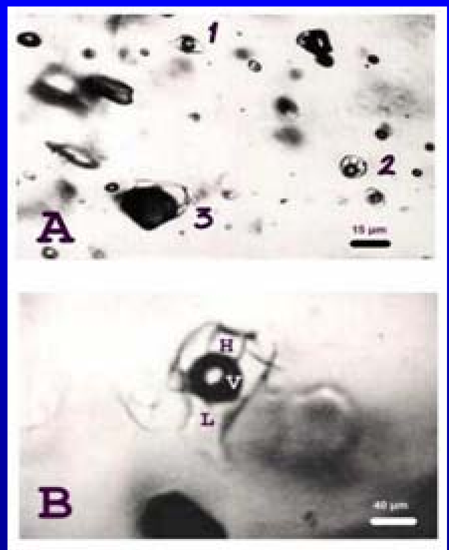


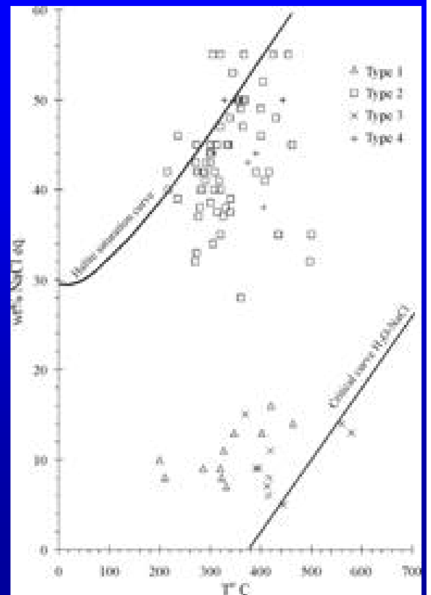
Melfos et al. (2002)

FLUID INCLUSIONS

- Four types of fluid inclusions in ore-related quartz
- Salinities from 5 to 55 wt% NaCl equiv
- Homogenisation temperatures varying mainly from 280 to 460 °C
- Trapping temperatures in quartz-pyrite-chalcopyrite veins from the phyllic alteration zones range from <u>360 to 420 °C</u> and record the main temperature range of copper deposition.
- Trapping pressures of the ore-forming fluids from 150 to 510 bar
- Boiling is considered to be the main process of ore formation







Melfos et al. (2002)

SULPHUR ISOTOPES

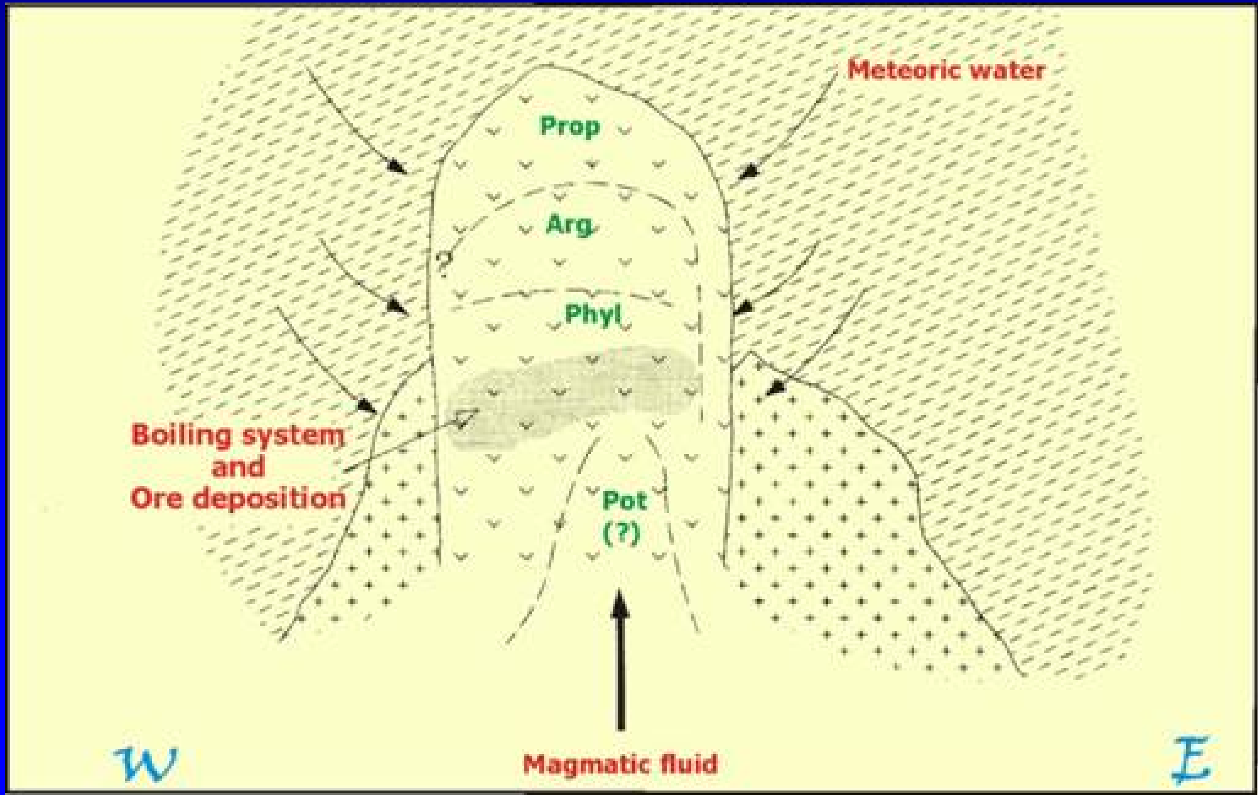
S-isotope compositions for the pyrite and molybdenite suggest an igneous derivation of sulphur.

	$\delta^{34}S$	
Sample	py	mol
M 80/3	3.79	3.76
M 80/6	3.99	3.75
M 80/7	4.34	3.69
M 80/12	4.31	-
M 80/12-1	4.25	-
Average	4.14	3.73

CHLORITE THERMOMETER

The application of the modified geothermometer to the chlorites from the propylitic alteration at the Maronia deposit yielded temperatures between 308 and 331 °C (320 °C on average)

Melfos et al. (2002)



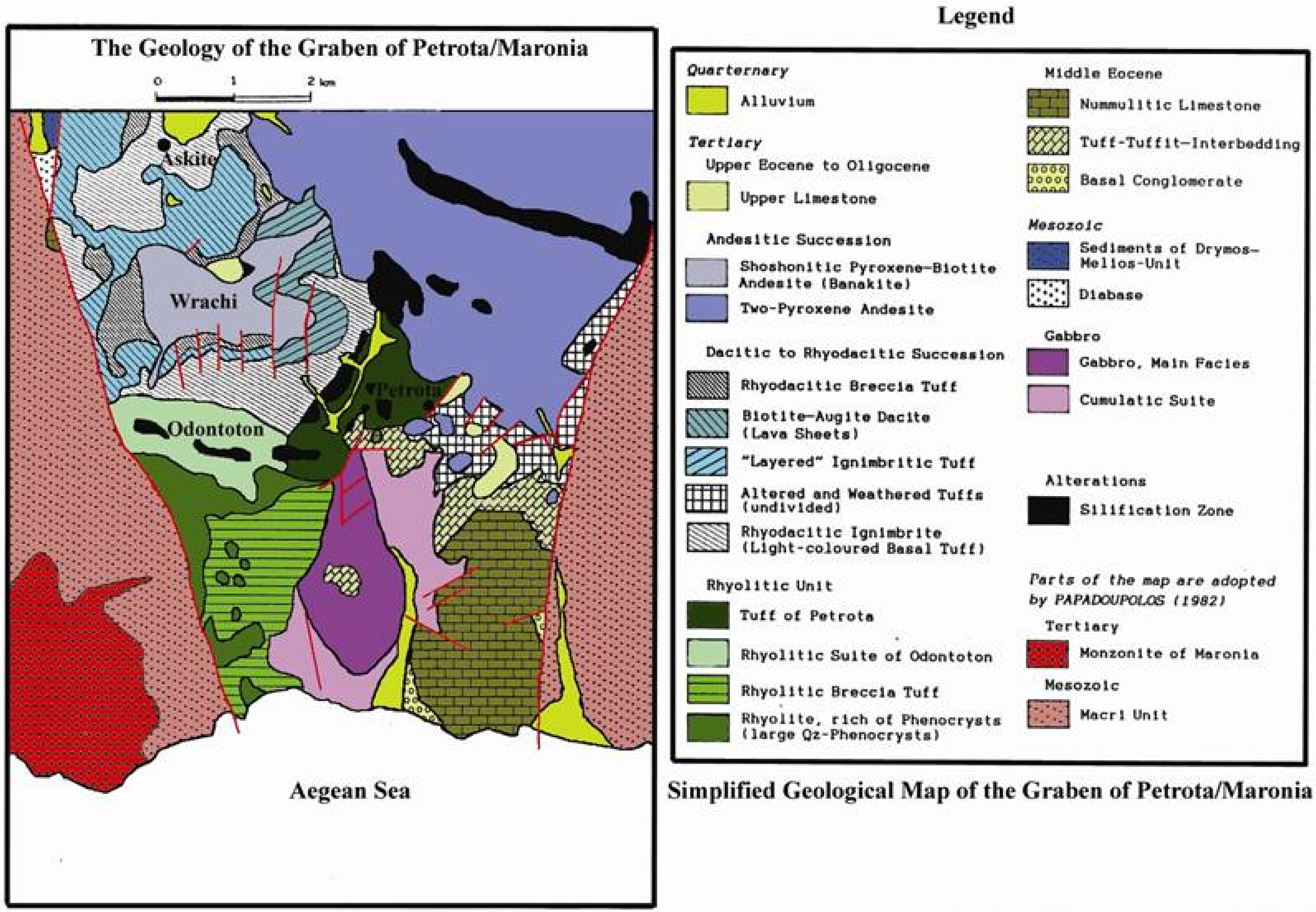
- The Maronia porphyry Cu-Mo deposit was formed in a subvolcanic environment during Tertiary
- Boiling is considered to be a potential cause for ore formation
- The main temperature range of Cu-Mo deposition was 360 to 420 °C

Melfos et al. (2002)

Perama Hill

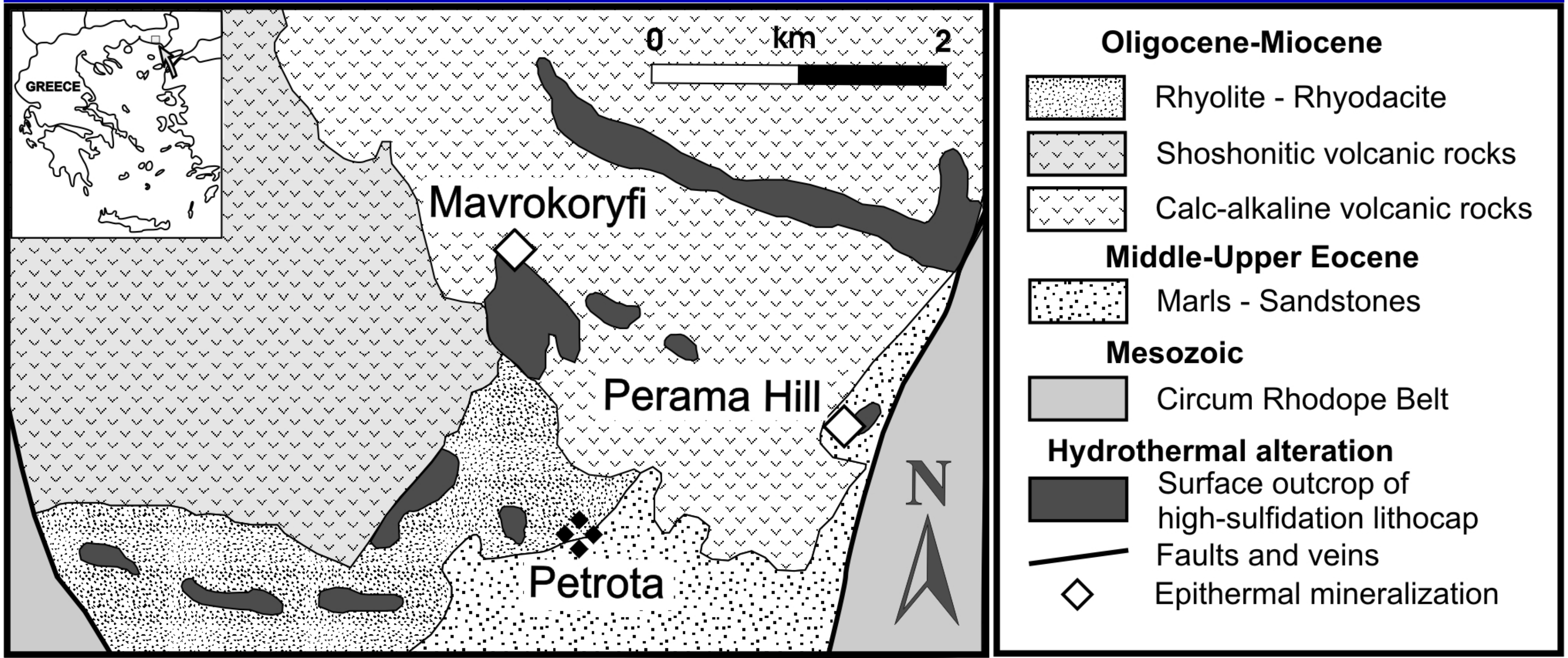
HS-IS epithermal Au-Ag-Te deposit

Geology of Petrota Graben



Simplified Geological Map of the Graben of Petrota/Maronia

Arikas & Voudouris (1998)



Voudouris (2006)

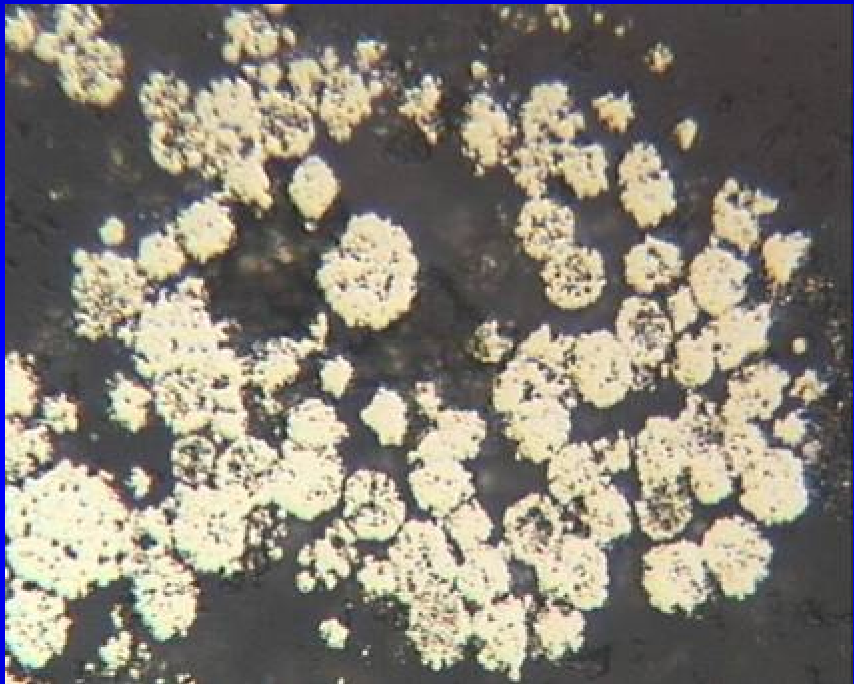
Perama Hill: Upper parts oxidized ore within silicified sandstone. Lower parts andesite breccia with primary HS ore

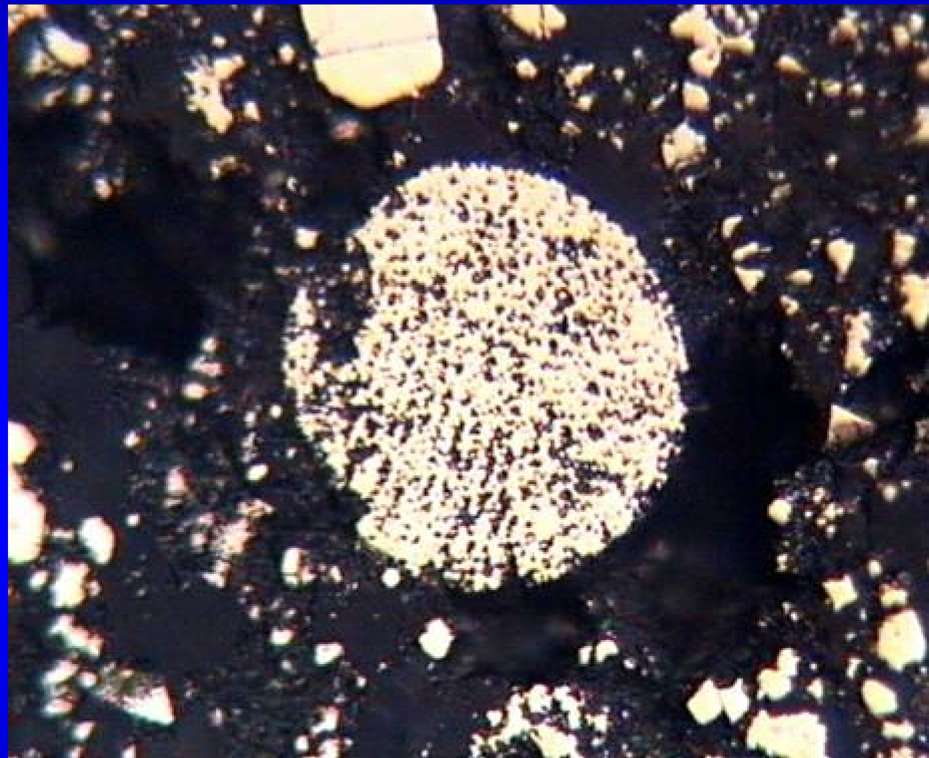
Perama Hill (upper parts): Native gold in oxidized Perama sandstone and in low-sulfidation banded quartz-barite veins

Perama Hill

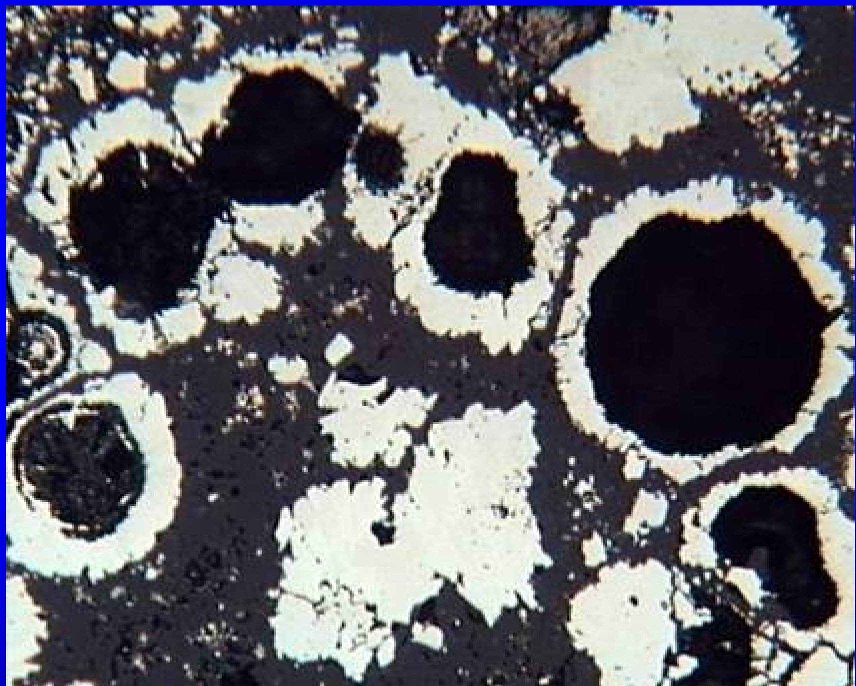
(lower parts): massive pyrite-enargite ore → base metals – tellurides barite veins

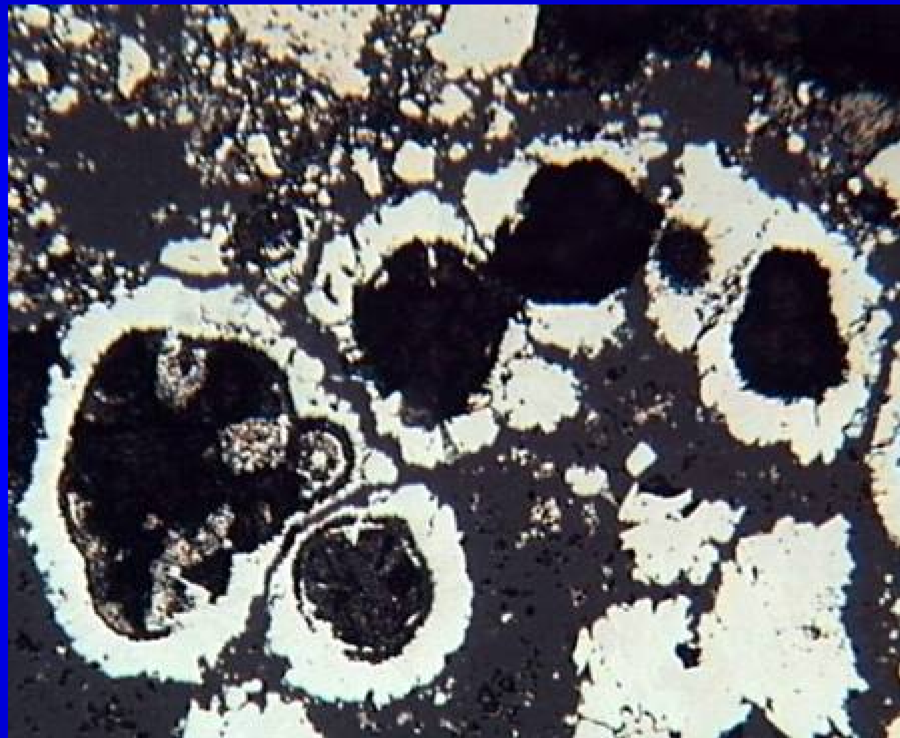
Framboidal pyrite: lower parts of Perama Hill



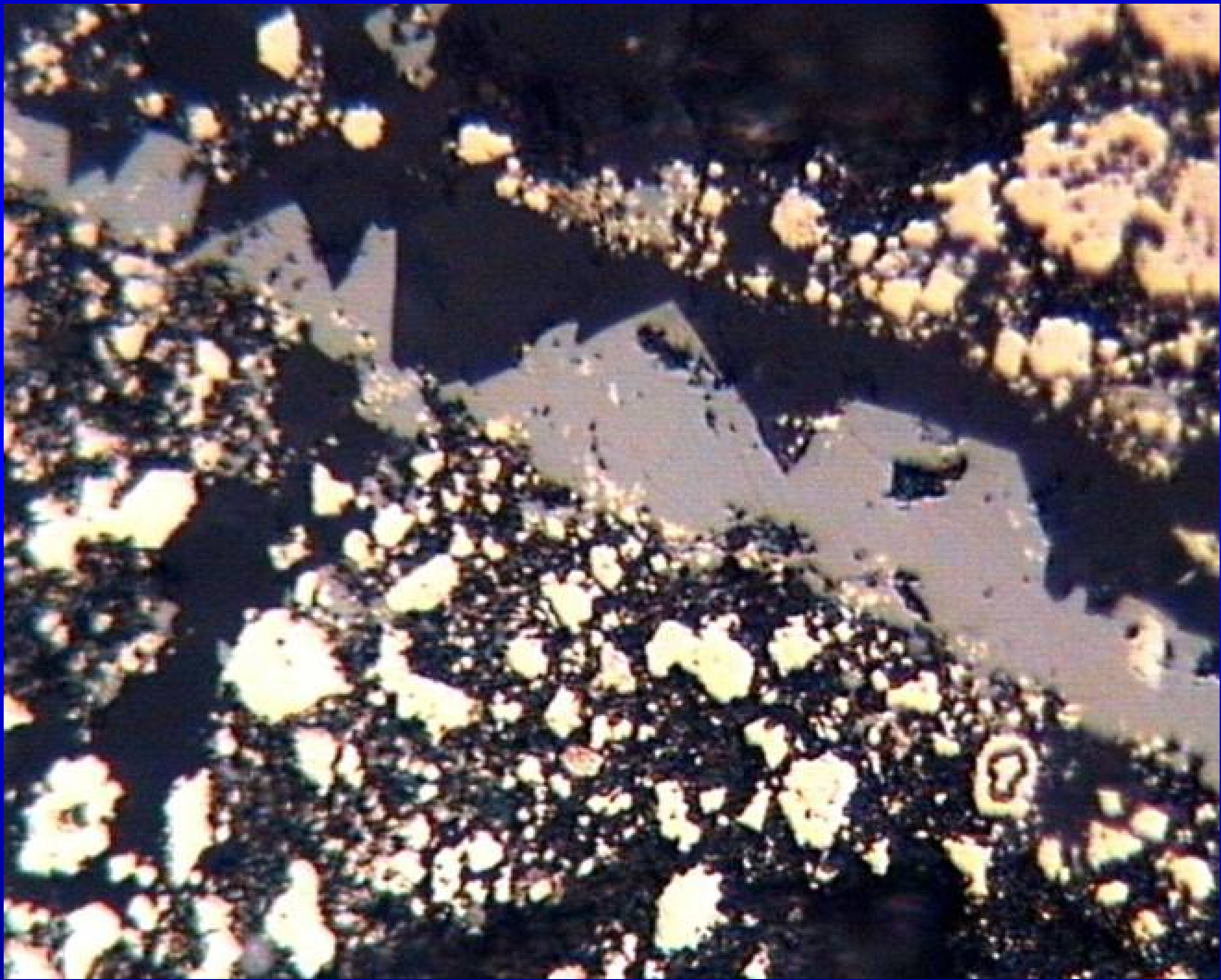


Microchimney-similar structures: lower parts of Perama Hill



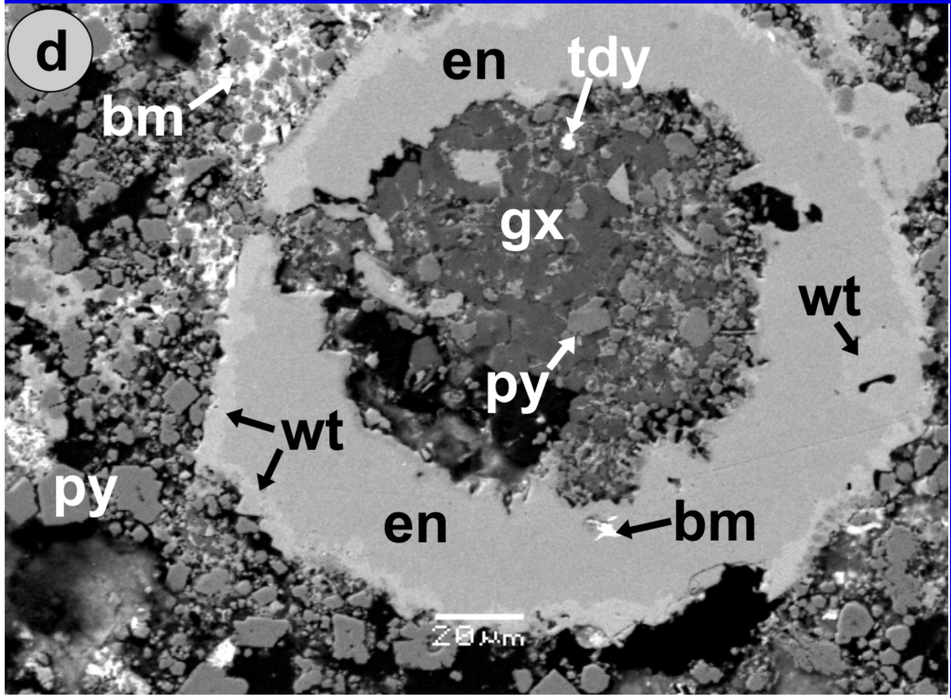


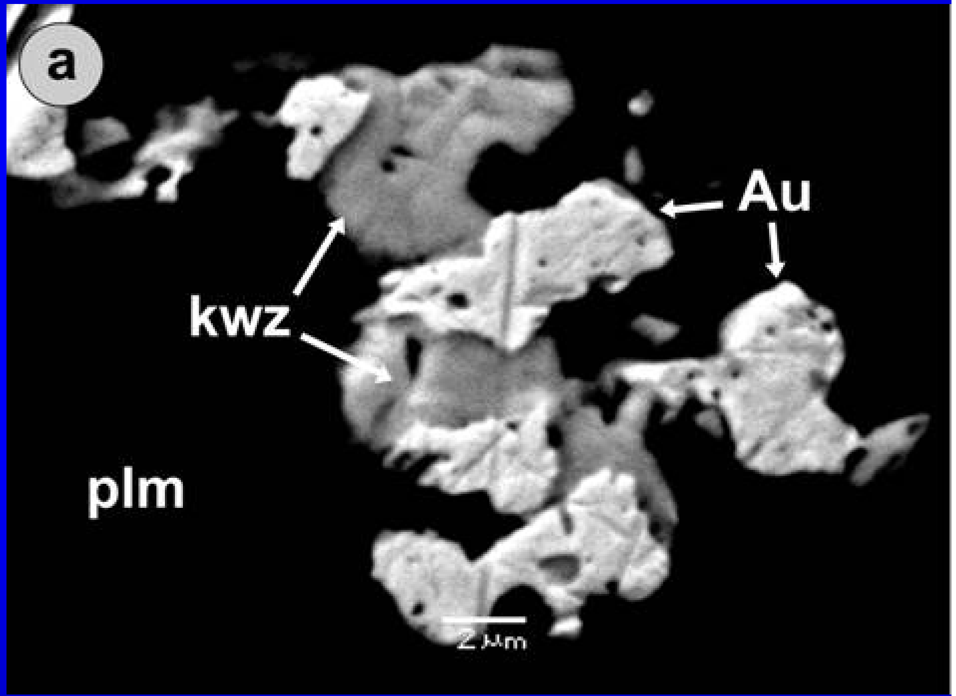
High-sulfidation enargitic ore at the lower parts of Perama Hill



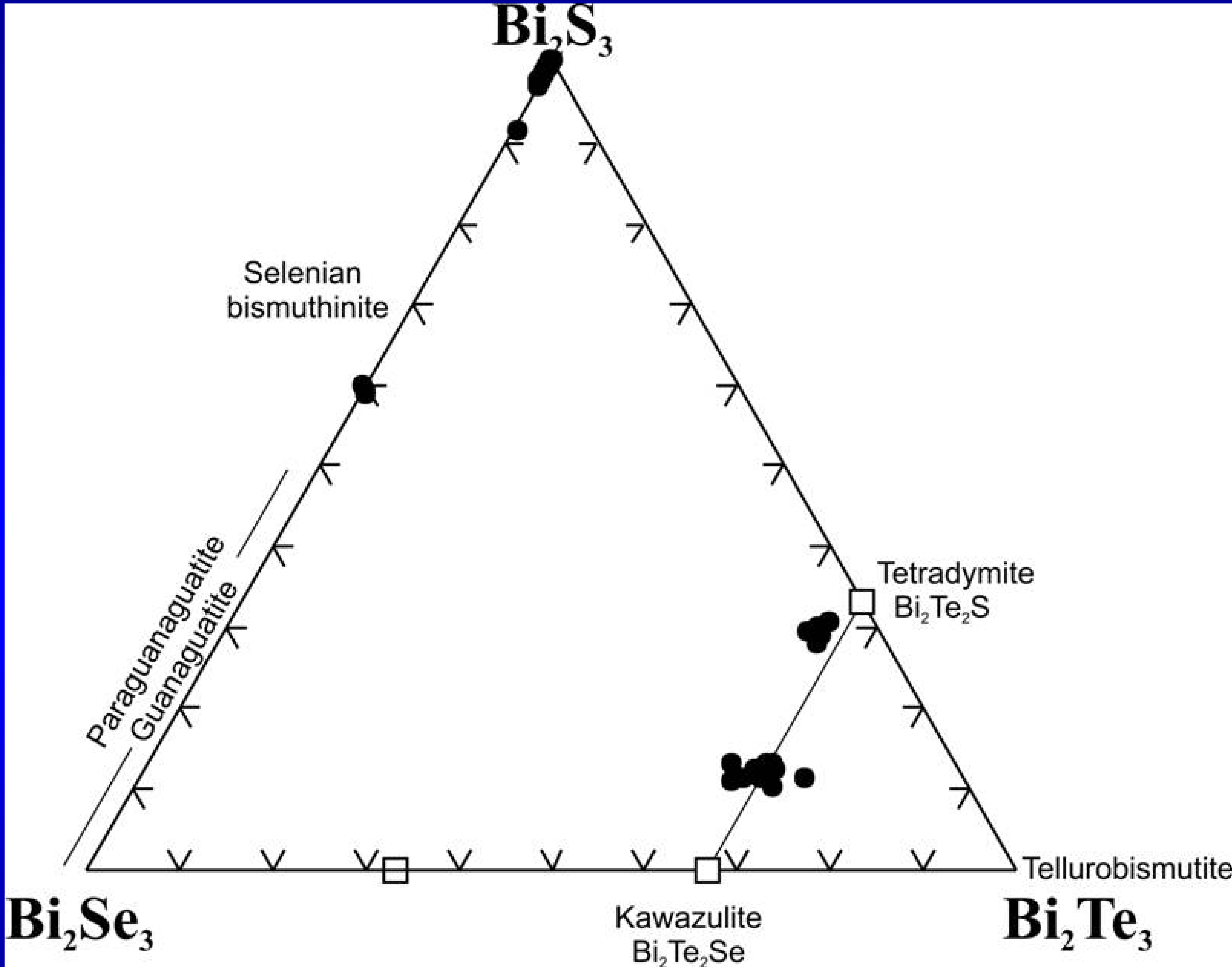
Bismuthinite, Enargite, Pyrite at the lower parts of Perama Hill

High-sulfidation enargitic ore at the lower parts of Perama Hill with tetradymite, kawazulite and native gold



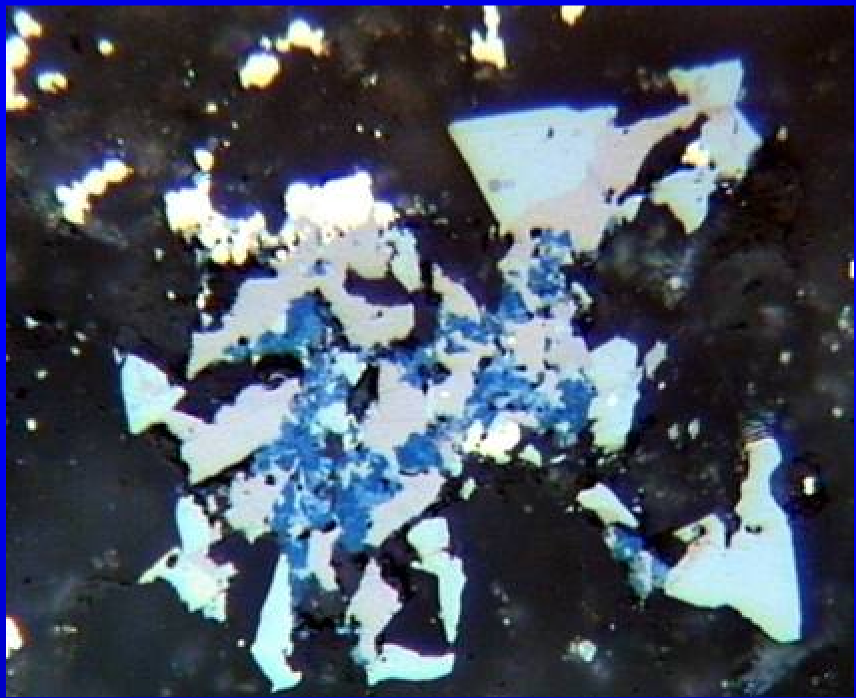


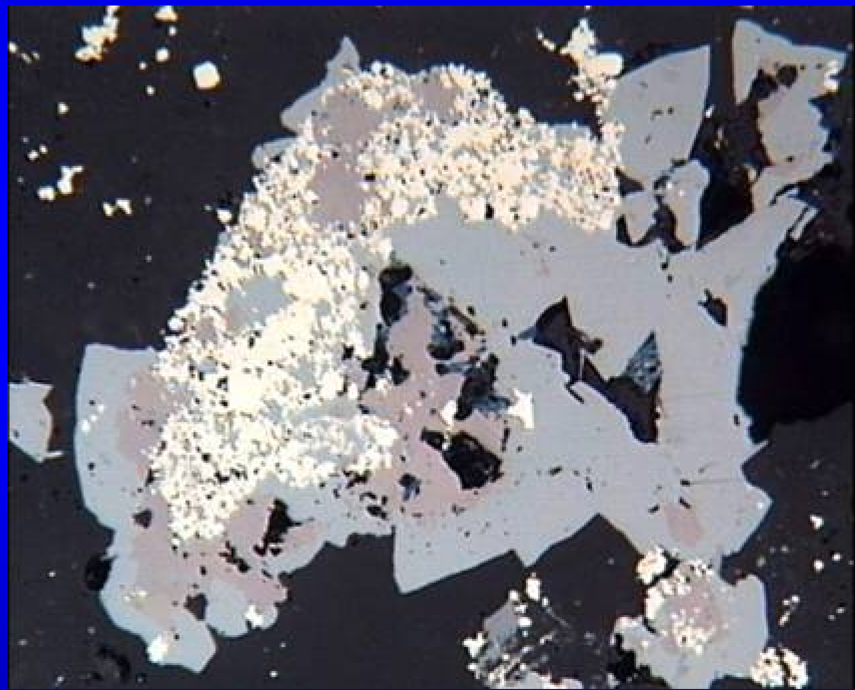
Voudouris et al. (2009b)



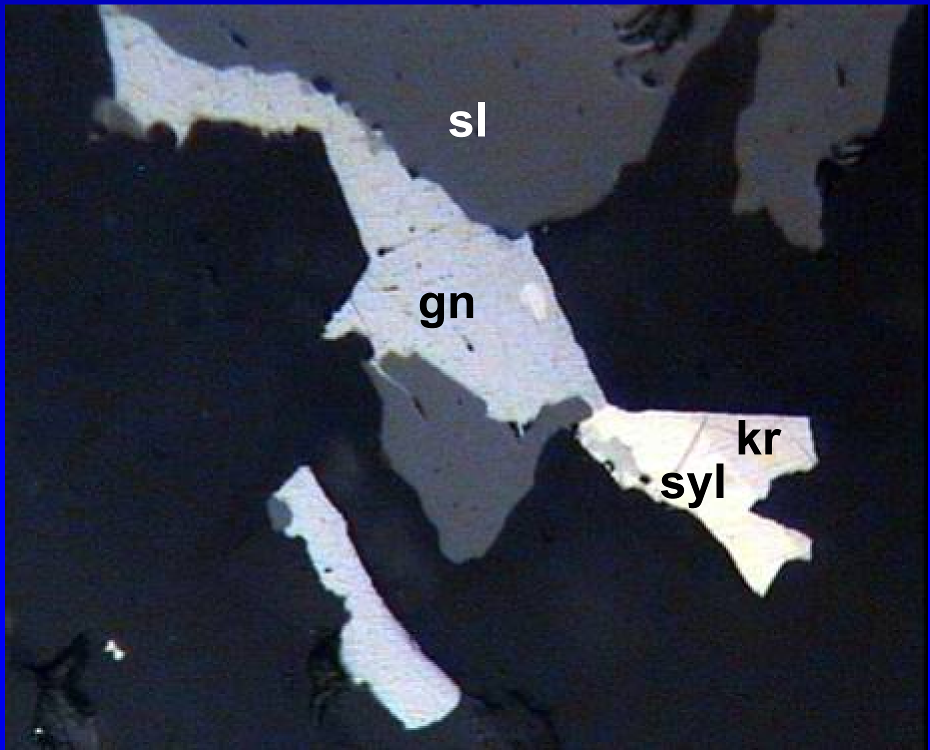
Voudouris et al. (2009b)

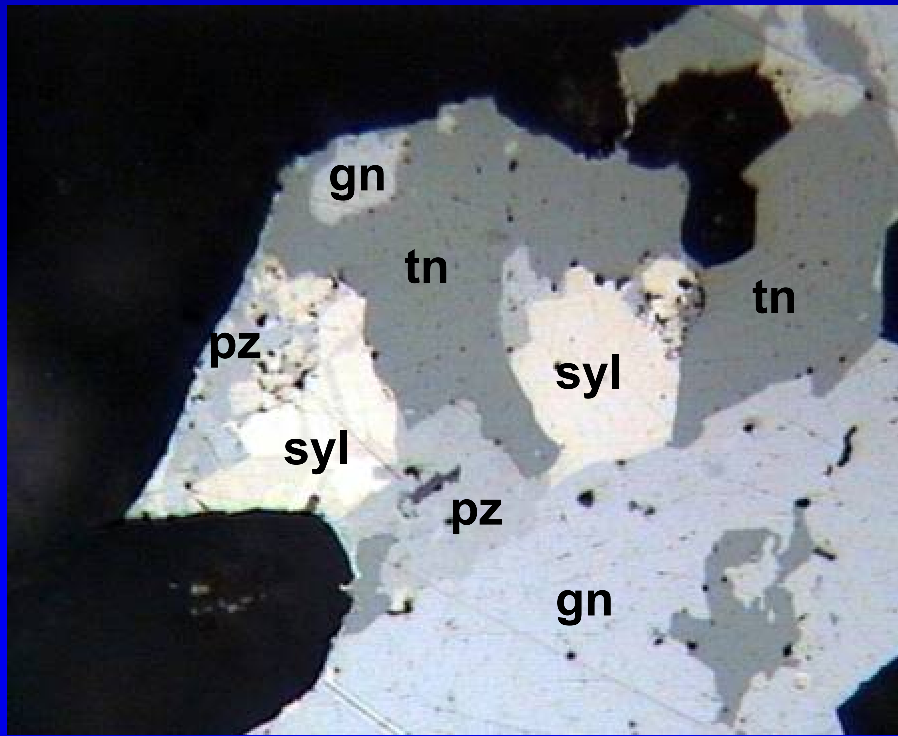
Tennantite postdates Enargite, Covelline at the lower parts of Perama Hill





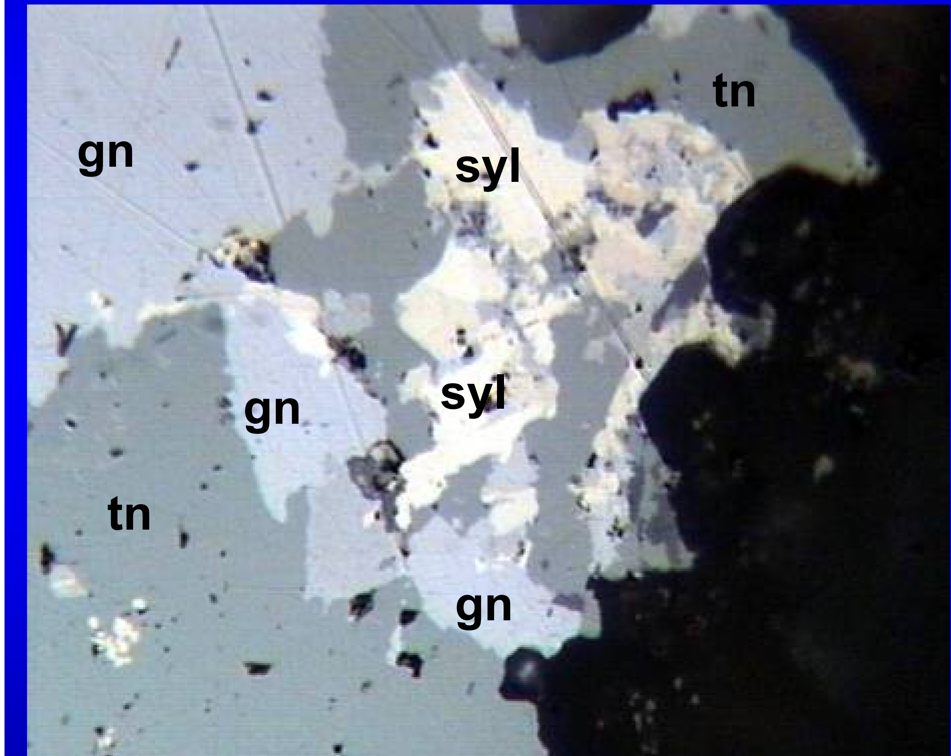
Au-Ag tellurides associated with galena and tennantite (lower parts of Perama Hill)

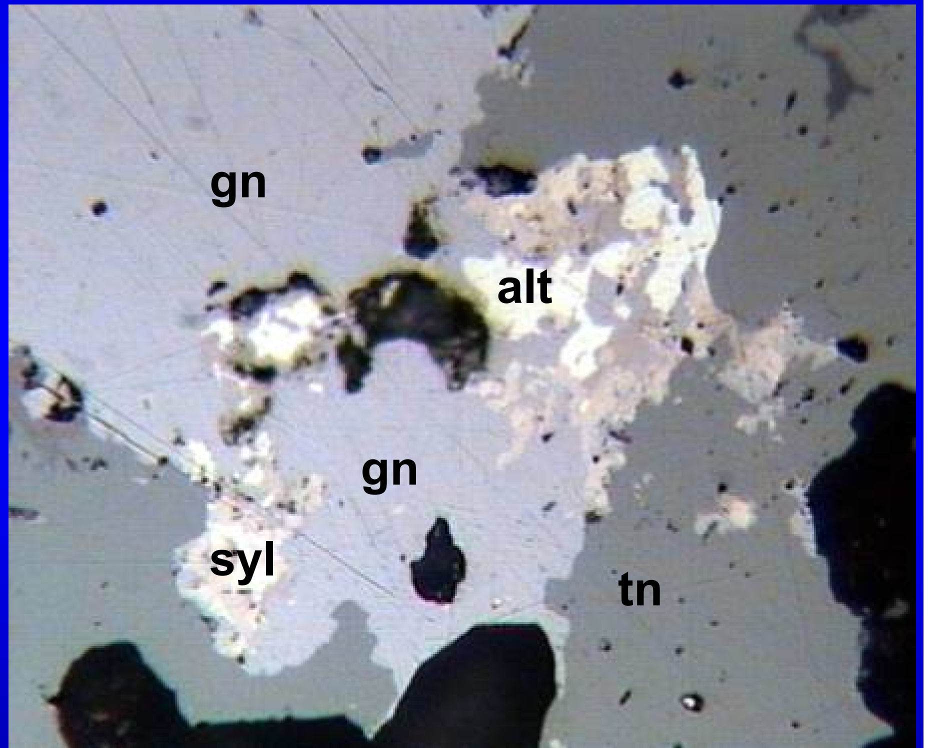




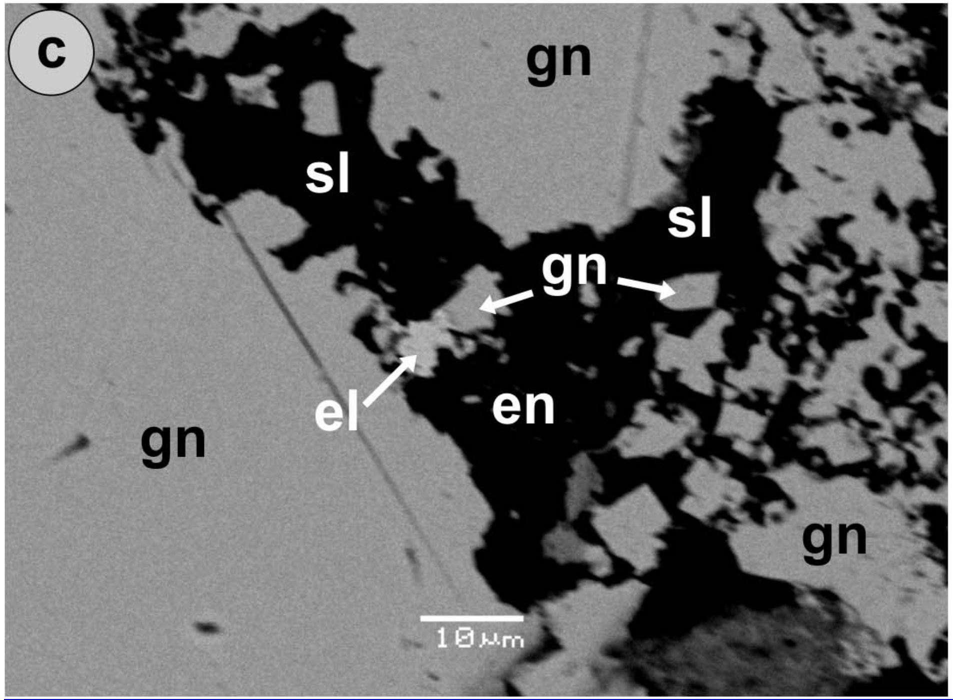
Sylvanite-petzite intergrowths are very common and probably the result of decomposition of γ-phase. The Au content in sylvanite ranges between 26.9 and 30.0 wt% and Ag between 8.6 and 12.5 wt%.

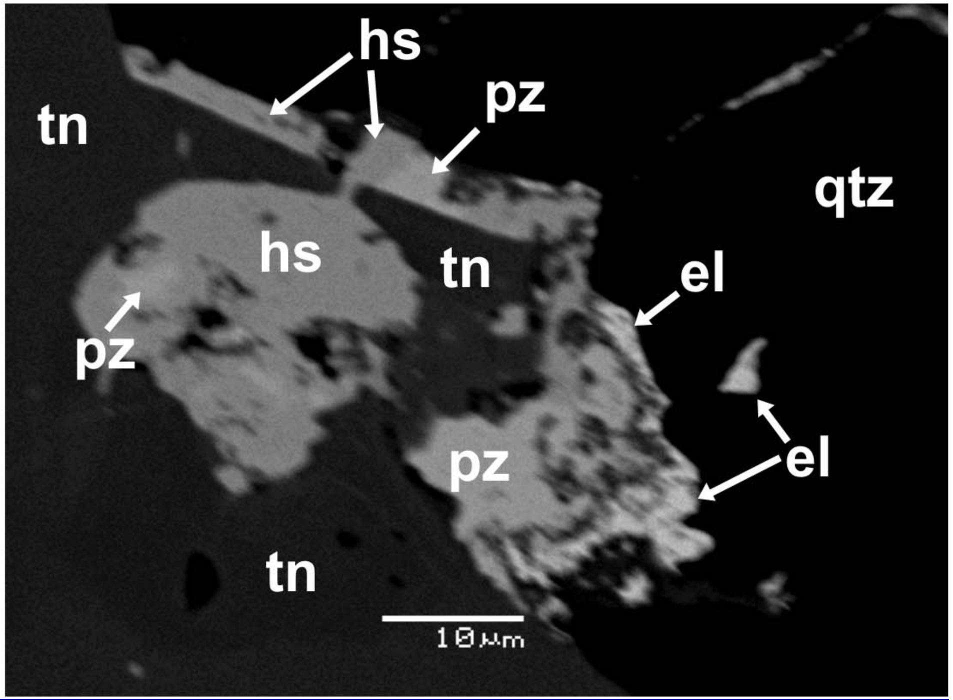
Au-Ag tellurides associated with galena and tennantite (lower parts of Perama Hill)





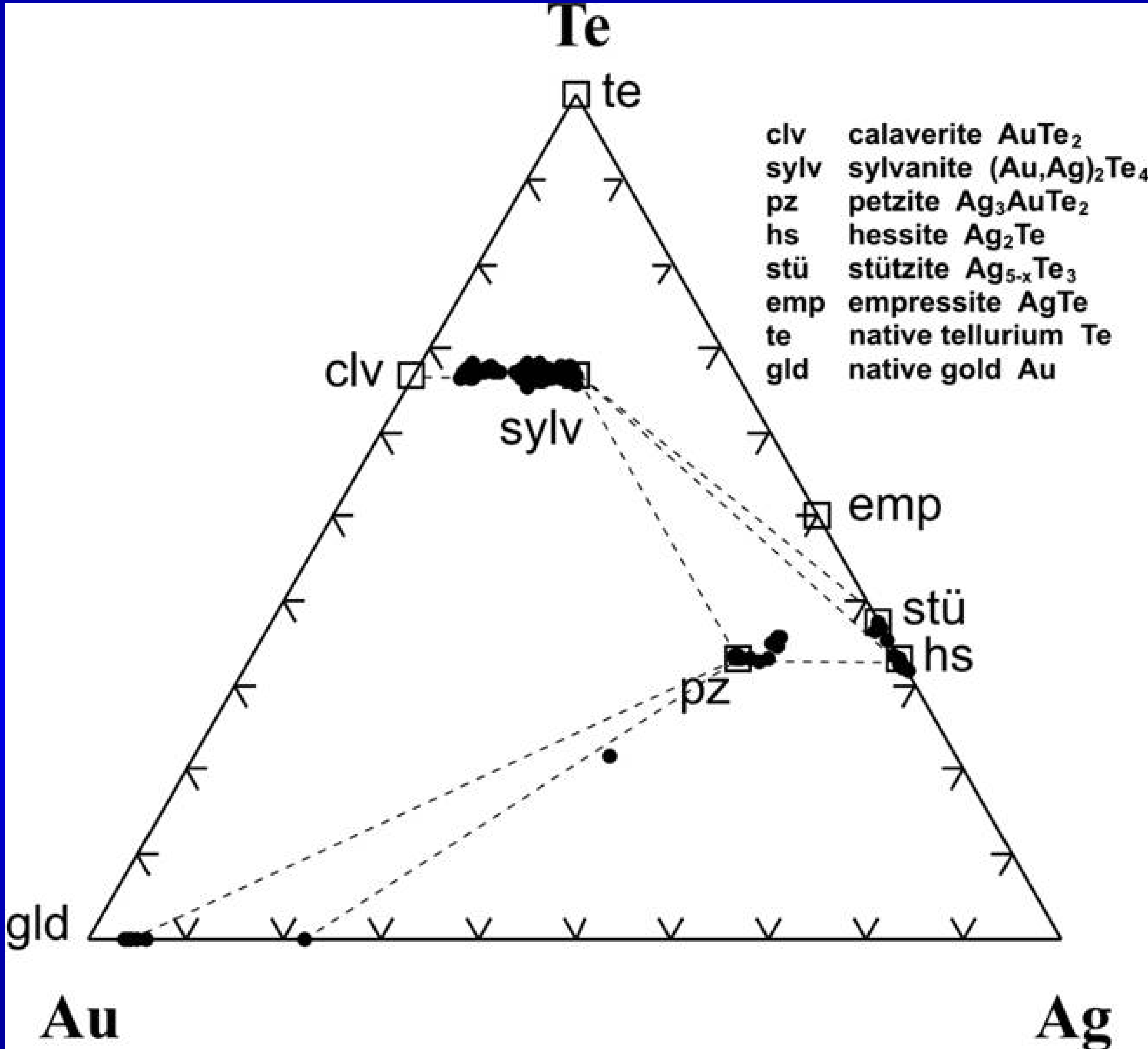
Electrum associated with Au-Ag tellurides (lower parts of Perama Hill)



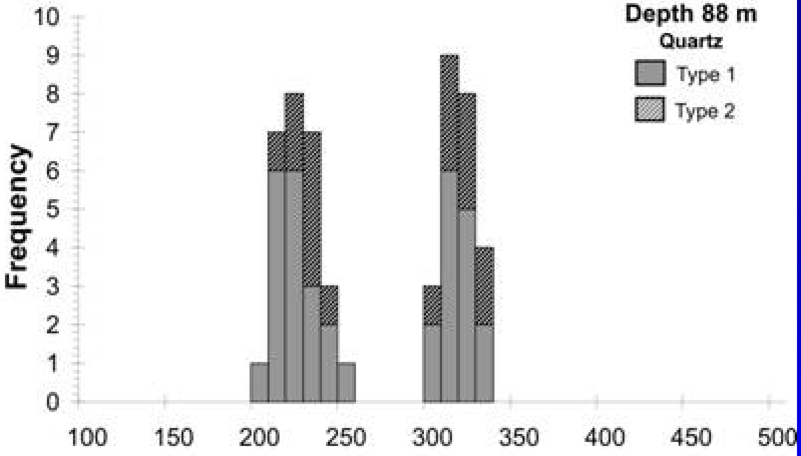


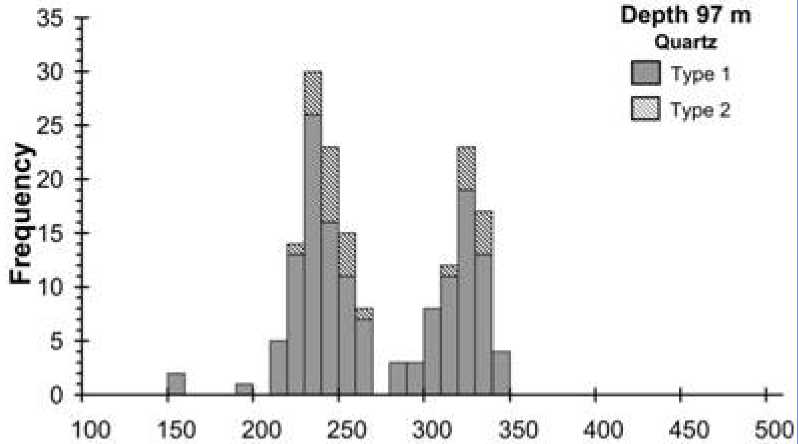
Voudouris et al. (2009b)

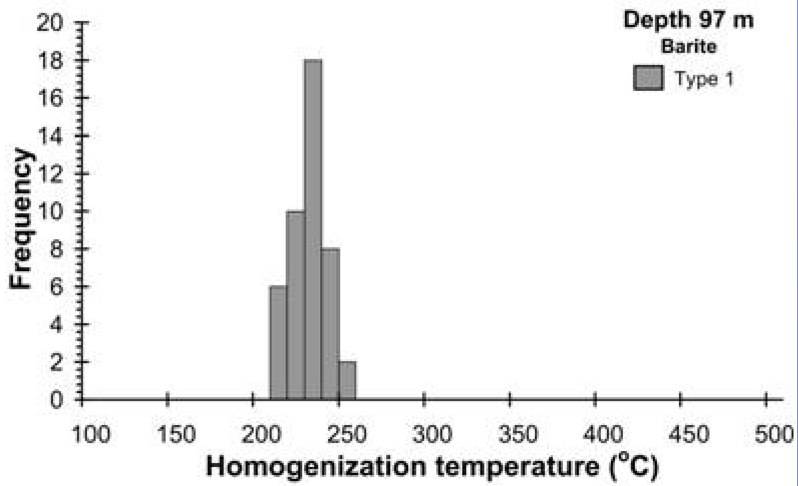
Au-Ag tellurides (lower parts of Perama Hill)

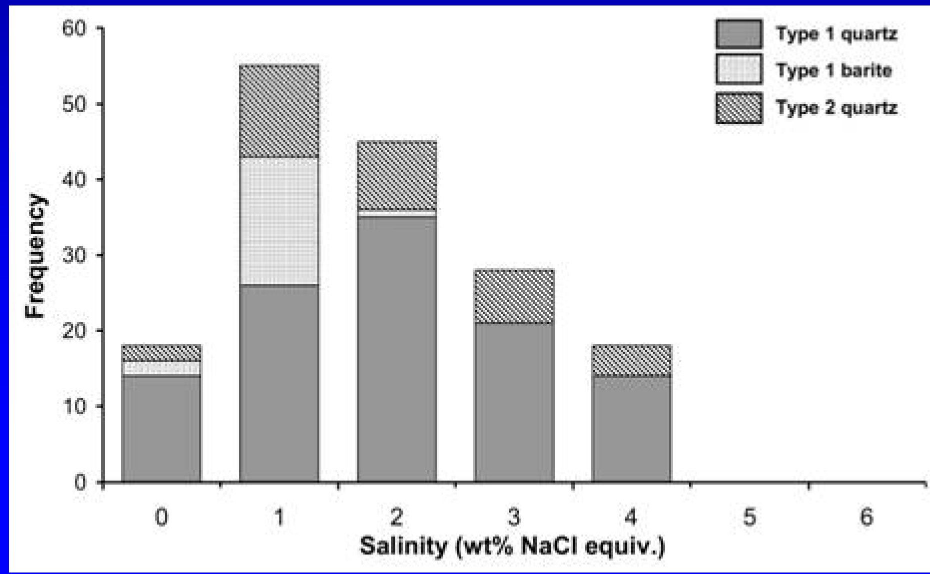


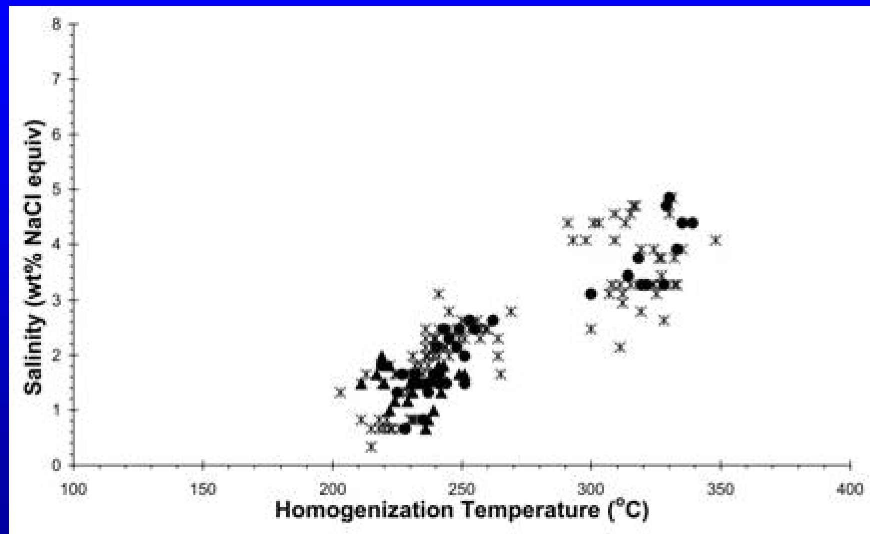
Fluid inclusion results (lower parts of Perama Hill



