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ERA·MIN2

RESEARCH & INNOVATION PROGRAMME ON RAW MATERIALS TO FOSTER CIRCULAR ECONOMY

ERA-MIN Joint Call 2019 (EU Horizon 2020 ERA-NET Co-fund Project ERA-MIN2, Grant agreement Nº 730238)

FCT Fundação para a Ciência e a Tecnologia

ANR

Ciências ULisboa

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cnrs

GEOCIÊNCIAS USP

What do mineralogical variations in contact metamorphic haloes tell us?

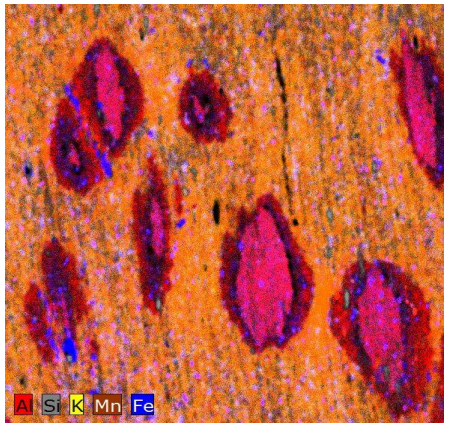
Michel Cathelineau, Marie-Christine Boiron, Gnieneman Yeo, Andrei Lecomte, Chantal Peiffert

Ícaro Dias da Silva, António Mateus, Ivo Martins

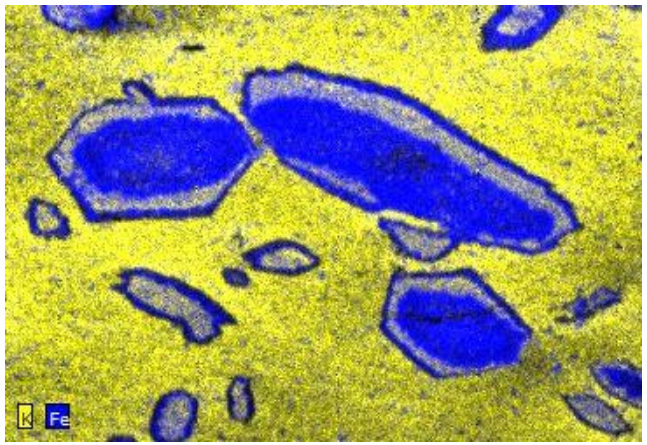
Beiras schist series

• studied from the point of view of sedimentological history, and its significance.
differences in stratigraphy >>> leading to ongoing studies by the Lisbon team

• significant changes in textures due to major deformation and transpositions associated with late-Variscan tectonics (work in progress in Lisbon)
Effects of contact metamorphism: detailed examples such as the Penamacor study (Ribeiro da Costa et al., 2013)



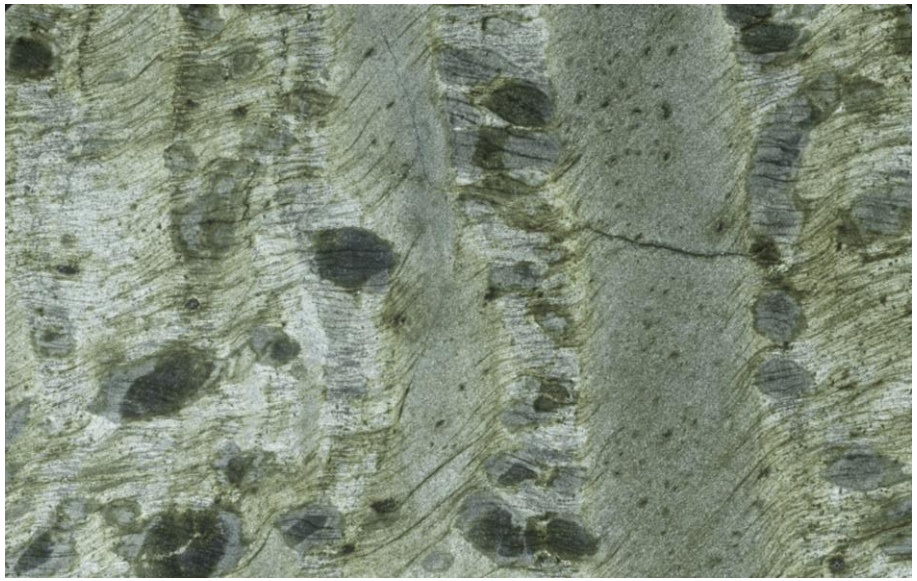
• Further north, pioneering studies on the effects of proximal mineralisation (Regoufe granite, Gaans et al, 1995)



• In the Gois-Segura strip, numerous but widely scattered data, generally in the immediate vicinity of intrusions (Argemela), or veins (Panasqueira, Argemela) (metric scale)
much less data integrated at a regional scale

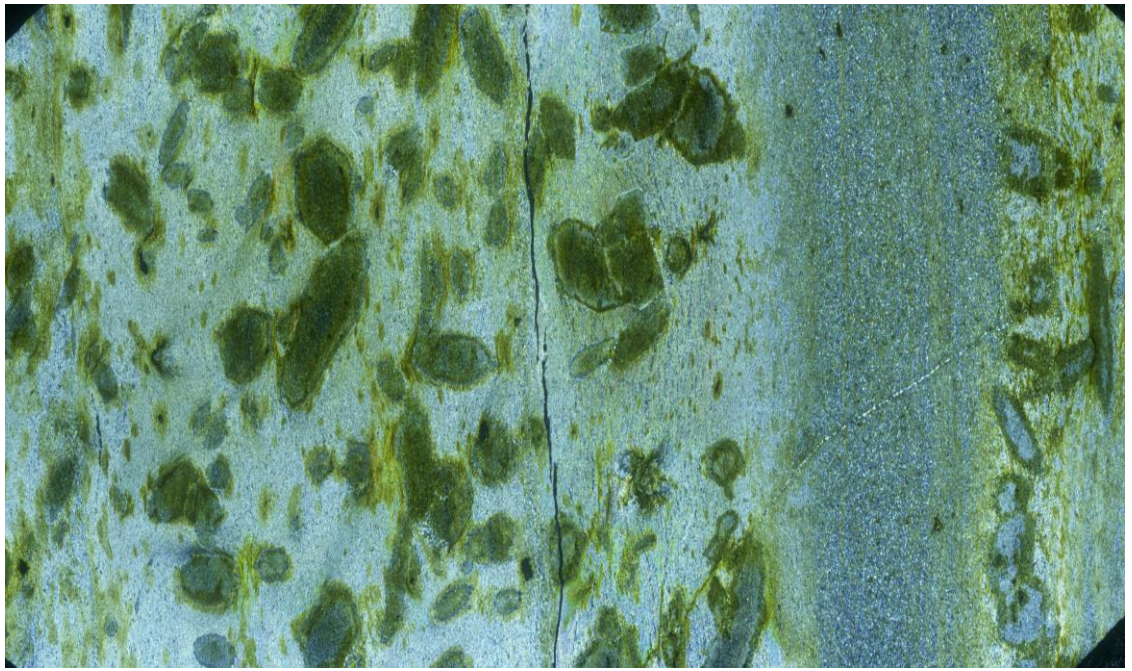
Contact
Metamorphism

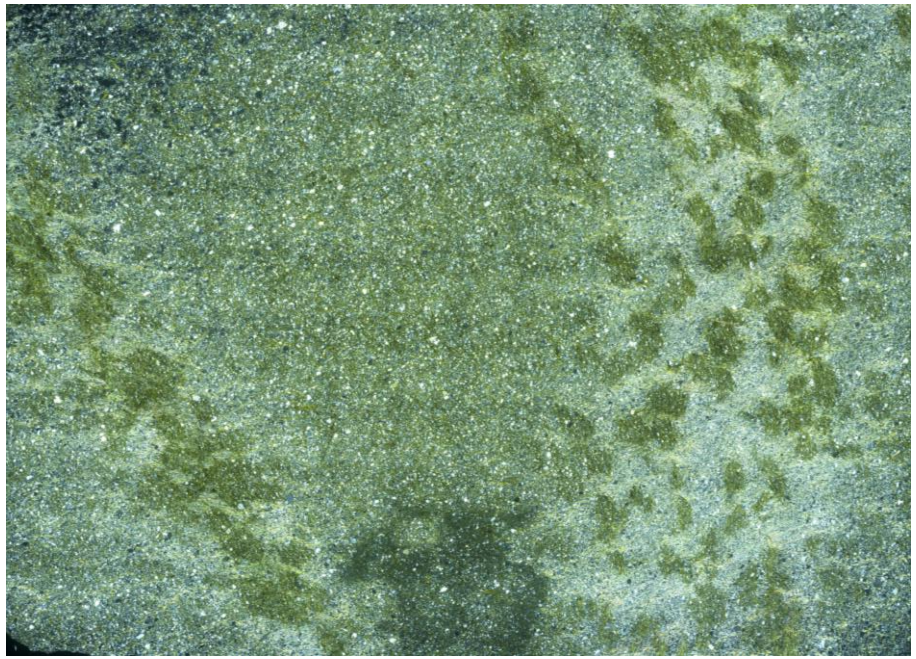
500m to 1km
at max of the granite
boundary

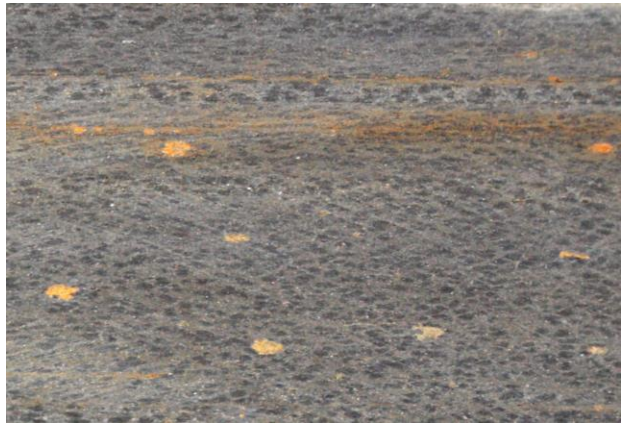


Development of spots is a function of lithology (Al-rich layers)

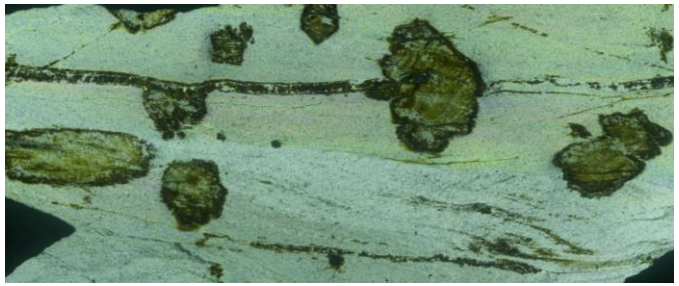
Spots : Absent of the quartz-mica layers

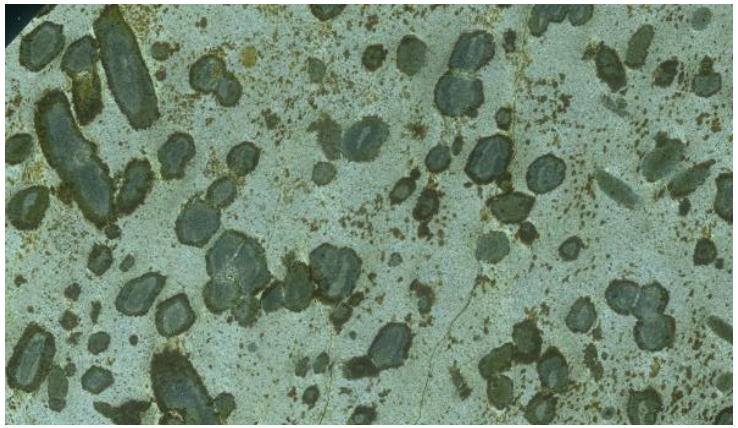


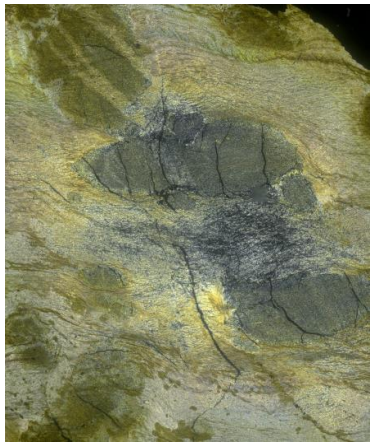




Sample scale





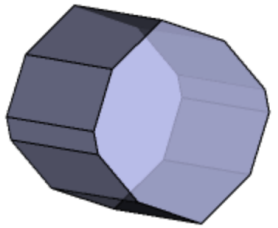


Thin section scale

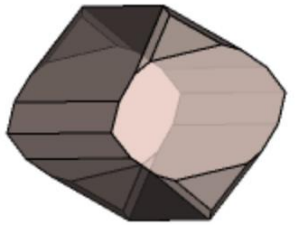
Spots : Great variety of shapes, sizes

only two minerals are generally invoked

Cordierite
$(Mg,Fe)_2Al_3(AlSi_5O_{18})^{\cdot}$
$^{+}n(H_2O,CO_2$



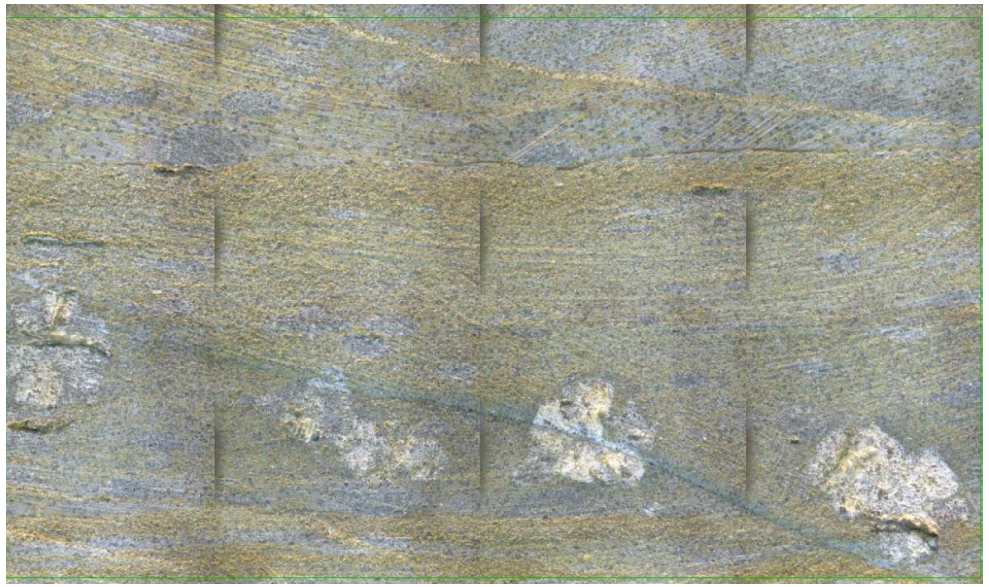
Andalusite
Al_2SiO_5

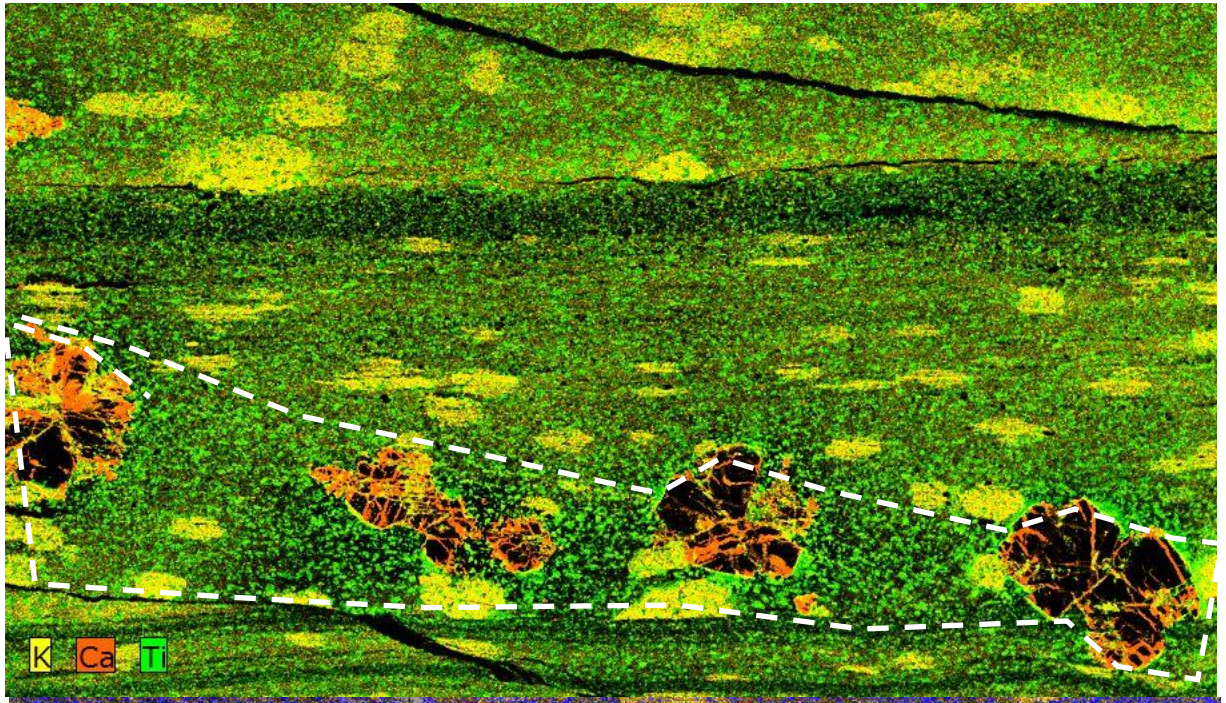


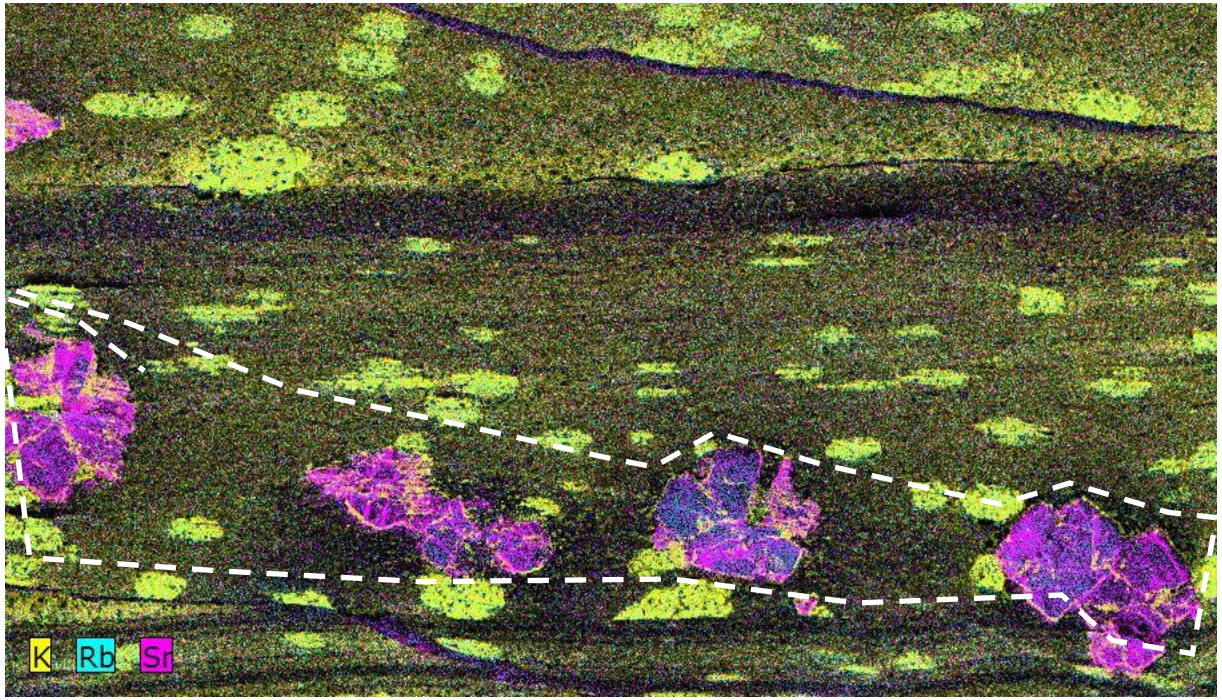
Better preserved (Coimbra area for instance)

