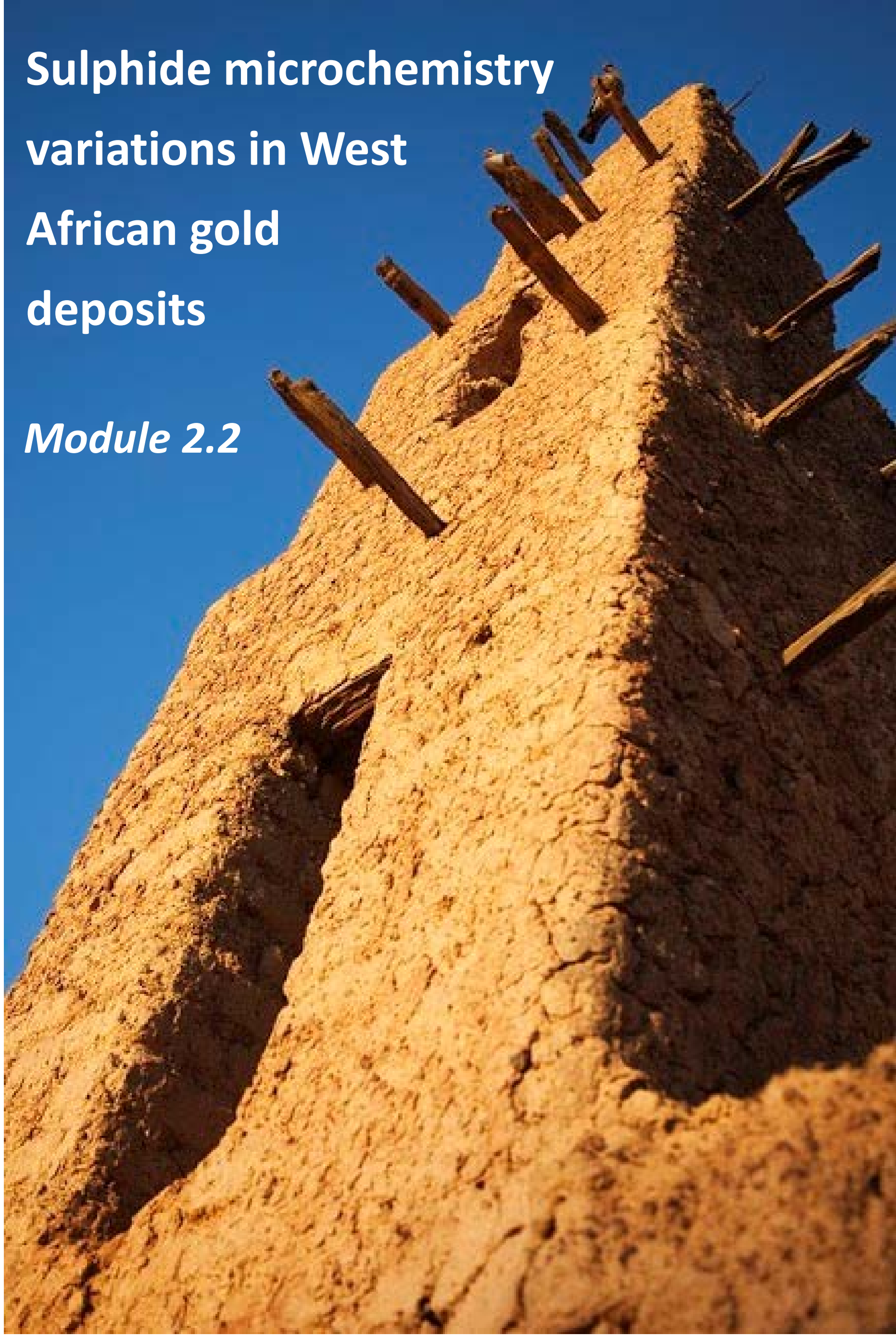
WAXI- West African Exploration Initiative

IXOA- L'Initiative d'Exploration Ouest Africaine

P934A West African eXploration Initiative



Sulphide microchemistry variations in West African gold deposits

Module 2.2

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Caracas, Venezuela

AMIRA INTERNATIONAL

Delivering solutions through collaboration

Centre for EXPLORATION TARGETING

WAXI - West African Exploration Initiative

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11 Sponsors in kind (Geological Surveys)

Liberia | Mali | Guinea | Niger | Burkina Faso

Ghana | Senegal | Togo | Sierra Leone | Mauritania

Côte d'Ivoire

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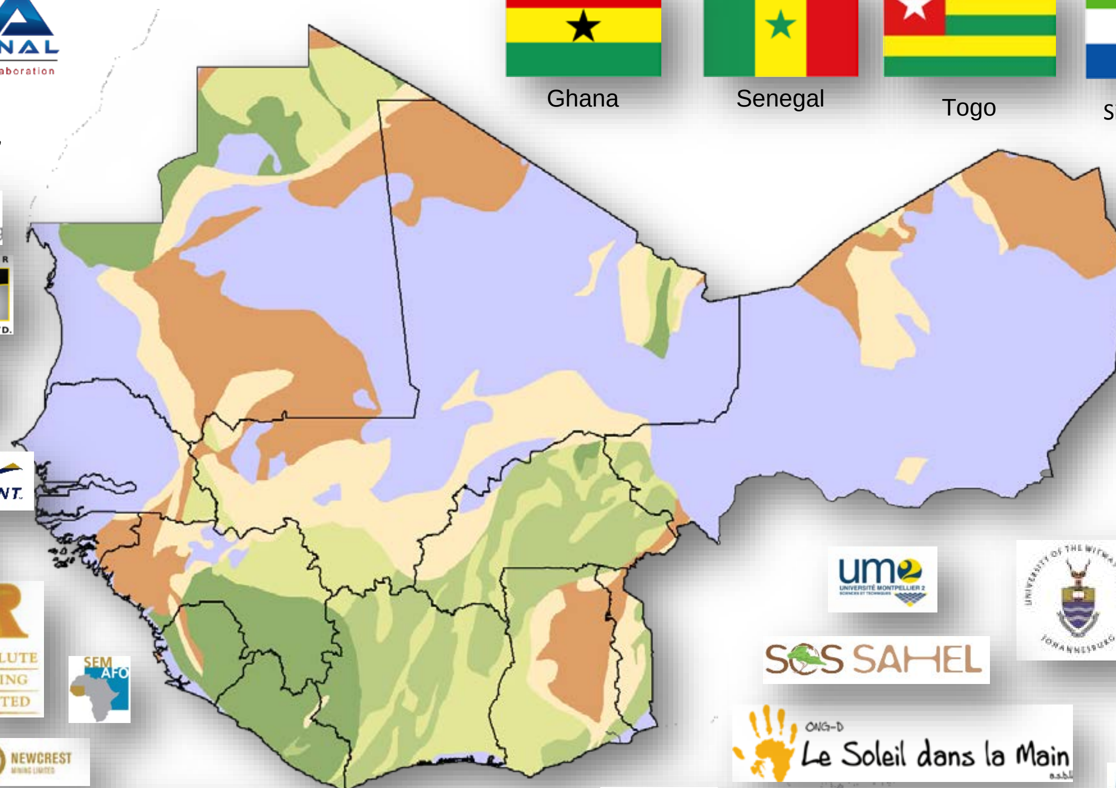
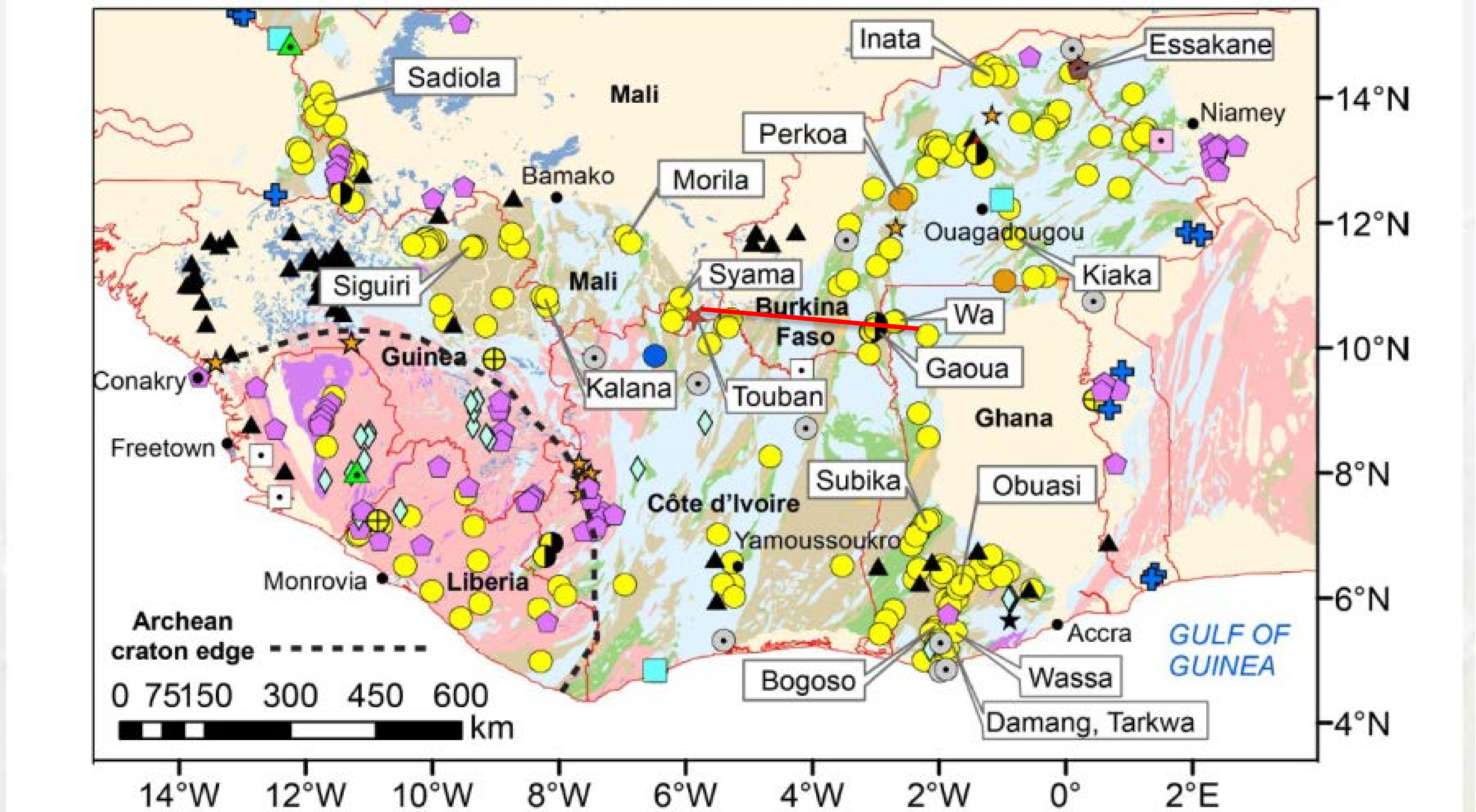
Delivering solutions through collaboration

36 Sponsors

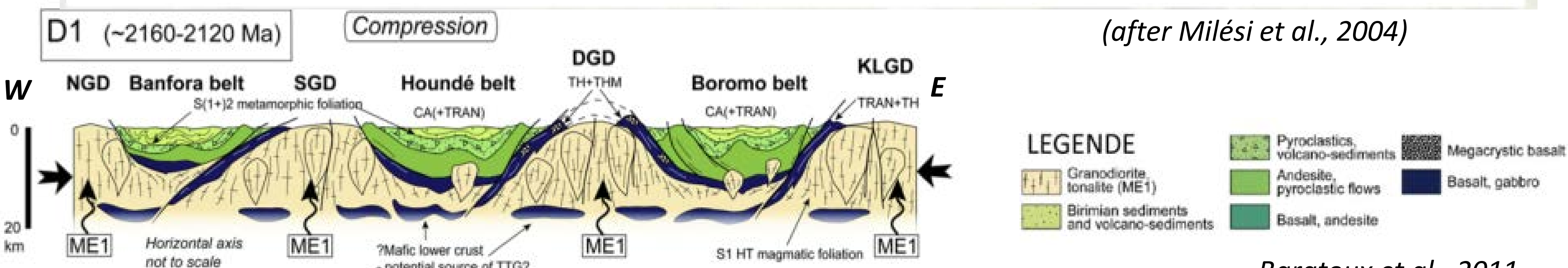


22 Research and Capacity Building Partners

→ 14 deposits studied



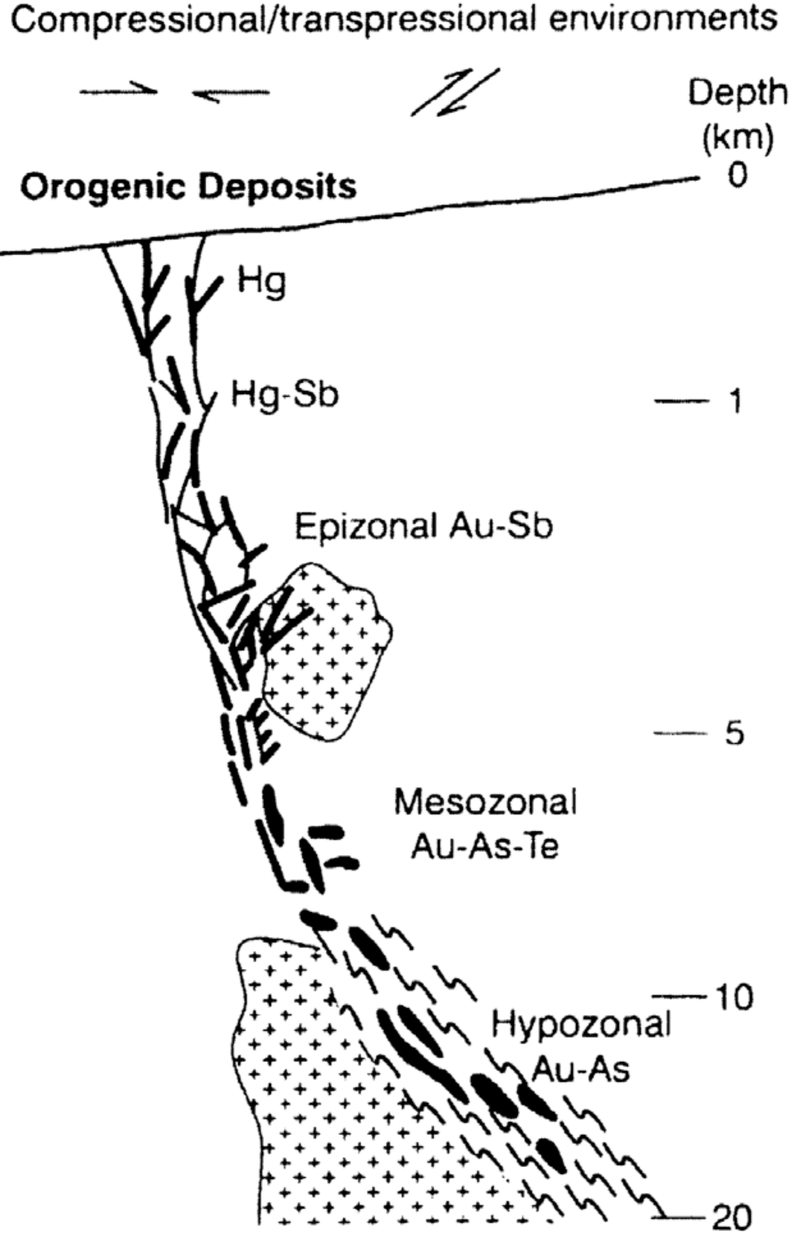
(after Milési et al., 2004)