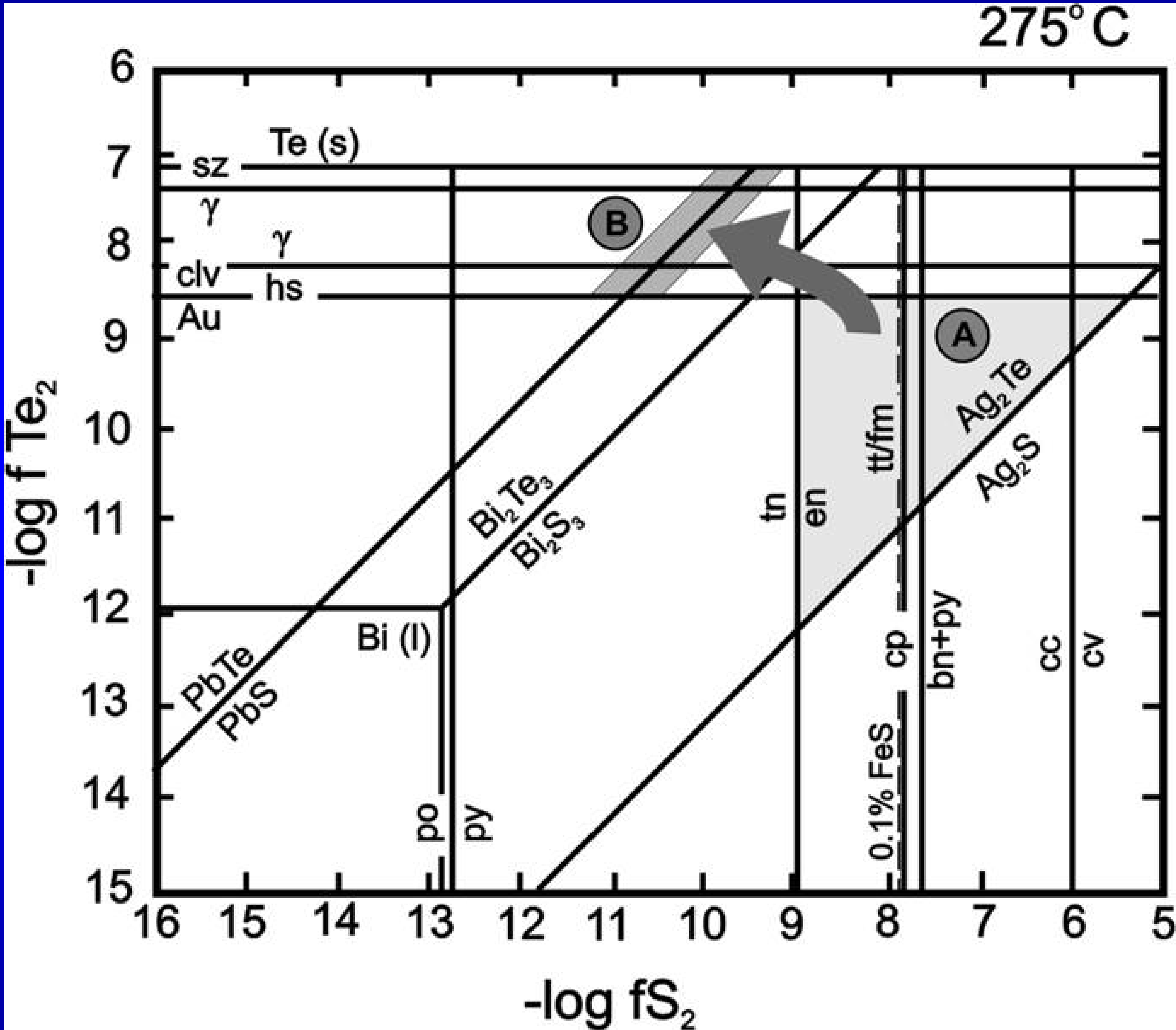








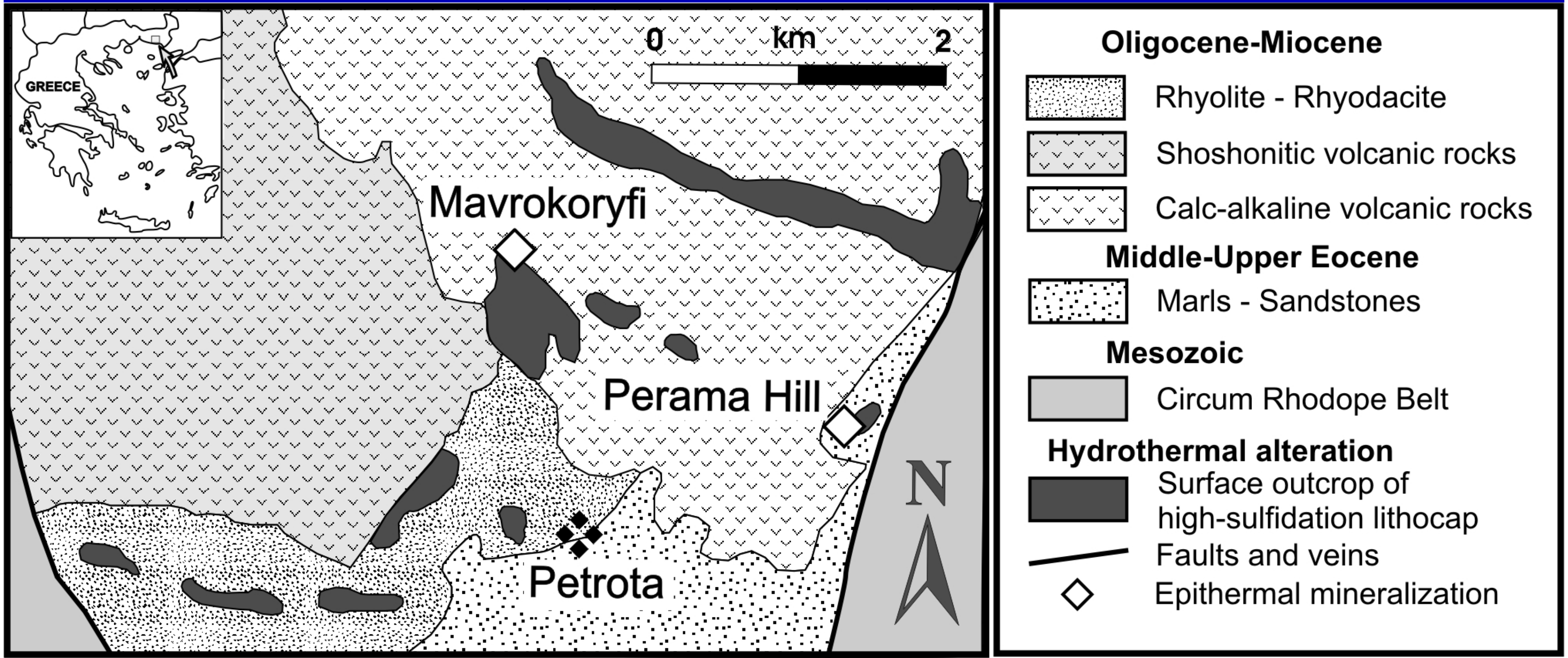
Evolution of ore fluids during mineralization at Perama Hill



Voudouris et al. (2007)

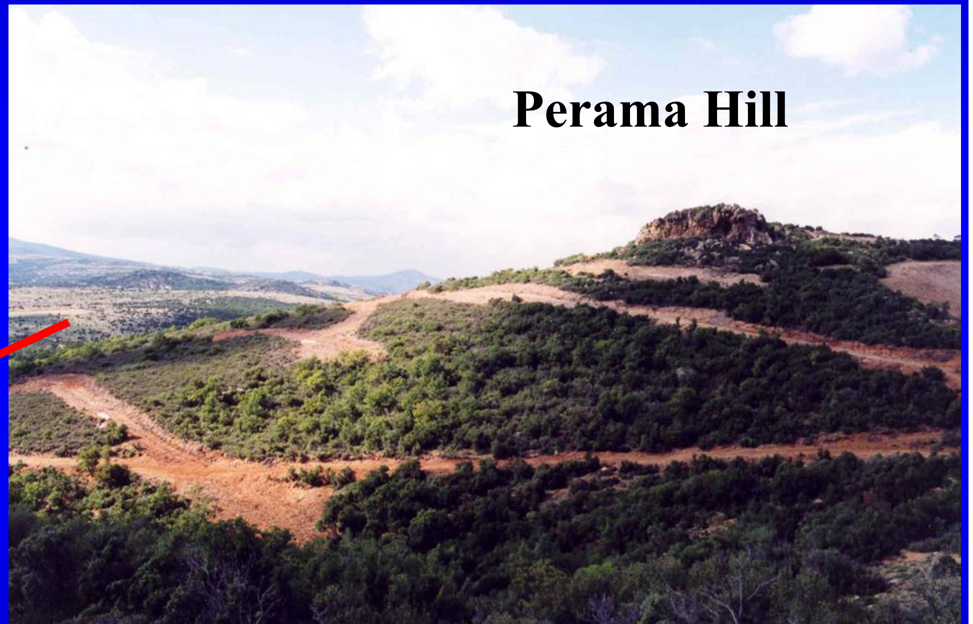
Mavrokoryfi

End-member HS epithermal Ag-Cu-Te mineralization

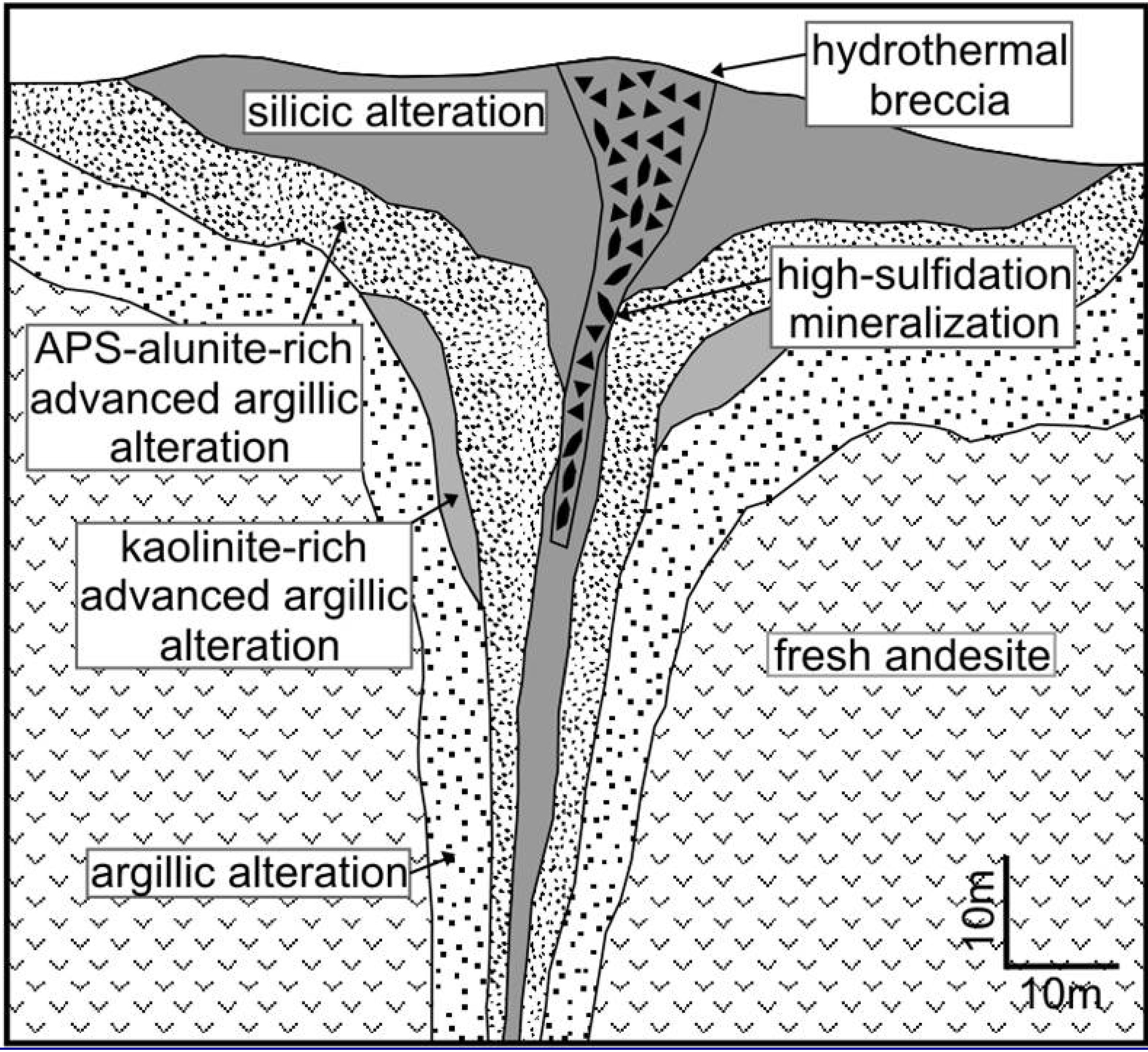


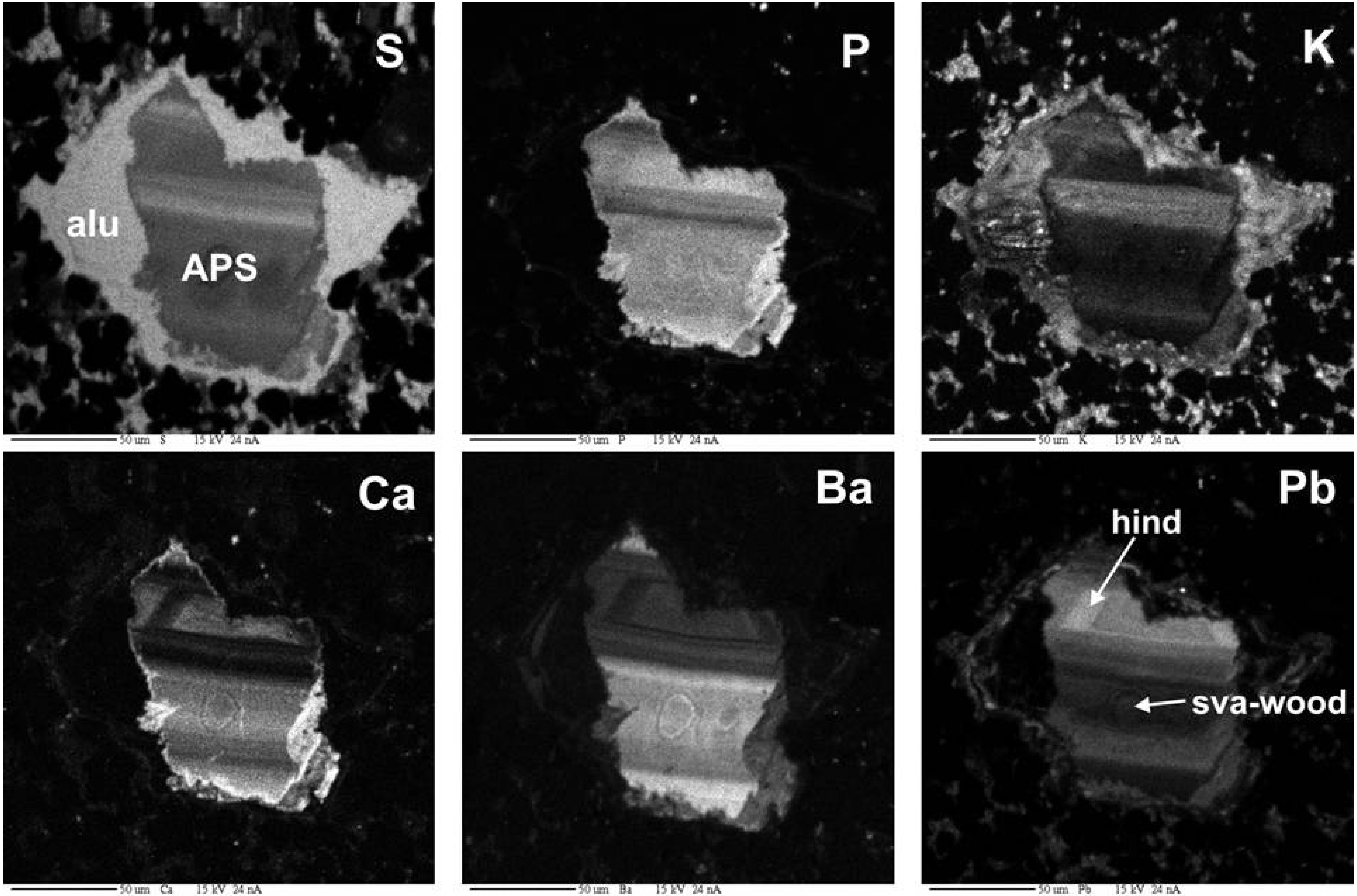
Voudouris (2006)

Perama Hill: Upper parts oxidized ore within silicified sandstone. Lower parts andesite breccia with primary HS ore. Mavrokoryfi: HS ore hosted in opalized andesites

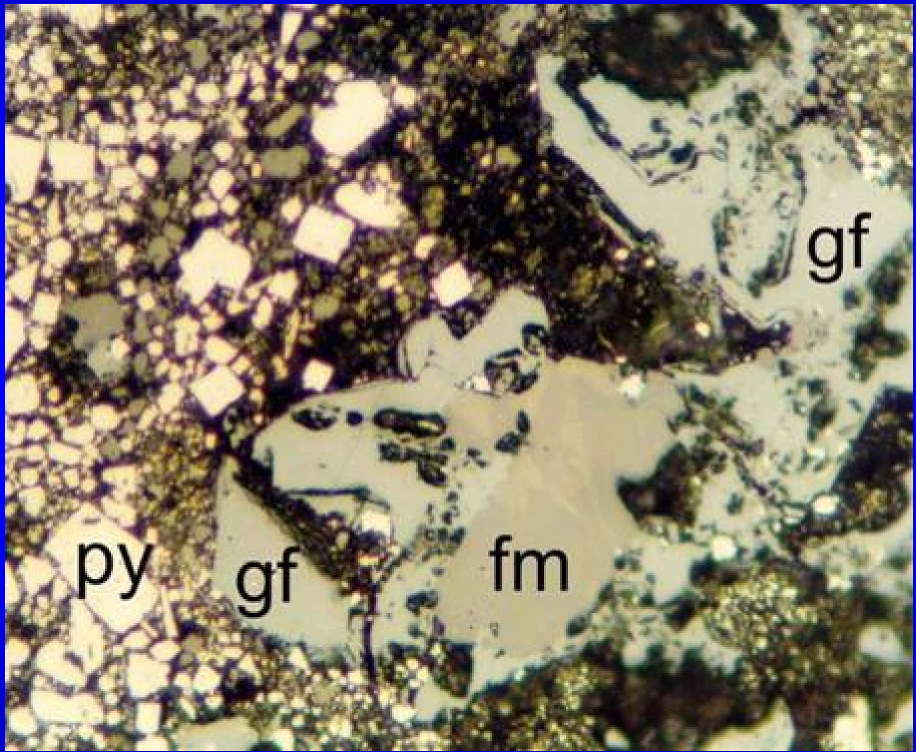


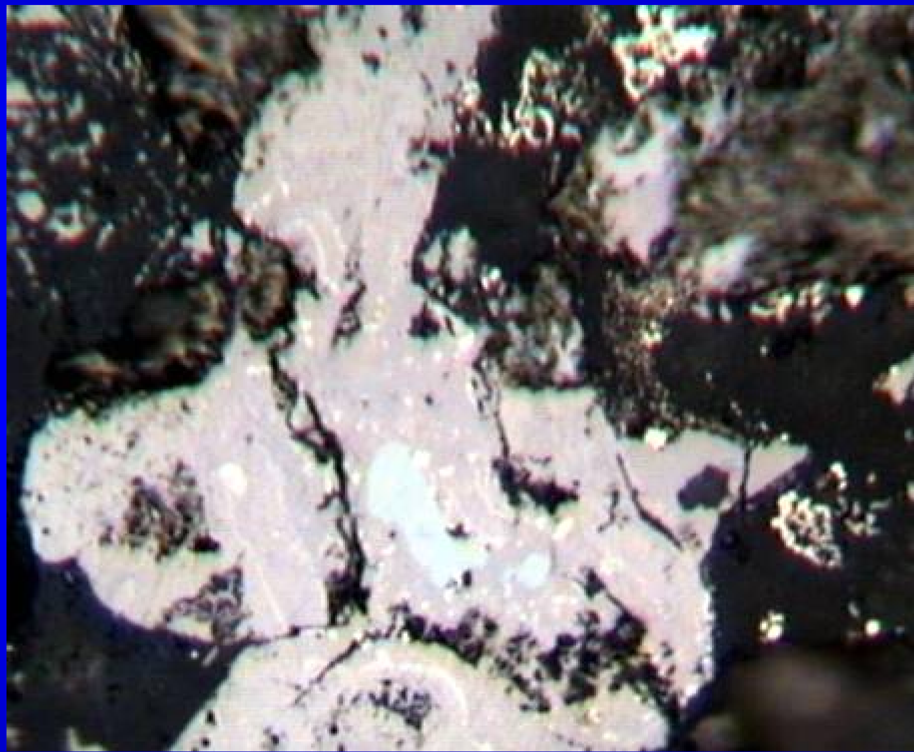
Mavrokoryfi: High-sulfidation mineralization within andesitic hyaloclastites

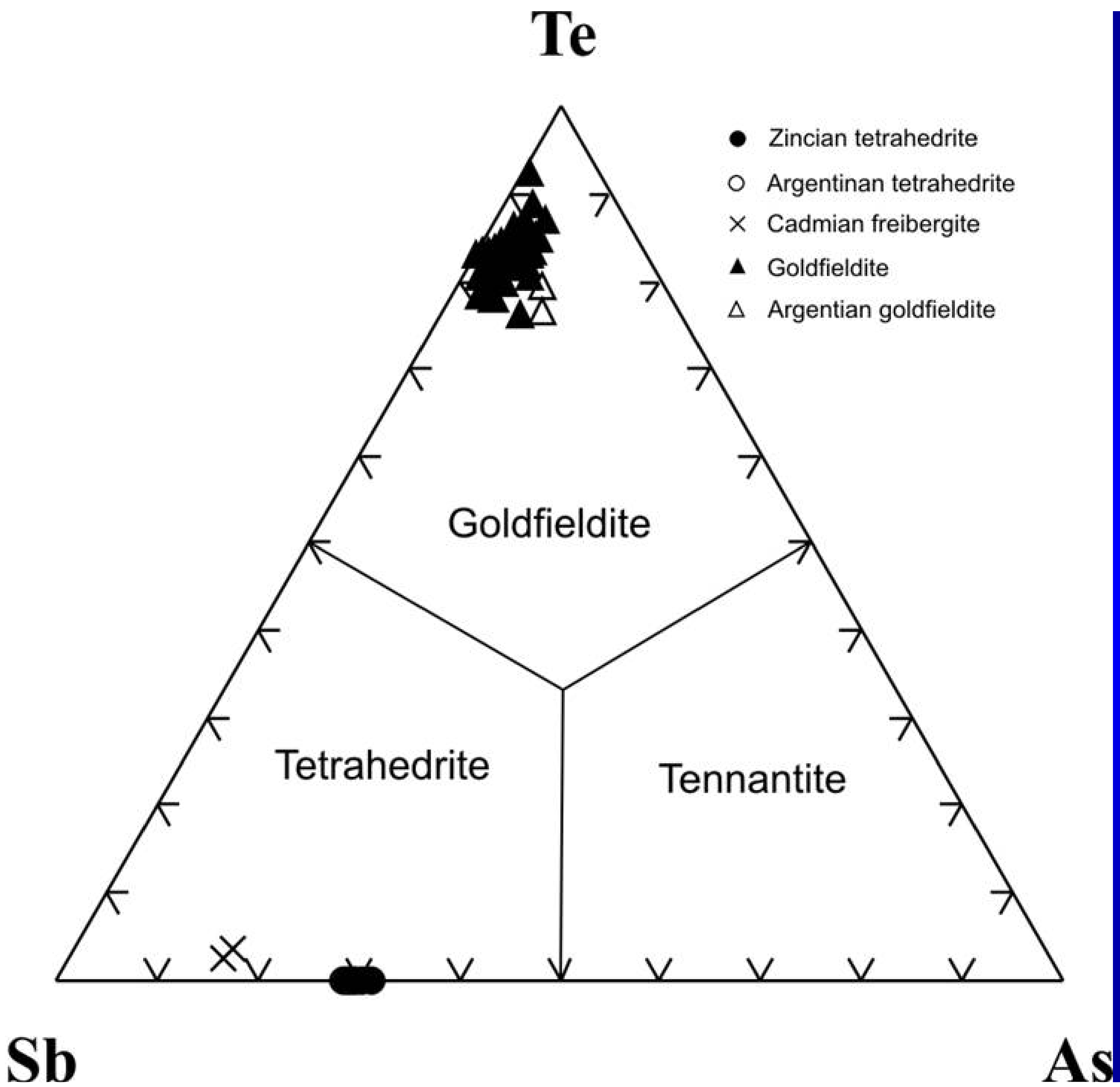

hydrothermal breccia
silicic alteration
high-sulfidation mineralization
APS-alunite-rich advanced argillic alteration
kaolinite-rich advanced argillic alteration
fresh andesite
argillic alteration
10m
10m


S
alu
APS
50 um S 15 kV 24 nA
P
50 um P 15 kV 24 nA
K
50 um K 15 kV 24 nA
Ca
50 um Ca 15 kV 24 nA
Ba
50 um Ba 15 kV 24 nA
Pb
hind
sva-wood
50 um Pb 15 kV 24 nA

Mavrokoryfi: Famatinite and Goldfieldite





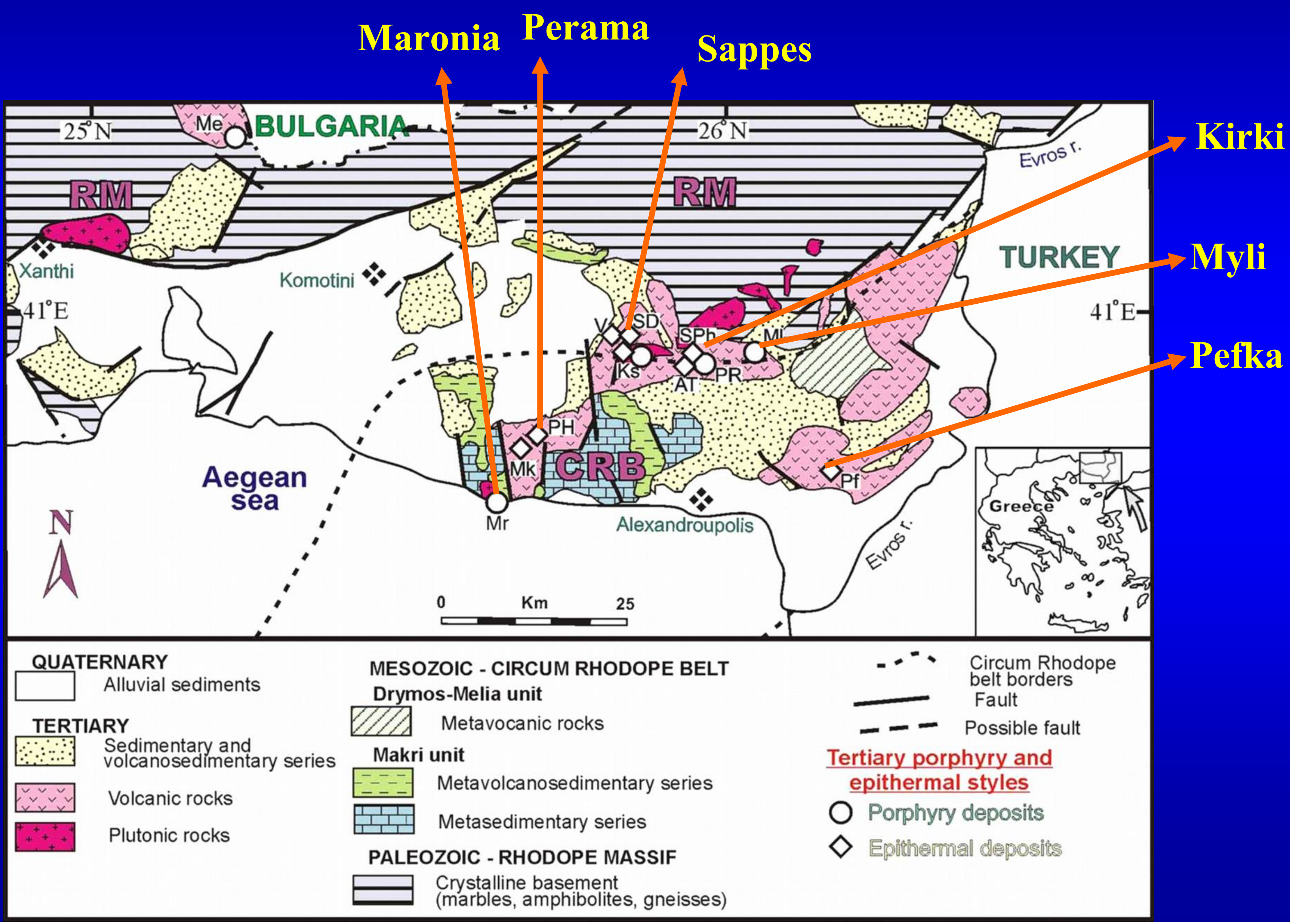


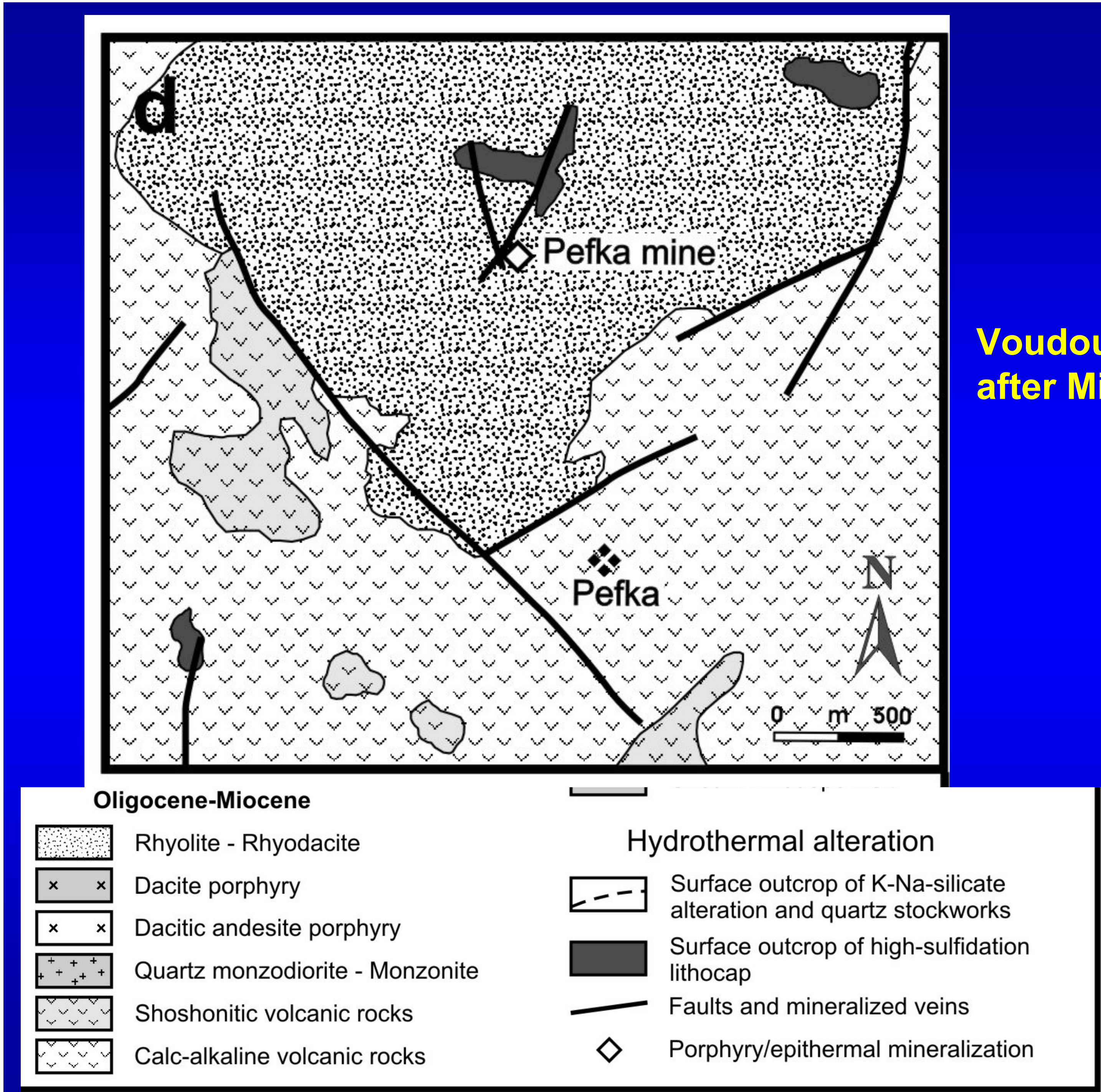
Te
Sb
As
Zincian tetrahedrite
Argentinan tetrahedrite
Cadmian freibergite
Goldfieldite
Argentian goldfieldite
Goldfieldite
Tetrahedrite
Tennantite

Pefka mine

HS-IS epithermal Au-Ag-Te deposit

Northeastern Greece: Regional Geology





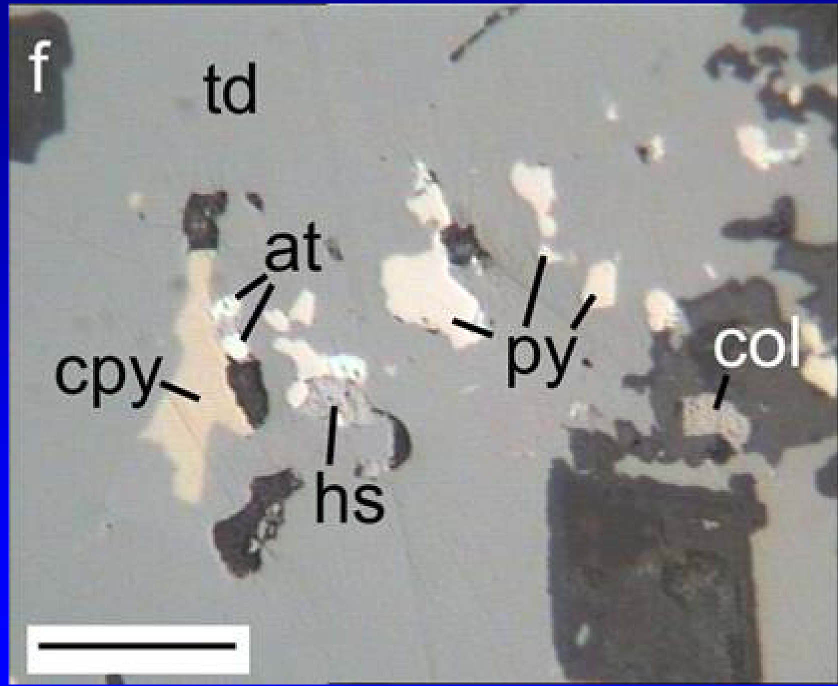
Voudouris (2006), modified after Michael et al. (1989b)

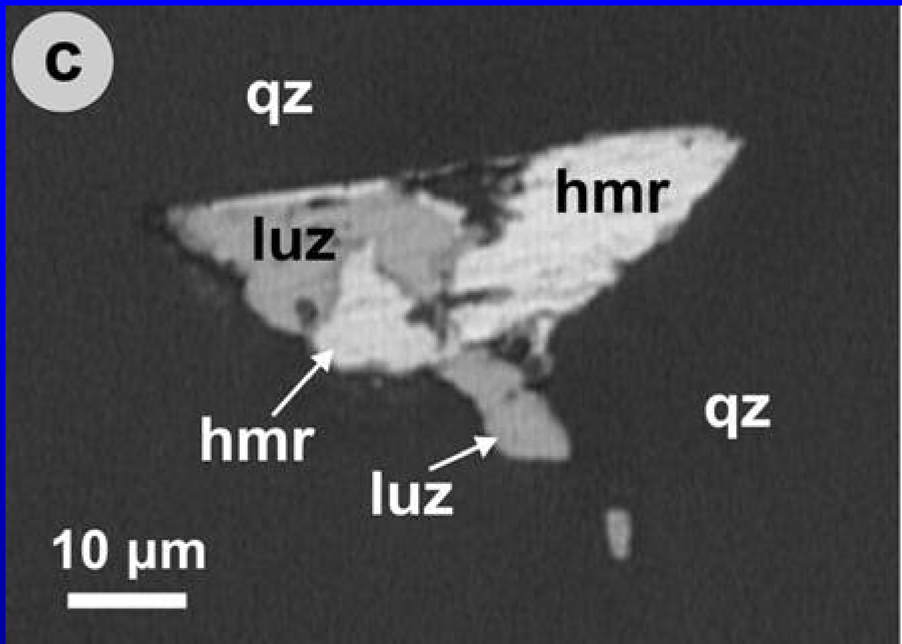
Pefka mine: Carbonate-quartz veins with Au-Ag tellurides postdate HS quartz veins with enargite)

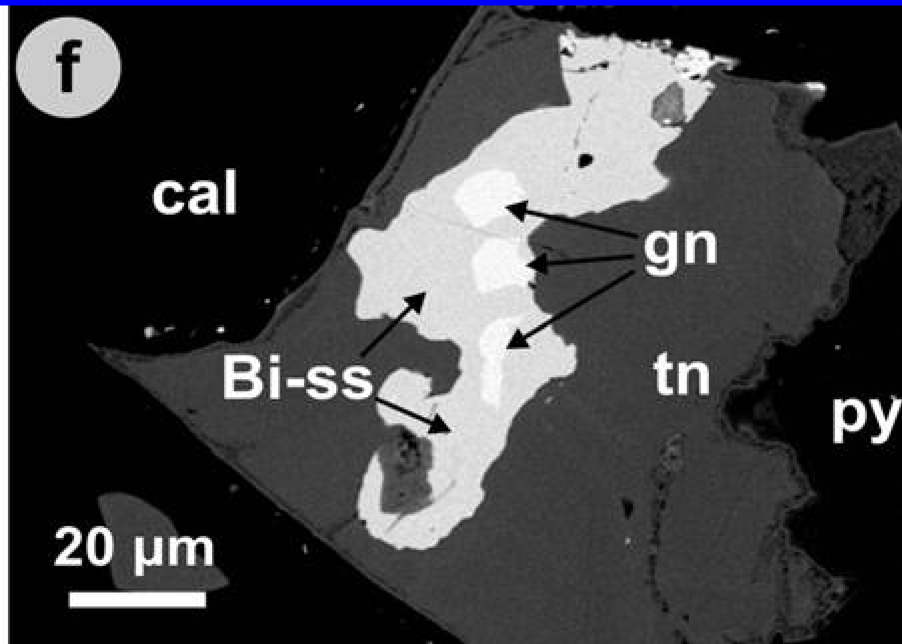



Pefka/W. Thrace

(luzonite, hessite, altaite, coloradoite, hammarite)

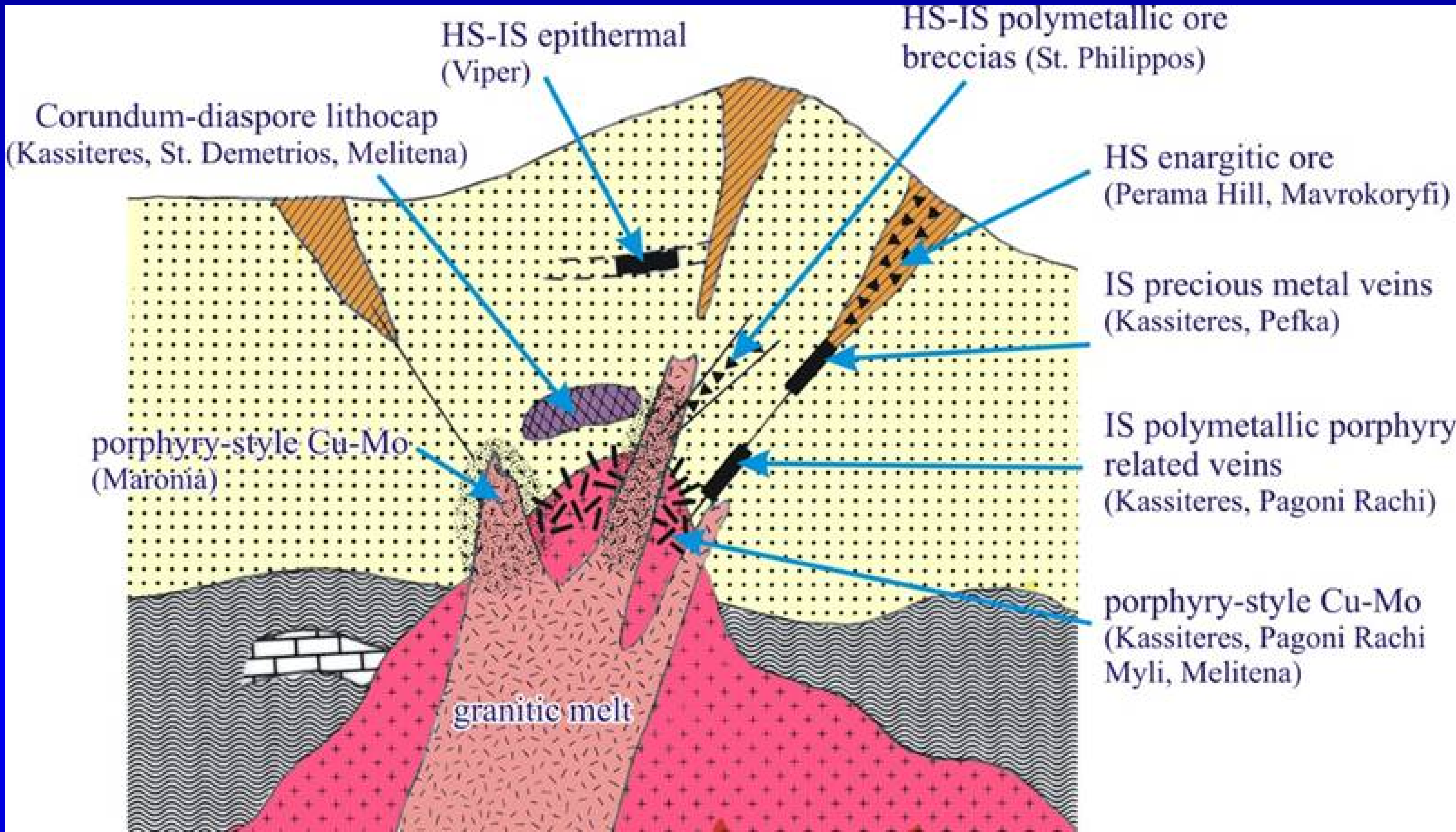






Voudouris (2006)

Porphyry-Epithermal relation

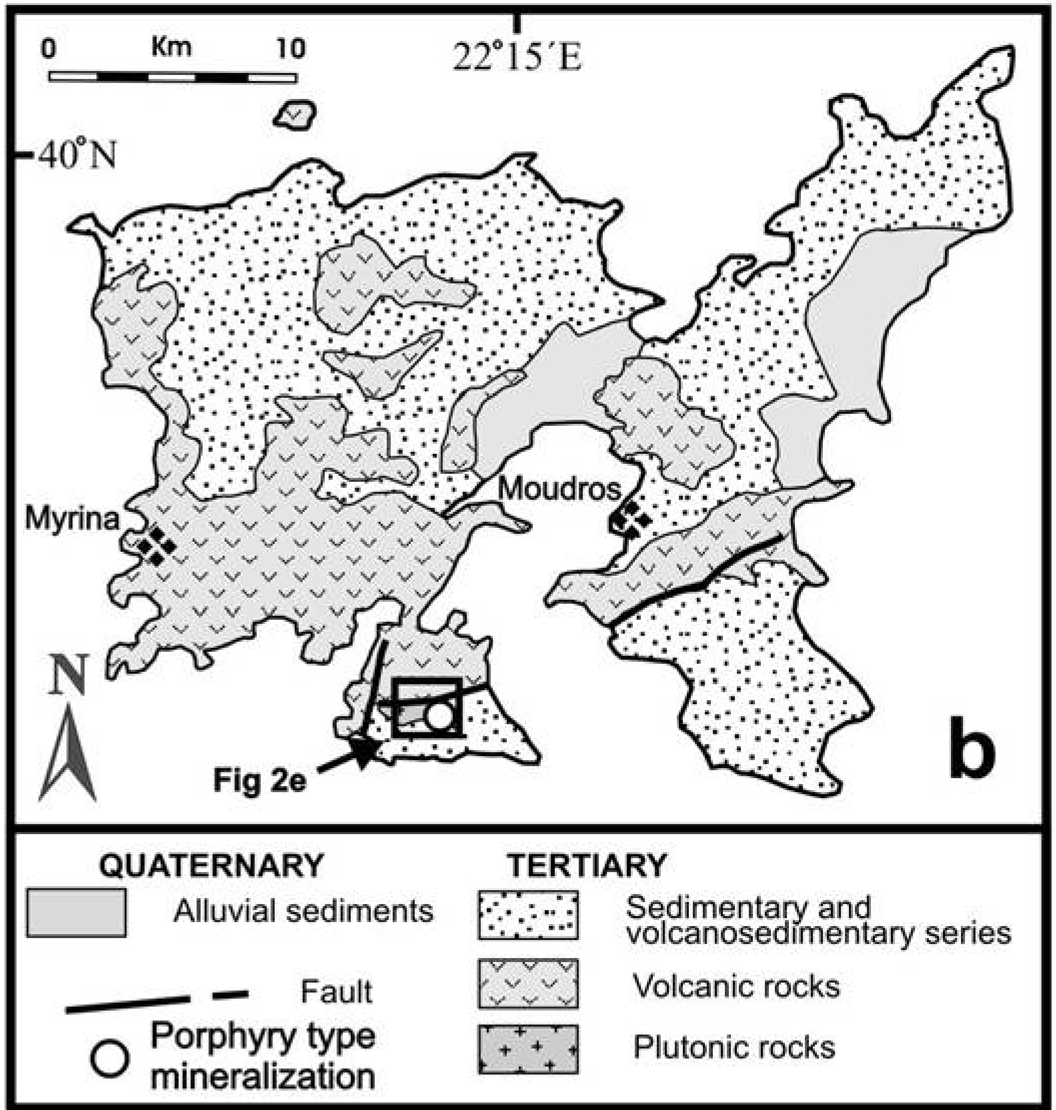


Maronia porphyry: Mineralised HS overprint. Perama Hill and Mavrokoryphi HS alongside
Kassiteres porphyry: Barren HS overprint Viper, St. Demetrios, Kassiteres HS & IS alongside
Pagoni Rachi porphyry: St. Philippos HS alongside
Melitena porphyry: Barren HS overprint
Myli porphyry: None known

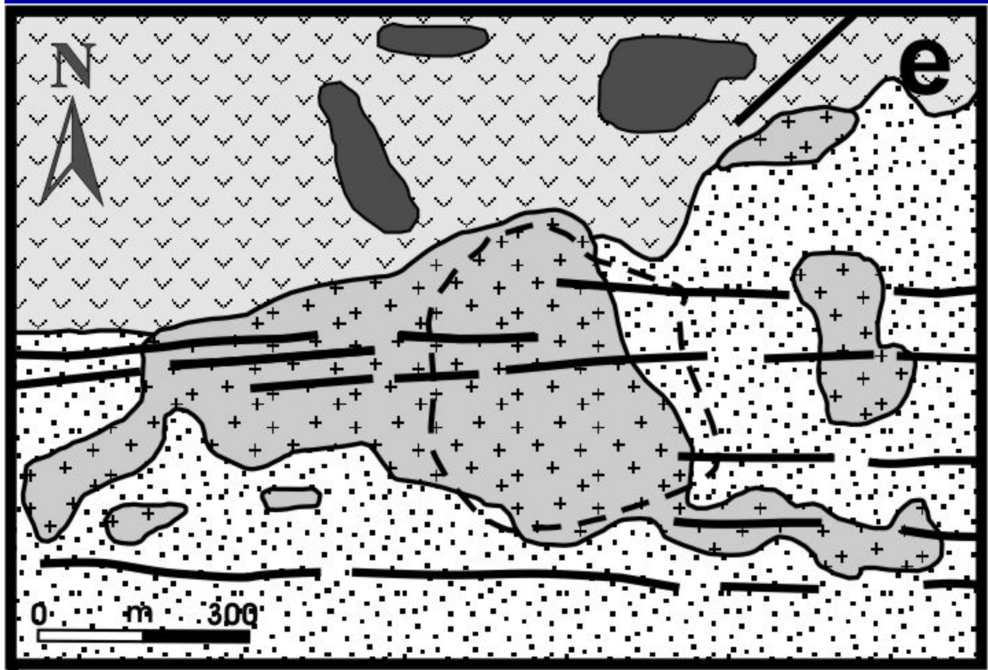
North Aegean porphyry-epithermal systems
Limnos & Lesvos islands
(Lower Miocene)

Limnos island

Porphyry-epithermal Cu-Mo-Au-Ag-Te prospect (Fakos)



Voudouris (2006)



Oligocene-Miocene

- Rhyolite - Rhyodacite
- Dacite porphyry
- Dacitic andesite porphyry
- Quartz monzodiorite - Monzonite
- Shoshonitic volcanic rocks
- Calc-alkaline volcanic rocks

Middle-Upper Eocene

- Marls - Sandstones
- Basal conglomerates

Mesozoic

- Circum Rhodope Belt

Hydrothermal alteration

- Surface outcrop of K-Na-silicate alteration and quartz stockworks
- Surface outcrop of high-sulfidation lithocap
- Faults and mineralized veins
- Porphyry/epithermal mineralization

Voudouris (2006)

Limnos island
(Fakos porphyry-epithermal Cu-Mo-Au-Ag-Te prospect)

Fakos monzonite-late lamprophyre dikes

Early potassic alteration porphyry Cu mineralization

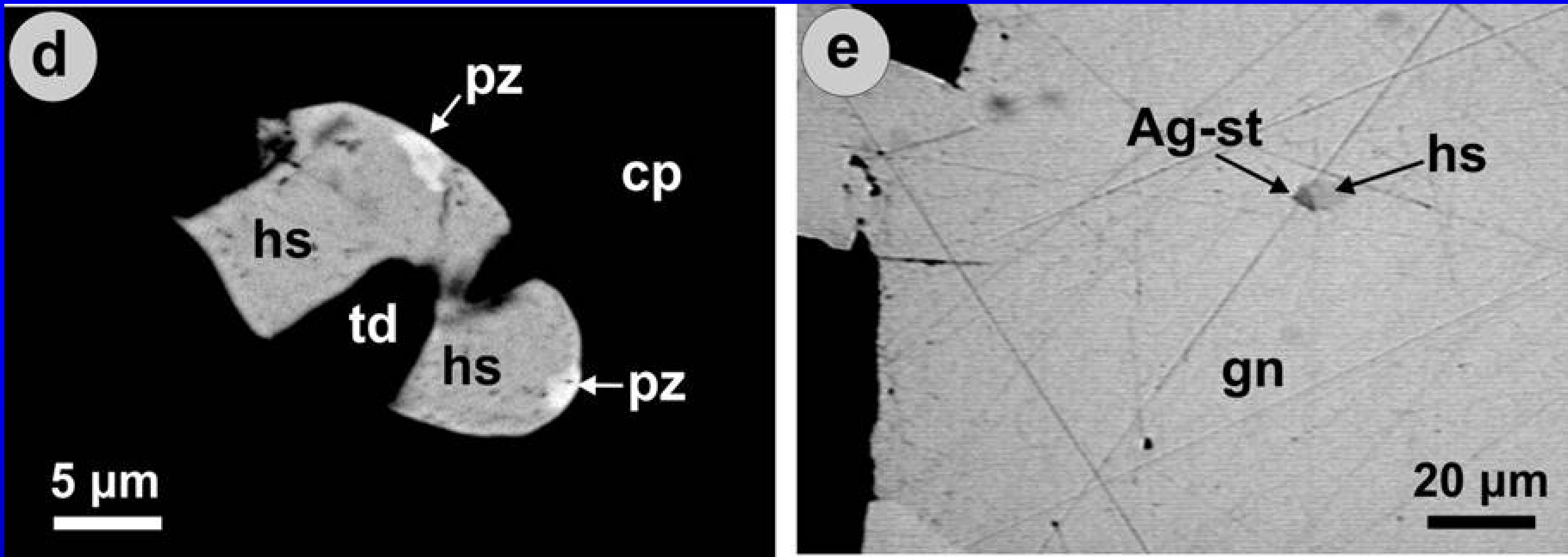
Sericite alteration
porphyry Mo mineralization

Sericite-tourmaline alteration Arsenopyrite-Au mineralization

Magmatic-hydrothermal advanced argillic alteration

Intrusion- and sediment-hosted late-stage quartz-carbonate Au-Ag veins

Limnos: hessite, petzite, electrum, Ag-sulfotelluride



Voudouris (2006)

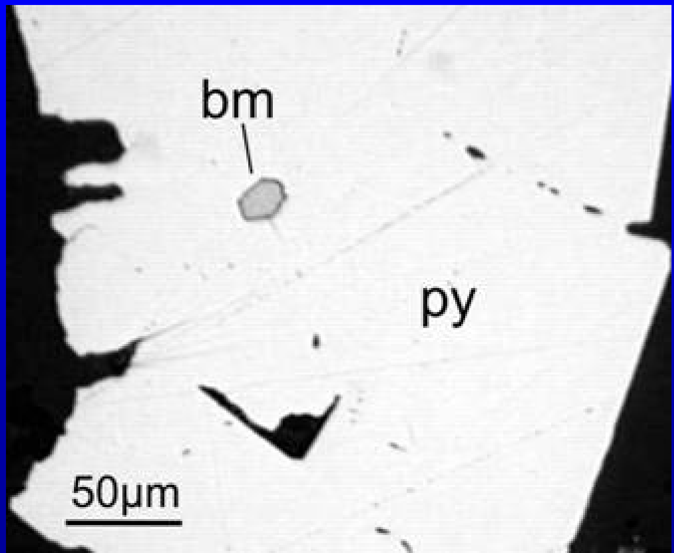
Peripheral Au-As-rich silica sinter

Lesvos island

Porphyry-epithermal Mo-Bi-Pb-Au-Te Stypsi prospect

Lesvos island: (porphyry-epithermal prospect)

Molybdenite and bismuthinite in quartz stockworks (Voudouris & Alfieris 2005)

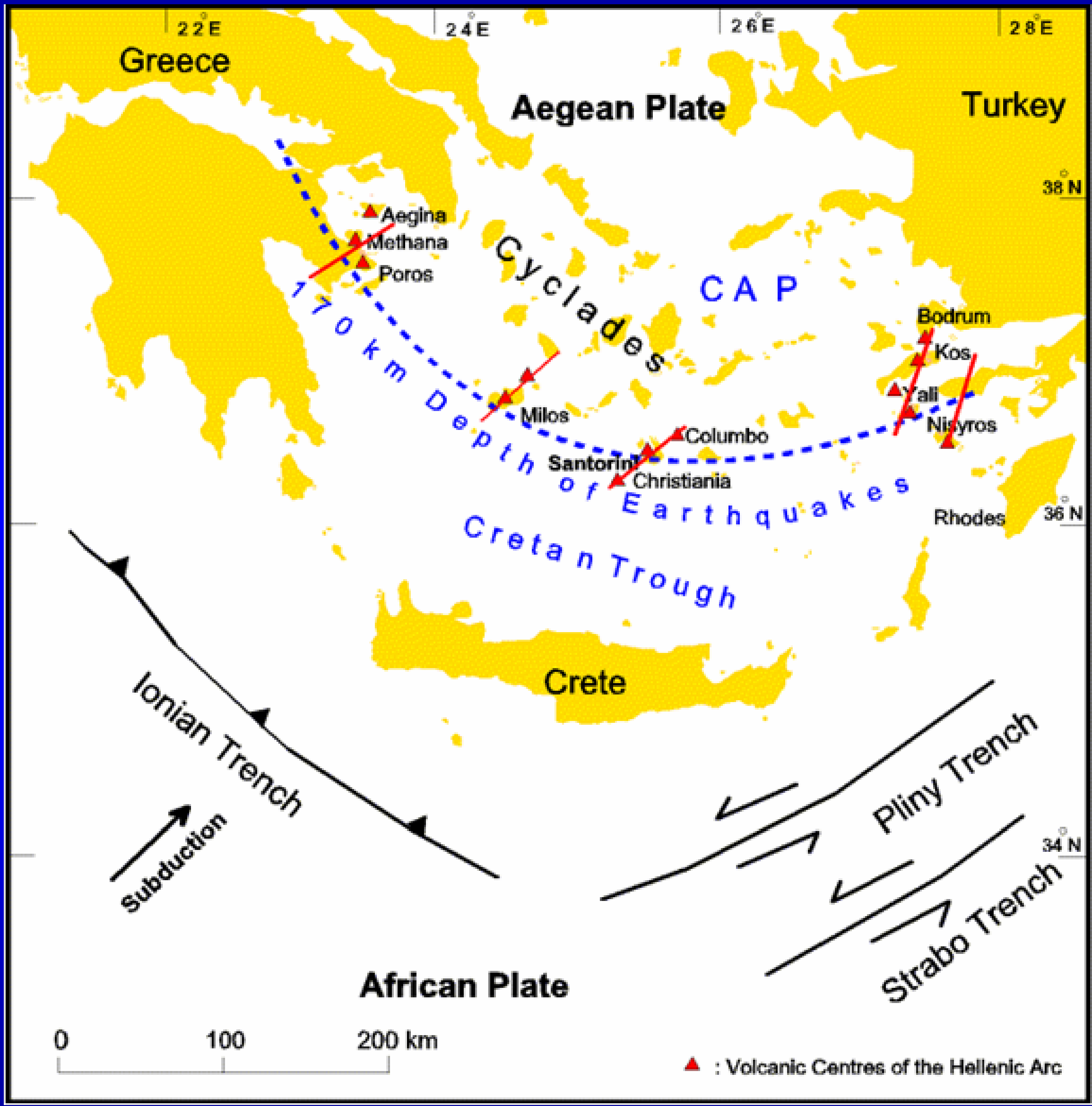


Epithermal systems
(Pliocene-Pleistocene)

Milos island

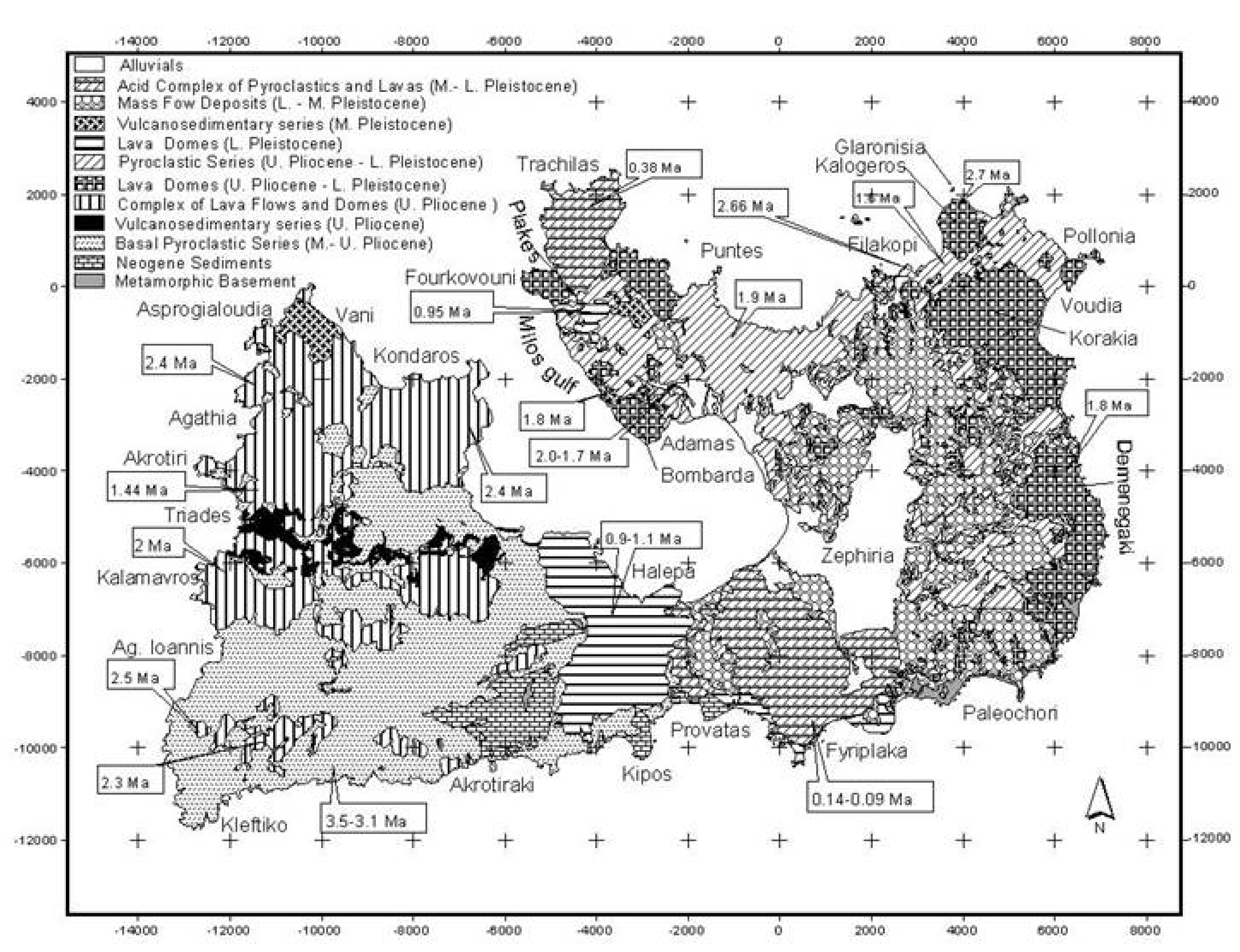
Shallow submarine epithermalAu-Ag-Pb deposits

South Aegean Volcanic Arc



Friedrich (2000)

General Geology



Fytikas et al. (1986), Stewart & McPhie (2006)

Phase I (3.5-3.1 Ma)

felsic cryptodome-pumice cone volcanoes

Phase I-II (3.0-2.7 Ma)

volcanosedimentary series

Phase II (2.7-1.4 Ma)

dacitic/andesitic lavas, pyroclastic flows and breccias on submarine and partially on subaerial environment.

