

Diversity of epithermal gold ore formation events in SE Europe: a record of a protracted 60 m.y.-long geodynamic and metallogenic evolution of the Tethyan arc

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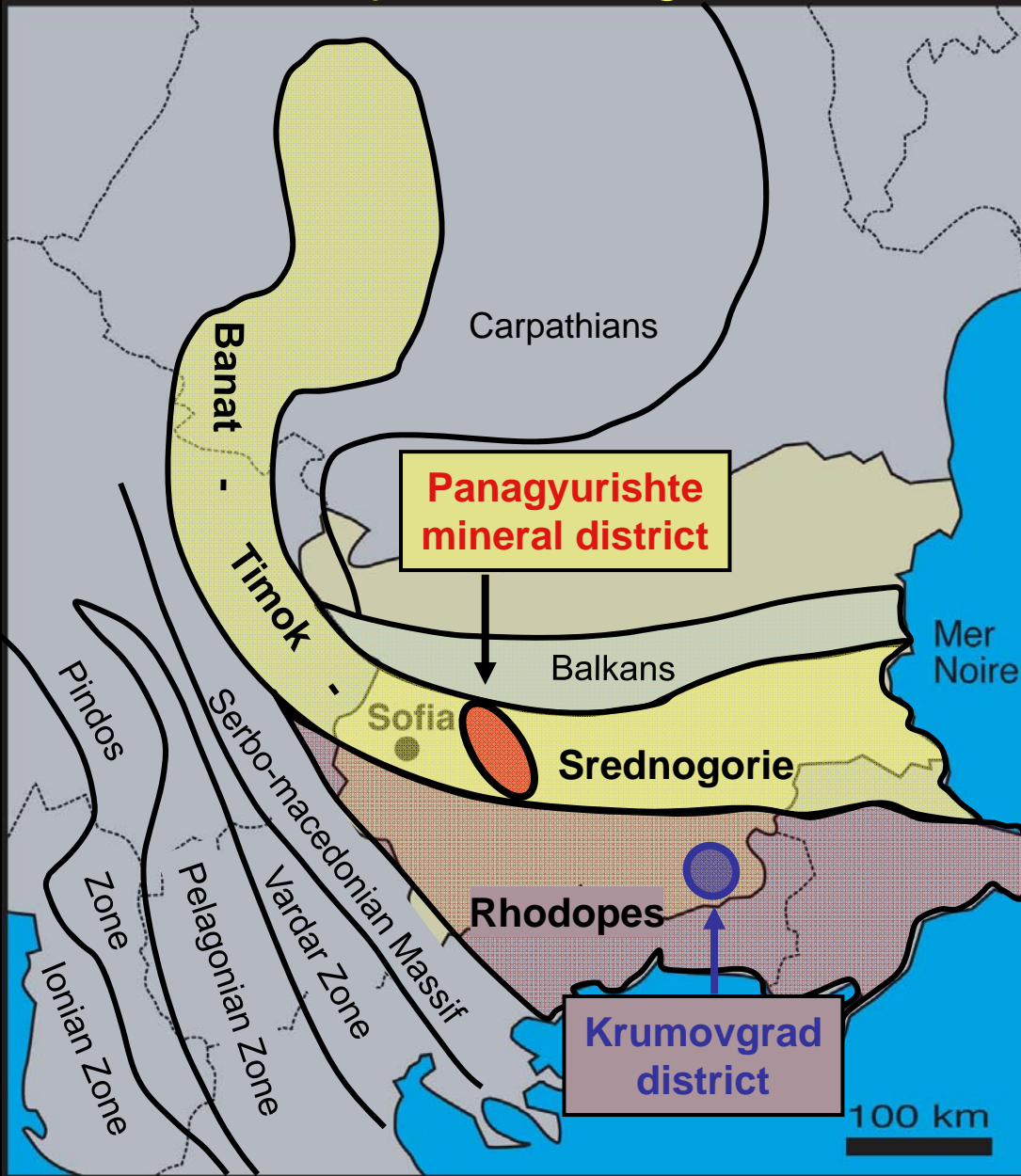
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Two major metallogenic zones in Bulgaria



Late Cretaceous Banat-Timok-Srednogorie Zone

~95% of Bulgarian Cu and Au has been produced in Panagyurishte district (Cu porphyries and epithermal):

Chelopech mine: one of the major European gold deposits (31 Mt - 3.5 g/t Au - 1.39% Cu).

Tertiary Rhodope Massif

Major recent gold discoveries:

Ada Tepe prospect (6.15 Mt - 4.6 g/t Au).

After Popov (1996)

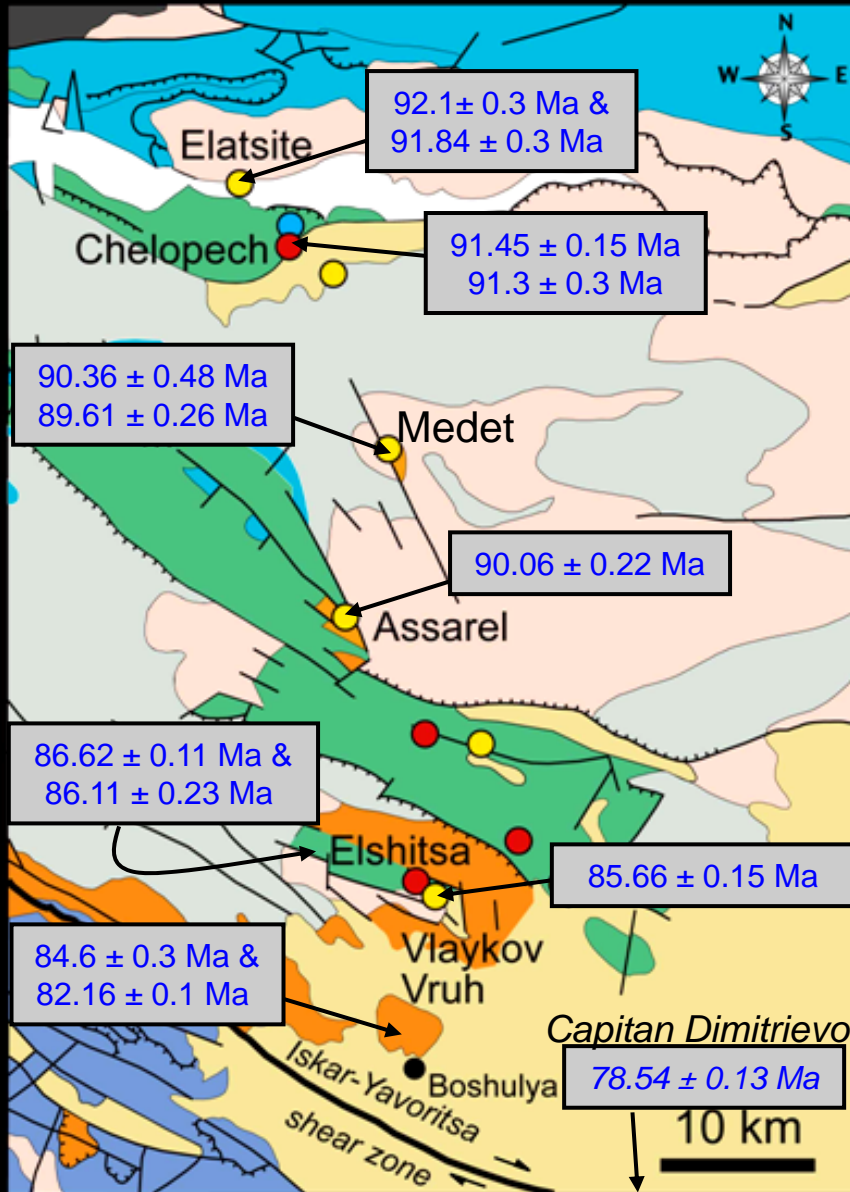
Geology and ore deposits of the Panagyurishte district



- Cainozoic sedimentary rocks
- Upper Cretaceous volcanic & sedimentary rocks
- Upper Cretaceous granitic rocks
- Triassic & Jurassic sedimentary rocks
- Paleozoic granitic rocks
- Lower Paleozoic metamorphic rocks
- Rhodopean type metamorphic rocks
- Srednogorie type metamorphic rocks
- Faults
- Thrusts
- Porphyry Cu-Au deposit
- Epithermal Cu-Au high-sulphidation deposit
- Epithermal vein-type base metal deposit

(After Cheshitev et al., 1995)

U-Pb ages of magmatic & ore forming events in the Panagyurishte district

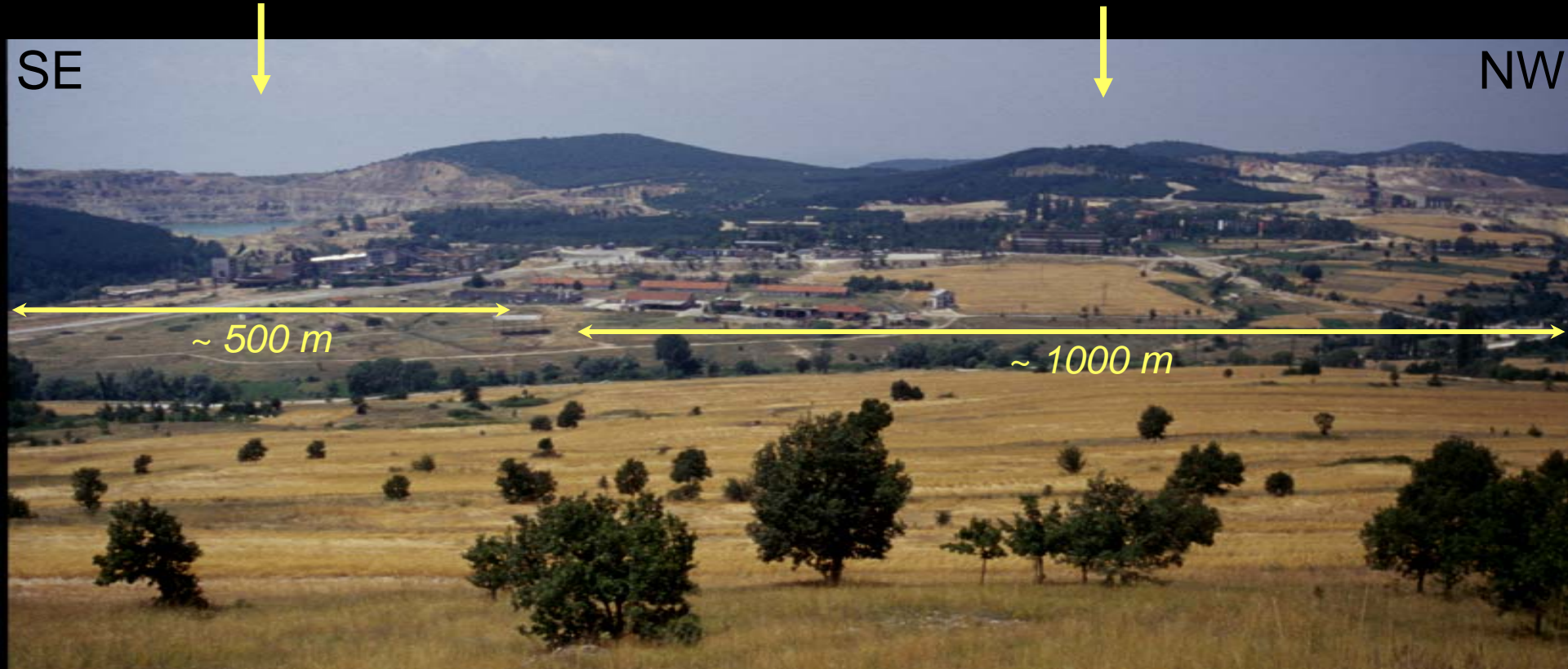


- Progressive age decrease from north to south of magmatic and ore forming events.
- Attributed to slab retreat, slab roll-back.
- Roughly coeval porphyry-Cu and high-sulfidation epithermal ore formation in a given locality.