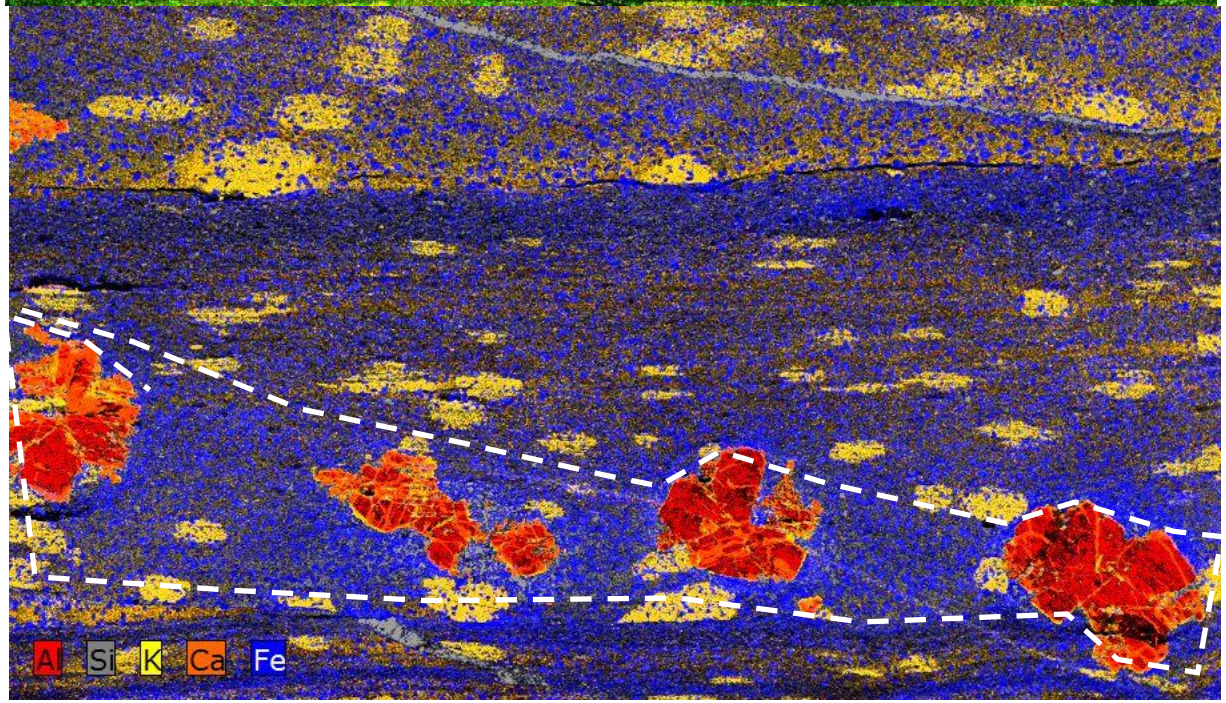
But in most areas, no relics are found,
crystals are entirely replaced or never existed

Andalusite preserved in the Coimbra area

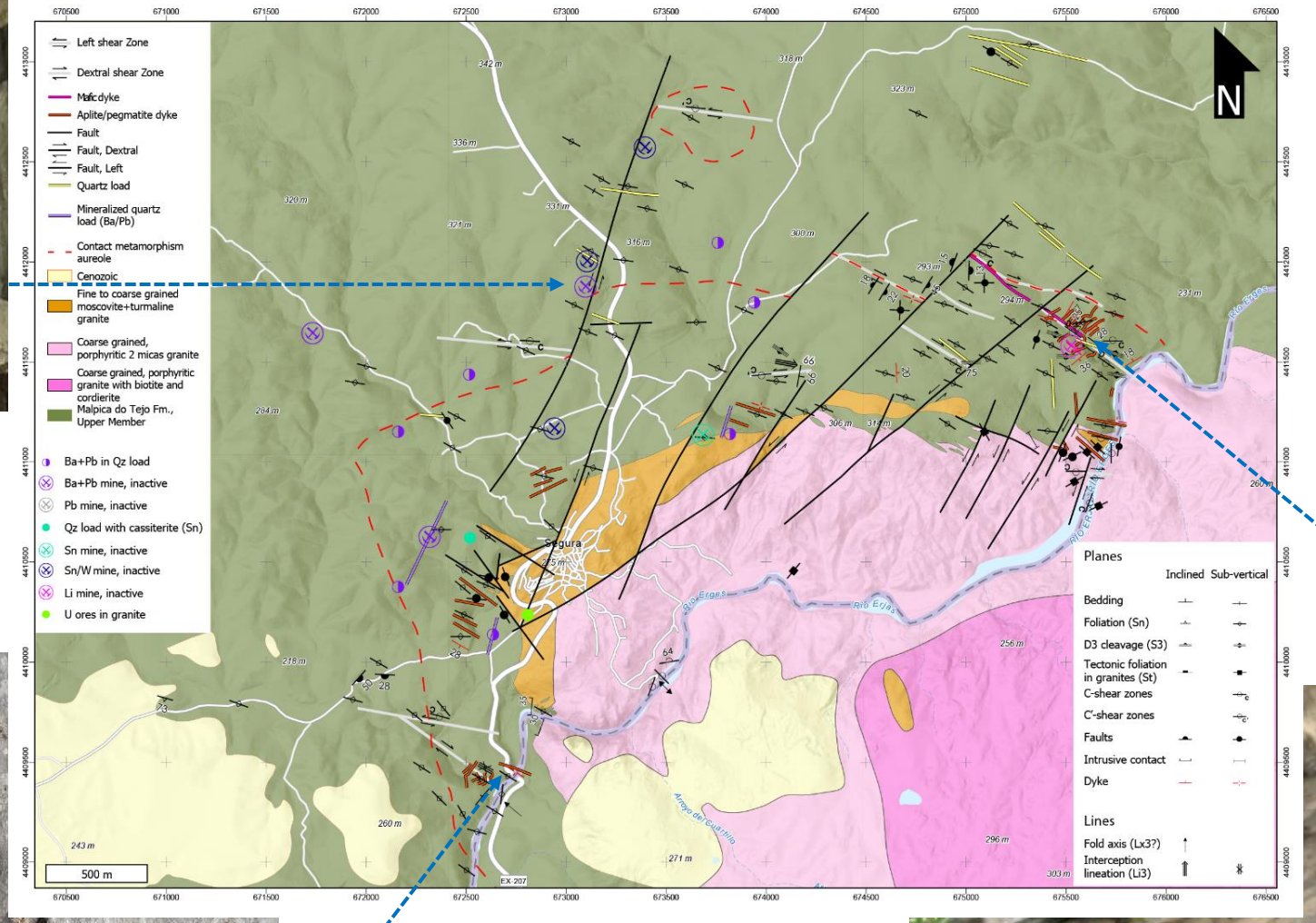


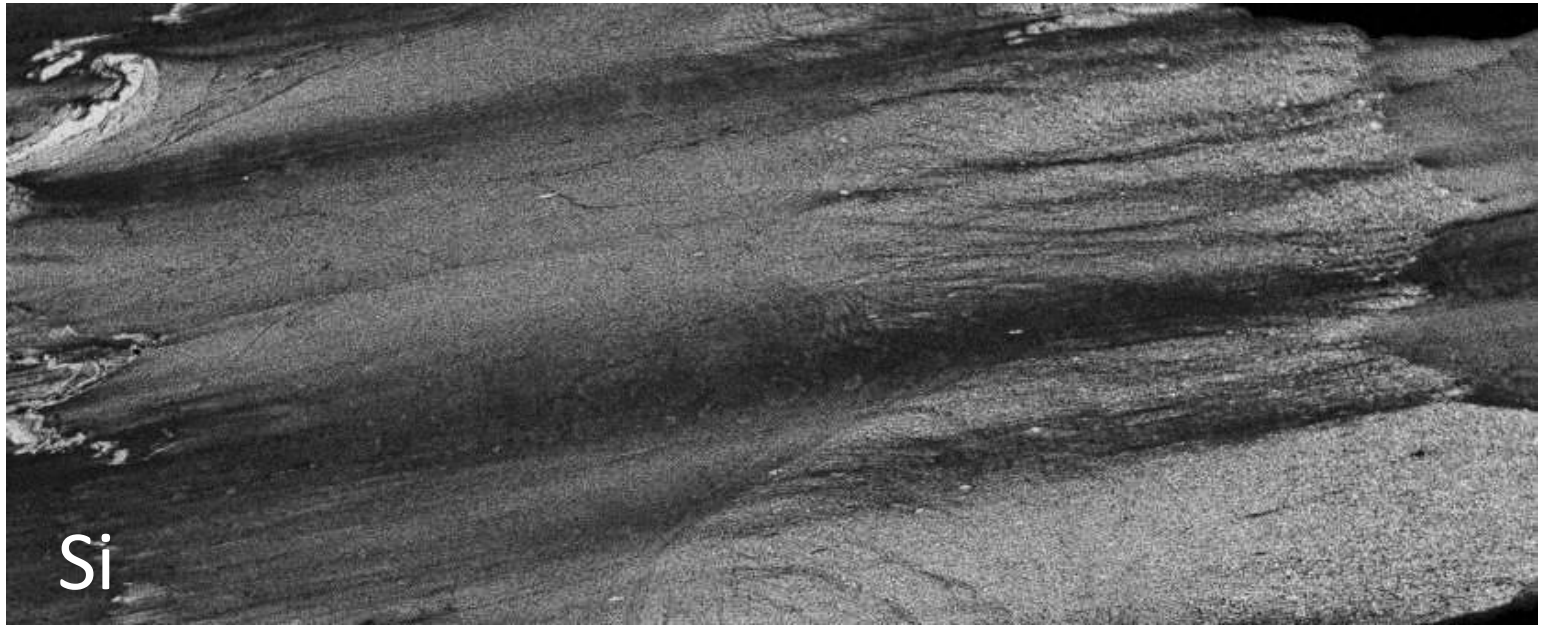






Example of the Segura area



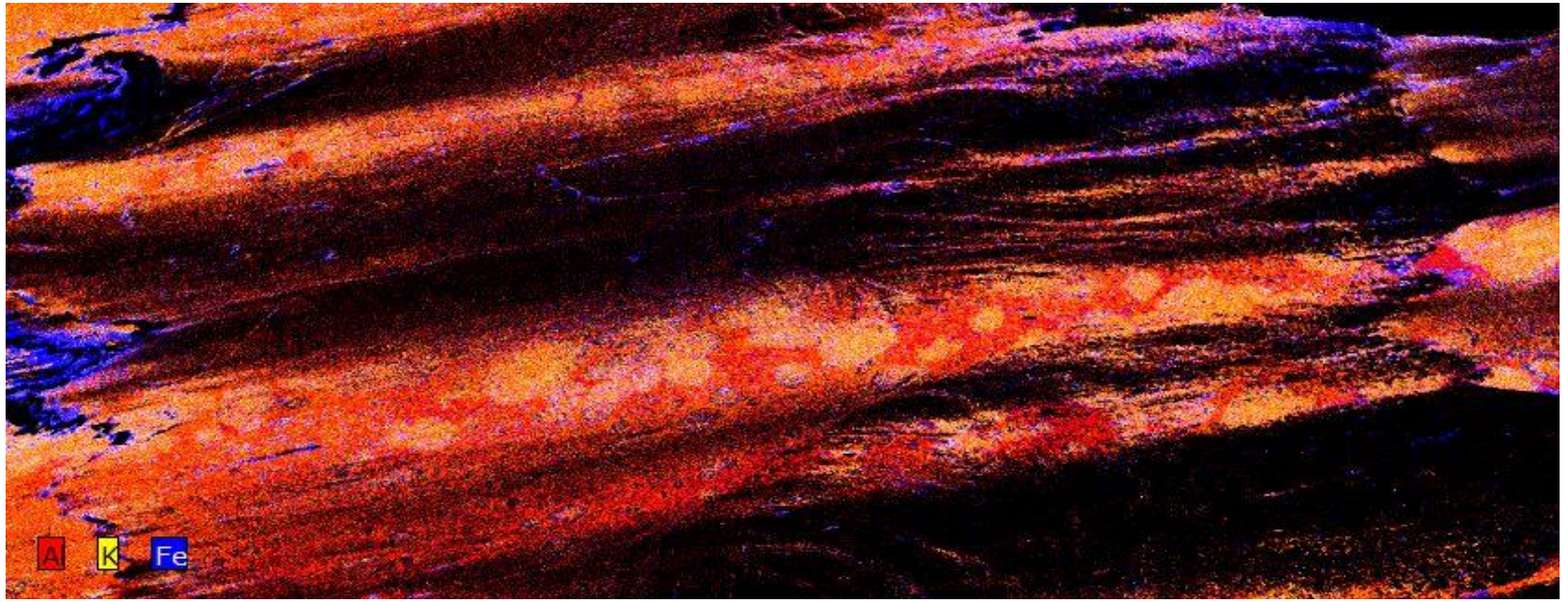


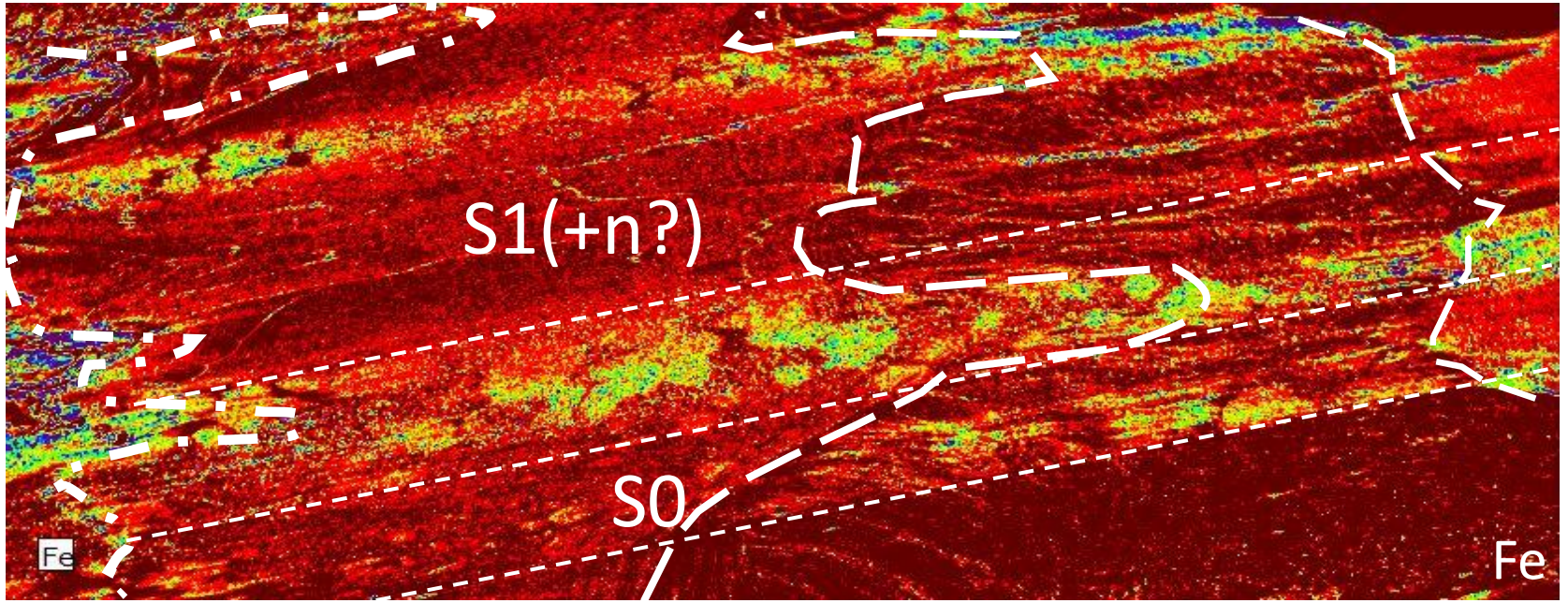
Extreme deformation of the schists

Transposition
Boudinage of comptent siliceous layers

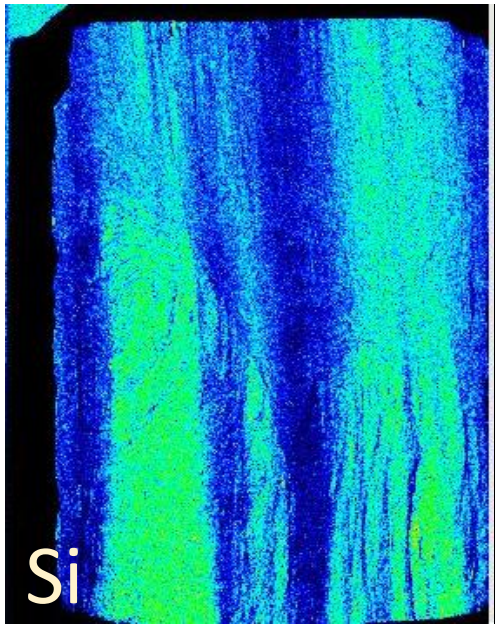
Deformation along the S2 planes
Enrichment in phyllosilicates along planes