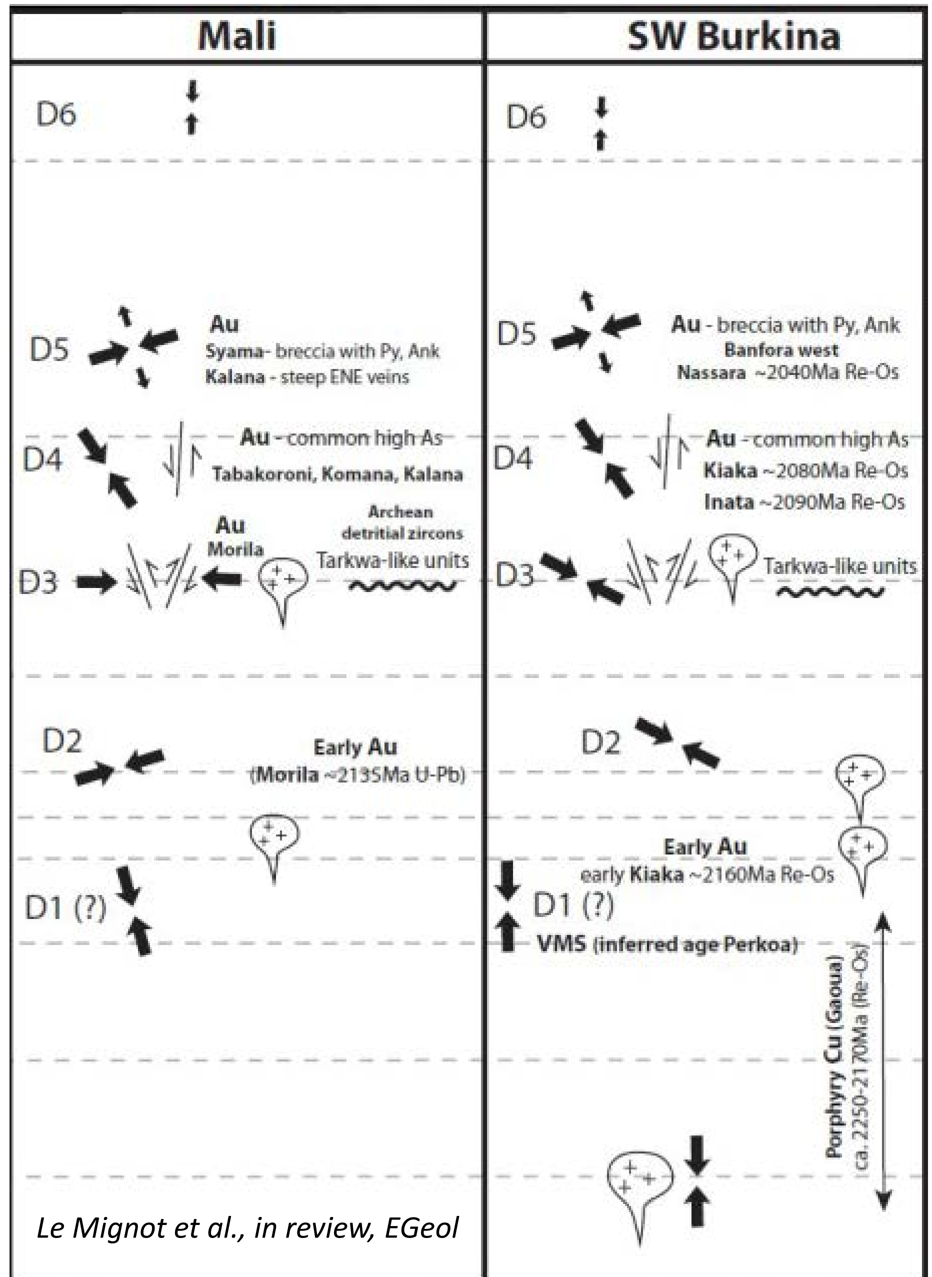
Baratoux et al., 2011

Orogenic gold deposits

→ Ebournean orogeny



Goldfarb et al., 2001

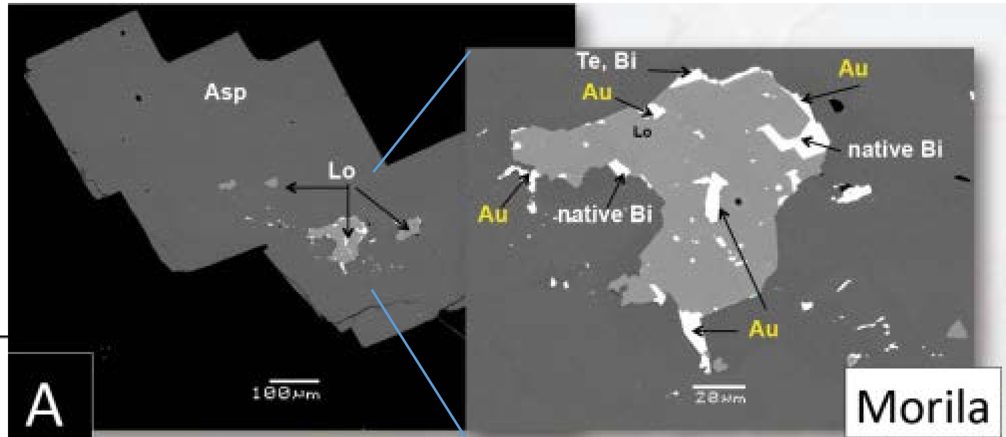


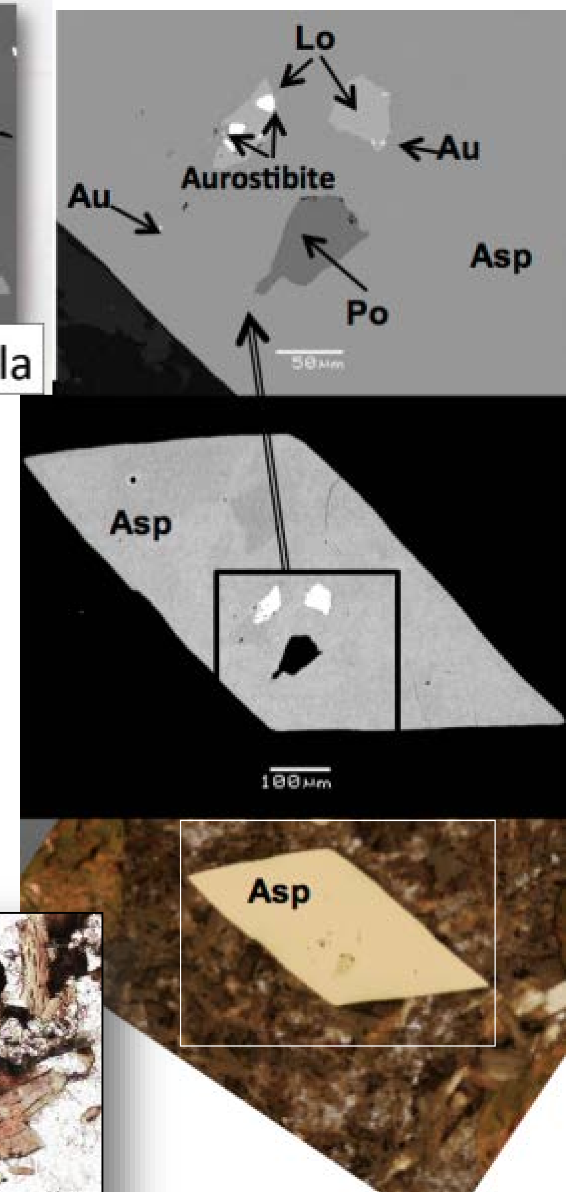
Le Mignot et al., in review, EGeol

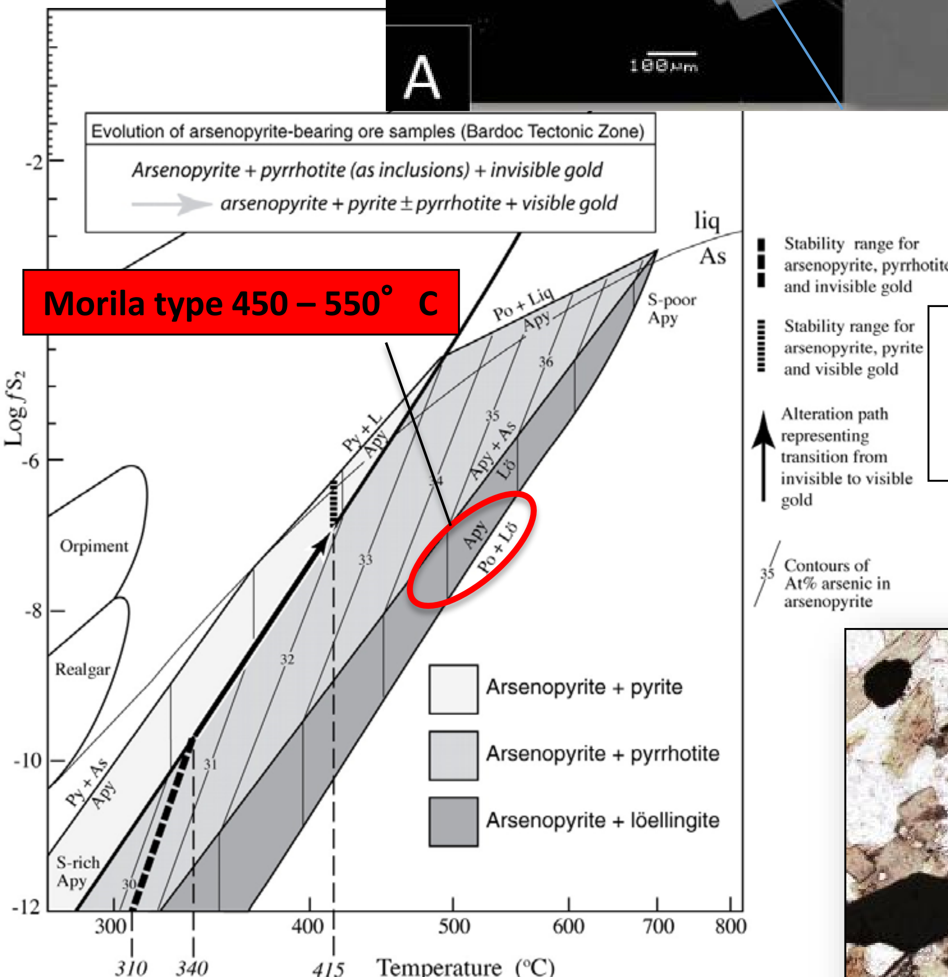
Emplacement conditions

determined from mineral parageneses

3 main types detected

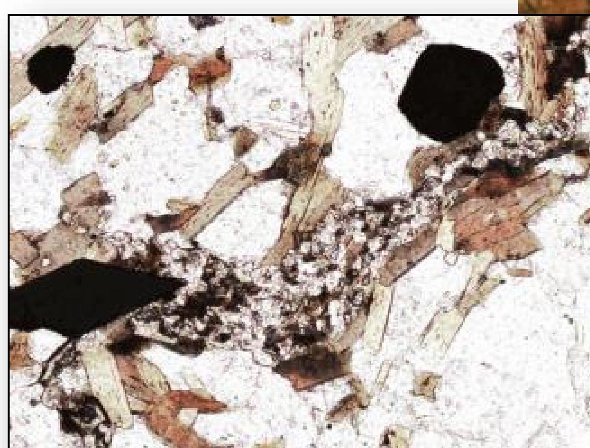






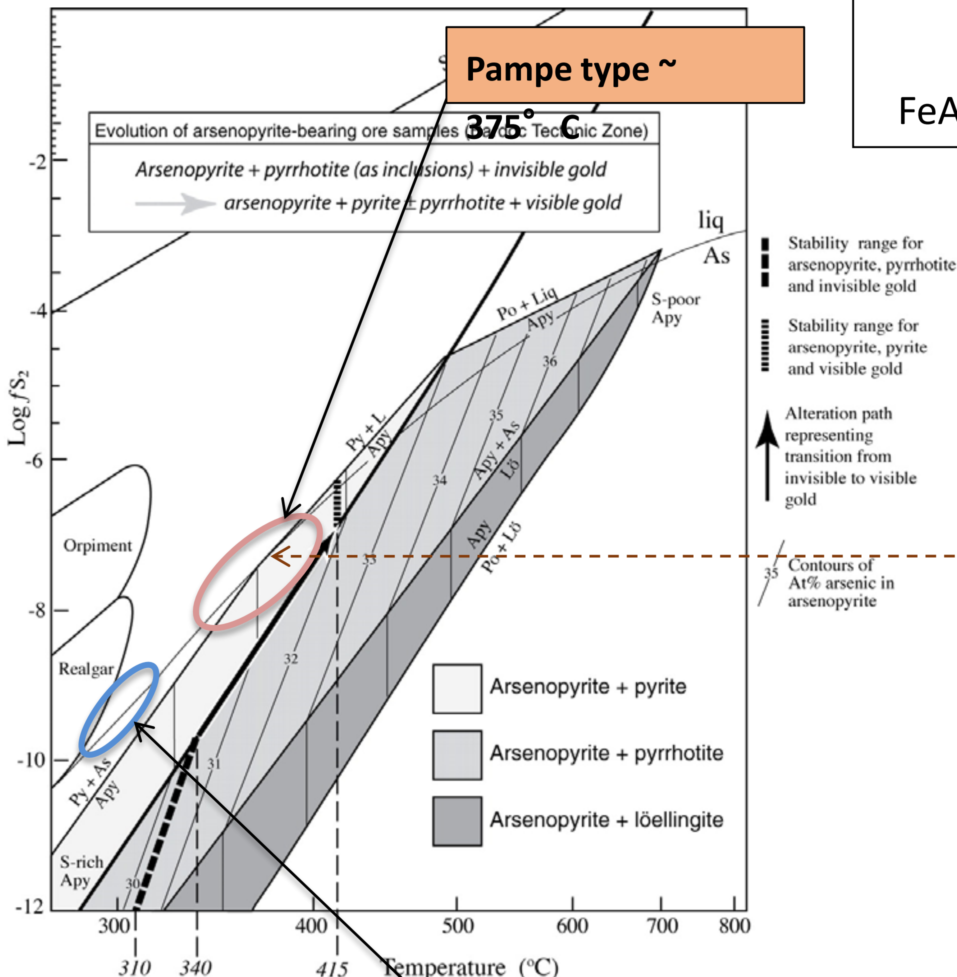
Apy - Po - Löe

$$2FeAsS \Leftrightarrow FeAs_2 + FeS + 1/2S_2$$



Apy - Py

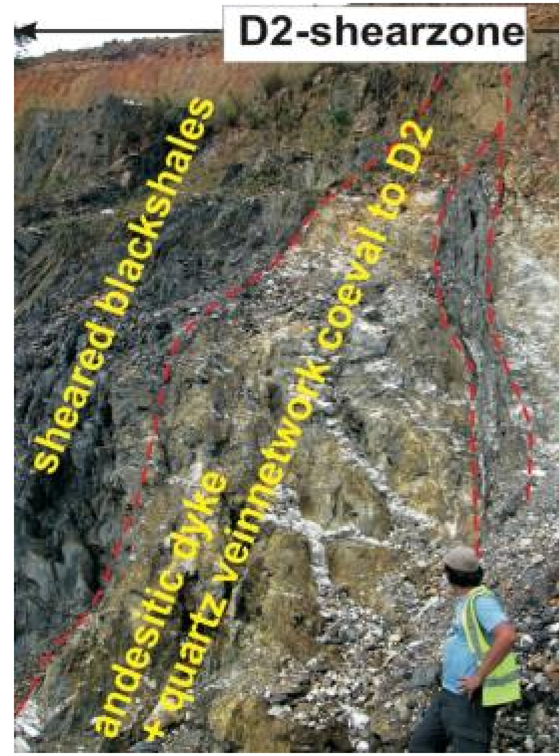
$$FeS_2 + As \Leftrightarrow FeAsS + 1/2S_2$$