Southern Panagyurishte mineral district

Vlaykov Vruh
Porphyry-Cu deposit

Elshitsa
Epithermal Cu-Au deposit



Chelopech: paragegenetic sequence



I: Massive banded pyrite

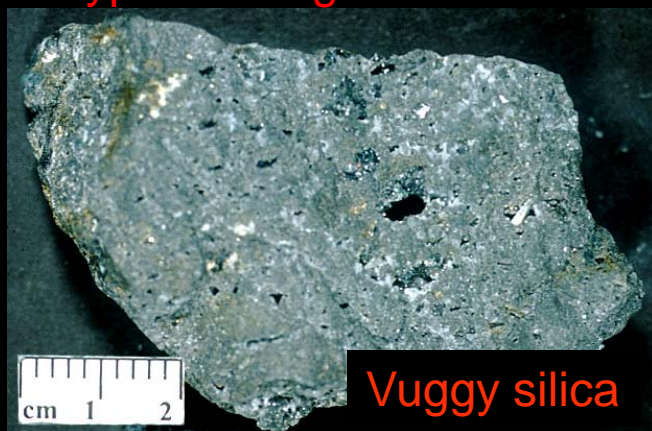


IIa: Enargite-Luzonite



IIb: Tennantite-Bornite
Chalcopyrite-Gold

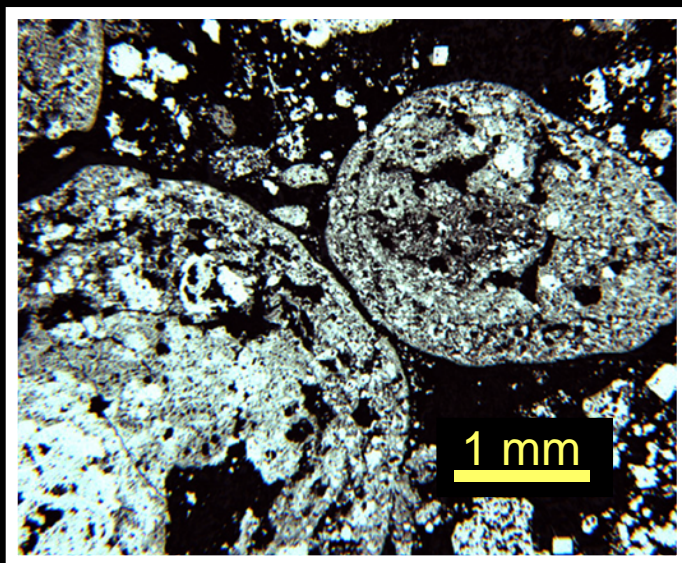
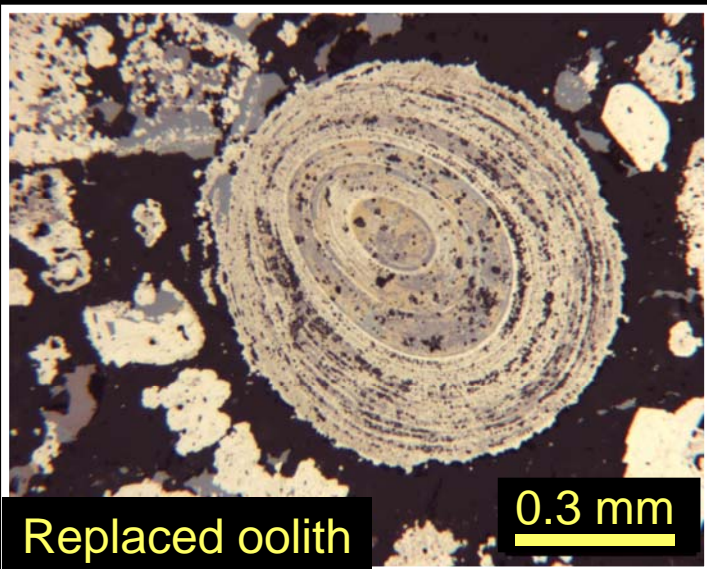
Advanced argillic alteration
Typical of high-sulfidation



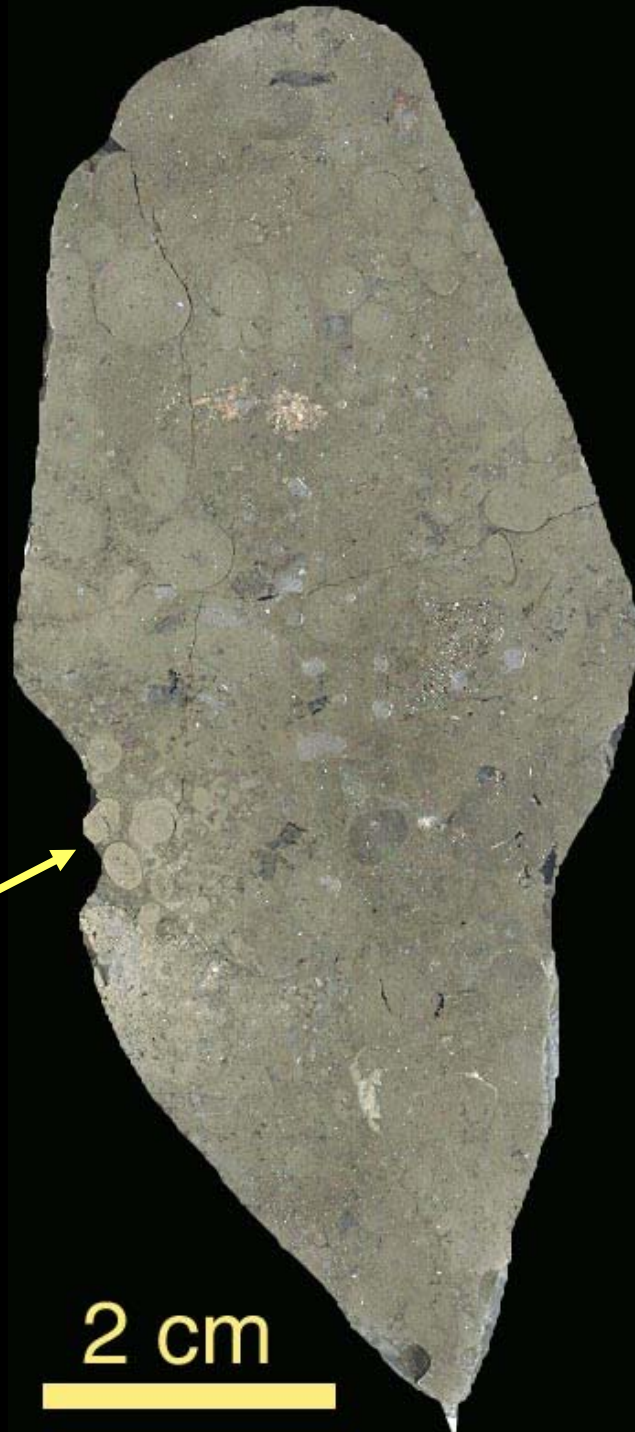
Vuggy silica



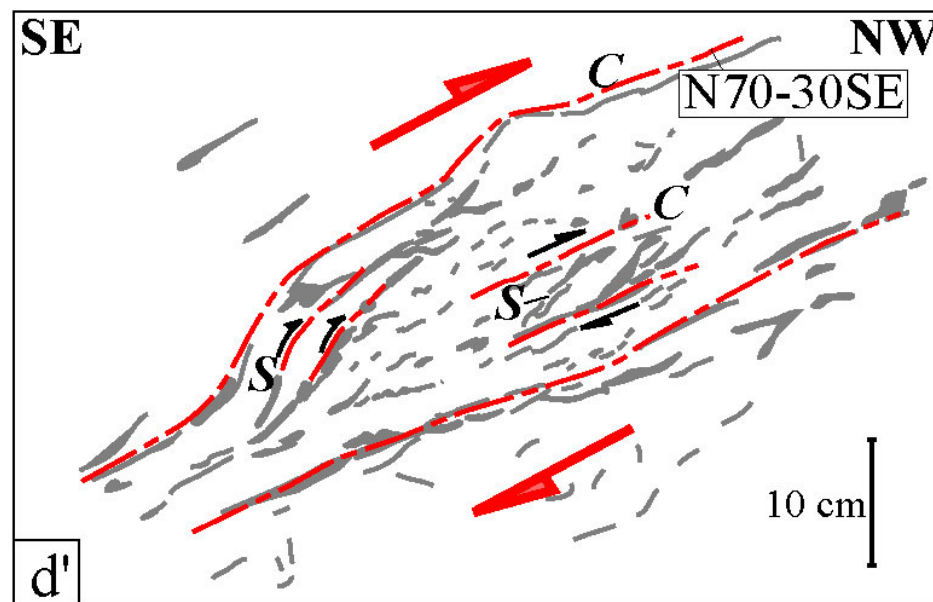
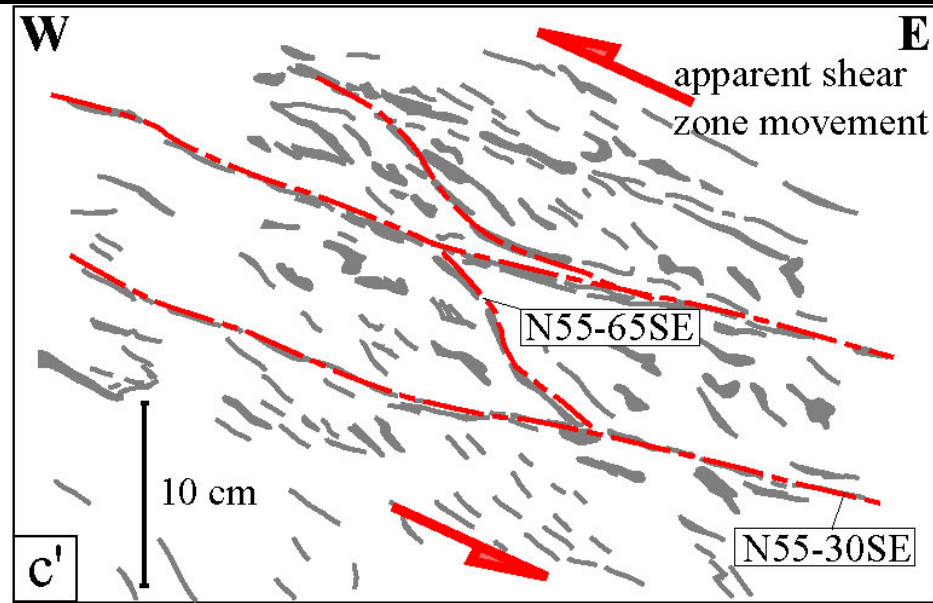
III: Sphalerite-Galena-Pyrite
-Baryte