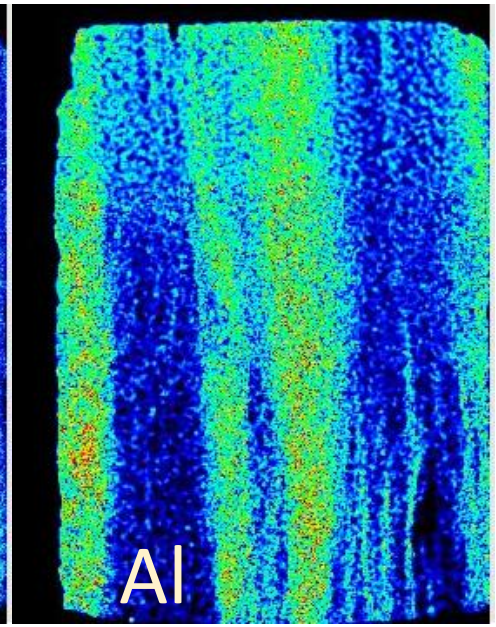
Synchronicity with contact metamorphism
Deformation of spots

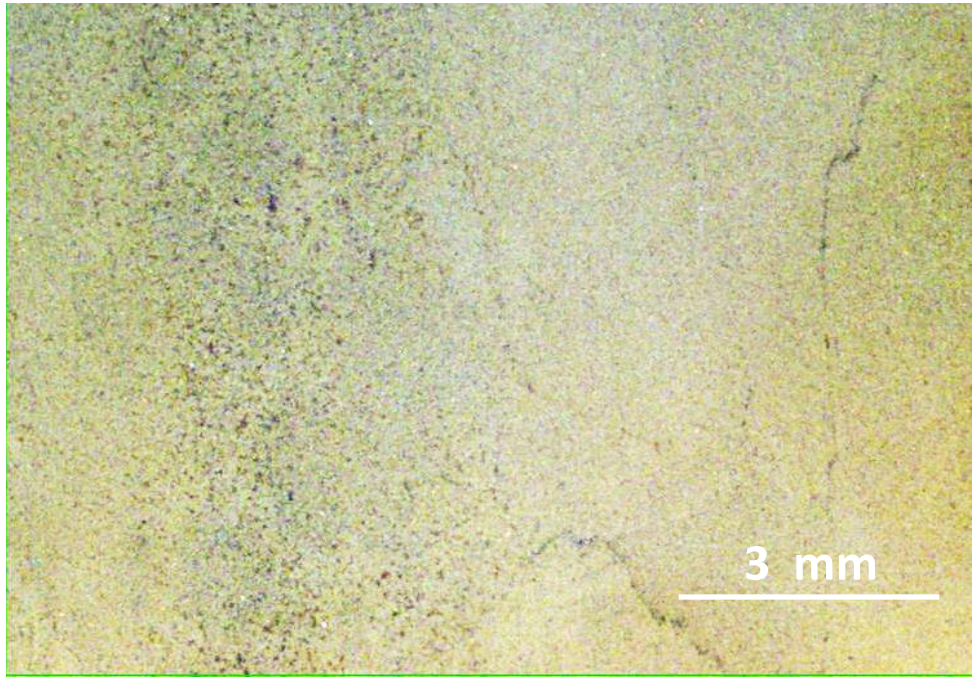

Al
K
Fe

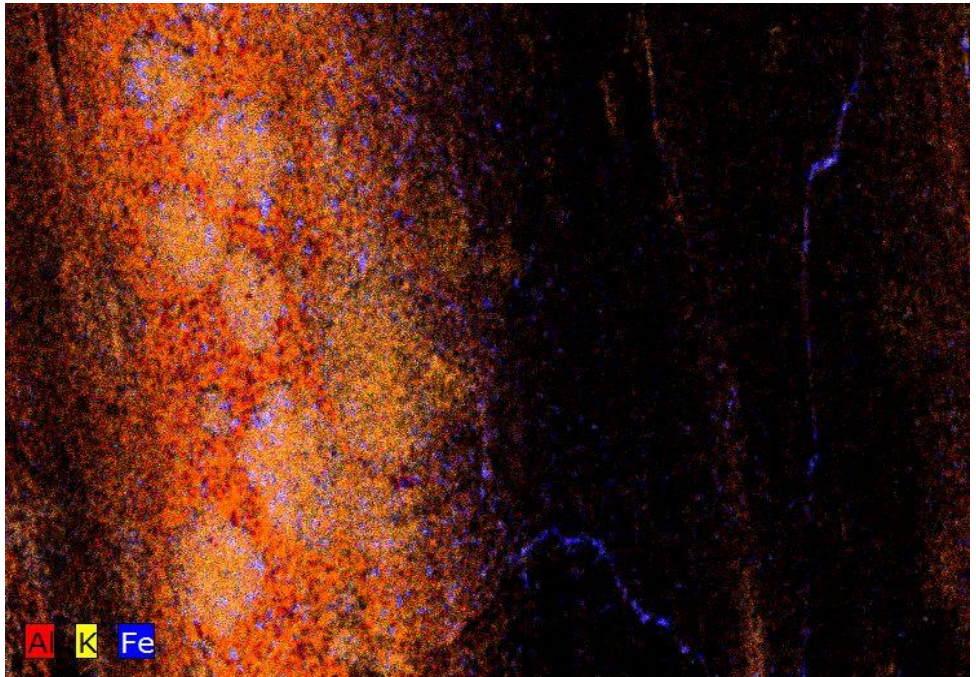

S1(+n?)
S0
Fe
Fe

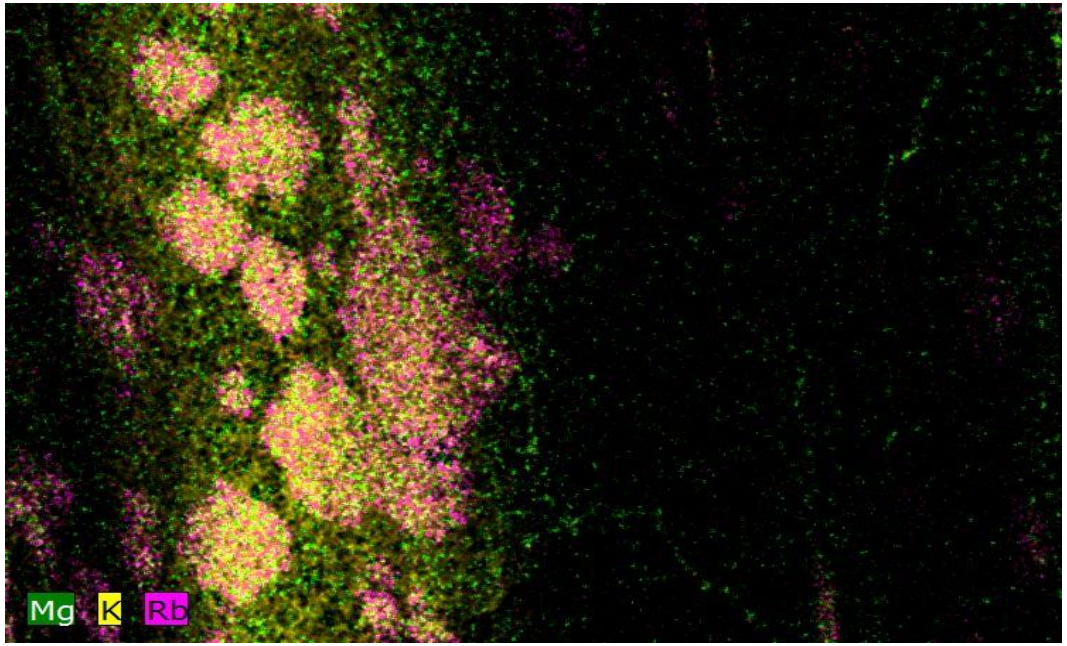
SEG 1-2

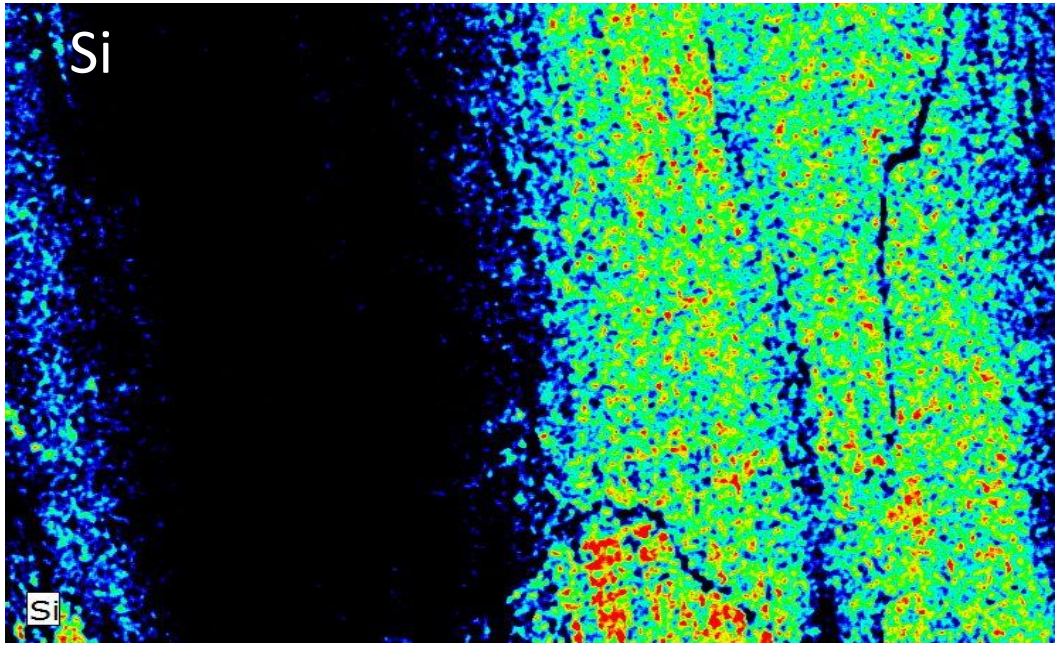


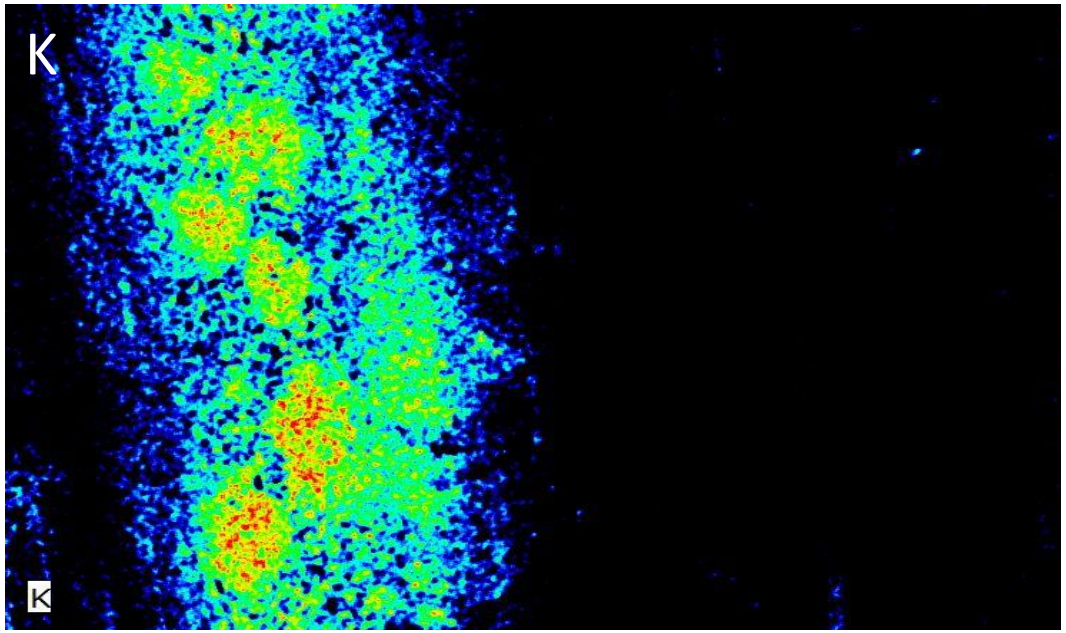


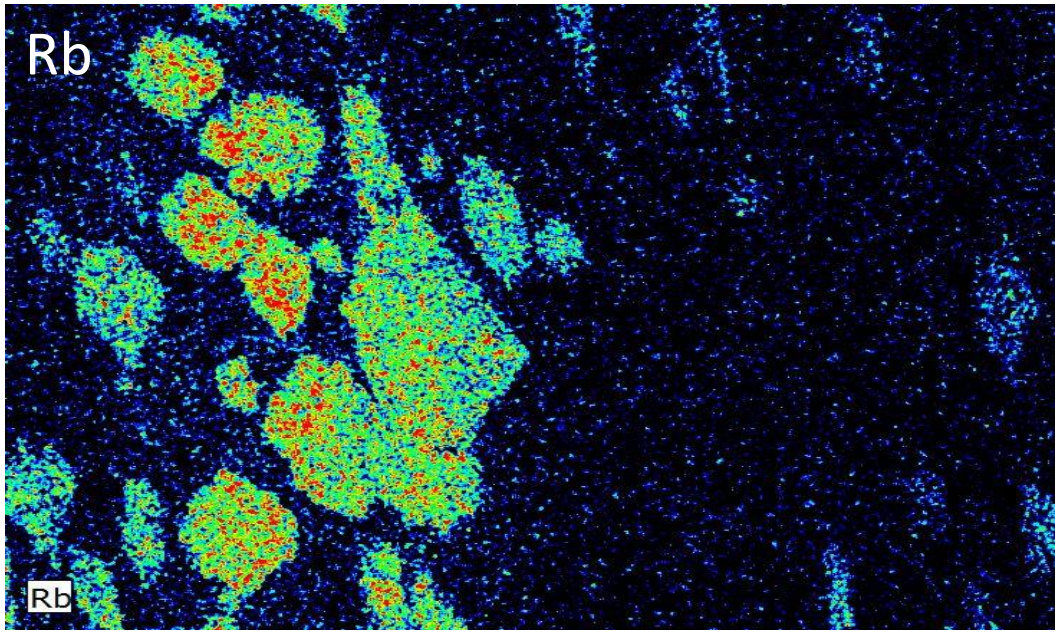




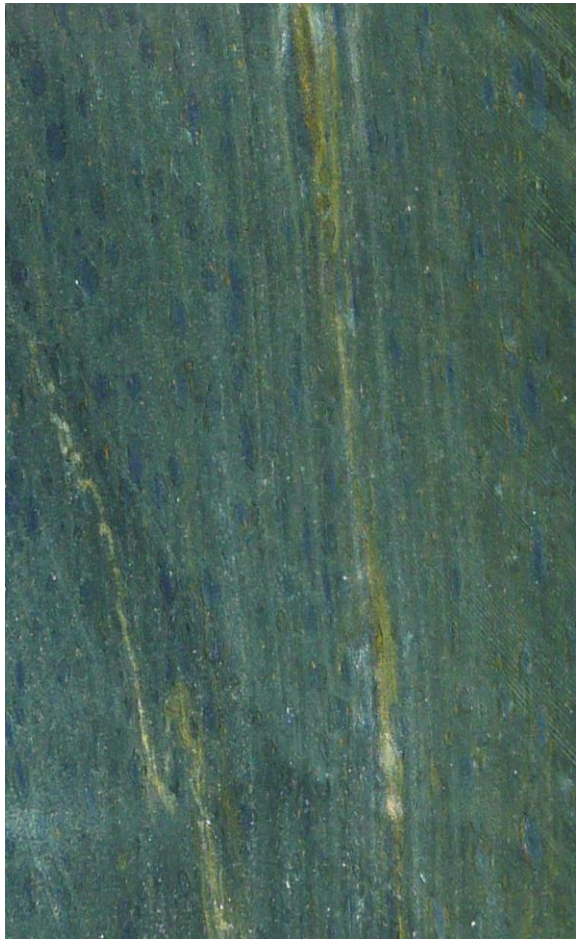

Mg
K
Rb

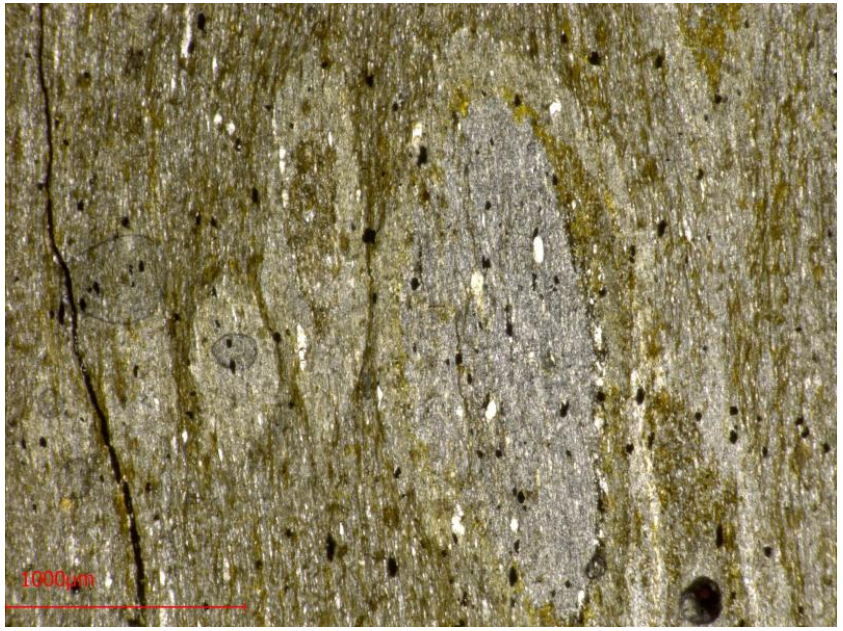

Si
Si

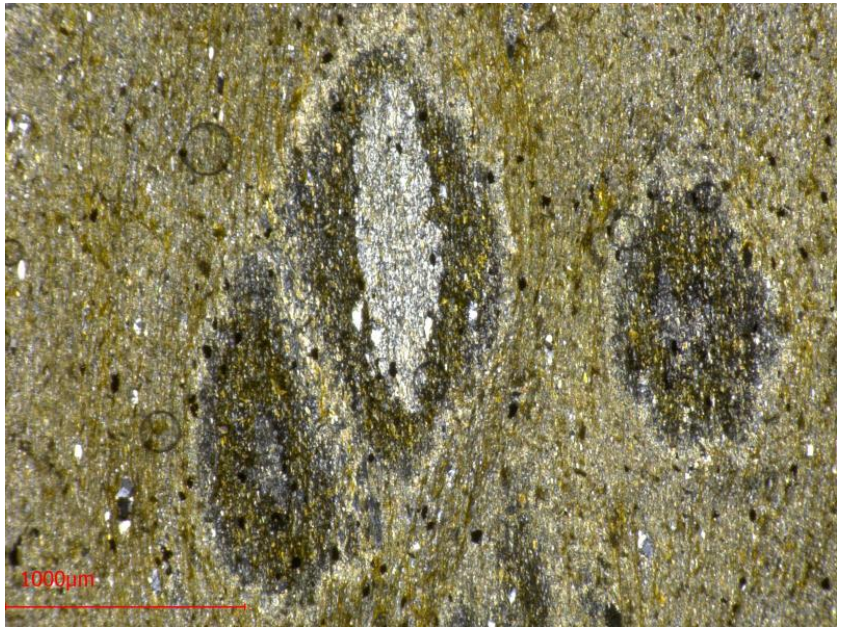

K
K


Rb
Rb