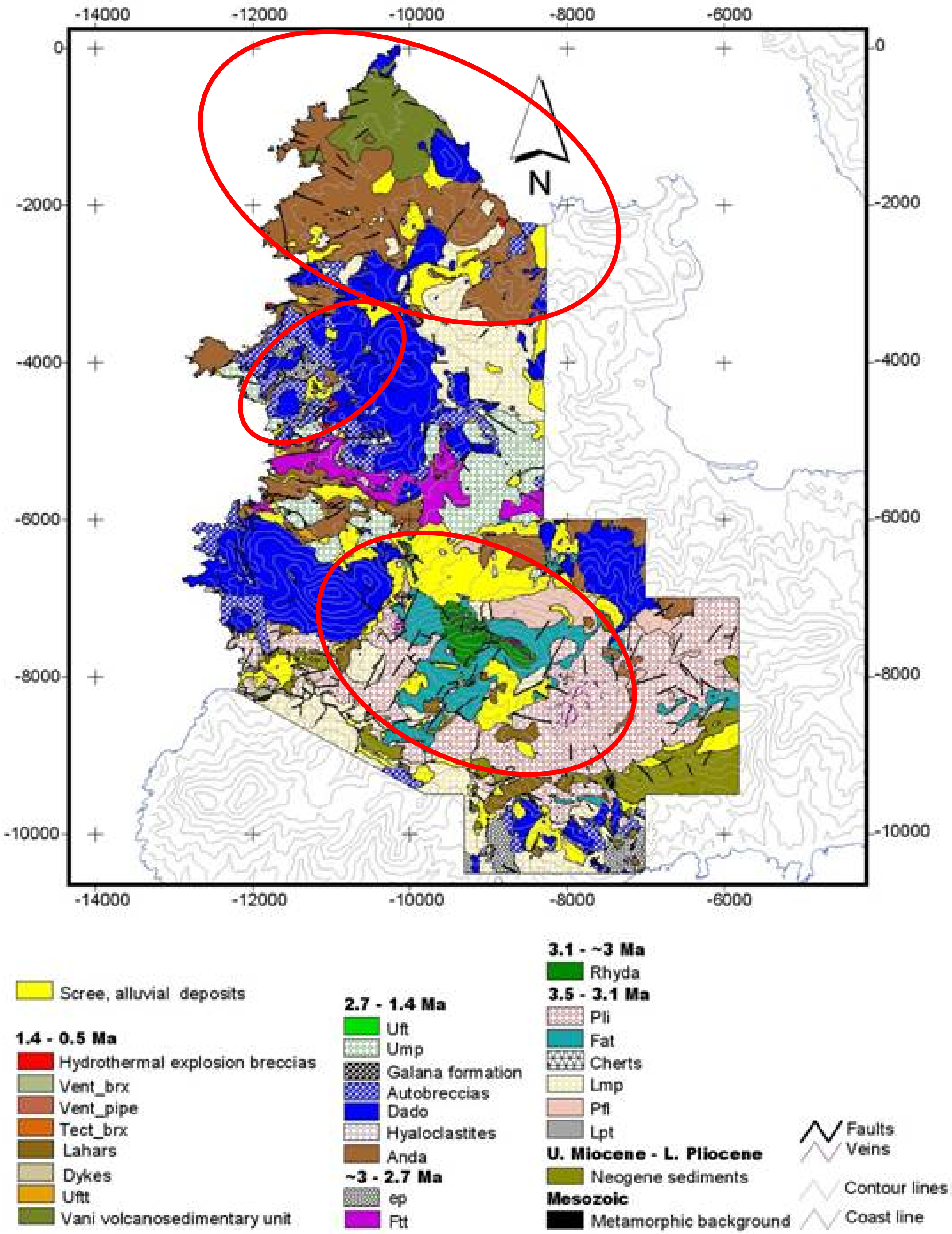
Phase III (1.4-0.5 Ma)

rhyolitic pumice-cone volcanoes/rhyolitic lavas, andesitic-dacitic pillow lavas

Phase IV (0.5-0.08 Ma)

rhyolitic lavas, pyroclastics, phreatic activity

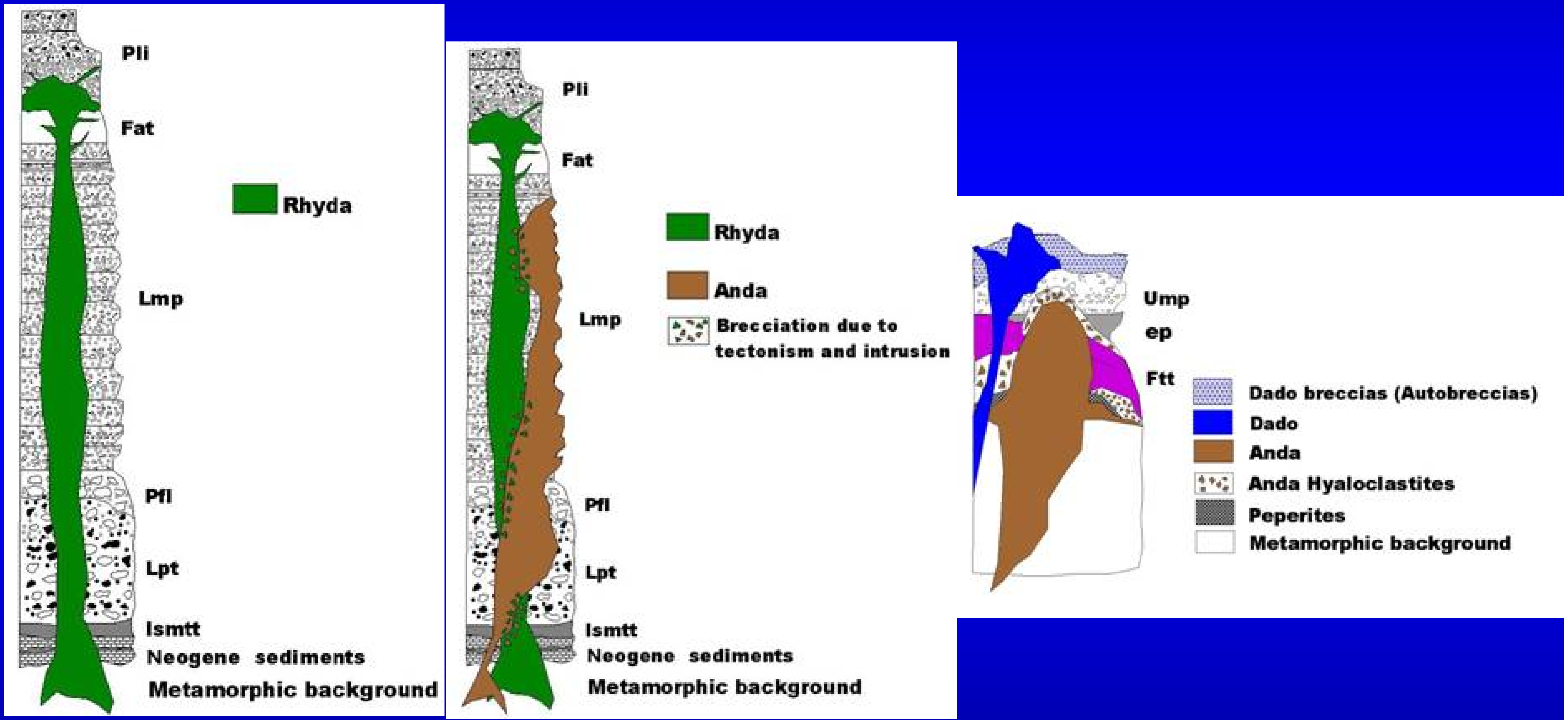

Vani
Mn-Ba
Agathia
Pb-Zn-Ag-Cu
Kondaros
Pb-Zn-Ag-Cu
Galana
Pb-Zn-Ag-Cu
Triades
Pb-Zn-Ag-Cu+/-Au
Chondro Vouno
Au-Ag-Pb-Zn-Cu
Amethyst
Au
Prof. Ilias
Au-Ag
Mavrovouni
Au-Ag



Geological map of western Milos

Alfieris (2006)

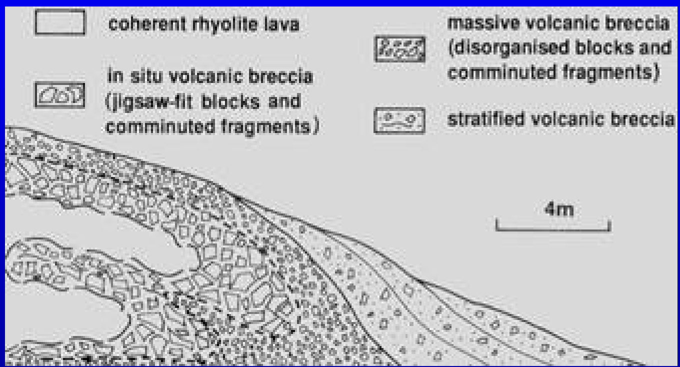
Three intrusive phases: magmatic products in a submarine-subaerial setting (Upper Miocene-Lower Pleistocene/ ~ 3.5 - 1.4 Ma)



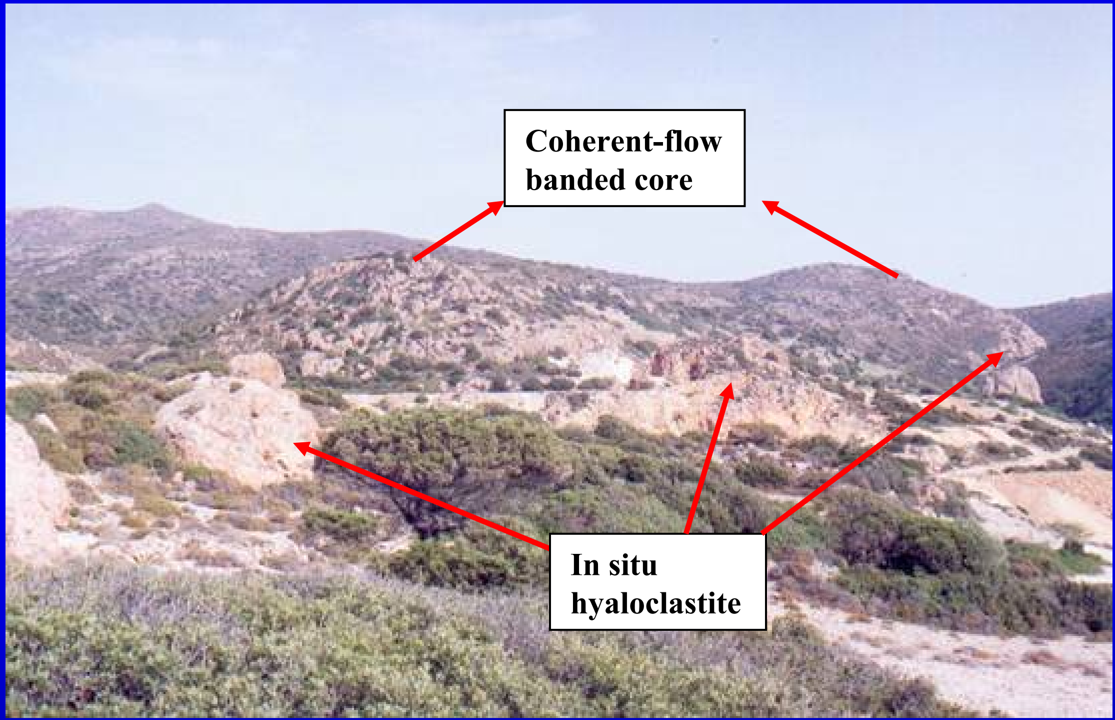
Alfieris 2006

Volcanosedimentary products (3-2.7 Ma), emplacement of dacitic-rhyodacitic-andesitic domes (Anda, Dado) in submarine to subaerial environment (2.7-1.4 Ma)

Reworked volcanosedimentary horizon (ep) at contact with in situ hyaloclastite subvolcanic dacitic breccia at Triades



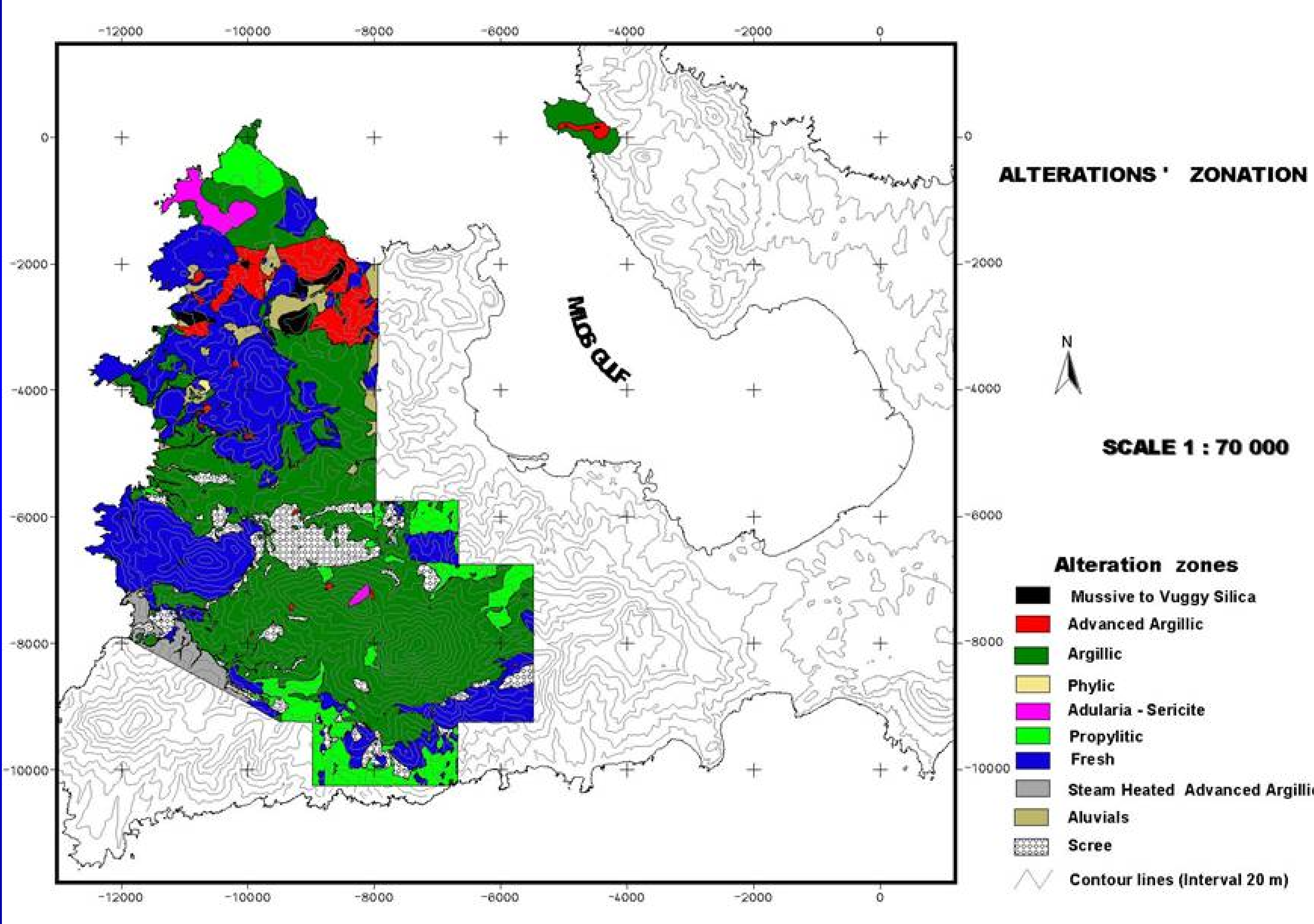
The coherent and the fragmented components of extrusive domes. From McPhie et al. (2003)



Dacite(Anda) domes emplaced along a quasi E-W direction at Triades
The coherent and hyaloclastic components are very well visible.

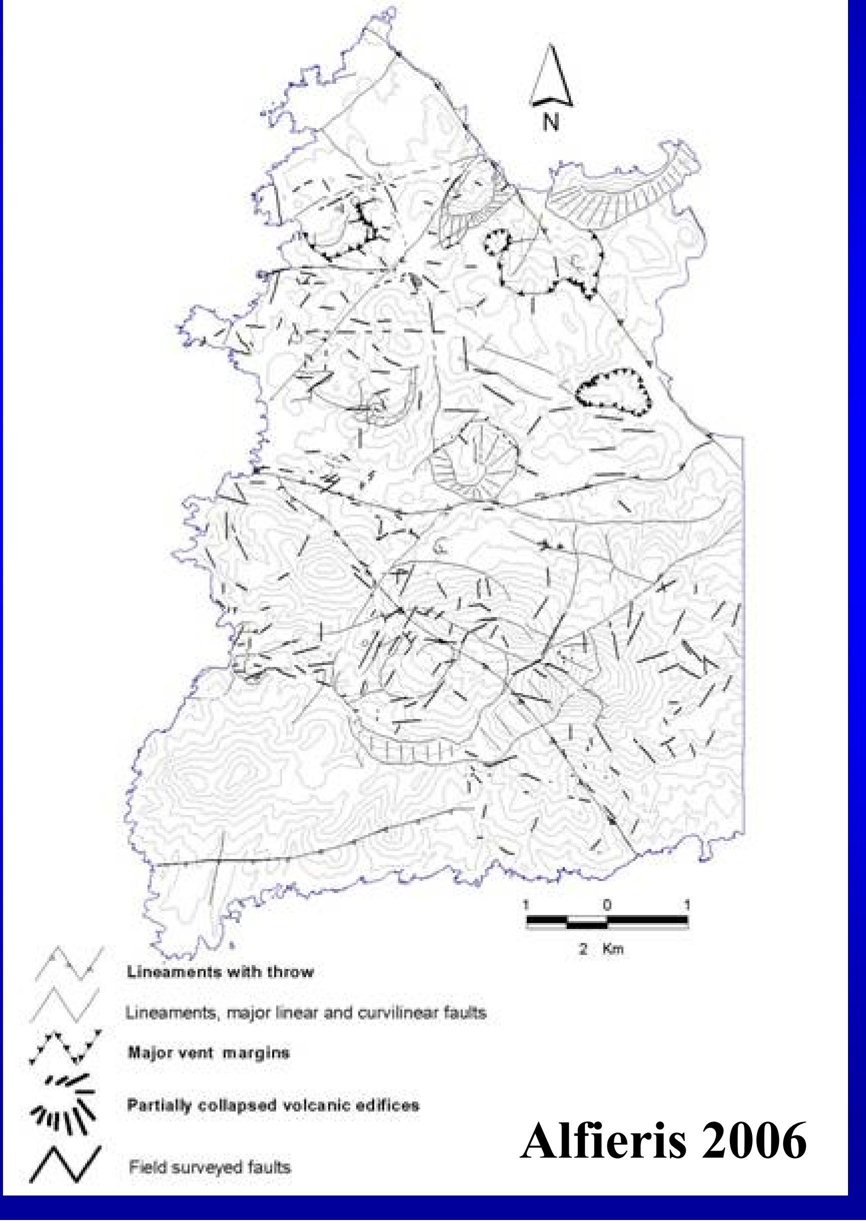
Alfieris 2006

Hydrothermal alteration zones

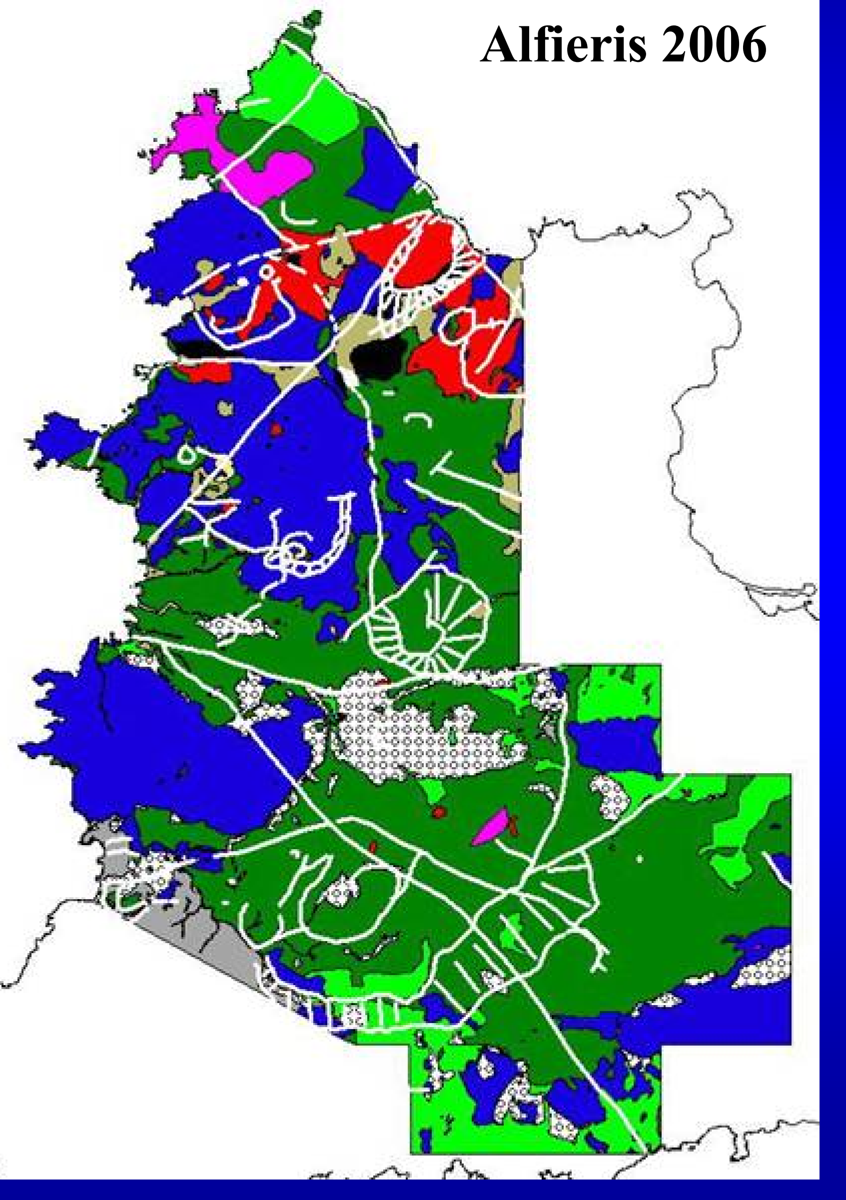


Alfieris 2006

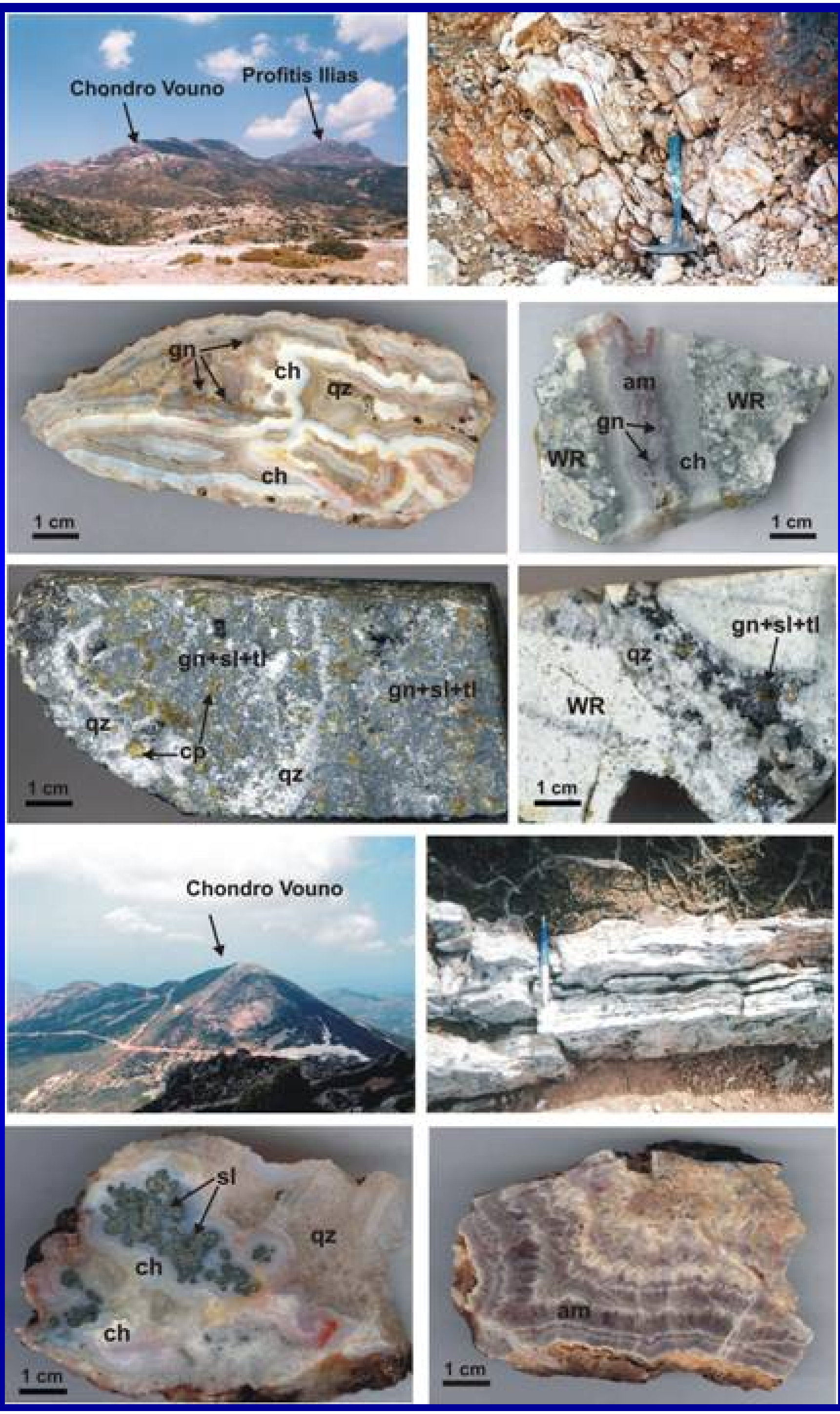
Two orthogonal fault sets (the first one with NW/SE and NE/SW directions and the second one with N-S and E-W directions), have influenced magmatism, hydrothermal alteration and mineralization.



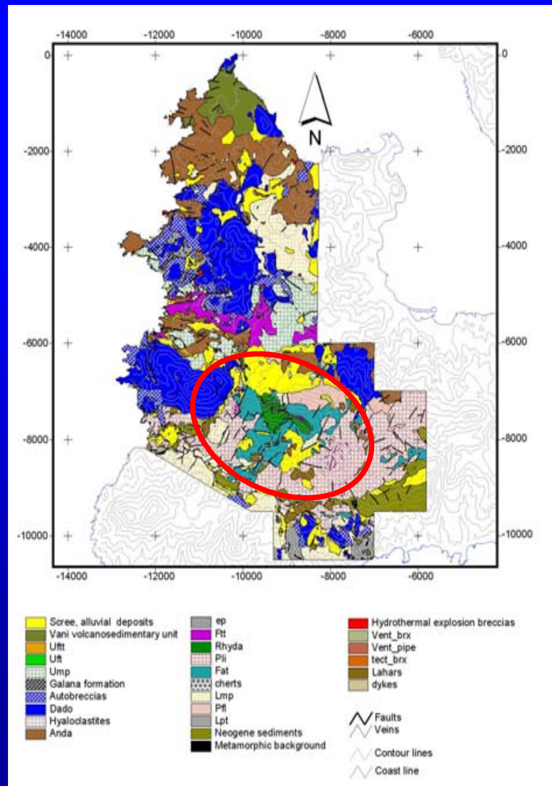
Alfieris 2006



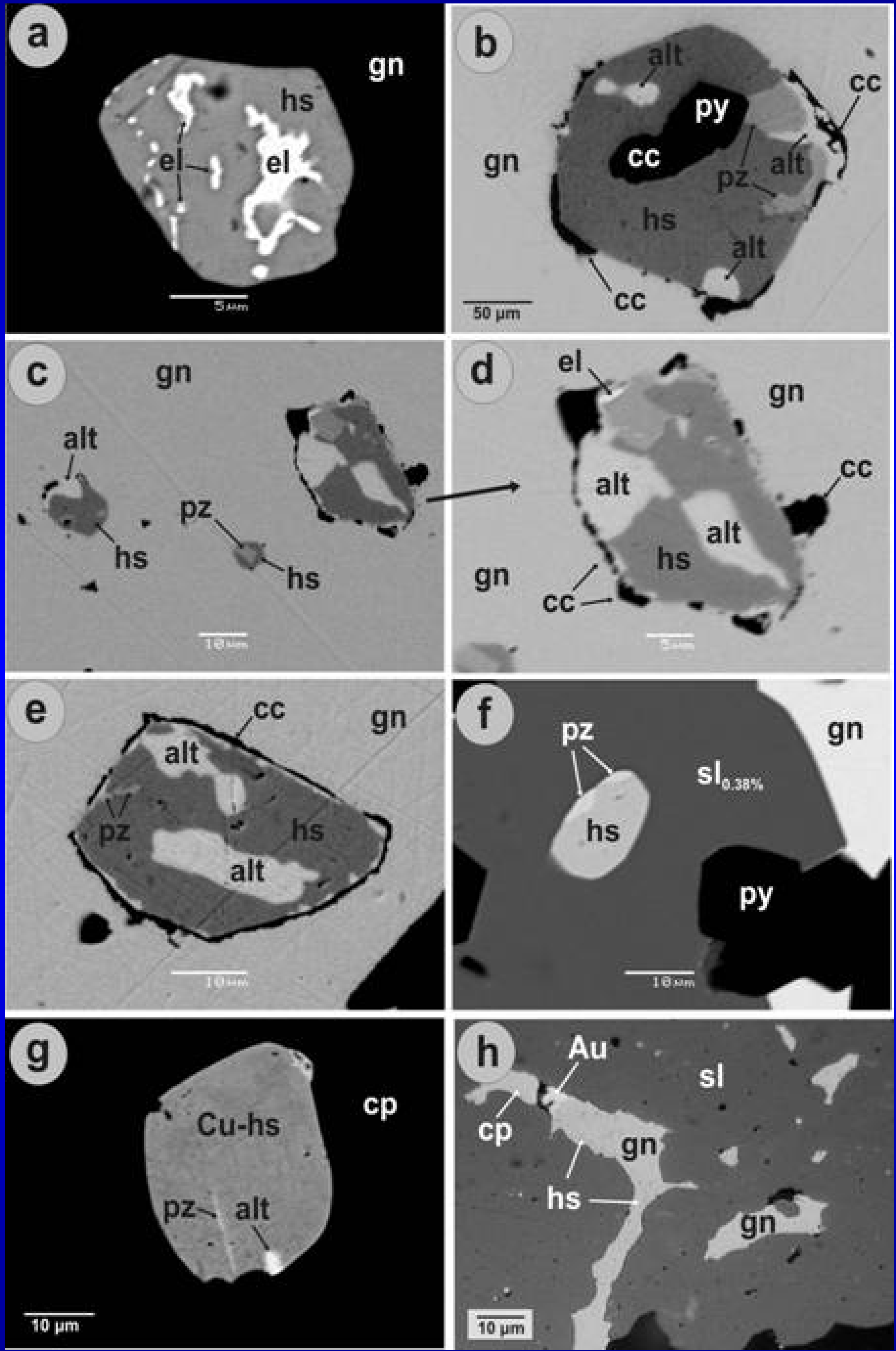
Alfieris 2006



Profitis Ilias - Chondro Vouno: Au-Ag-telluride IS mineralization in quartz-adularia veins hosted by brecciated dacite-rhyolite flow dome (Rhyda). Au-Ag mineralization extends into overlying ash and pumice tuffs.



Alfieris 2006

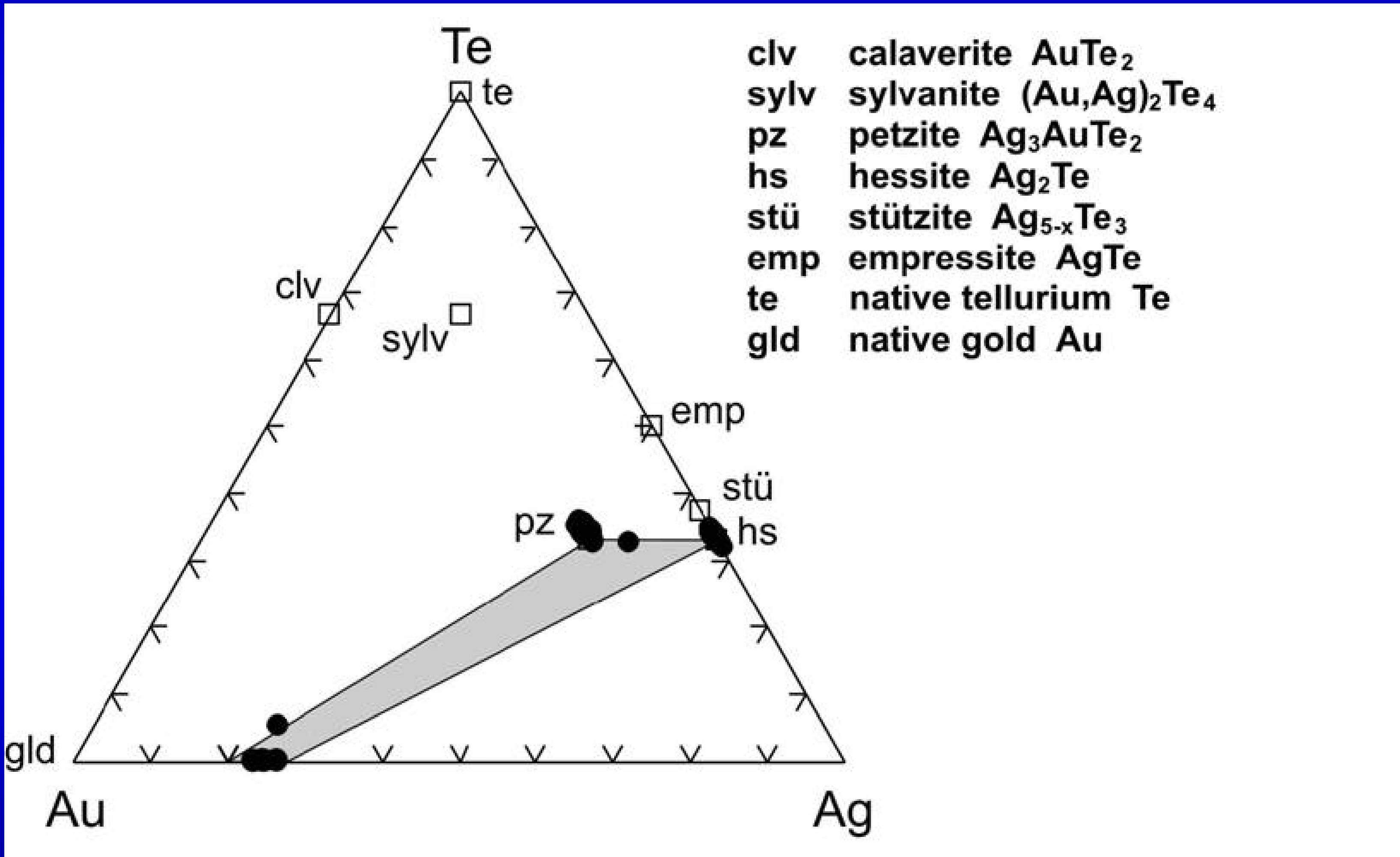


Profitis Ilias deposit

Precious metal mineralization in drillhole material from the deeper levels of the deposit (elevation 220m above sea level). This mineralization is characterized by pyrite followed by an assemblage composed of hessite, altaite, petzite, native gold, chalcocite, galena and chalcopyrite and finally by sphalerite.

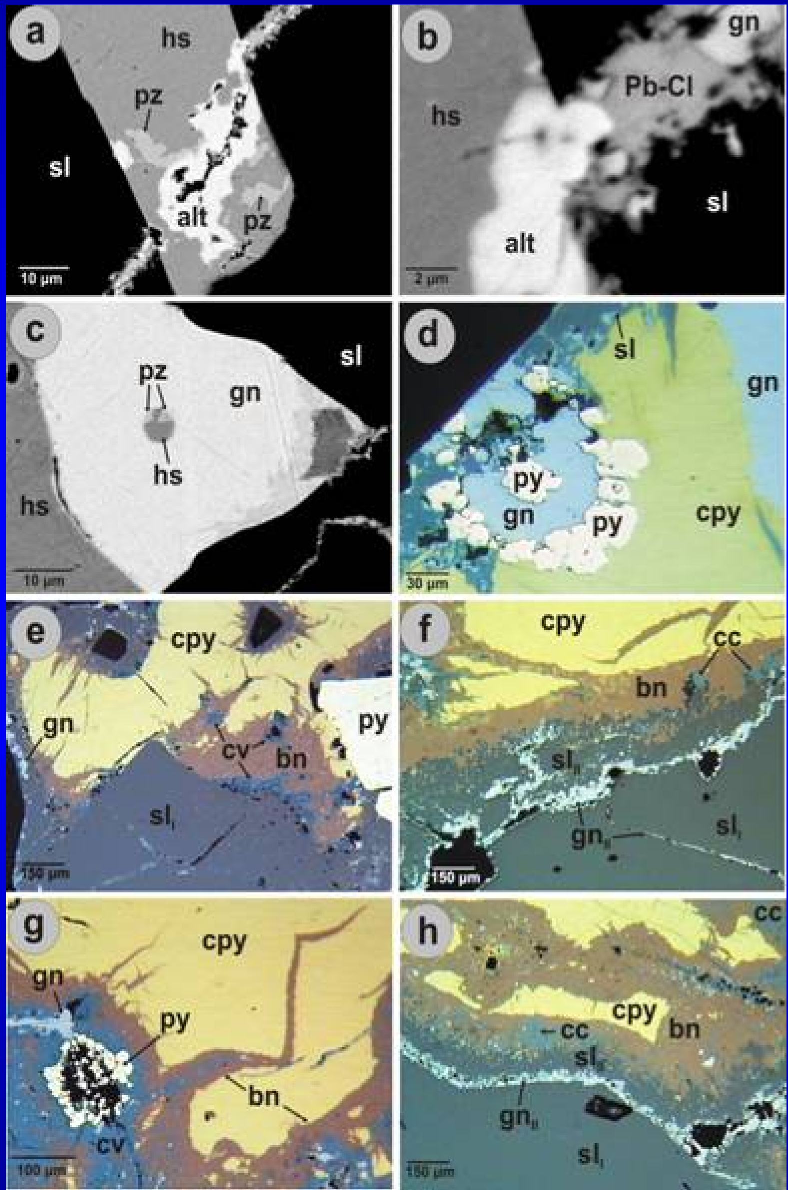
Alfieris 2006

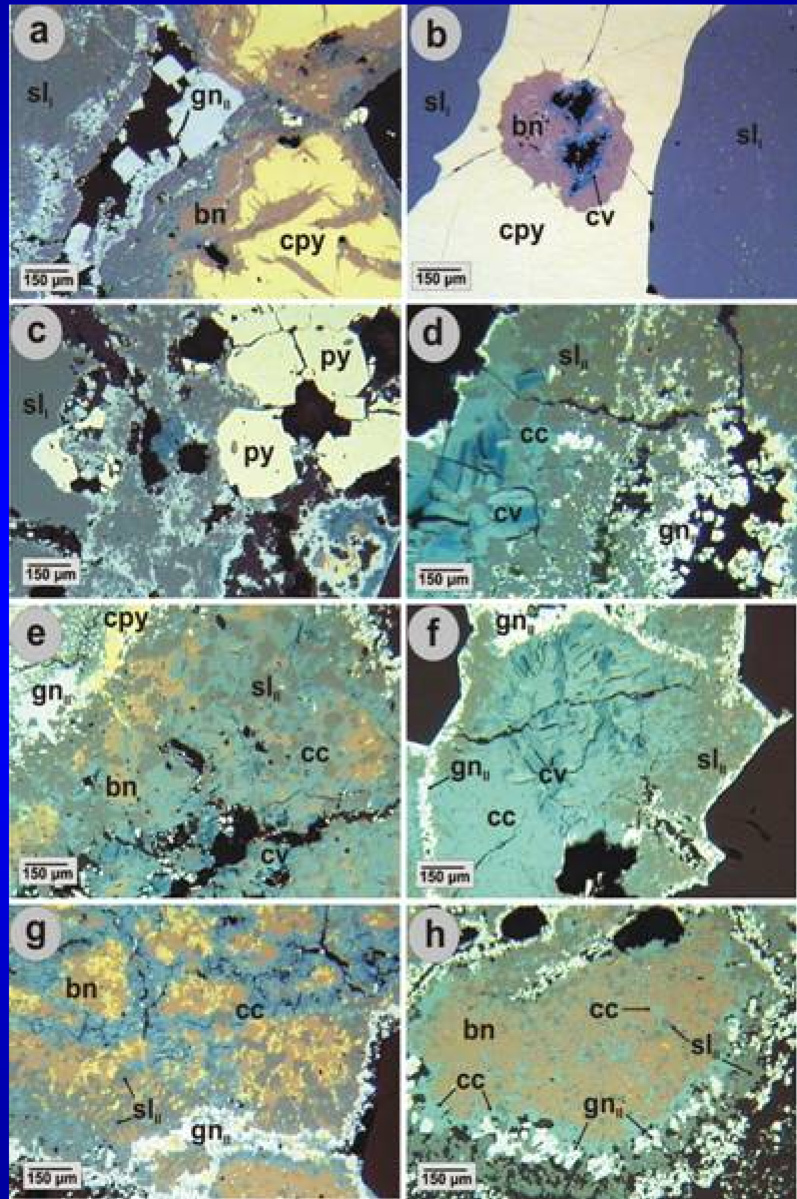
Ternary Au-Ag-Te diagram (atomic proportions) for mineral compositions analyzed in the present study. Theoretical compositions are shown as open squares, whereas solid lines indicate compositions of coexisting phases.



Alfieris 2006, Alfieris and Voudouris 2006

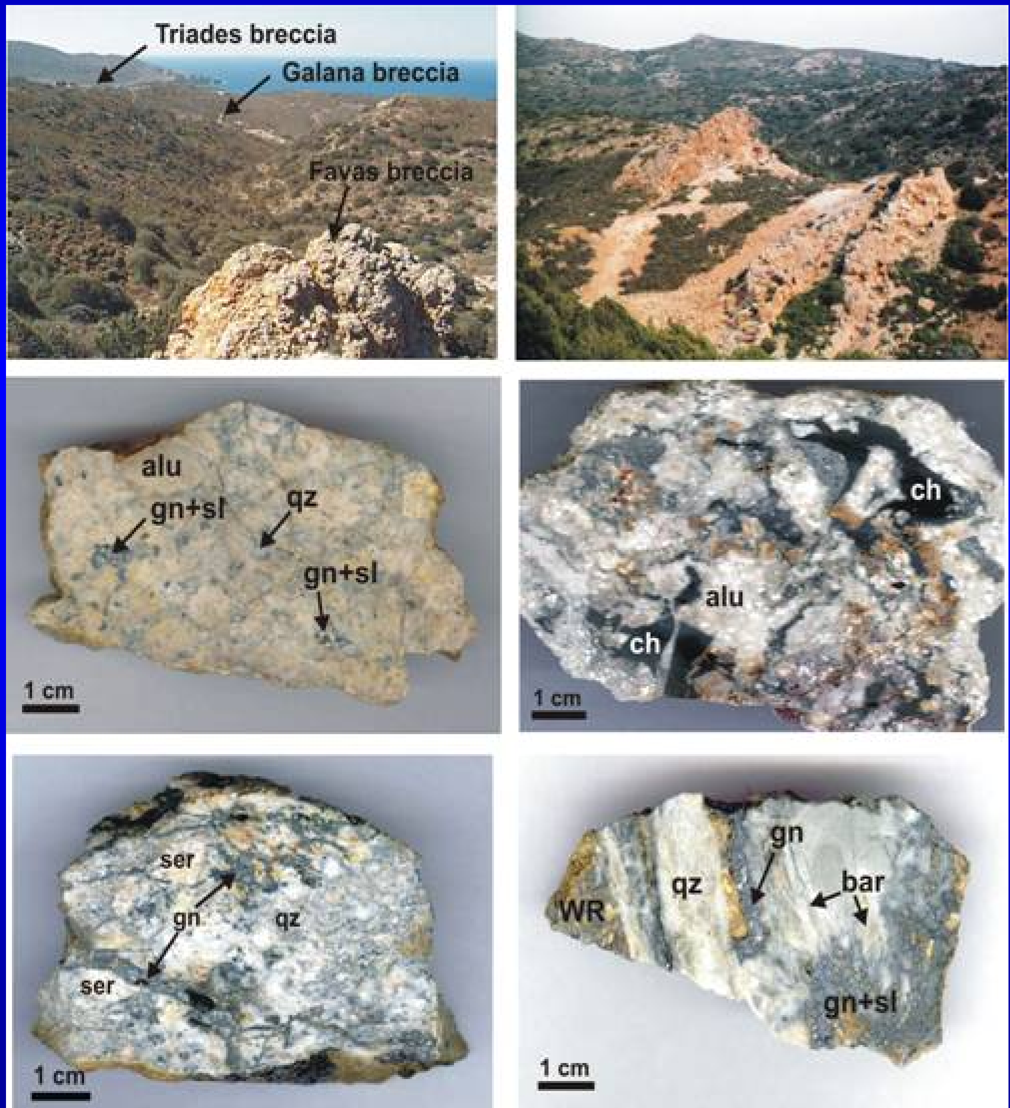
Profitis Ilias deposit: **a second mineralizing event introduces copper sulfides, galena overprints tellurides and earlier sulfides. Evidence of seawater oxidation**

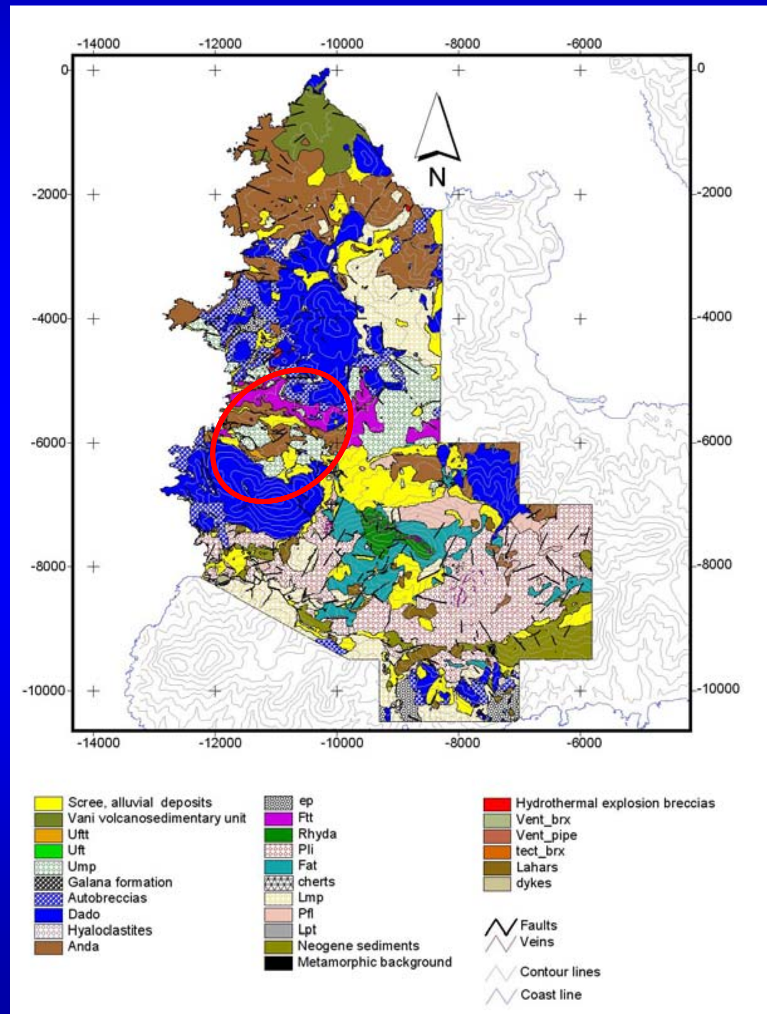




Alfieris 2006, Alfieris and Voudouris 2006

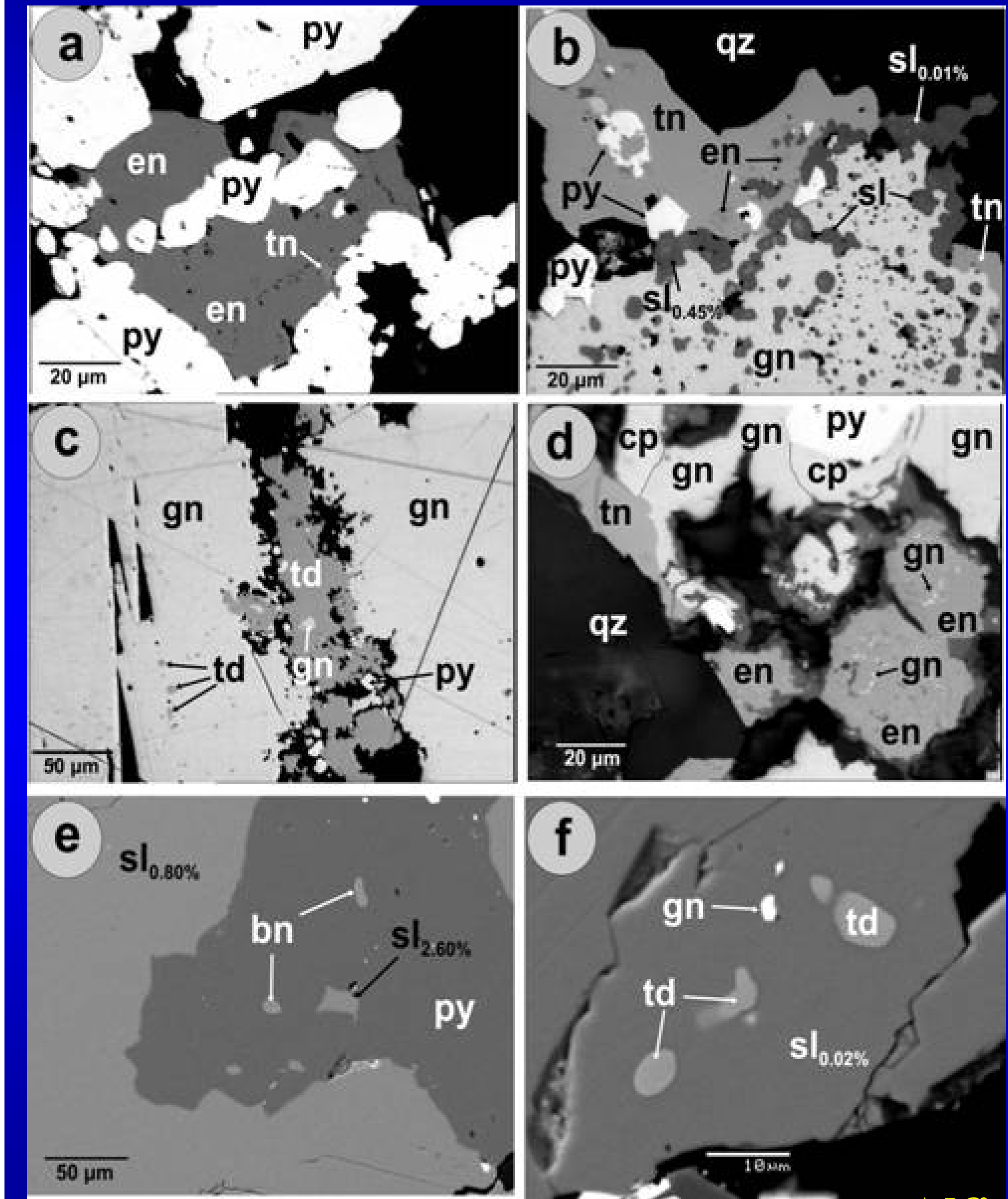
Triades-Galana: Pb-Zn-Ag-Cu HS mineralization hosted in submarine pumiceous lapilli tuffs (Lmp), fossiliferous tuffs (Ftt), tuffaceous and epiclastic marine sediments (ep) and in flow-banded andesitic-dacitic-rhyodacitic subvolcanic bodies (Anda, Dado). Multistage breccia zones and quartz-baryte veins.



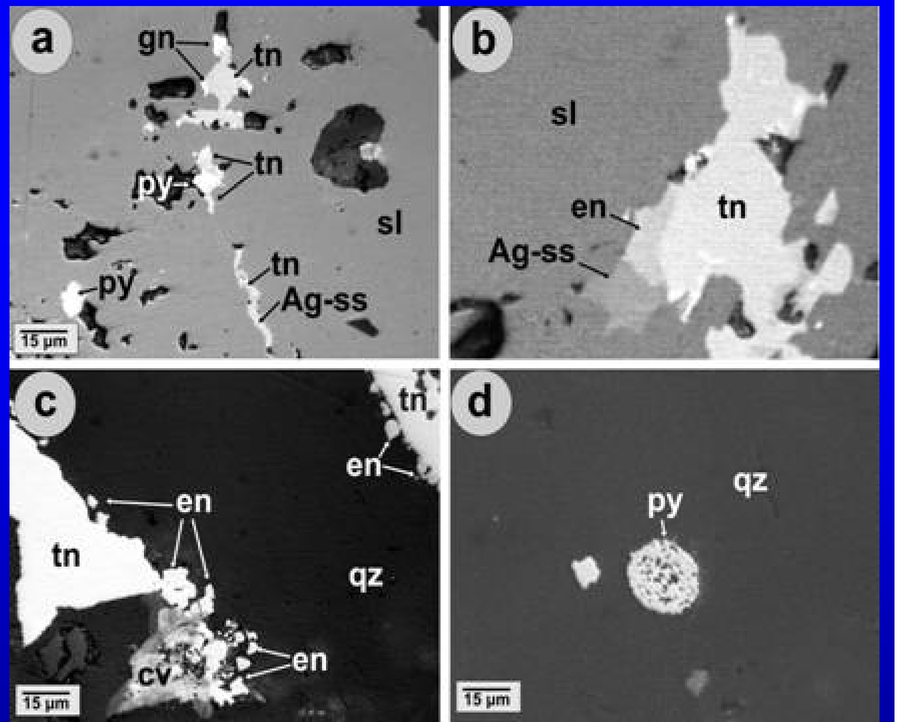


Alfieris 2006

Ore textures

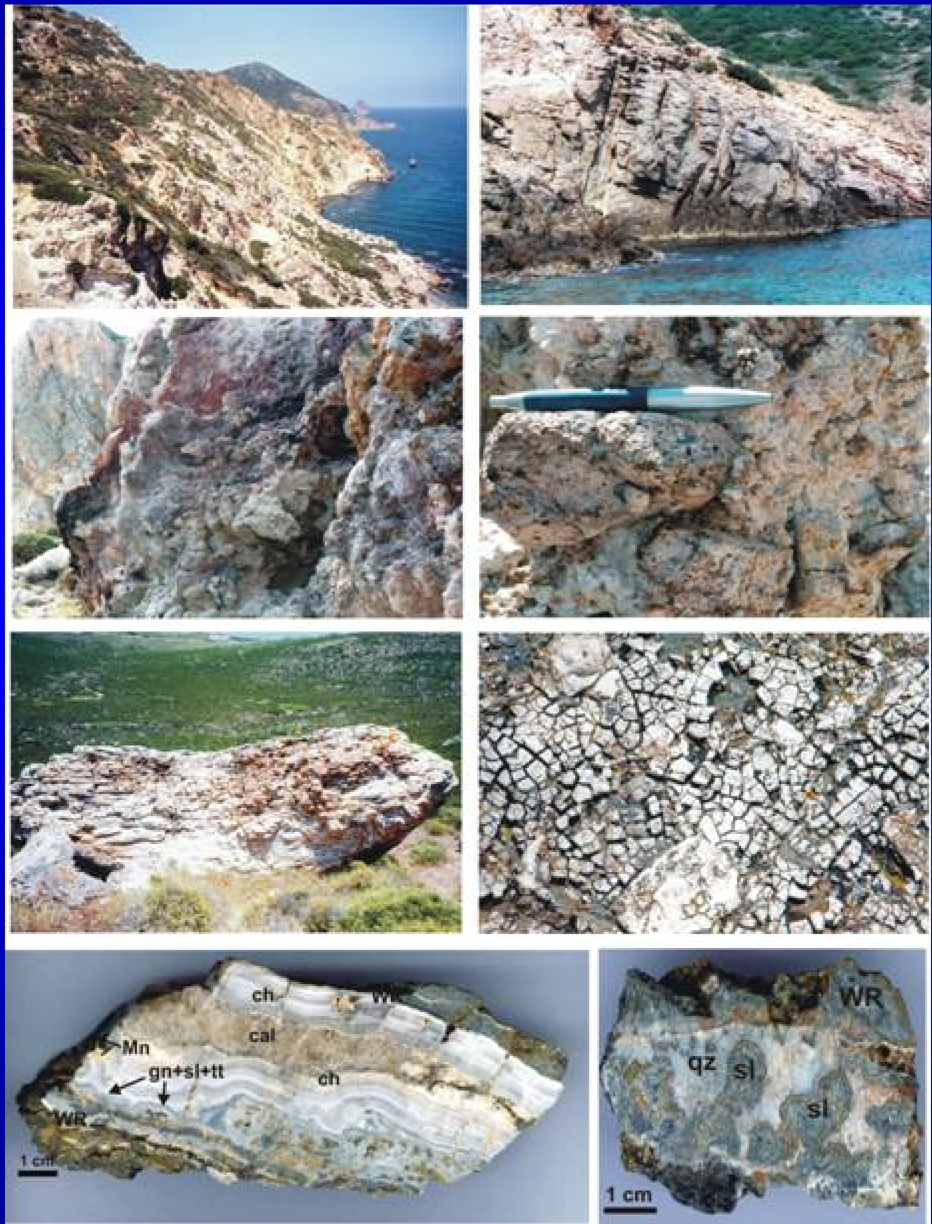


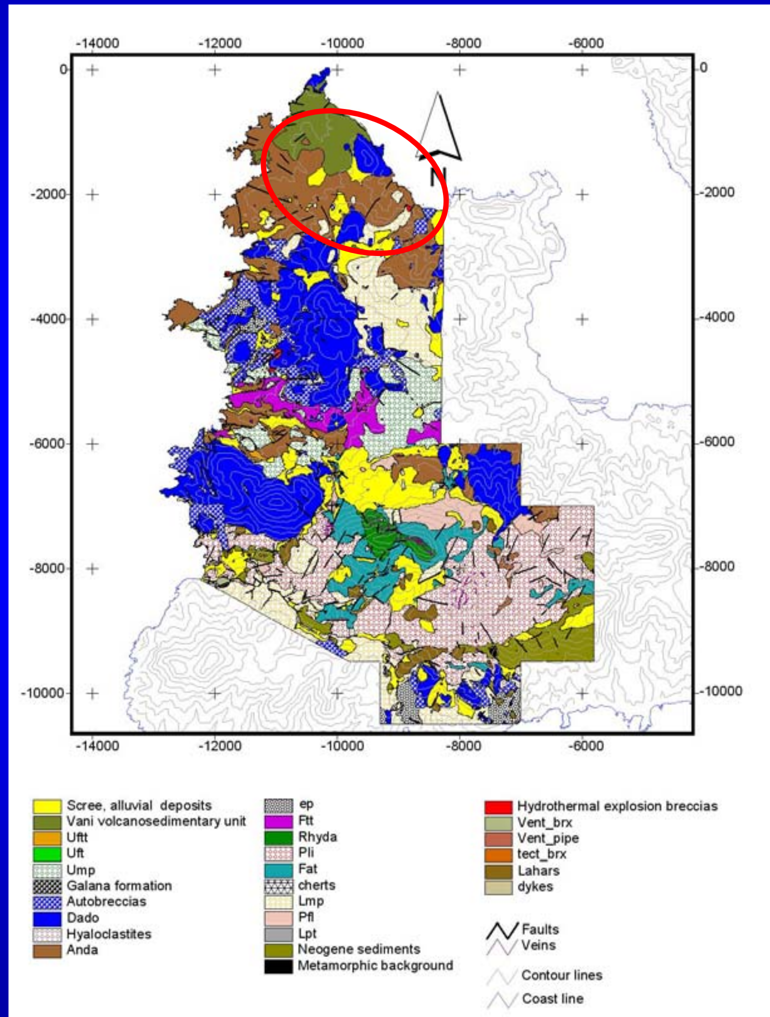
Triades-Galana: py + Fe-rich sl → cpy + ga + Fe-poor sl + tn/tt → en +cv. Gangue minerals are barite, kaolinite, sericite, adularia and quartz. Late framboidal pyrite



Alfieris 2006, Alfieris and Voudouris 2006

Kondaros-Katsimouti: Pb-Zn-Ag-Mn mineralization in brecciated and crustiform/colloform banded quartz-carbonate-barite-adularia veins,hosted in dacite flow dome (Dado) and partly in the pumiceous lapilli tuff unit (Lmp) .