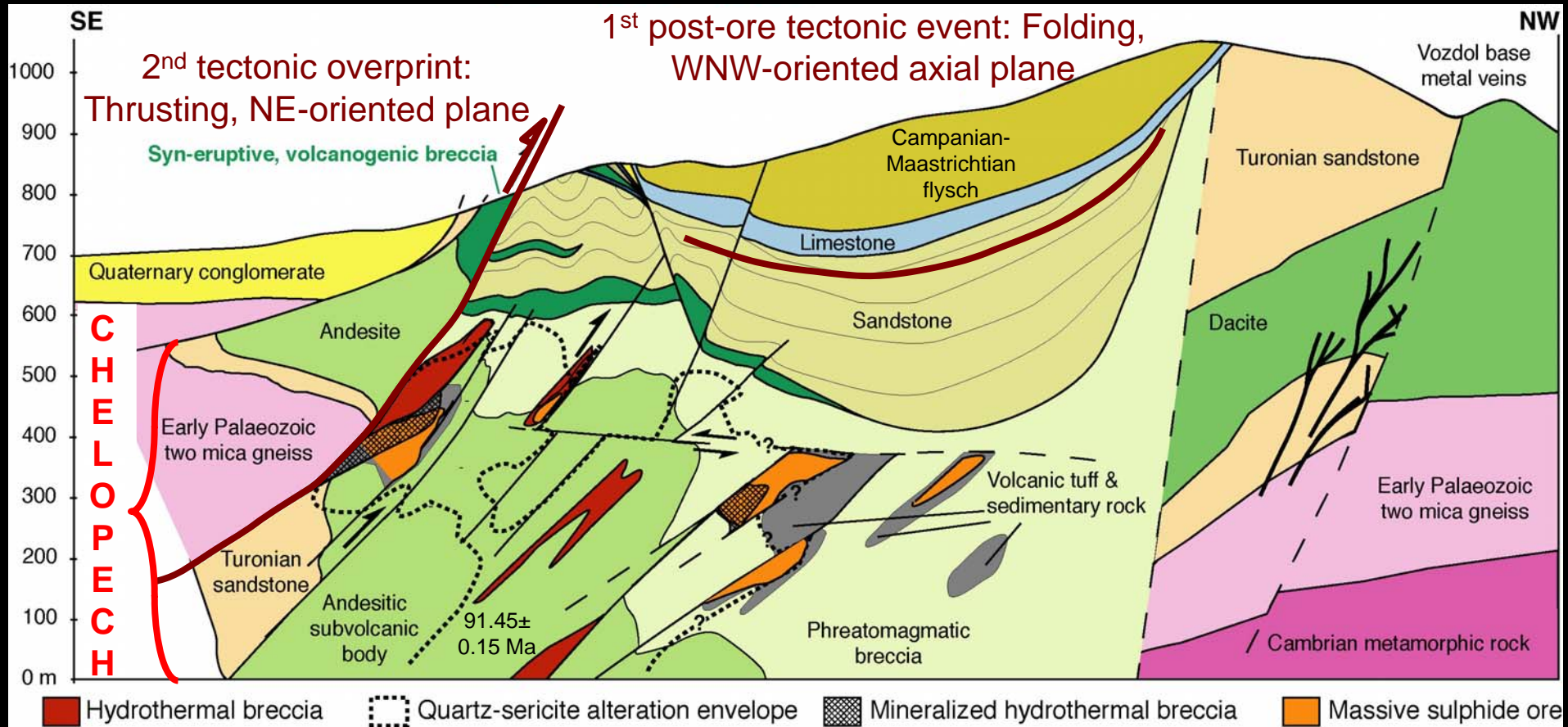
Replaced accretionary lapilli



Alpine tectonic overprint at Chelopech (*Chambefort & Moritz, 2006*)



Post-ore formation tectonic overprint at the Chelopech high-sulfidation deposit

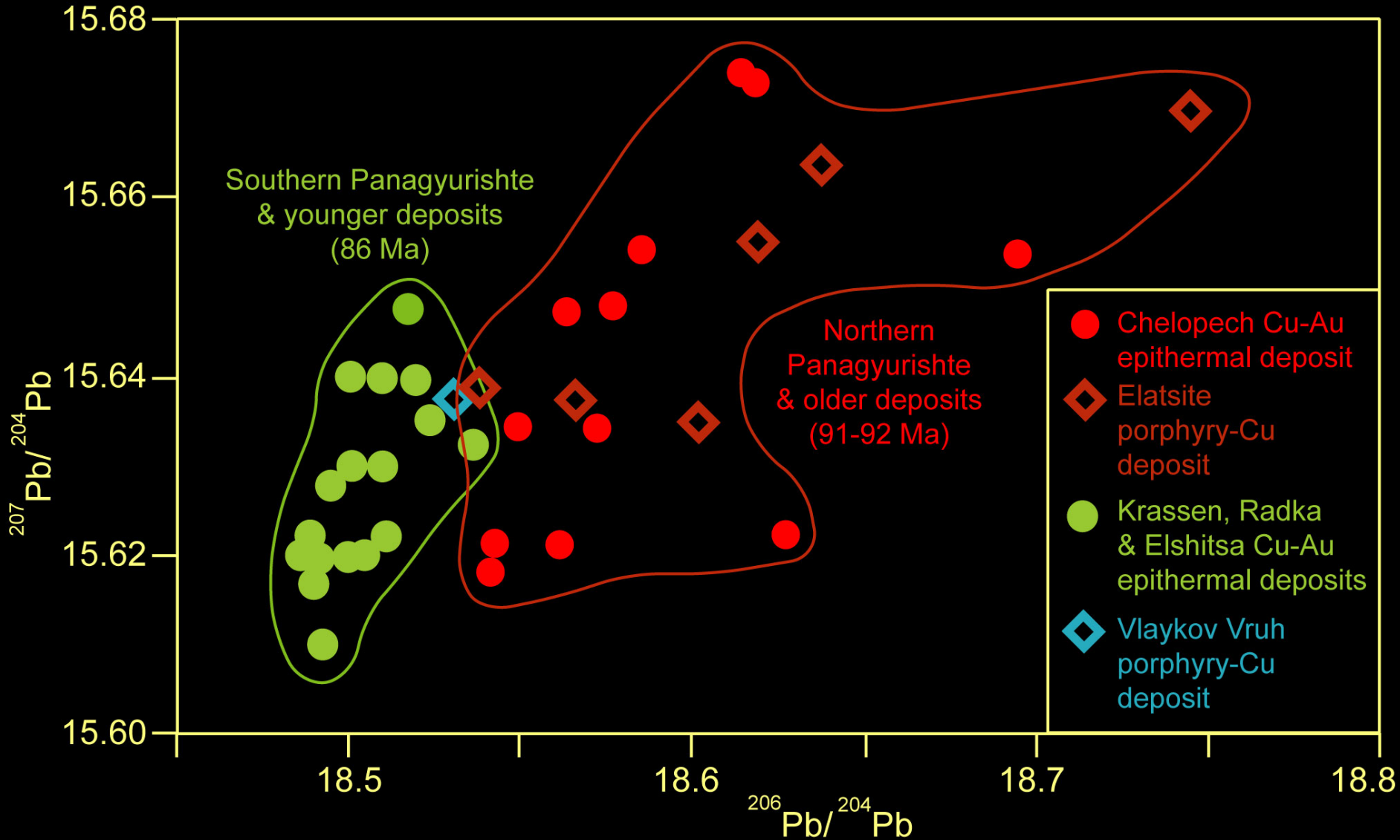


Chambefort and Moritz (2006)

Exceptional preservation of the Late Cretaceous epithermal deposit attributed to:

- Turonian to Maastrichtian sedimentary rock cover, &
- Tertiary (?) NE-oriented thrusting (linked to recent dextral strike-slip tectonics?).

Same metal source in epithermal Cu-Au & porphyry-Cu deposits from the Panagyurishte district: Pb isotope data from sulfides

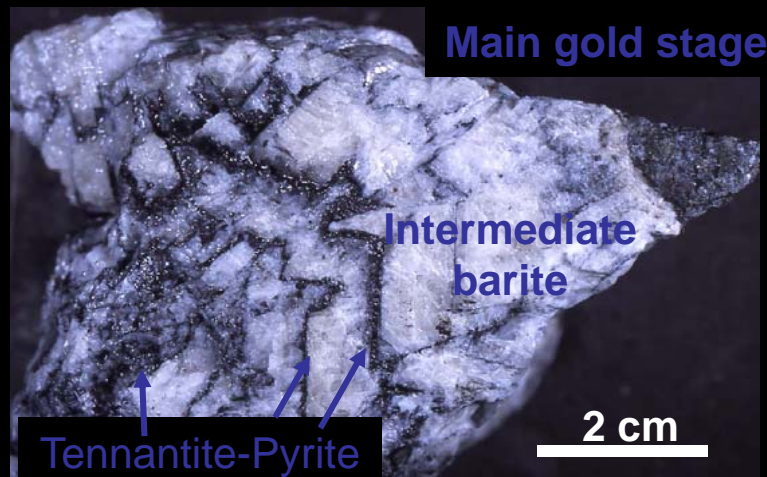


Data sources - Chelopech: Moritz (unpublished); Elatsite: Von Quadt et al. (2002);
Krassen-Radka-Elshitsa-Vlaykov Vruh: Kouzmanov et al. (submitted) & Amov (1986).