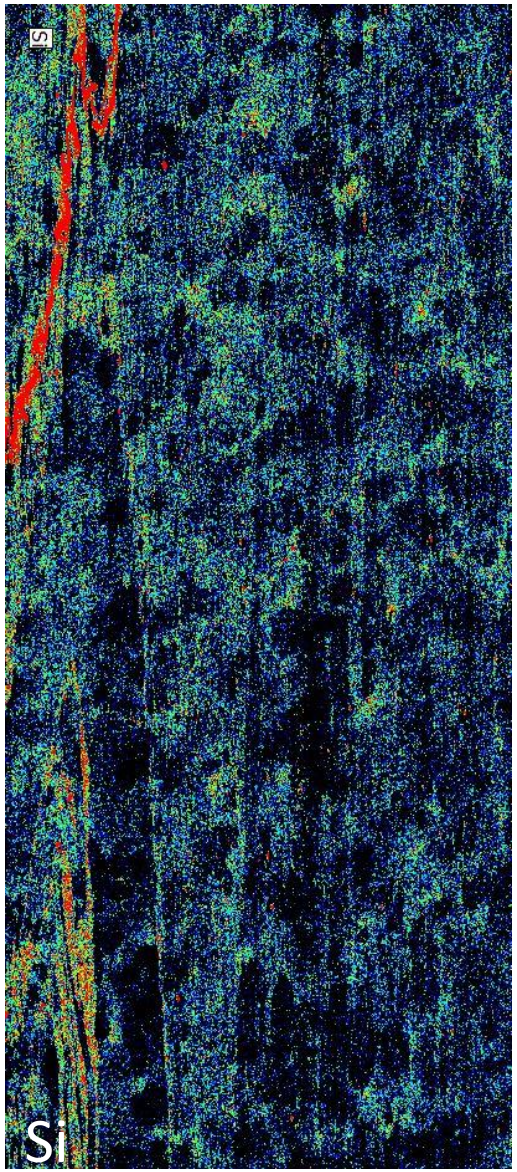
SEG 3/4/5 schist

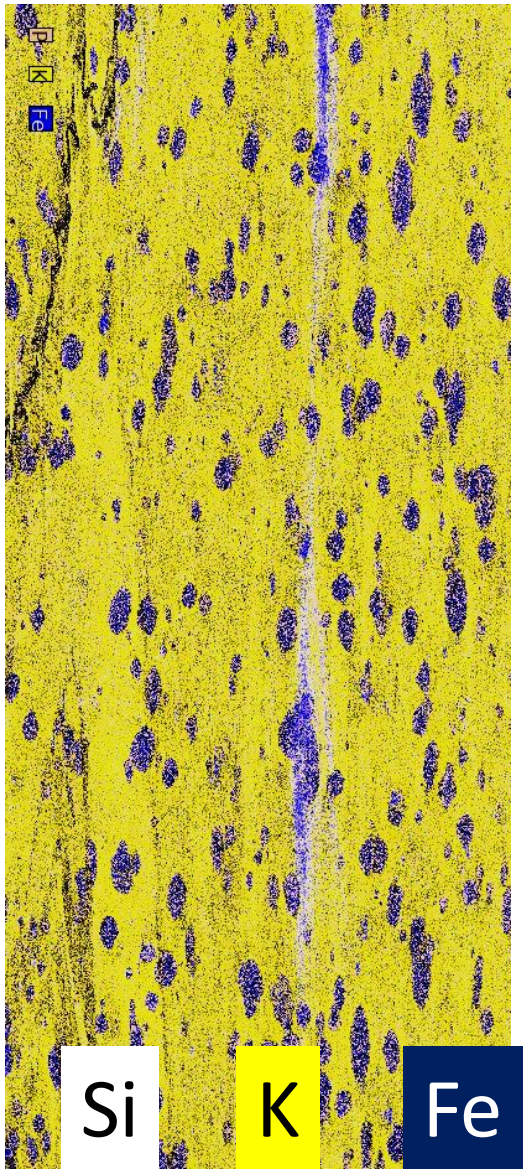


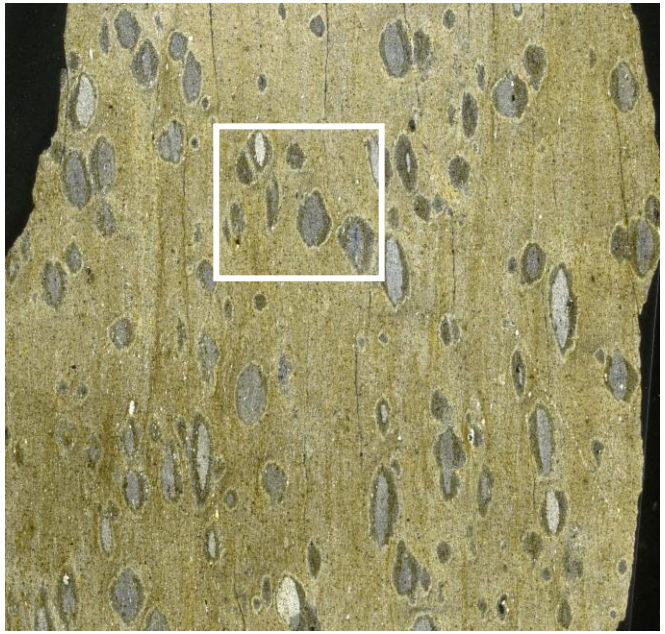


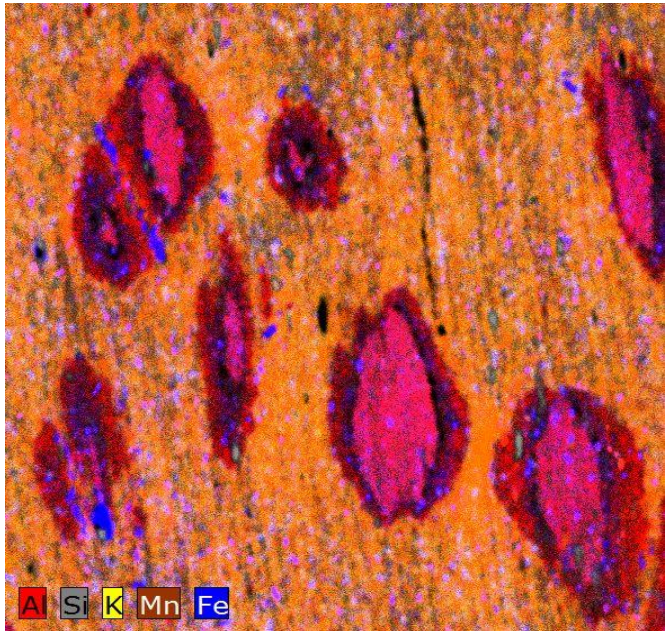


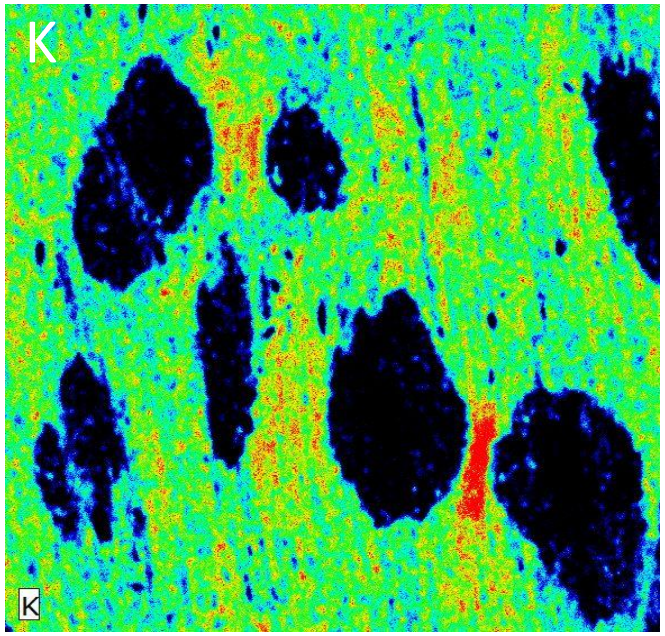
Spotted schists – 500 to 1km around the batholith + effects of dyke intrusions

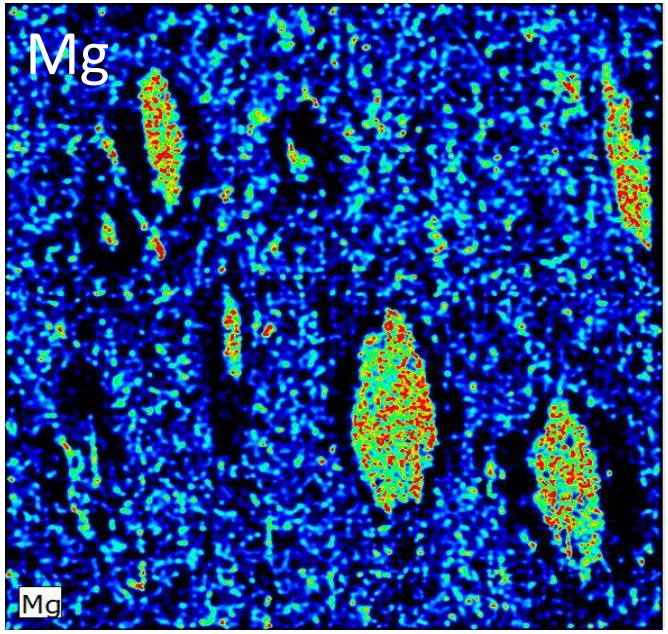






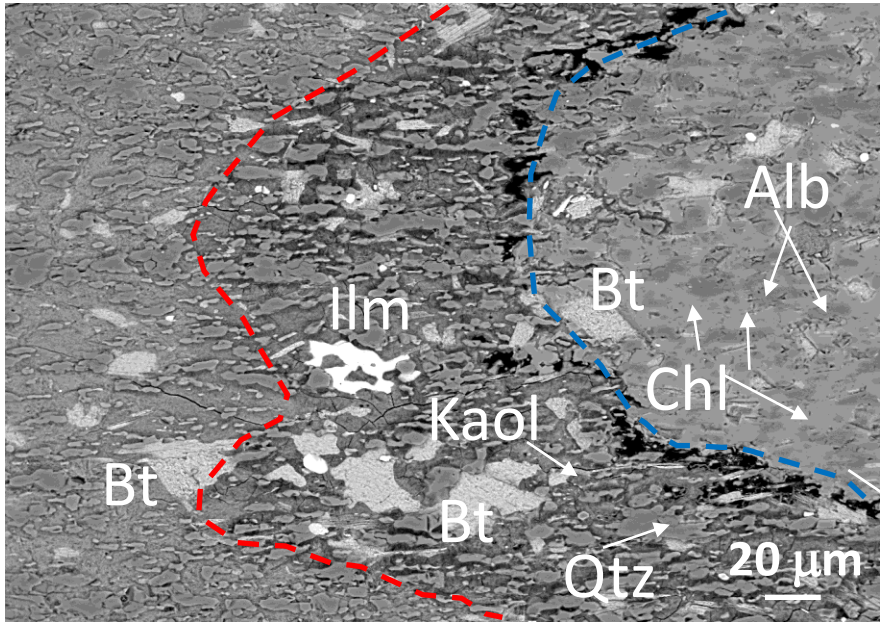


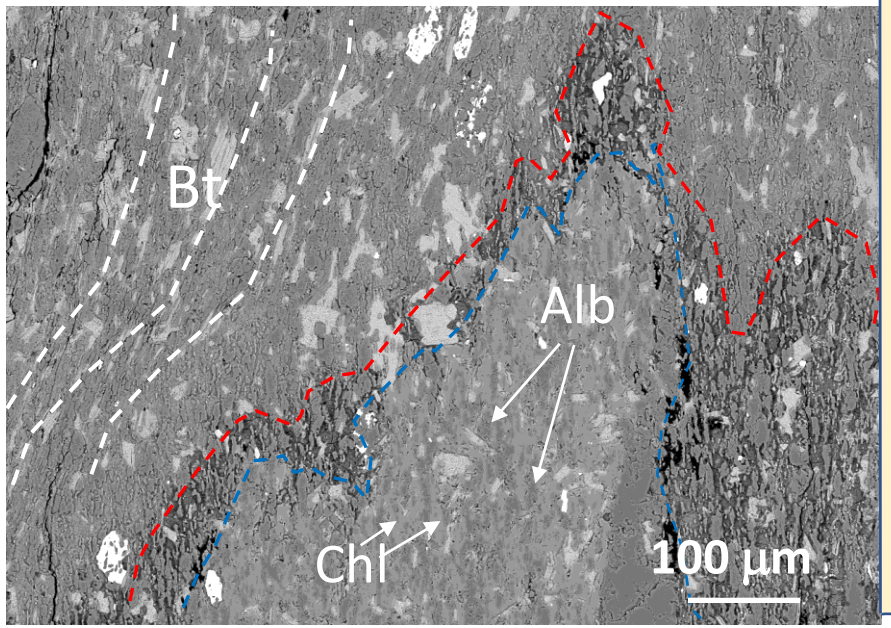


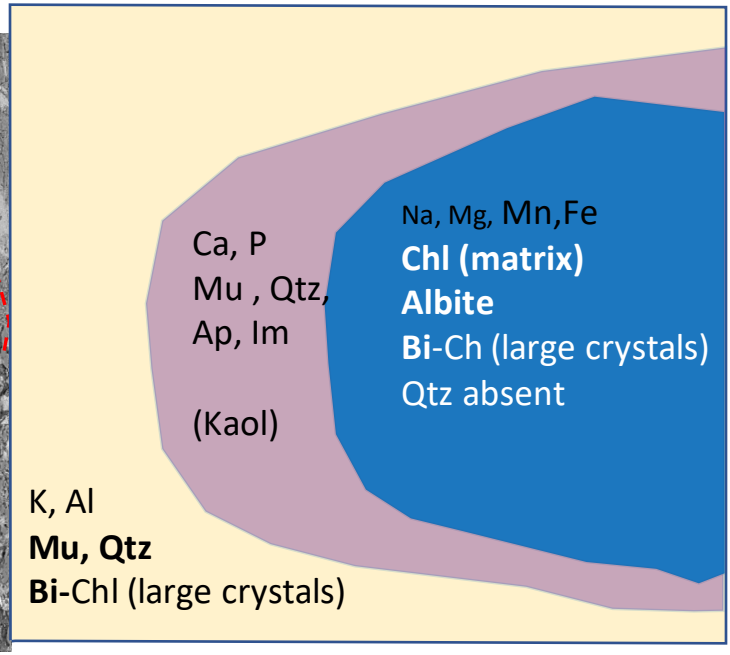


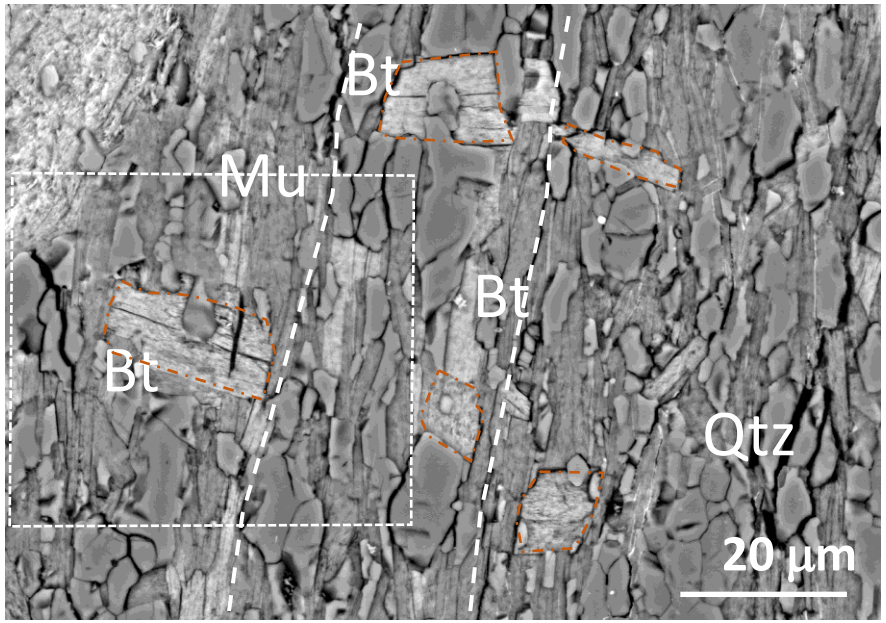
Spots are memory of:

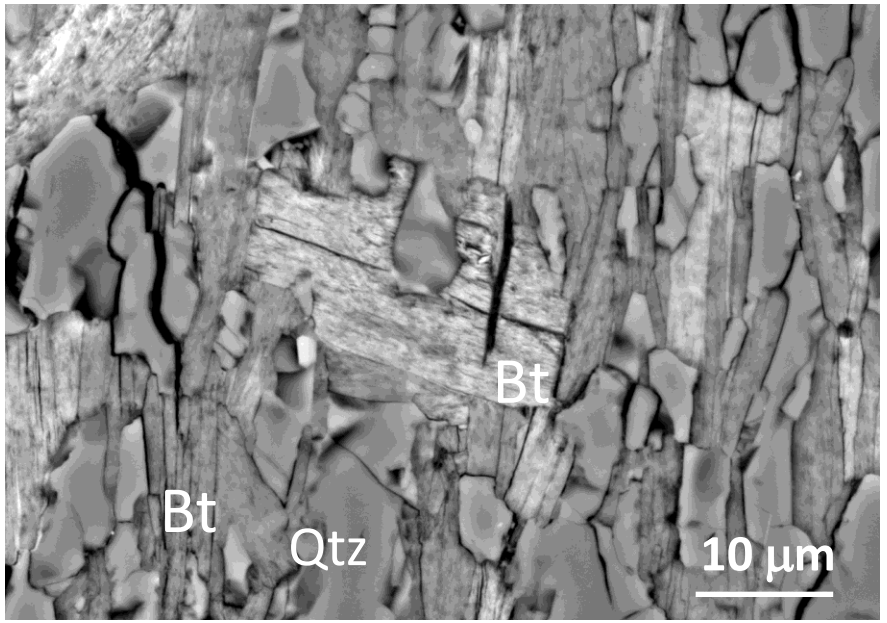
- Deformation
- Mineral segregation
- Contact metamorphism
- Effects of fluids
- Retromorphic conditions

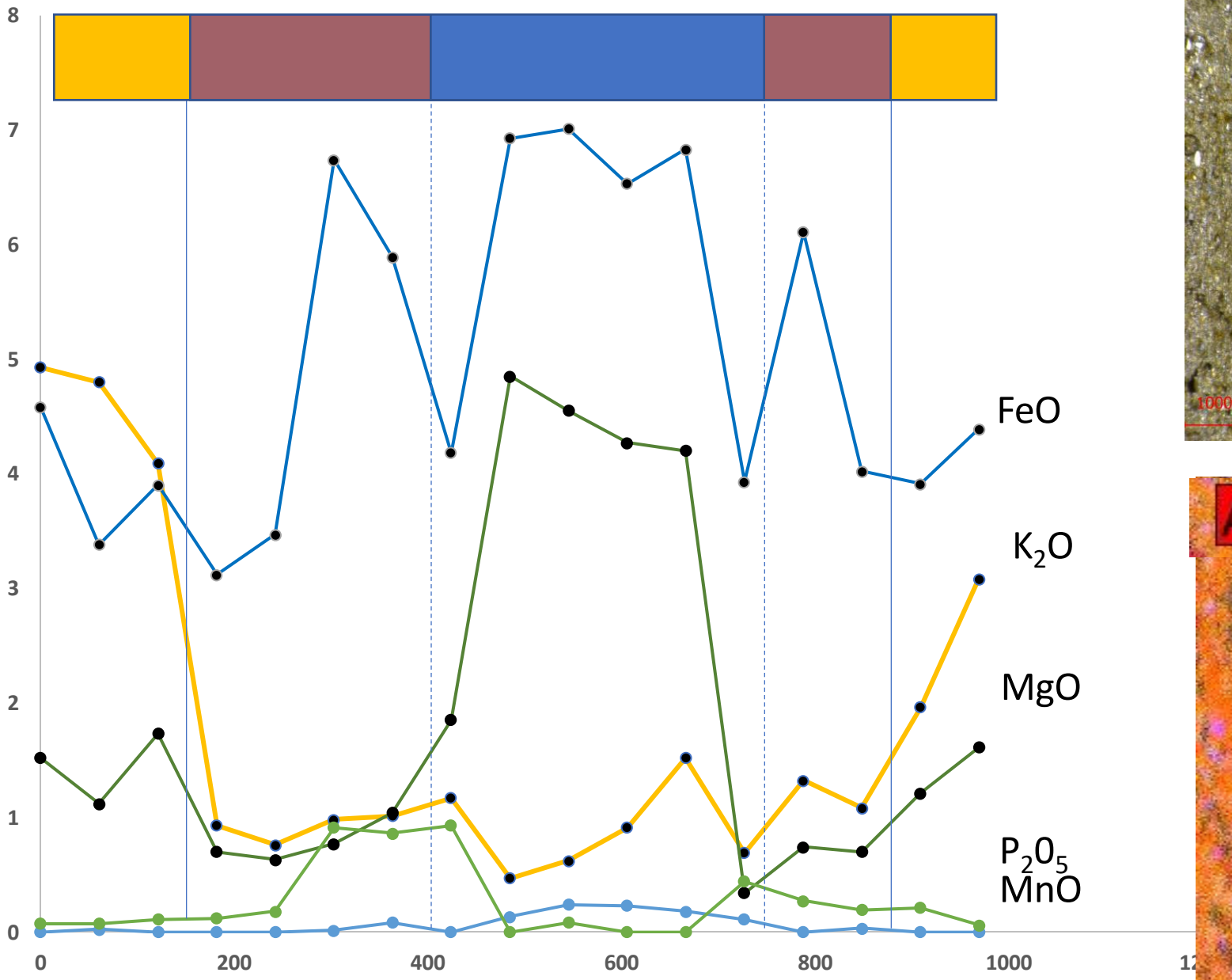

Alb
Ilm
Bt
Chl
Kaol
Bt
Bt
Qtz
20 µm

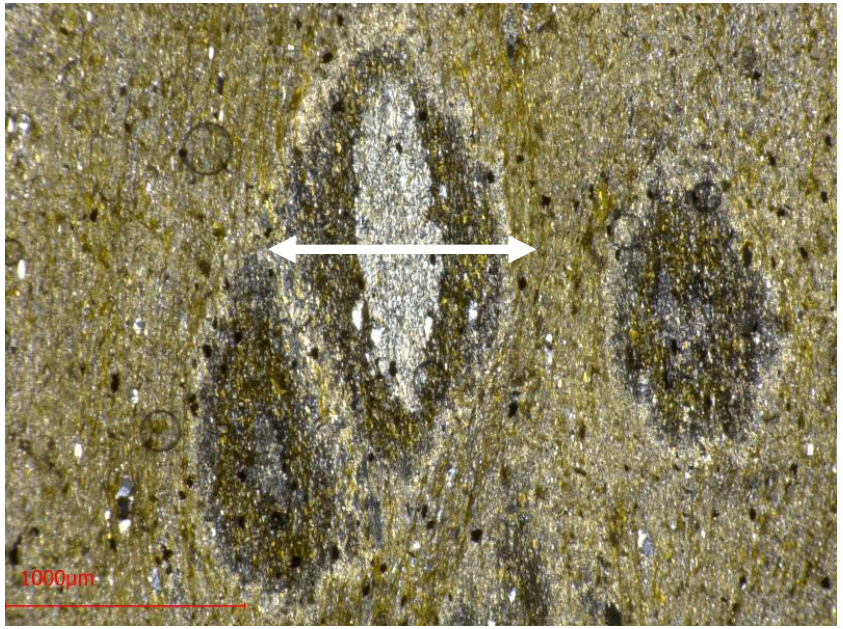

Bt
Alb
Chl
100 µm

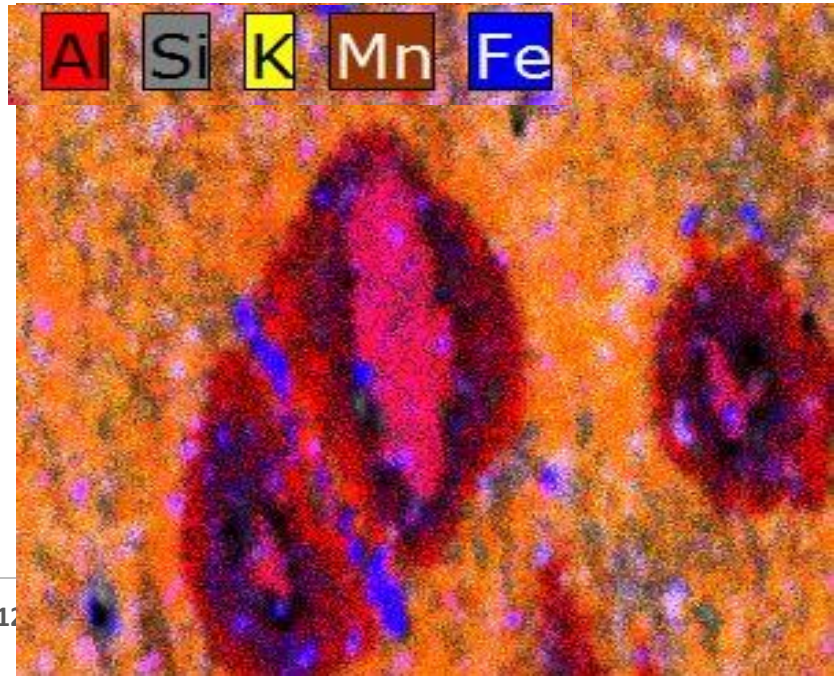

Na, Mg, Mn,Fe
Chl (matrix)
Albite
Bi-Ch (large crystals)
Qtz absent
Ca, P
Mu , Qtz,
Ap, Im
(Kaol)
K, Al
Mu, Qtz
Bi-Chl (large crystals)

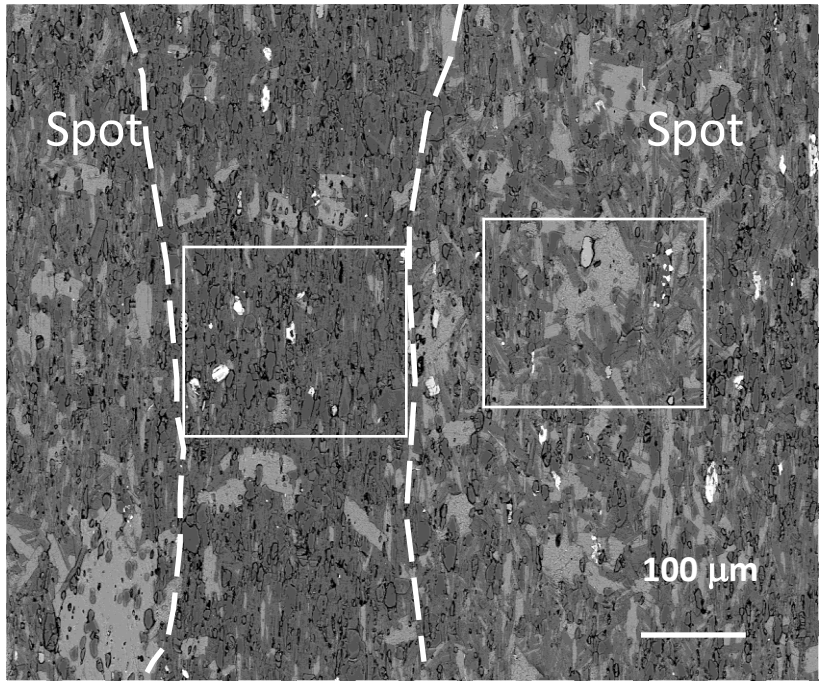

Bt
Mu
Bt
Bt
Qtz
20 µm


Bt
Bt
Qtz
10 µm


8
7
6
5
4
3
2
1
0
0
200
400
600
800
1000
FeO
K2O
MgO
P205
MnO

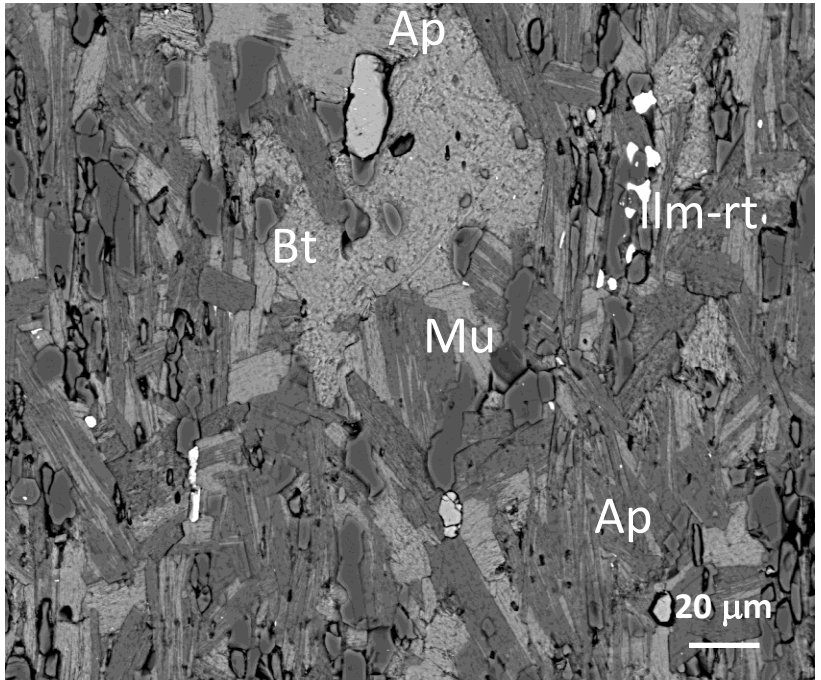

1000µm

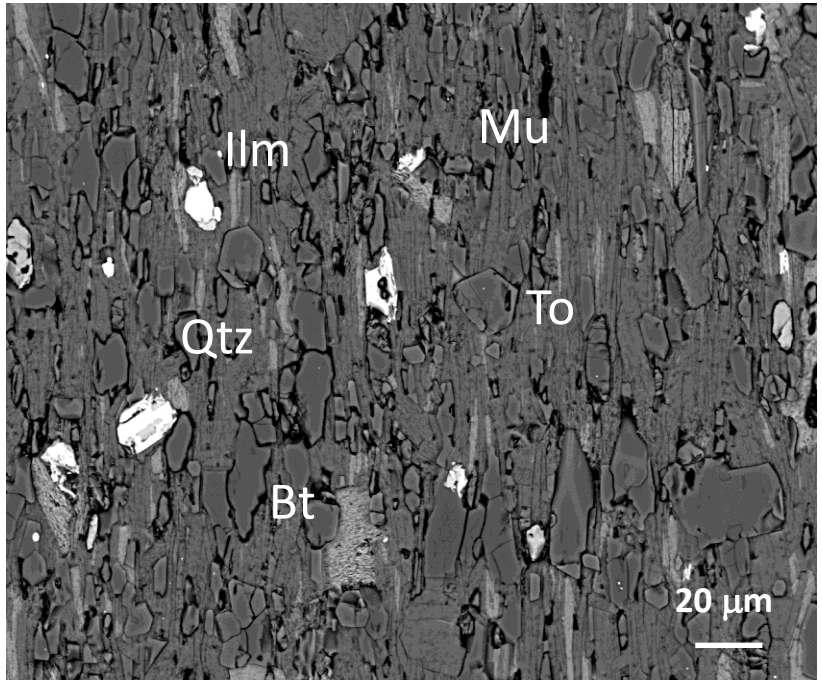

Al
Si
K
Mn
Fe



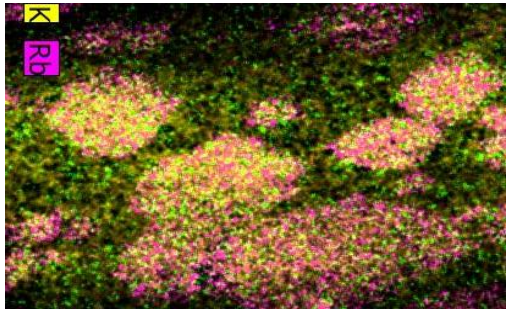
Spot: K, Al, Rb
Mu (matrix) as plates
Qtz less abundant
Bi-Ch (large, abundant)
(Ilm-Rt) Ap, Mon