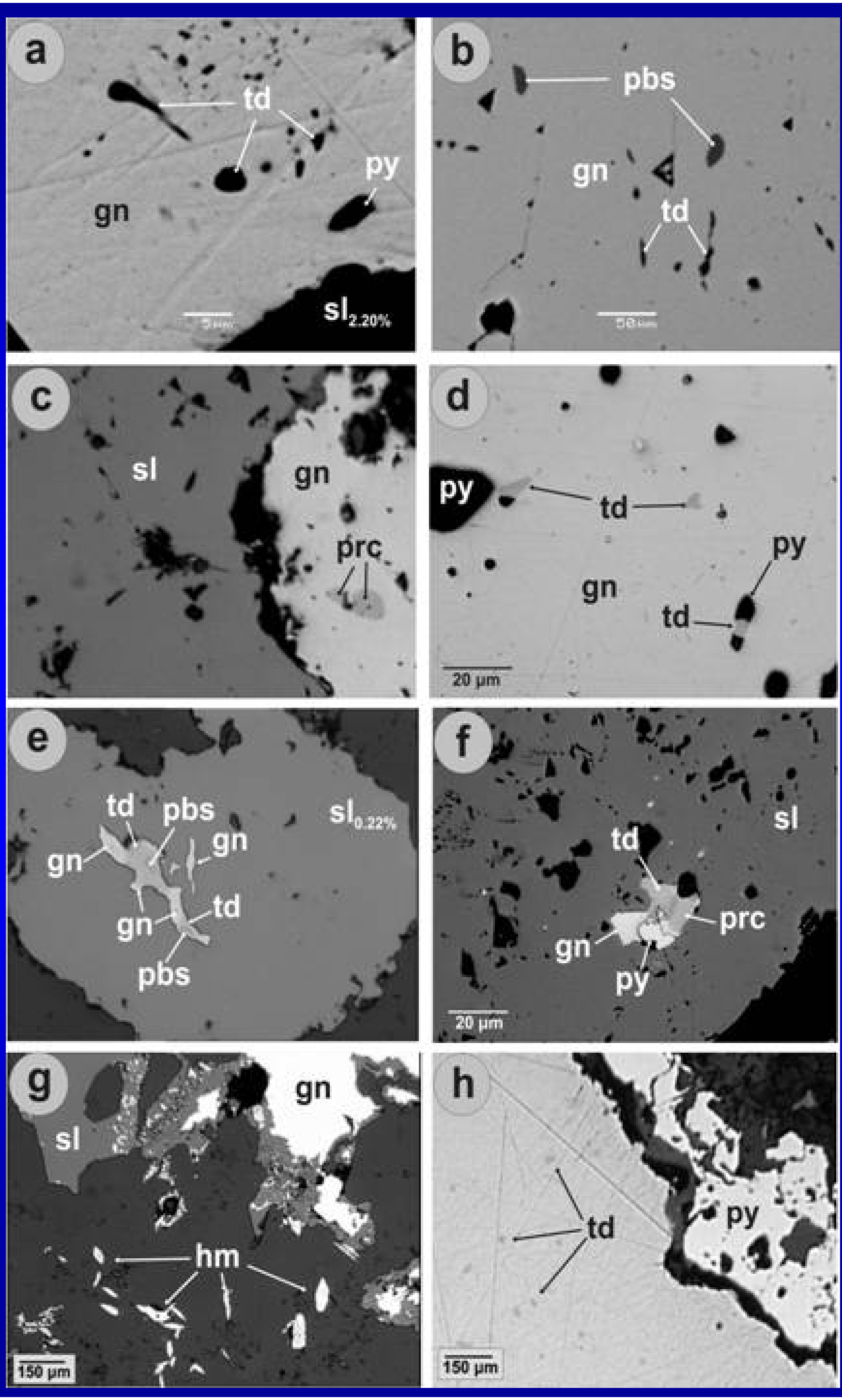




Alfieris 2006

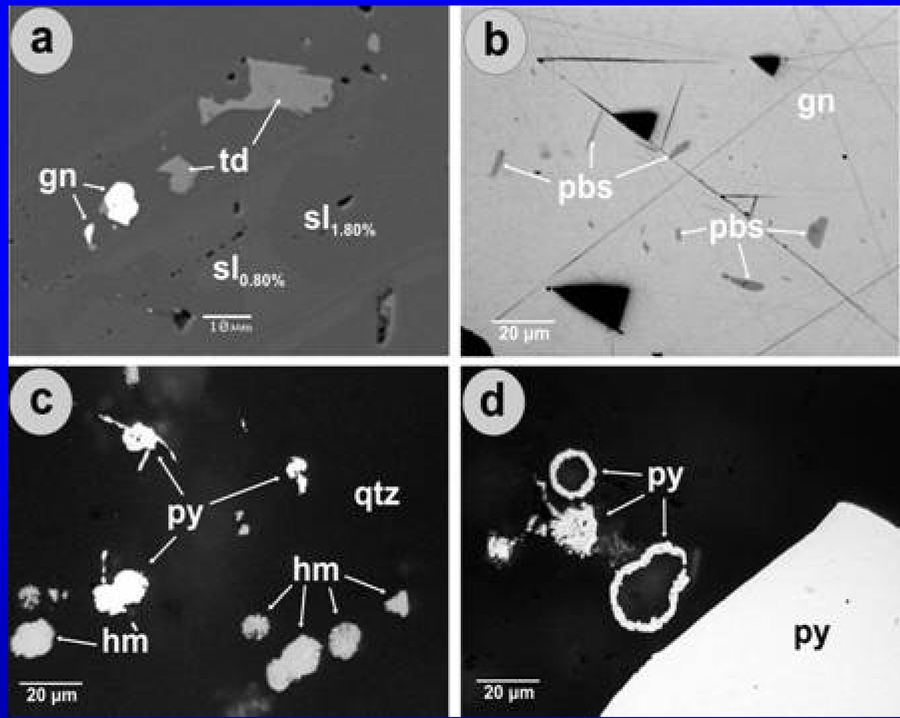
Kondaros base-Katsimouti:

Early deposition of sl → py + ga + pbs/prc +Ag-tt + hm + cpy. Gangue minerals are barite, calcite, adularia, and quartz



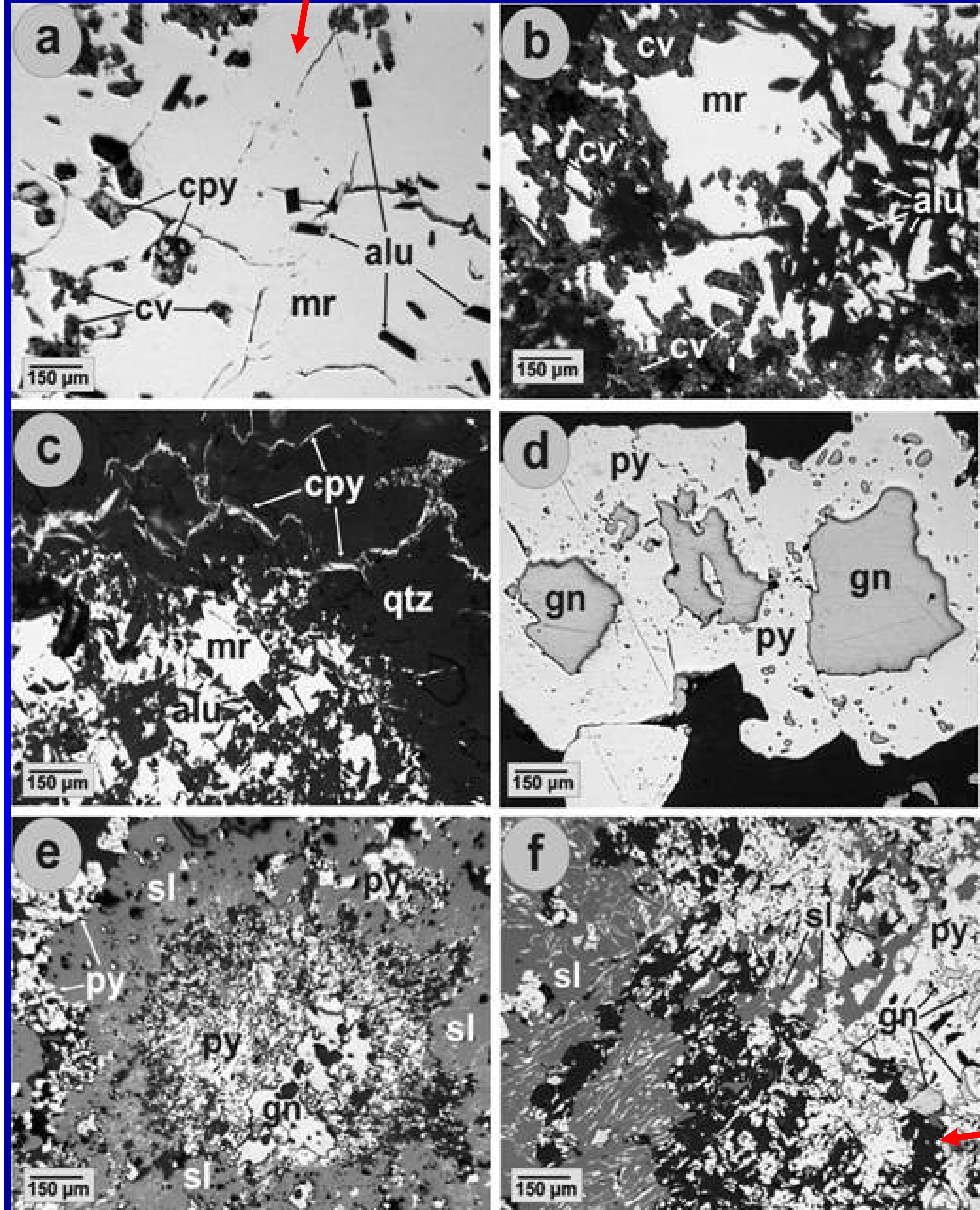
Katsimouti

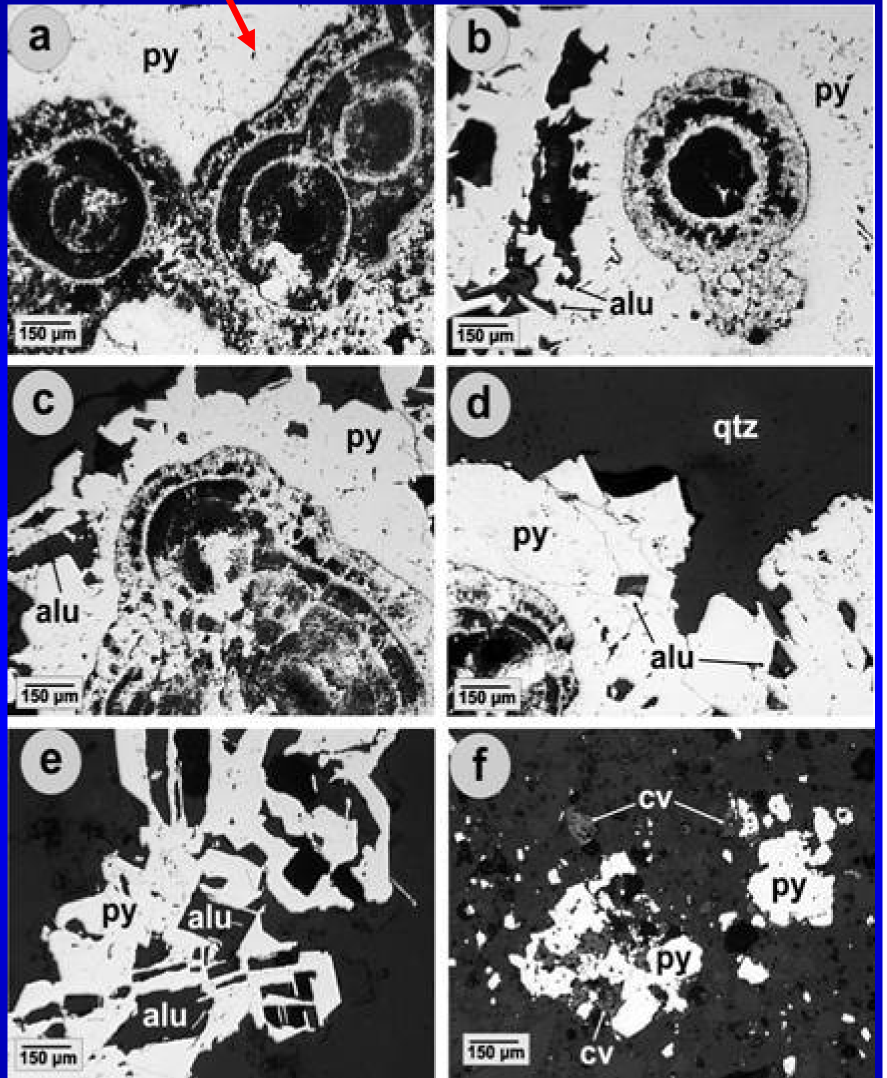
Kondaros base



Alfieris 2006, Alfieris and Voudouris 2006

Kondaros upper level: high-sulfidation mineralization

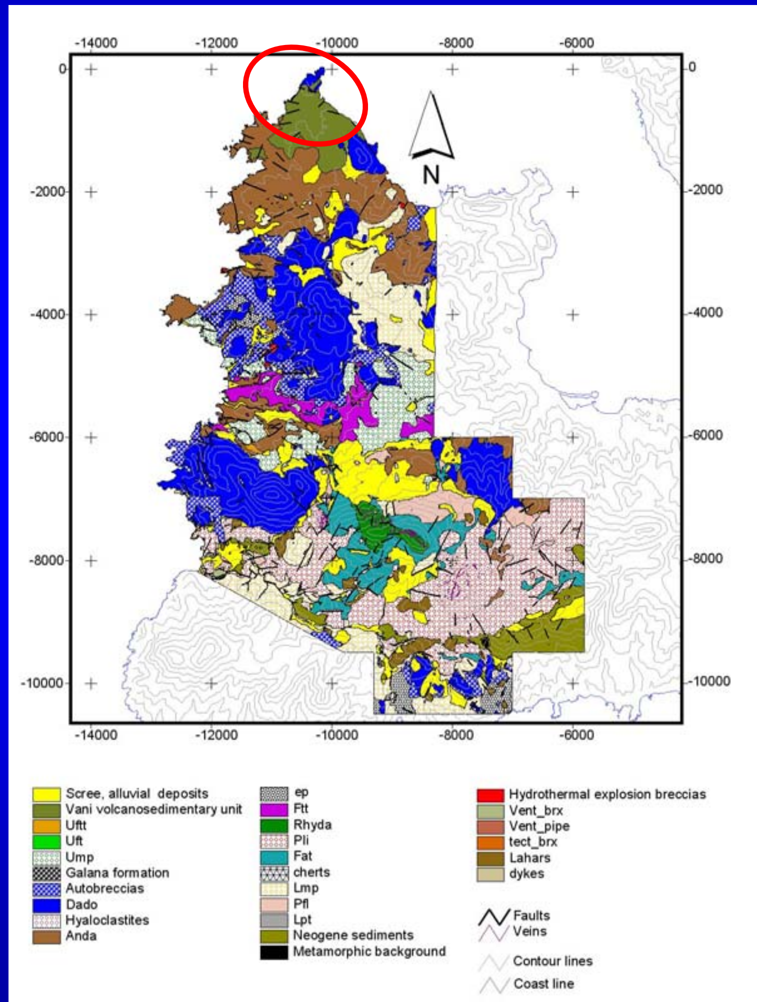




Kondaros base: IS mineralization

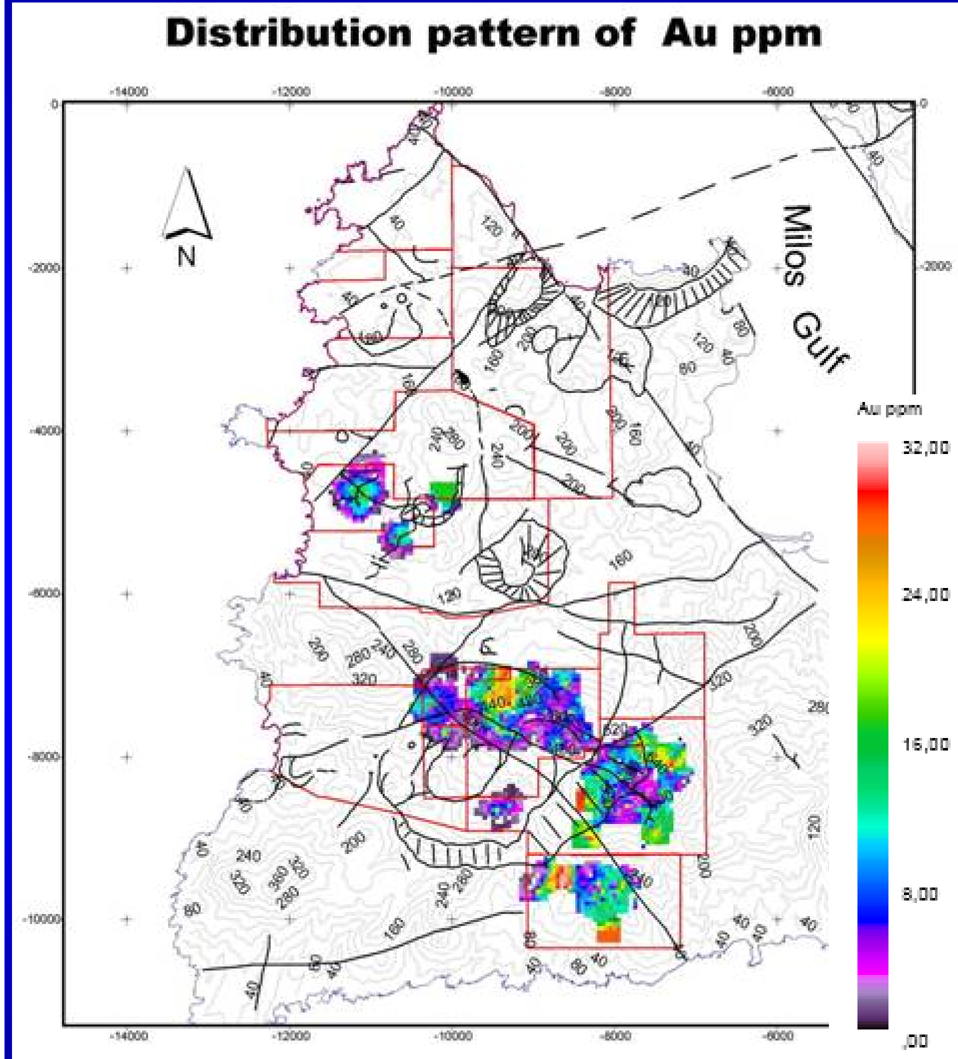
Alfieris 2006, Alfieris and Voudouris 2006

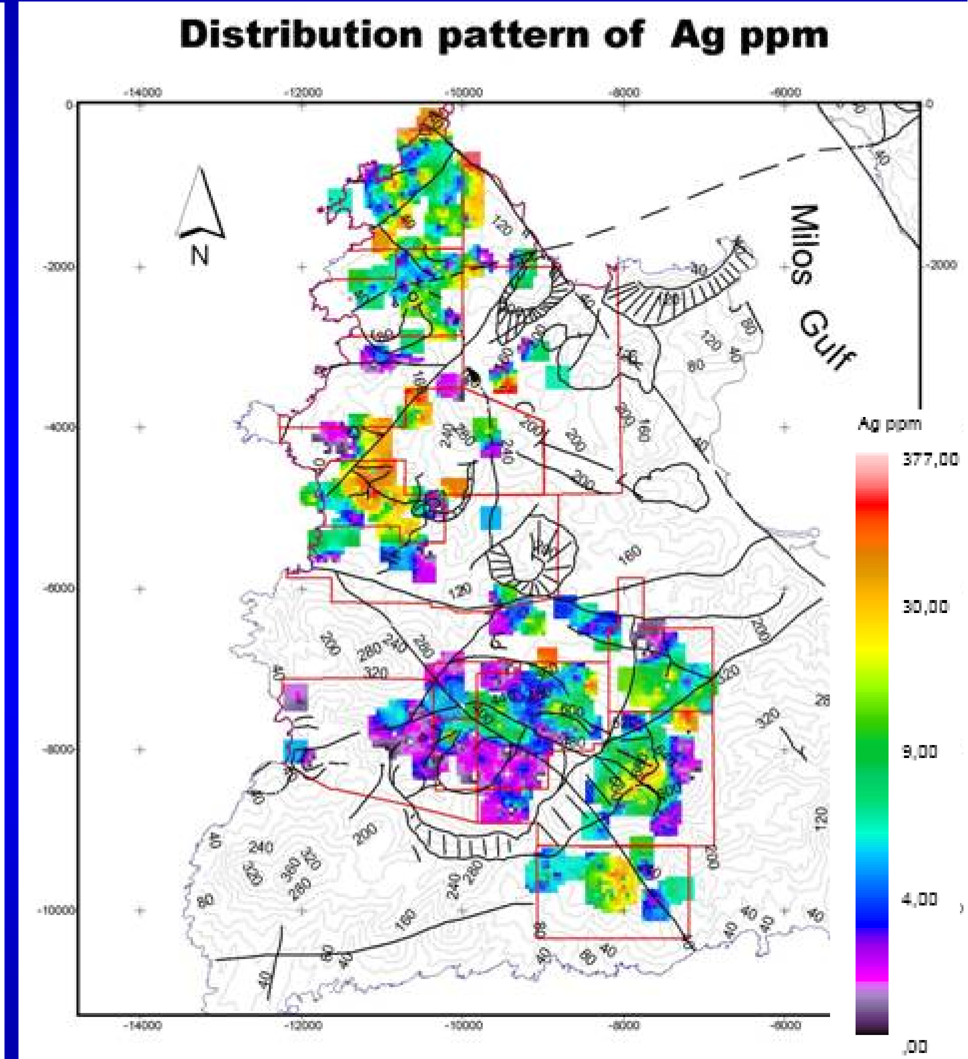
Vani Mn-Pb-Zn deposit: stratiform mineralization hosted in volcaniclastic sandstones, tuffs underlain by Anda, Dado lavas and domes. Seafloor deposition - White smokers (Plimer 2000)



Alfieris 2006

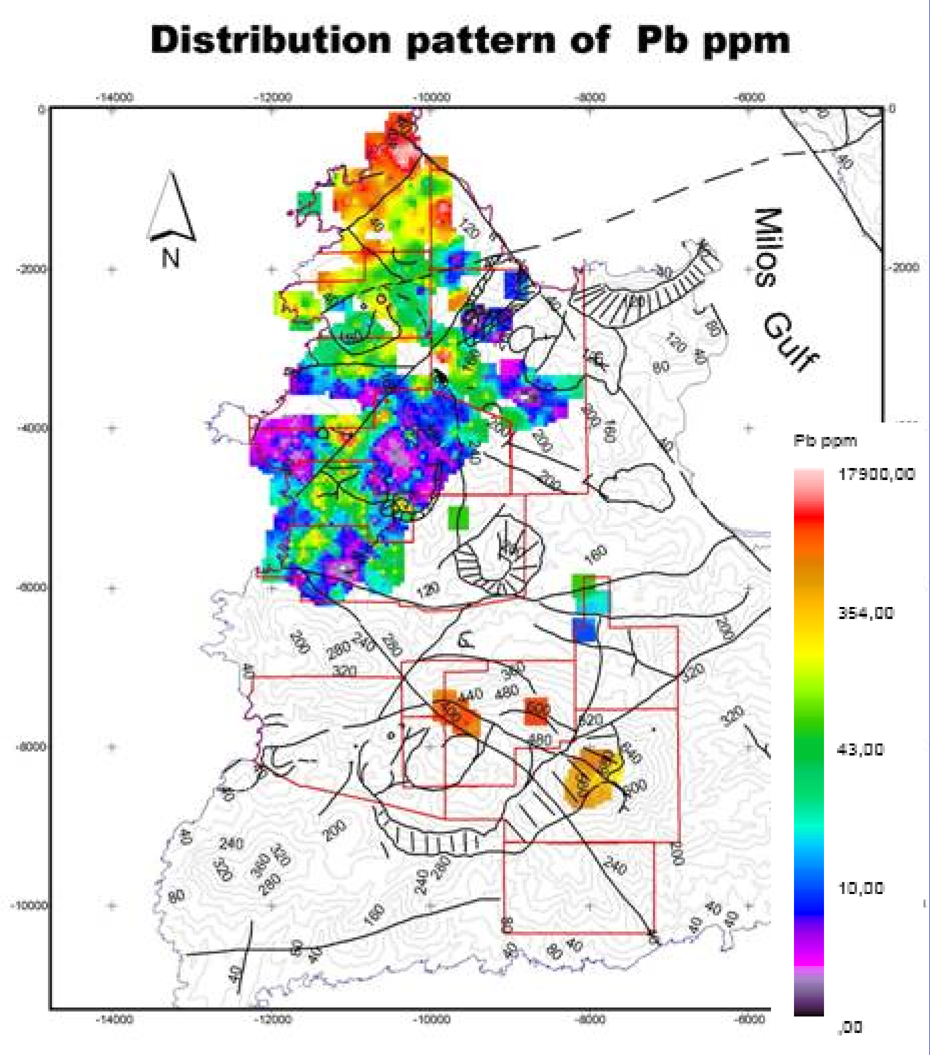
Distribution of Au, Ag

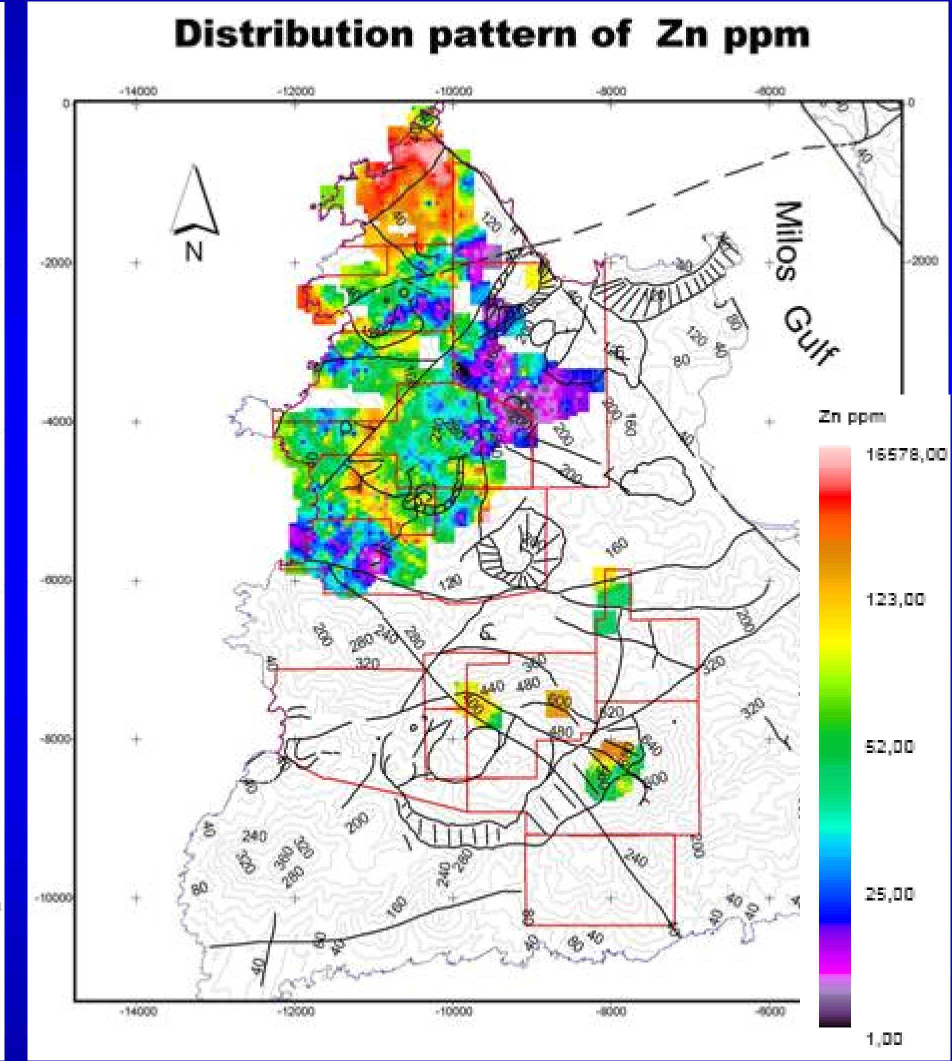




Alfieris 2006

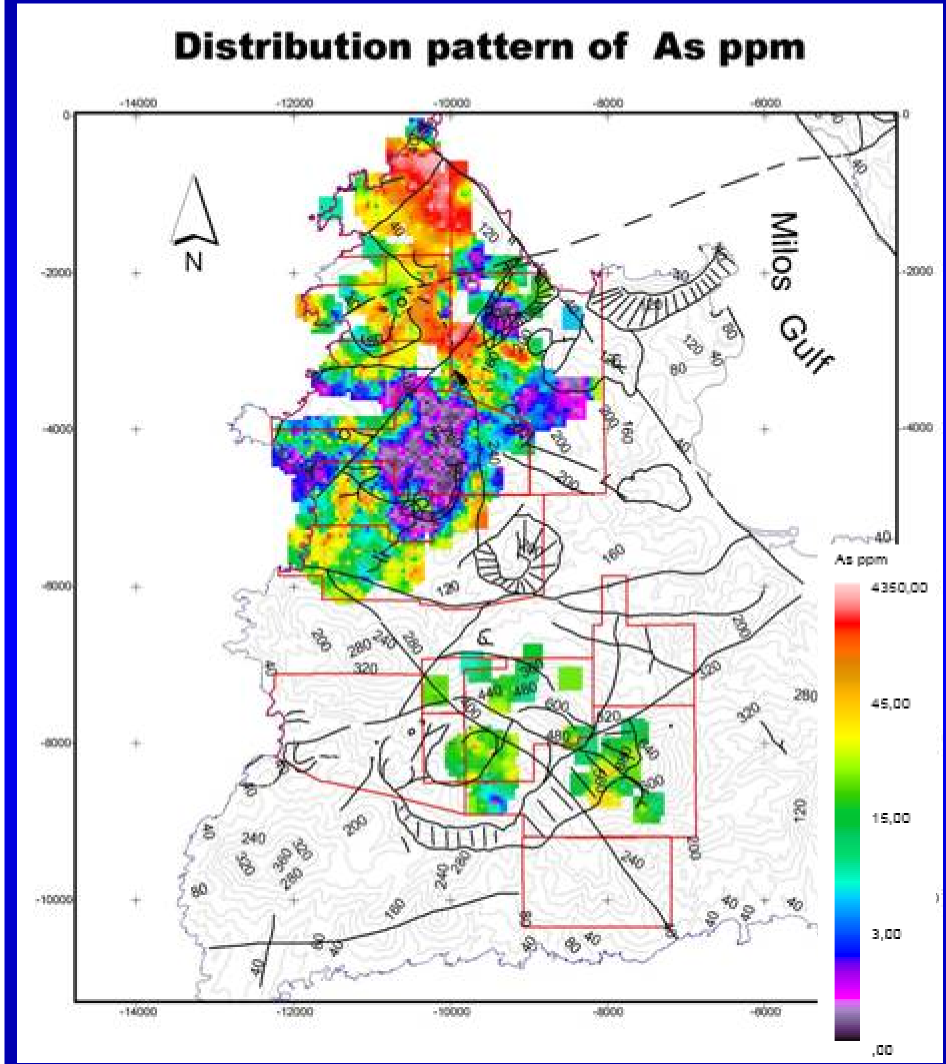
Distribution of Pb, Zn

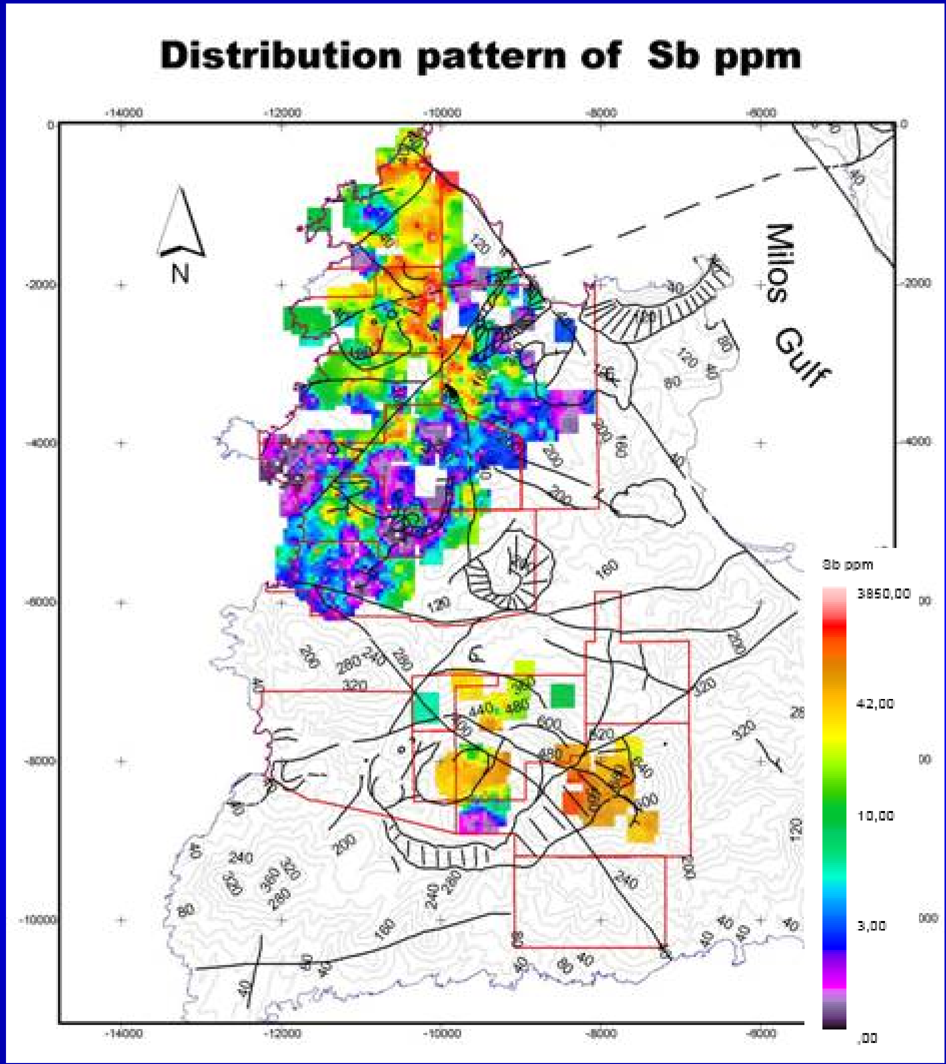




Alfieris 2006

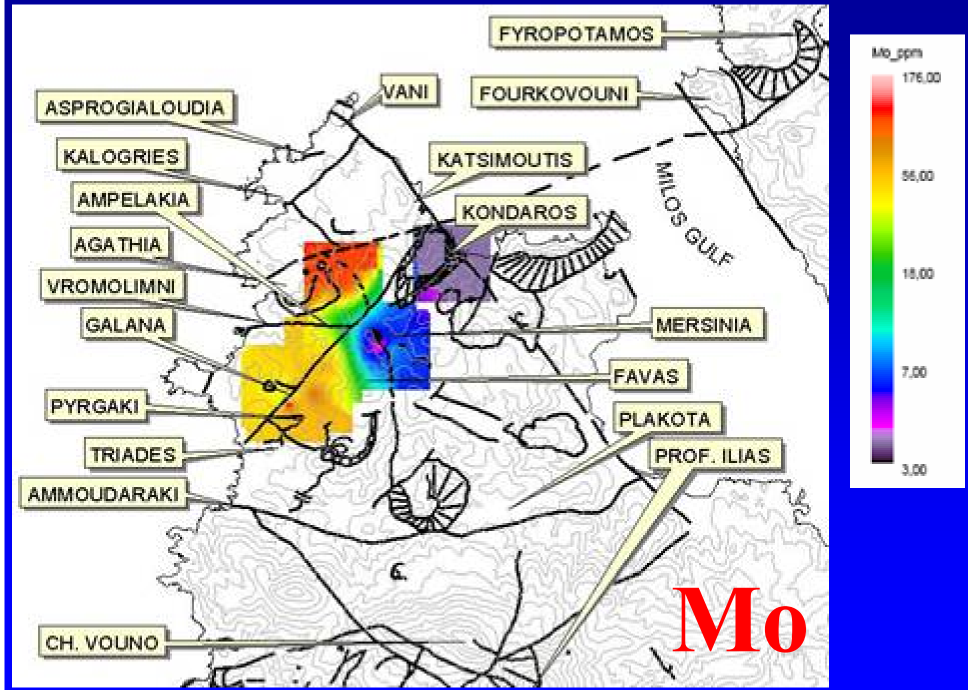
Distribution of As, Sb

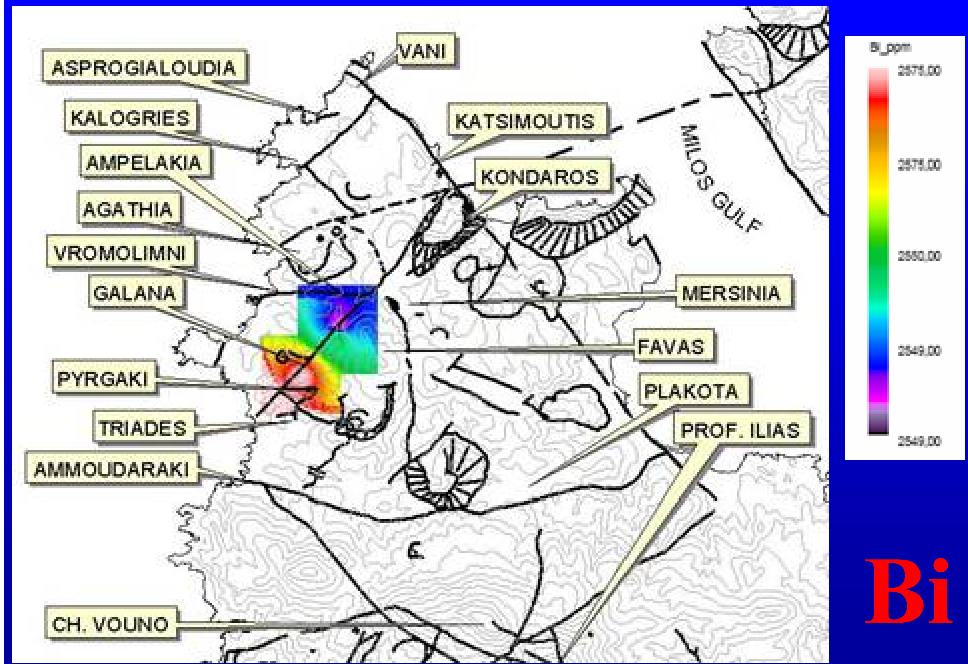




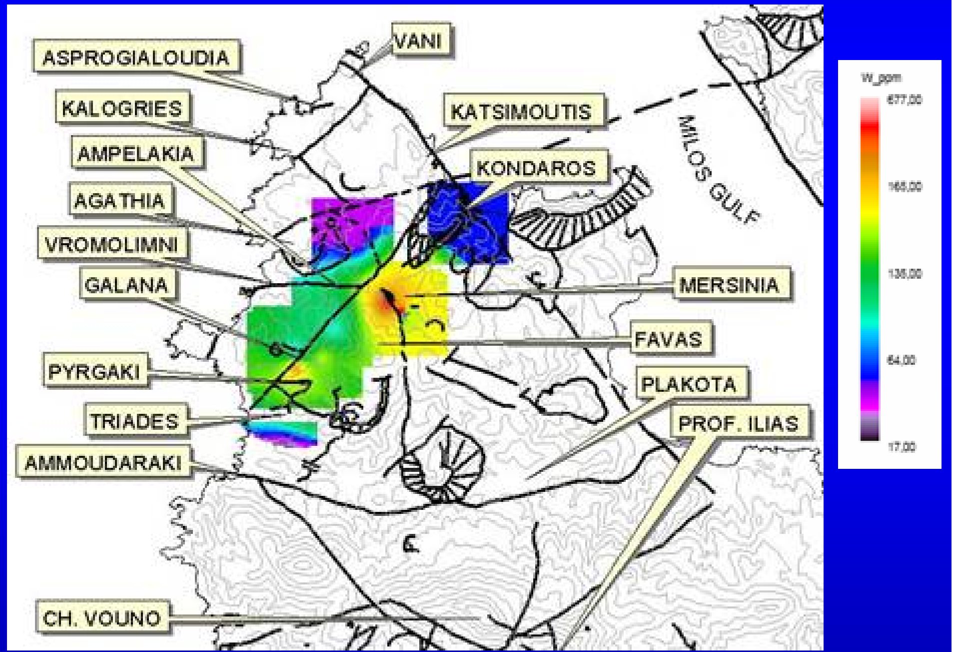
Alfieris 2006

W, Mo, Bi enrichment at Triades-Galana





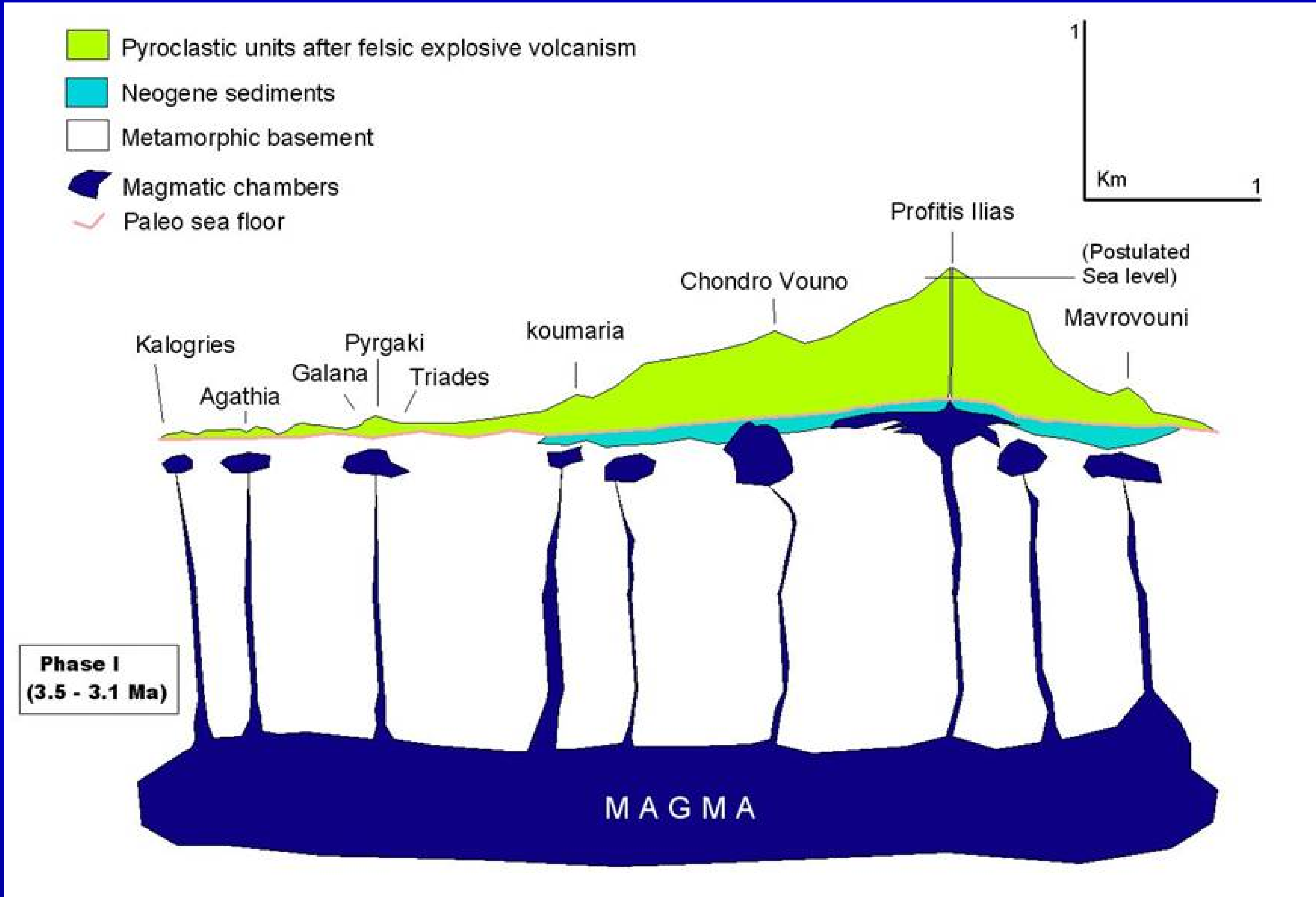
Bi



W

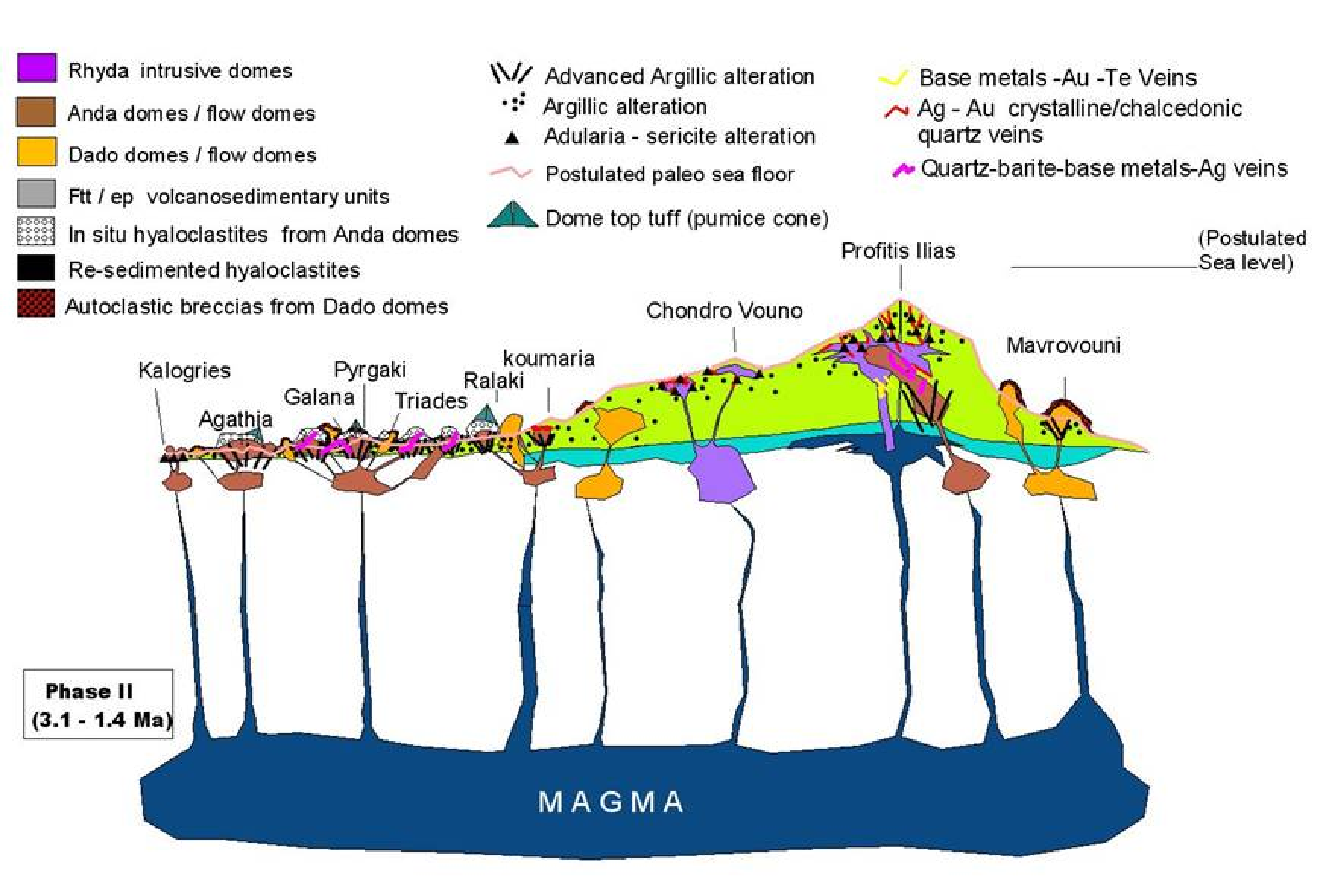
Alfieris 2006

Evolution of magmatism and mineralization in western Milos (Phase I)



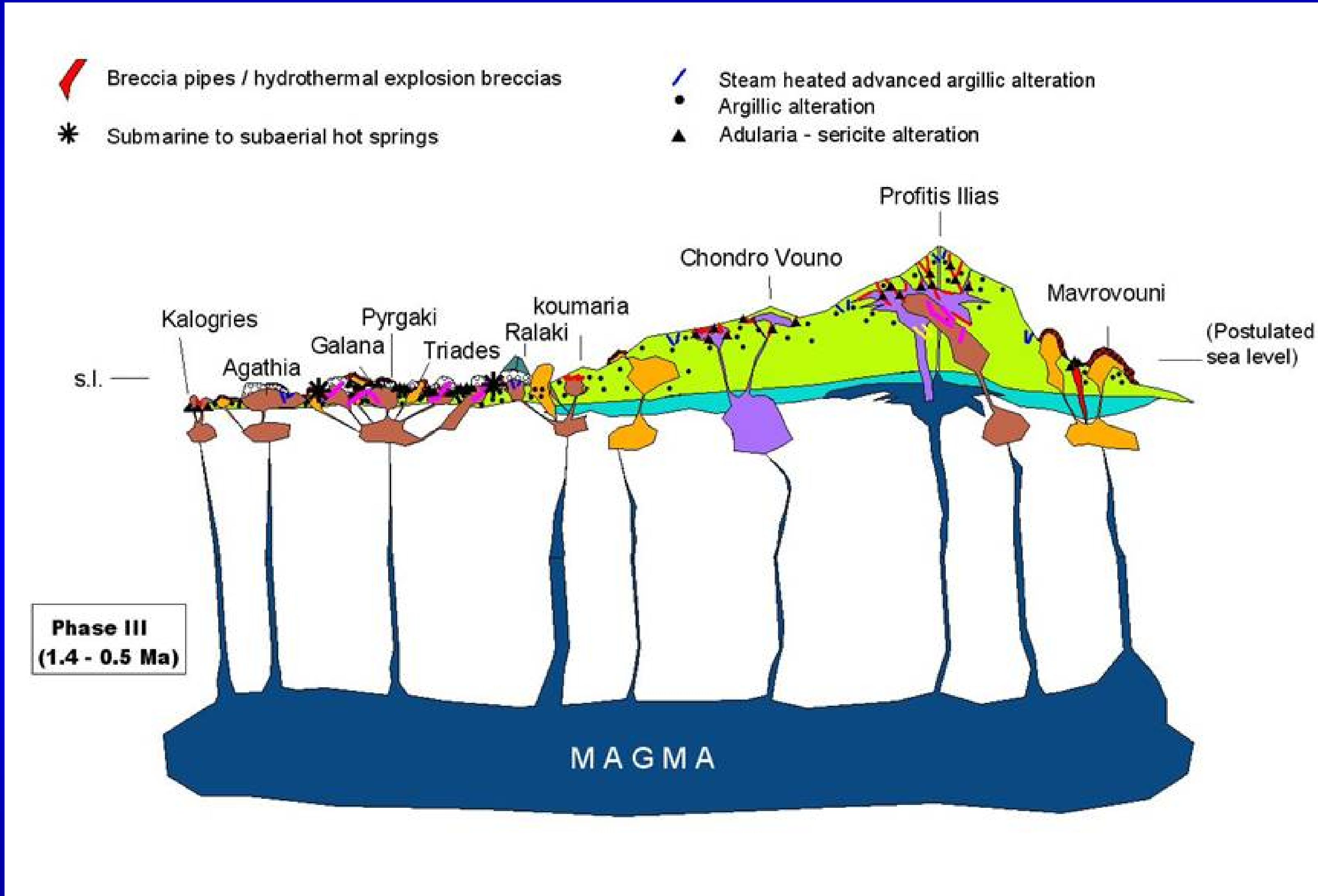
Alfieris 2006

Evolution of magmatism and mineralization in western Milos (Phase II)



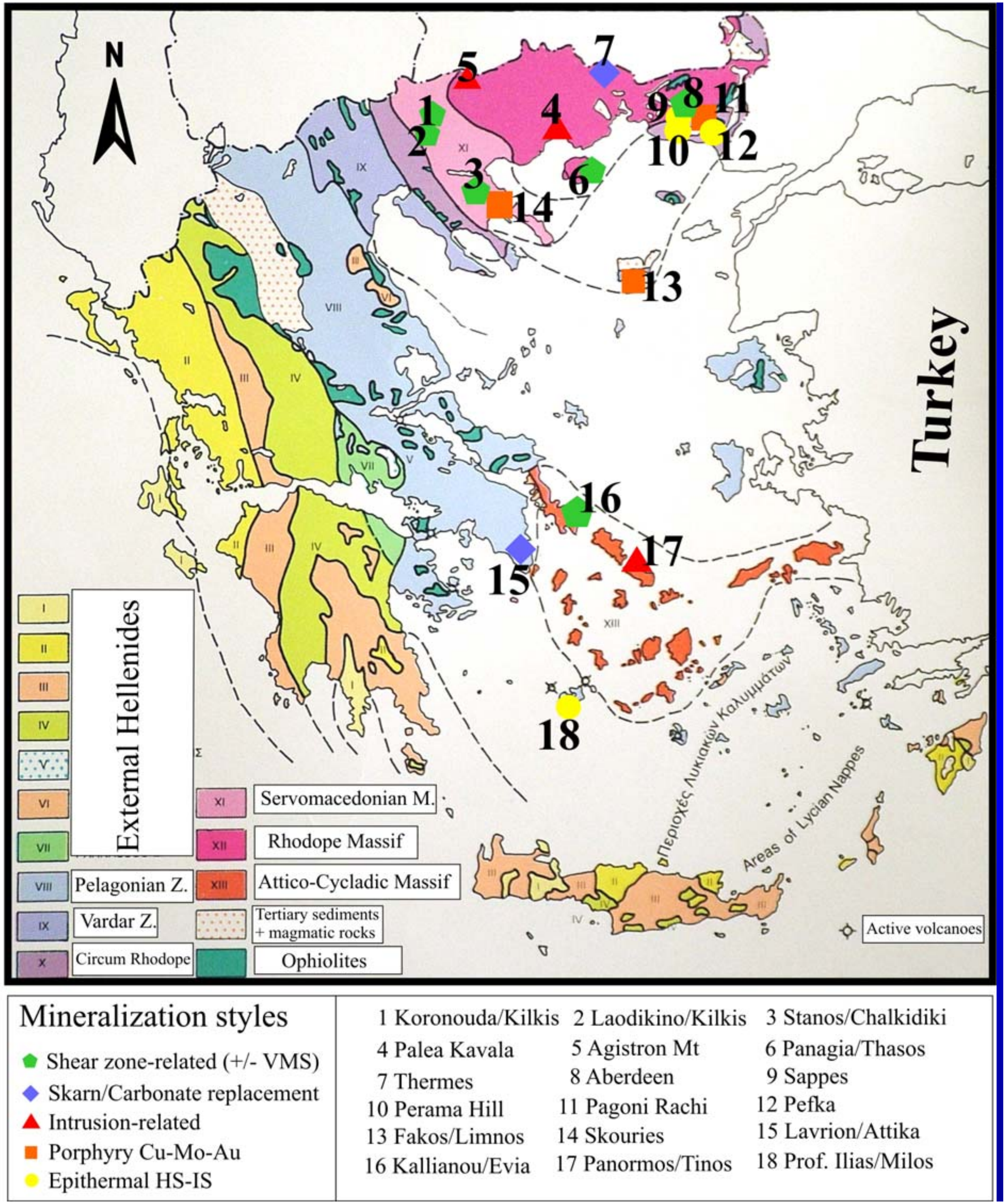
Alfieris 2006

Evolution of magmatism and mineralization in western Milos (Phase III)



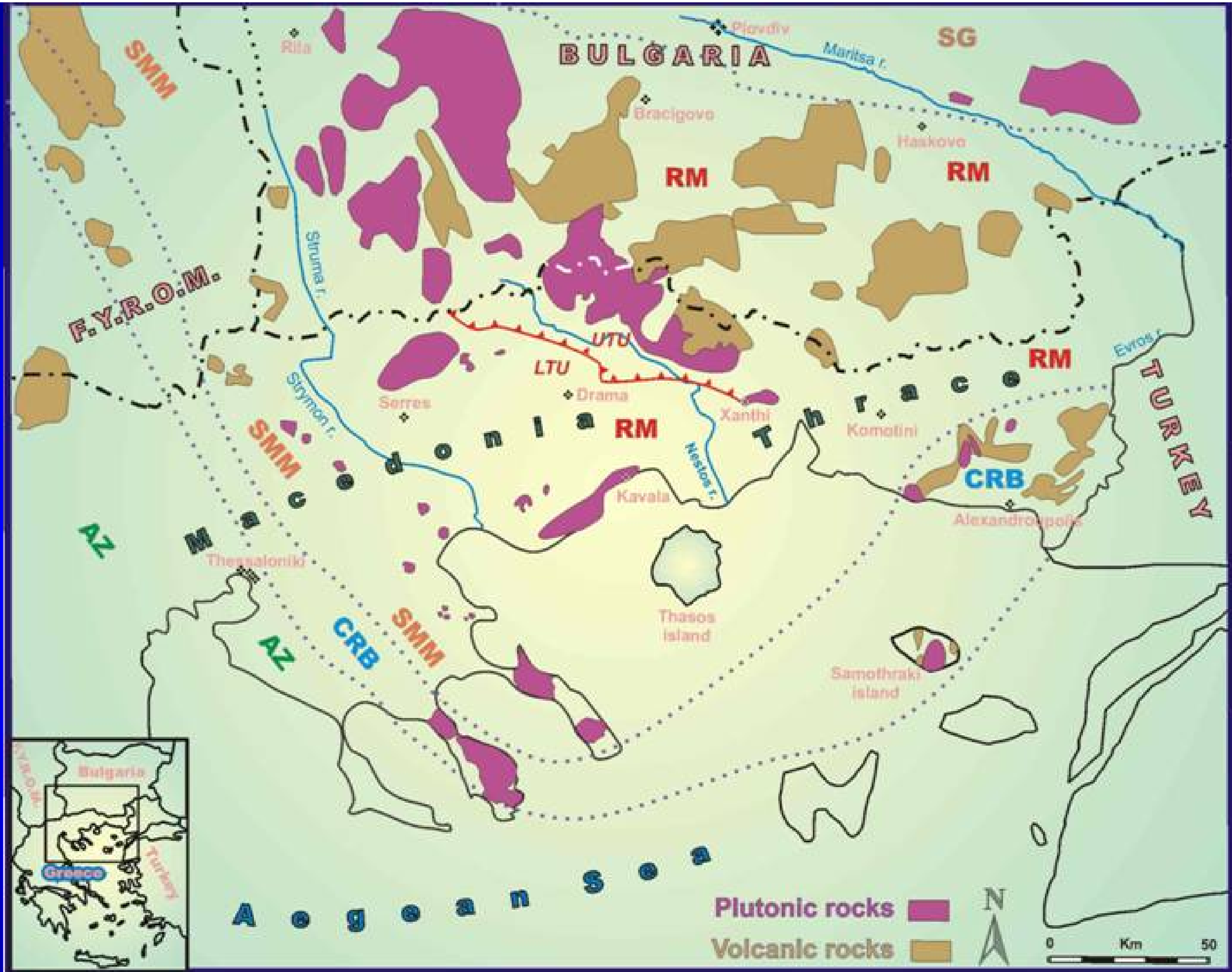
Alfieris 2006

Simplified geologic map of the Hellenides (I.G.M.E. 1983) and location of the gold-bearing mineralization in the Attico-Cycladic complex



Reduced Intrusion-related Mo-W-Au-Bi systems

Kimmeria/Xanthi, Kavala, Lavrion



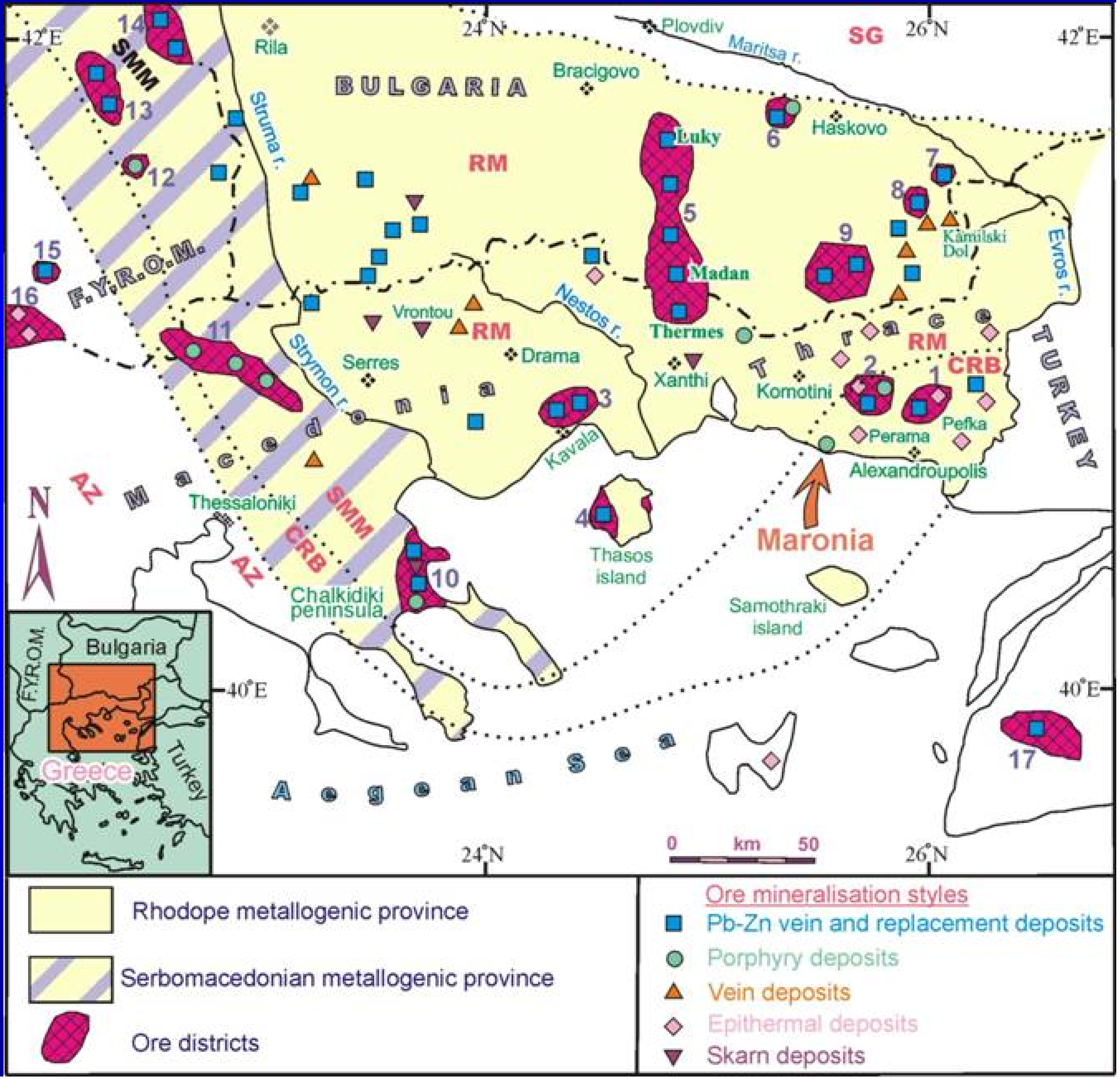
Oligocene-Miocene magmatic rocks (plutonic and volcanic) in Southern Balkan peninsula

Distribution of the Tertiary ore districts and deposits within the Rhodope and the Serbomacedonian metallogenic provinces in the southern Balkan peninsula.