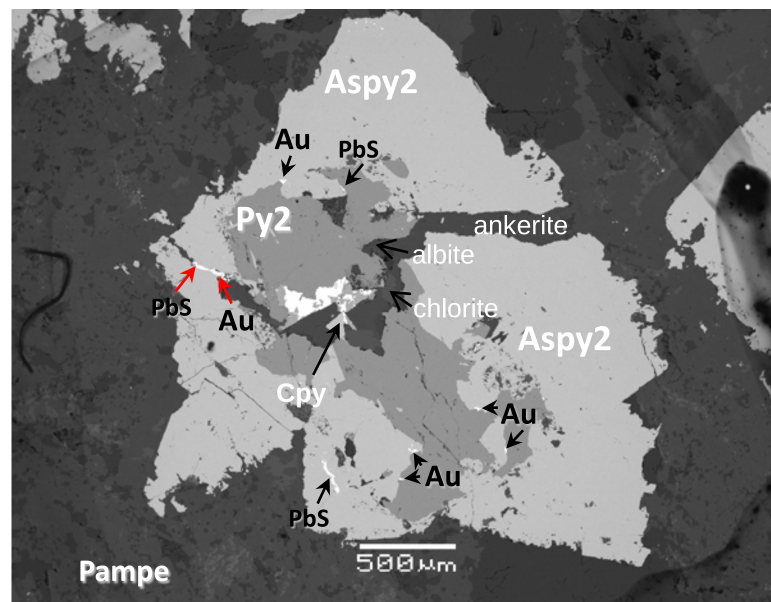


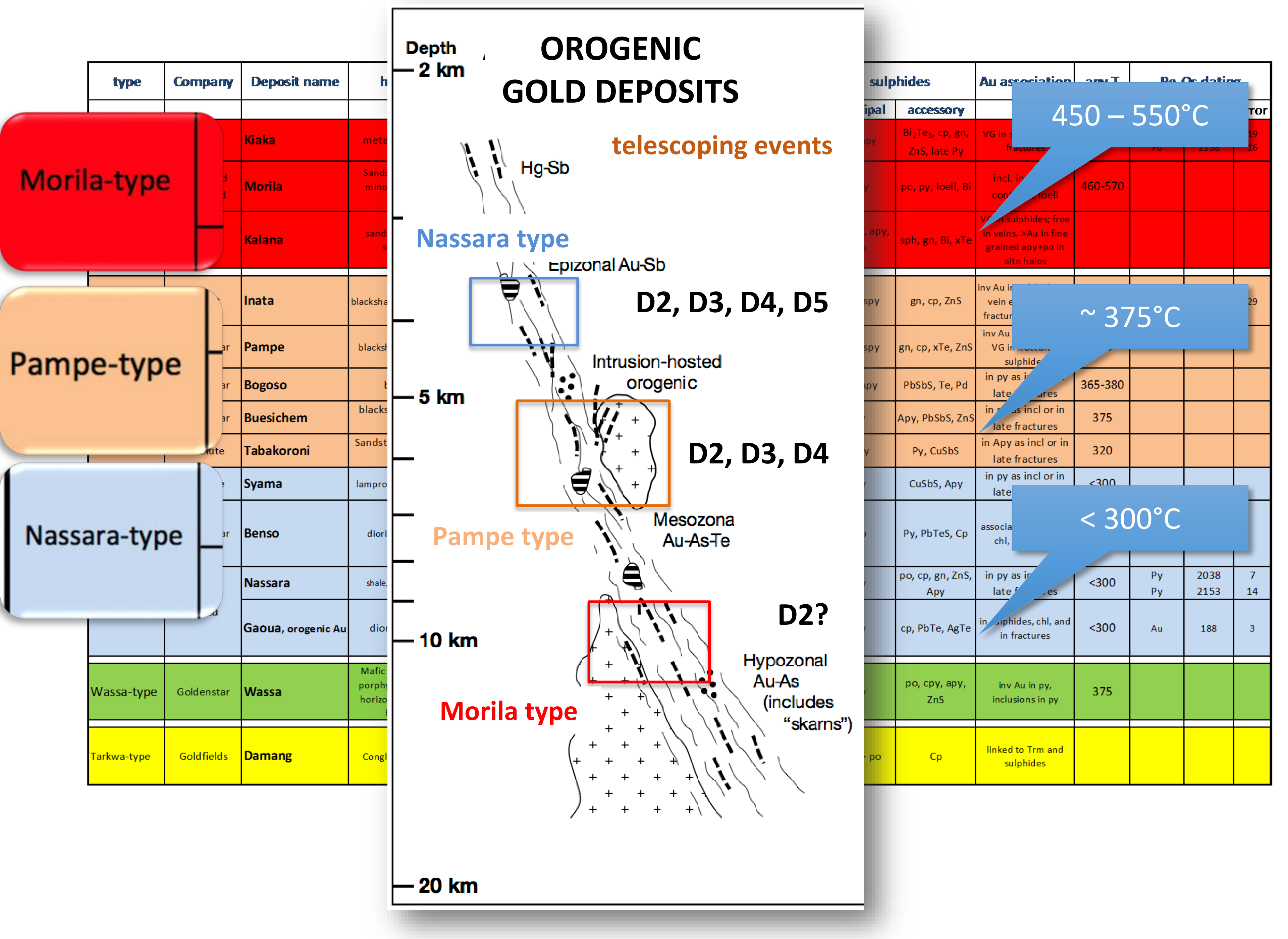
Nassara type
<300° C

FeS_2

Py

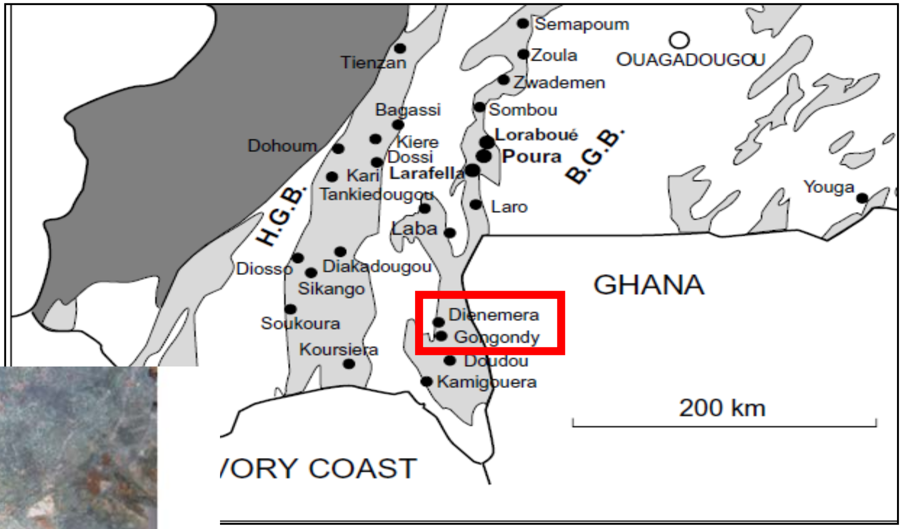


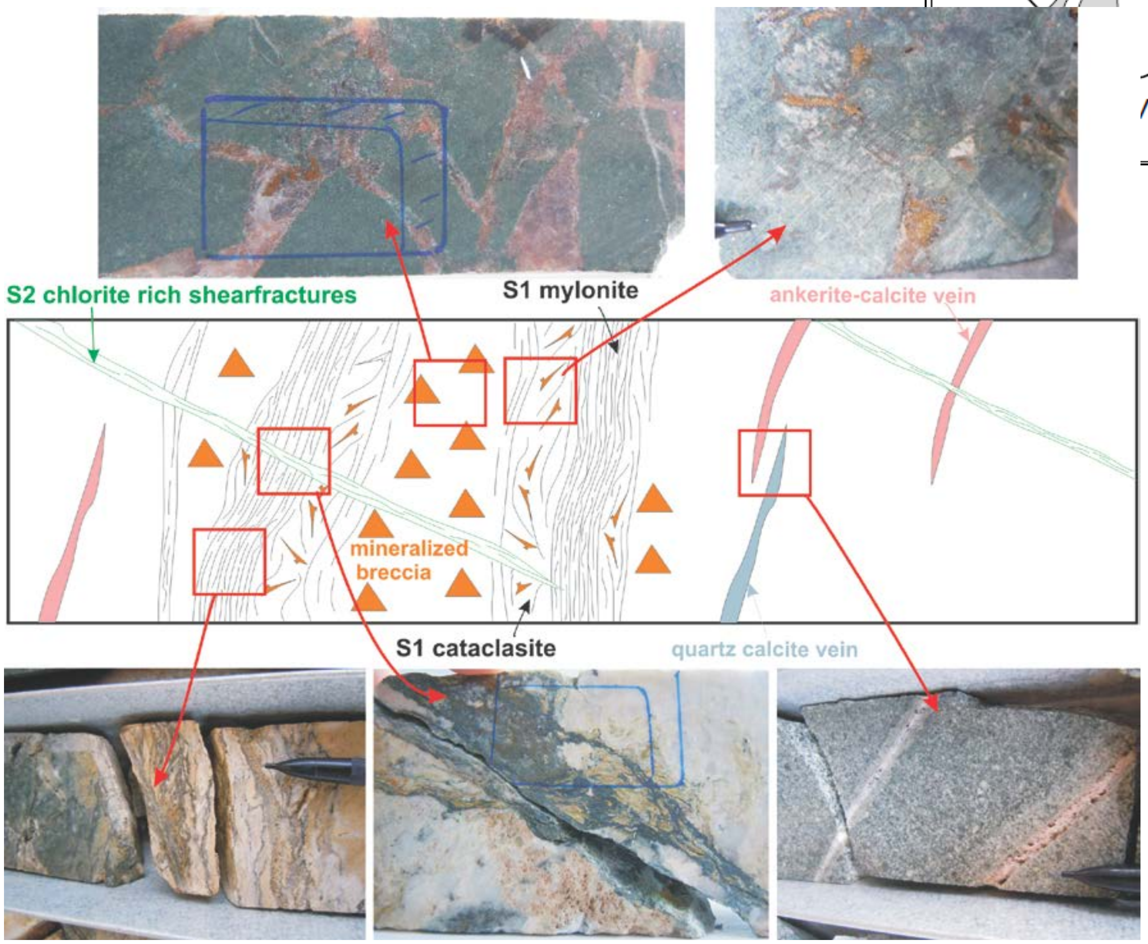




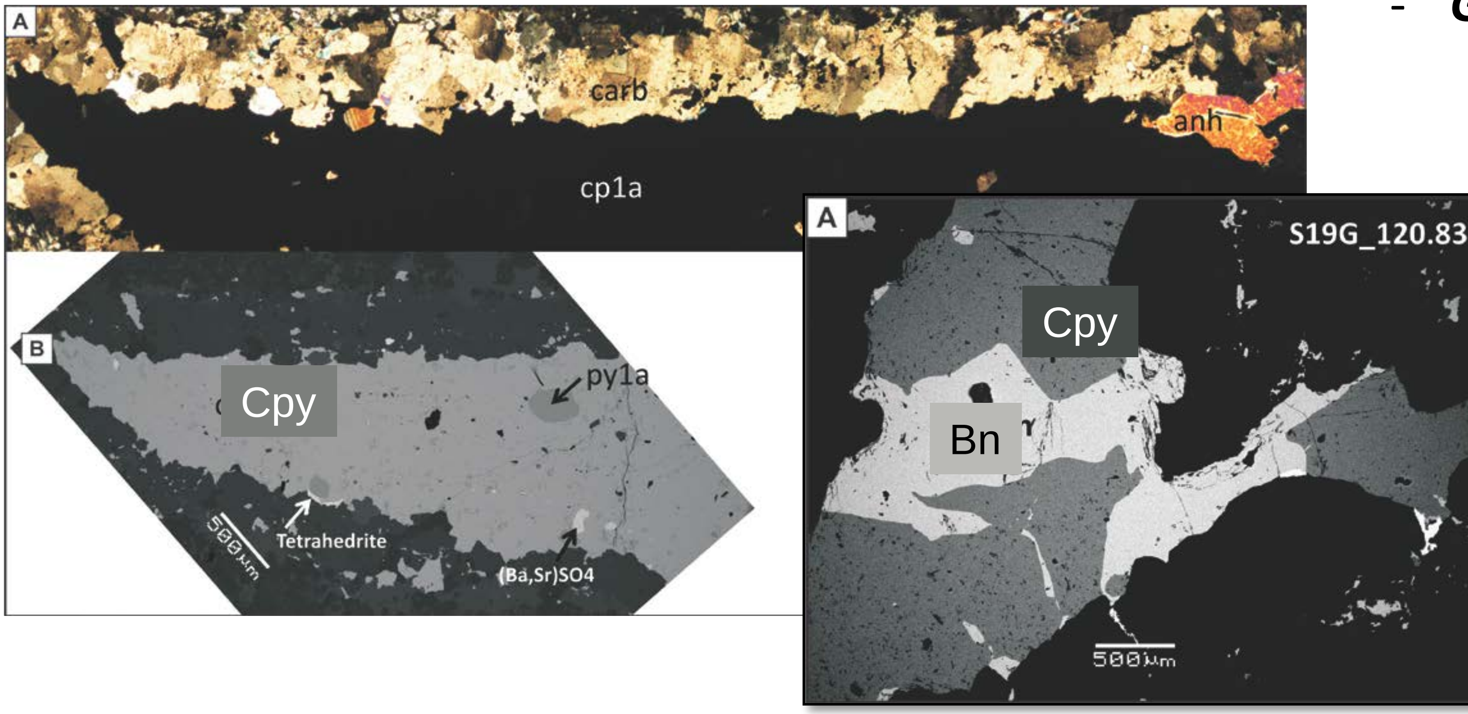
OROGENIC GOLD DEPOSITS
Depth
2 km
5 km
10 km
20 km
telescoping events
Hg-Sb
Nassara type
Epizonal Au-Sb
D2, D3, D4, D5
Intrusion-hosted orogenic
D2, D3, D4
Mesozona Au-As-Te
Pampe type
D2?
Hypozonal Au-As (includes "skarns")
Morila type
450 – 550°C
~ 375°C
< 300°C
Morila-type
Pampe-type
Nassara-type
type
Company
Deposit name
sulphides
accessory
Au association
Re-Os dating
Kiaka
Morila
Kalana
Inata
Pampe
Bogoso
Buesichem
Tabakoroni
Syama
Benso
Nassara
Gaoua, orogenic Au
Wassa-type
Goldenstar
Wassa
Tarkwa-type
Goldfields
Damang
Bi2Te3, cp, gn, ZnS, late Py
po, py, loell, Bi
460-570
sph, gn, Bi, xTe
VG in sulphides; free in veins. >Au in fine grained apy+po in altn halos
gn, cp, ZnS
gn, cp, xTe, ZnS
PbSbS, Te, Pd
365-380
Apy, PbSbS, ZnS
375
in Apy as incl or in late fractures
Py, CuSbS
320
CuSbS, Apy
in py as incl or in
Py, PbTeS, Cp
po, cp, gn, ZnS, Apy
<300
Py
2038
2153
cp, PbTe, AgTe
in fractures
Au
188
po, cpy, apy, ZnS
inv Au in py, inclusions in py
Cp
linked to Trm and sulphides

- *Gaoua district*



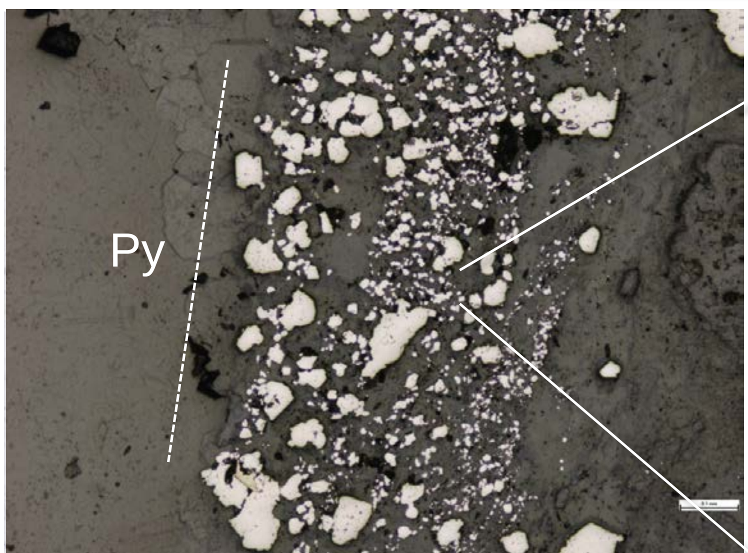


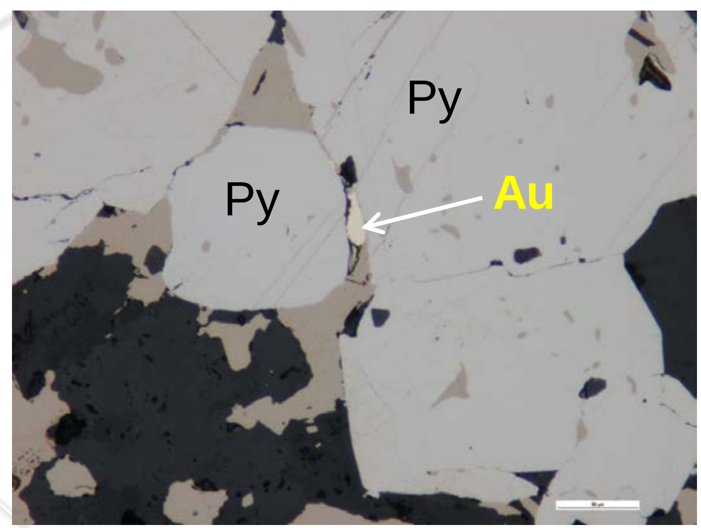
- ***Gaoua district***



porphyry Cu mineralization

orogenic gold





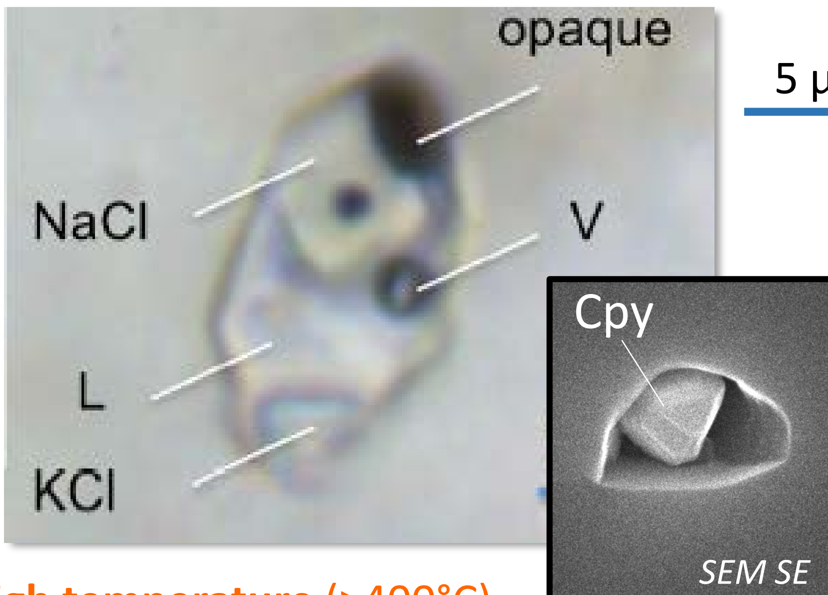
Fluid inclusion evidence

Porphyry stage

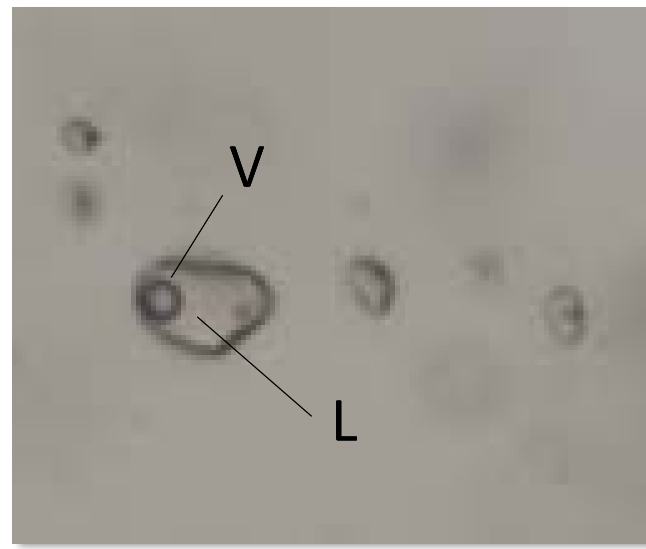
Orogenic stage

Solid-bearing H_2O fluid inclusion with salts and a **chalcopyrite** crystal

H_2O and **H_2O-CO_2** fluid inclusions



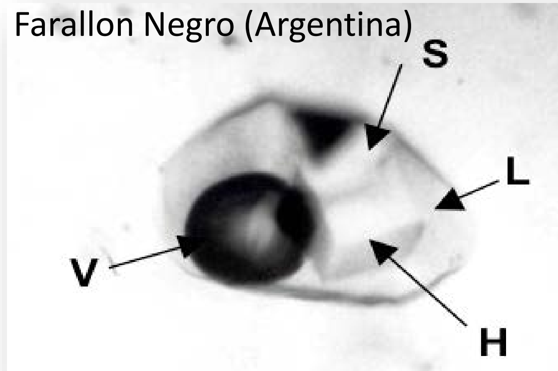
5 µm

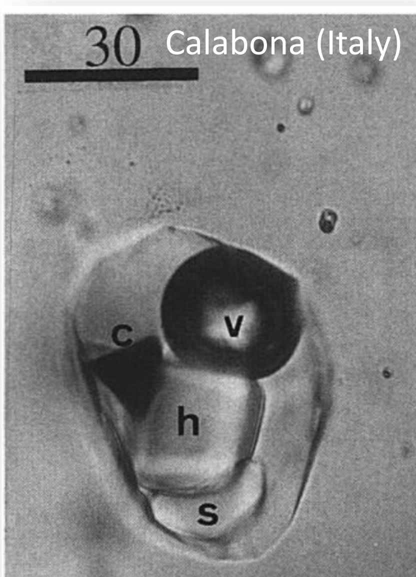


High temperature (>400°C)
high salinity (>30 wt% NaCl eq)
orthomagmatic fluid

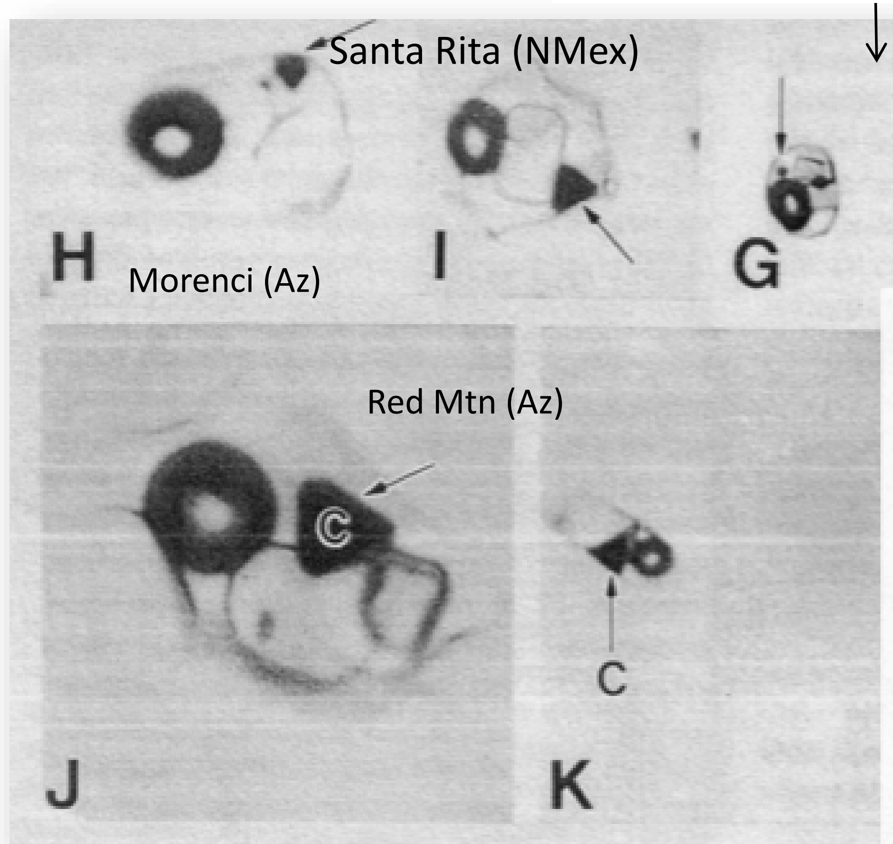
Low temperature (<200°C)
moderate salinity (13-24 wt% NaCl eq)
hydrothermal fluid