Matrix: Na, (K), Al, Fe, Mg.
Albite, **Qtz** more abundant
Tourmaline
Mu
Bi-Chl (large crystals)
Ilmenite-Rt





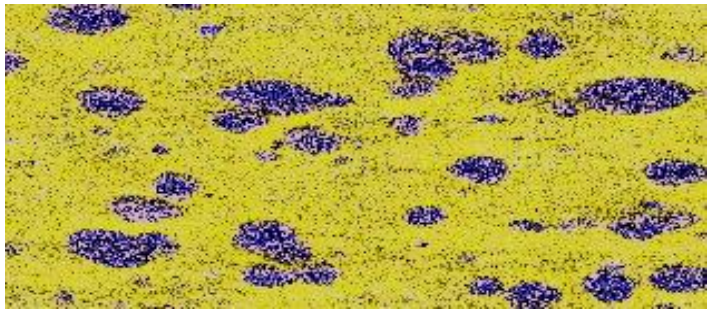
Site SEG1-2



Na, (K), Al, Fe, Mg. **Albite**,
Qtz more abundant
Tourmaline
Mu, (matrix)
Bi-Chl (large crystals)
Ilmenite-Rt

K, Al, Rb
K-micas (matrix) as plates
Qtz less abundant
Bi-Ch (large patch)more abundant
(Ilm-Rt)
Ap, Mon

Site SEG3-(4-5)

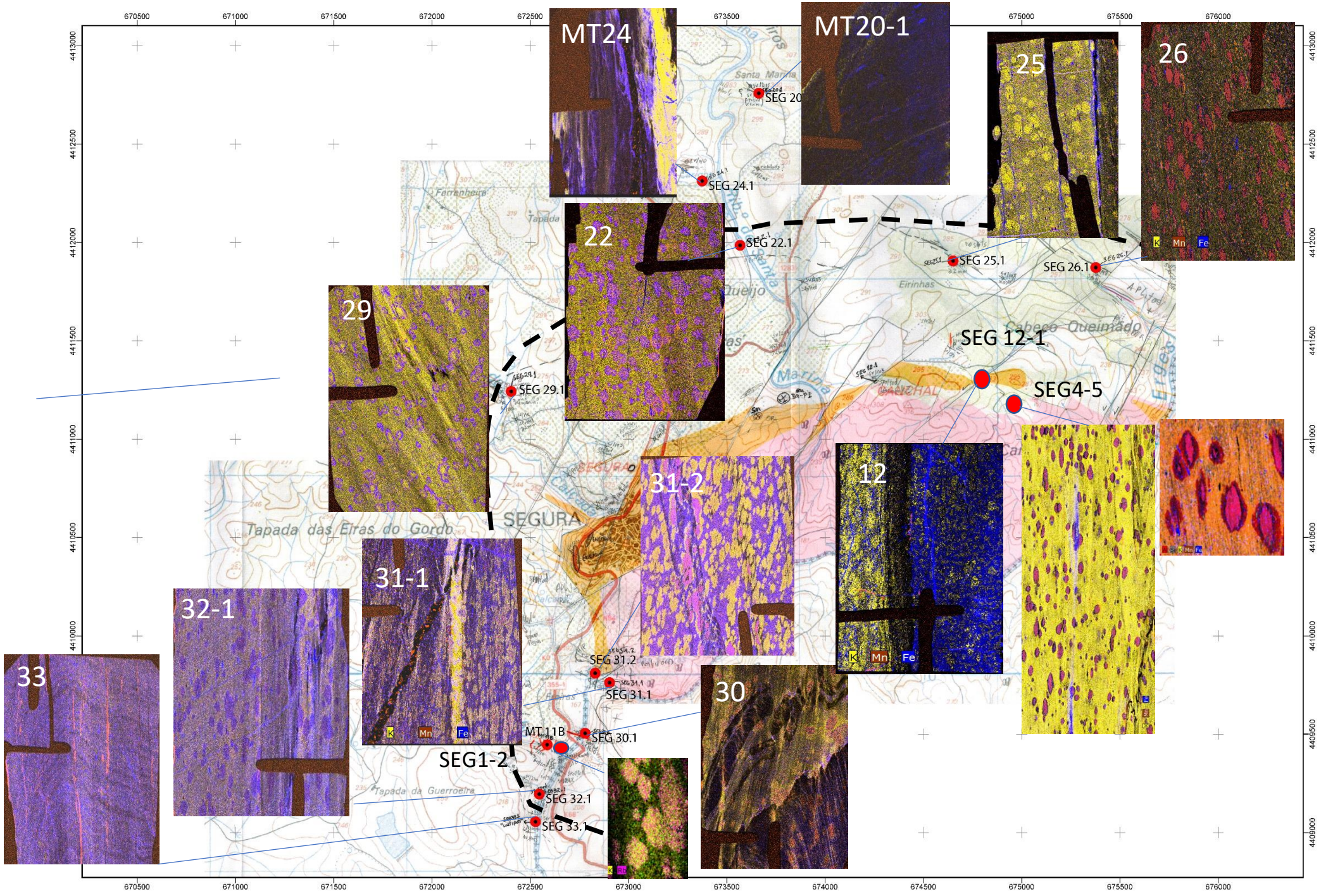


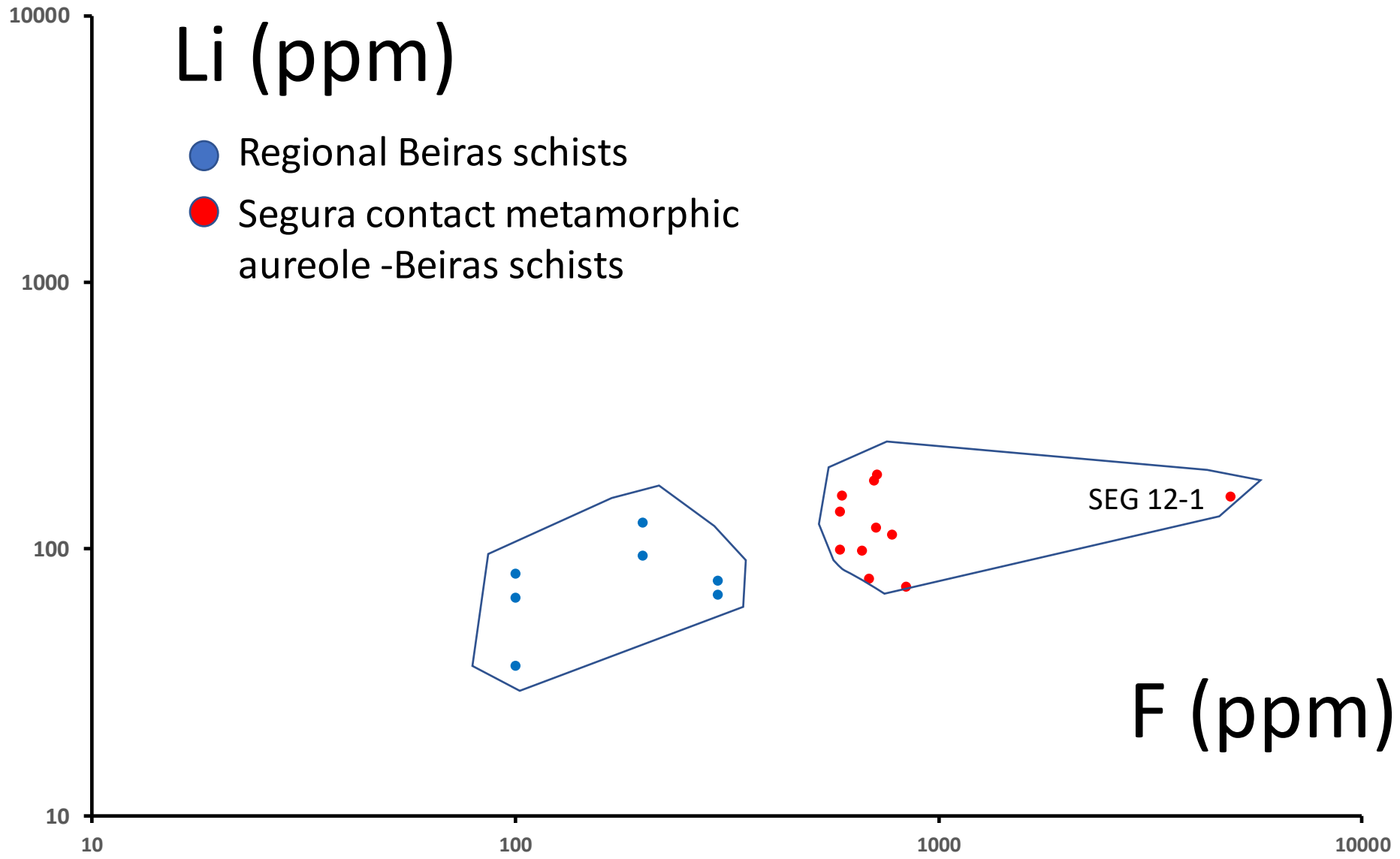
Ni, Ca, P
Ap (Ca enrichment ?)
Mu dissolution ? Ni ?

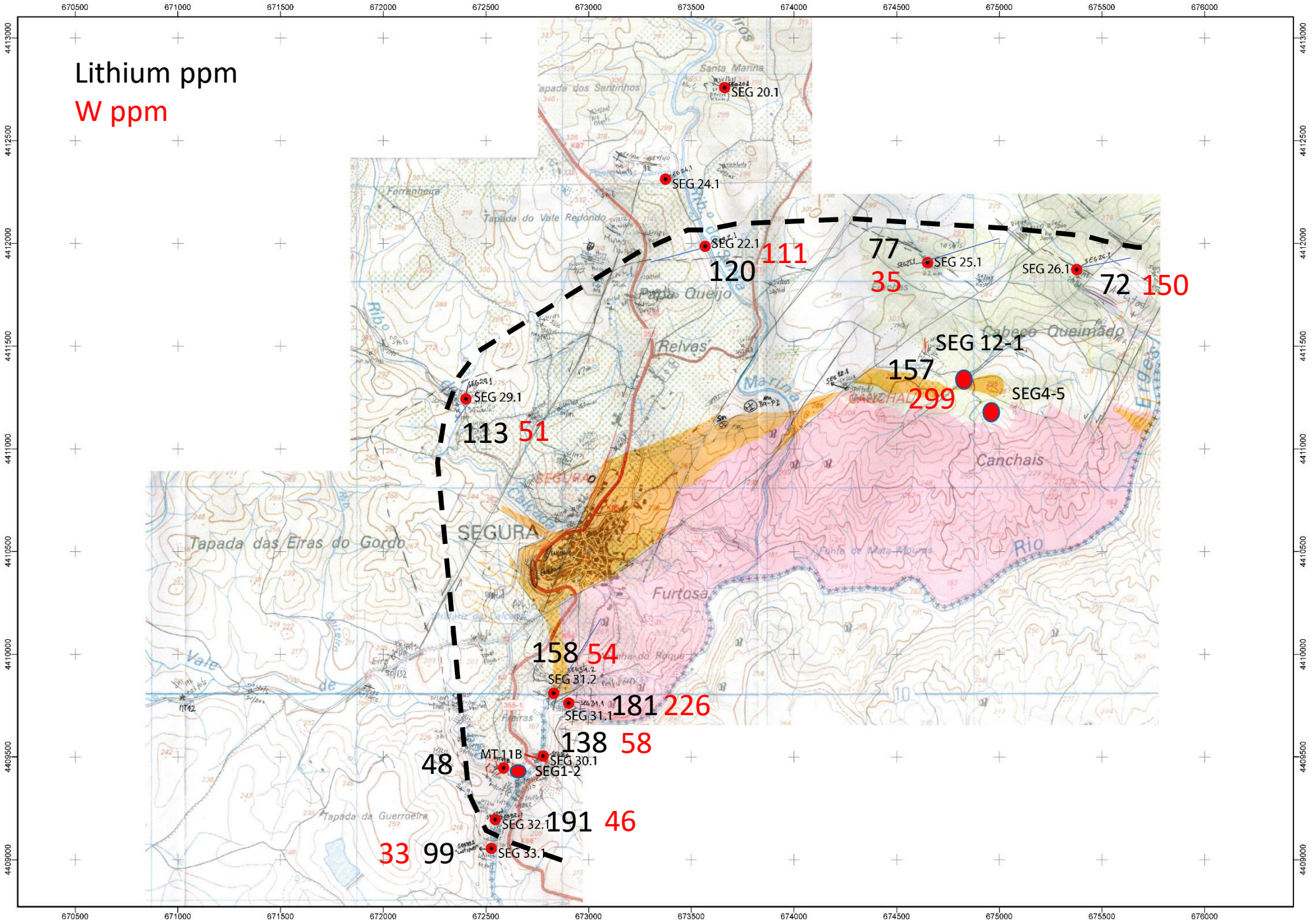
Na, Mg,
Mn,Fe
Chl (matrix)
Albite
Bi-Ch (large patch)
Qtz absent

K, Al
Mu, Qtz

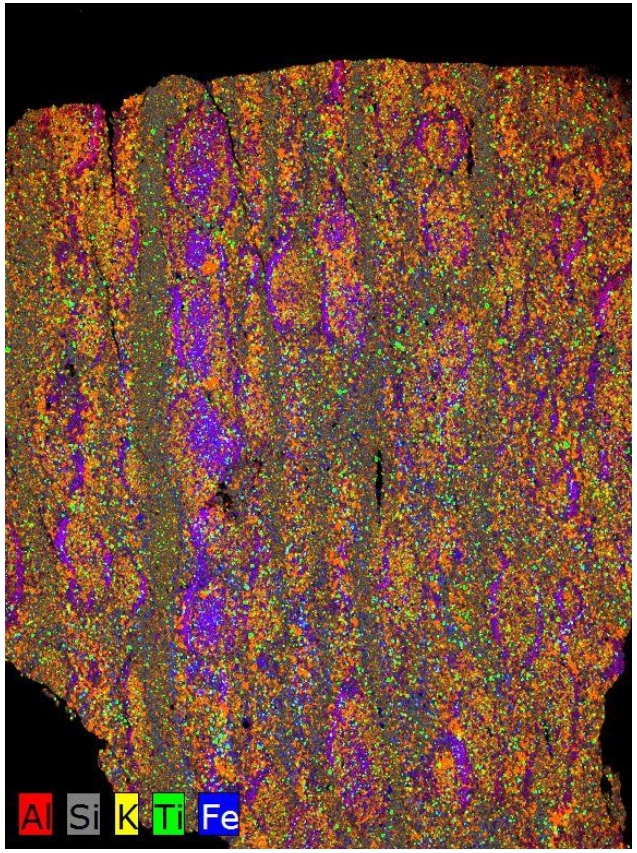
Bi-Chl (large crystals)

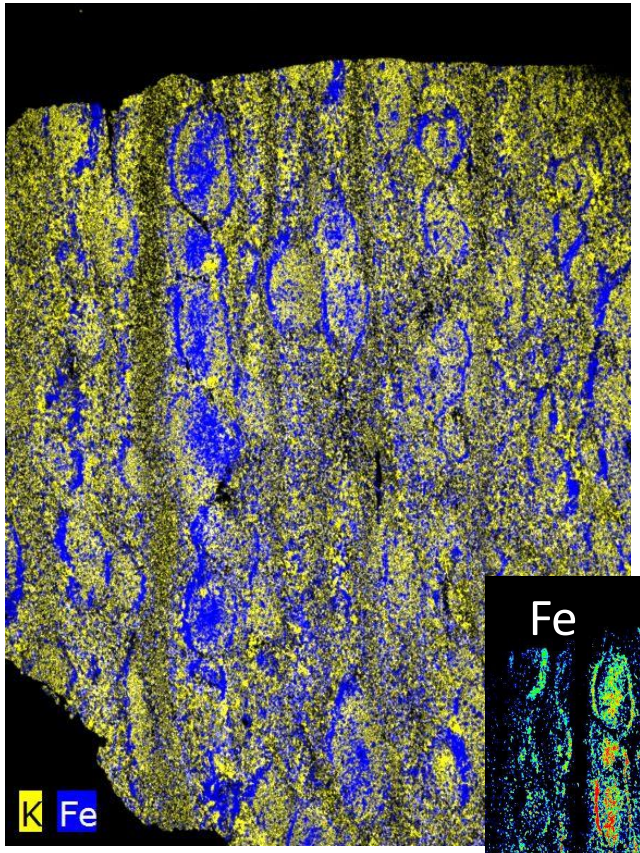

MT24
MT20-1
25
26
22
29
31-2
12
31-1
32-1
33
30
SEG 24.1
SEG 22.1
SEG 25.1
SEG 26.1
SEG 29.1
SEG 12-1
SEG4-5
SEG 31.2
SEG 31.1
MT.11B
SEG 30.1
SEG1-2
SEG 32.1
SEG 33.1
SEGURA
Tapada das Eiras do Gordo
Tapada da Guerroeira
Cabeço Queimado
Eirinhas
Ferrenheira
Tapada
Queijo
Marina
K
Mn
Fe
670500
671000
671500
672000
672500
673000
673500
674000
674500
675000
675500
676000
4413000
4412500
4412000
4411500
4411000
4410500
4410000
4409500
4409000


Li (ppm)
Regional Beiras schists
Segura contact metamorphic aureole -Beiras schists
SEG 12-1
F (ppm)
10000
1000
100
10
10
100
1000
10000