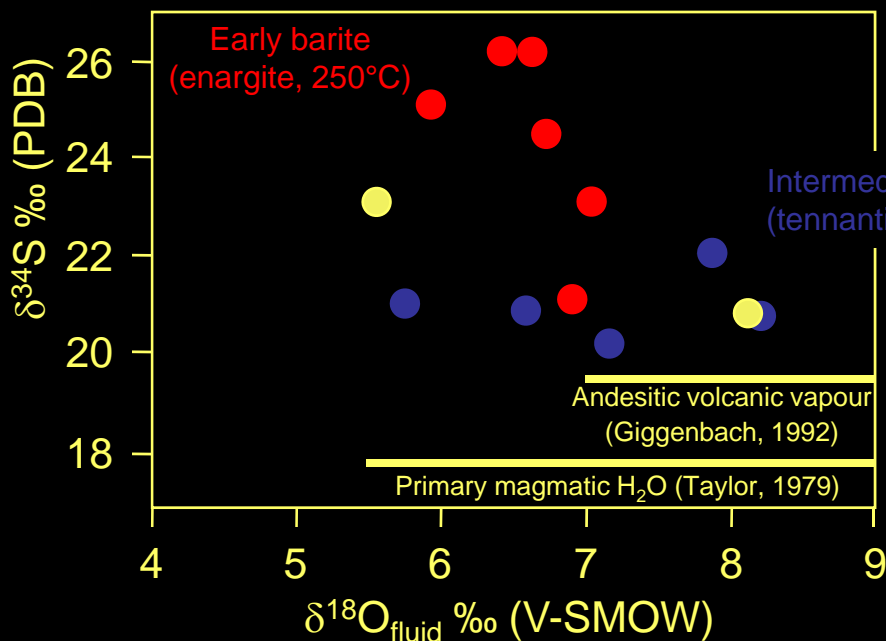
Isotopic composition of different barite generations at the Chelopech high-sulfidation deposit: main ore stage



S isotope thermometry = 240-250°C
 Th fluid inclusions enargite = 200-243°C



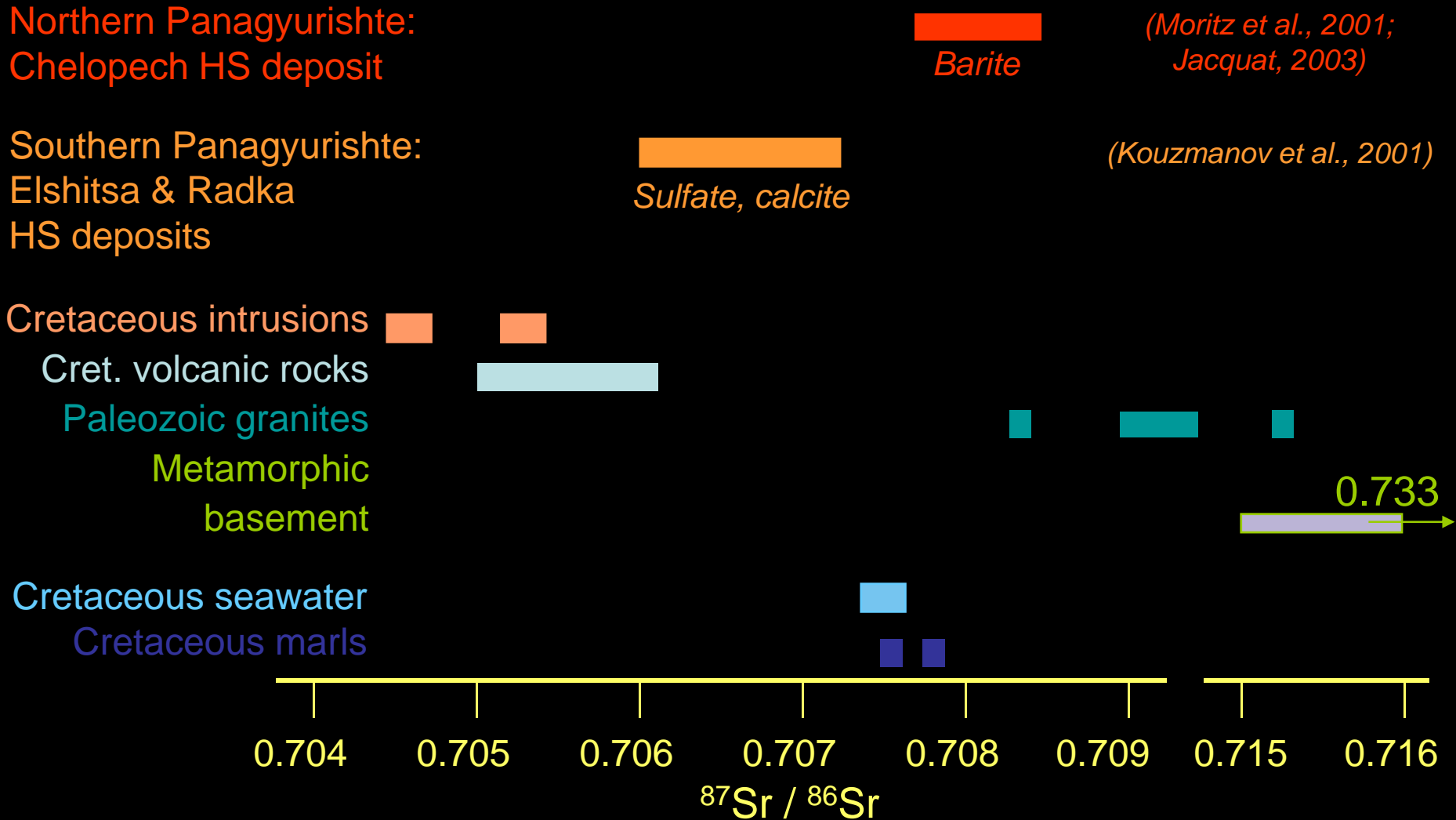
S isotope thermometry = 218-222°C
 S isotope thermometry, late
 Pb-Zn-Ba stage (post-gold): 226°C



Oxygen isotopic compositions:
 Predominantly magmatic origin

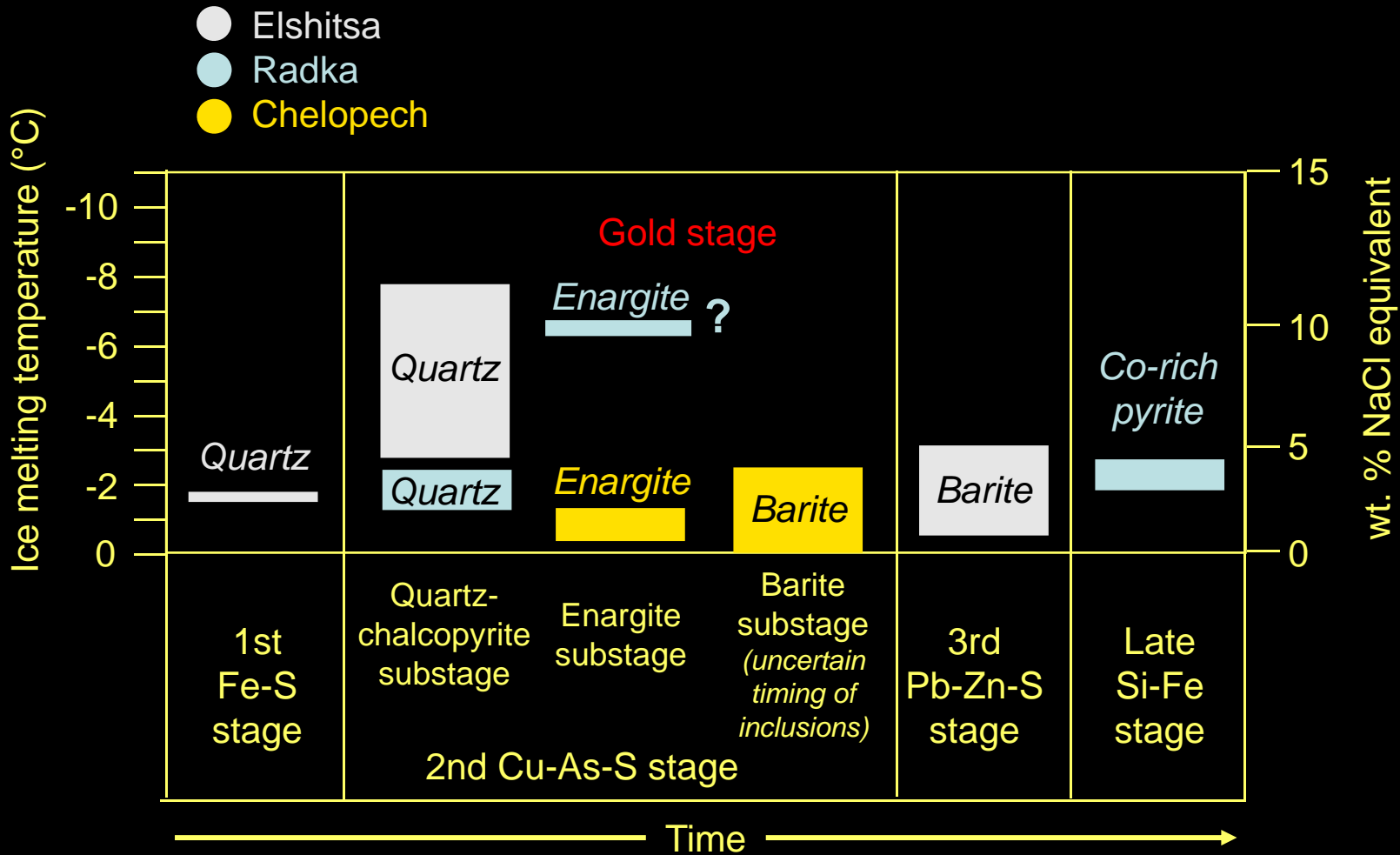
Sulfur isotopic compositions:
 Magmatic origin

Sr isotopes: ore fluid-basement rock interactions in the epithermal ore deposits from the Panagyurishte district

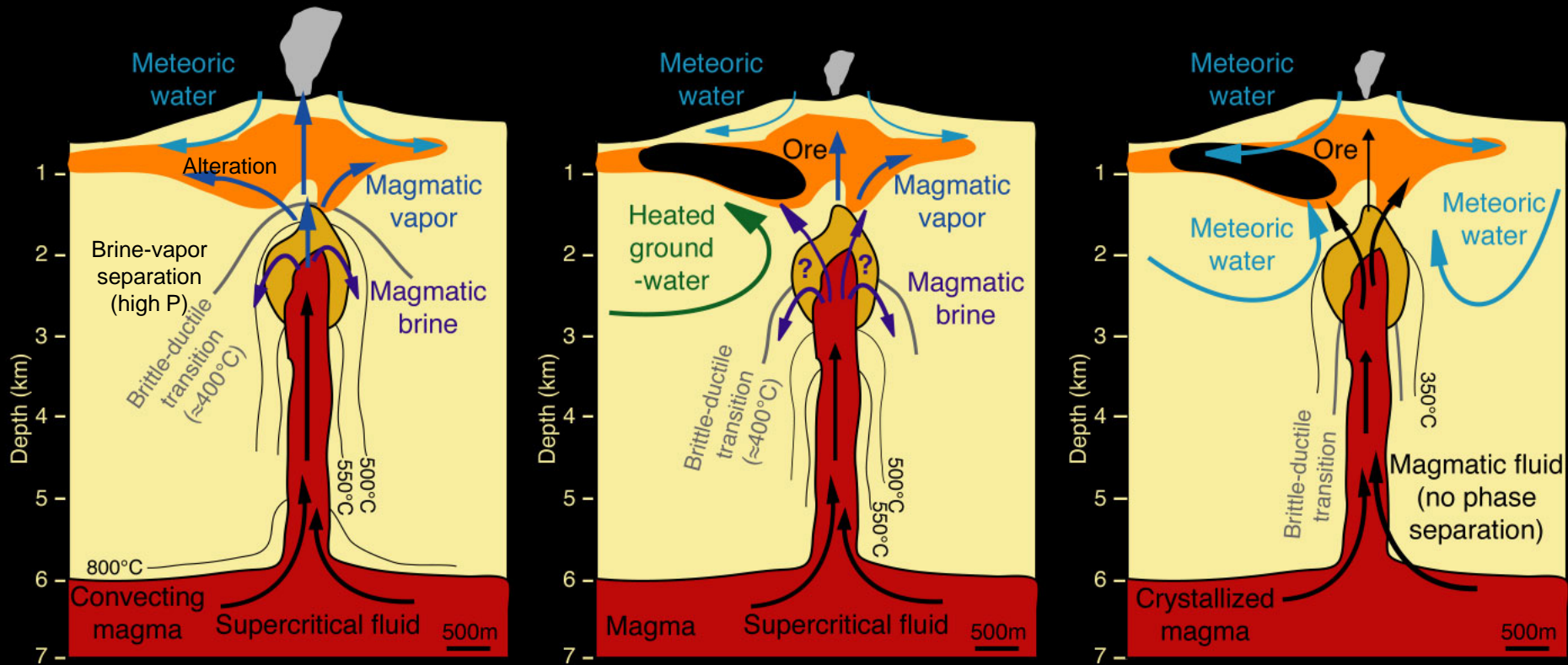


Whole-rock data corrected for 80 Ma & 90 Ma in the Southern & the Northern Panagyurishte district, respectively.