Porphyry systems elsewhere in the world



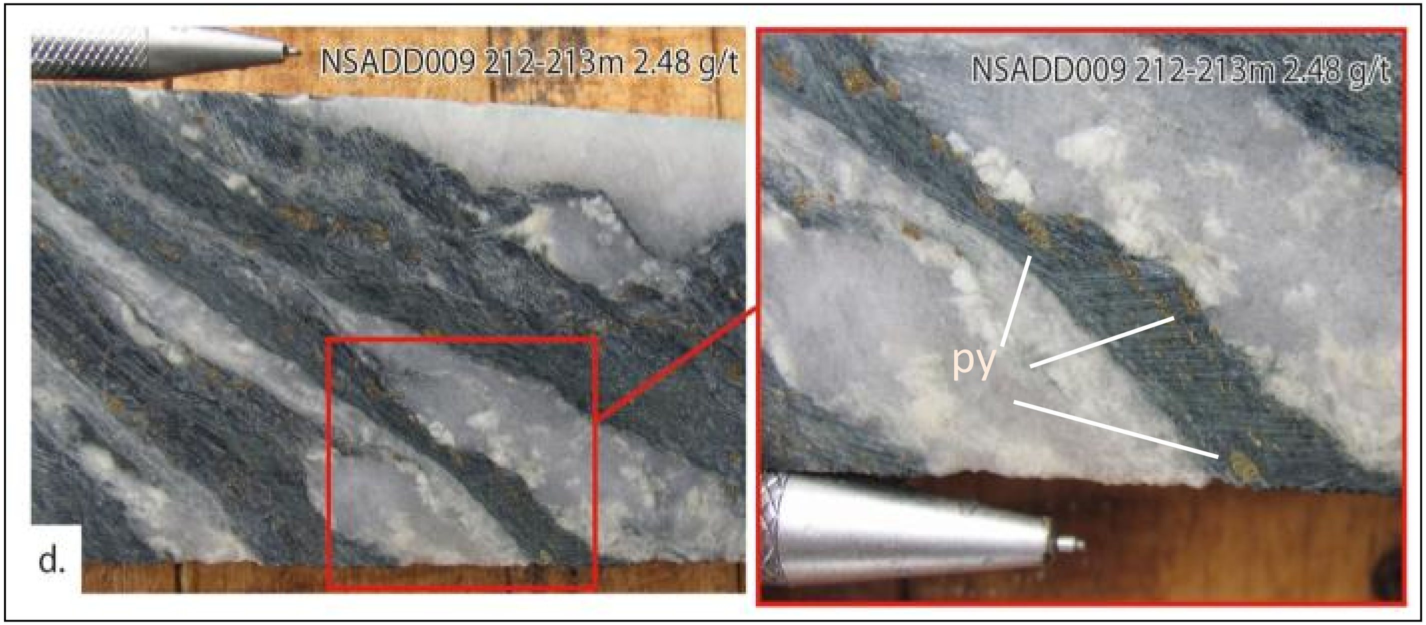


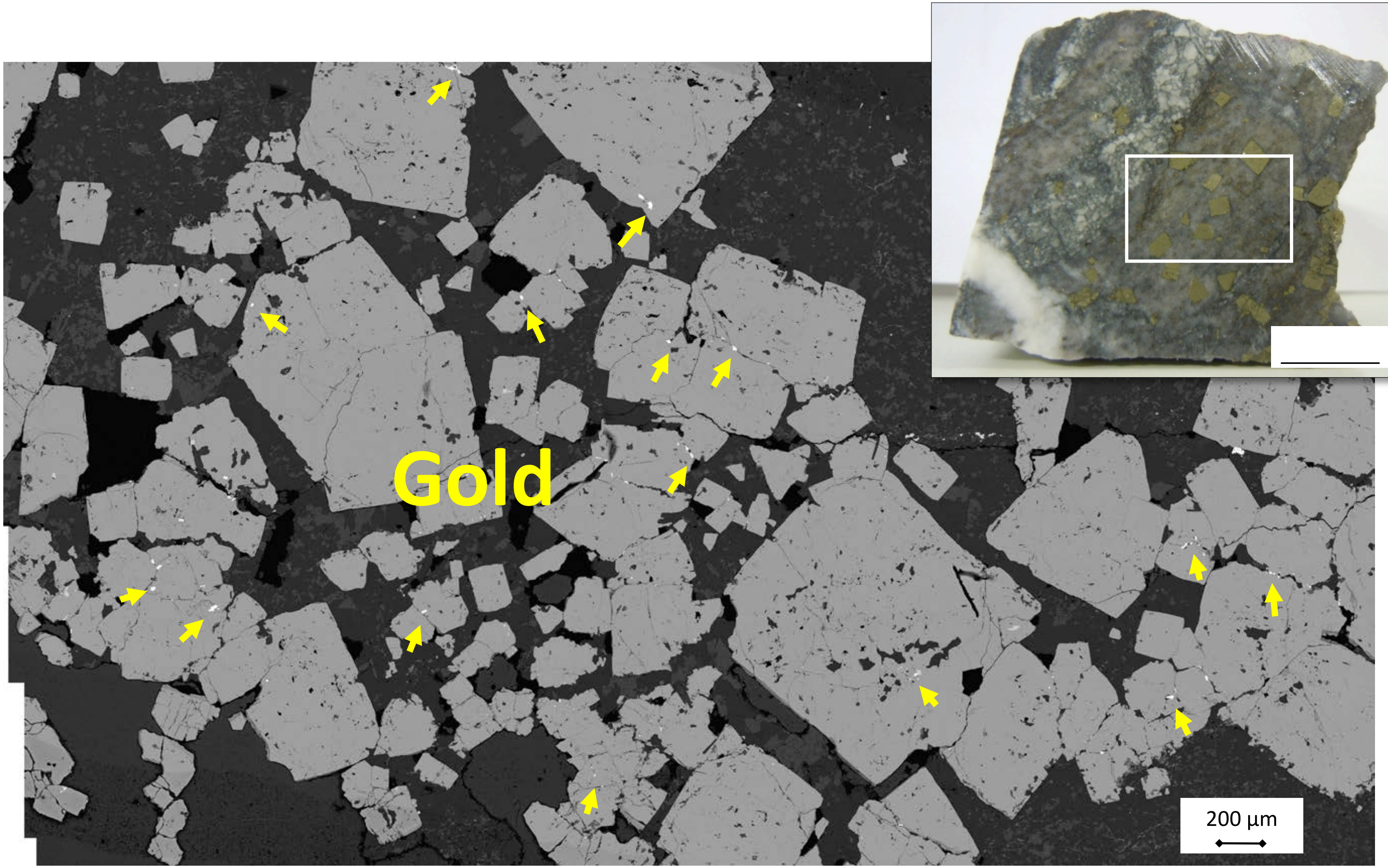
Grasburg (Indonesia)



…back to orogenic deposits!

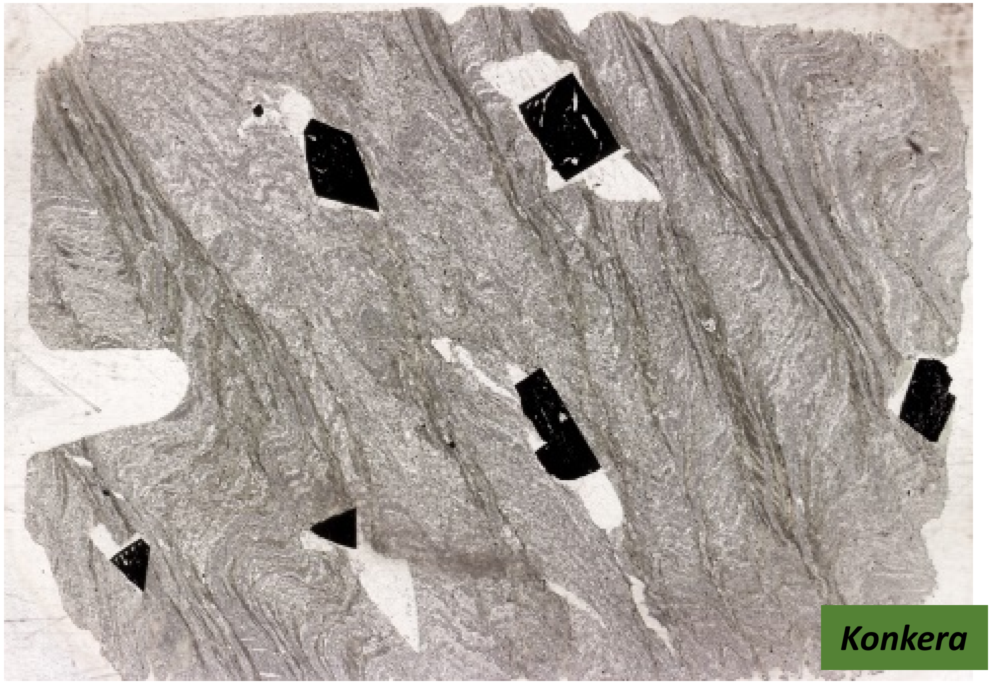
Sulphide distribution

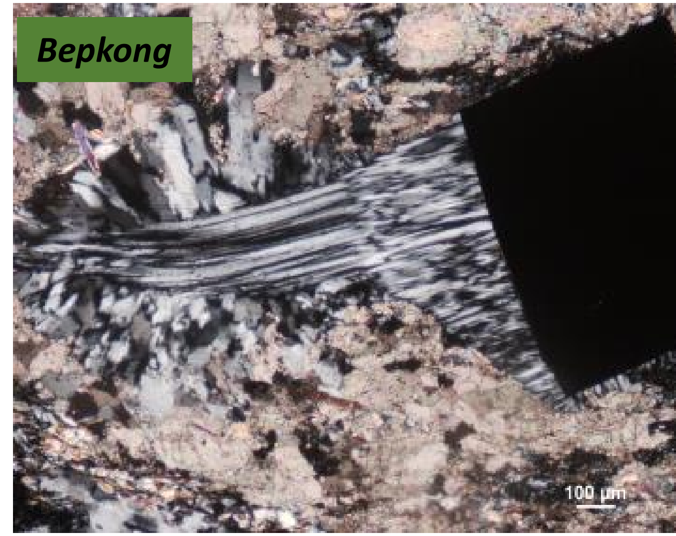


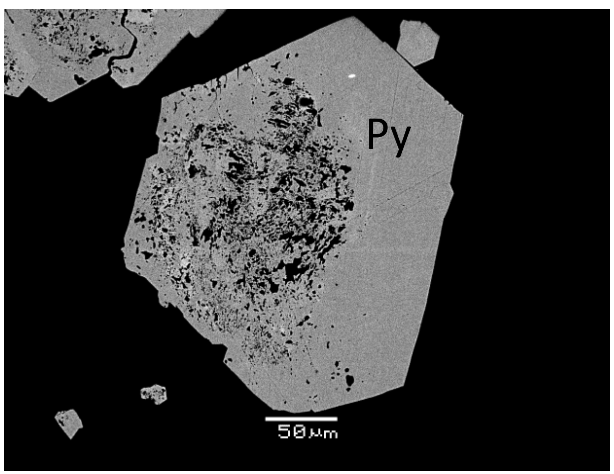


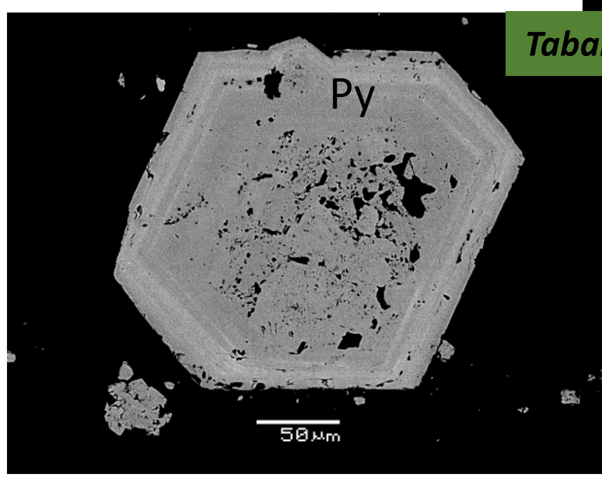
Gold intimately associated with pyrite (or apy)