RM=Rhodope Massif
SMM=Serbomacedonian Massif
CRB=Circum Rhodope Belt
AZ=Axios Zone
SG=Srednogorie Zone

1. Esymi
2. Kirki-Sapes
3. Kavala
4. Thasos
5. Thermes-Madan-Luky
6. Spahievo,
7. Lozen
8. Madjarovo
9. Zvezdel
10. Chalkidiki
11. Kilkis (Doirani-Gerakario-Vathi-Pontokerasia)
12. Buchim-Damjan
13. Kratovo-Zletovo
14. Osogovo-Sasa-Toranica
15. Borov Dol, 16. Aridea-Kozuf
17. Balikesir

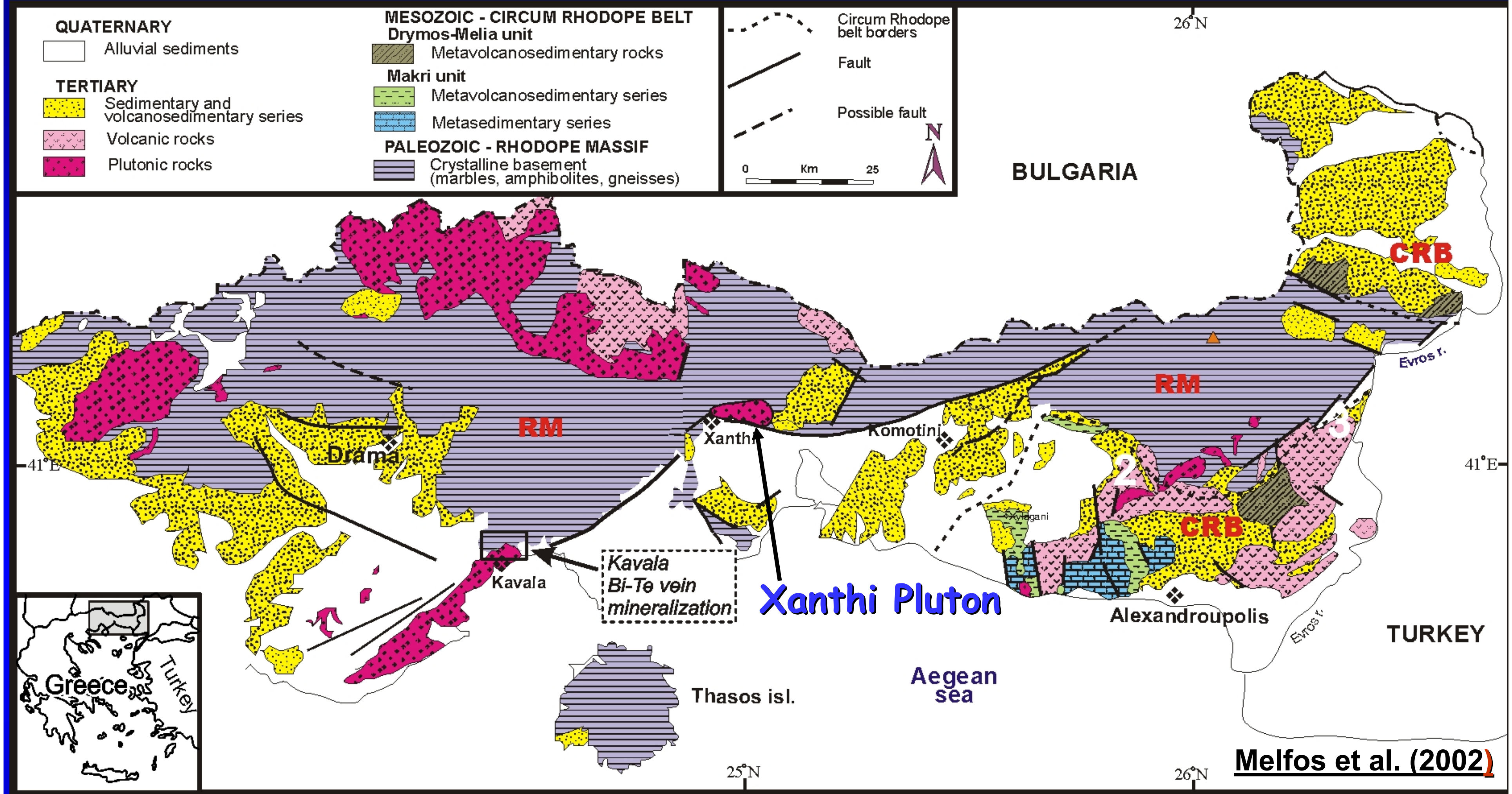
from Melfos et al. (2002)



Kimmeria/Xanthi

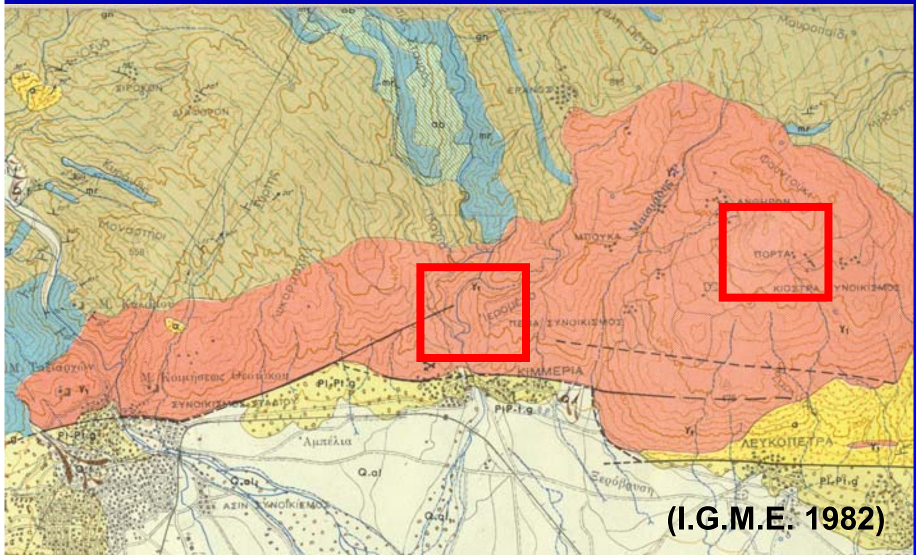
Intrusion-related

Mo-W-Cu-Au-Bi system

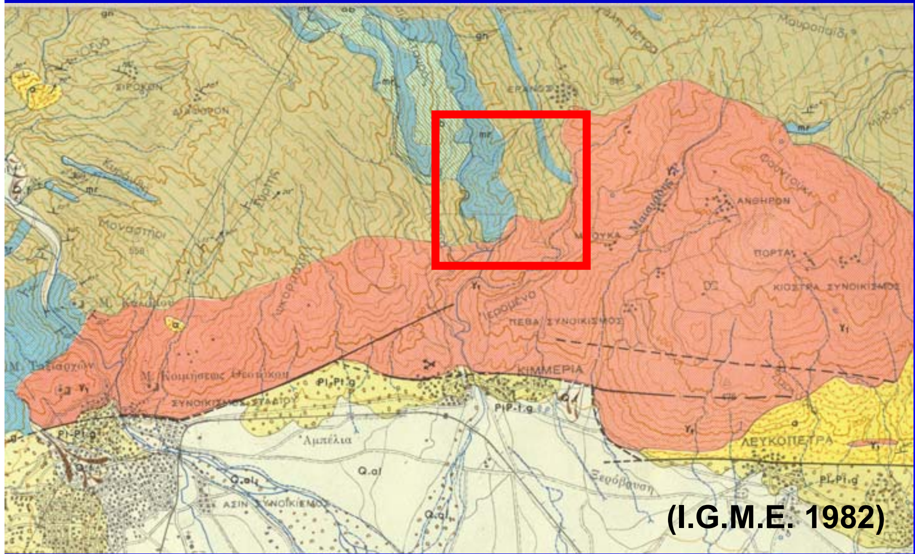


The Xanthi pluton intruded the gneisses and marbles of the Palaeozoic-Mesozoic Rhodope metamorphic complex, along the Xanthi-Komotini fault.

Intrusion-hosted Mo-W-Bi-Au-rich sheeted quartz veins

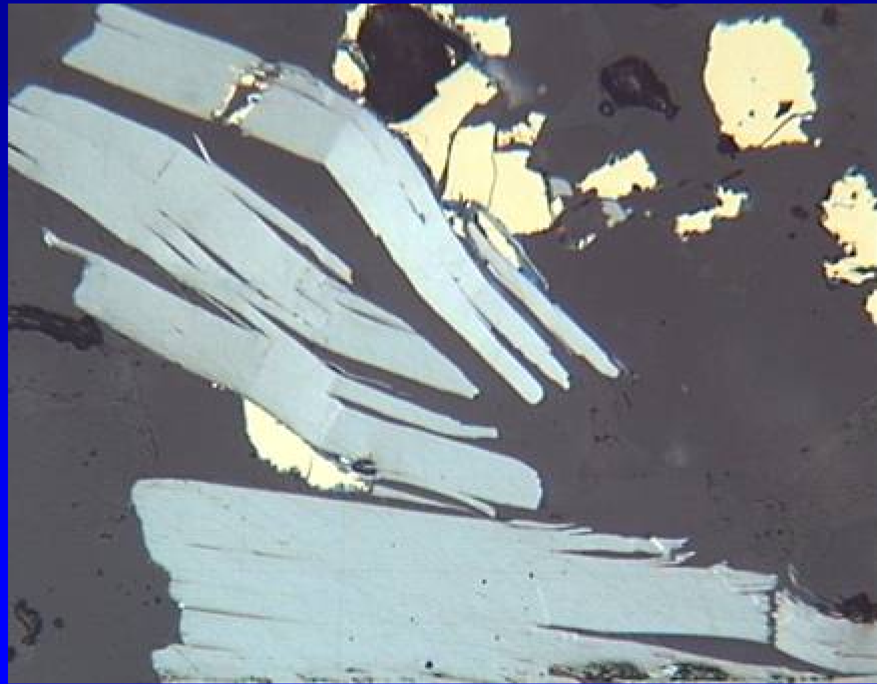


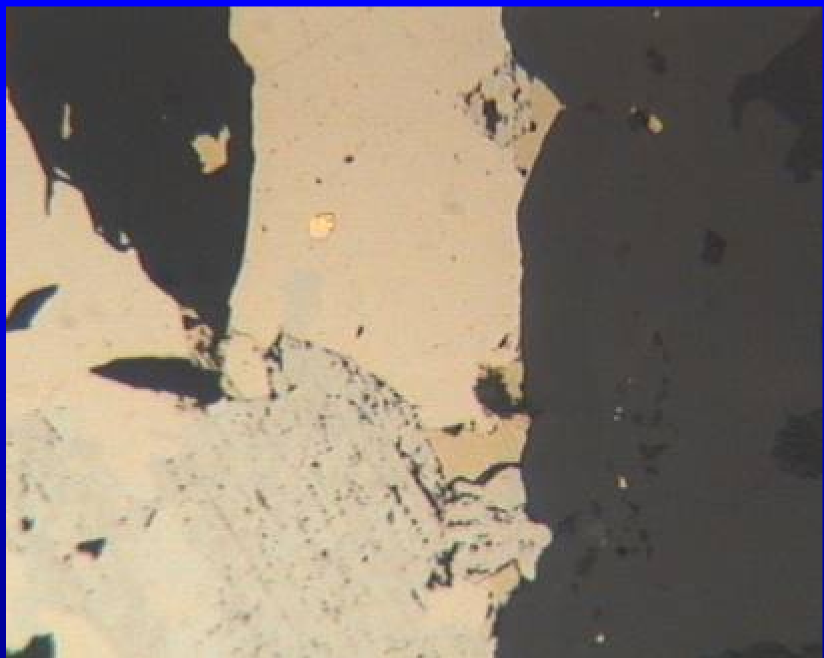
Mo-W-Cu-Au skarn at marble-granodiorite contact



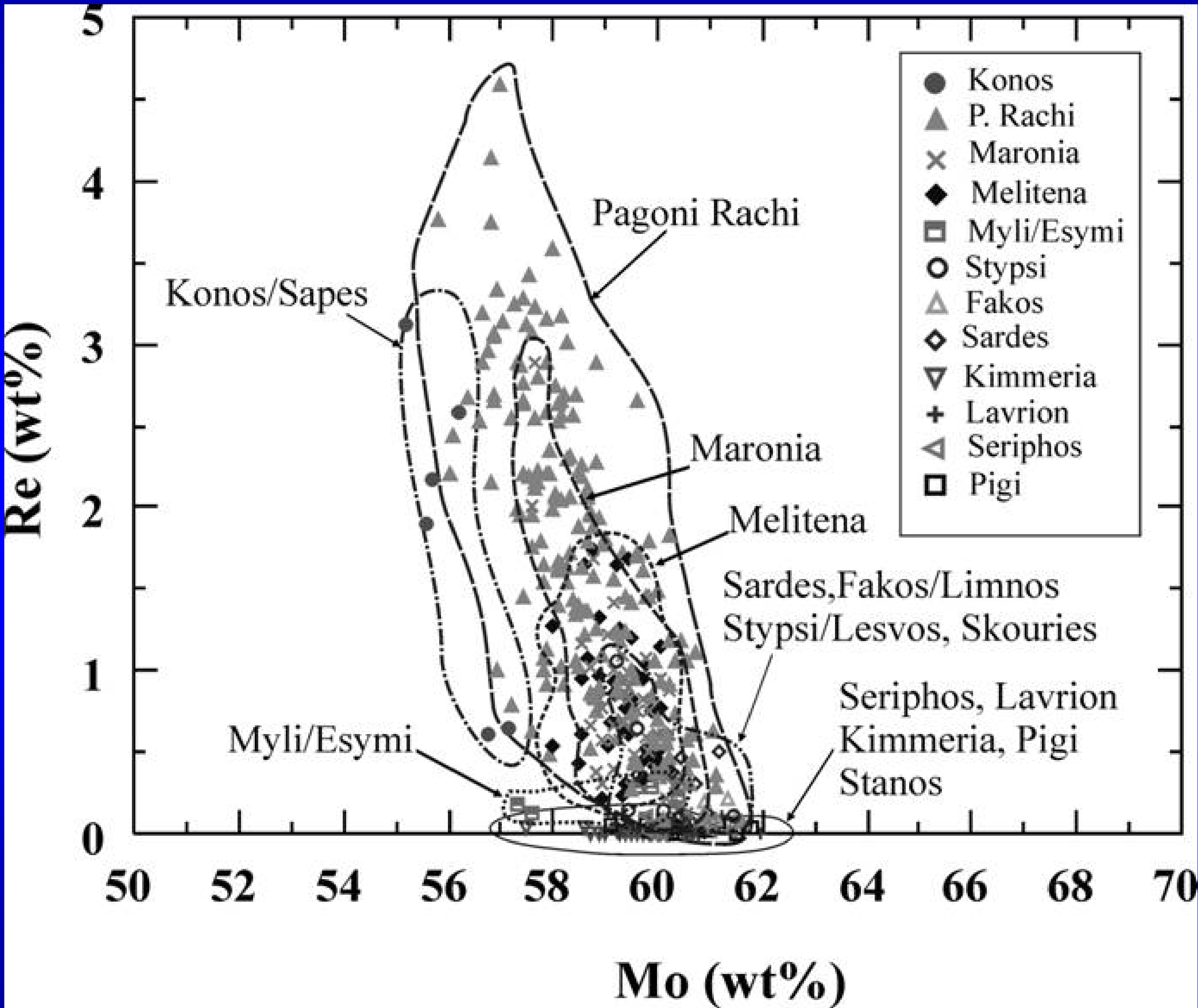
Intrusion-hosted Cu-rich quartz veins

Molybdenite, native Au, chalcopyrite in skarn and intrusion-hosted mineralization





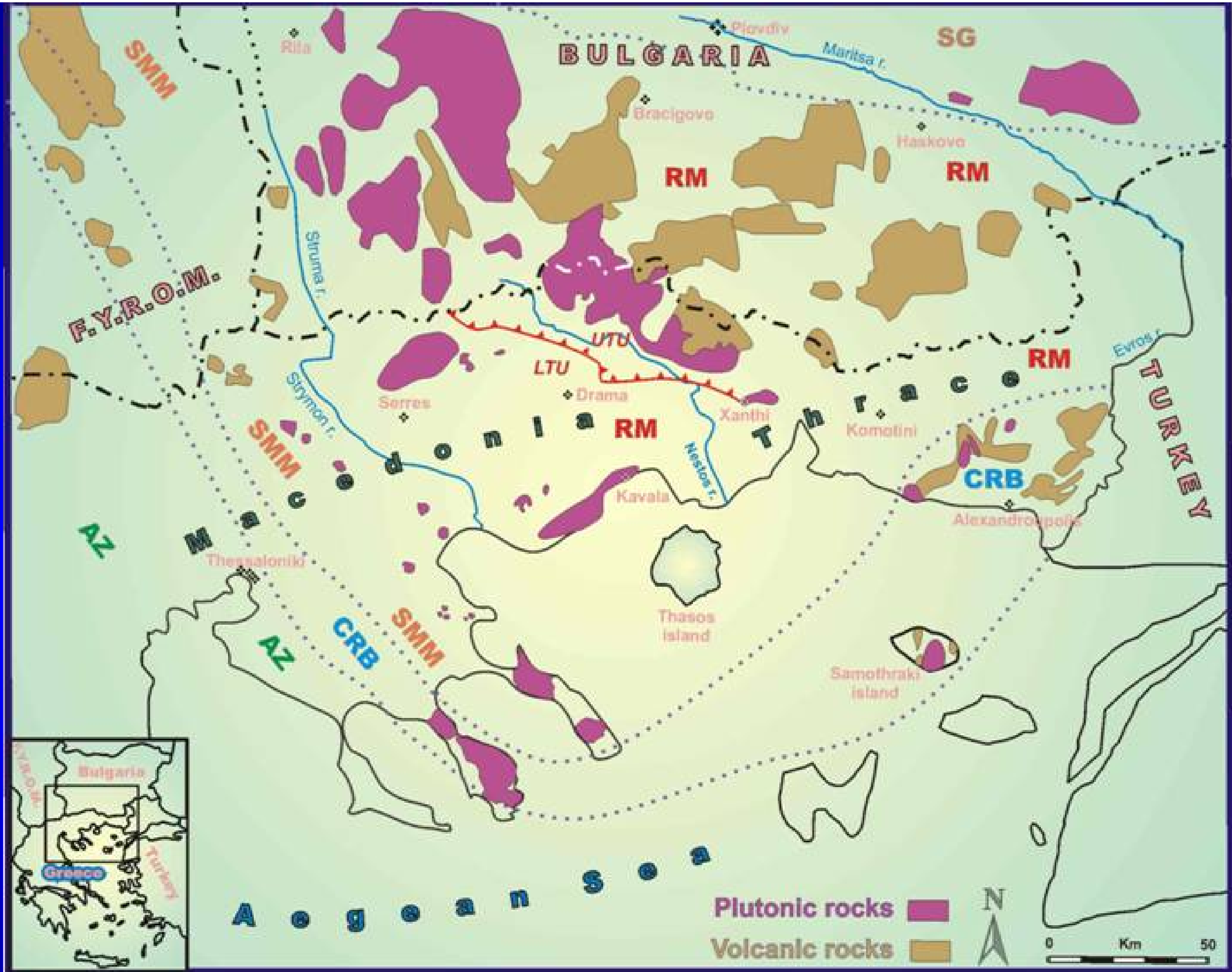
Re-content in Molybdenite from various mineralization types in Greece



Voudouris et al. (2010a)

Kavala

Intrusion-related Au-Bi-Te system



Oligocene-Miocene magmatic rocks (plutonic and volcanic) in Southern Balkan peninsula

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10. Chalkidiki
11. Kilkis (Doirani-Gerakario-Vathi-Pontokerasia)
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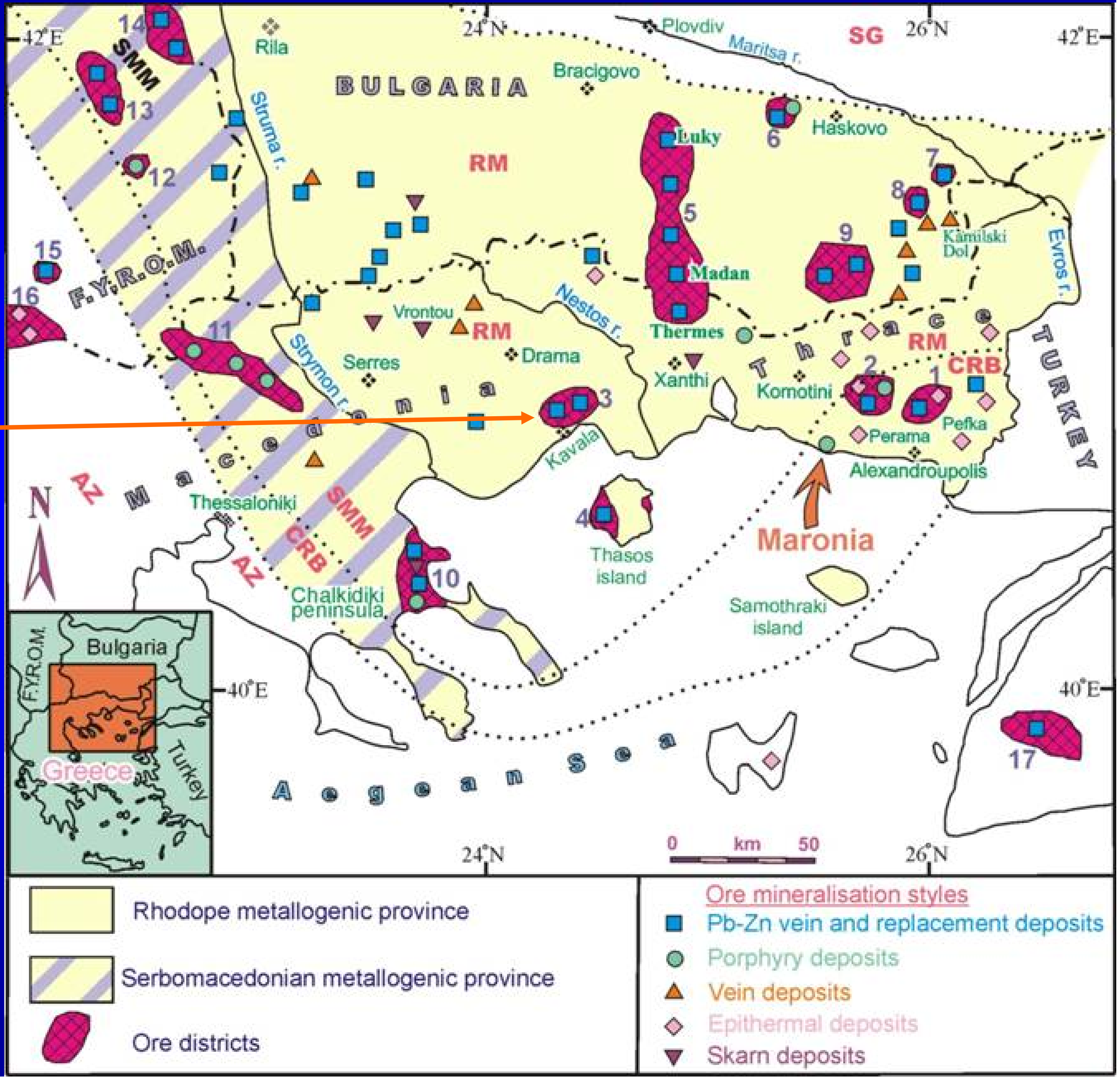
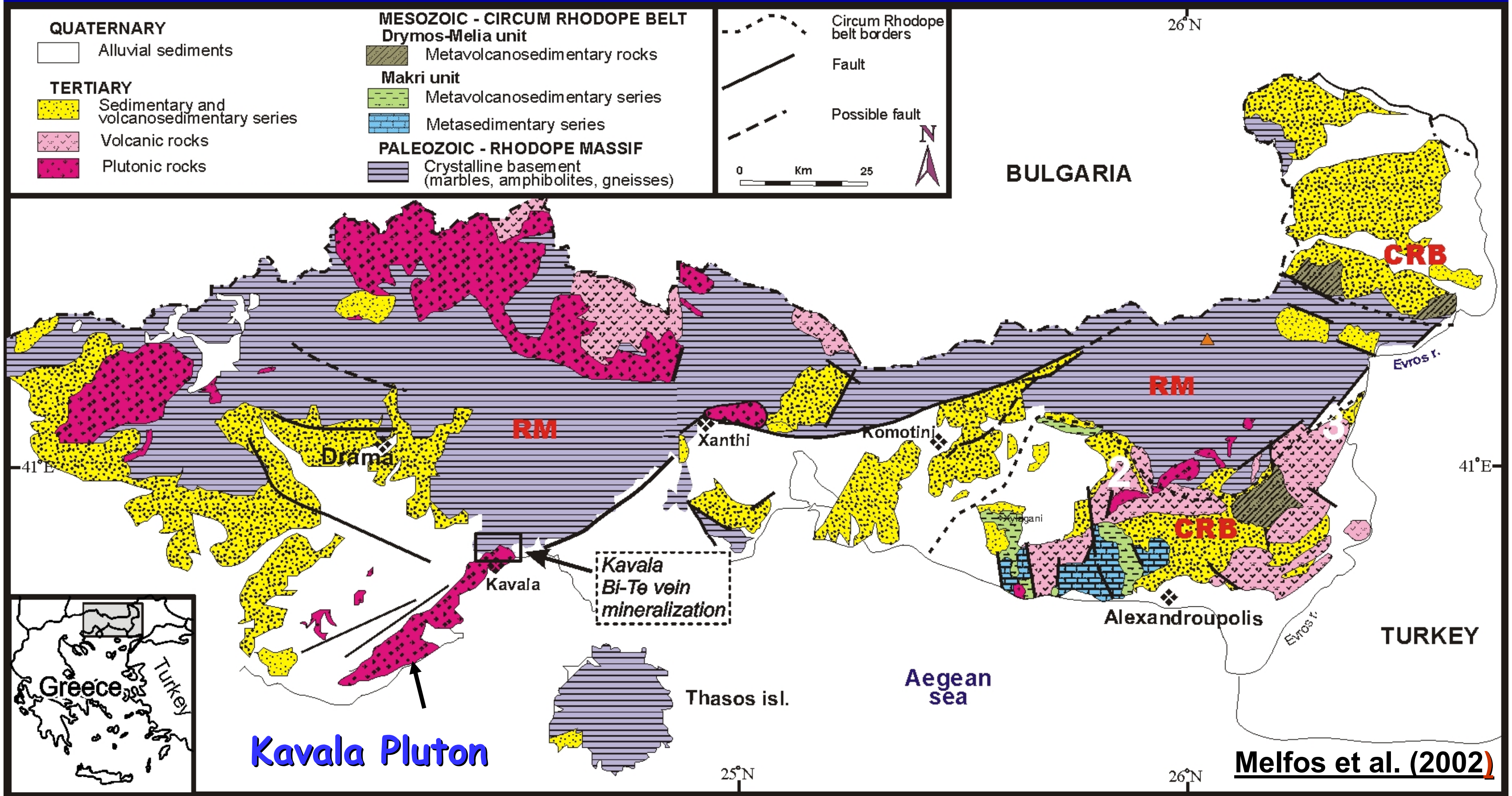
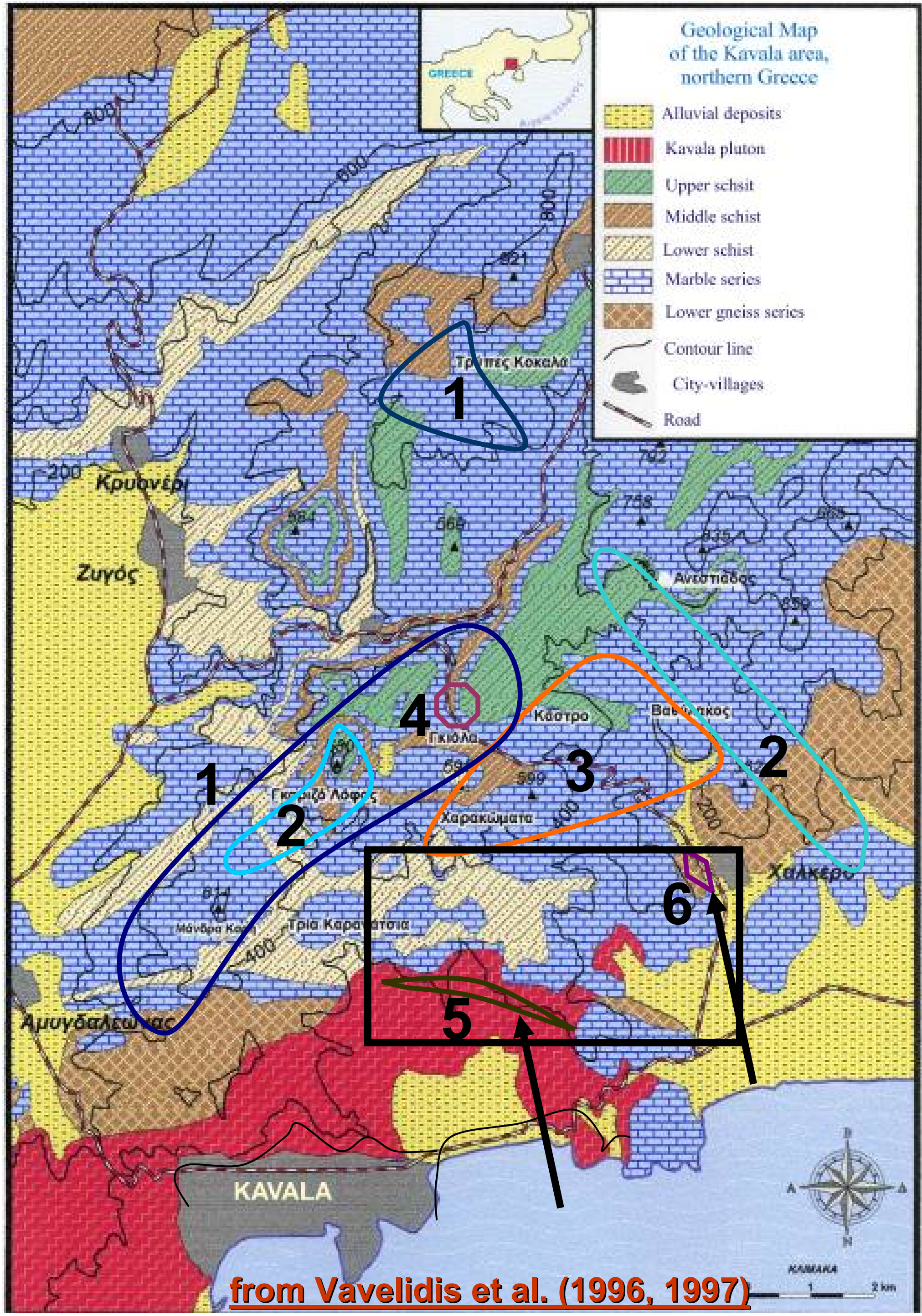
13. Kratovo-Zletovo
14. Osogovo-Sasa-Toranica
15. Borov Dol, 16. Aridea-Kozuf
17. Balikesir

from Melfos et al. (2002)





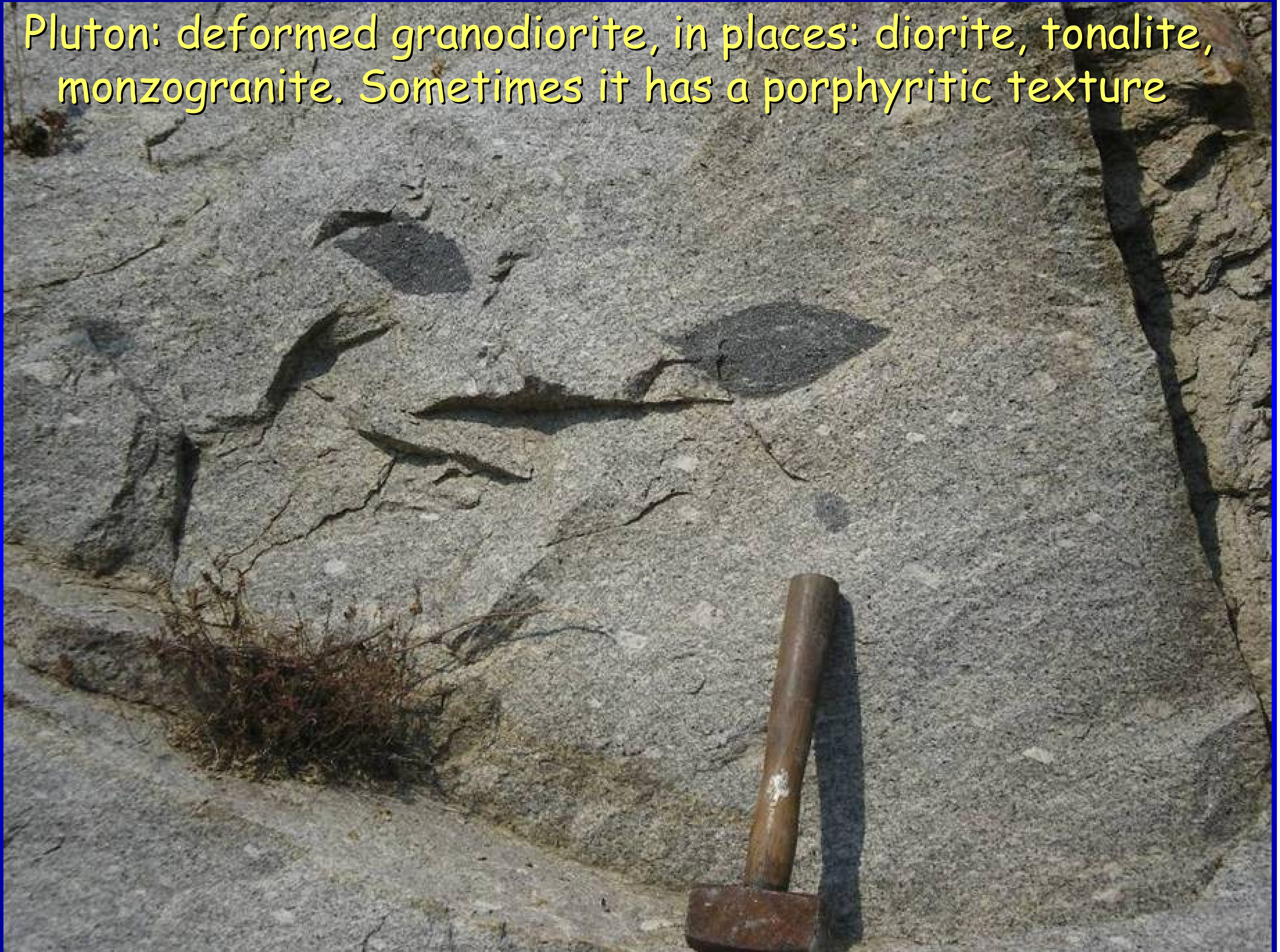
The Early Miocene Kavala pluton intruded the gneisses and marbles of the Palaeozoic-Mesozoic Rhodope metamorphic complex, along the Kavala-Komotini fault.



The intrusion-related ore system is dominated by a SE-NW trending system of veins, which crosscut the Kavala pluton (5), 2000 m long and up to 5 m wide, at its northeast border. Mineralized quartz veins are also found at the adjacent gneisses and marbles at Chalkero locality(6).

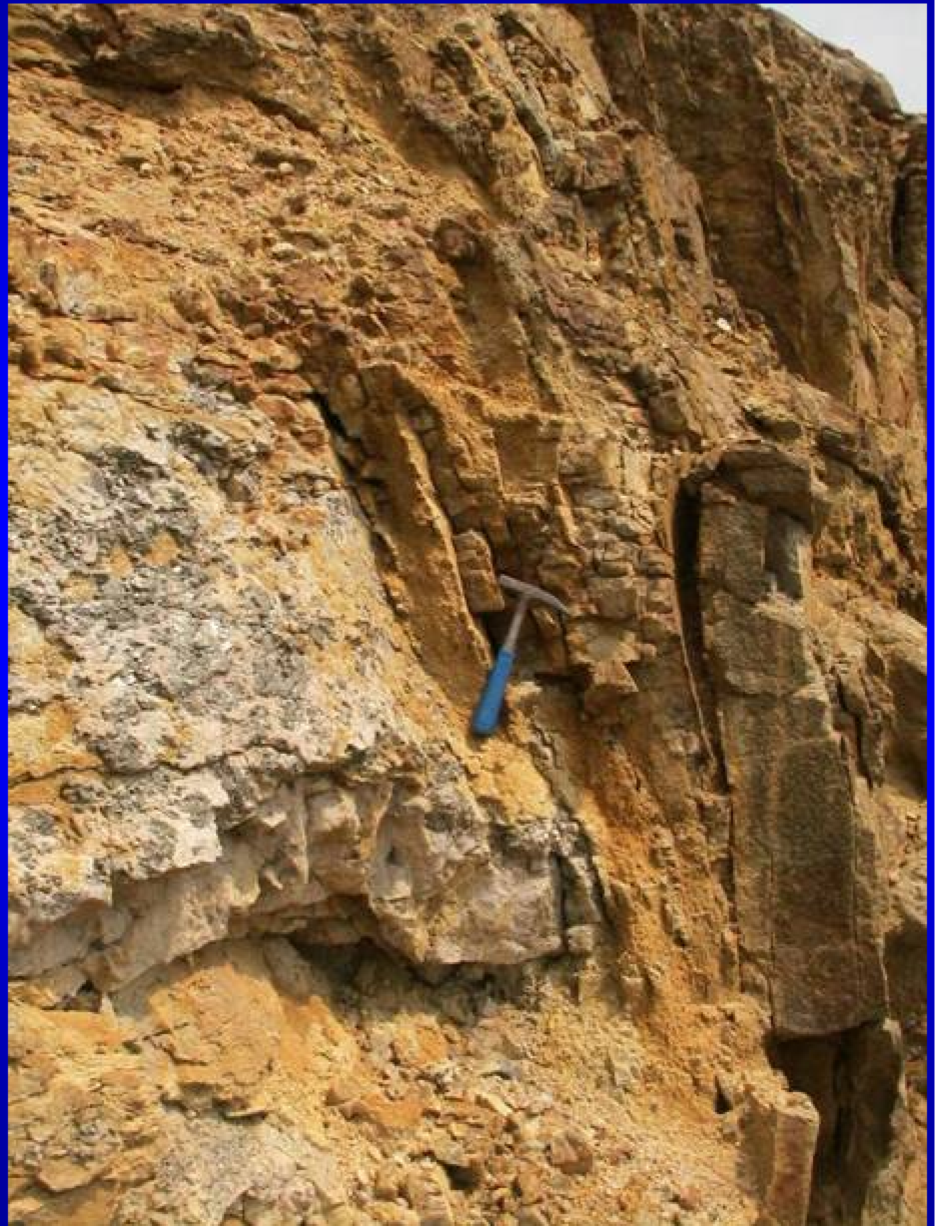
In addition, four main types of ore mineralization had been distinguished: (1) Pb-Zn-Ag-bearing Fe-Mn-oxidized bodies; (2) Au-bearing Fe-Mn-oxidized bodies; (3) Au-bearing pyrite-chalcopyrite ore bodies and (4) Au-bearing pyrite-arsenopyrite ore bodies

Pluton: deformed granodiorite, in places: diorite, tonalite, monzogranite. Sometimes it has a porphyritic texture

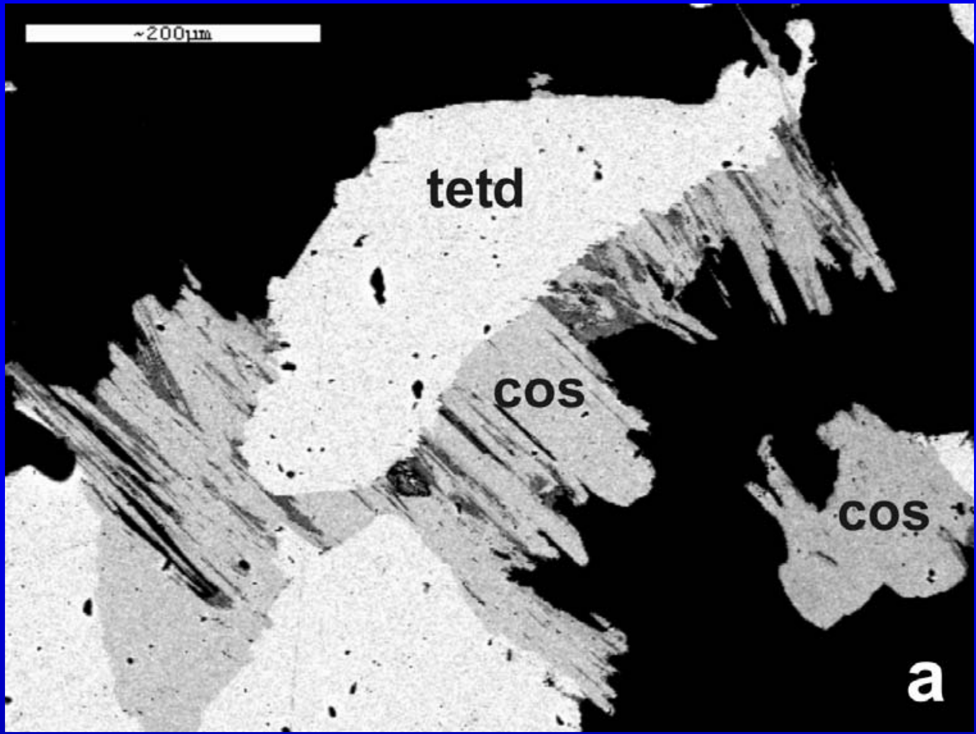


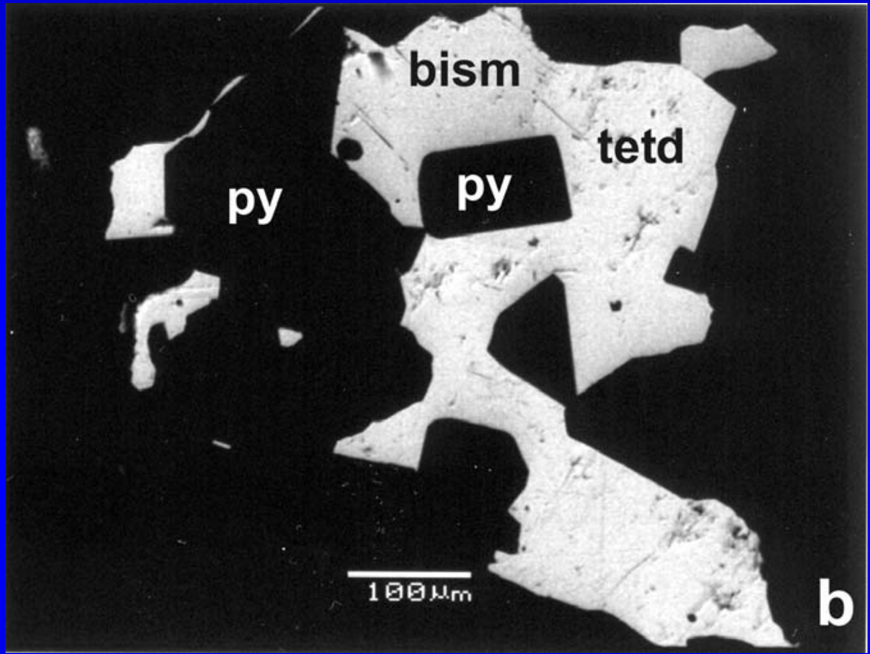
Intrusion-hosted sheeted quartz-pyrite veins

Boudins with massive pyrite within the pluton



The mineralogical composition of the veins consists of: pyrite, tetradymite (Bi_2Te_2S), bismuthinite (Bi_2S_3), cosalite ($Pb_2Bi_2S_5$) and Sb-lillianite ($Pb_3Bi_2S_6$)



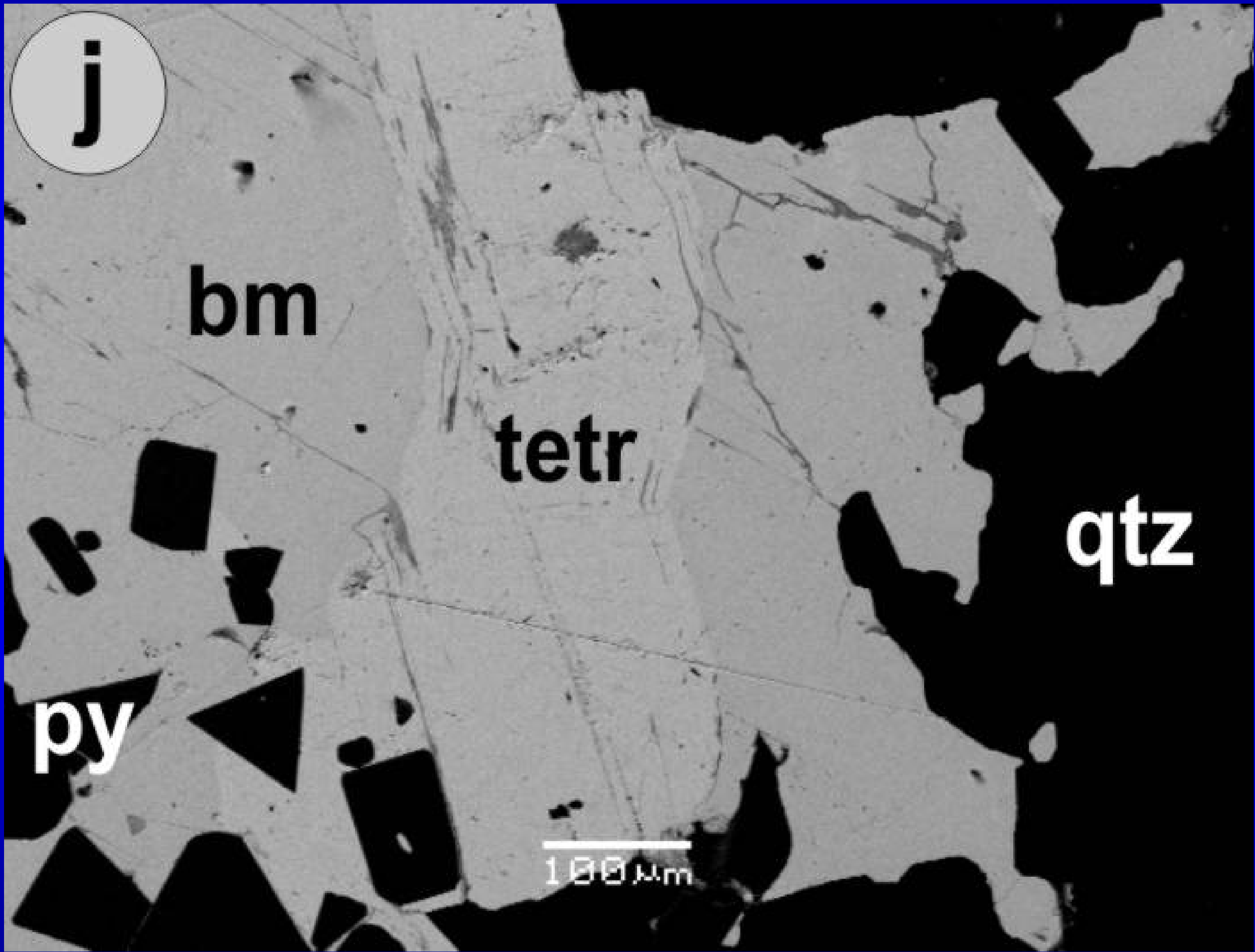


Melfos et al. (2008)

Chalkero/Kavala: Metamorphic rock-hosted quartz veins. Shear zone-related Au-Bi-Te mineralization

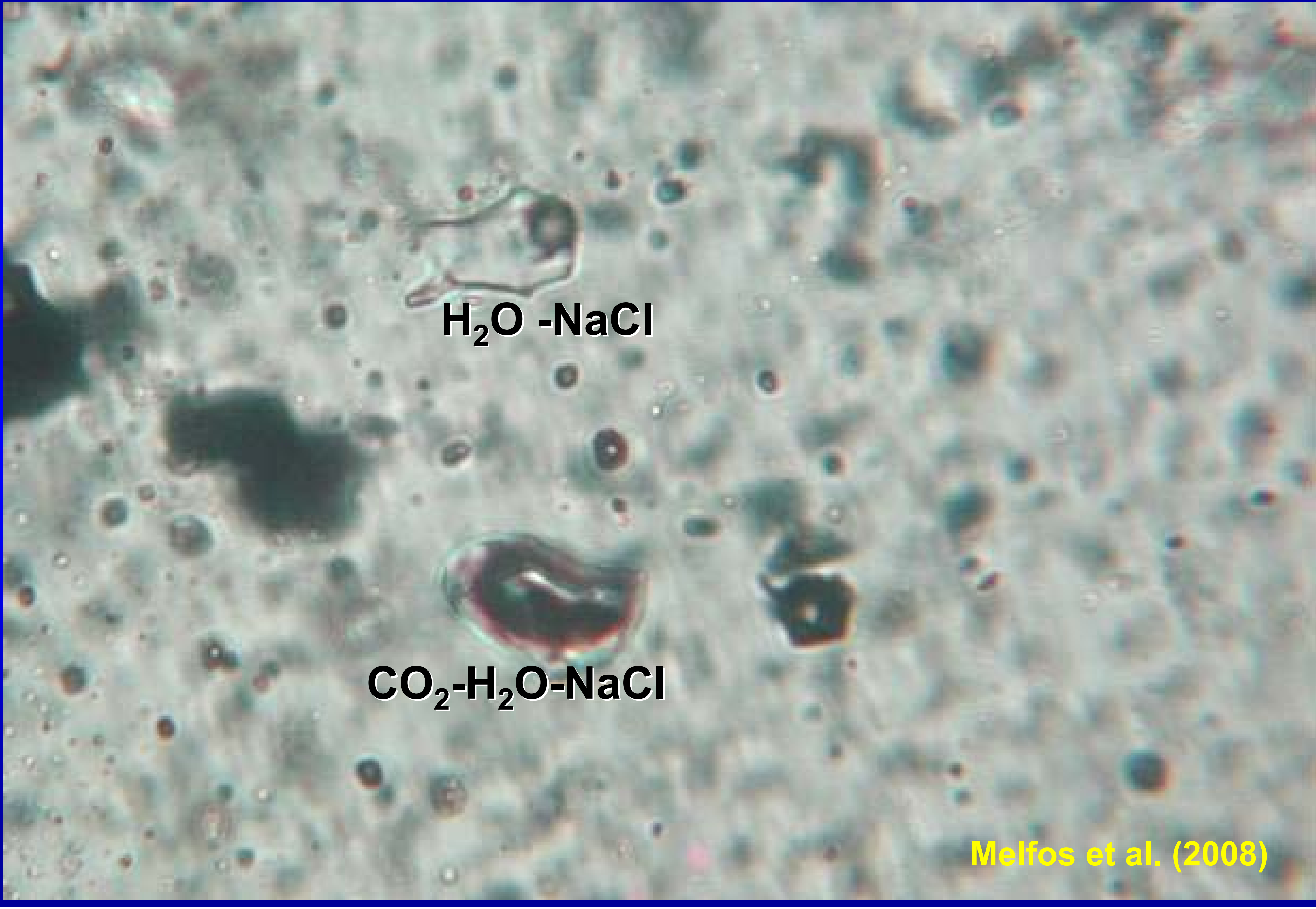
Chalkero/Kavala: shear-zone related quartz-tetradymite-Au

Chalkero/Kavala: tetradymite, bismuthinite



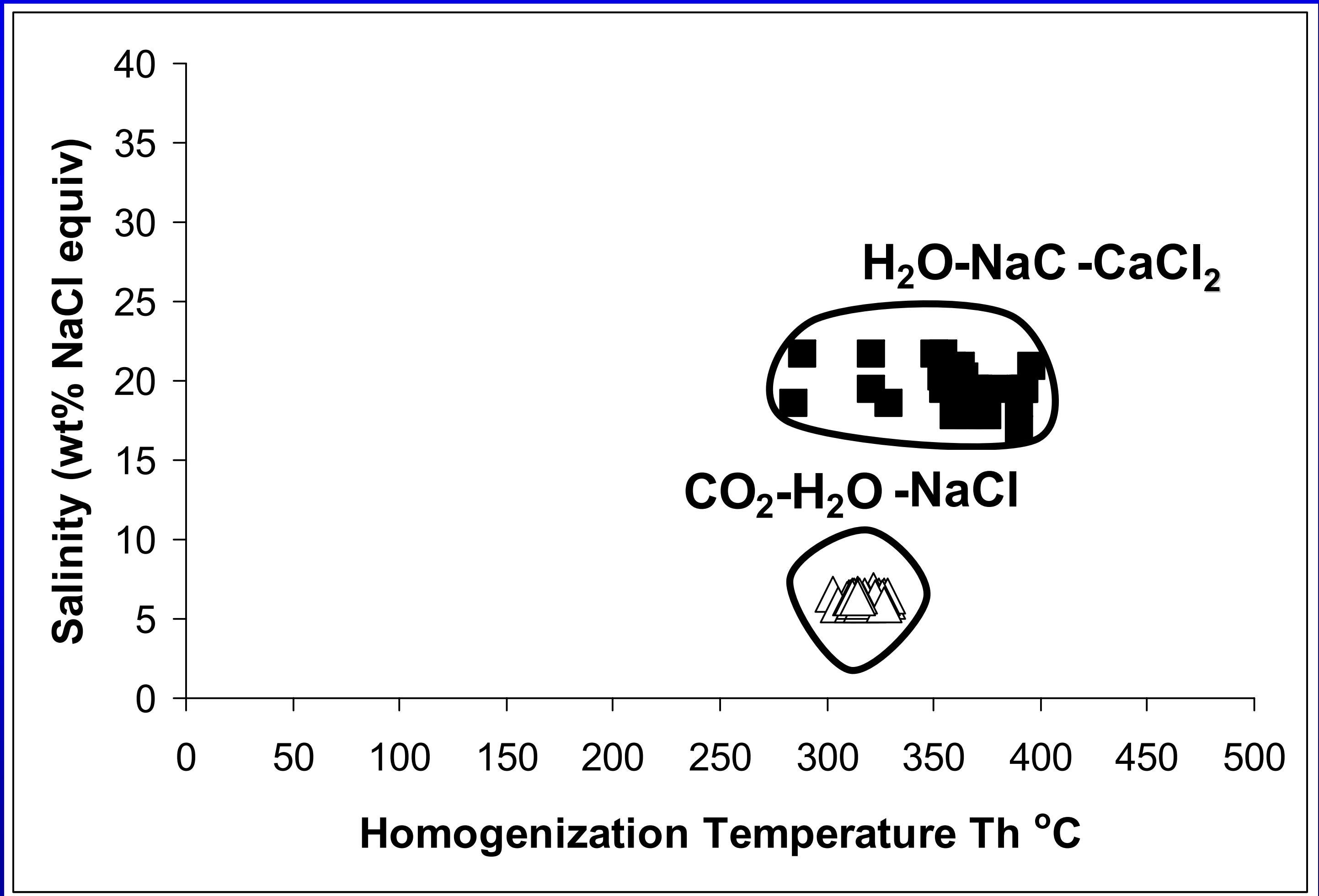
Palea Kavala: Carbonate rock-hosted oxidized Mn-Fe-Au mineralization

Kavala-Chalkero veins: Fluid inclusion study



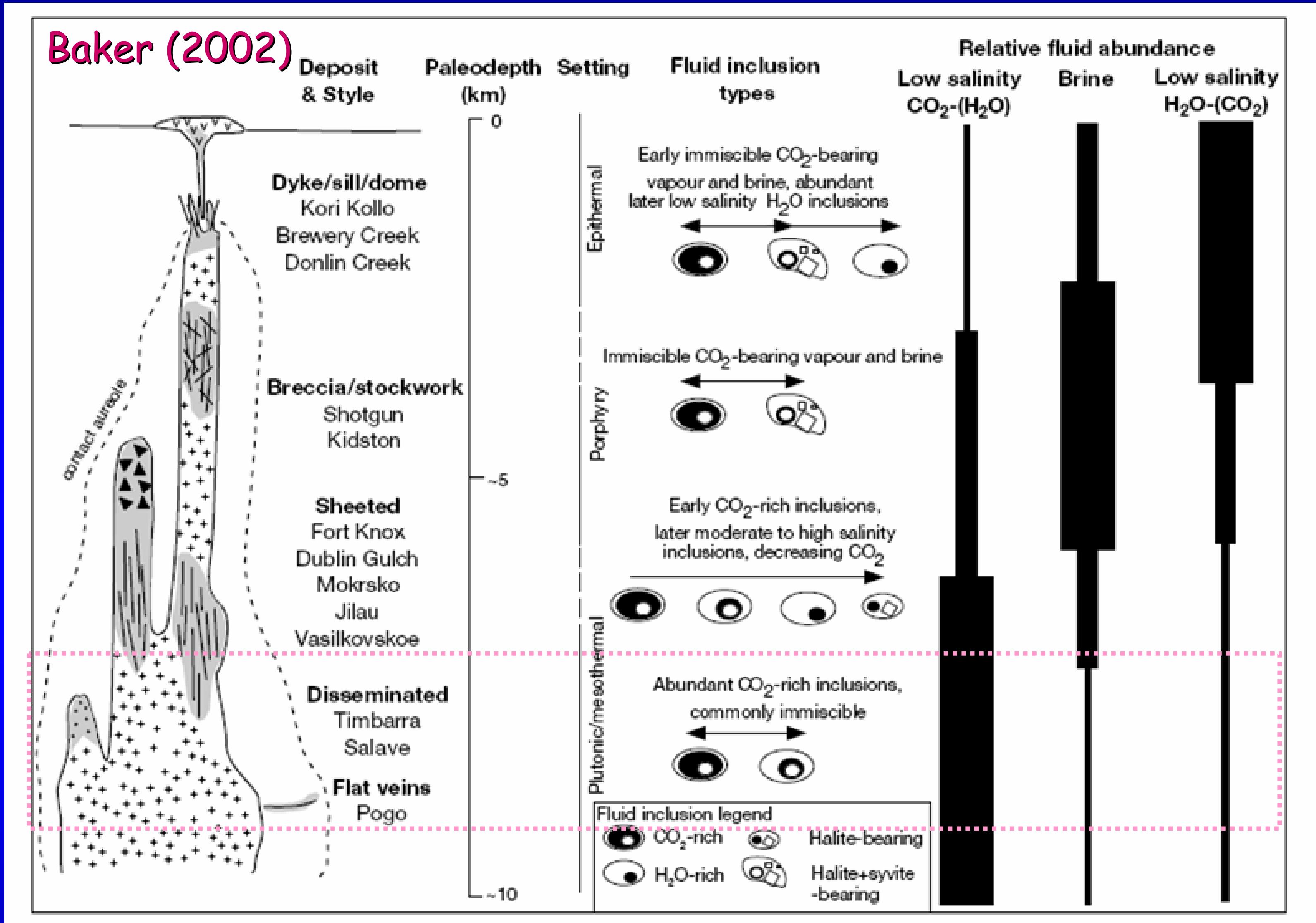
The fluid inclusion study shows that two immiscible fluids were present during entrapment:

1. CO_2-H_2O-NaCl fluid with low salinity (6-7 wt% NaCl equiv.) and
2. H_2O-NaCl-$CaCl_2$ fluid with moderate salinity (17-22 wt% NaCl equiv.)