Fluid inclusion salinities in HS epithermal Cu-Au deposits from the Panagyurishte district (fragmentary data)

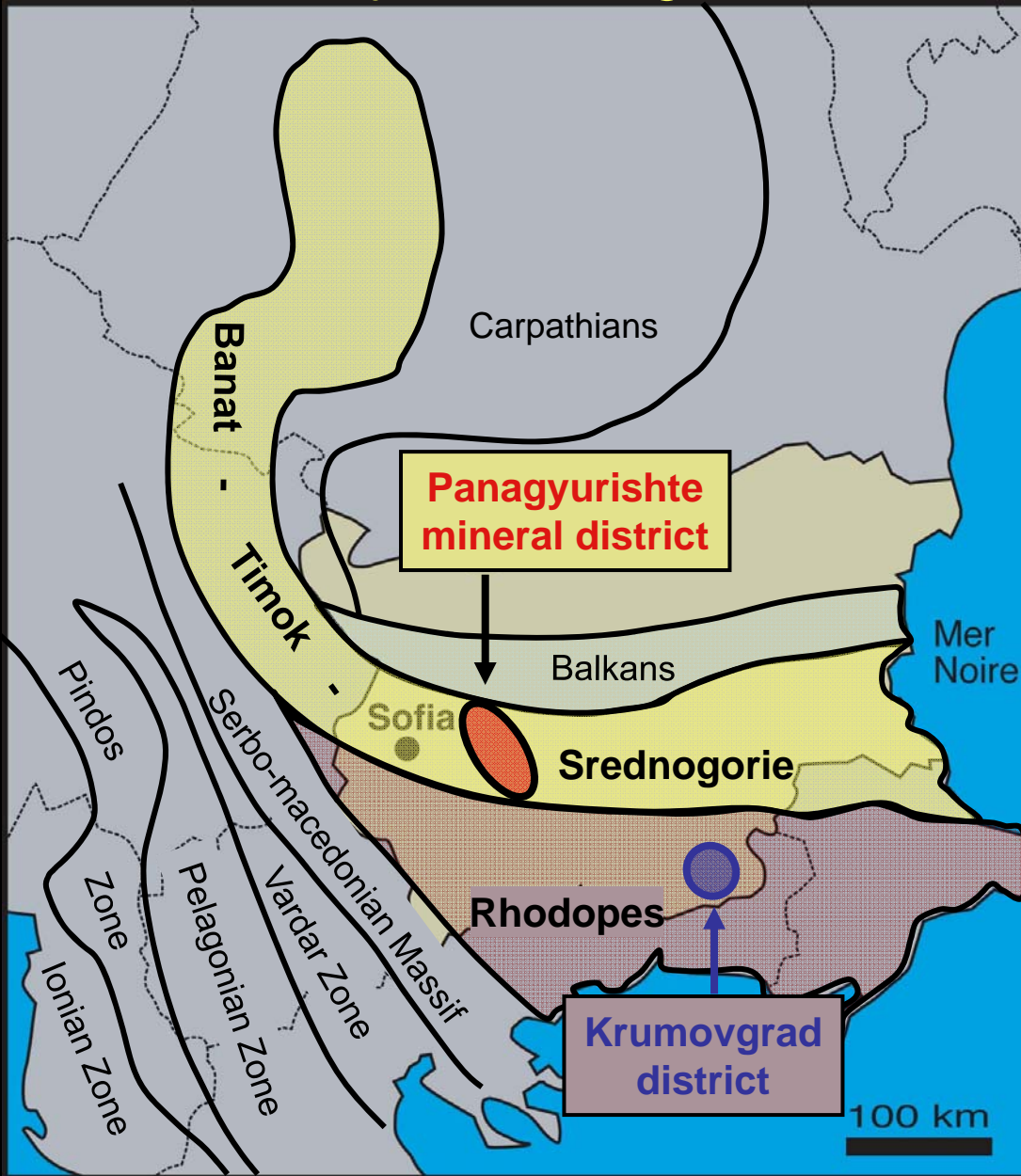


High sulfidation - porphyry relationship



After Arribas (1995), Shinohara & Hedenquist (1997), Fournier (1999) & Heinrich et al. (1999)

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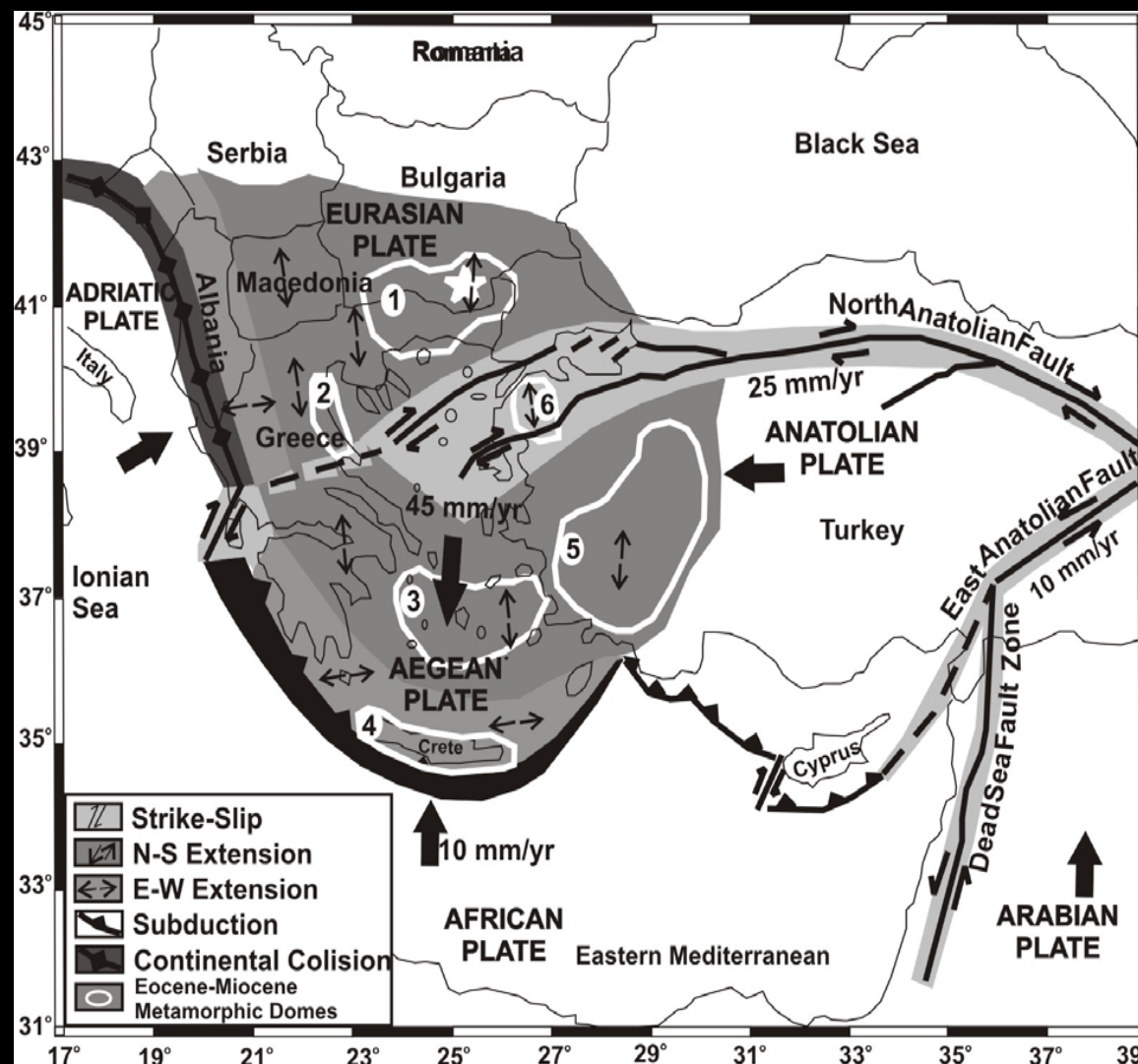
Tertiary Rhodope Massif

Major recent gold discoveries:

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After Popov (1996)

Eastern Rhodopes: Regional tectonic control



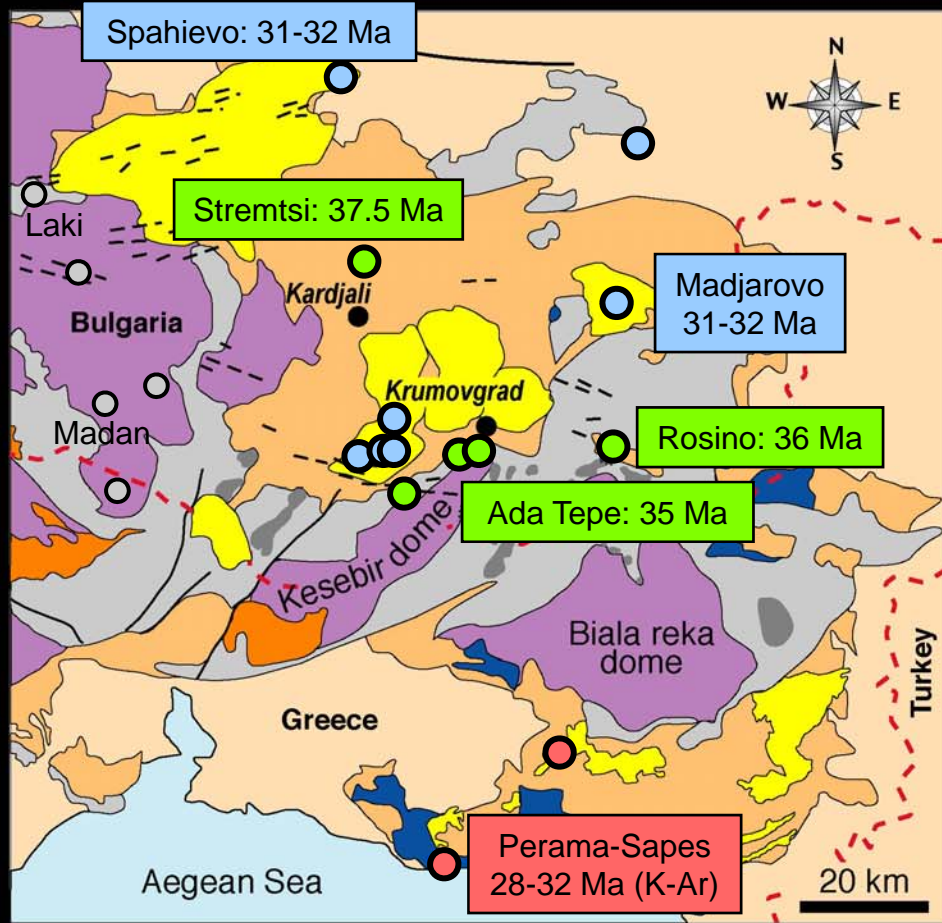
✓ Since the Cretaceous the Aegean Region experienced series of continental collision events, followed by syn- and post-orogenic extension in back arc region.