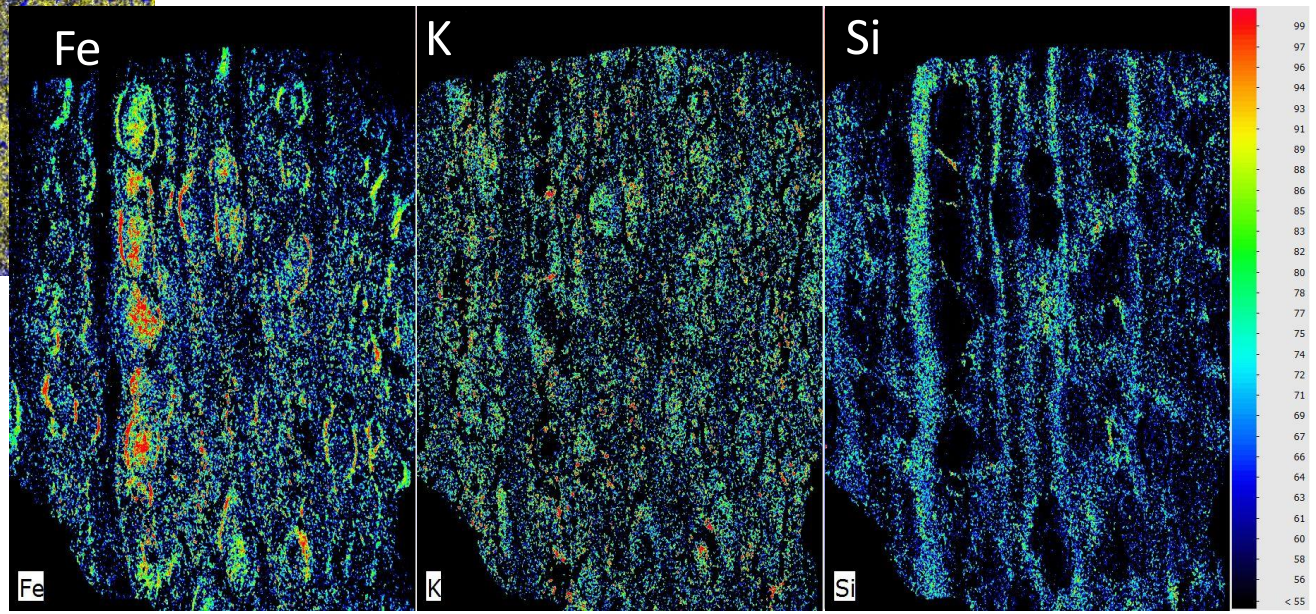

Lithium ppm
W ppm
SEG 20.1
SEG 24.1
SEG 22.1
111
120
77
35
SEG 25.1
SEG 26.1
72
150
SEG 12-1
157
299
SEG4-5
SEG 29.1
113
51
SEGURA
Canchais
Furtosa
158
54
SEG 31.2
SEG 31.1
181
226
138
58
MT 11B
SEG 30.1
48
SEG1-2
SEG 32.1
191
46
33
99
SEG 33.1
Tapada das Eiras do Gordo
Tapada do Vale Redondo
Cabeço Queimado
Relvas
Rio
670500
671000
671500
672000
672500
673000
673500
674000
674500
675000
675500
676000
4413000
4412500
4412000
4411500
4411000
4410500
4410000
4409500
4409000

Mata da Rainha

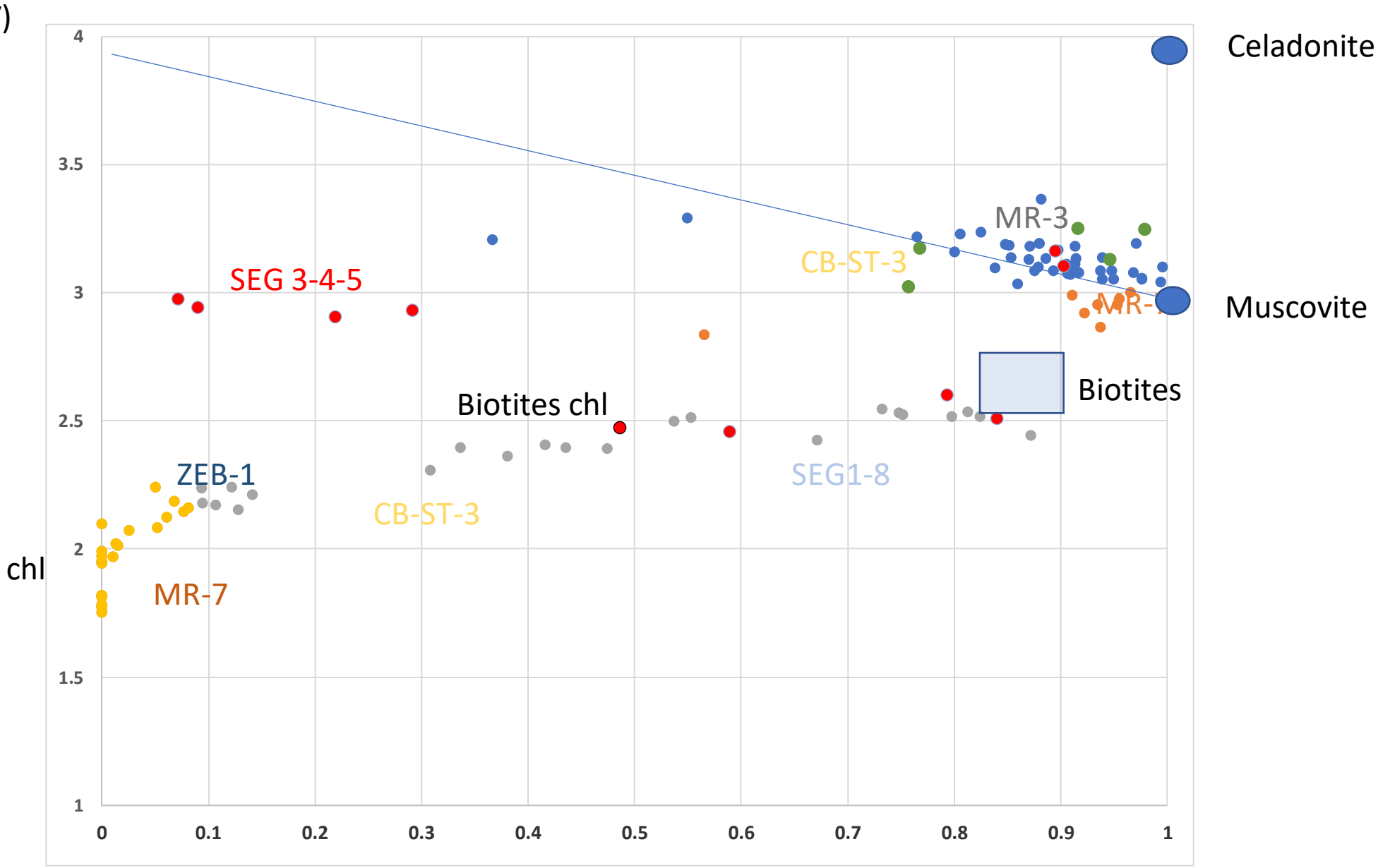




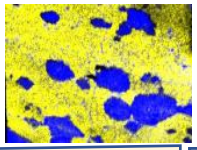
Tourmalinisation of spots
Followed by muscovitisation

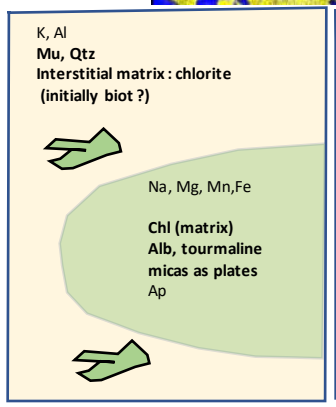


Spot crystal-chemistry (Musc, Bt >Chl)

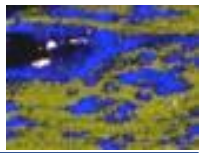


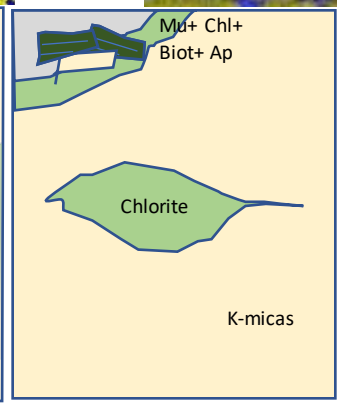
ZEB1



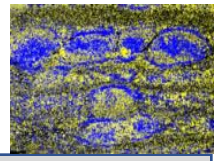


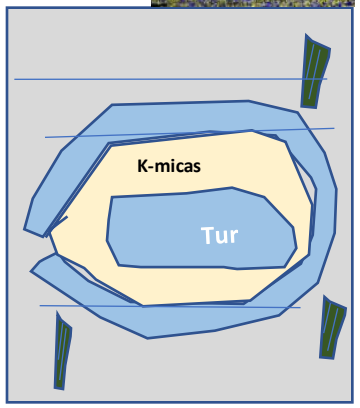
MR7



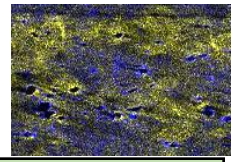


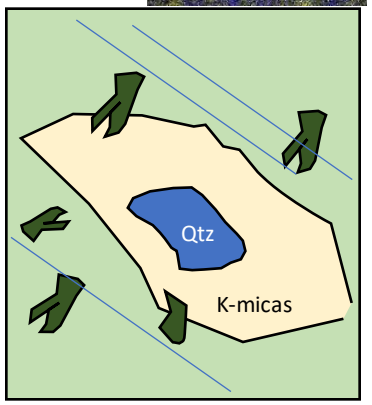
MR3



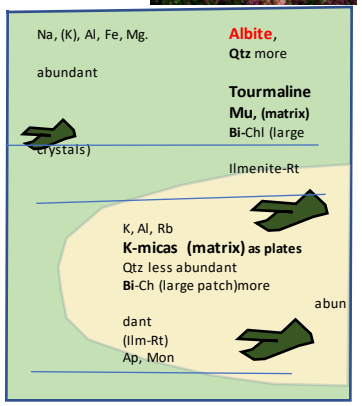


CB-ST3

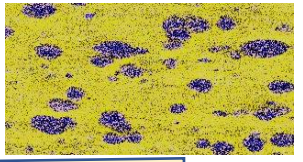


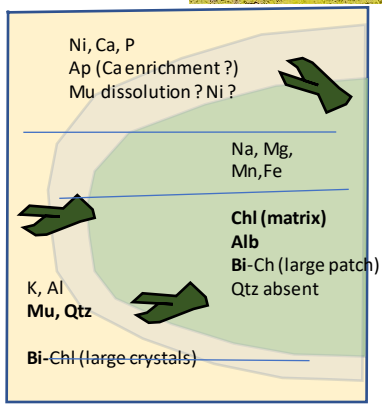


SEG1-2

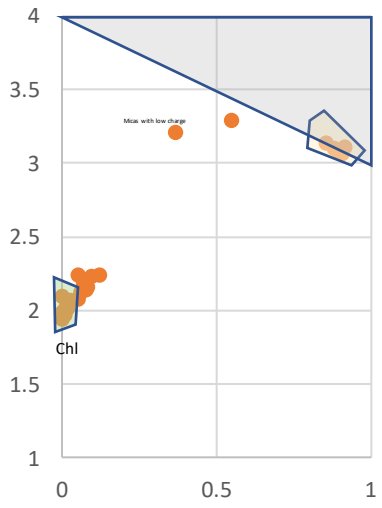


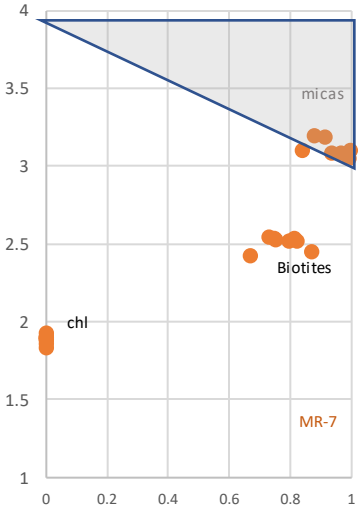
SEG3-4-5

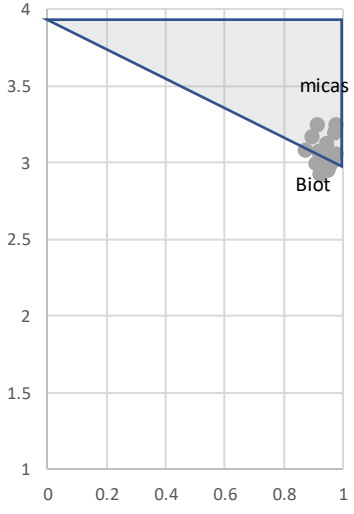


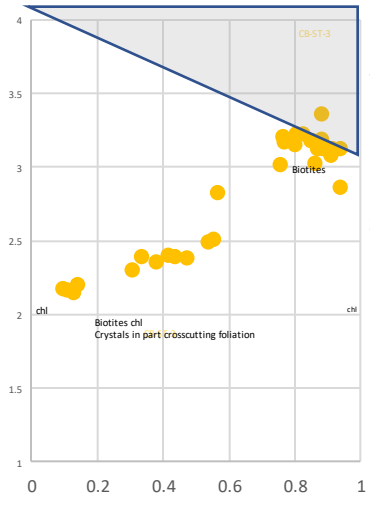


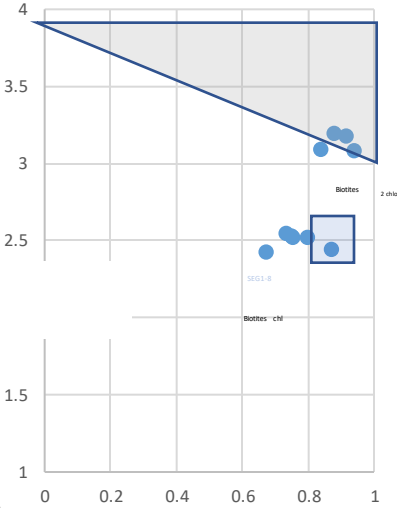
No albite
Ilmenite >> rutile
Spots = quartz nodule + halo rich in K-micas
Outside : Qtz+ matrix of biot-chl + euhedral biotites(chl)