Melfos et al. (2008)

Spry et al. (2010)

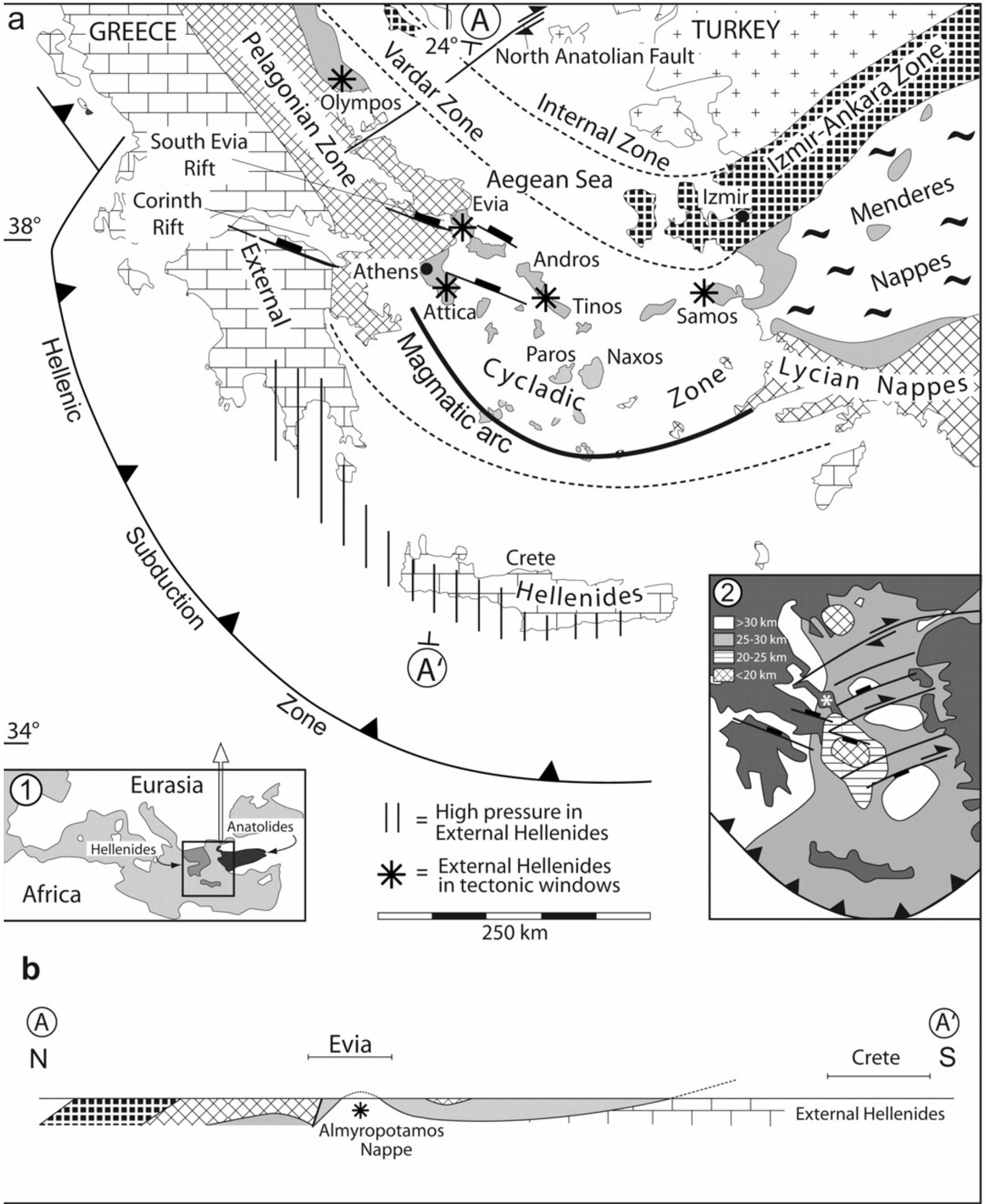


The Kavala ore deposit is characterized as a deep system, according to Baker's (2002) classification of the intrusion-related systems.

Melfos et al. (2008), Spry et al. (2010)

Lavrion intrusion-related deposit

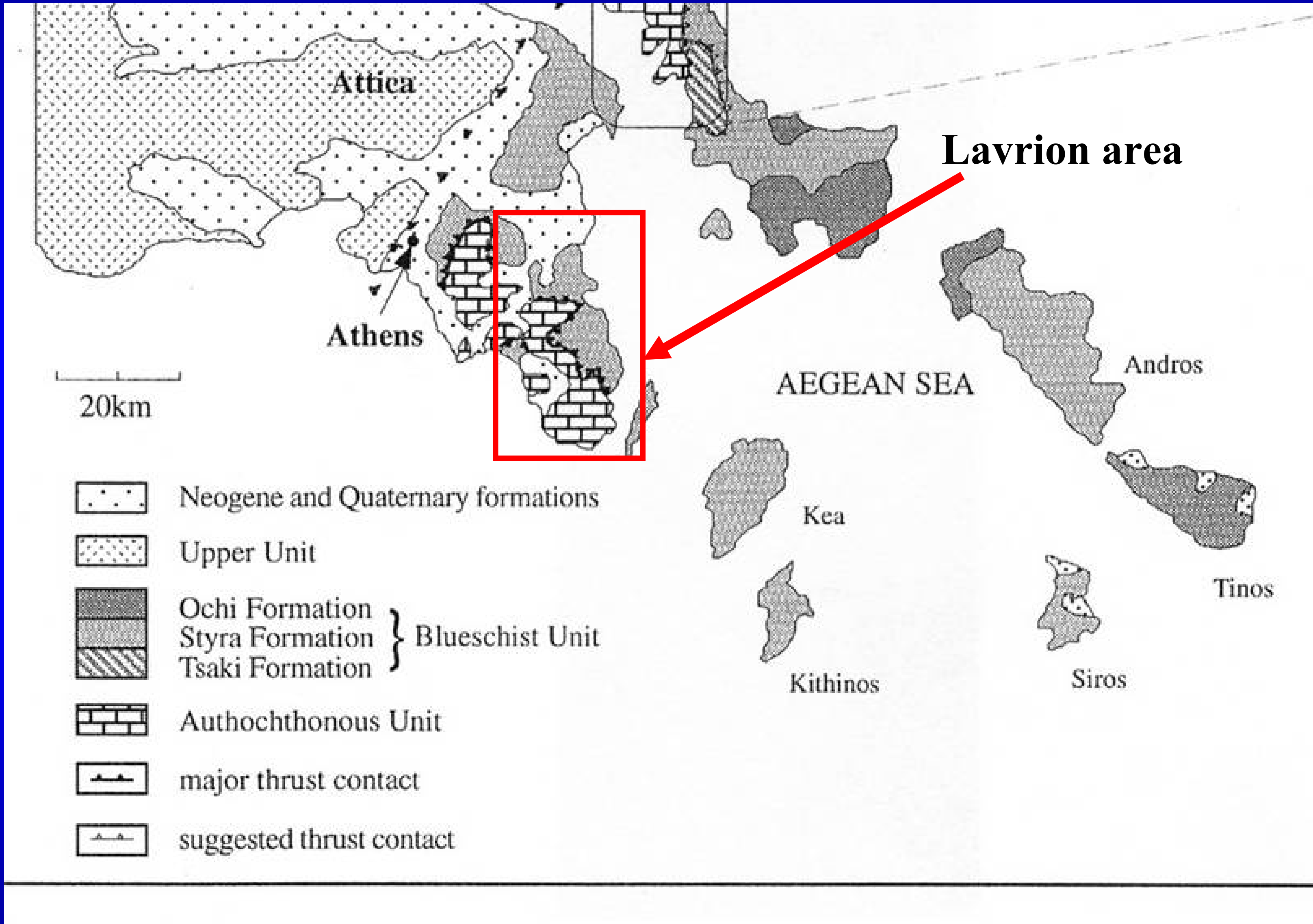
Intrusion-hosted sheeted Mo-W veins
Skarn W-Bi-Te
Manto Pb-Zn-Cu-Ag-Bi-Au
Vein-type Pb-As-Sb-Ag



Generalized tectonic map of the Aegean region showing major tectonic units and present-day position of the Hellenic subduction zone.

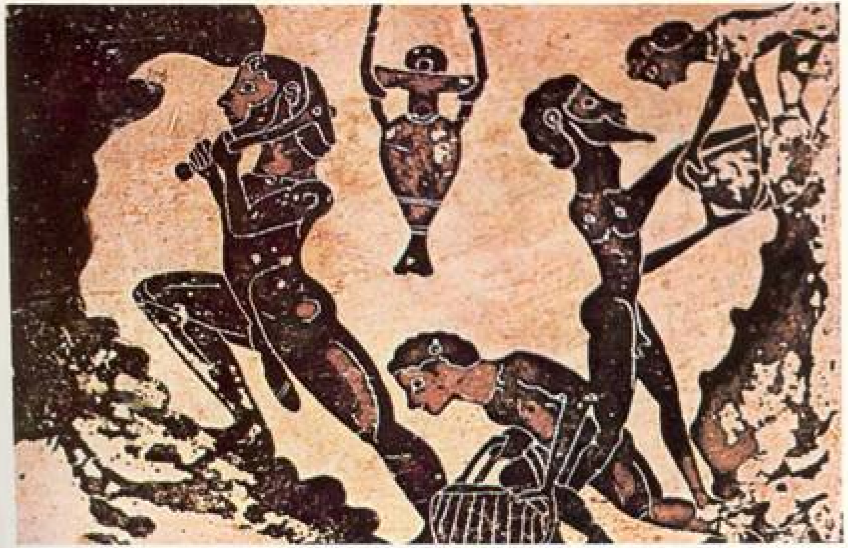
Ring et al. 2007

Lavrion: Regional Geology

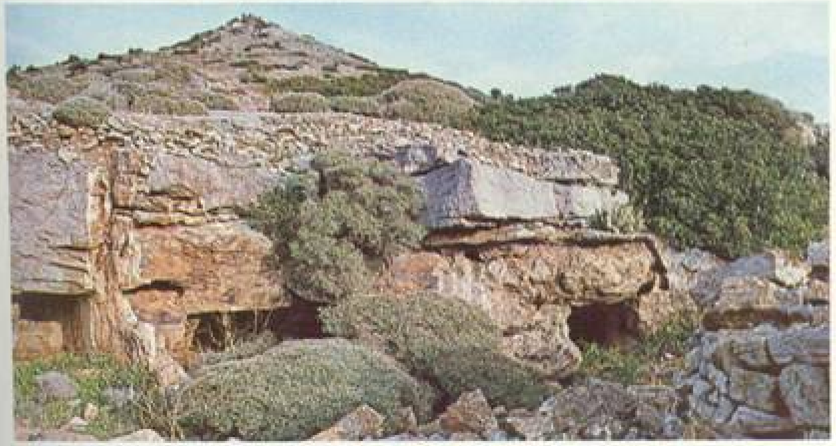


Shaked et al. 2000

Lavrion: History



9-6. Représentation d'une mine à une plaque antique du 5e siècle av. J.C. Trouvé près de Corinthe. Mus. Berlin est.

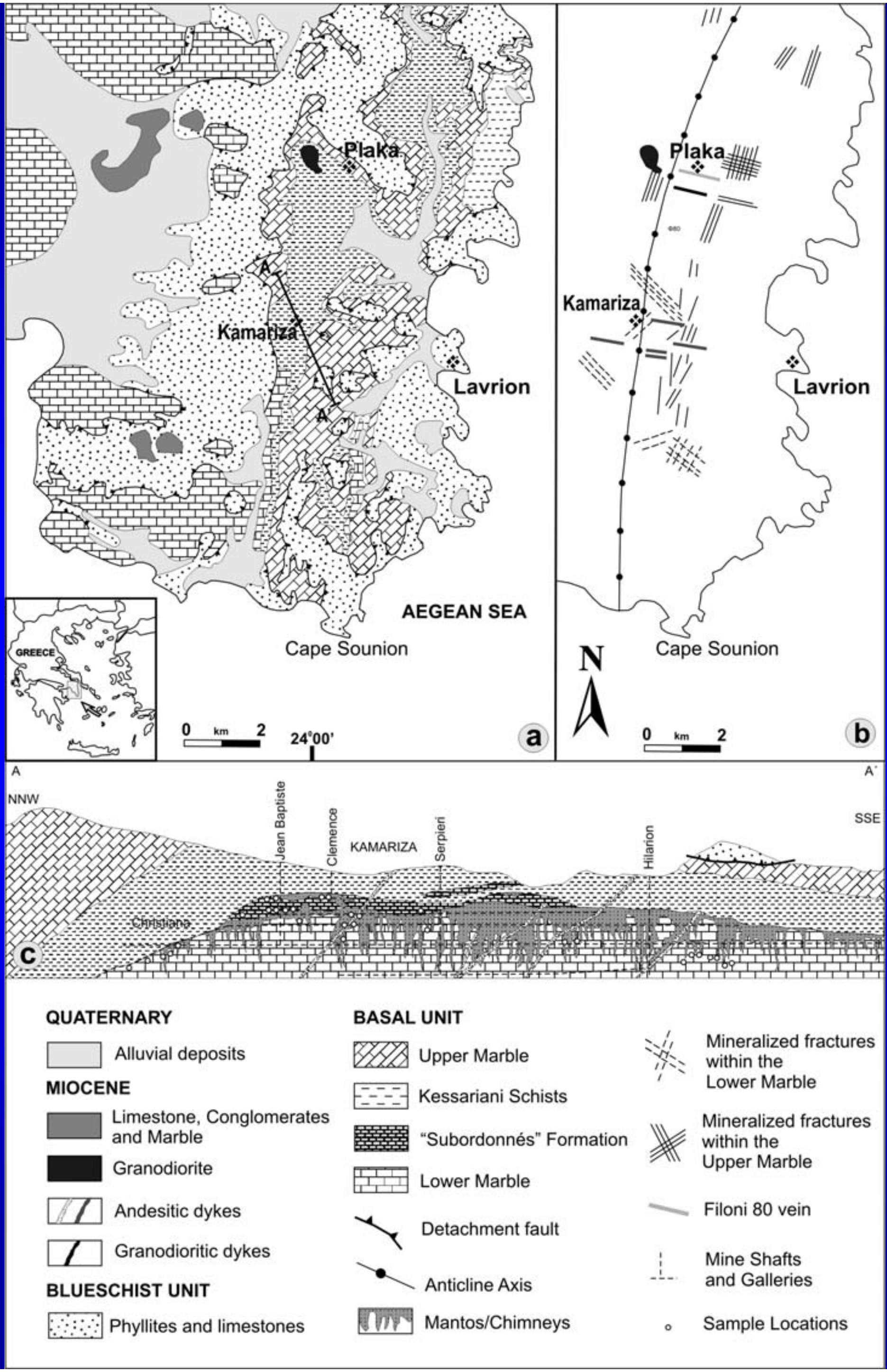


9-7. Thoricos. La colline de Vélatouri. Entrée au 1er contact par une galerie.

- **From earlier than 1000 B.C up to 1980 famous for the silver and base metal production**
  - **3500 tones of Ag and 1.4 Mt Pb production during ancient times. In modern times 0.92 Mt of Ag-rich Pb**
  - **More than 1000 shafts and underground working with a total length of more than 2000 km**

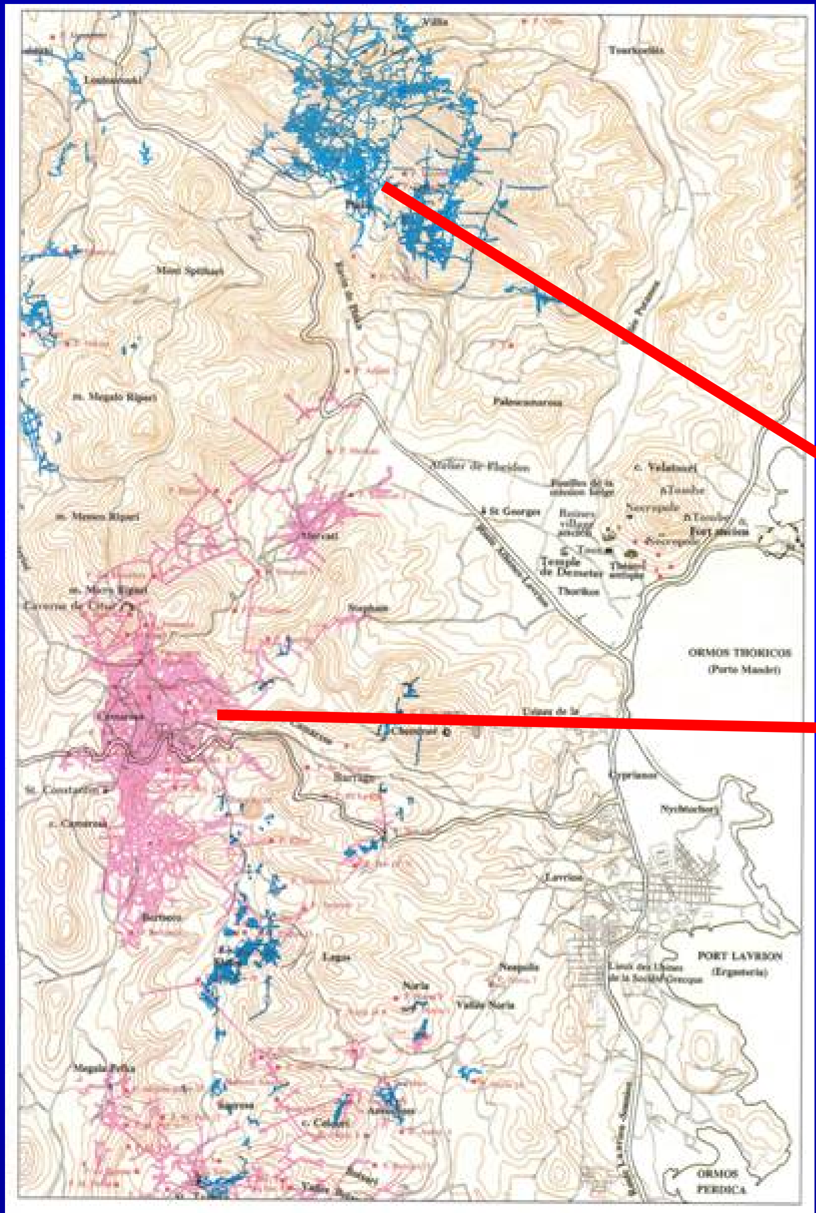
Conophagos (1980)

Regional geology



Voudouris et al. (2008b) modified after Marinos and Petrachek 1956

Metalliferous contacts



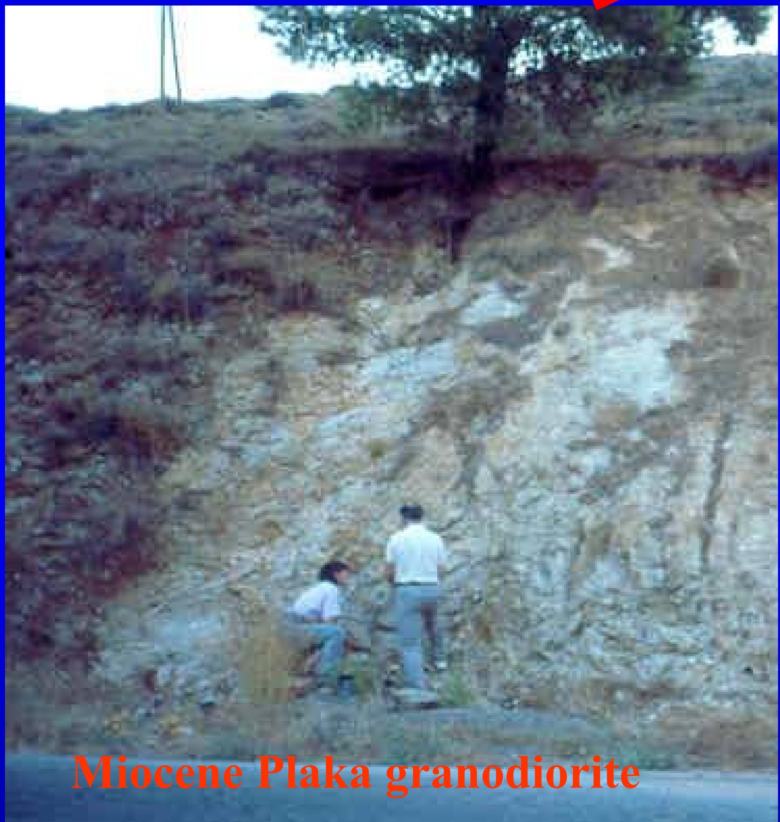
The majority of the ores of Lavrion occur mainly within the autochthon system, particularly at the contacts of the marbles with the schists.

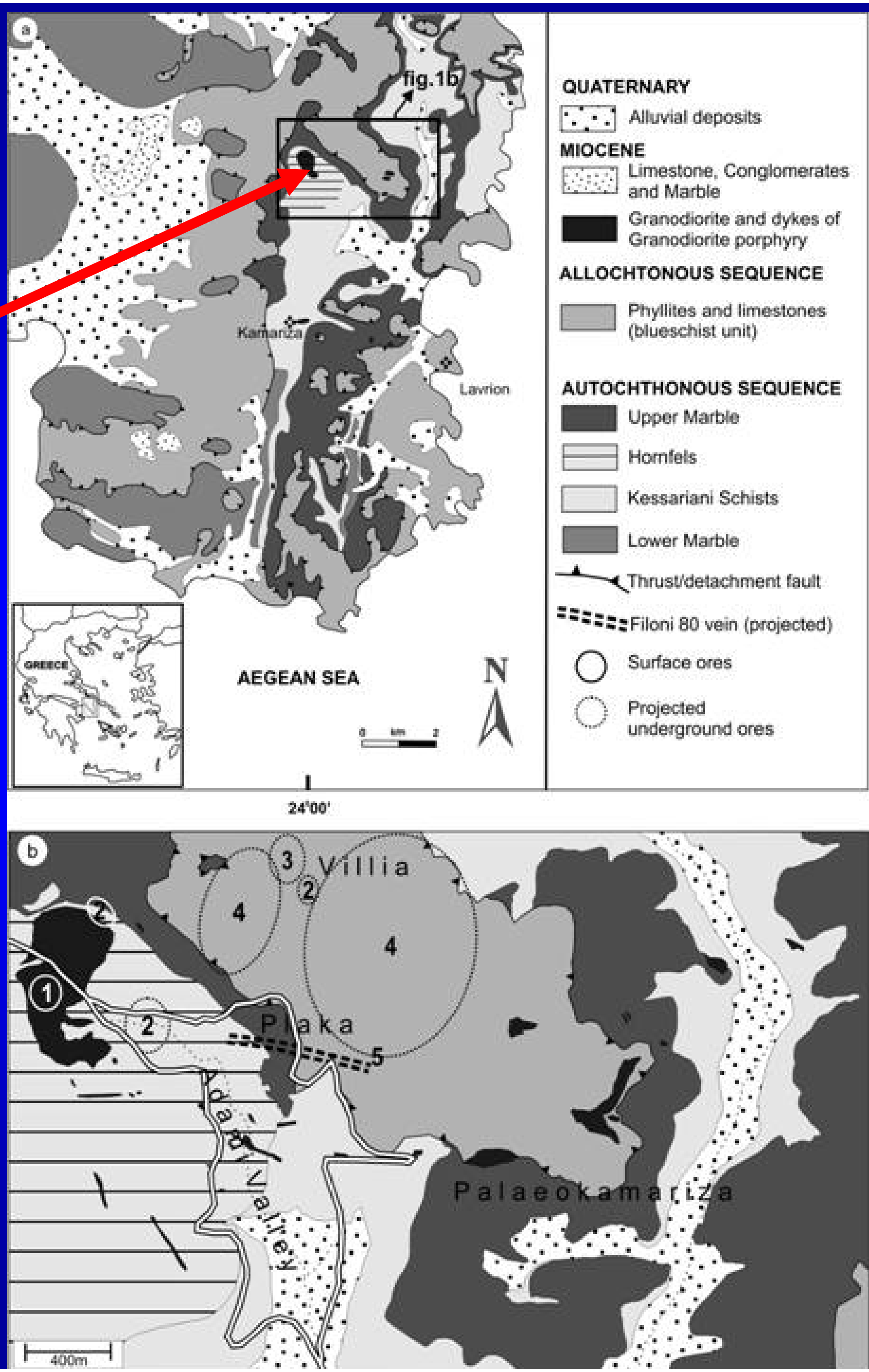
Plaka: Galleries along the contacts I and II

Kamariza: Galleries along the contact III

Conophagos (1980)

Plaka area, geology

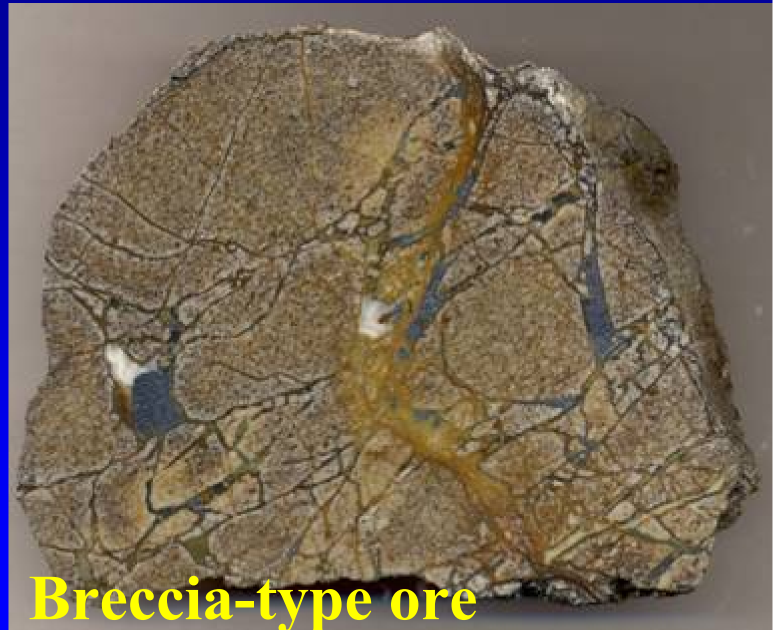




Voudouris et al. (2008a)

Plaka deposit

Granodiorite-hosted Mo-W ore



Breccia-type ore

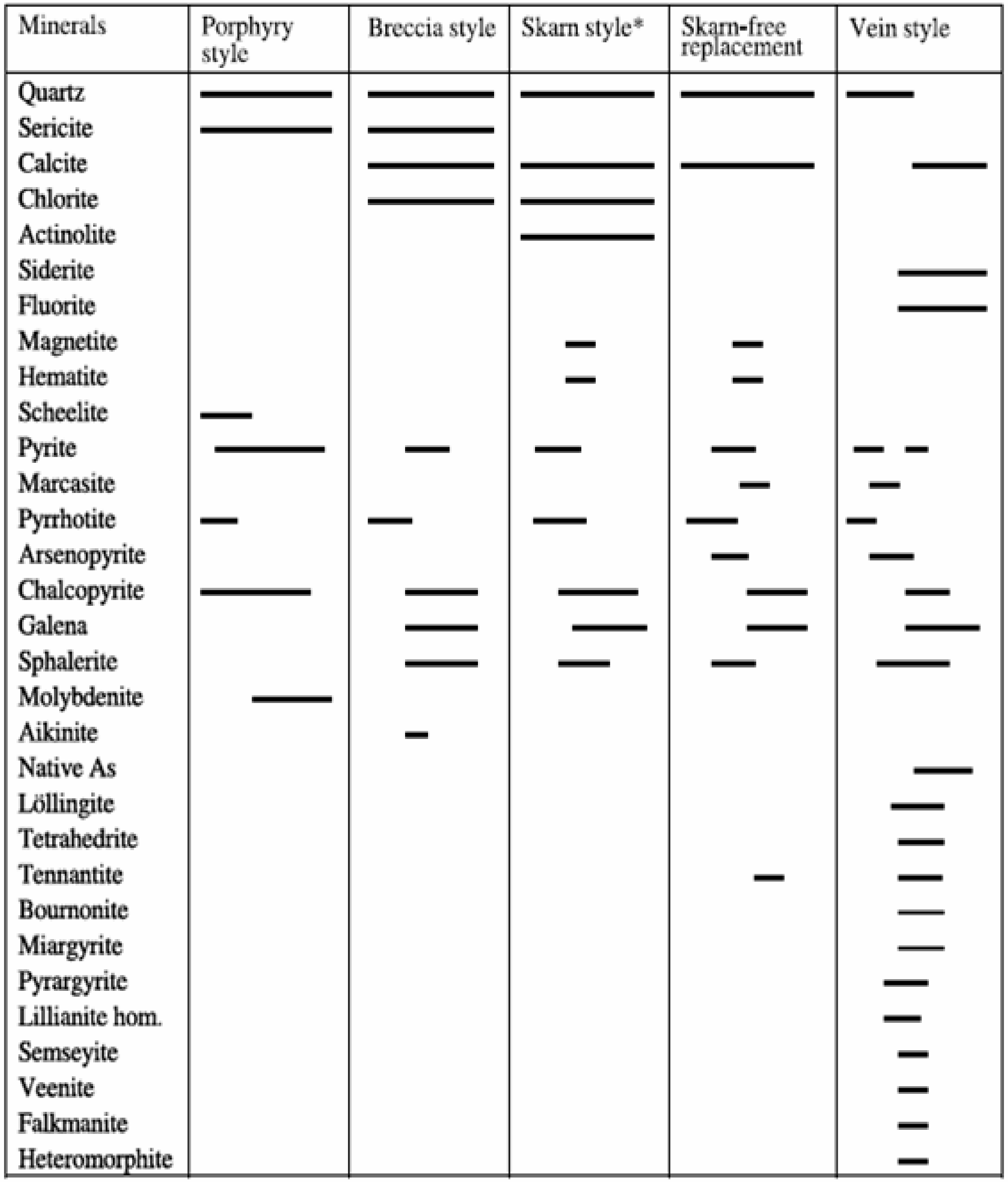
Skarn-type ore

Skarn-type ore

Plaka deposit

Plaka deposit

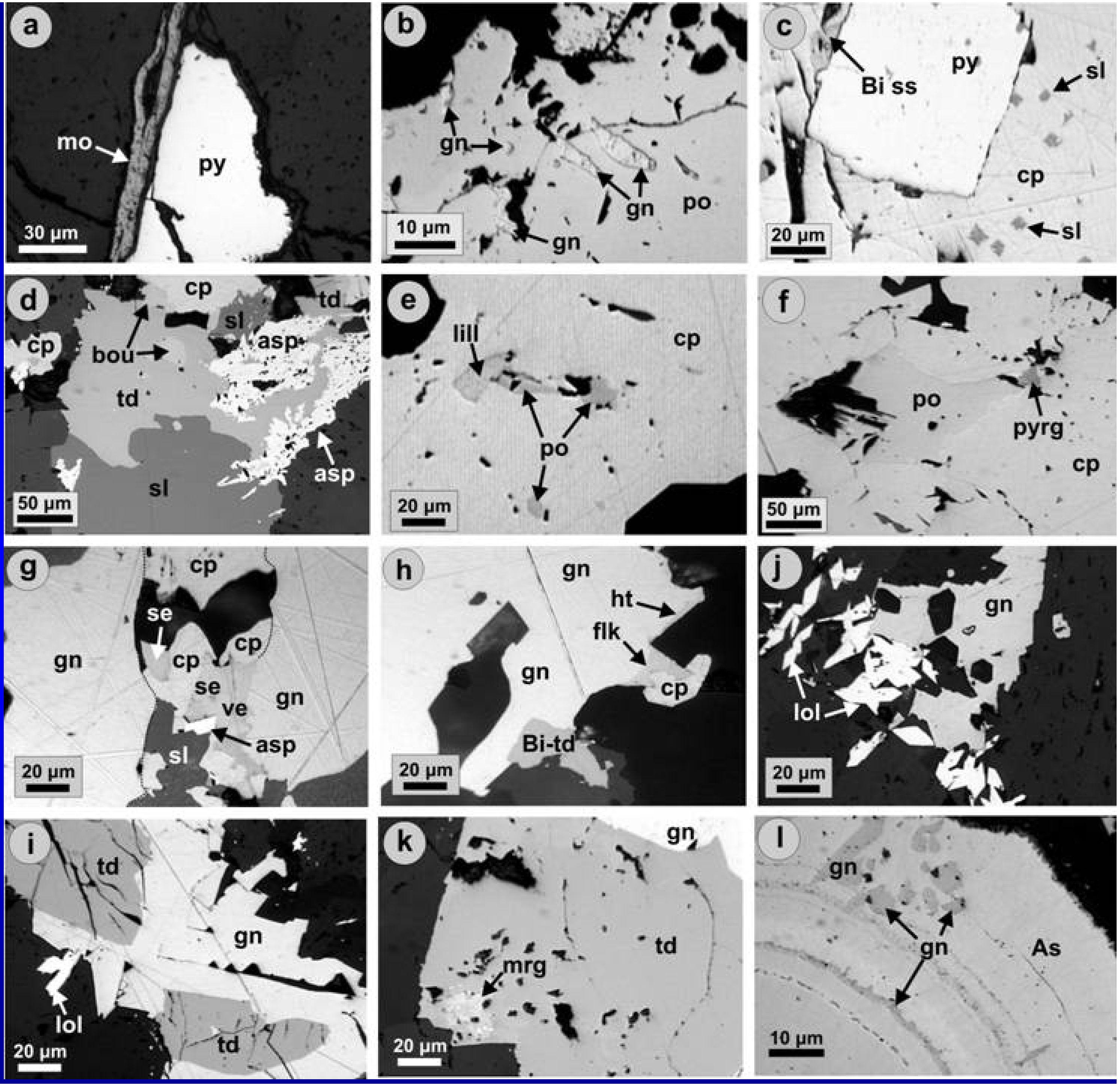
Table 1. *Paragenetic sequence of ore and alteration minerals in the Plaka polymetallic deposit*



*Only retrograde stage

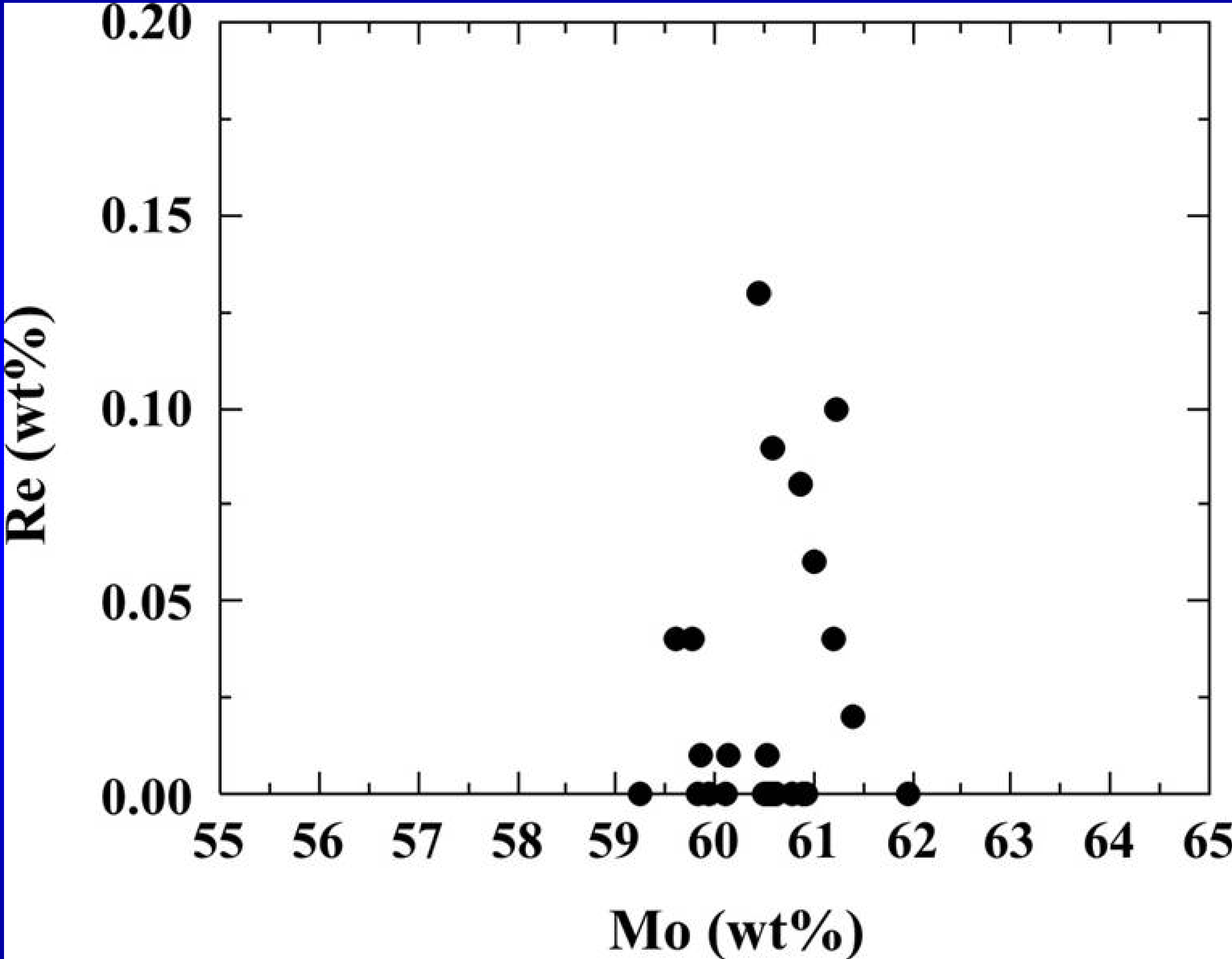
Voudouris et al. (2008a)

Plaka deposit



Voudouris et al. (2008a)

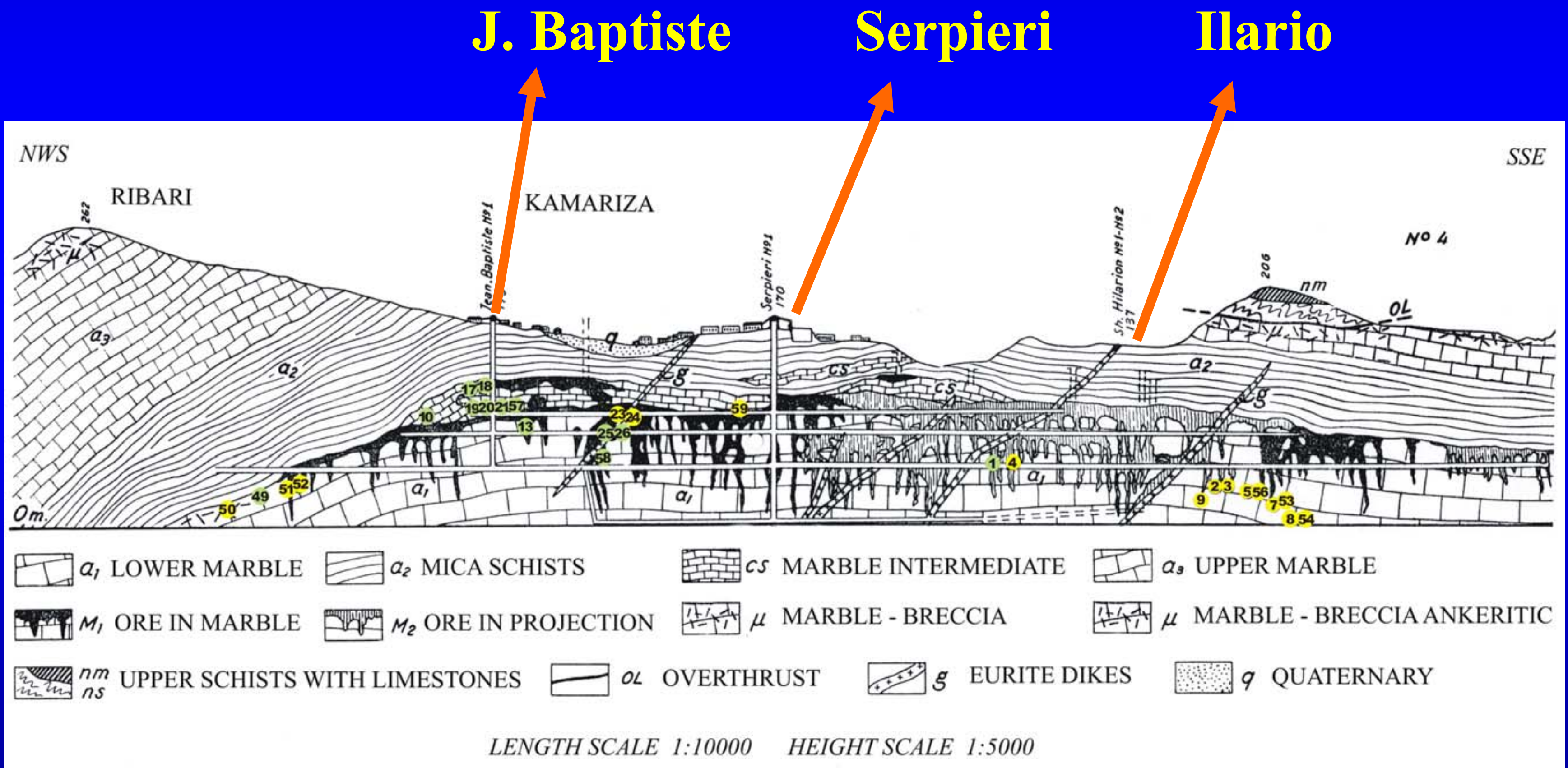
Plaka deposit: Re-free molybdenites



Voudouris et al. (2008a)

Kamariza deposit

Distal from Plaka granodiorite. Manto and chimney-type Pb-Zn-Ag-Cu-Au ore deposition in III contact



Kamariza cross-section modified after Marinos & Petraschek (1956)

Kamariza deposit - Intrusives

Propylitic alteration

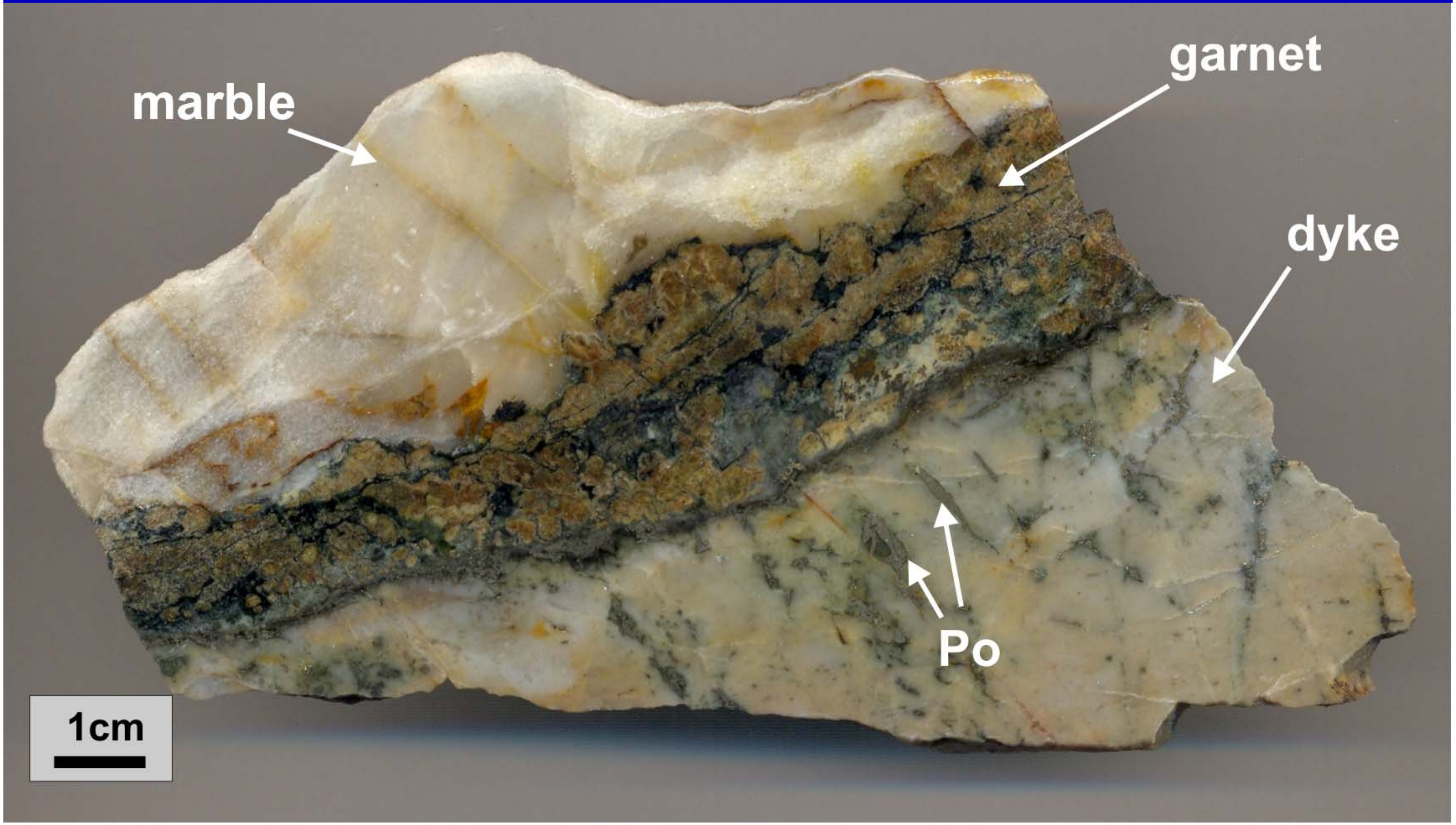
Sericite-kaolinite-carbonates

Porphyritic dikes of andesitic and dacitic composition are common in the Ilario and Jean Baptiste mines.

The dikes are subvertical, stricking E-W and crosscut the autochthonous system.

Most of the dikes are hydrothermaly altered.

Kamariza deposit
first occurrence of skarn mineralization

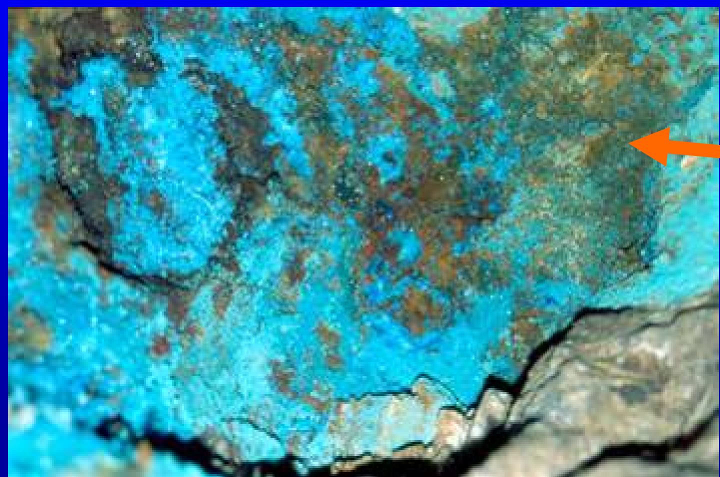


Kamariza deposit: massive sulfide mantos and vein-type ores. Quartz-fluorite-carbonate gangues

Massive sulfide ore

Galena-rich ore

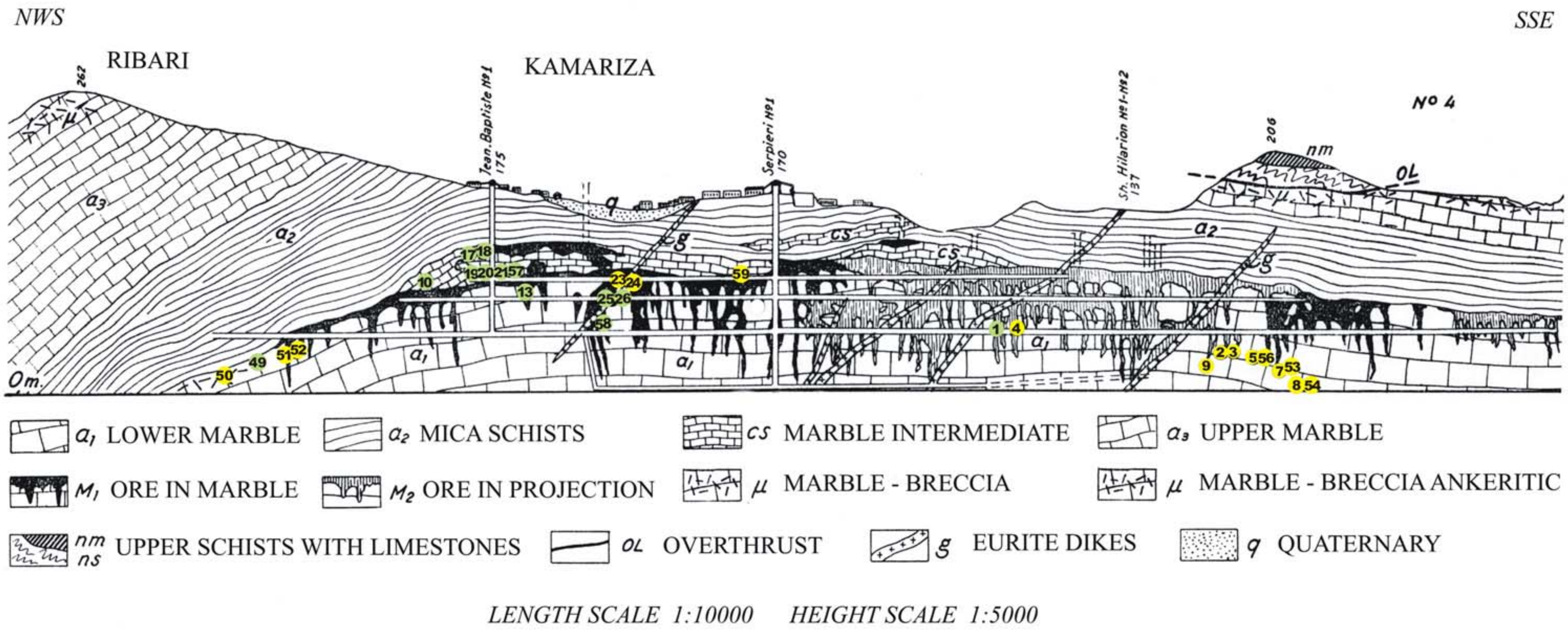
Vein-type Cu-rich ore



Cu-rich ore

Bulk ore analyses

All the samples are characterized by high contents of As (>10000 ppm), and Sb (up to 3650 ppm), and relatively high contents of Bi (up to 300 ppm) and Sn (up to 520 ppm). Te (up to 3.4ppm) and Se (up to 1.8ppm) were also detected (Voudouris & Economou-Eliopoulos 2003)



Kamariza cross-section modified after Marinos & Petraschek (1956)

Paragenetic Sequence

The textural features of the ore indicate that early formed pyrite is followed by :

Fe-rich sphalerite, arsenopyrite and then by a

copper-rich assemblage composed of:

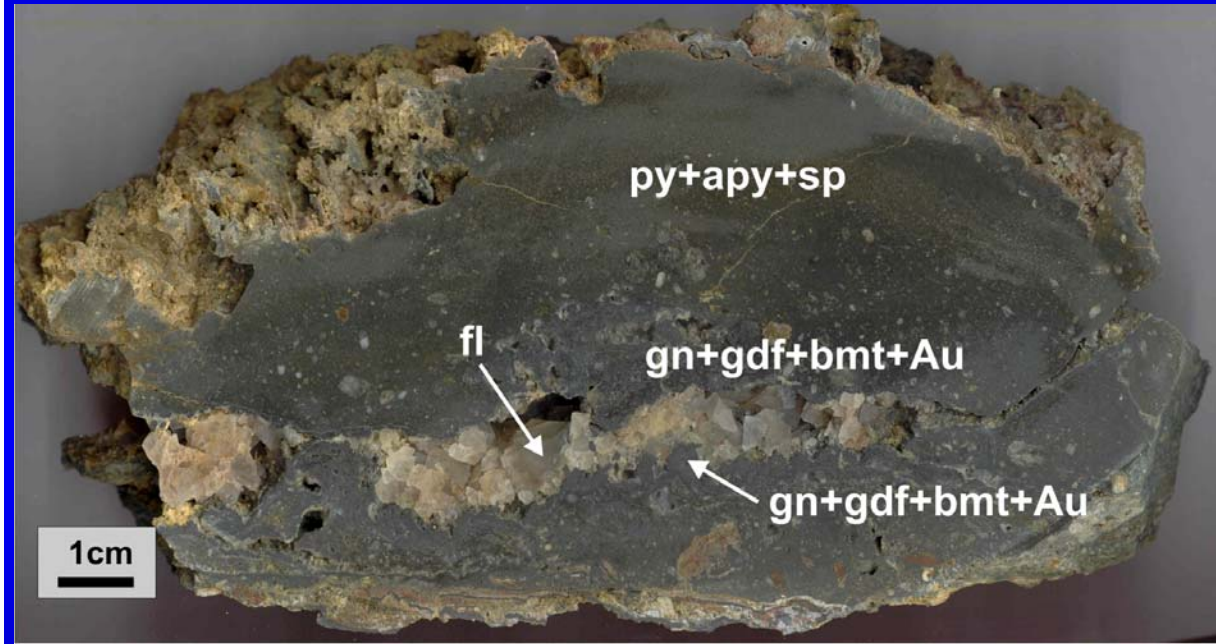
- chalcopyrite
- low-Fe sphalerite
- enargite
- tetrahedrite series minerals
- Bi-Cu-Pb-Ag-sulfosalts
- galena
- native gold
- gersdorfite
- petrukite

Table 1 Paragenetic sequence of ore and gangue minerals in various carbonate replacement deposits in the Kamariza area

Minerals	Stage I	Stage II	Stage III
Quartz	—	—	
Carbonates		—	—
Sericite	—		
Fluorite		—	—
Pyrite	—	—	—
Pyrrhotite		—	
Arsenopyrite	—		
Chalcopyrite		—	
Galena	—	—	—
Sphalerite	—	—	
Tetrahedrite		—	
Tennantite		—	
Enargite/Luzonite		—	
Covellite		—	
Cu-matildite		—	
Gersdorffite		—	
Bismuthinite		—	
Native Au		—	
Sb-bismuthinite		—	
Native Bi		—	
Lillianite-hom		—	
Petrukite		—	
Wittichenite		—	
Emplectite		—	
Aikinite		—	
Mummeite		—	
Ag-Cu-Bi ss		—	
Bournonite		—	
Semseyite		—	
Boulangerite		—	
Stephanite			—
Pyrargyrite			—
Ramdohrite			—

hom homologues, *ss* sulfosalt

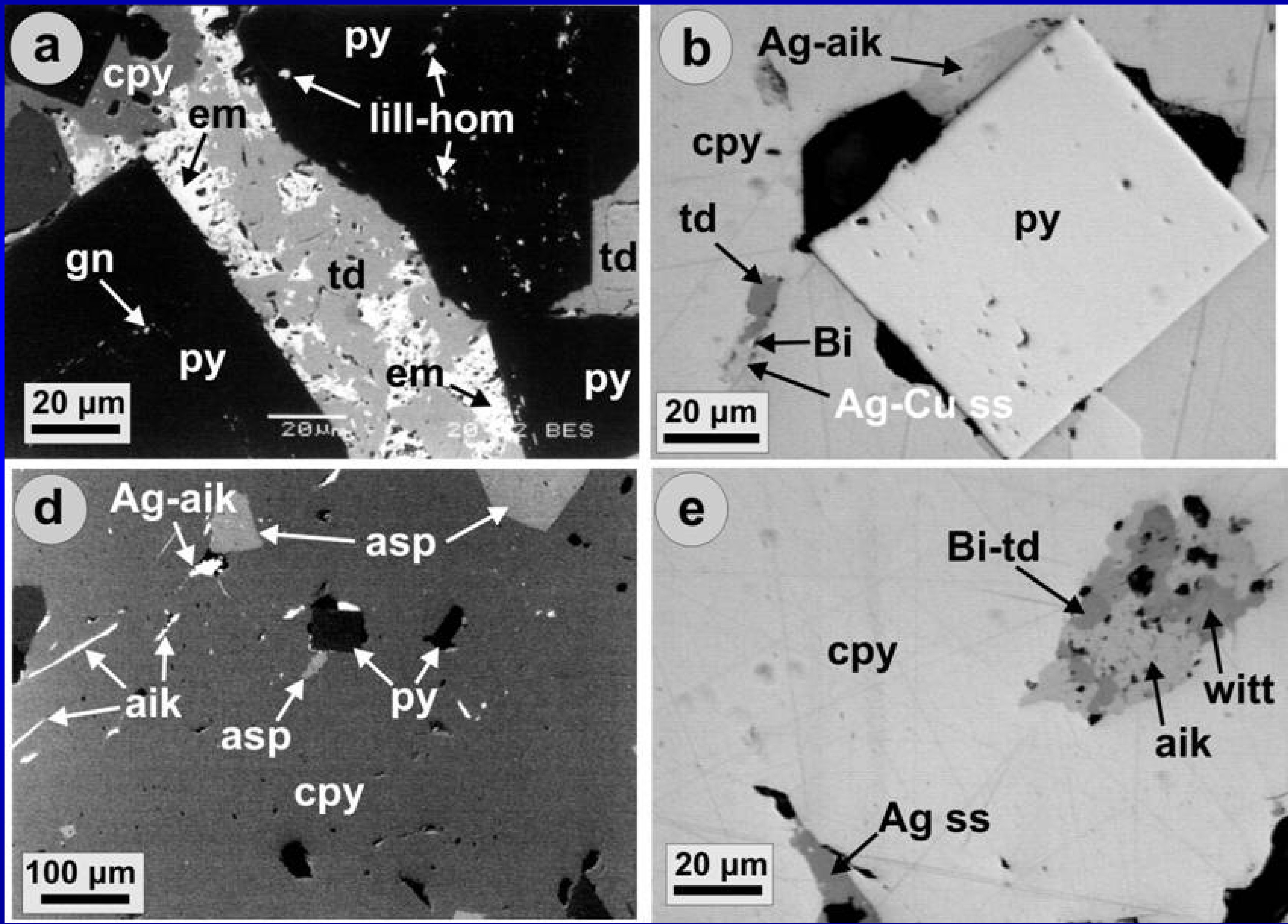
Paragenetic Sequence



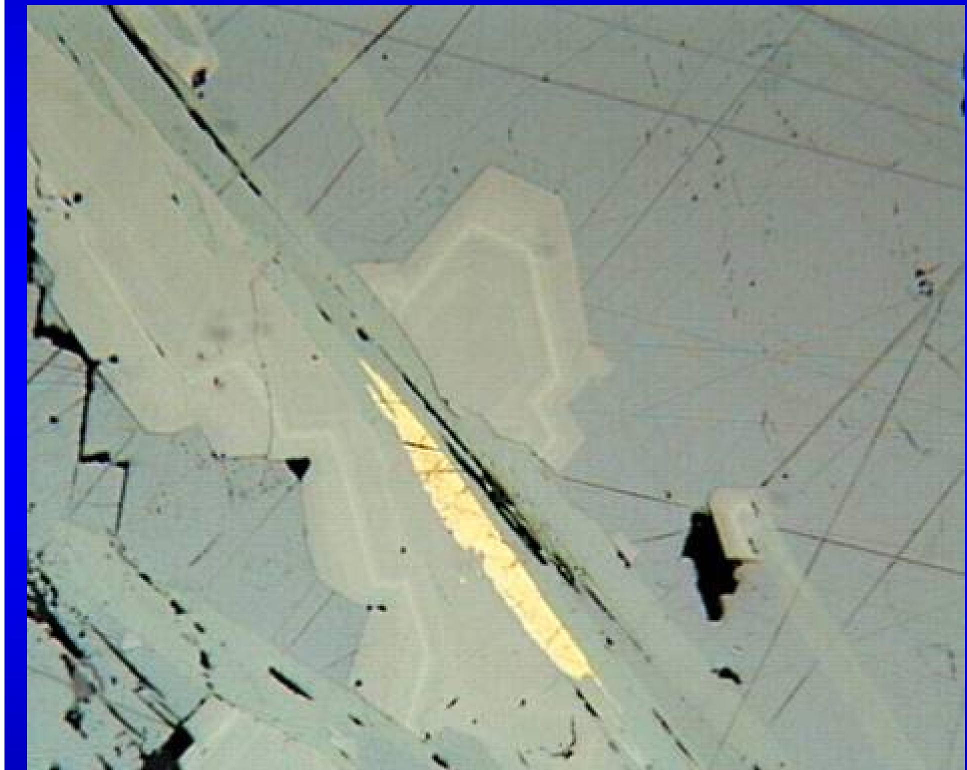
Vein-type Au-Bi-Ni ore

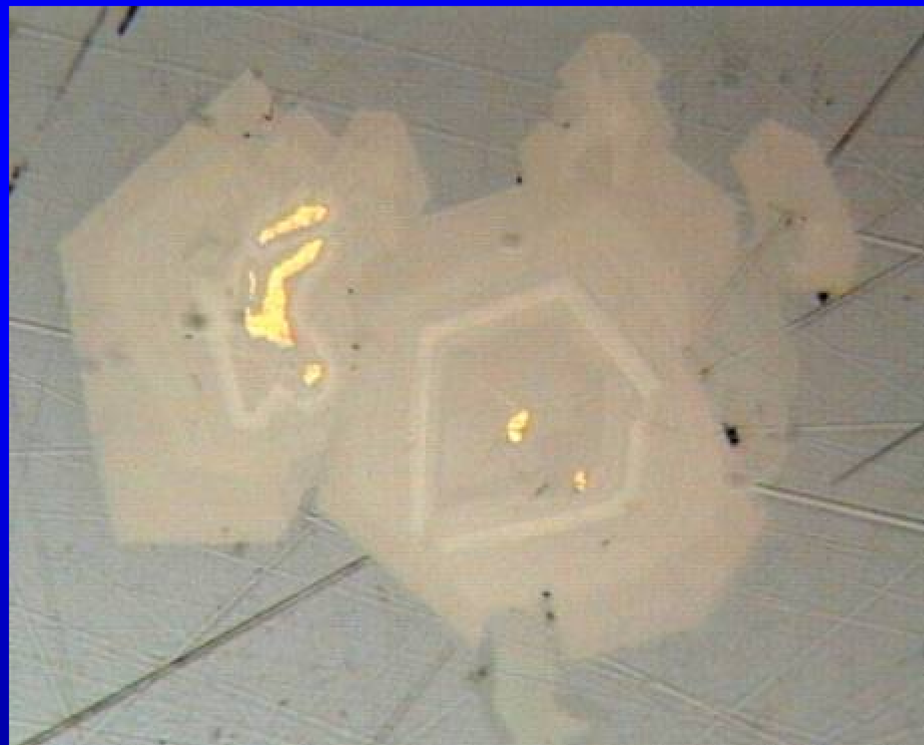
Voudouris et al. (2008b)