✓ Tertiary extension: dome complex formation, fast uplift, followed by volcanic activity.

✓ One of the most active, present day continental extensional setting in the world: rapid stretching of upper crust and exhumation of lower crust.

✓ Similarities with Basin and Range Province: extensional back-arc tectonic setting considered to be the first order control for Carlin gold province

Tertiary epithermal prospects in Rhodopes

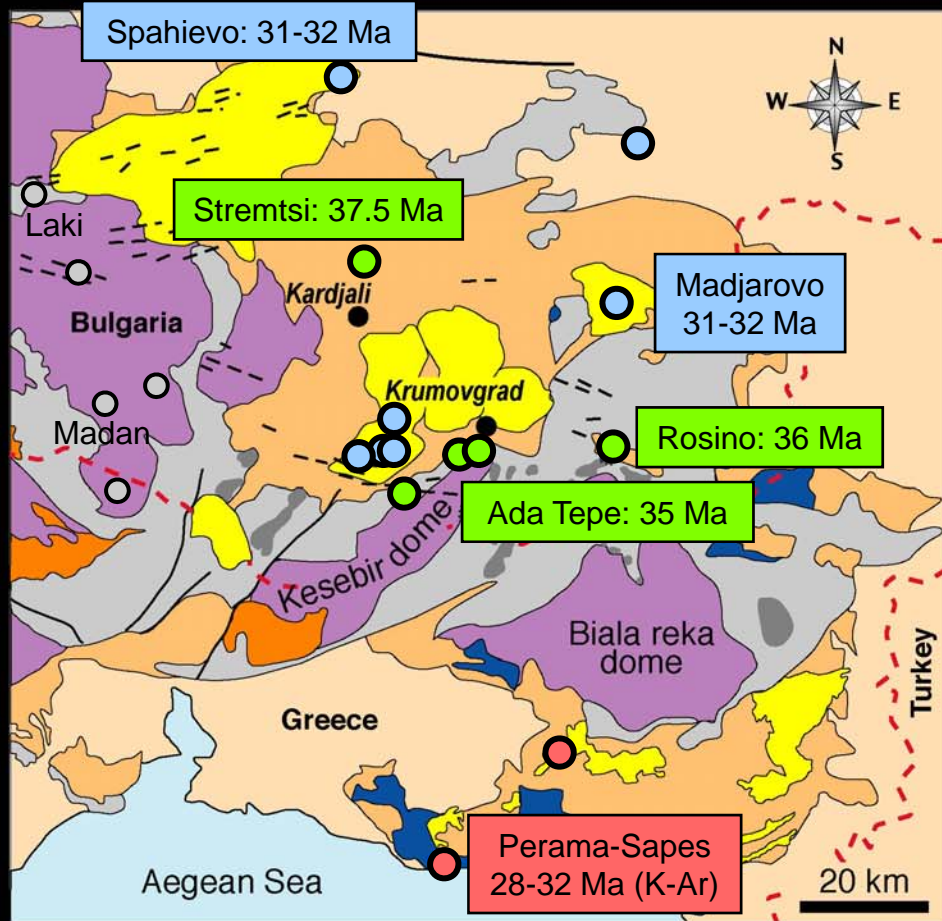


- Metamorphic-hosted Pb-Zn replacement & vein deposits (29-31 Ma)

- Volcanic-hosted base metal ± gold ± silver epithermal deposits ($^{40}\text{Ar}/^{39}\text{Ar}$ ages, Singer & Marchev, 2000; Marchev & Singer, 2002).
- Volcanic-hosted gold-copper epithermal deposits (K-Ar ages, Pècskay et al., 2003).
- Sedimentary rock-hosted low sulfidation epithermal gold deposits ($^{40}\text{Ar}/^{39}\text{Ar}$ ages, Marchev et al., 2004; Spikings, 2007, pers. comm.).

Unrelated to and older than local magmatism.
Associated with metamorphic core complexes.
Origin of ore-forming fluids: still a matter of debate.

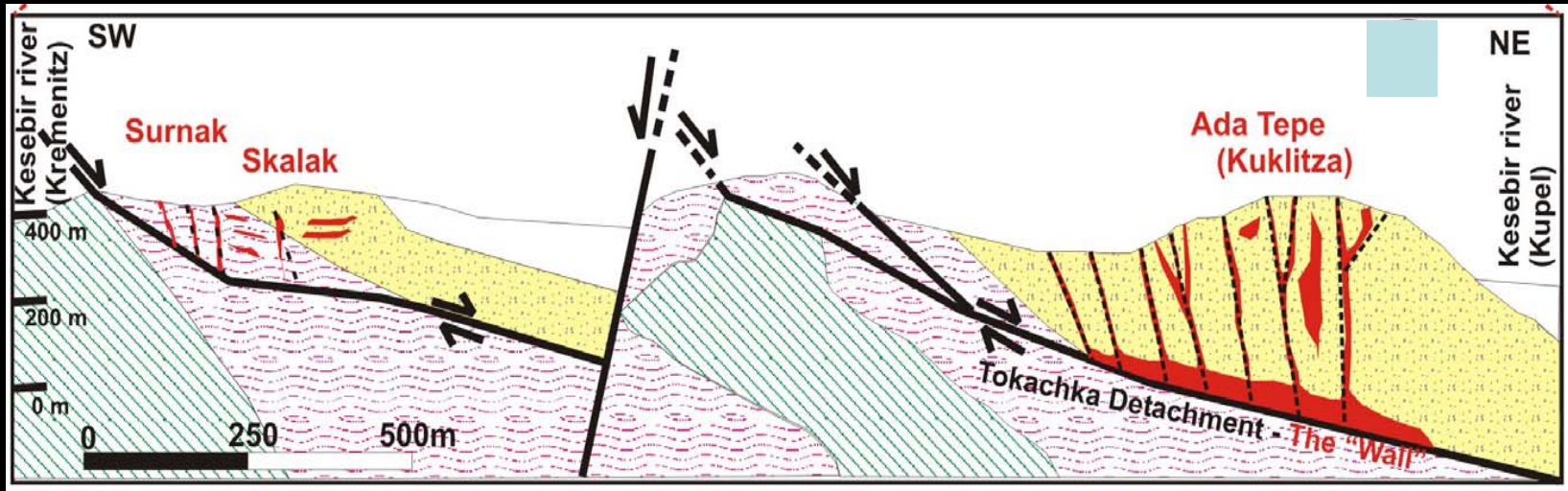
Tertiary epithermal prospects in Rhodopes



Sedimentary rock-hosted, low sulfidation epithermal prospects:

The $^{40}\text{Ar}/^{39}\text{Ar}$ age range (~35-37.5 Ma) indicates that on a regional scale, this was a long-lasting metallogenic event (extensional tectonics).

Tertiary sedimentary rock-hosted low sulfidation epithermal prospects



- Combined lithological and structural control on ore body geometry.
- Massive, siliceous ore body formed at the hanging wall of detachment.
- Steeply dipping veins in Tertiary breccia conglomerates.



Tertiary sedimentary rock-hosted low sulfidation epithermal prospects

The coincidence of feeder, reactive and permeable lithologies favored gold transport and precipitation over extended areas.

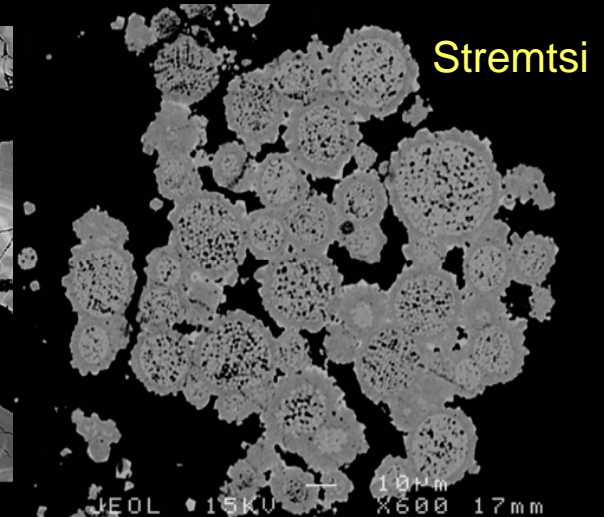
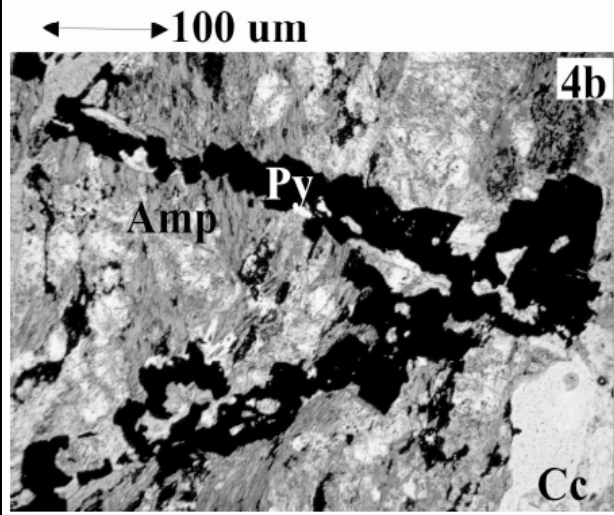
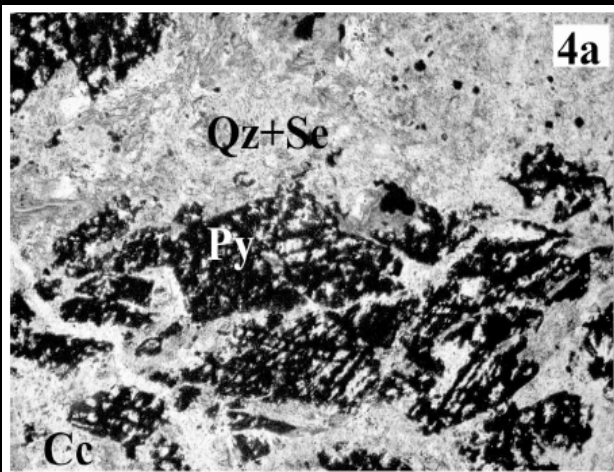


- Some rock units acted as major pH buffers ==> minor impact on desulphidation of an H₂S-bearing fluid.
- Reaction with marbles, marls and granitic rocks: acid neutralisation.
- H₂S-bearing fluid was maintained at near neutral pH conditions ==> transport of gold was optimized over extended areas.

Tertiary sedimentary rock-hosted low sulfidation epithermal prospects

Precipitation mechanisms: de-sulphidation, boiling & mixing ==> various ore types.