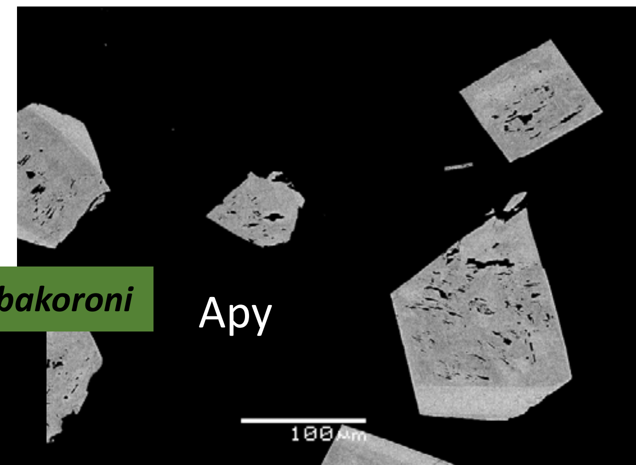
Sulphide evolution

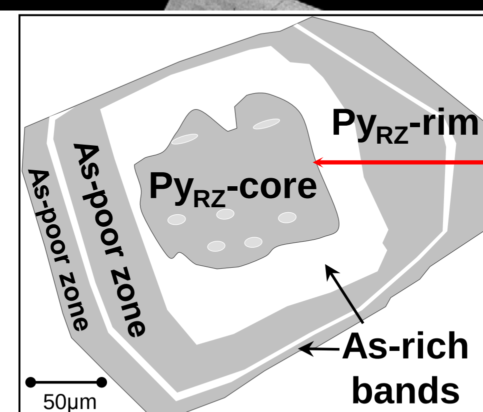








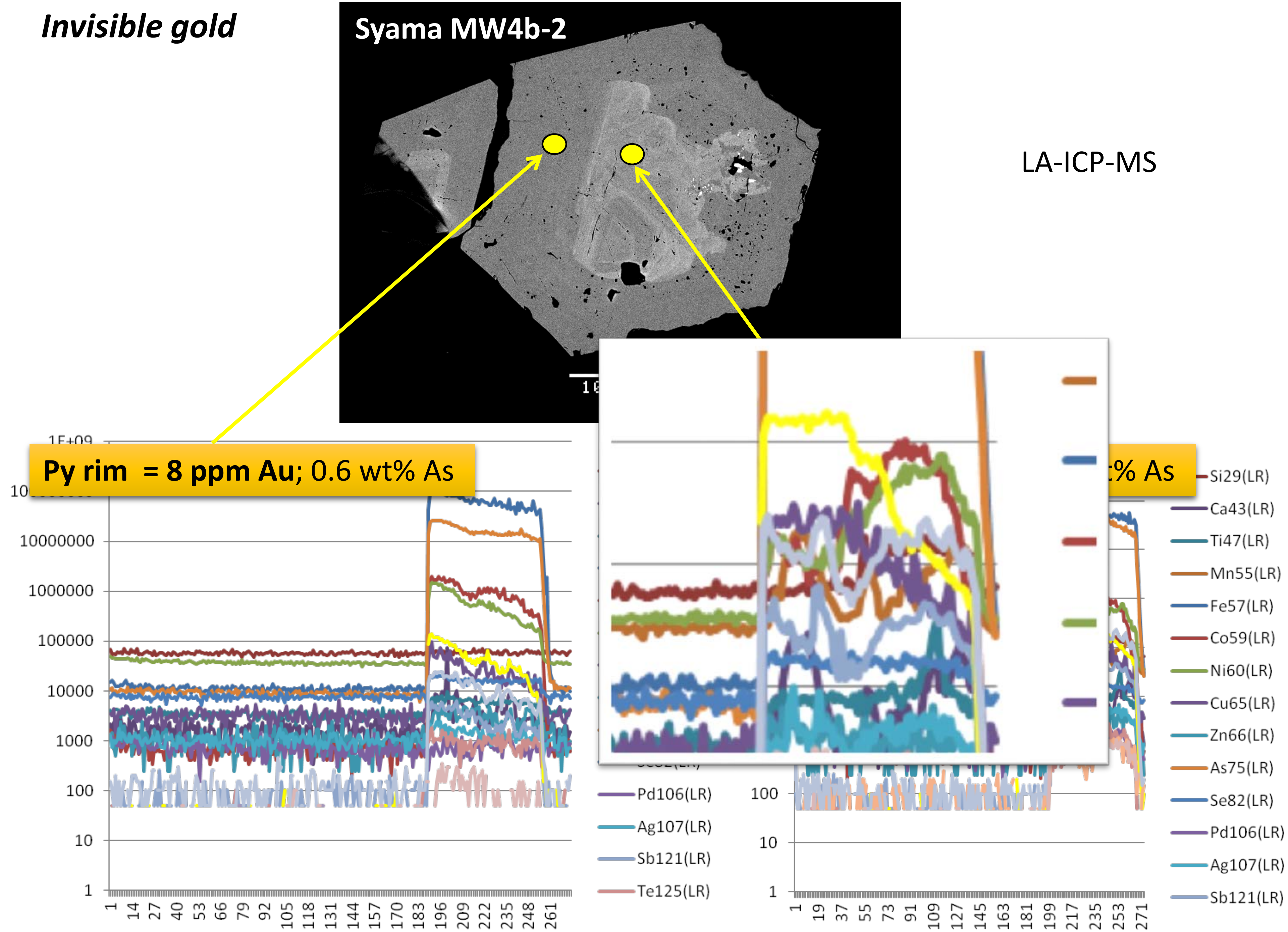




As distrubution → several generation of py and apy

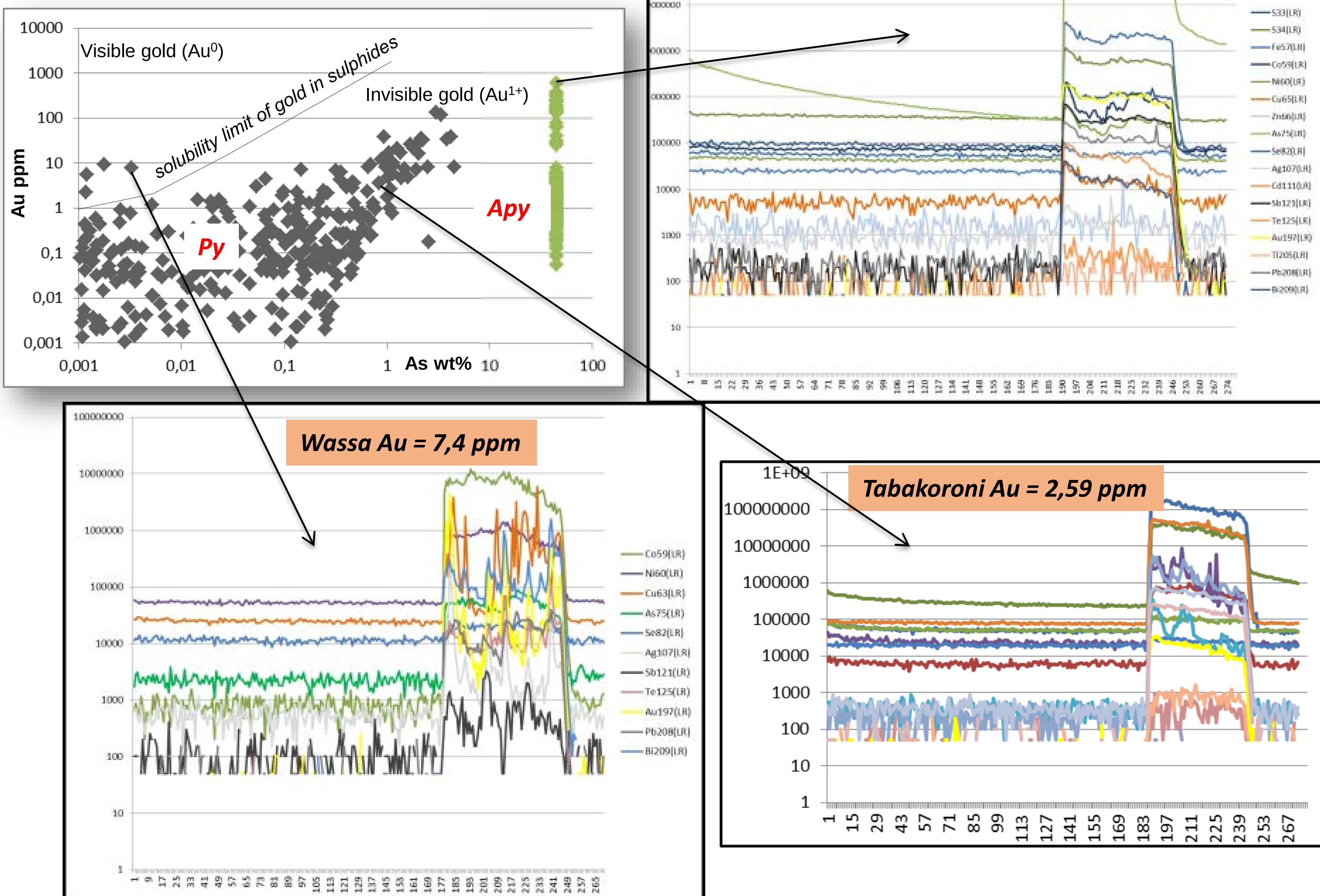
Invisible gold

LA-ICP-MS

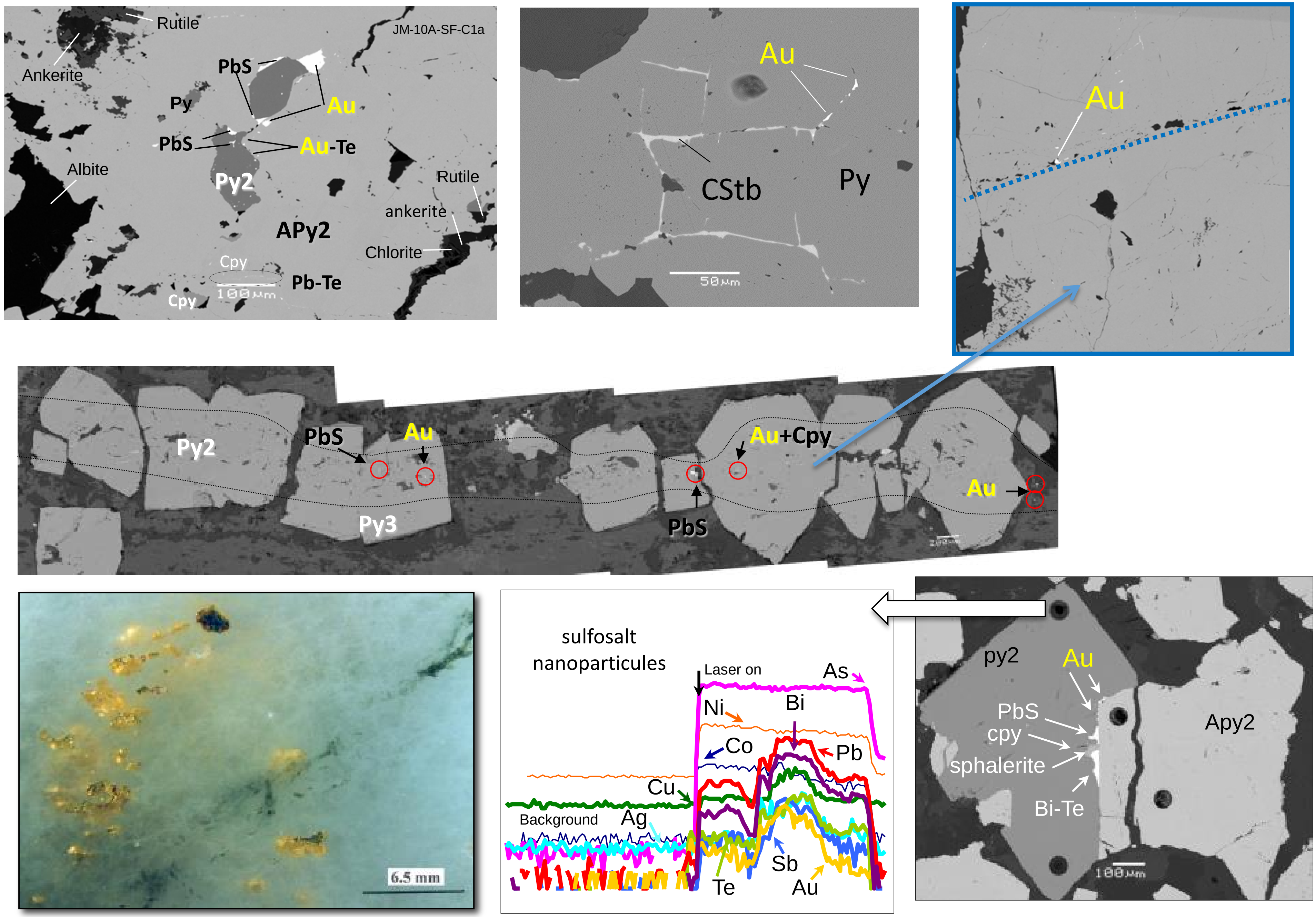


Invisible gold

Reich et al., 2005

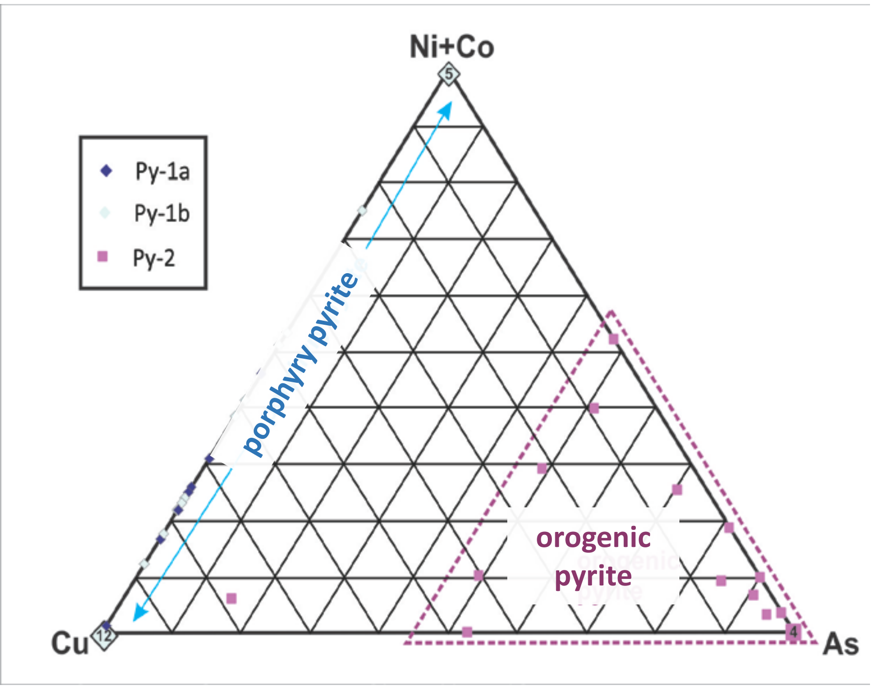


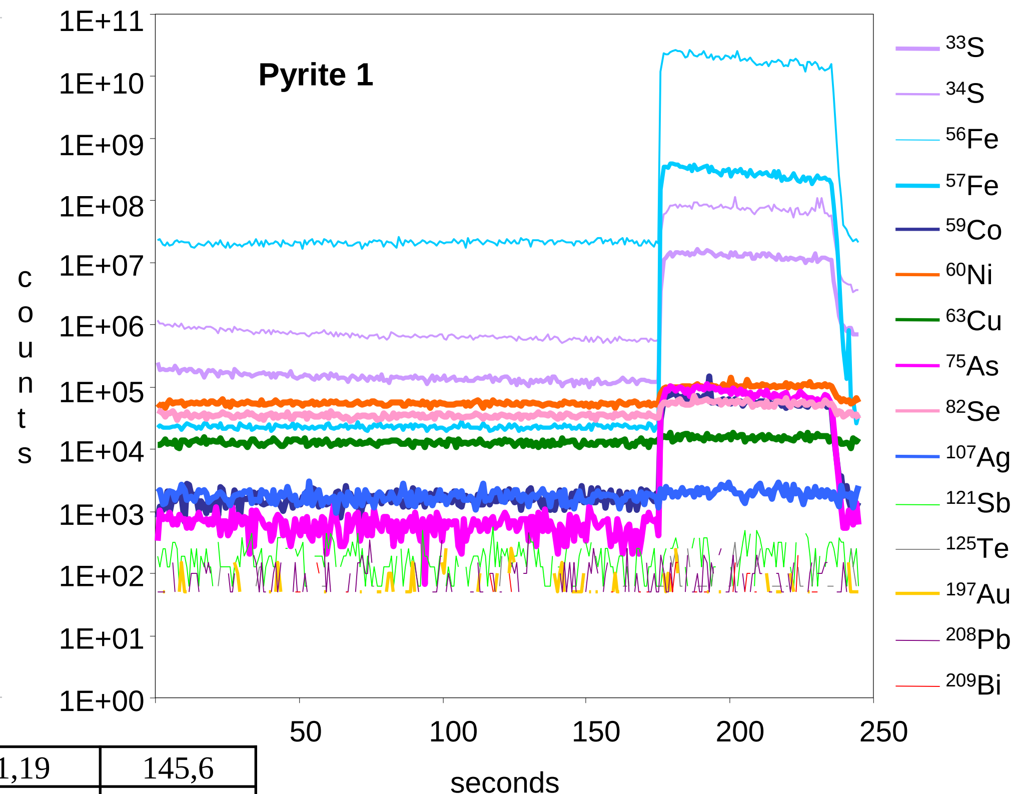
Visible gold



- ***Gaoua district***

Microprobe and LA-ICP-MS analyses of pyrite and chalcopyrite

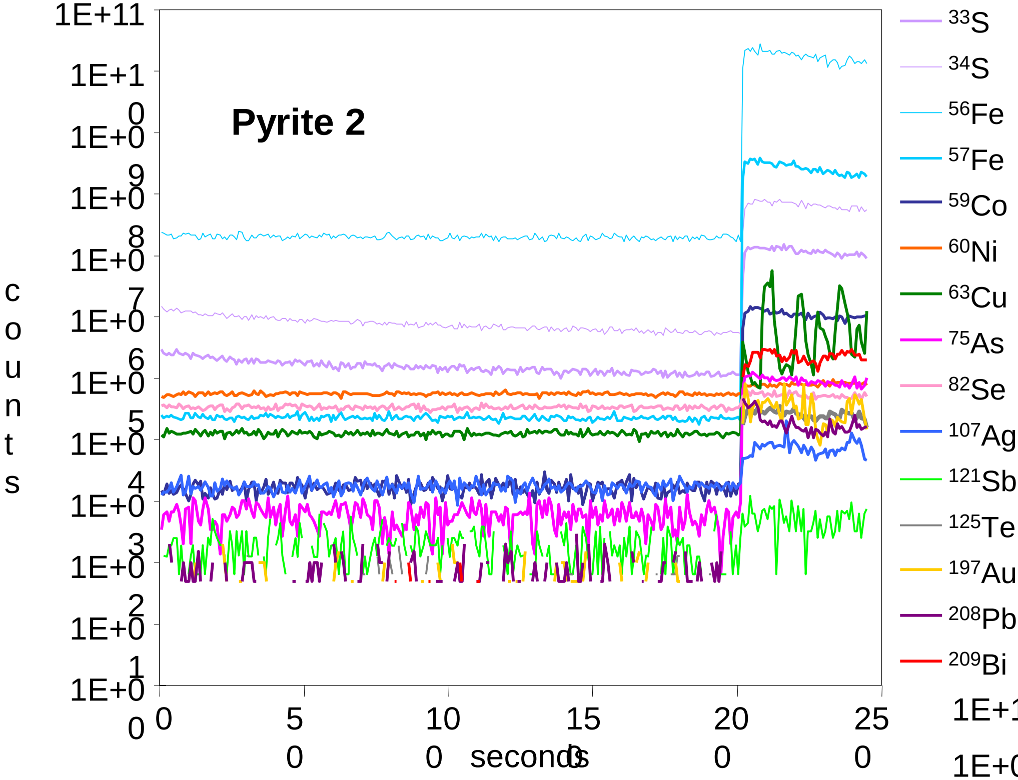




Ni (ppm)	4,41	385,7	4,92	1,78	1,19	145,6
Cu (ppm)	0,2	0,6	0,21	0,22	0,22	0,18
As (ppm)	4,9	0,287	9,42	5,88	11,28	17,8
Se (ppm)	38,26	100,62	35,81	33,54	52,25	71,49
Ag (ppm)	0,0057	0,0061	0,0079	0,0076	0,0074	0,0054
Sb (ppm)	0,203	<0,073	0,063	<0,062	0,164	<0,056
Te (ppm)	0,11	0,204	0,037	0,0211	25	<0,0039
Au (ppm)	***0,00122***	***<LOD***	***<LOD***	***0,00365***	***0,00405***	***<LOD***
Pb (ppm)	0,00346	0,00371	0,00067	0,00127	<0,00044	0,00055
Bi (ppm)	0,0077	0,00084	0,00026	0,00586	0,00013	0,00096

Pyrite 1

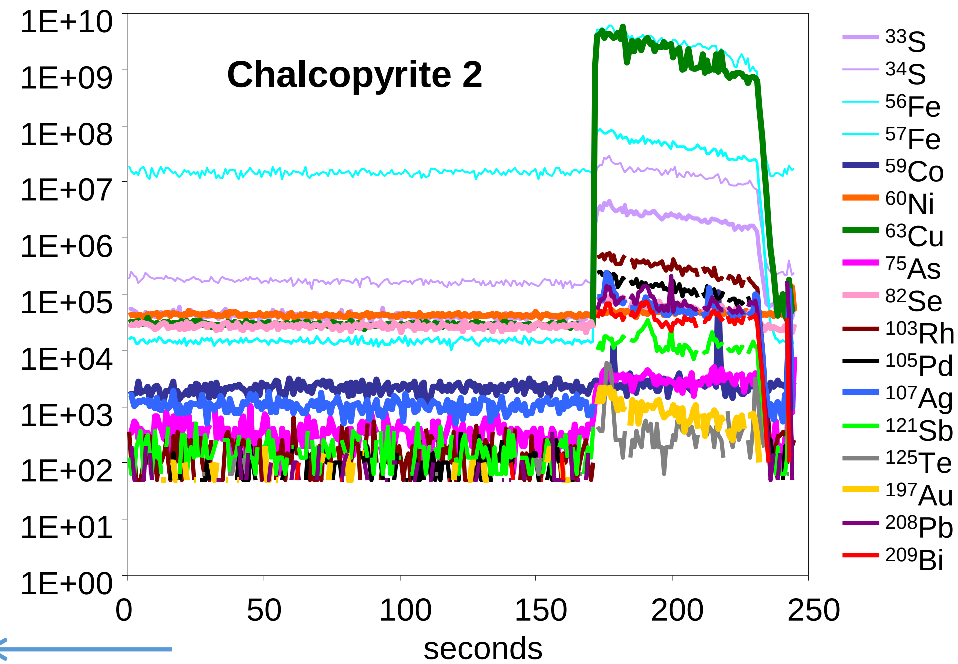
Porphyry



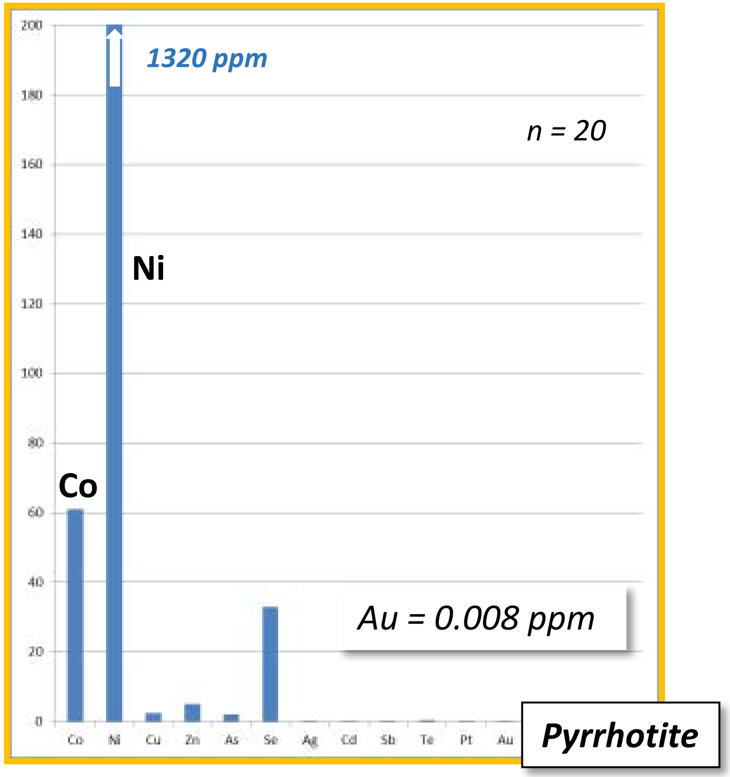
sample	S19-267.5A-C4-1	S19-267.5A-C8-1
Ni (ppm)	2,39	2,45
Cu (ppm)	163,94	77,1
As (ppm)	6,93	11,69
Se (ppm)	34,84	36,11
Ag (ppm)	0,0472	0,139
Sb (ppm)	0,183	0,95
Te (ppm)	5,13	19,07
Au (ppm)	***0,334***	***2,22***
Pb (ppm)	0,0629	0,566
Bi (ppm)	0,696	4,47

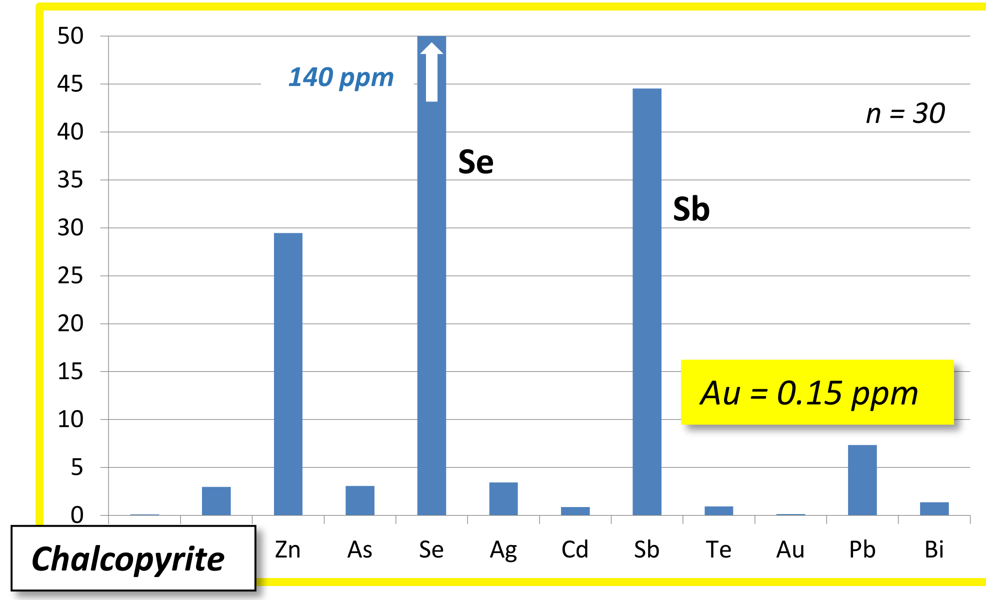
Orogenic

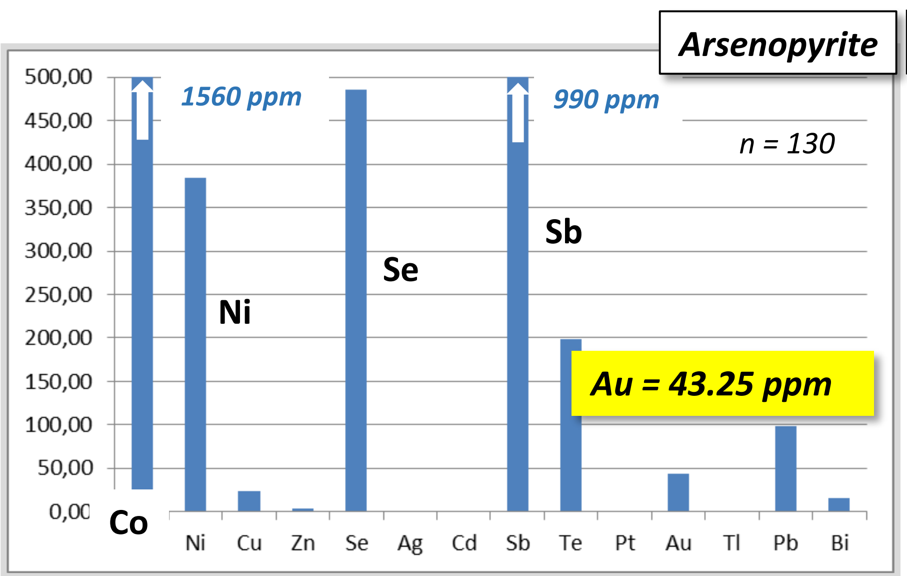
SAMPLE	S44-249-C1-2	S44-249-C2-1	S44-249-C3-1	S44-346-C1-2	S44-346-C3-1	S44-346-C2-1
Ni (ppm)	25,70	2,36	1,63	3,89	2,49	2,22
Cu (ppm)	3491149	352197	351523	339379	342389	351170
As (ppm)	4,80	1,06	0,37	0,14	0,36	0,10
Se (ppm)	1719,73	182,98	152,79	219,94	176,49	183,99
Ag (ppm)	32,74	4,97	2,43	2,32	2,92	1,92
Sb (ppm)	528,10	164,60	23,42	75,16	108,21	40,72
Te (ppm)	3,54	1,46	0,24	0,15	0,23	0,13
Au (ppm)	***0,61***	***0,23***	***0,01***	***0,34***	***0,16***	***0,11***
Pb (ppm)	21,69	8,48	0,60	1,13	1,52	0,65
Bi (ppm)	10,95	2,56	0,29	0,49	0,61	0,27