Kamariza/Lavrion deposit

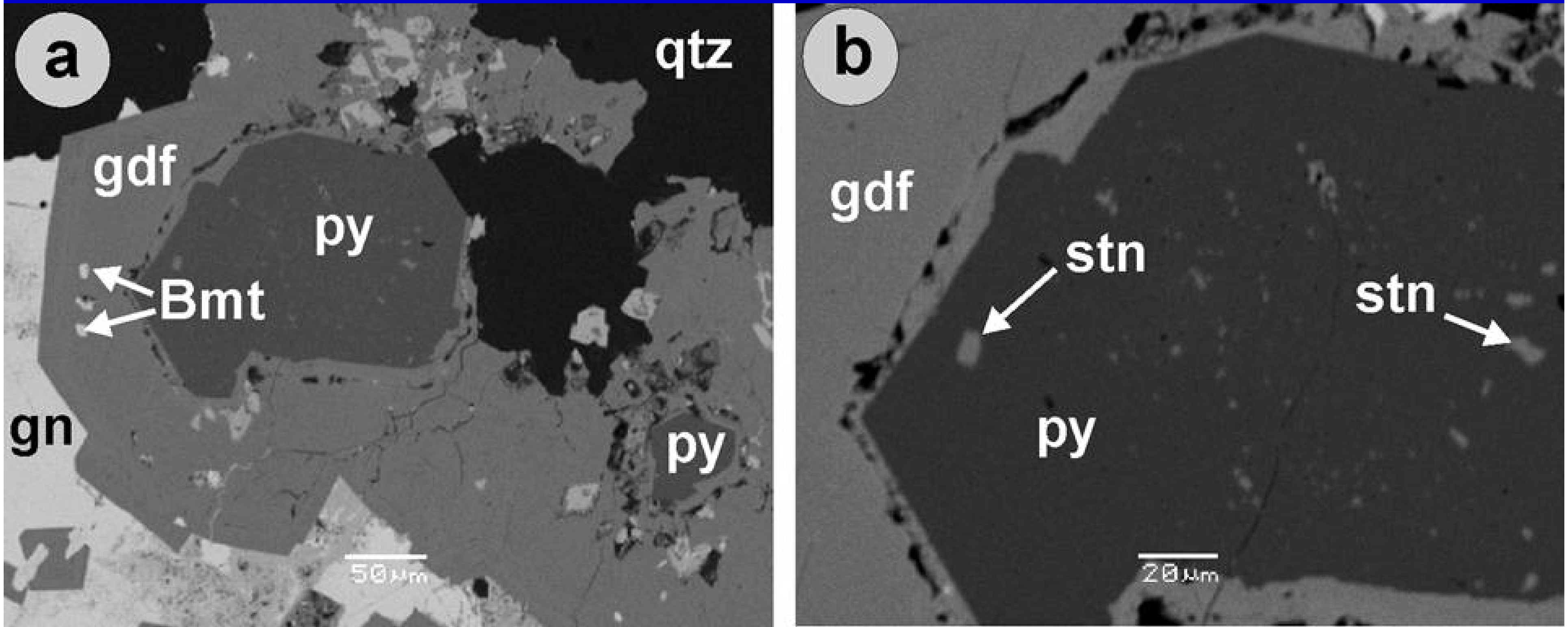


Kamariza deposit: Bismuthinite, native gold, gersdorffite included in galena

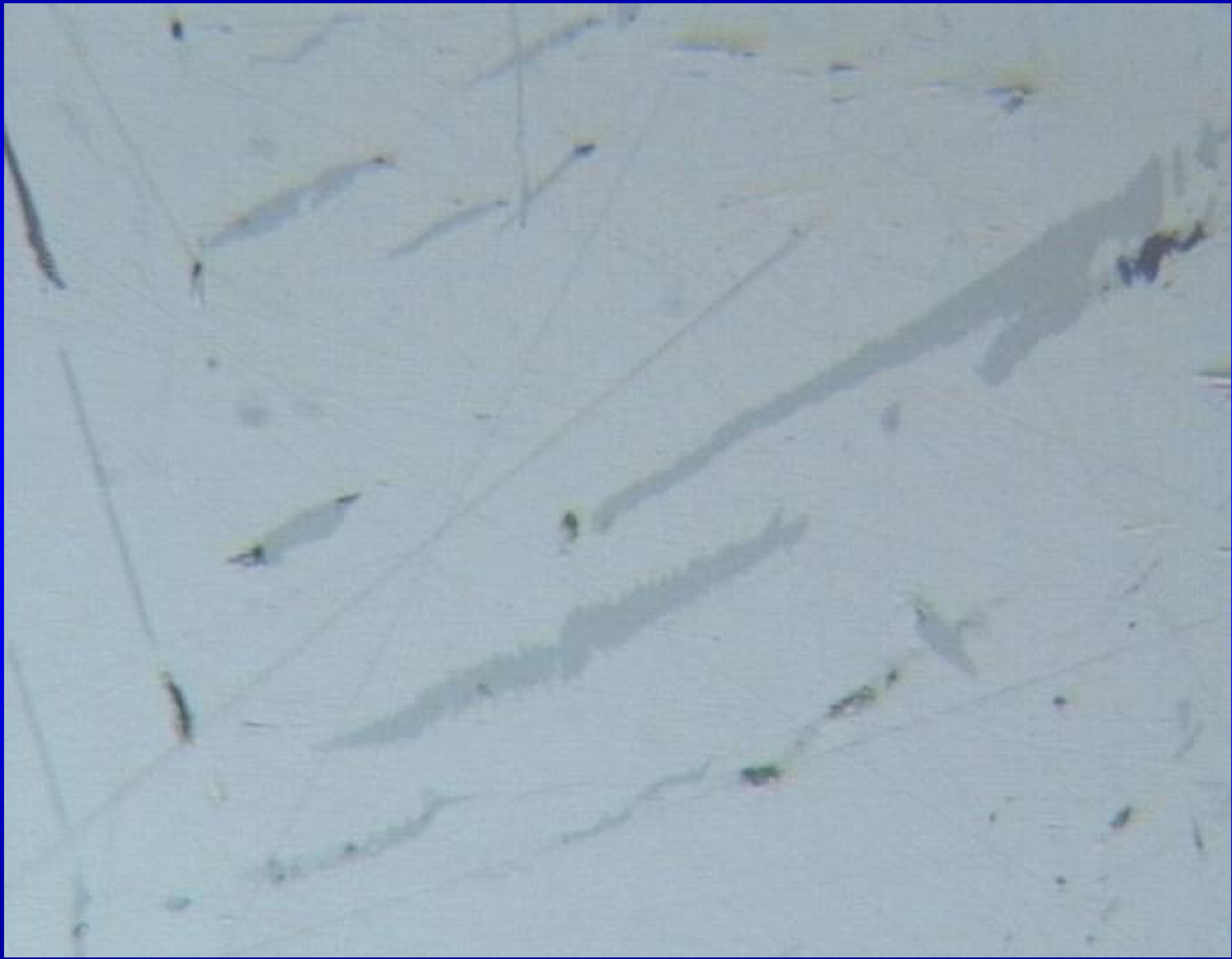




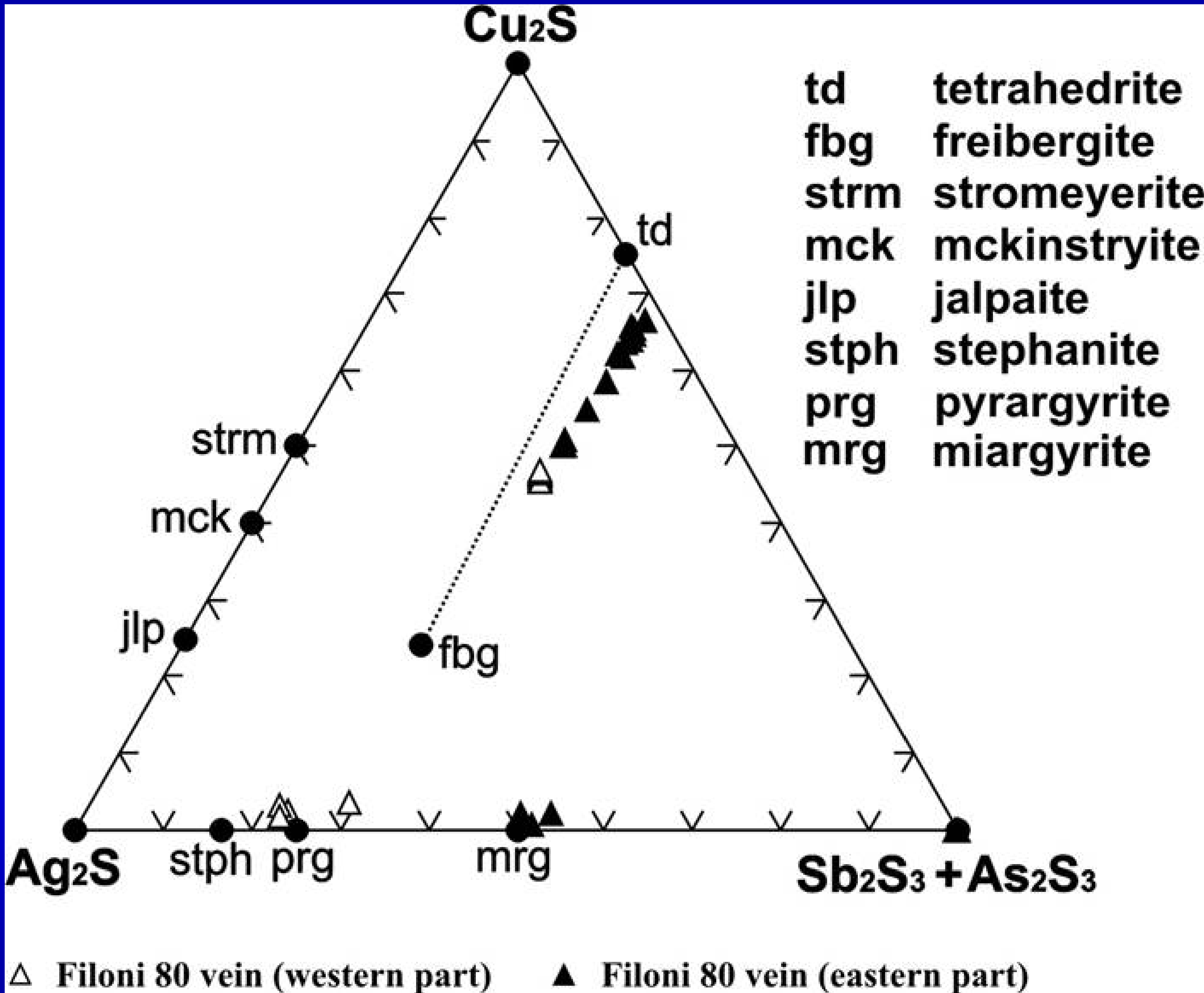
Kamariza deposit: Stannite included in pyrite



Kamariza deposit: Stephanite included in galena

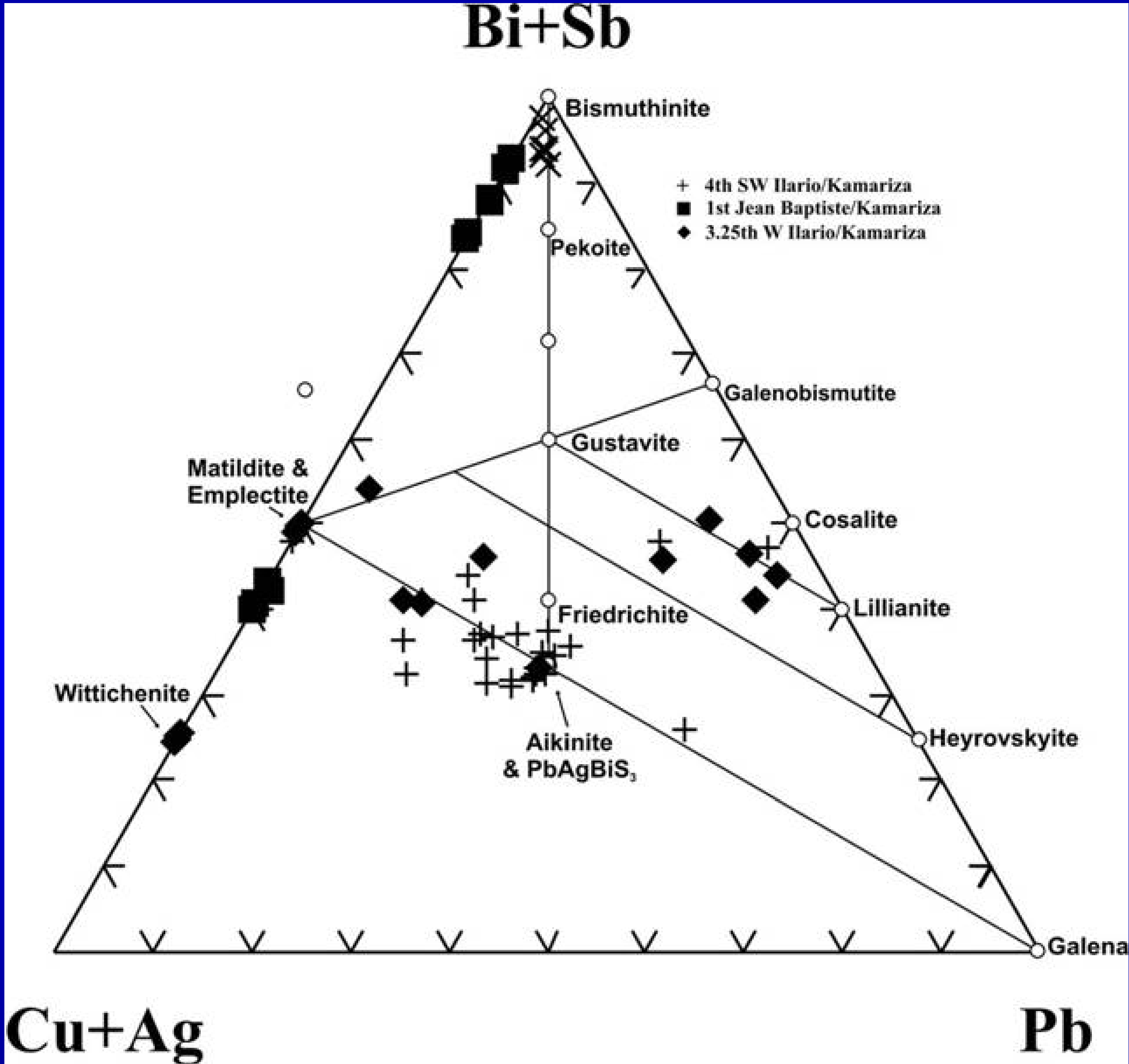


Plaka deposit



Voudouris et al. (2008a)

Kamariza deposit



Voudouris et al. (2008b)

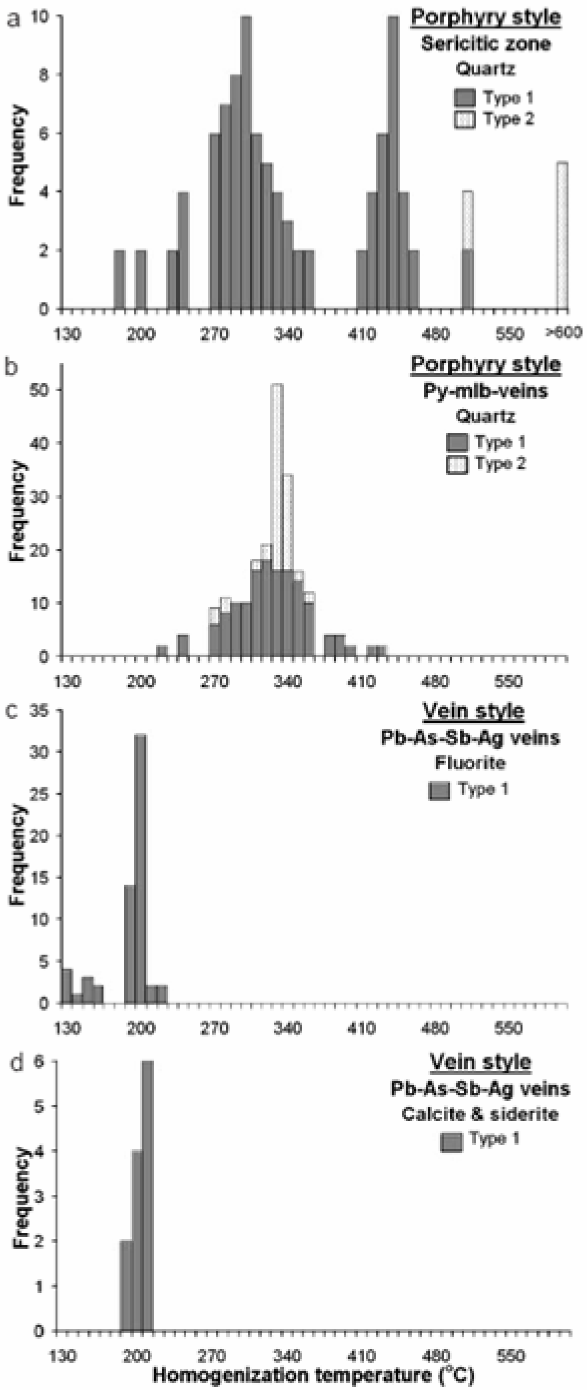
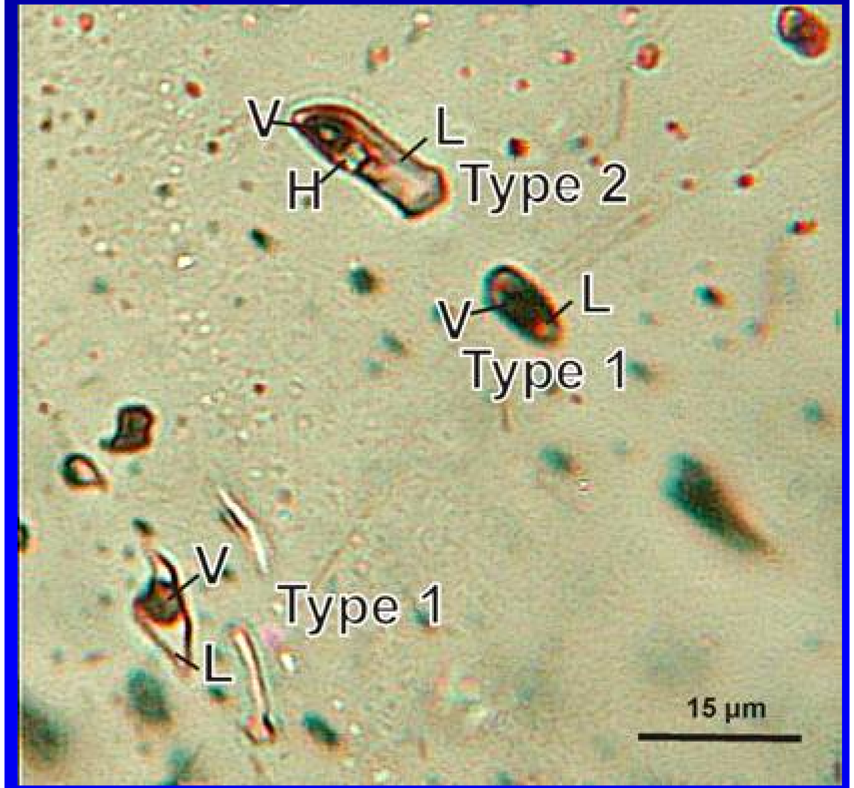


Fig. 9. Homogenization temperatures of fluid inclusions from the Plaka/Lavrion porphyry- and vein-style mineralizations. *Type 1* two-phase liquid-rich aqueous inclusions. *Type 2* three-phase halite-bearing liquid-rich inclusions. *Py* pyrite, *mlb* molybdenite

Plaka deposit



Voudouris et al. (2008a)

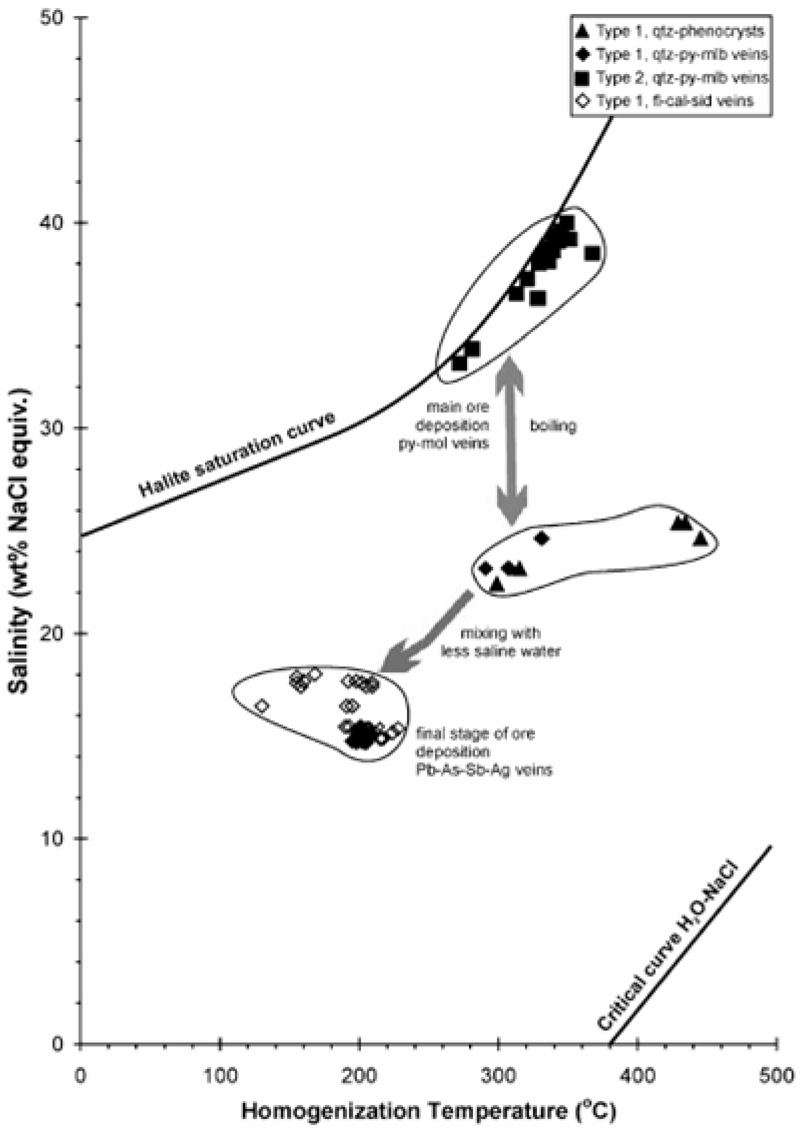
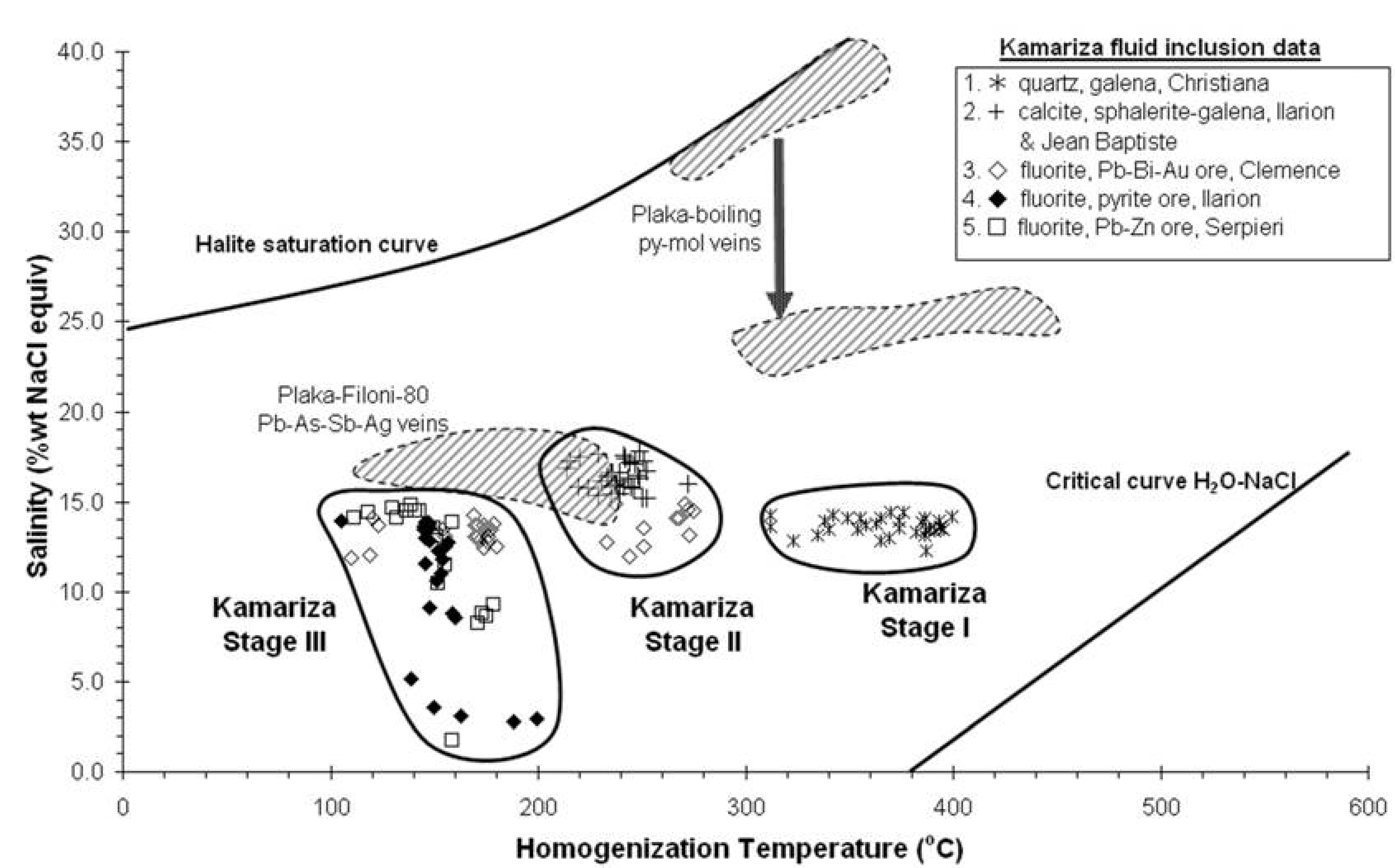


Fig. 11. Homogenization temperatures versus salinity plot for the fluid inclusions from the Plaka porphyry and vein mineralization styles. Salinity was calculated using the equation of Potter et al. (1978) and Bodnar (1993). NaCl saturation curve (halite + liquid + vapour curve) and critical point curve of the system H_2O-NaCl are also shown (data from Sourirajan and Kennedy, 1962; Haas, 1976). Trends of decreasing temperatures and salinities are represented by thick grey lines with arrows. *Qtz* quartz, *py* pyrite, *mlb* molybdenite, *fl* fluorite, *cal* calcite, *sid* siderite

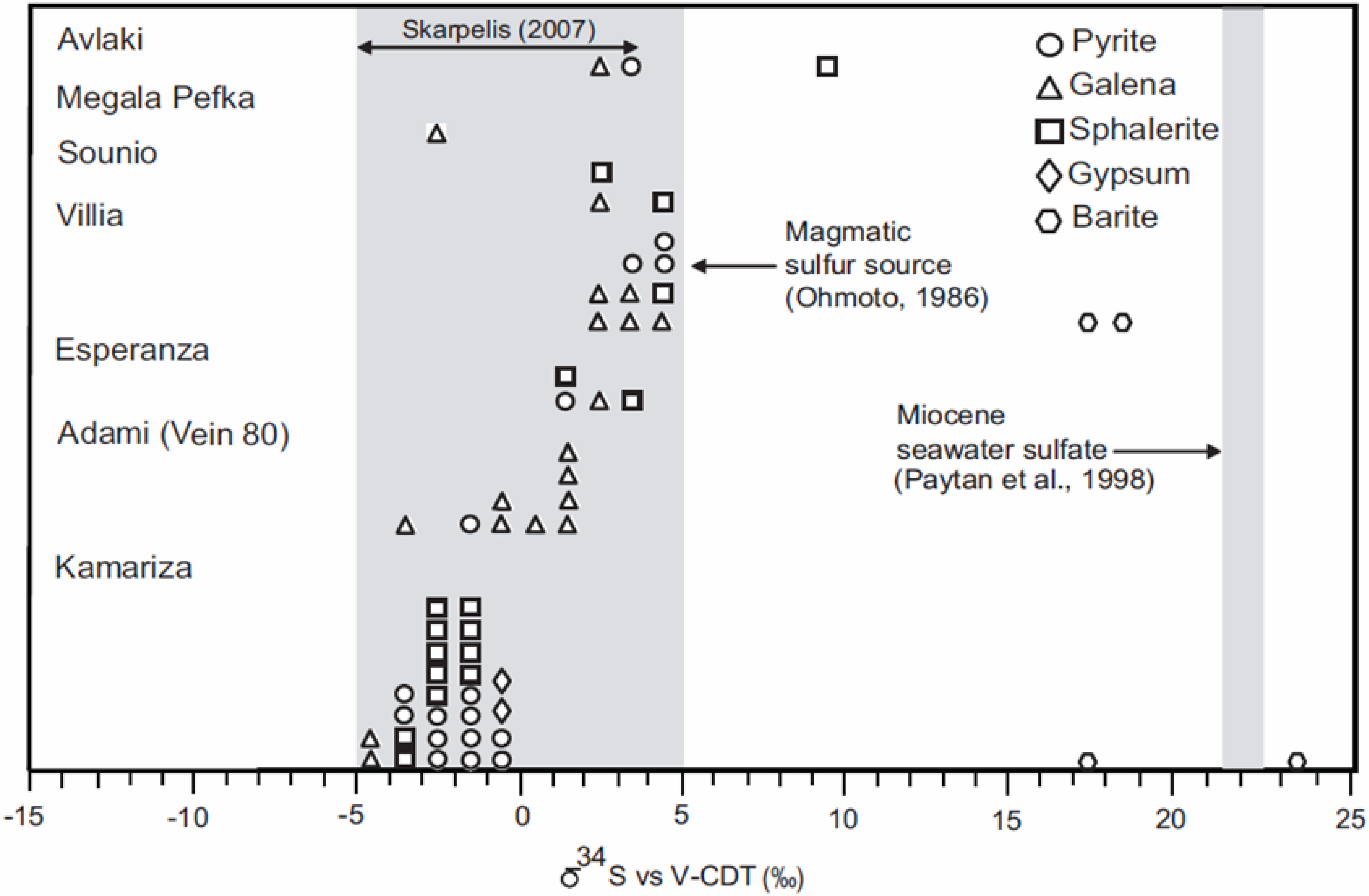
Plaka deposit

Voudouris et al. (2008a)

Kamariza deposit



Voudouris et al. (2008b)

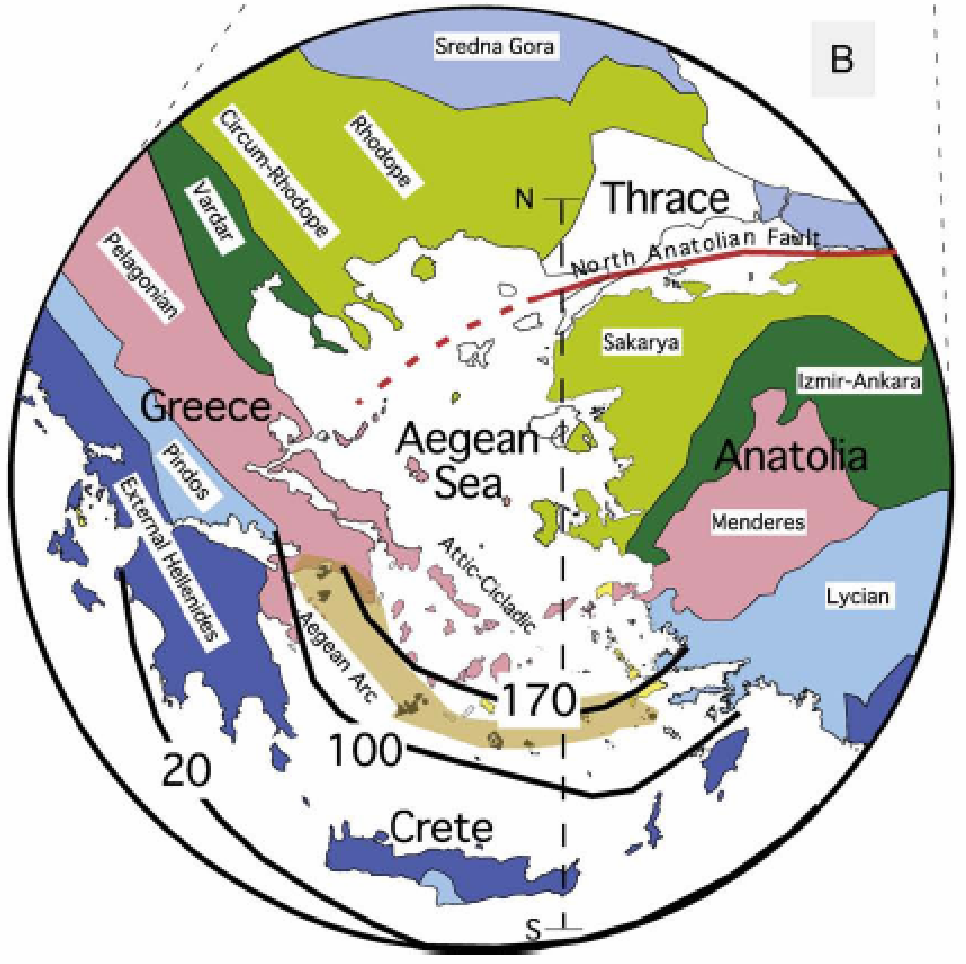


Bonsall et al. (2007)

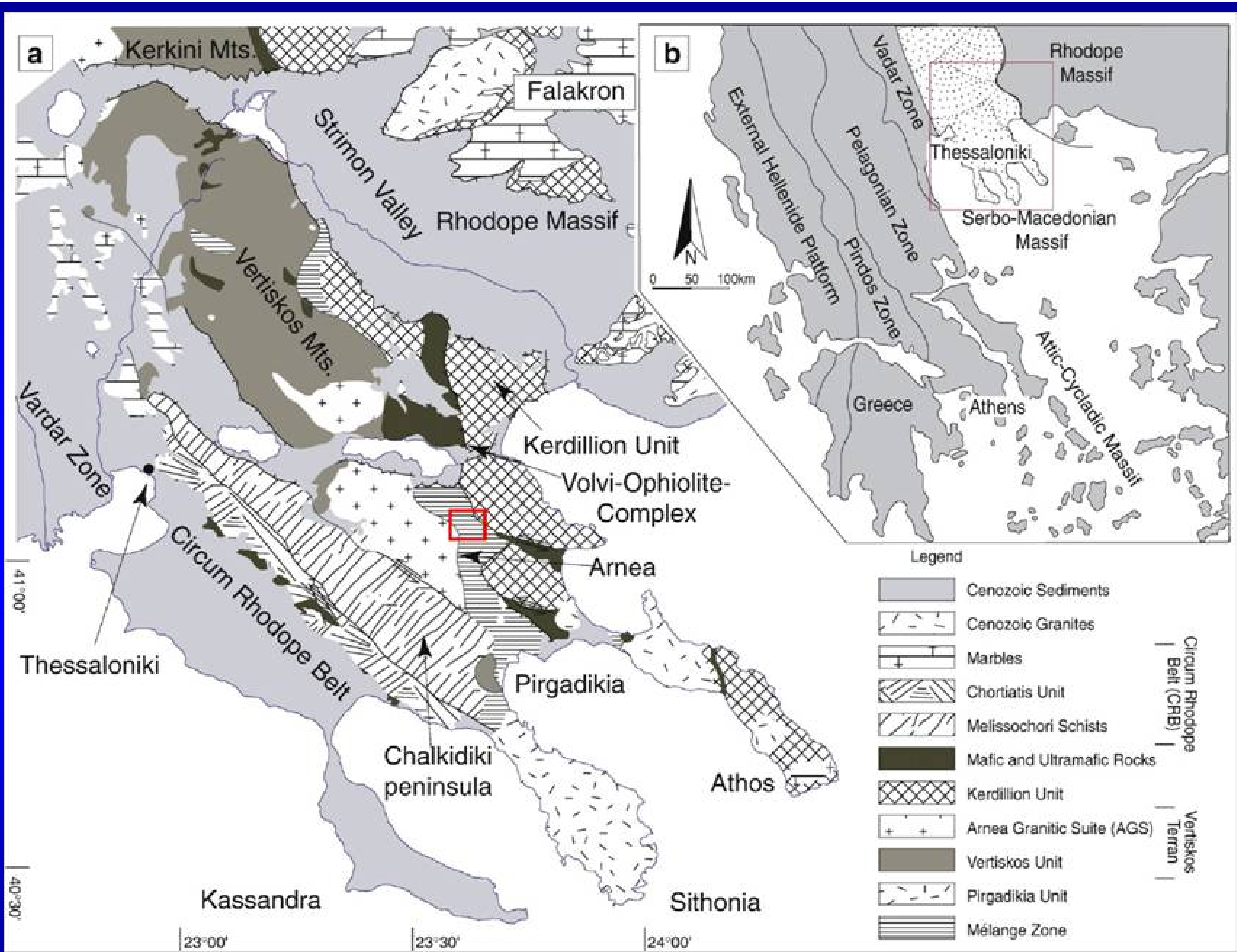
Shear zone-related (orogenic?) Cu-Au-Bi-Te prospects

Stanos/Chalkidiki:

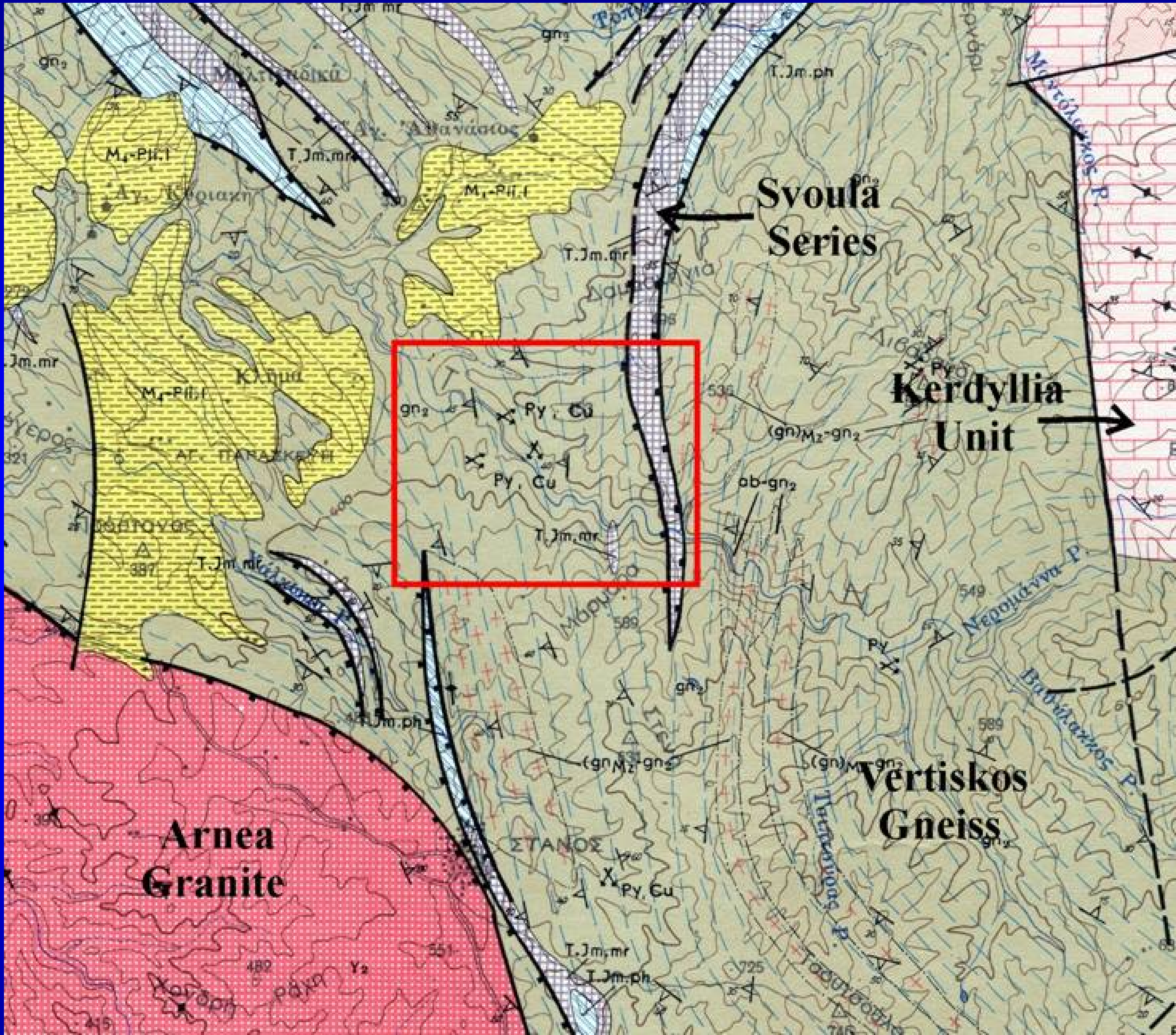
Shear zone-related Au-Ag-Bi-Te-Cu veins in metamorphic rocks of the Servo-Macedonian Massif



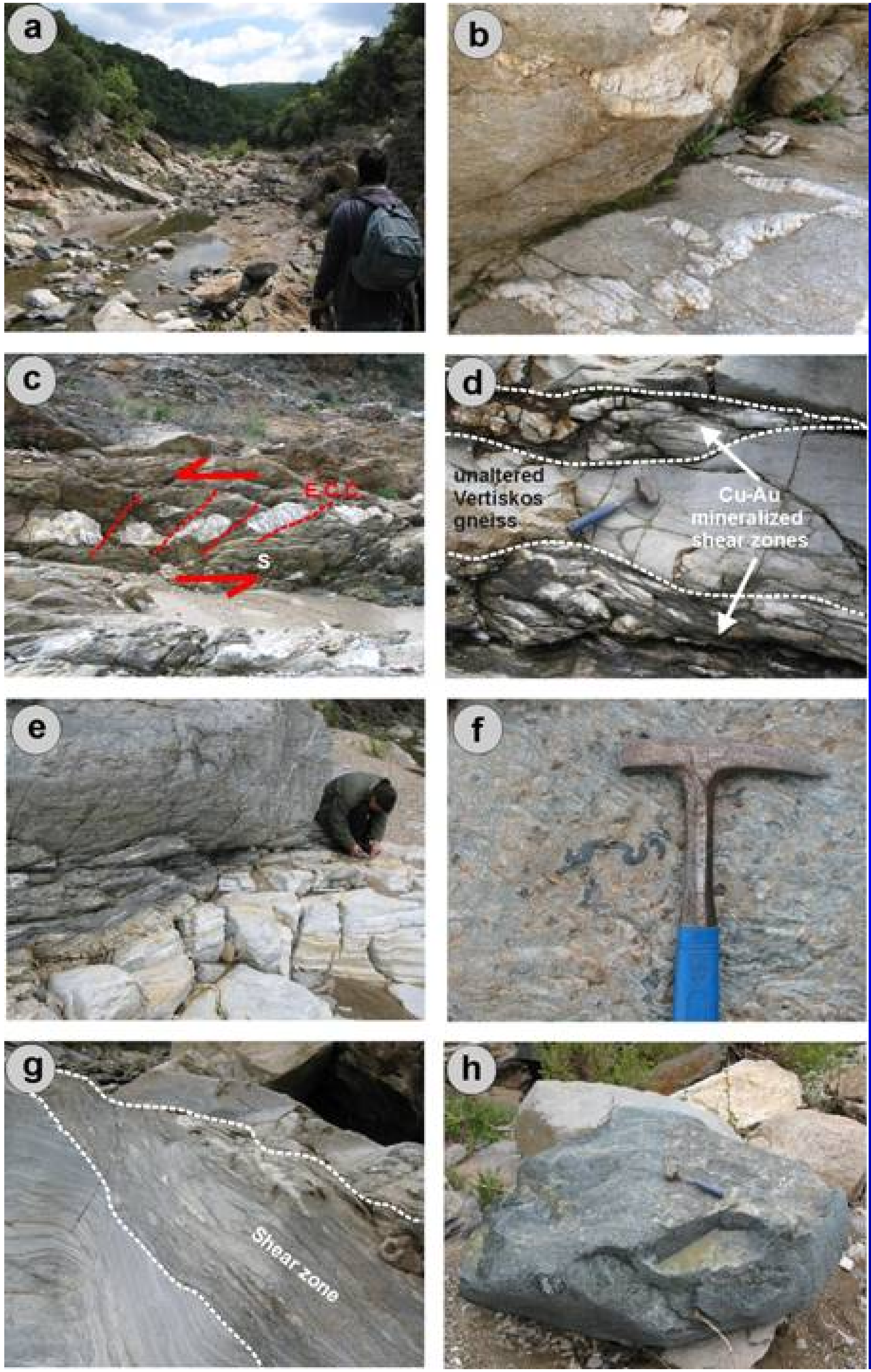
Agostini et al. (2009)



Himmerkus et al. (2006)

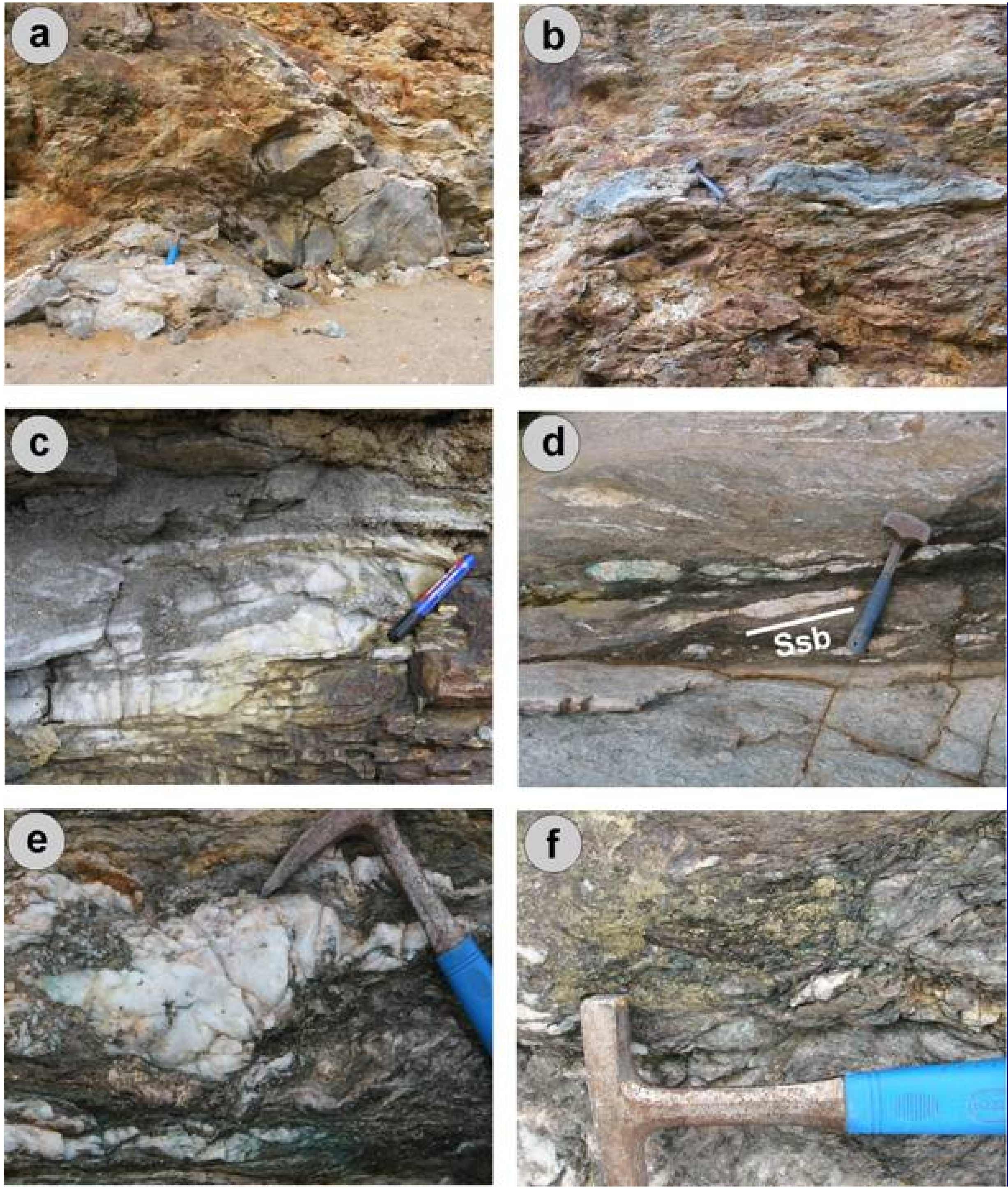


I.G.M.E. (Kockel et al. 1977)



The Cu-Au mineralization of Stanos area is hosted by regional NE-SW trending shear zones within the crystalline Servomacedonian Massif on the Chalkidiki Peninsula, North Greece. The ore bodies are located along the contact between the orthogneisses of Silurian age of the Vertiskos terrane and marbles and garnet-graphite schists of the Svoula series. The copper-gold mineralization of Stanos is structurally-controlled and is restricted to high-strain shear zones within gneisses that developed late during regional ductile shearing. This deformation event is related to southwestward overthrusting of the Vertiskos unit onto the Svoula lithologies under upper-greenschist to lower-amphibolite facies metamorphism.

Voudouris et al. (2010c)

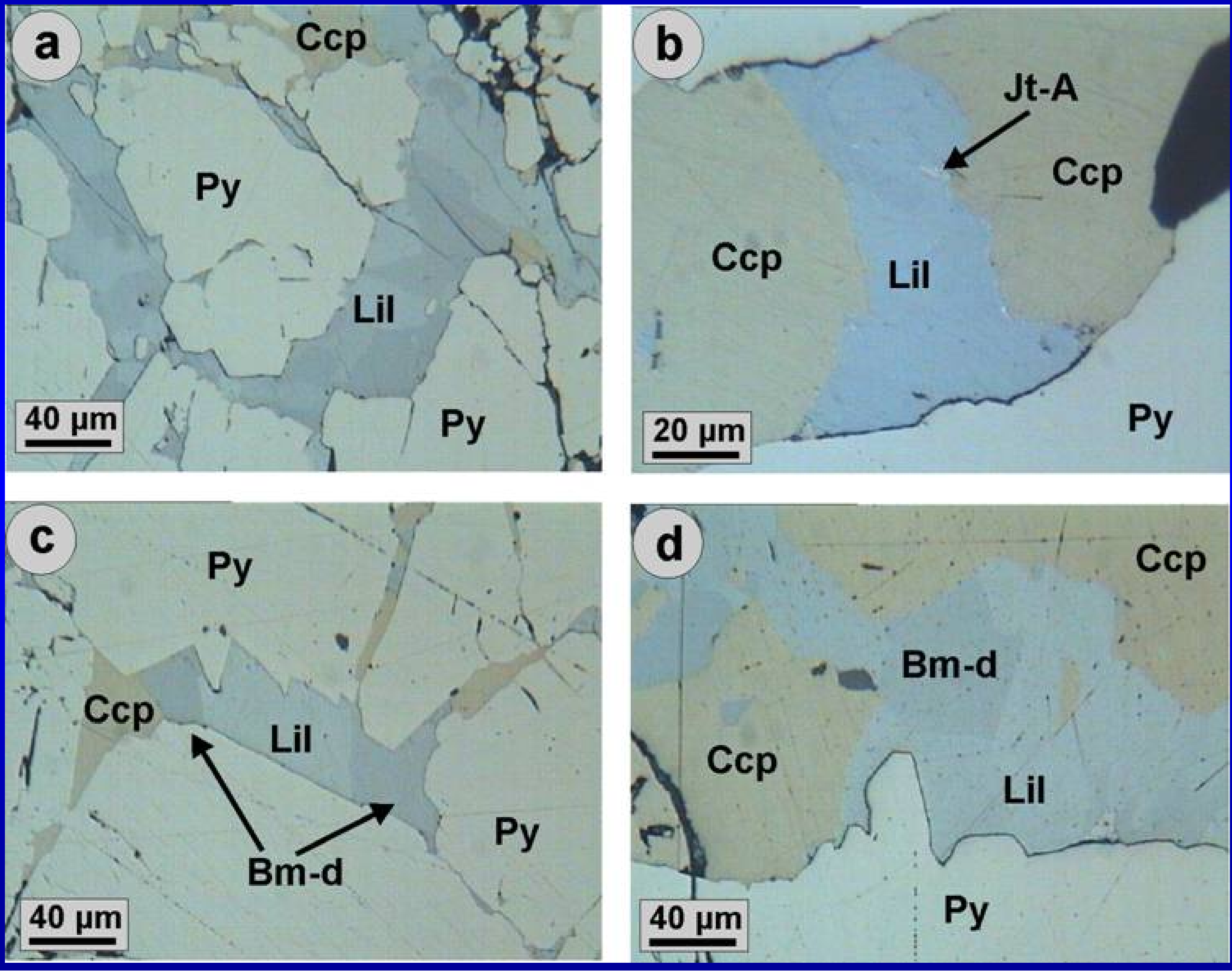


Voudouris et al. (2010c)

Stanos/Chalkidiki: shear-zone related Au-Cu-Bi-Te prospect

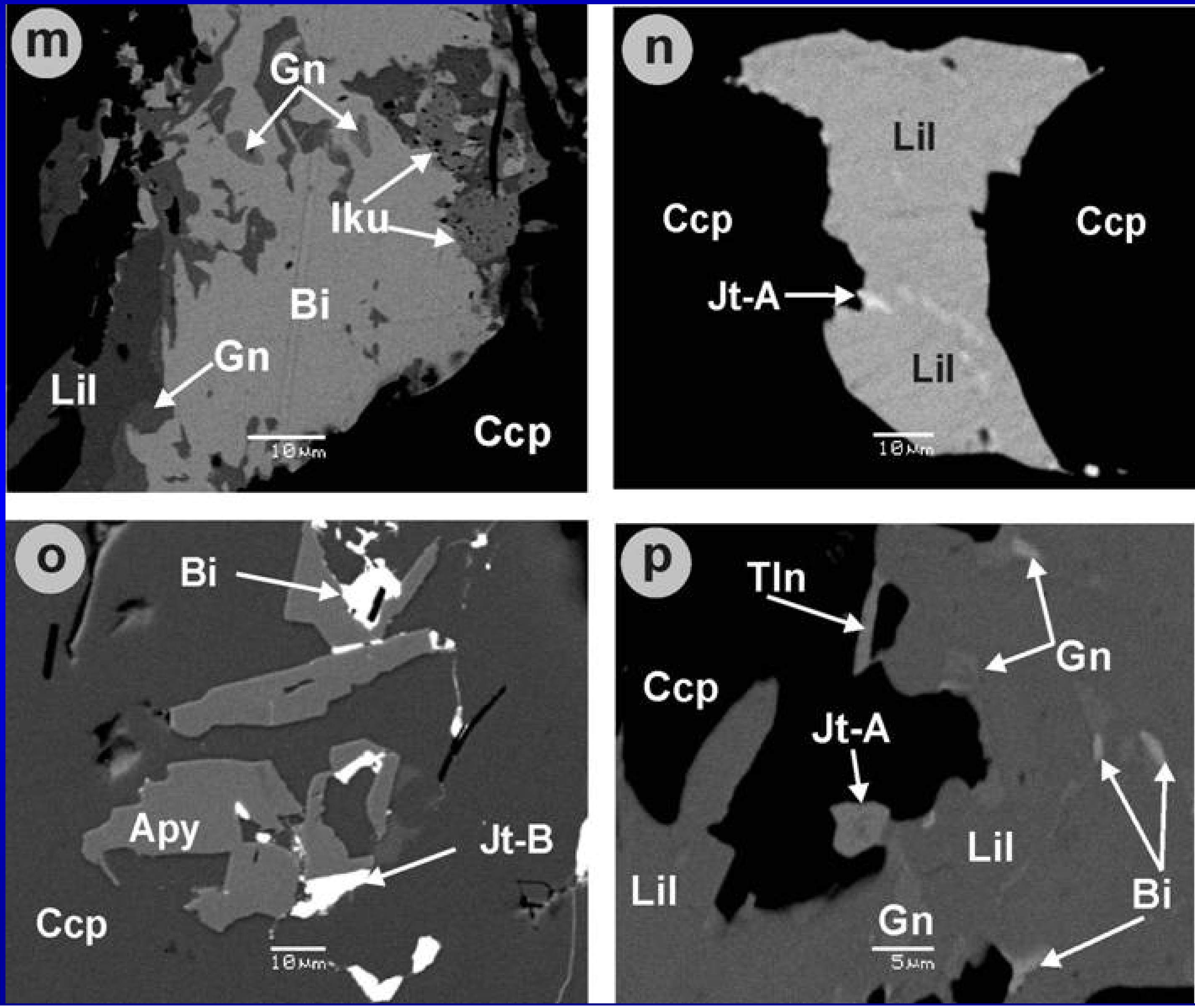
Stanos/Chalkidiki:

Lillianite homologues and bismuthinite derivatives

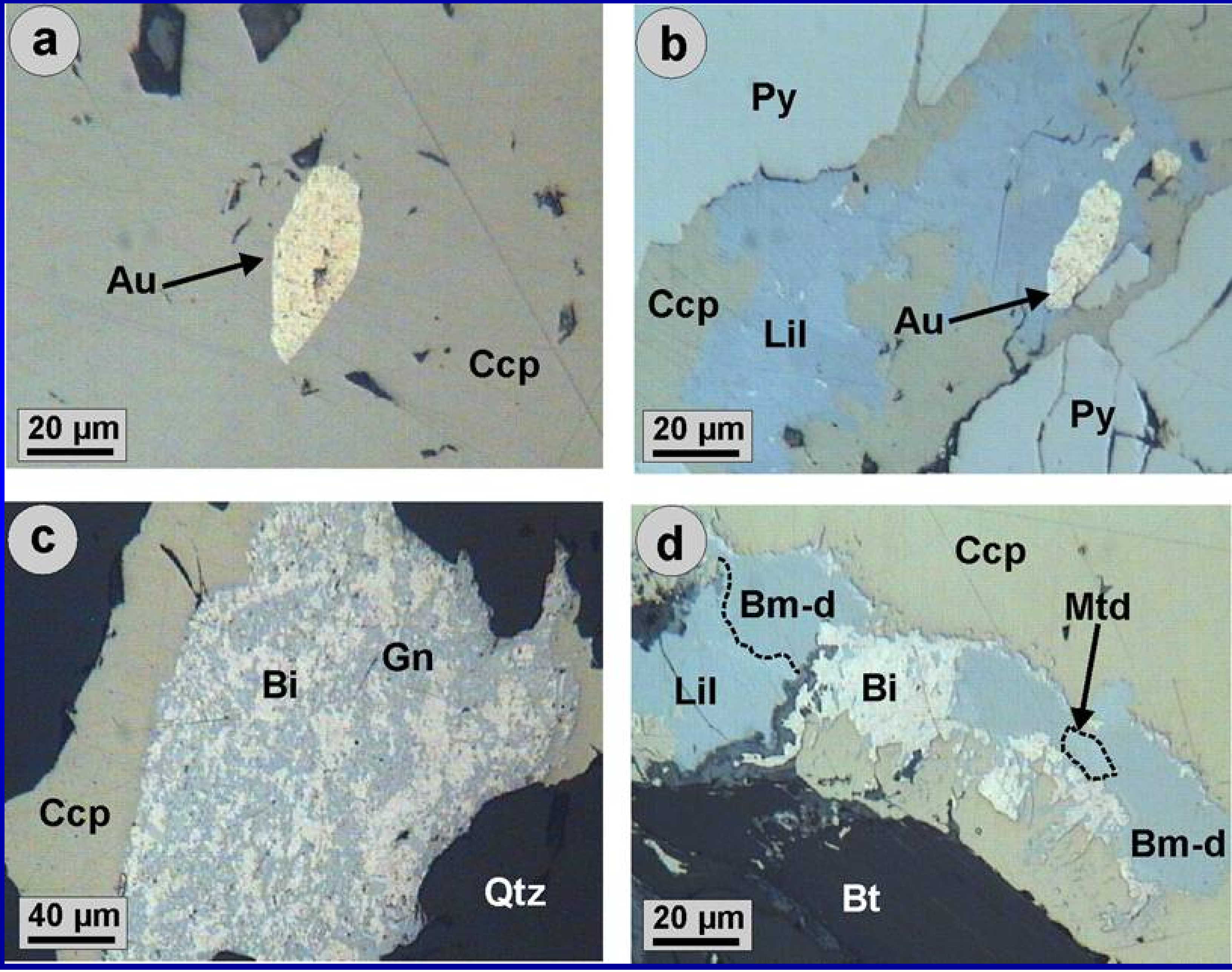


Stanos/Chalkidiki:

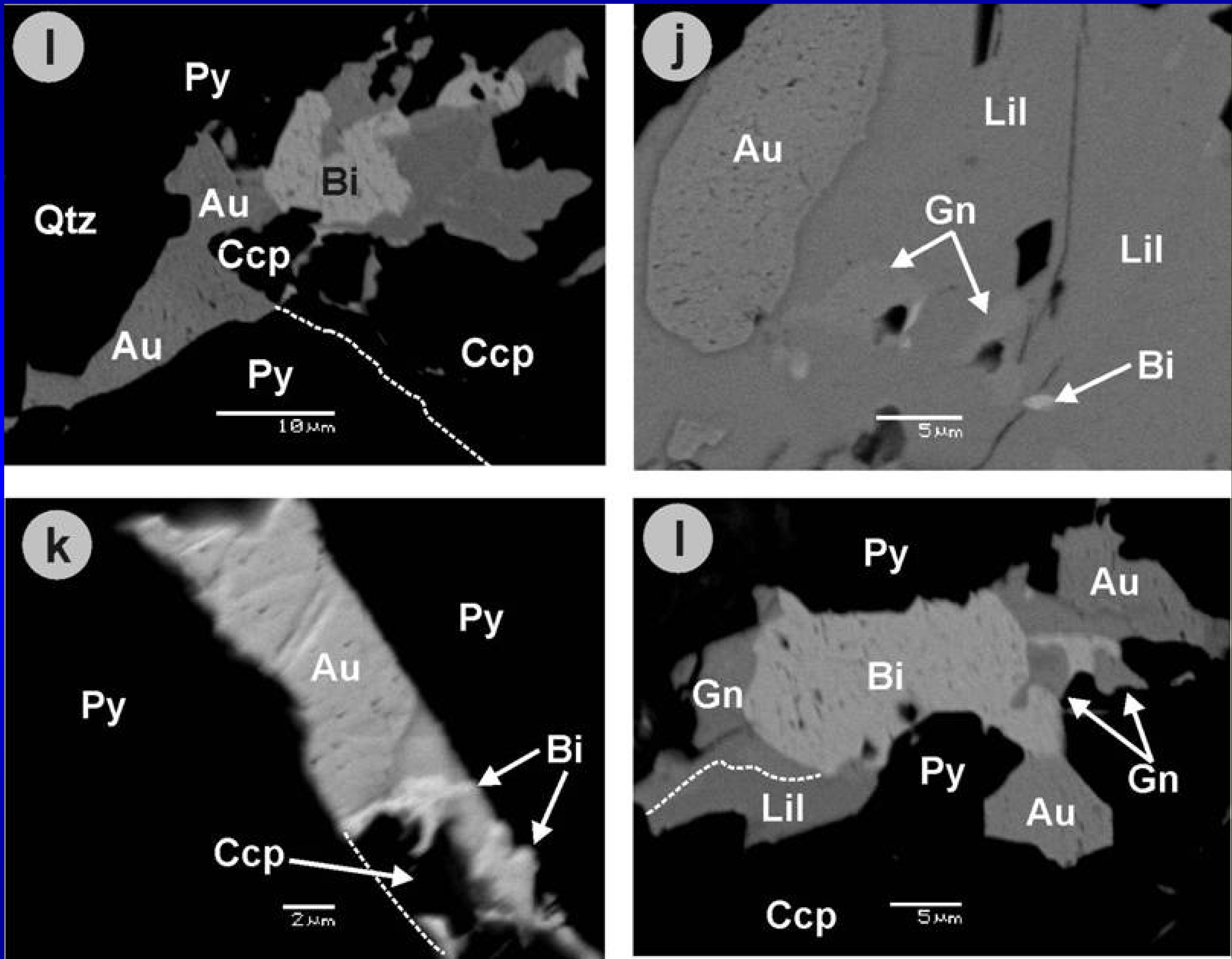
Ikunolite, Joseite-A, Joseite-B, Telluronevskite



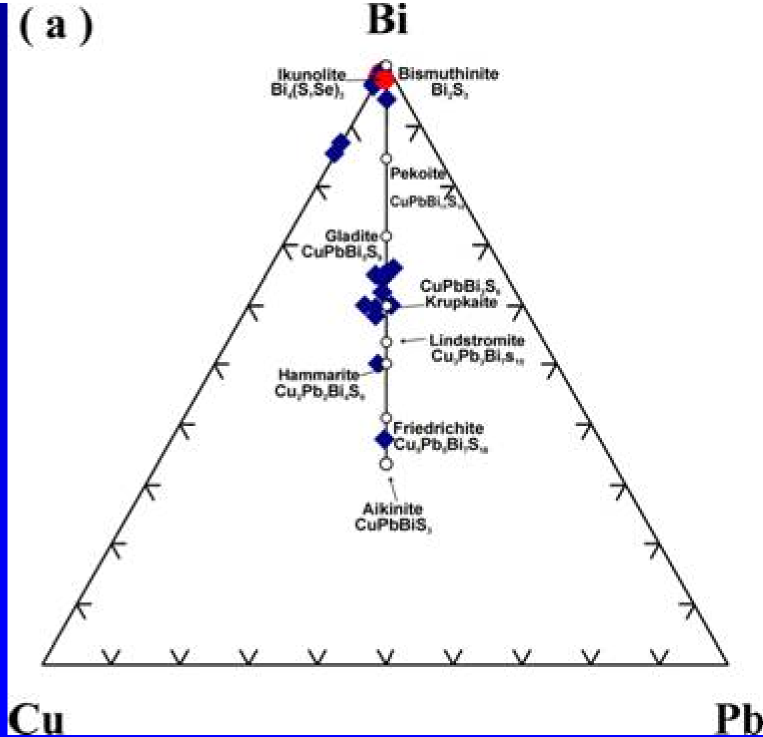
Stanos/Chalkidiki: Electrum and native Bismuth

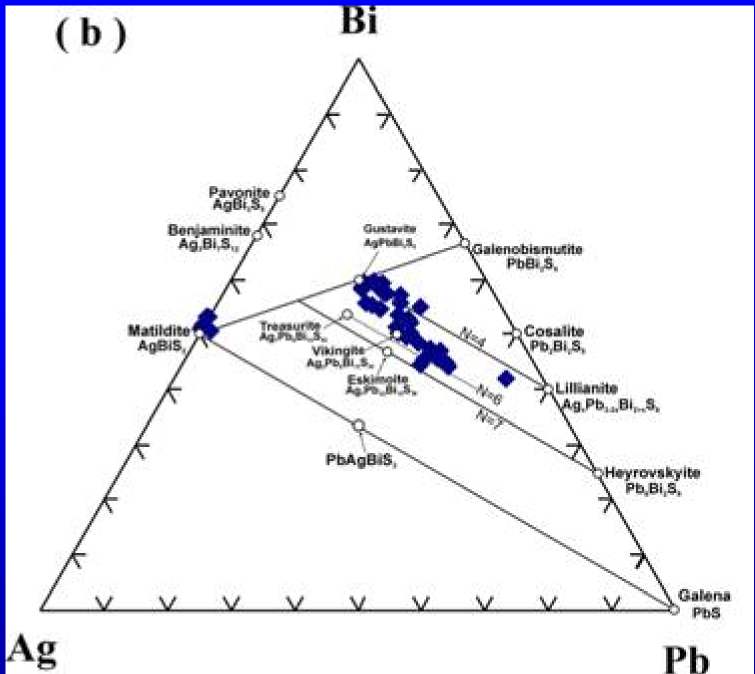


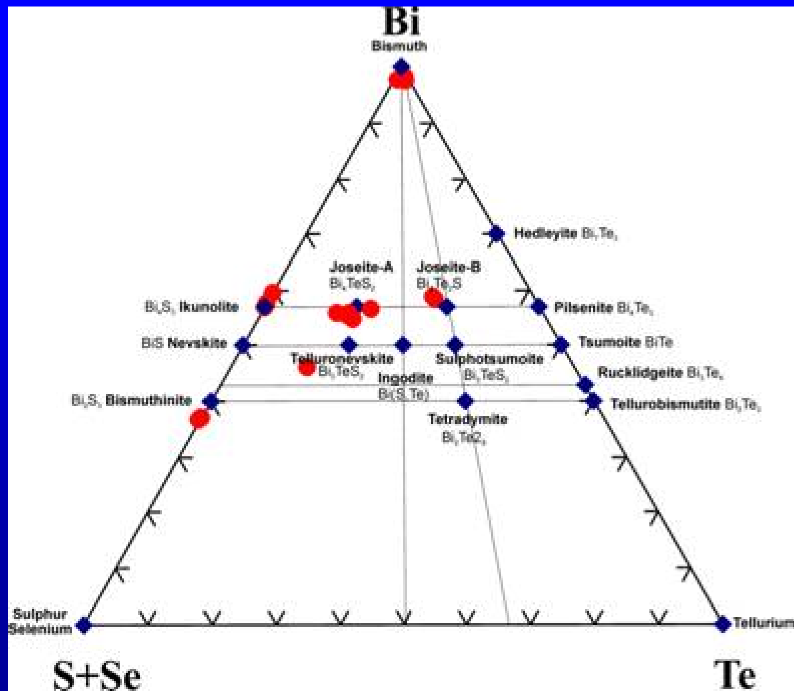
Stanos/Chalkidiki: Electrum and native Bismuth



Stanos/Chalkidiki: Bi-sulfosalts, Bi-tellurides

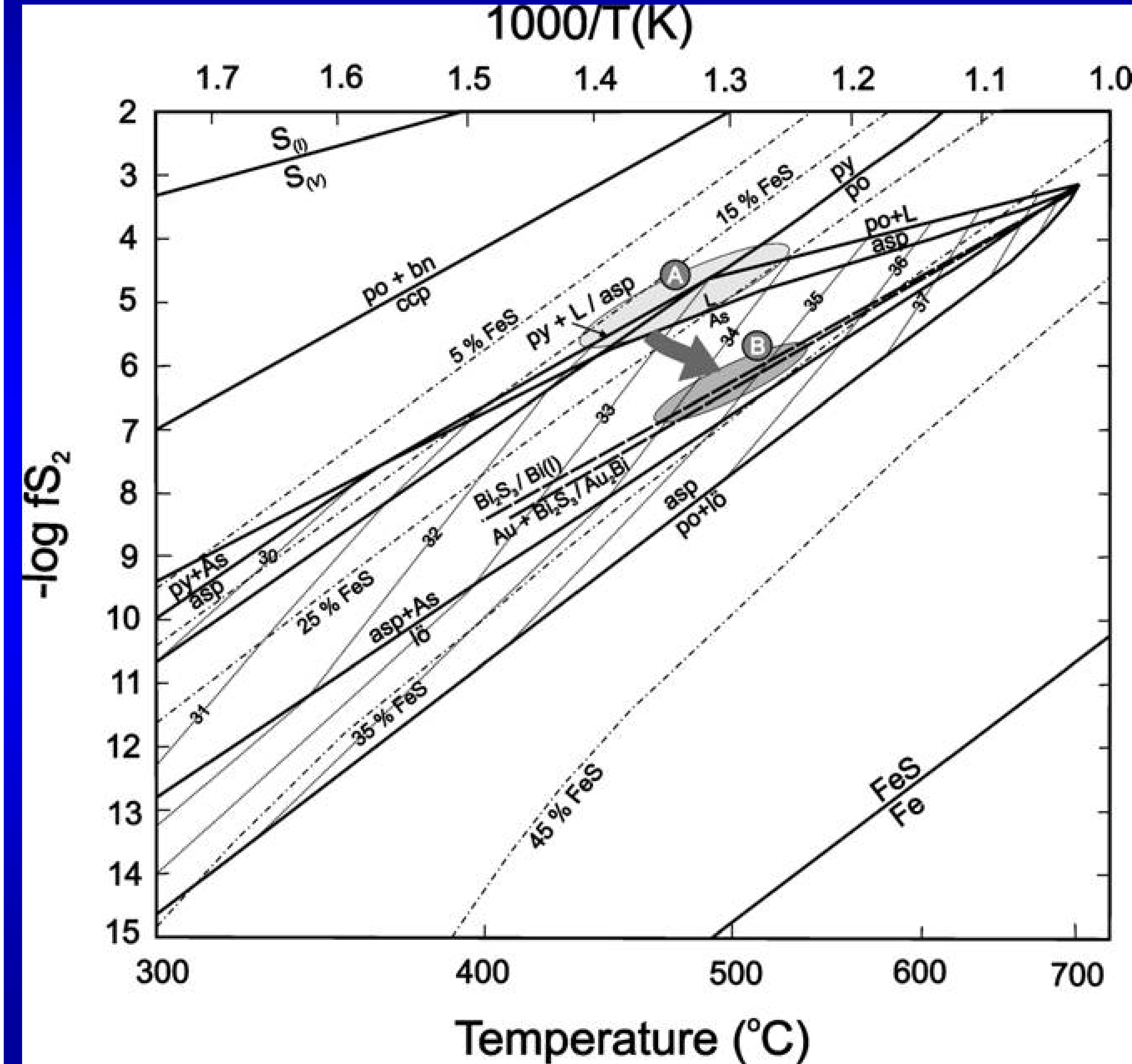






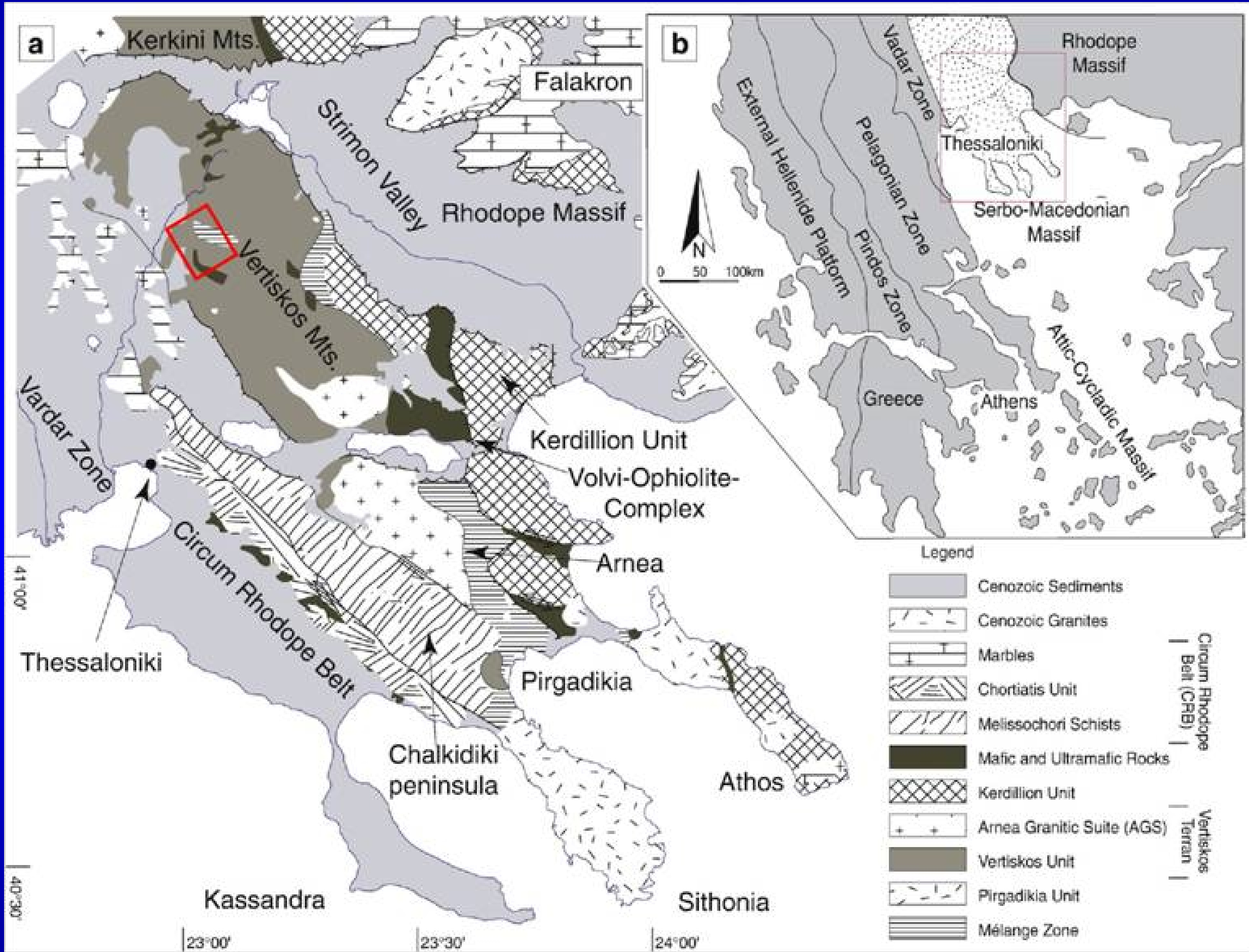
Voudouris et al. (2010c)

Stanos/Chalkidiki: Geochemical environment of ore formation



Voudouris et al. (2010c)

Koronouda-Laodikiono/Kilkis: shear-zone related Cu-Bi-Au

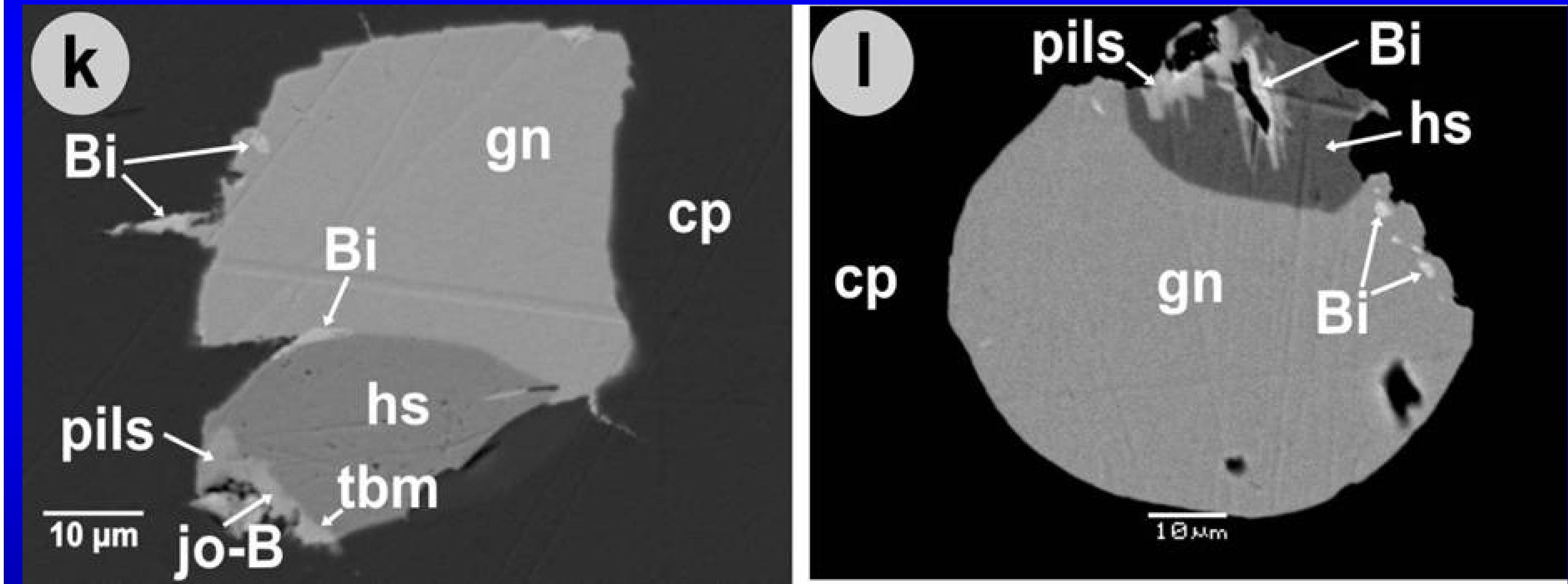


Himmerkus et al. (2006)

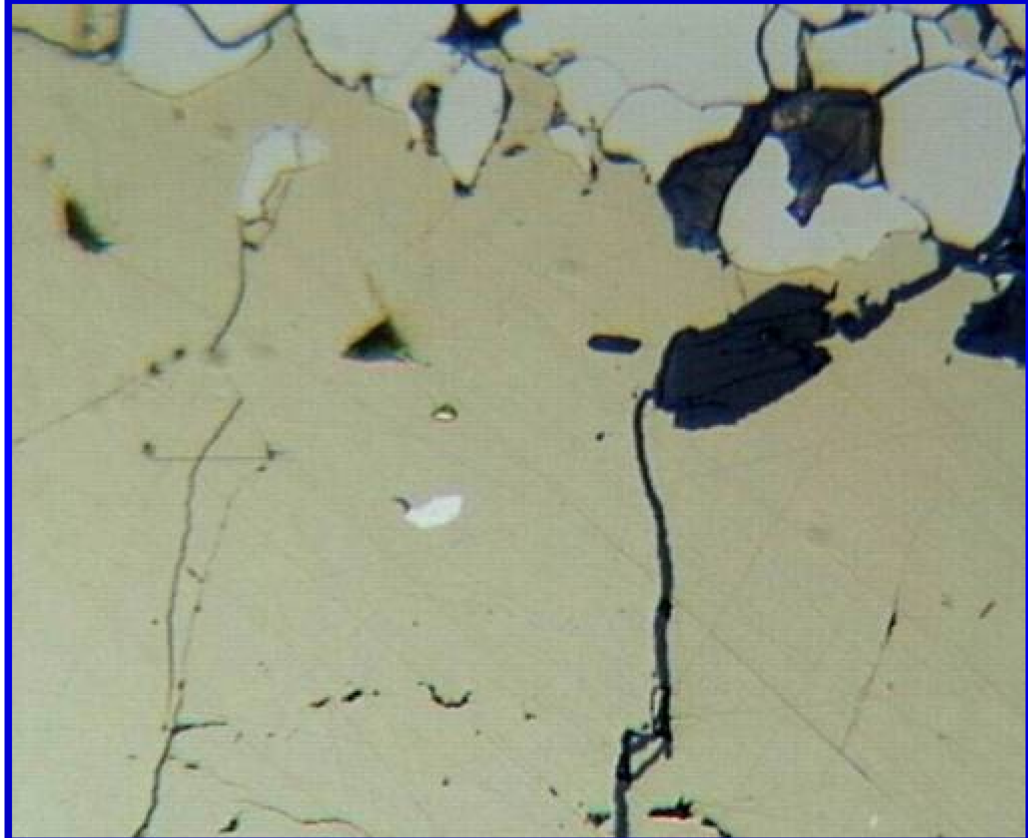
Laodikino/Kilkis

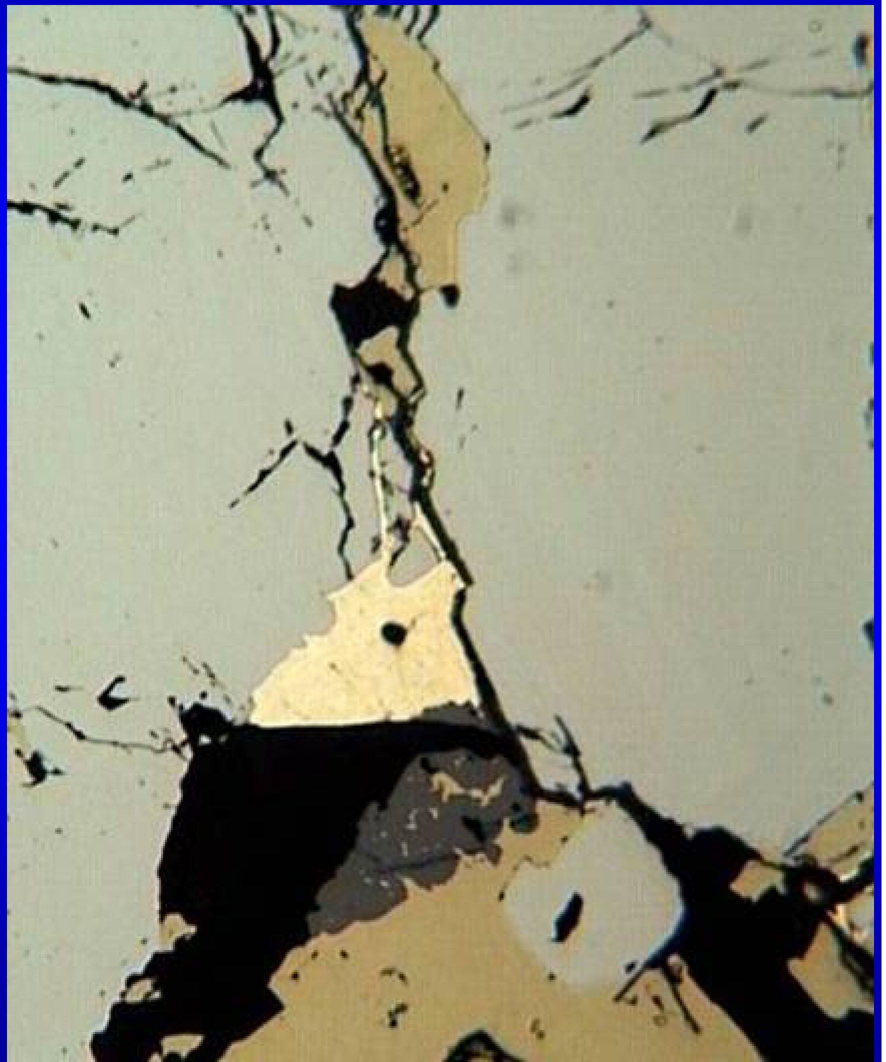
Koronouda/Kilkis

Koronouda/Kilkis: joseite-B ($Bi_{3.92}Au_{0.05}Te_{1.93}Se_{0.04}S_{0.98}$), pilsenite ($Bi_{3.80}Te_{2.85}S_{0.35}$), tellurobismuthite ($Bi_{2.05}Te_{2.78}S_{0.17}$), hessite



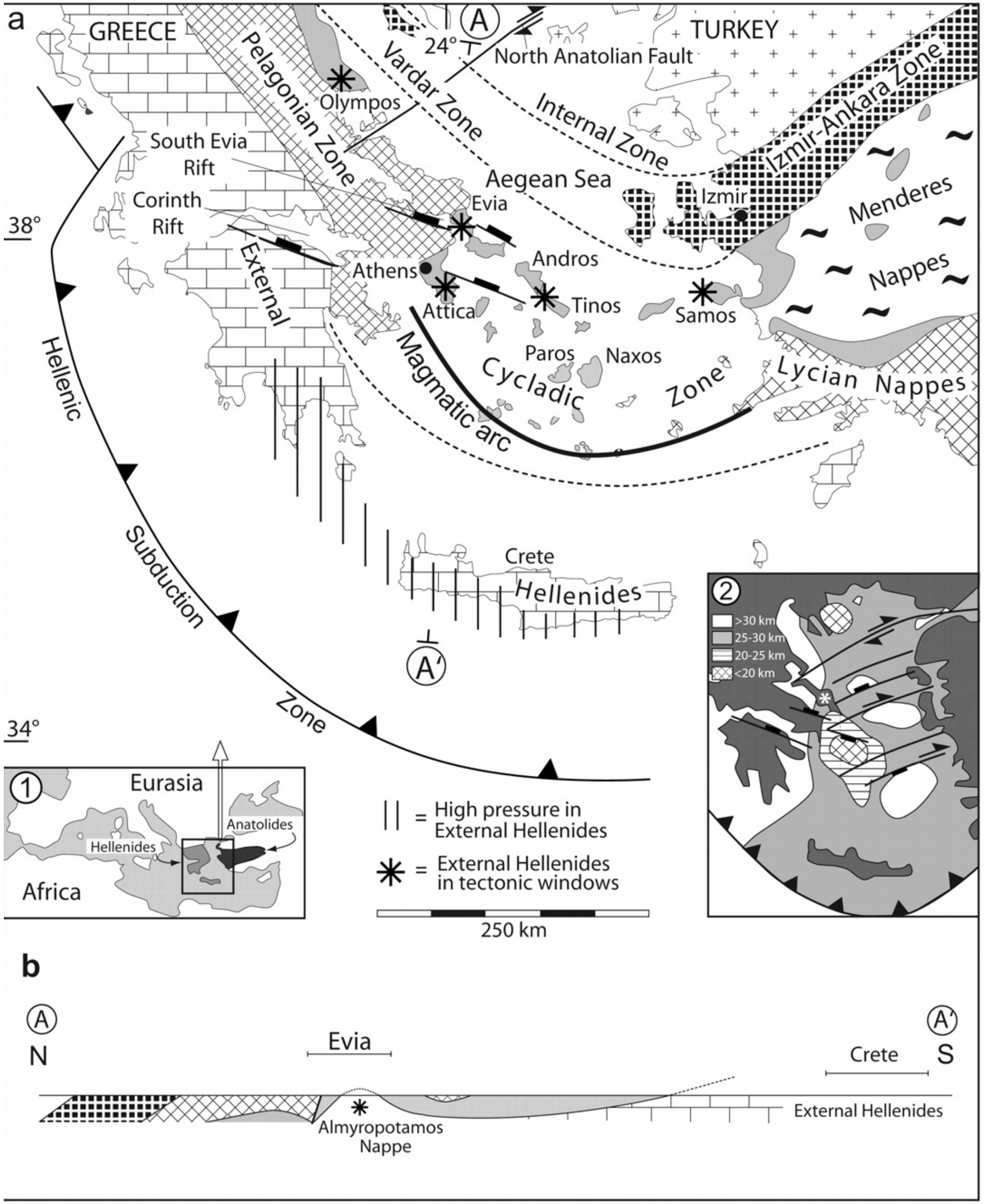
Laodikino/Kilkis: pilsenite ($Bi_{3.97}Te_{3.03}$) included in chalcopyrite





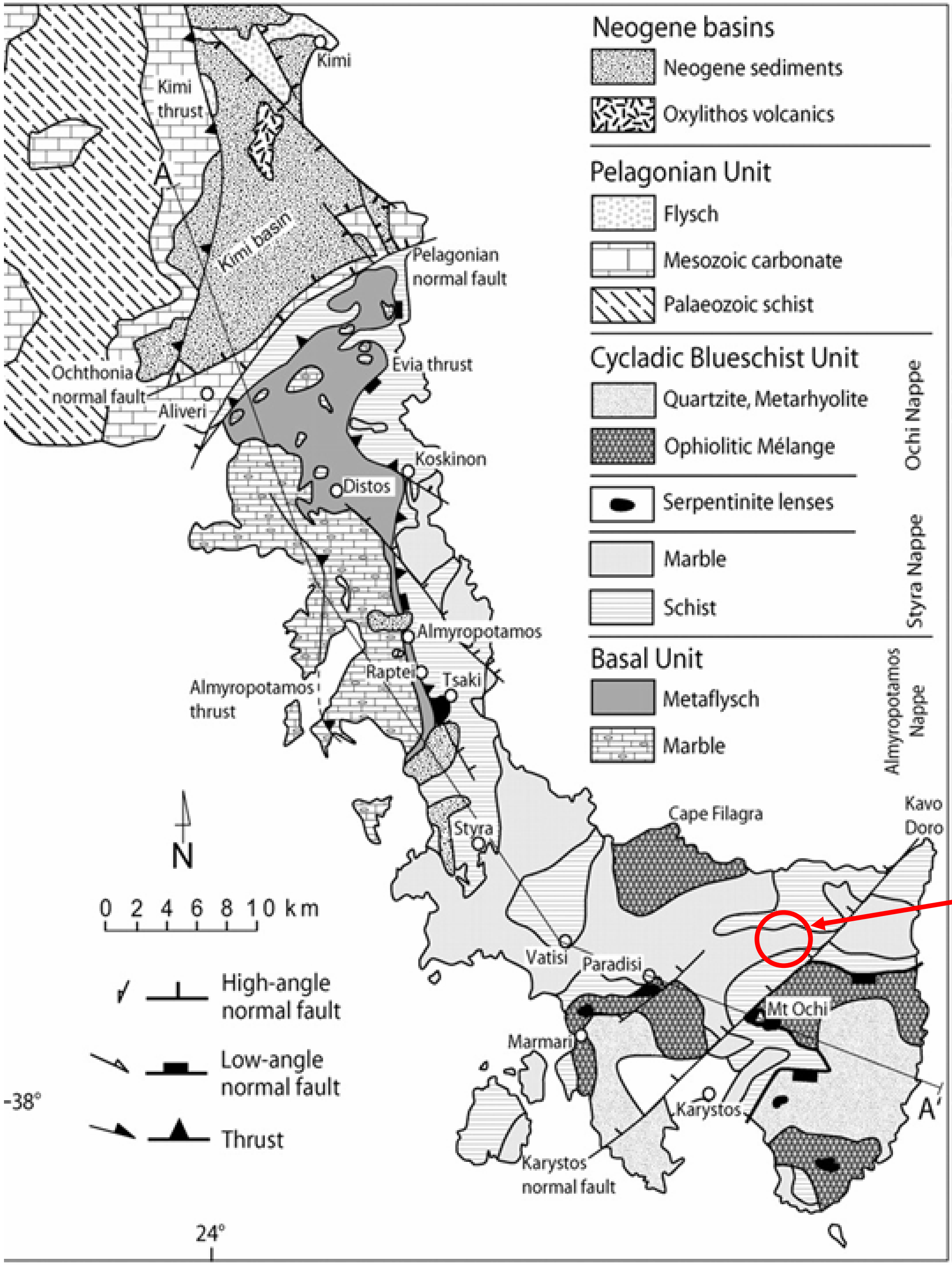
Kallianou Evia island

Shear zone-related Au-Ag-Te veins in metamorphic rocks of the Cycladic Blueschist Unit



Generalized tectonic map of the Aegean region showing major tectonic units and present-day position of the Hellenic subduction zone.

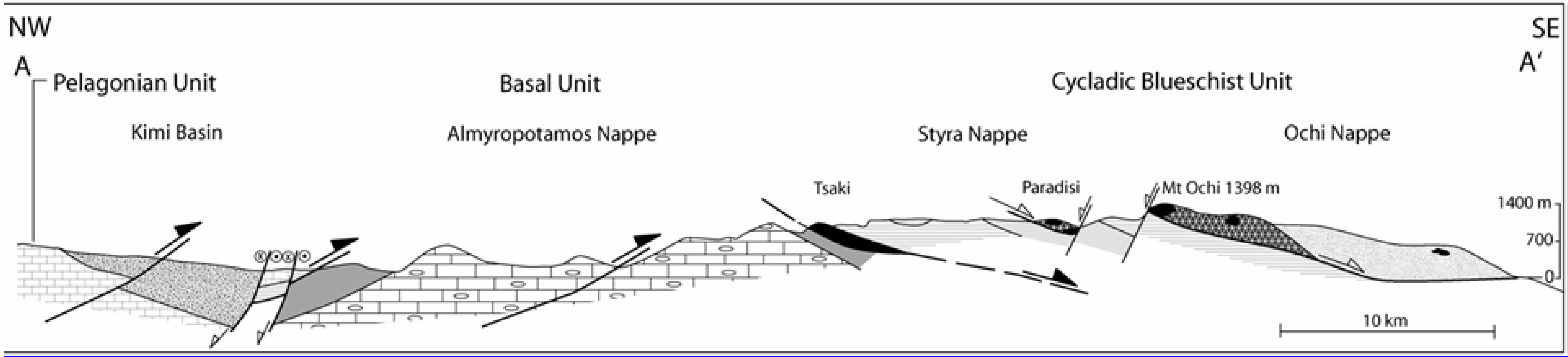
Ring et al. (2007)



Tectonic map of southern Evia showing major structures and tectonic contacts between units

Ring et al. (2007)

NW–SE cross-section through the nappe pile of southern Evia



Ring et al. (2007)

Kallianou/S. Evia: shear-zone related quartz veins

Au-Ag-Te-bearing milky quartz veins in the Kallianou area are hosted in mica schists and marbles of the Cycladic Blueschist Unit

The quartz veins (up to 3m thick and 100m long) generally strike NW-SE and are discordant with respect to syn-metamorphic structures. The veins were formed under ductile to brittle deformation, and in the footwall block of an exhumed metamorphic core complex.

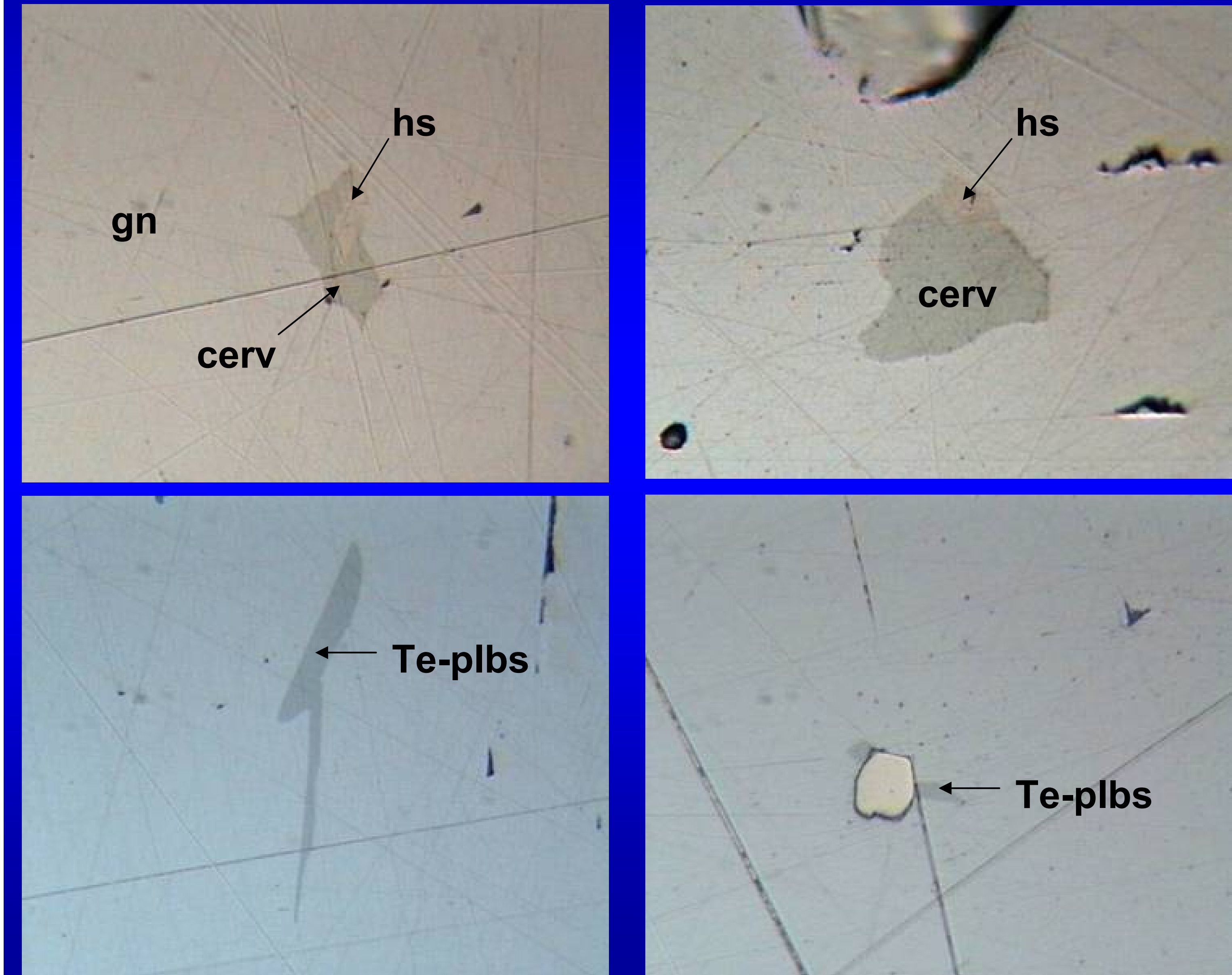
Kallianou/S. Evia: shear-zone related quartz veins

Ore minerals in the veins occur in masses (up to 10 vol %) to disseminations, filling fractures or cementing brecciated quartz fragments. The ore mineralogy consists of pyrite, arsenopyrite, löllingite, sphalerite, chalcopyrite, tetrahedrite, galena, gold, pearceite, sylvanite and argentite.

The main gangue minerals include quartz and calcite, whereas wallrock alteration consists of chlorite, muscovite, albite and calcite.

Voudouris & Spry (2008)

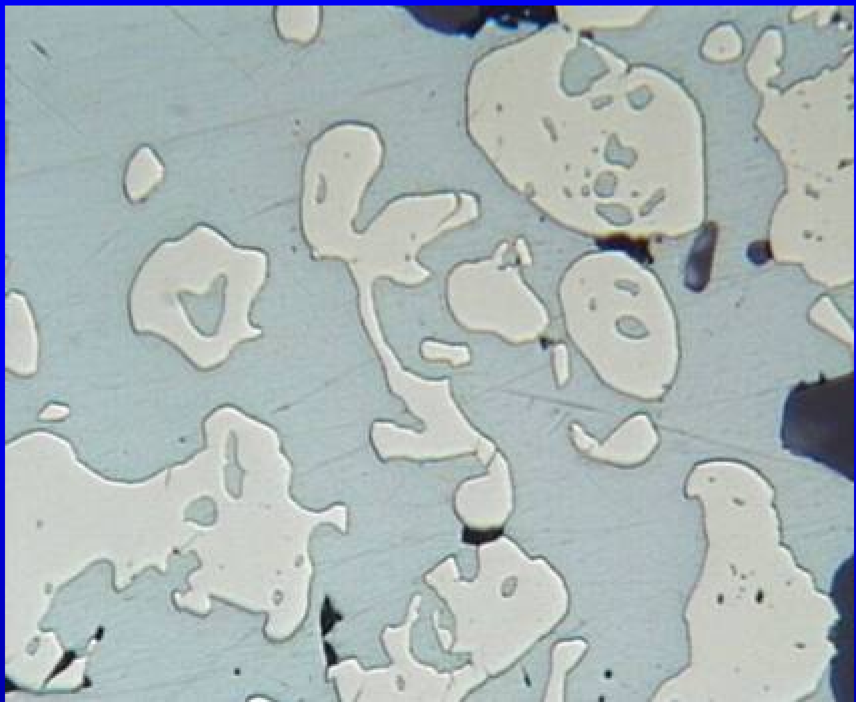
Kallianou: minerals of the cervelleite-group, Te-polybasite and hessite.

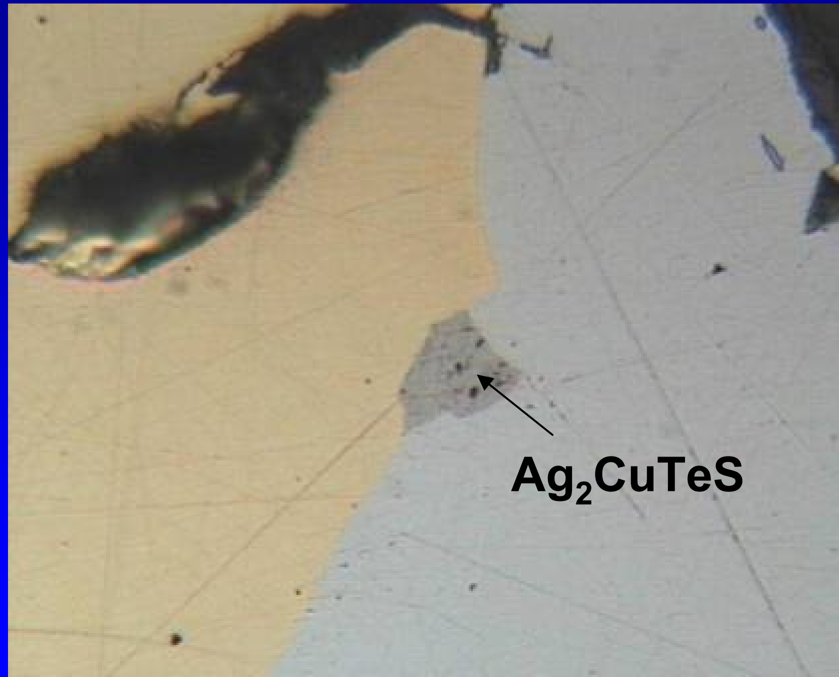


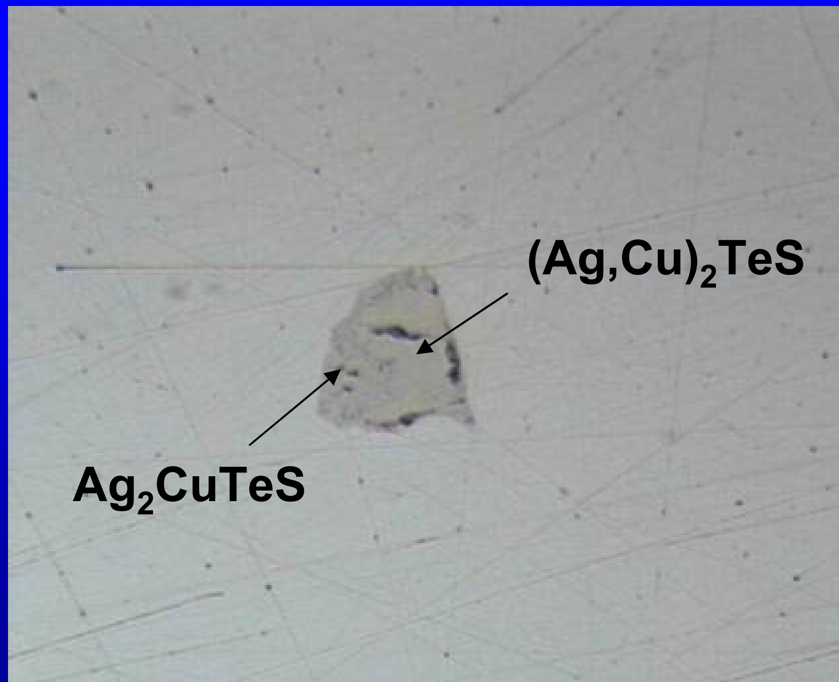
Voudouris & Spry (2008)

Kallianou:

unammed Ag_2CuTeS and $(Ag,Cu)_2TeS$ minerals

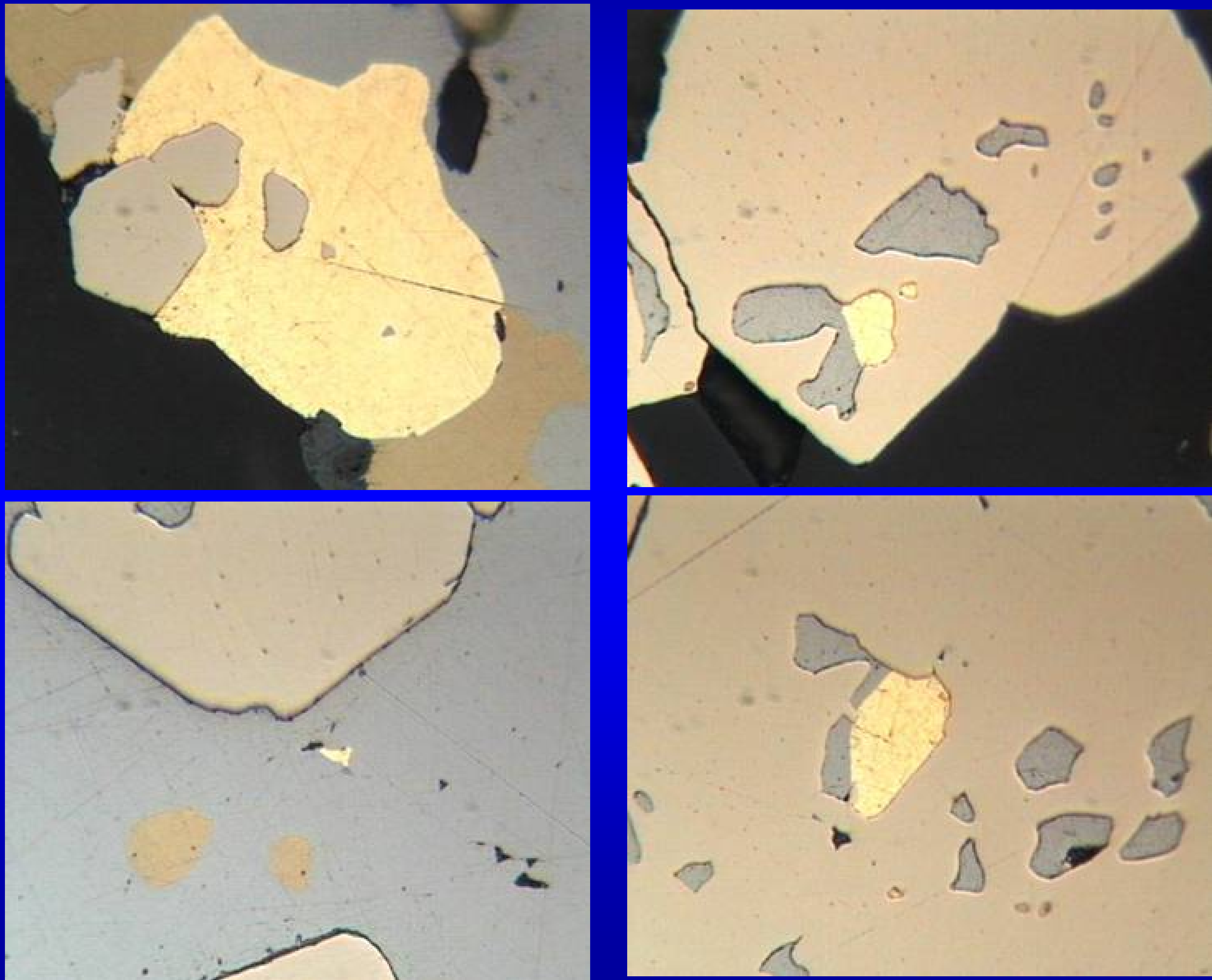






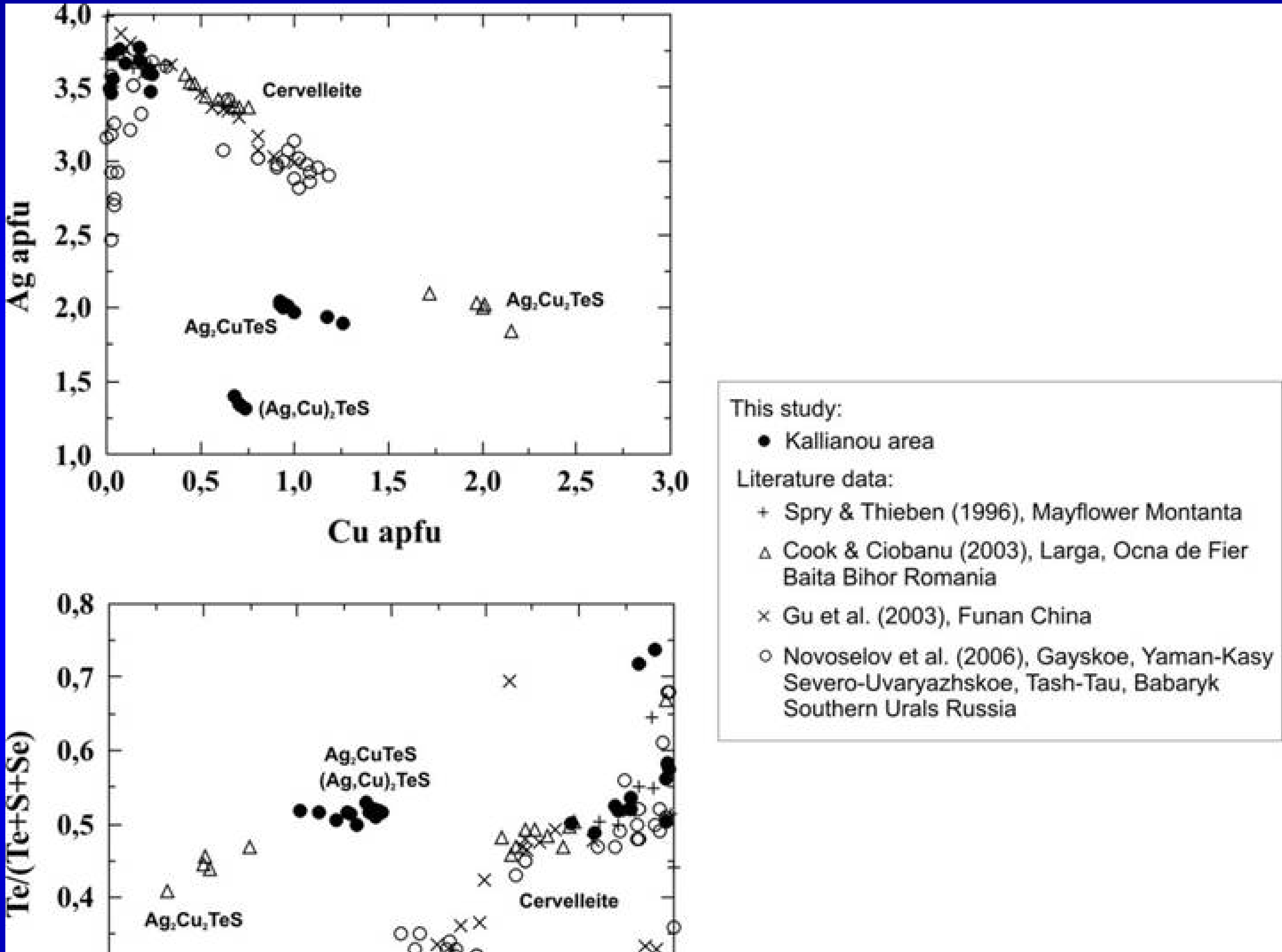
Voudouris & Spry (2008)

Kallianou/S. Evia: electrum



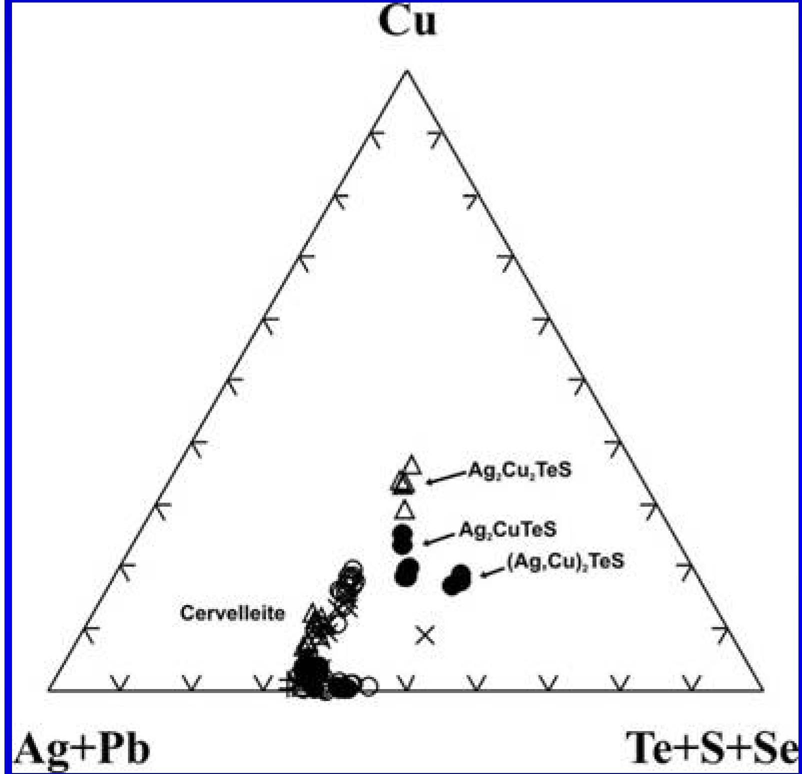
Voudouris & Spry (2008)

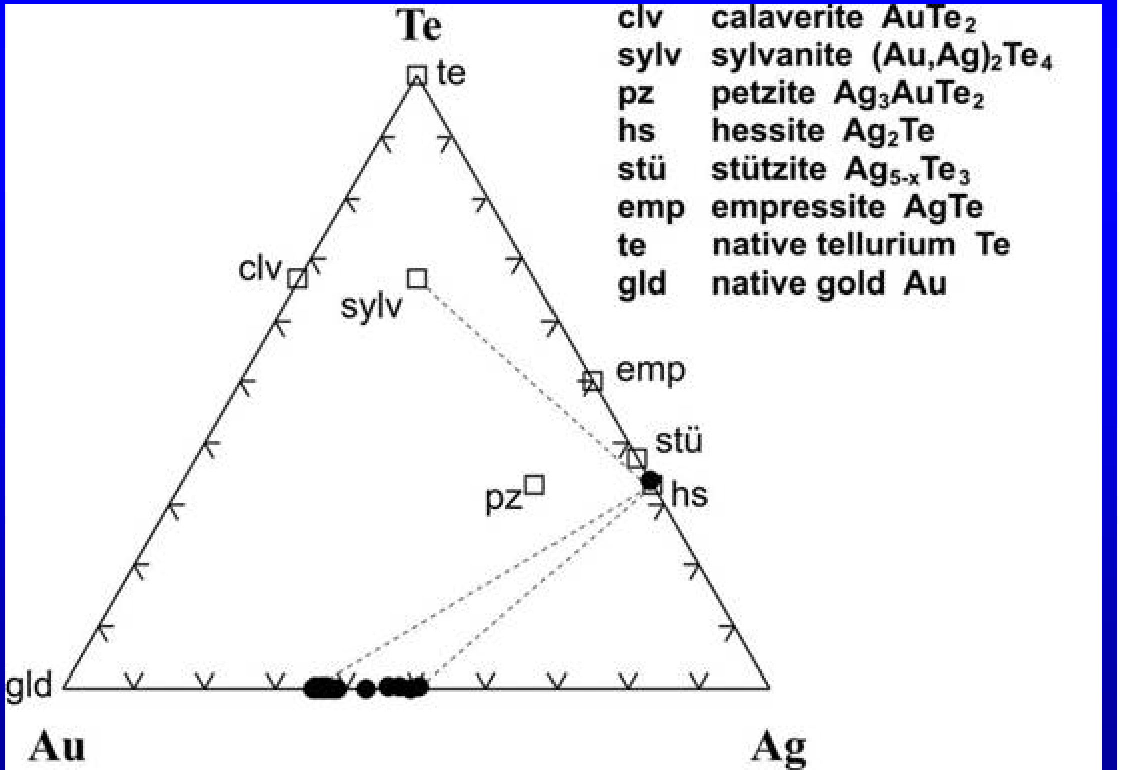
Kallianou: Ag-Cu sulfotellurides



Voudouris & Spry (2008)

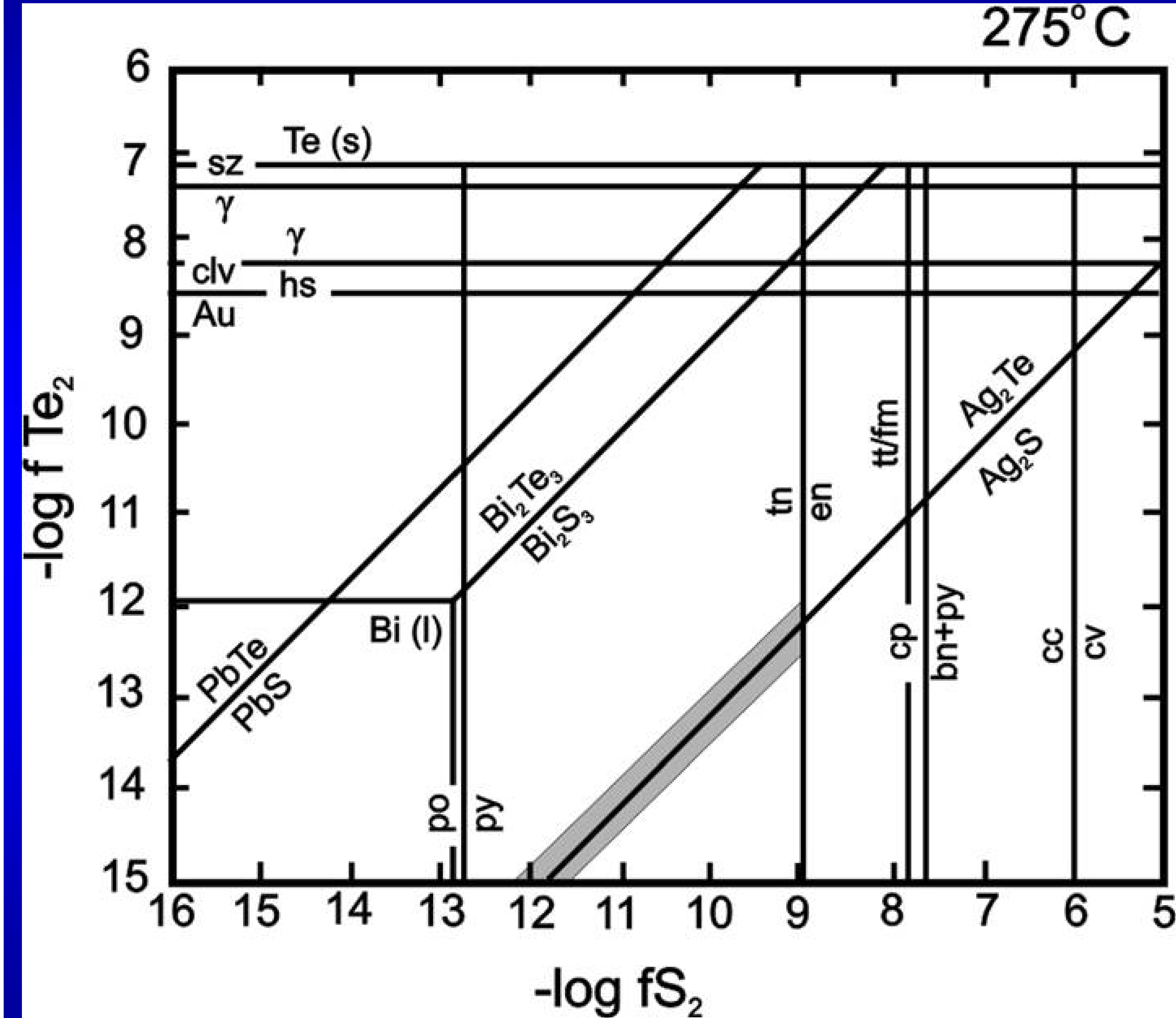
Kallianou/S. Evia: Ag-Cu sulfotellurides, electrum and hessite





Voudouris & Spry (2008)

Conditions of formation for Ag-Cu sulfotellurides



Voudouris & Spry (2008)

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