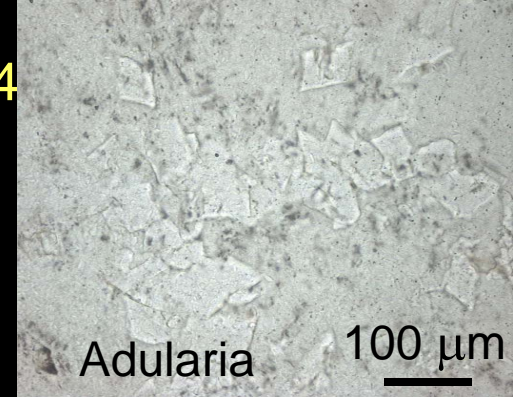
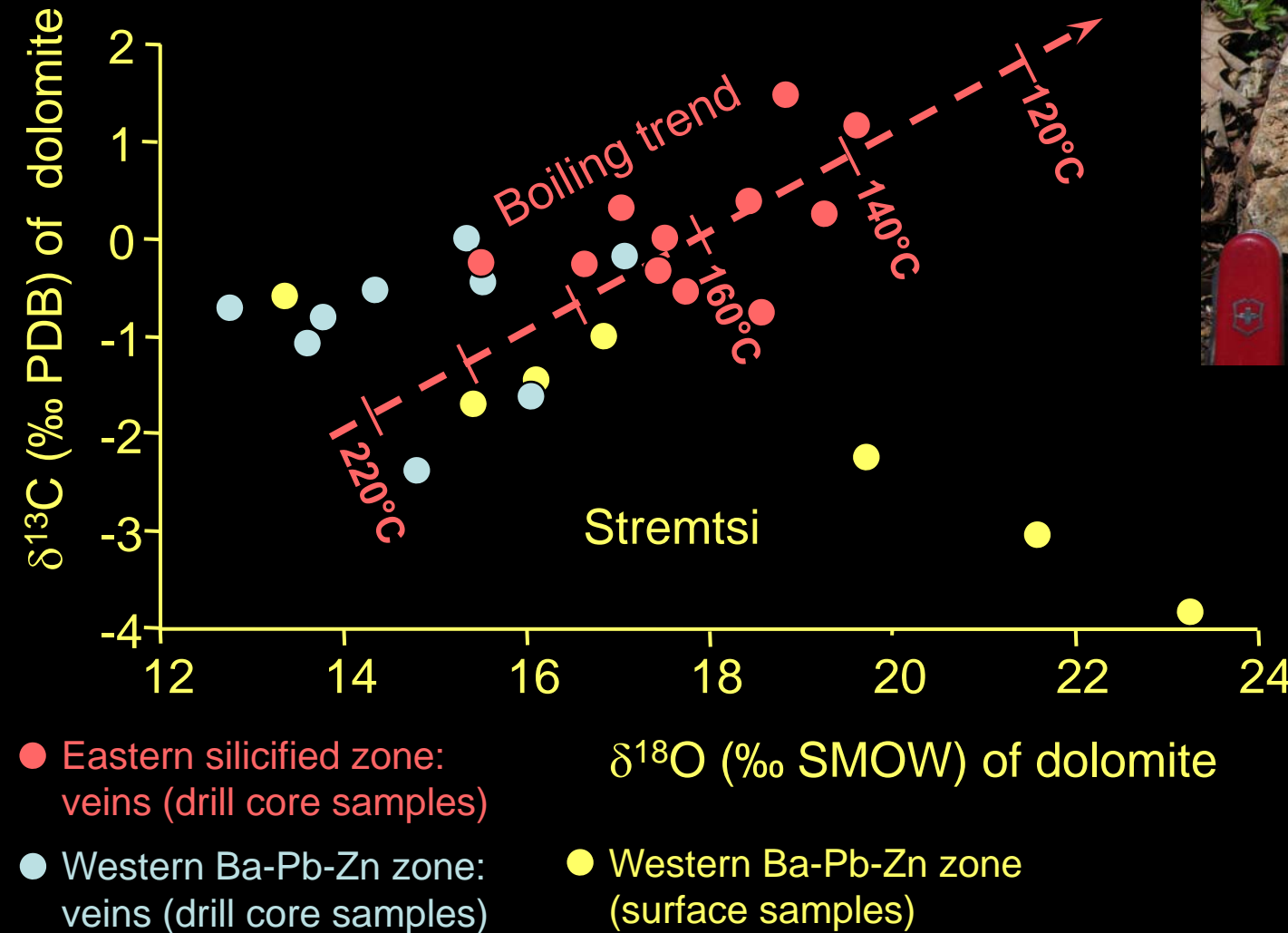
- Amphibolites & serpentinites, with Fe-bearing minerals: favourable for desulphidation of an H₂S-bearing fluid: Pyrite replaces amphiboles along cleavages & fractures.
- Sulphidation of Fe in host rocks favours precipitation of As-rich pyrite.



Up to 6-8 wt% As in pyrite rims

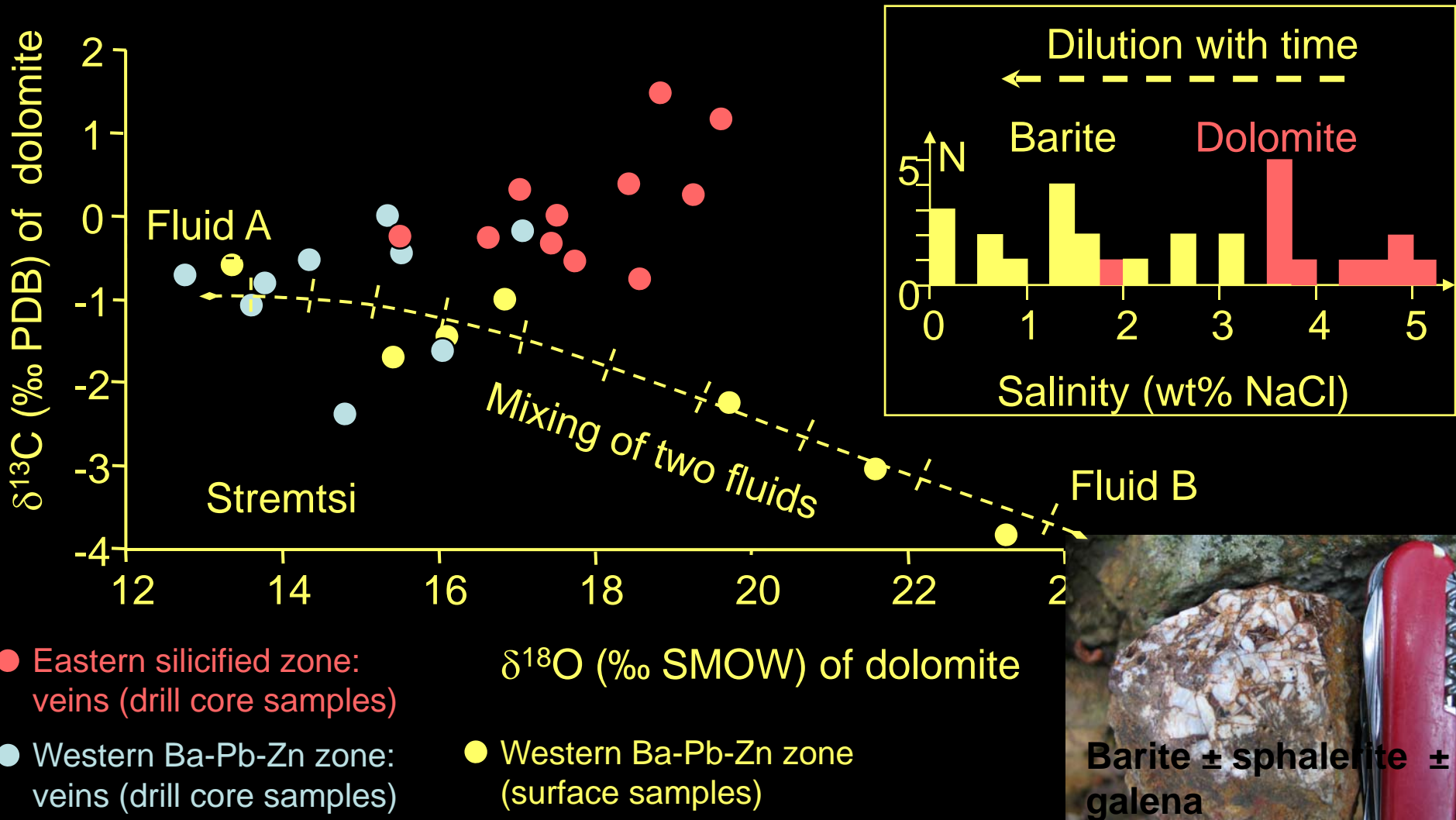
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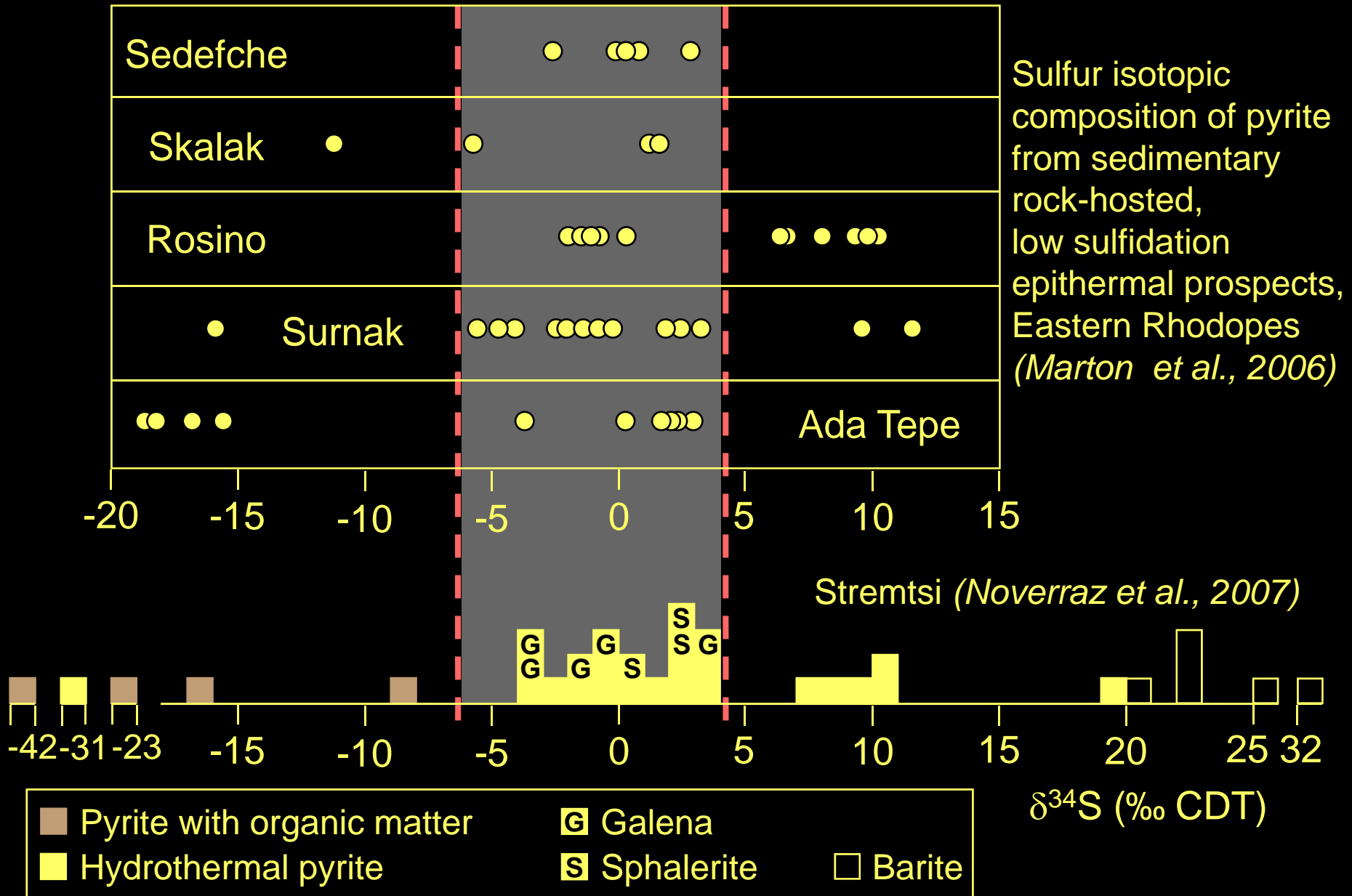