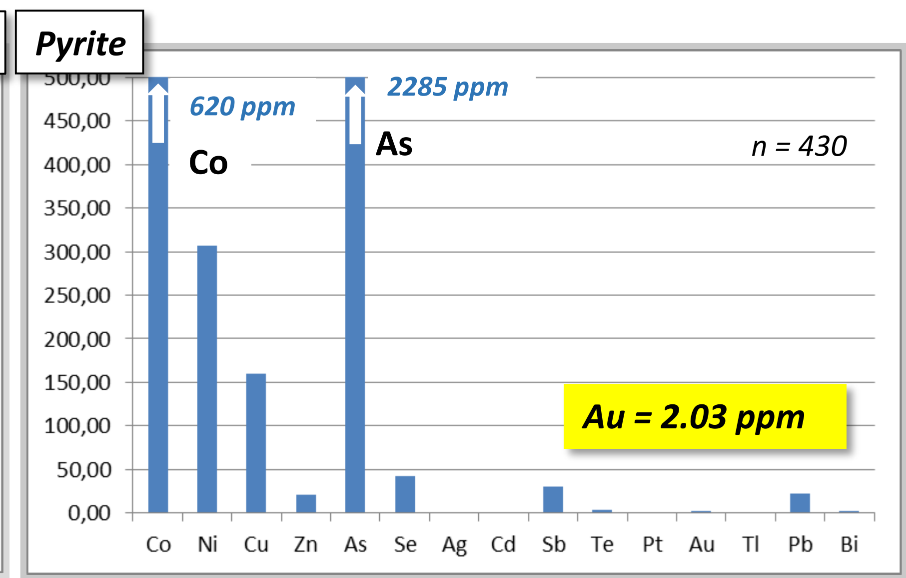


Comparative trace chemistry of sulphides

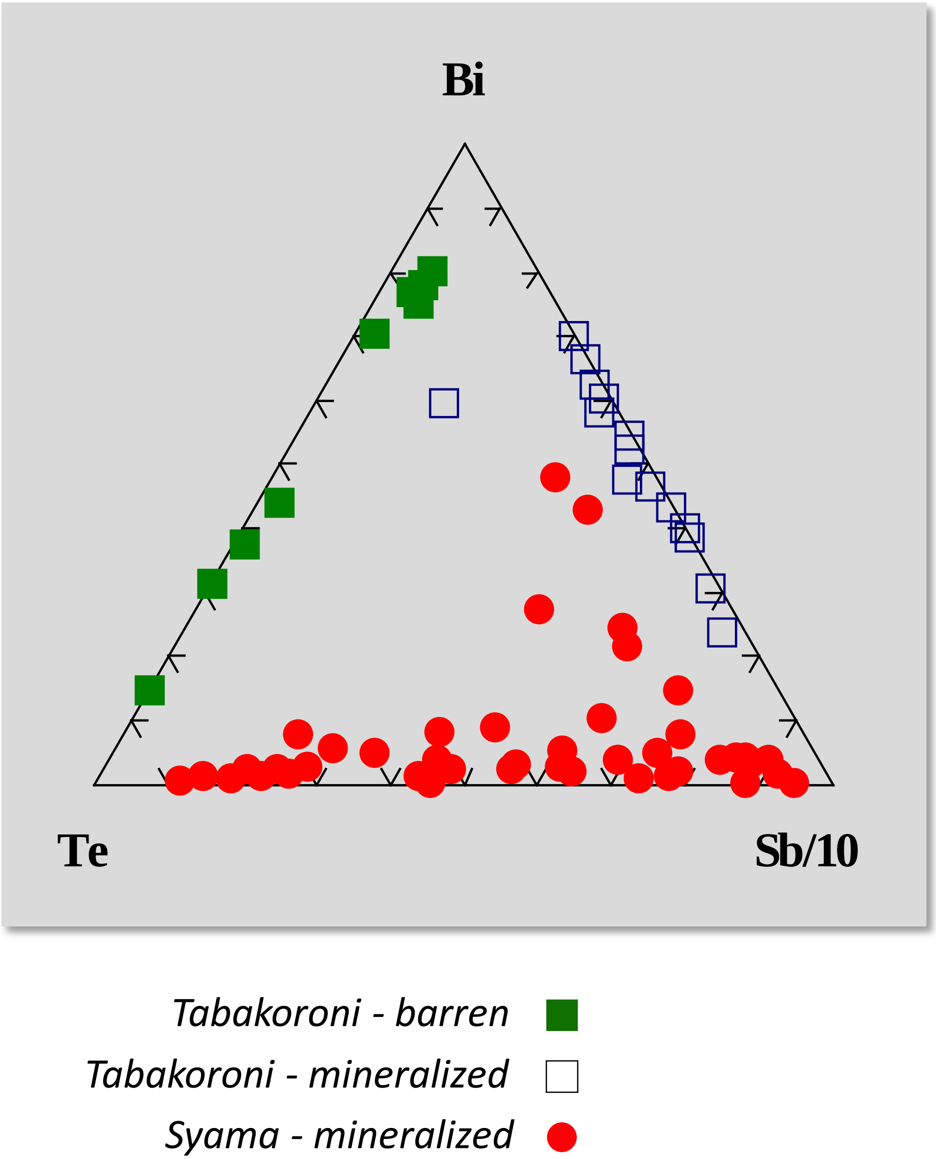


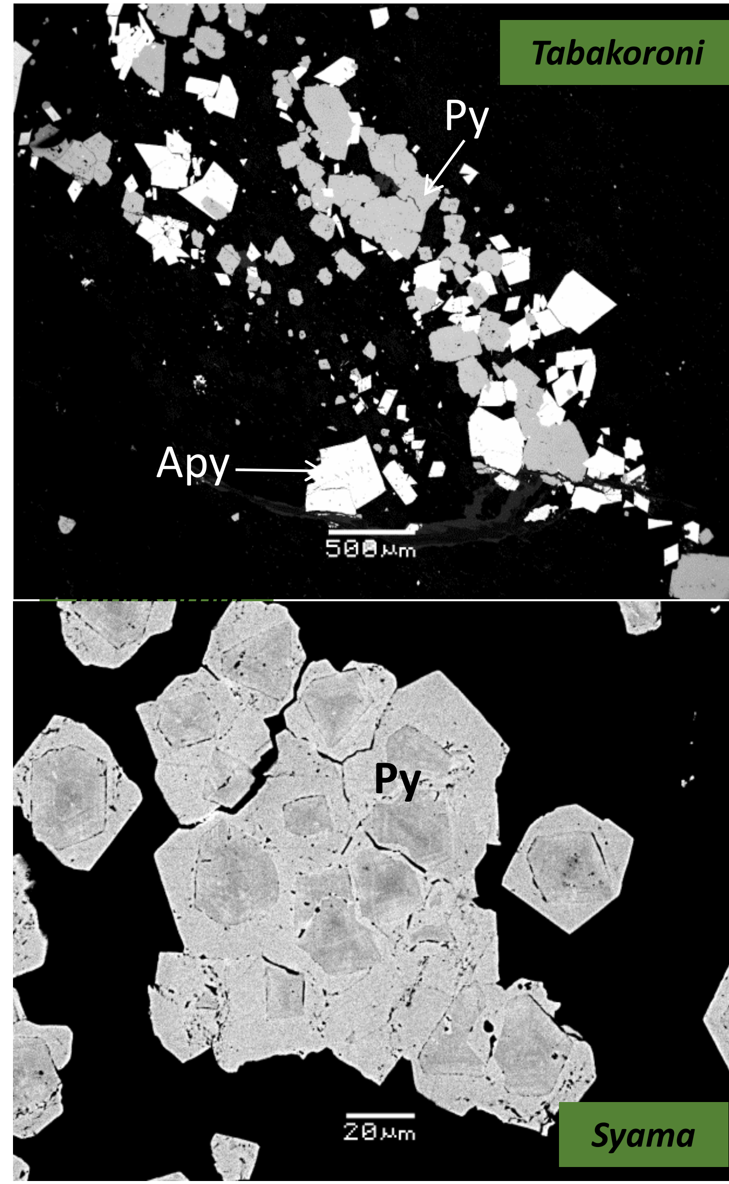




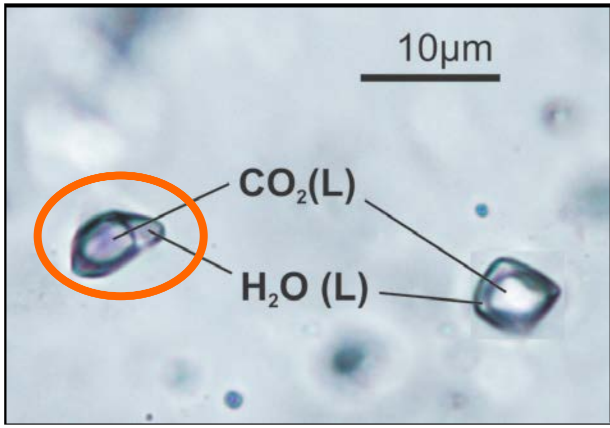


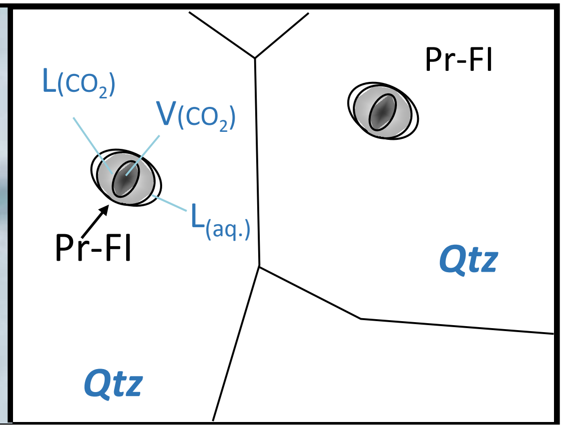
Geochemical signature of mineralized *vs* barren zones – Footprinting?