Tertiary sedimentary rock-hosted low sulfidation epithermal prospects

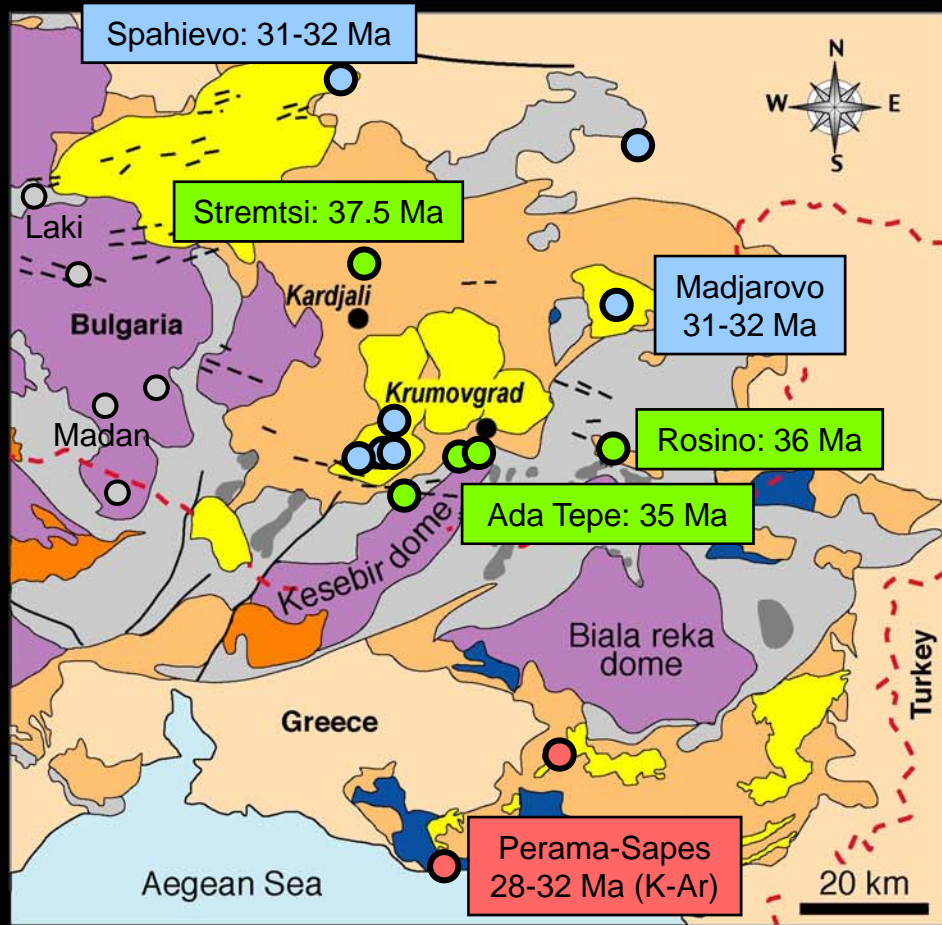
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$\delta^{34}\text{S}$ values: same fluid on regional scale



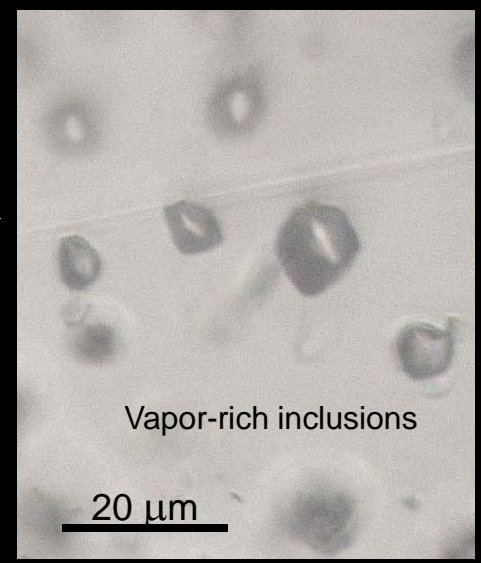
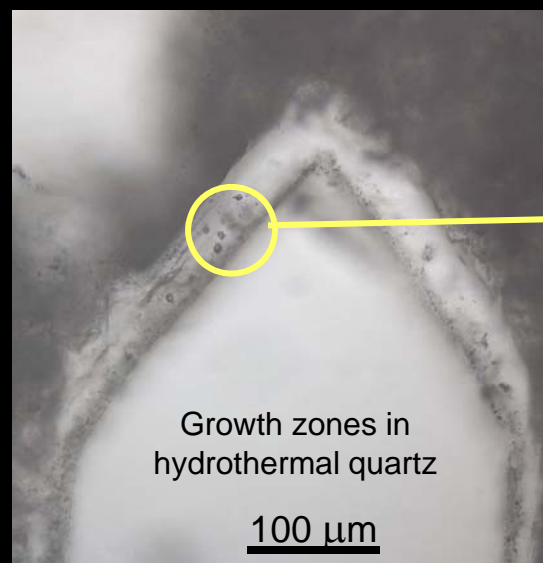
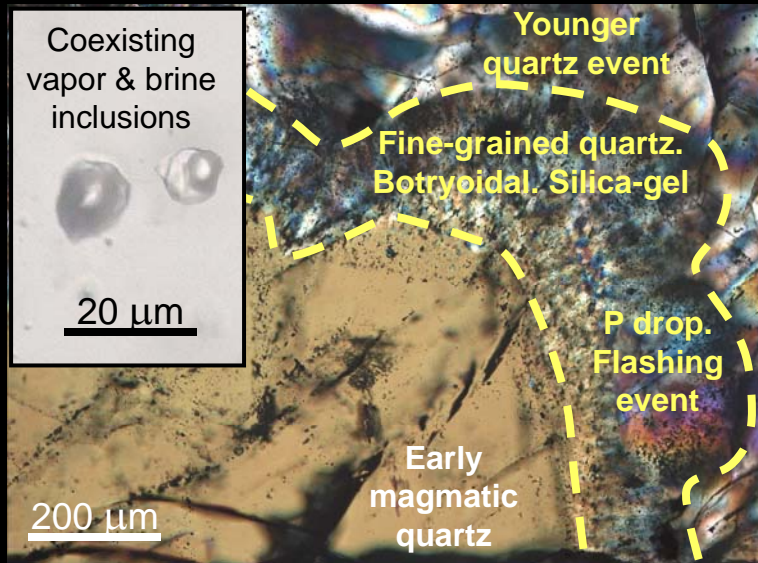
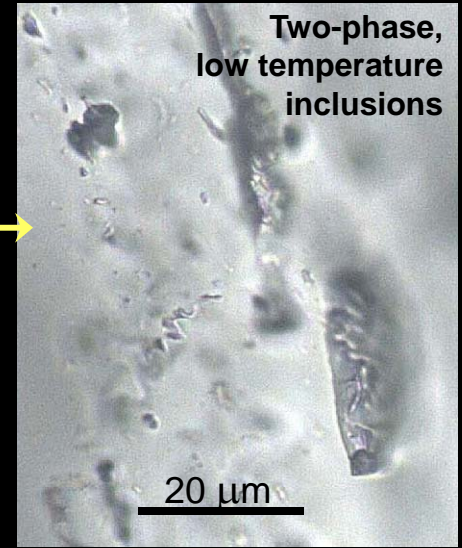
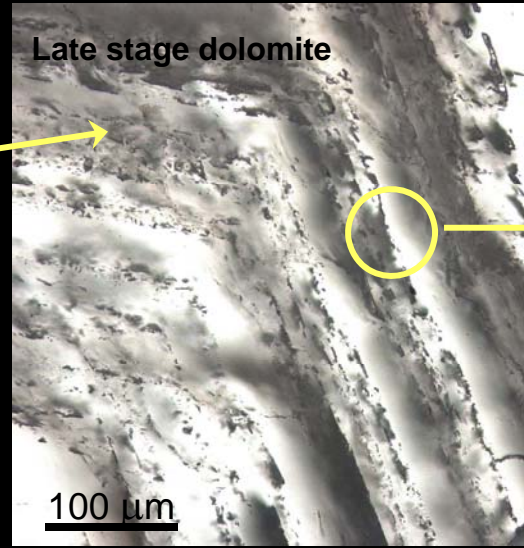
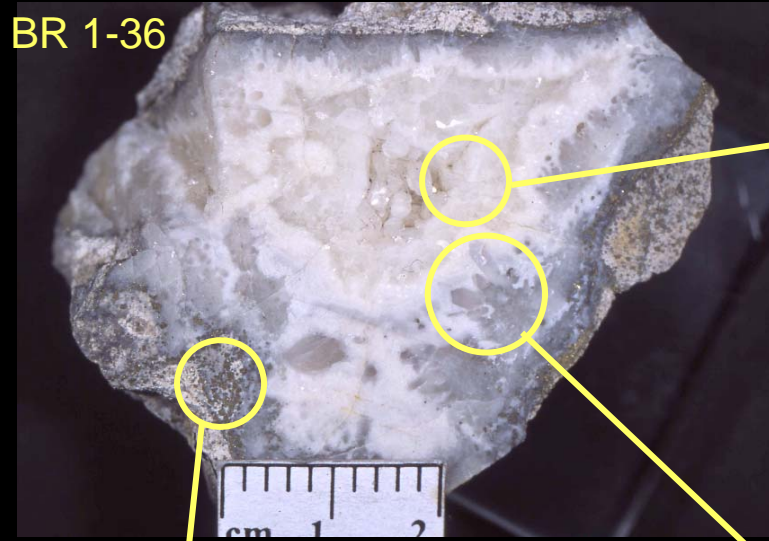
Tertiary epithermal prospects in Rhodopes



Sedimentary rock-hosted, low sulfidation epithermal prospects:

A regional, long-lasting event, which has a similar spatial extension as the deposits of the Carlin-trends or detachment-related gold deposits in the Western U.S.A.

Breznik: Paragenesis & fluid types



Breznik: Porphyry-epithermal:telescoping