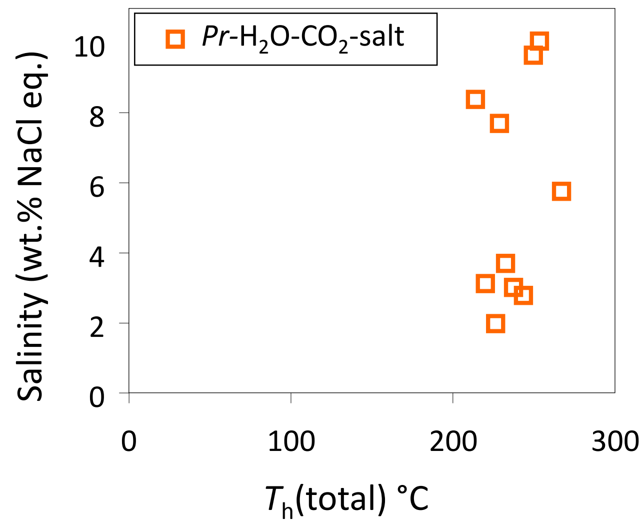


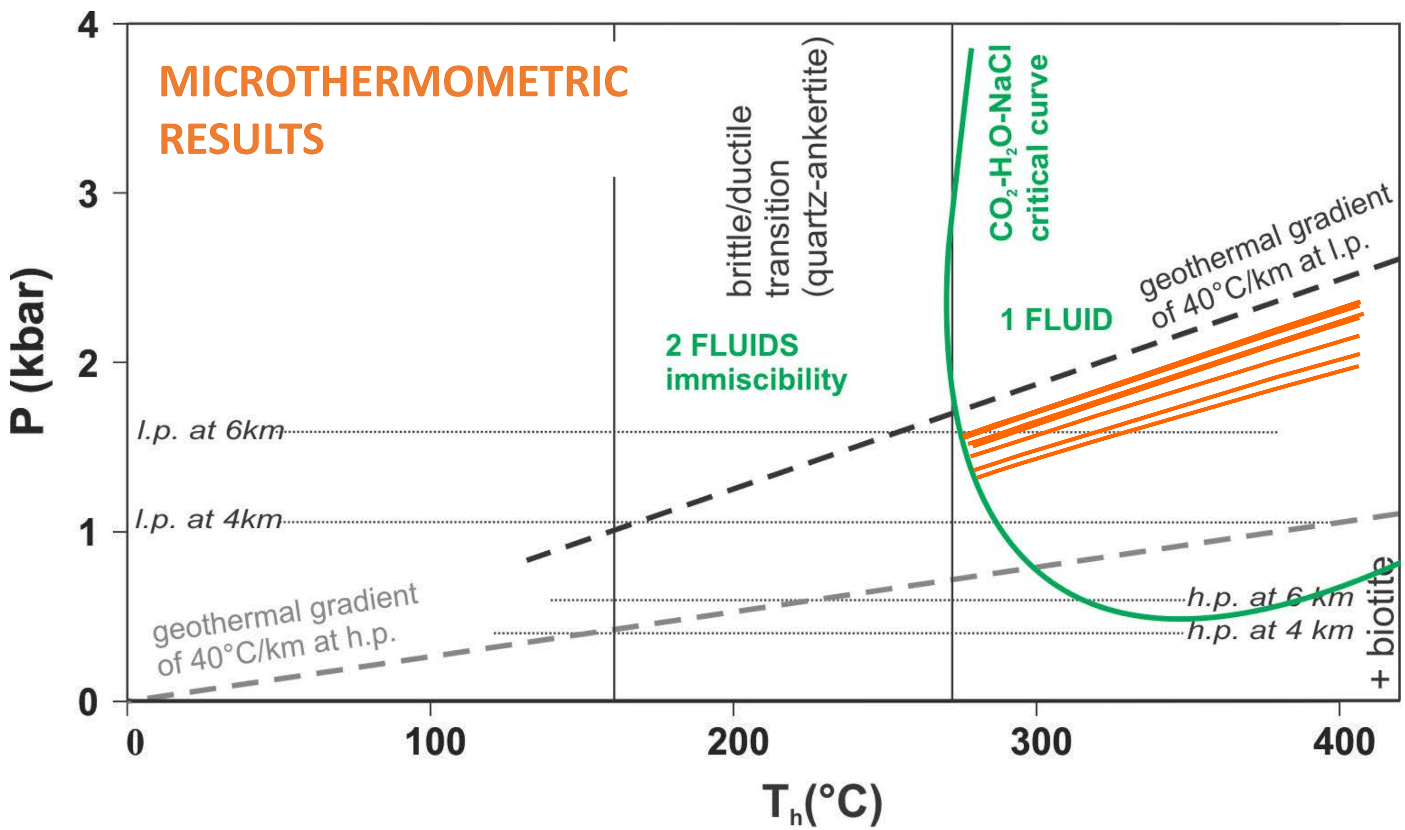


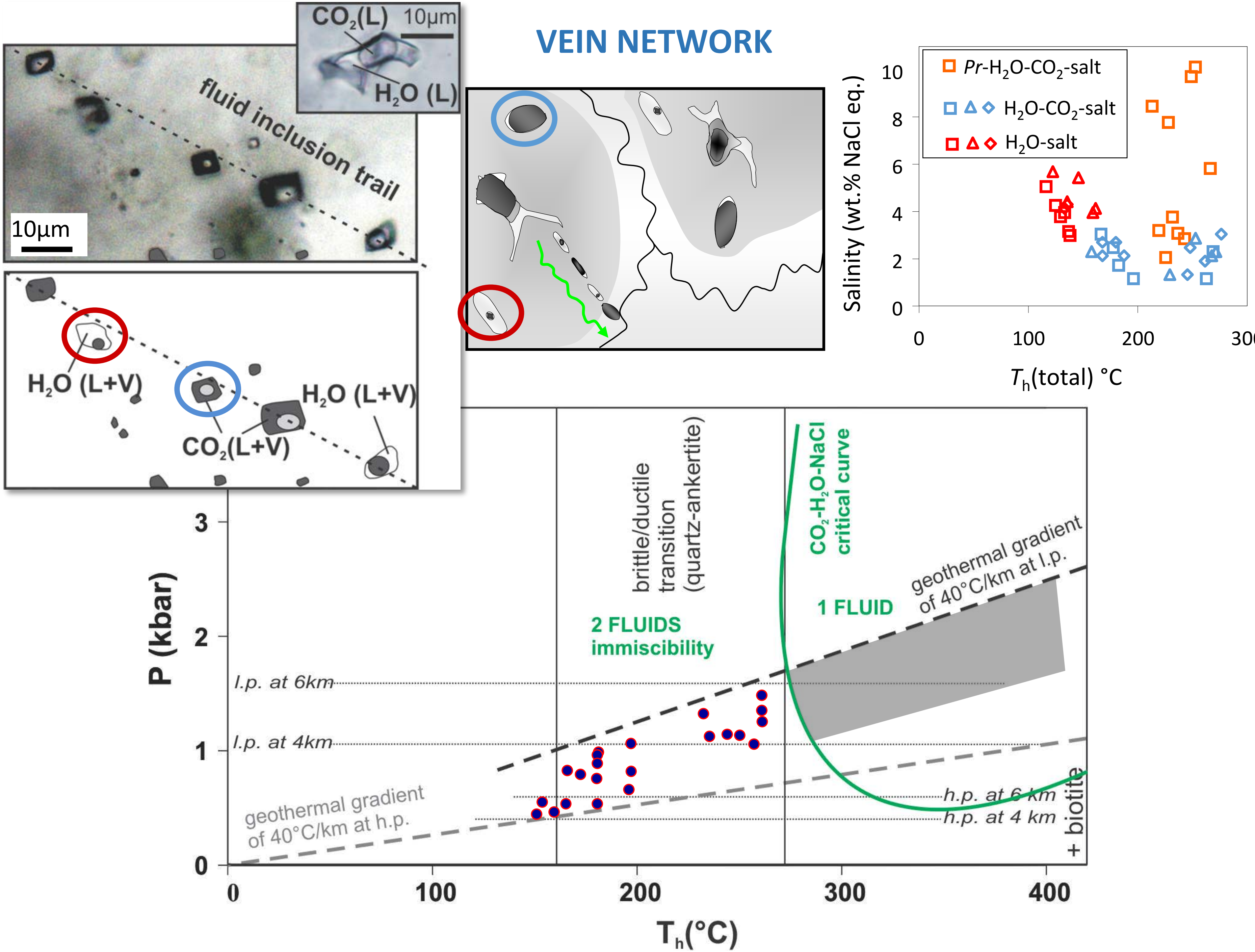
VEIN NETWORK



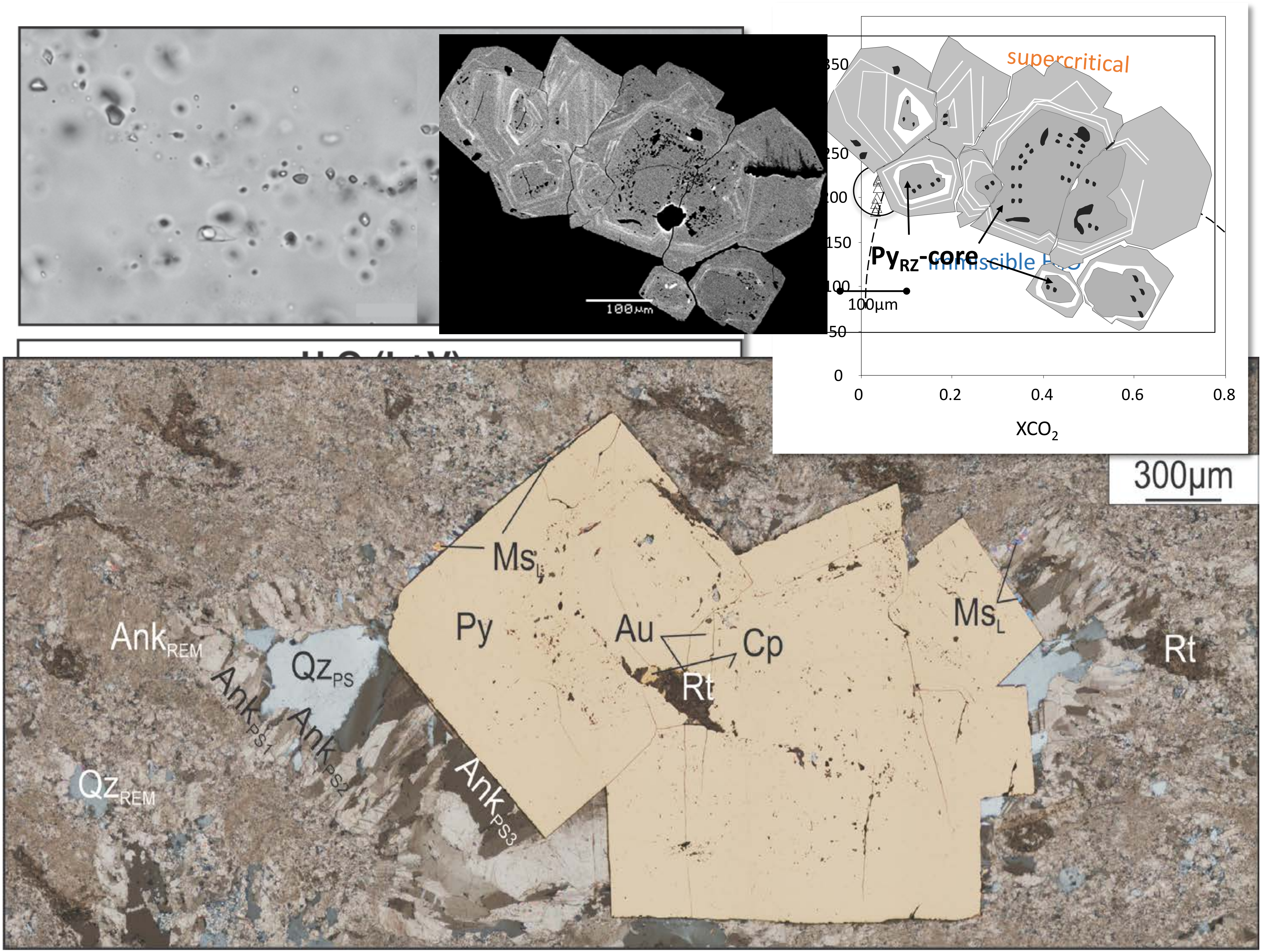






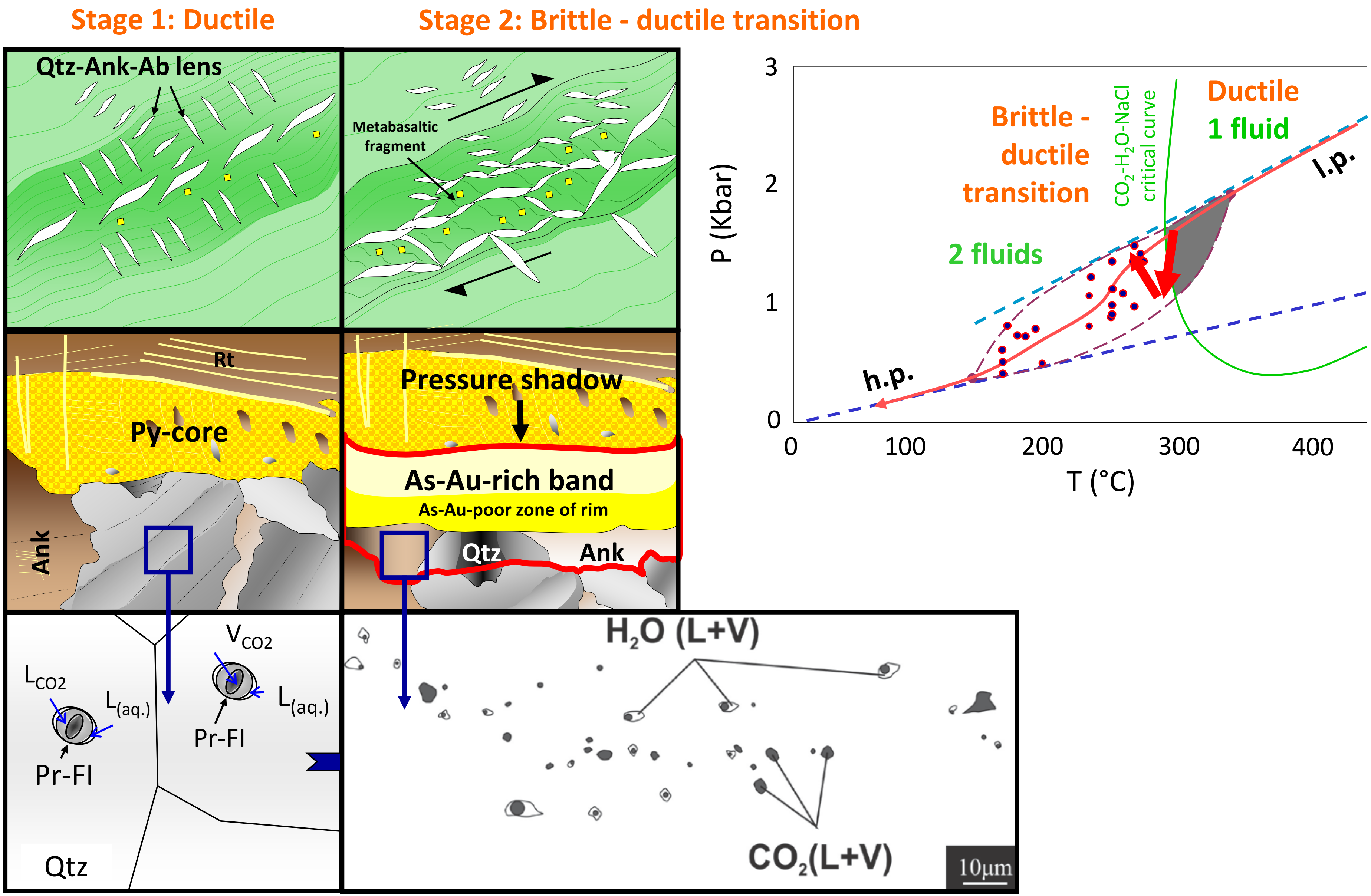


VEIN NETWORK
CO2(L)
10µm
H2O (L)
fluid inclusion trail
10µm
H2O (L+V)
H2O (L+V)
CO2(L+V)
Pr-H2O-CO2-salt
H2O-CO2-salt
H2O-salt
Salinity (wt.% NaCl eq.)
Th(total) °C
0
2
4
6
8
10
0
100
200
300
brittle/ductile transition (quartz-ankertite)
CO2-H2O-NaCl critical curve
2 FLUIDS immiscibility
1 FLUID
geothermal gradient of 40°C/km at l.p.
geothermal gradient of 40°C/km at h.p.
l.p. at 6km
l.p. at 4km
h.p. at 6 km
h.p. at 4 km
+ biotite
P (kbar)
0
1
2
3
0
100
200
300
400
Th(°C)



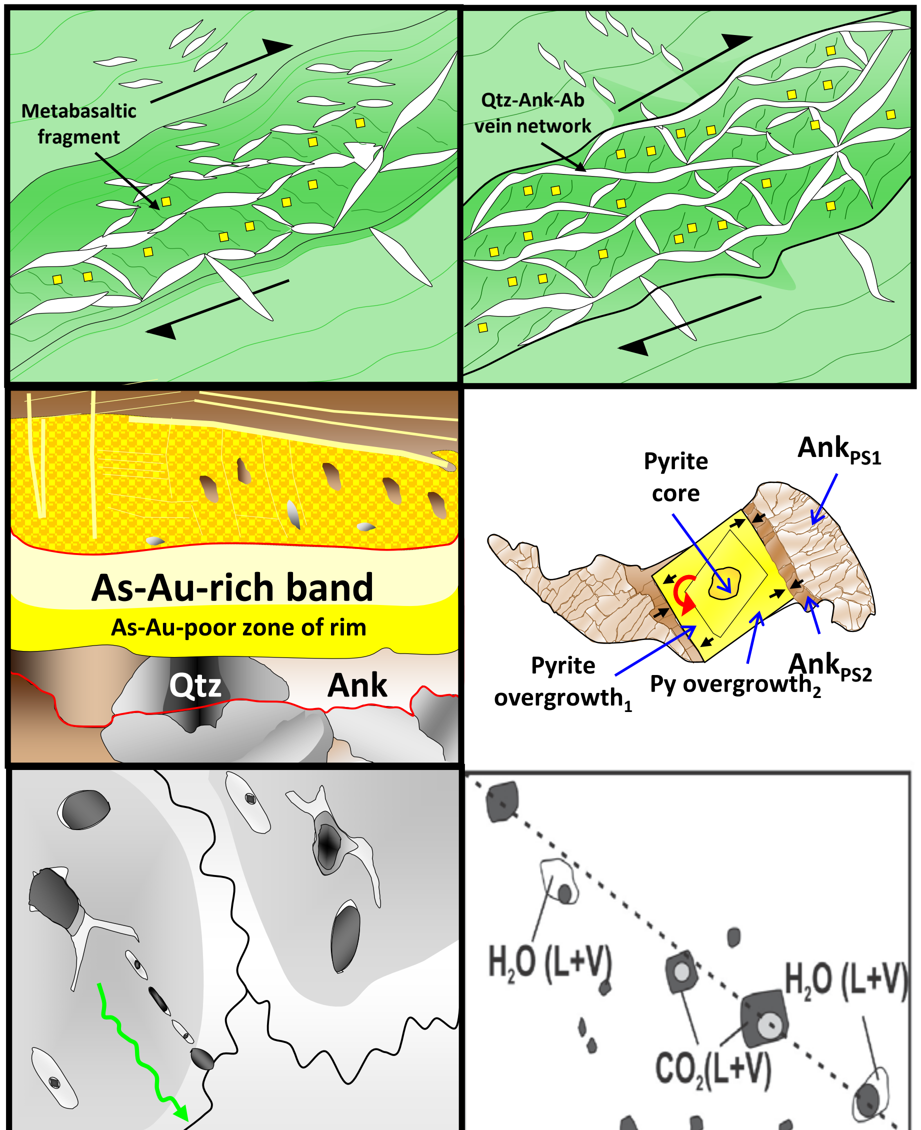
100µm
supercritical
Py$_{RZ}$-core
100µm
0
0.2
0.4
0.6
0.8
XCO$_2$
300µm
Ms$_L$
Ms$_L$
Py
Au
Cp
Rt
Rt
Ank$_{REM}$
Qz$_{PS}$
Ank$_{PS1}$
Ank$_{PS2}$
Ank$_{PS3}$
Qz$_{REM}$

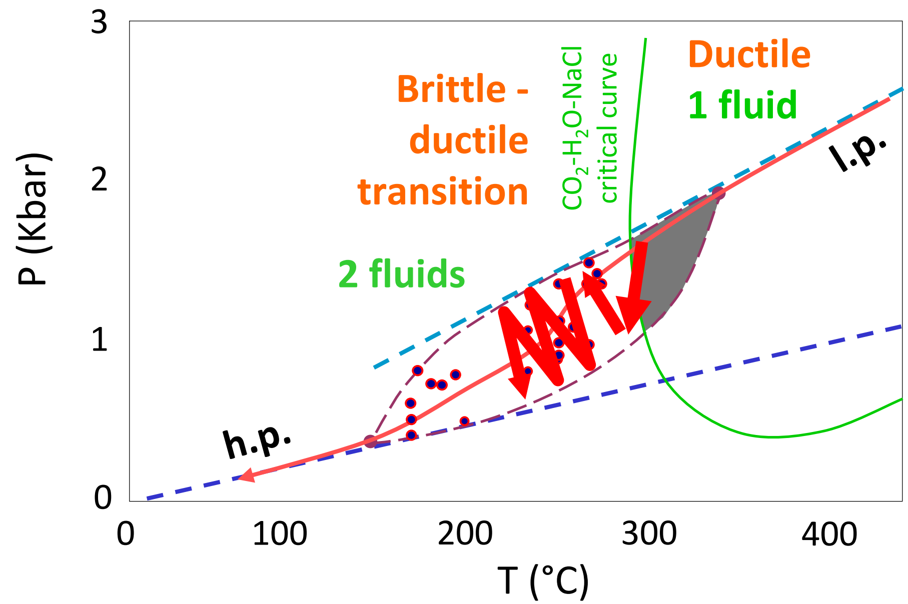
Model for the formation of the zoning and mineralization

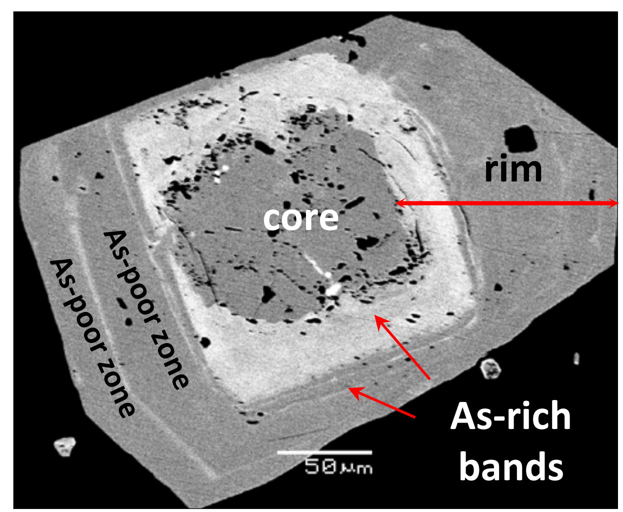


Model for the formation of the zoning and mineralization

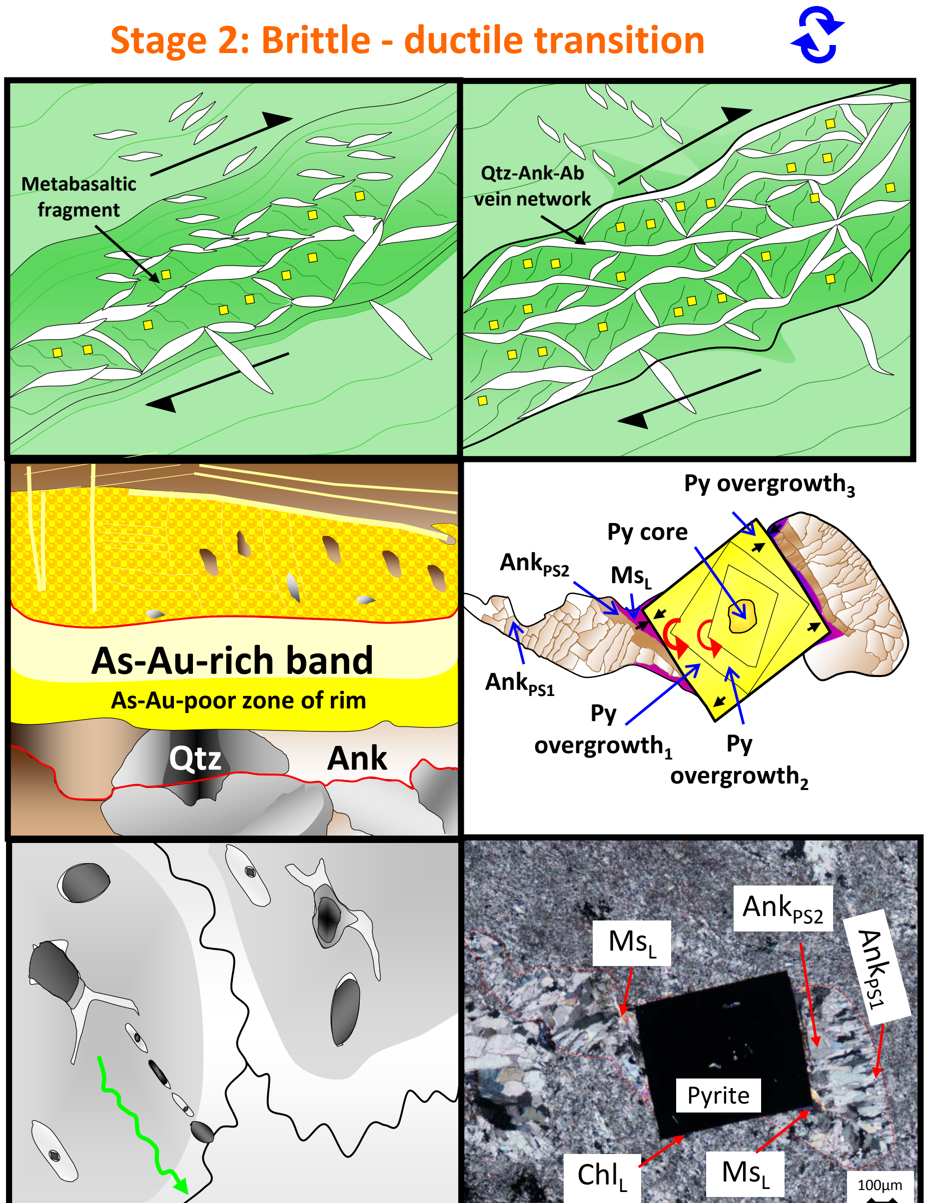
Stage 2: Brittle - ductile transition

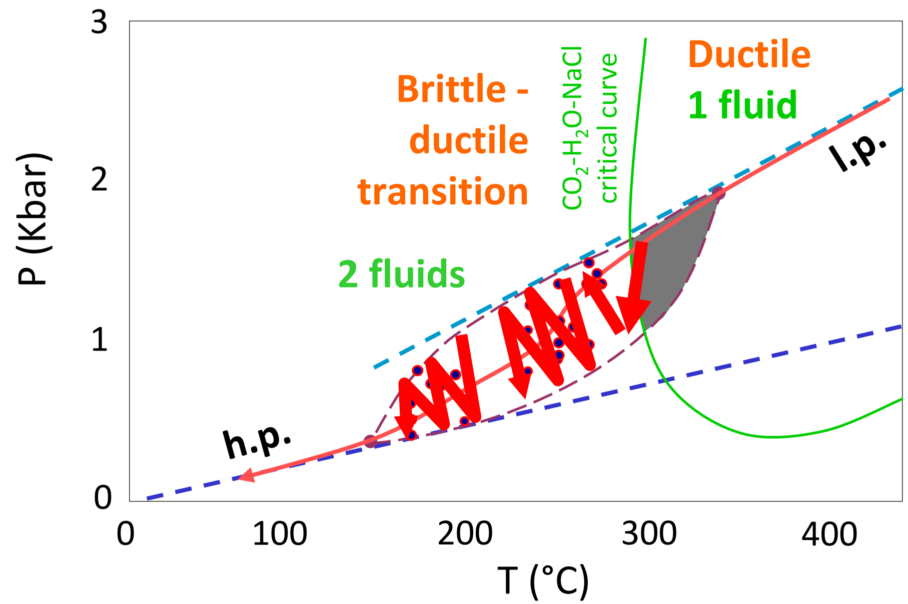


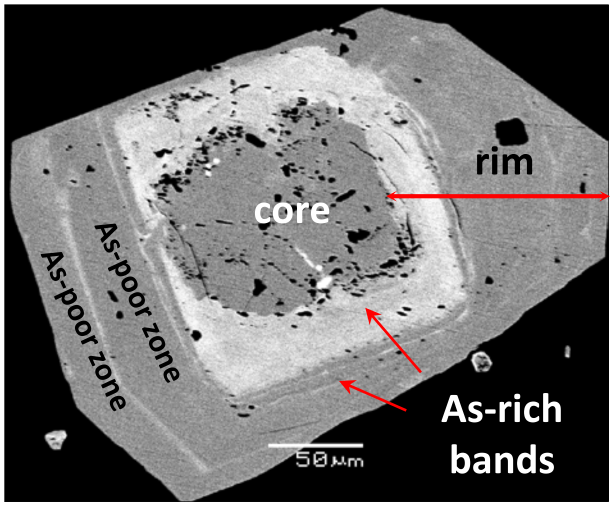




Model for the formation of the zoning and mineralization

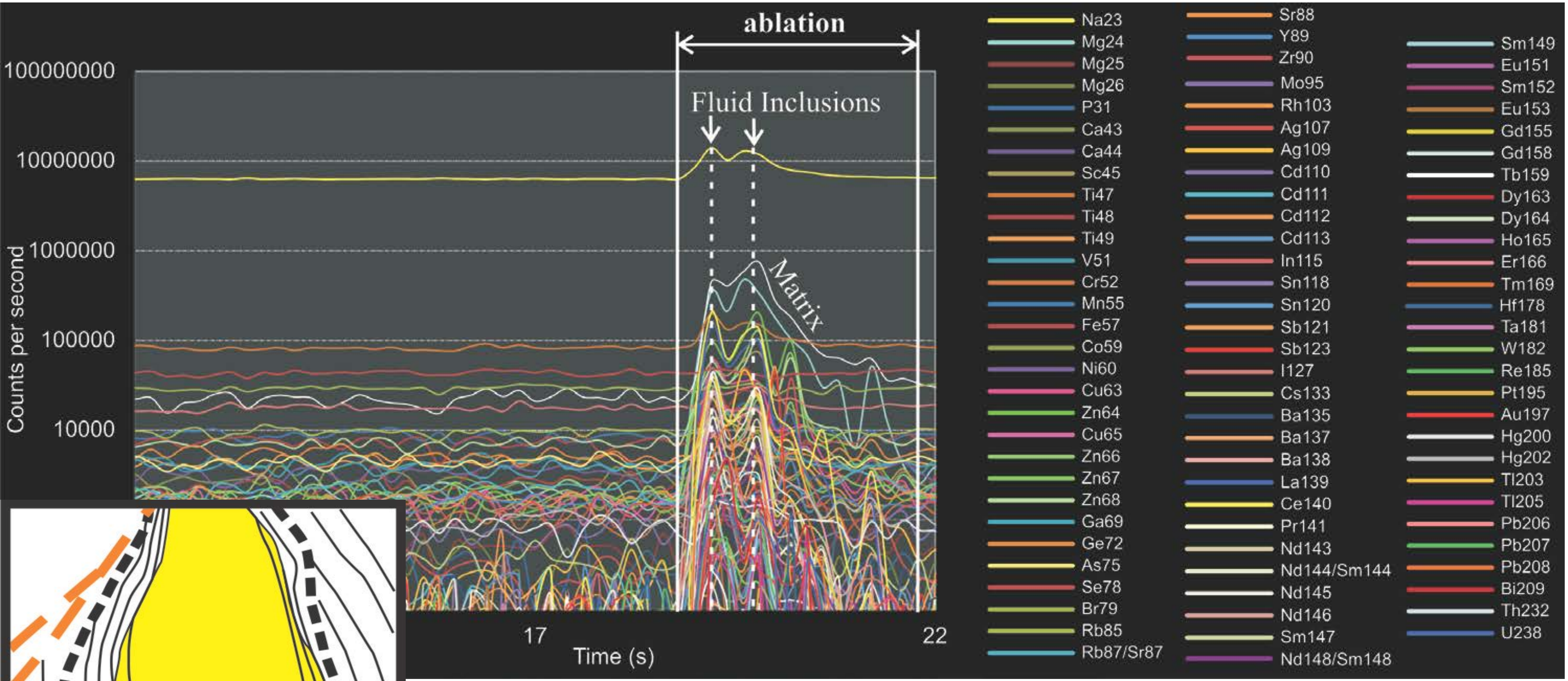


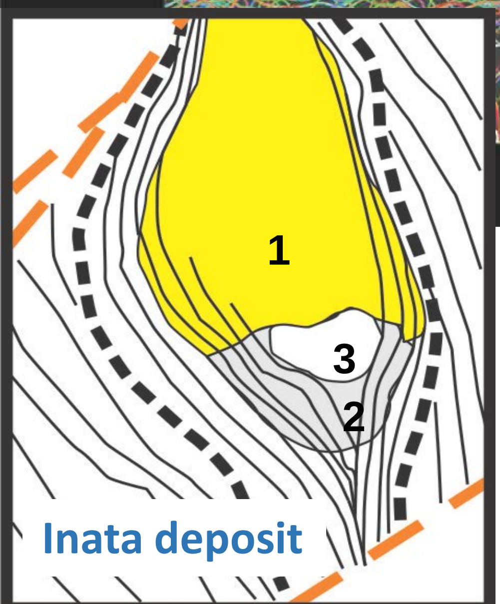




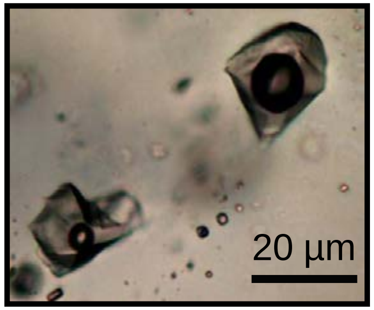
Elemental analysis of fluid inclusions

By Femtosecond Laser Ablation-Time of Flight-Inductively Coupled Plasma Spectrometry





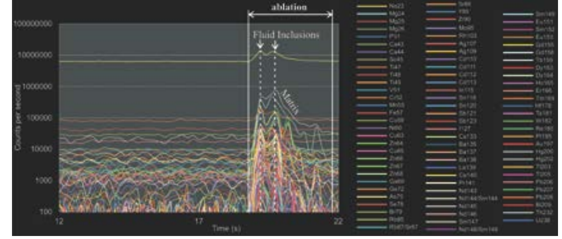
Example of early D_2 aqueous fluid inclusions

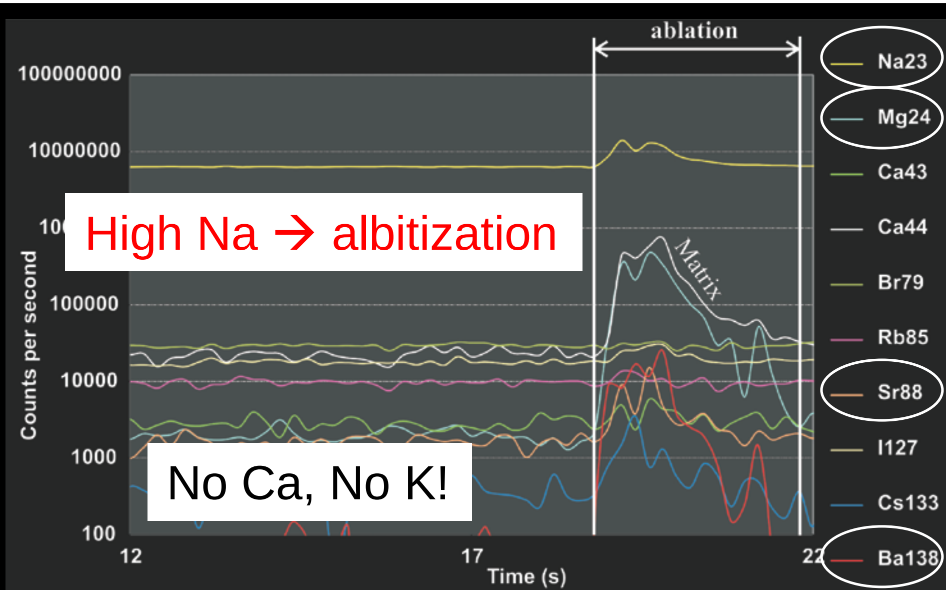


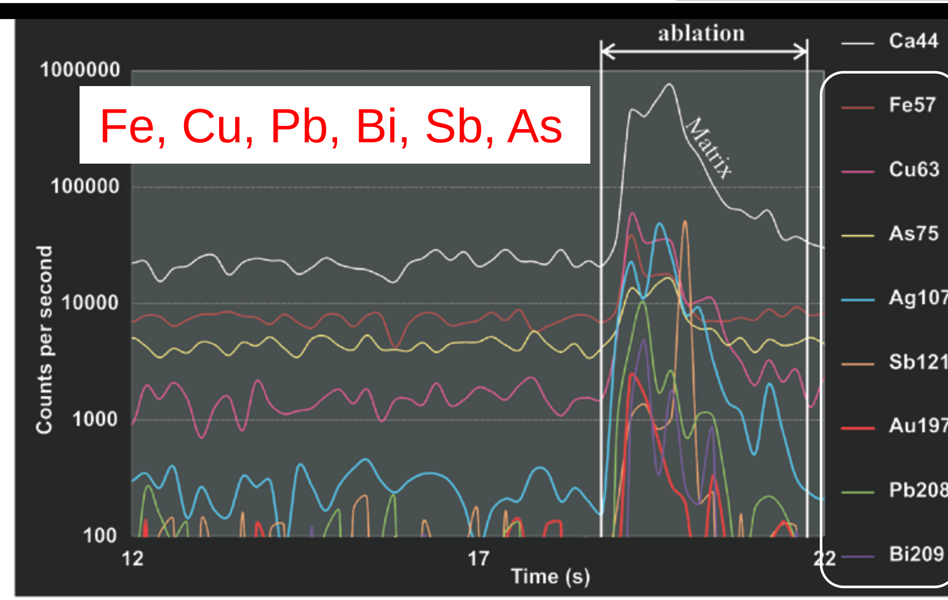
1: albitized diorite dyke
2: sheared quartz
3: undeformed quartz

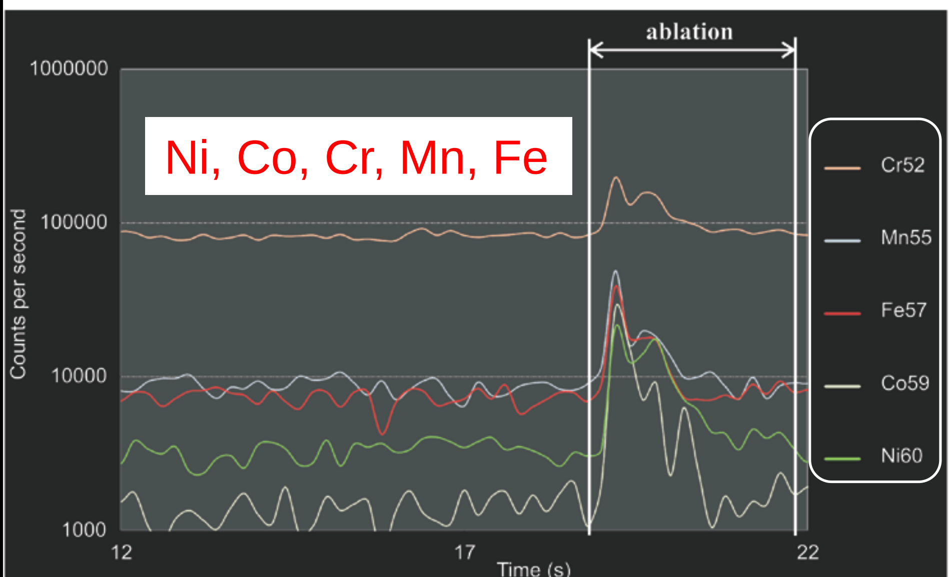
Elemental analysis of fluid inclusions

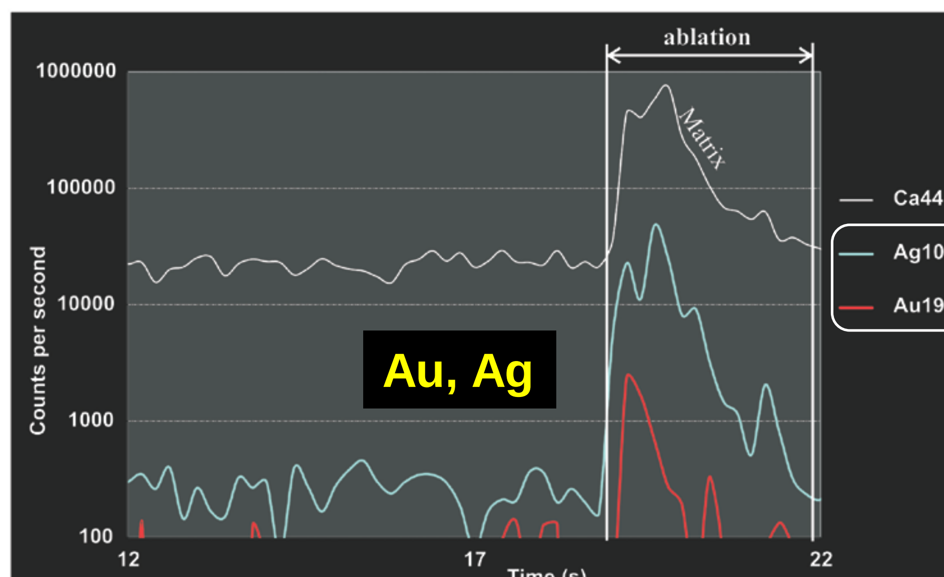
Selection of elements





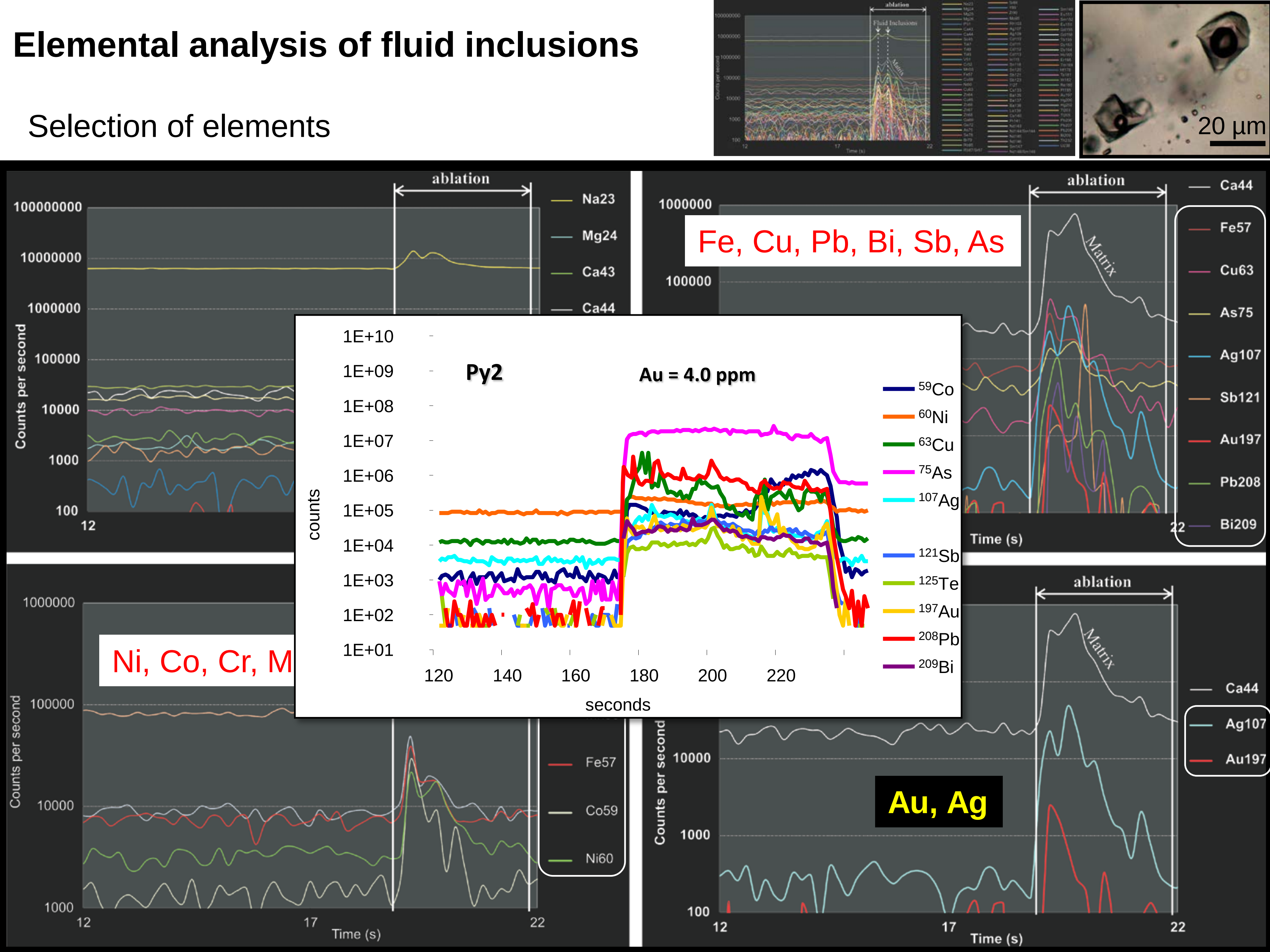






Elemental analysis of fluid inclusions

Selection of elements



Experimental synthesis of Au-As bearing pyrite

How does Au - As intake into pyrite work?

(collaboration G. Pokrovski, GET, Toulouse)

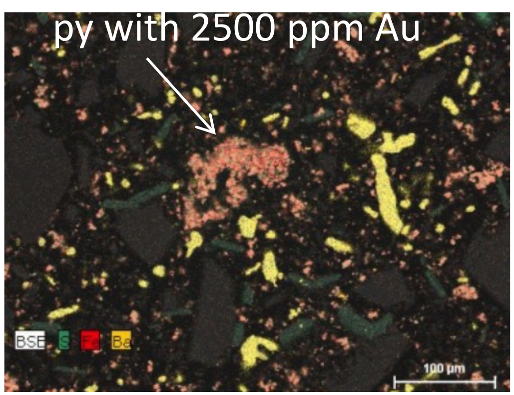
Initial solution in equilibrium with native Au :
S + NaOH ou K2S2O3+HCl ±KCl ± silicates

200-500°C, 500-1500 bar

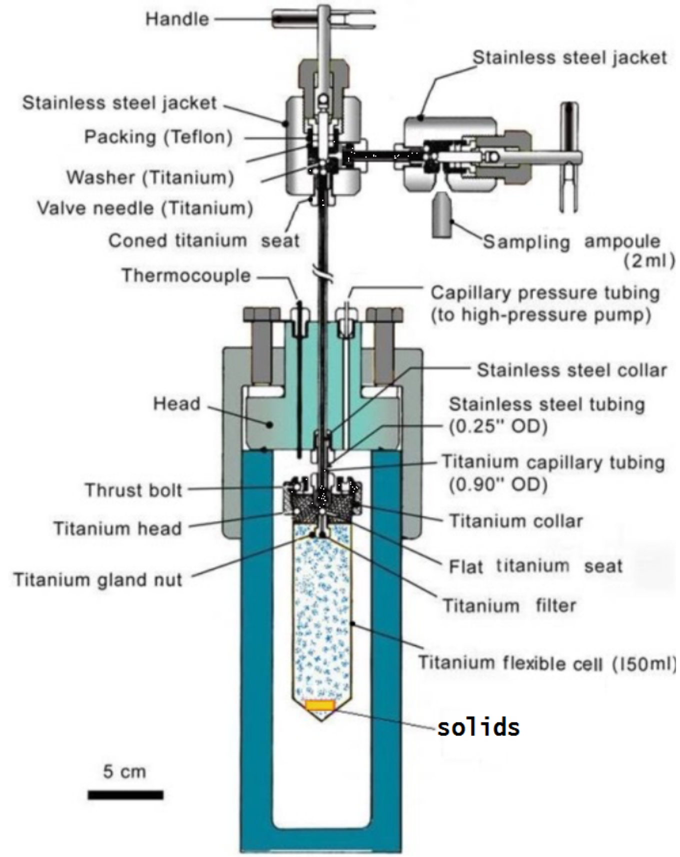
Major species in solution:
H_2S, HSO_4^-, SO_4^{2-}, S_3^-
$Au(HS)_2^-$, AuHS, 'Au-S_3'

Injection of $FeCl_2$ or $FeSO_4$ solution

Coprecipitation of pyrite and gold



False-colour SEM BSE image



Flexible-cell hydrothermal reactor

Thanks for the attention