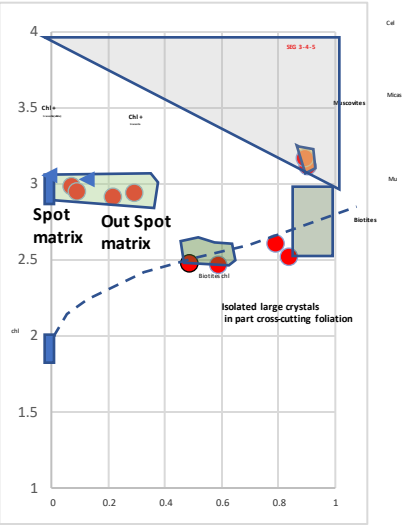




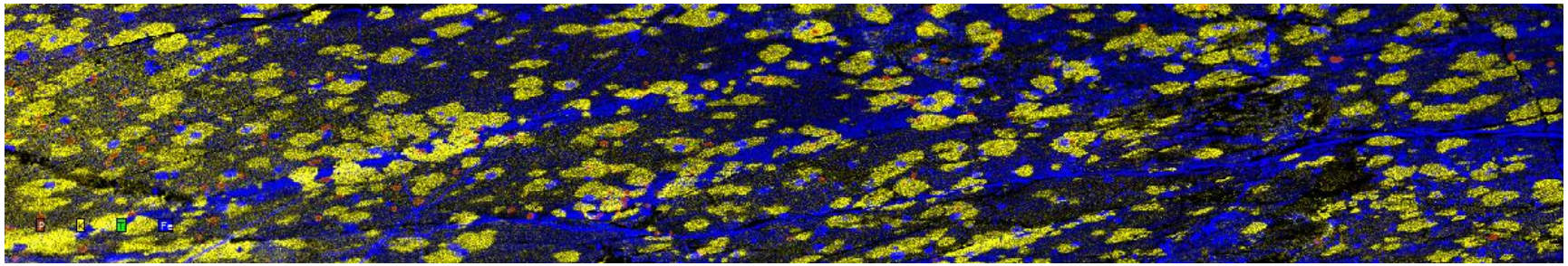


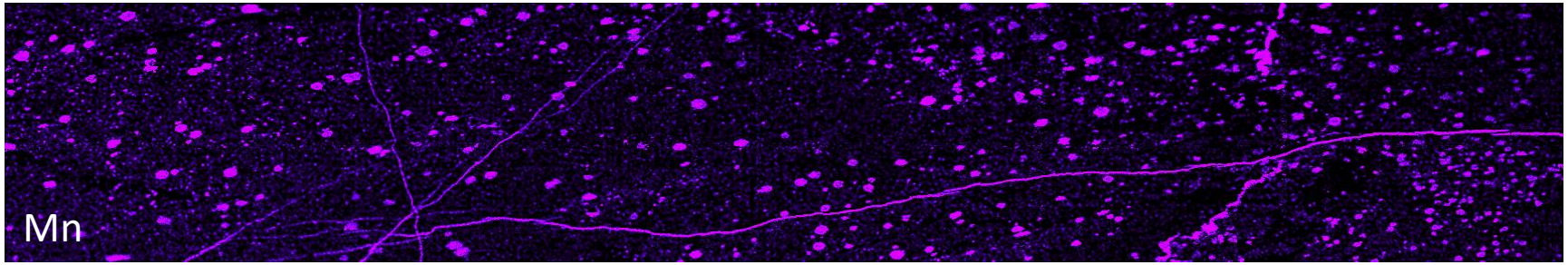




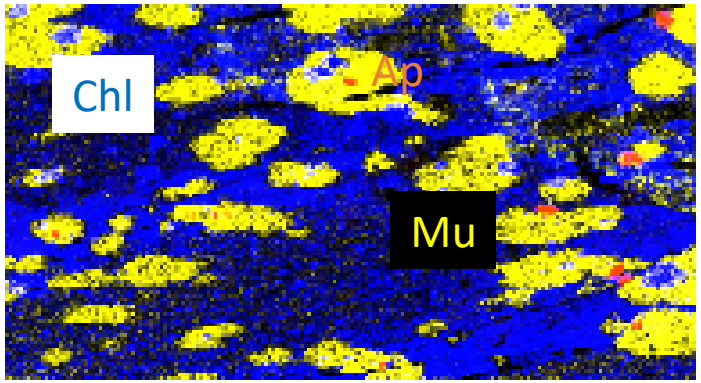


Slight contamination of some chlorites by micas



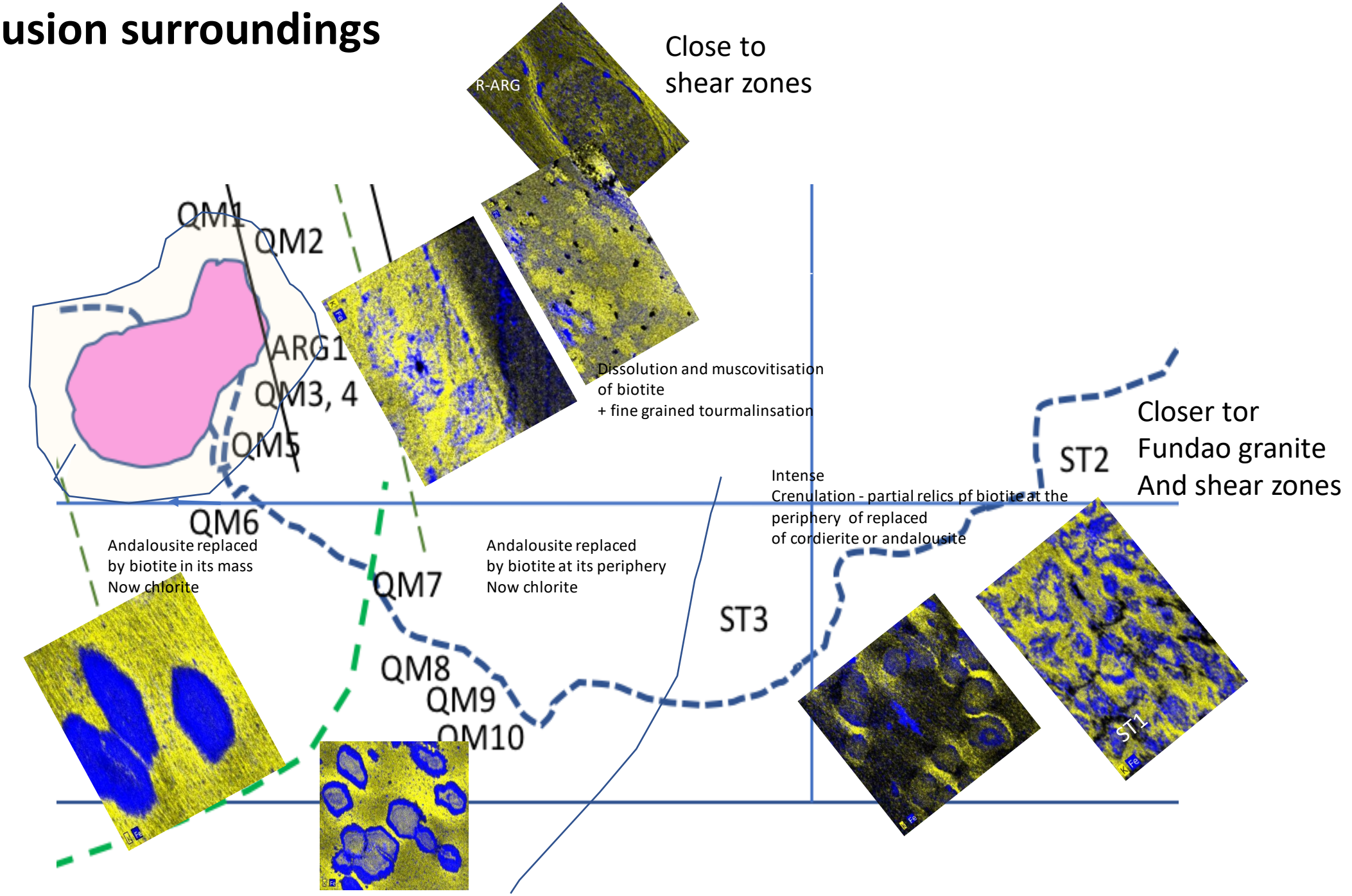


Spots 1 : replaced by muscovite
K-Rb
Spots2 : Fe-Mn

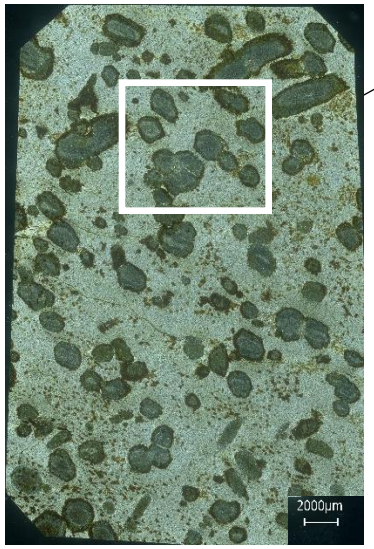


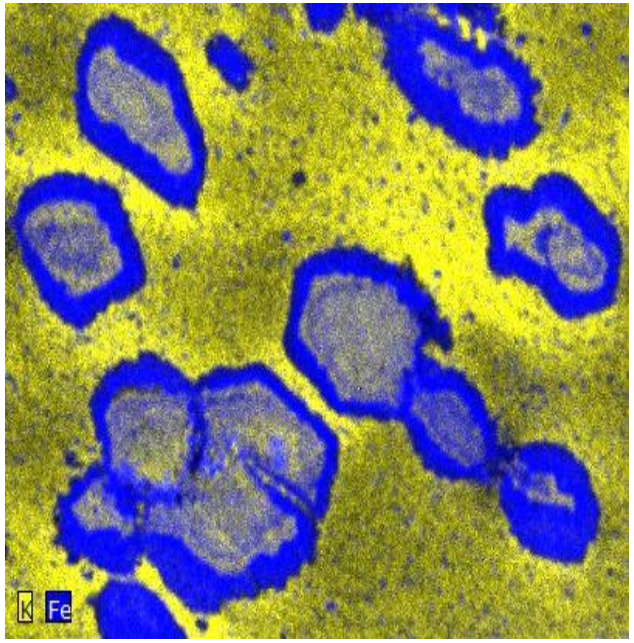
Panasqueira
XX-4a
L3_D9_R1_AW33

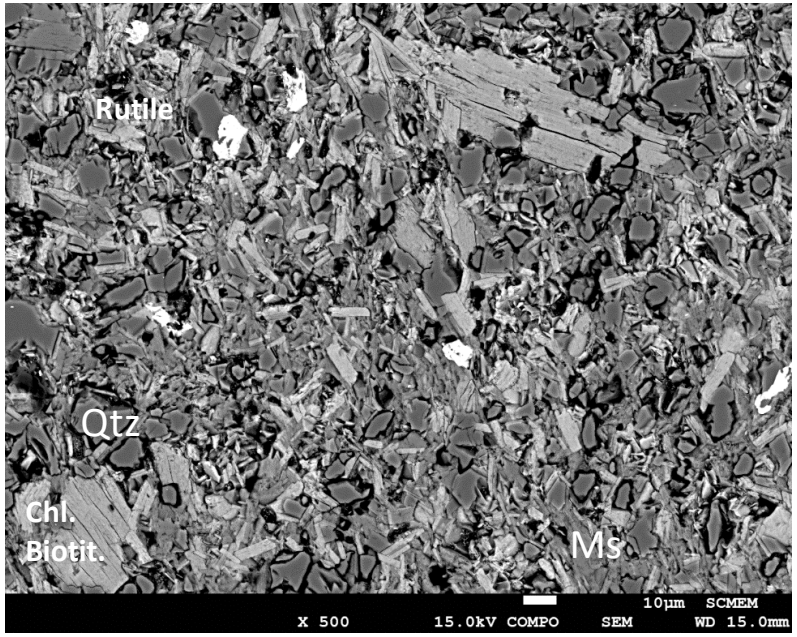
Argemela intrusion surroundings



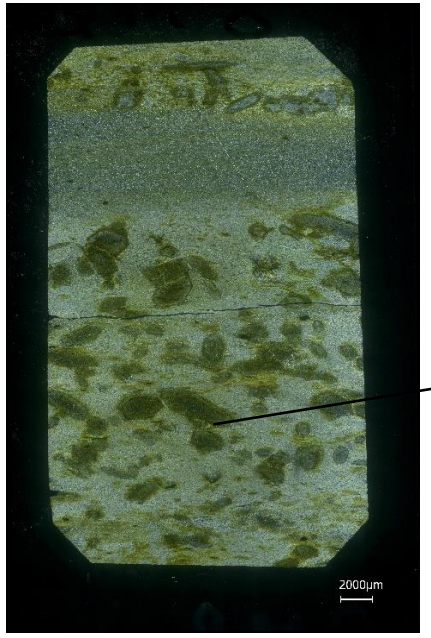
QM 10

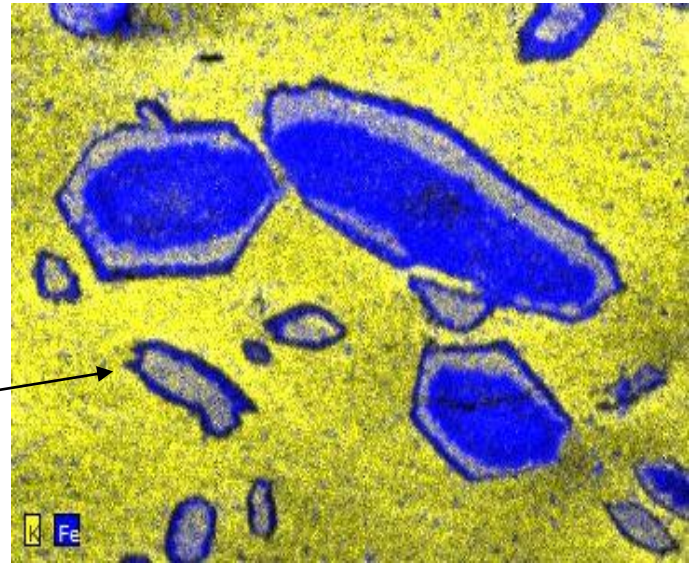






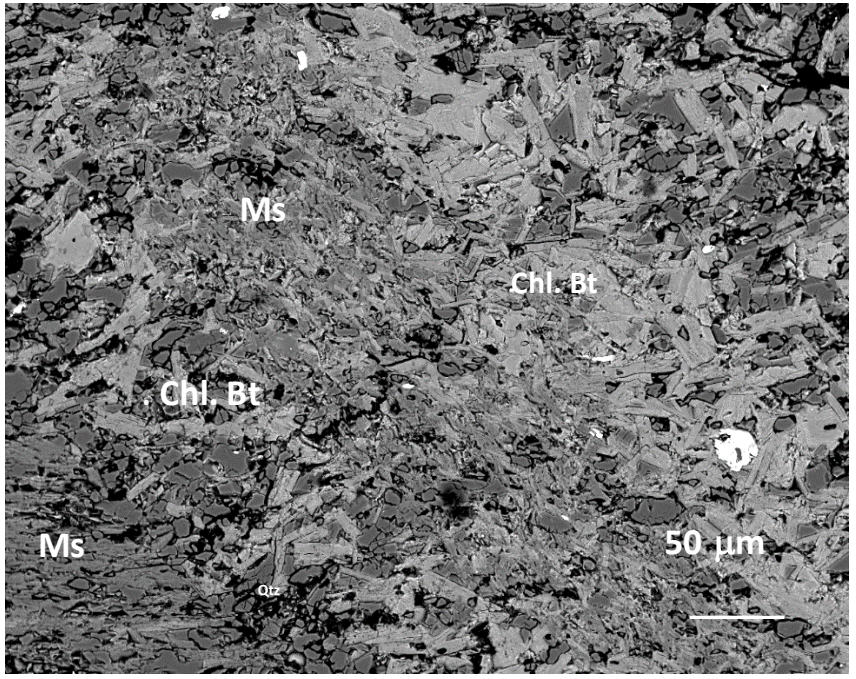
QM-8





Cordierite

- Bt+ Ms
- Chl (+Ms)



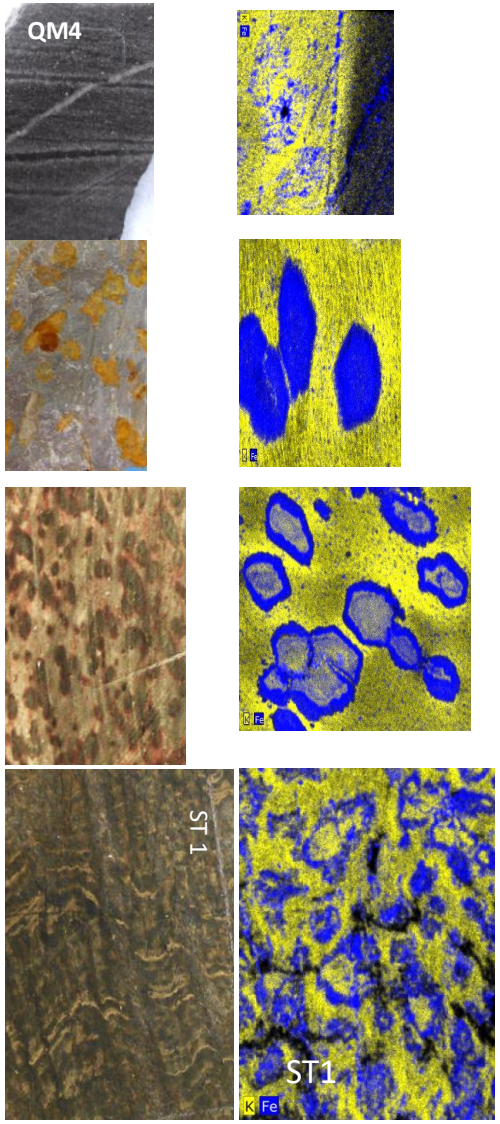
Argemela intrusion

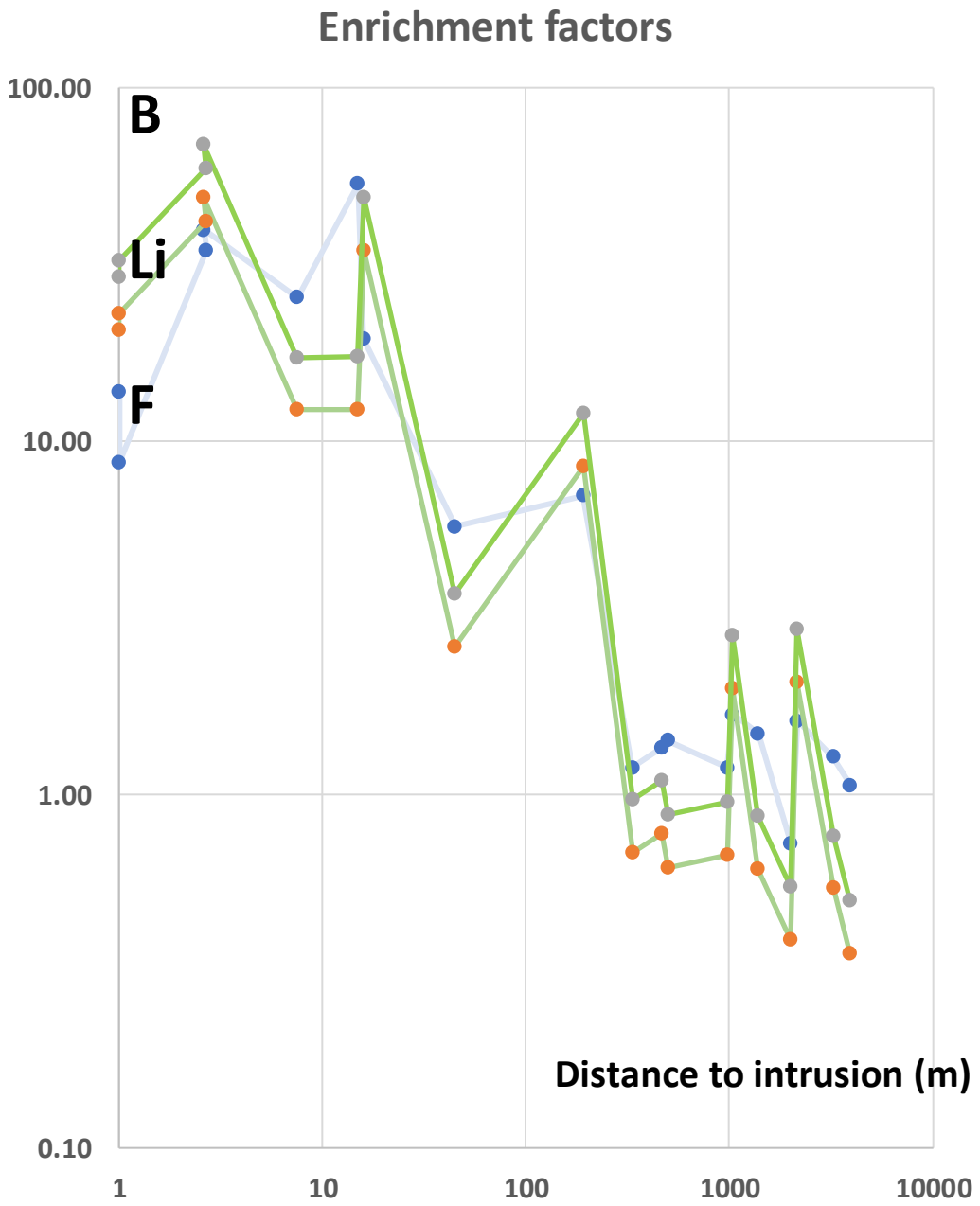
Tourmalinisation aureole ± phosphates

Muscovitisation aureole, replacement of biotite
Phantom of cordierite

Muscovitisation in the mass of schists
Cordierite inherited (intact shape), replaced by biotite and muscovite

Cordierite replaced partially by biotite at the periphery
Strong deformation of cordierite





Age of cordierite, link with which granite ?
Why a systematic retromorphosis in the greenschist facies at the regional scale ?

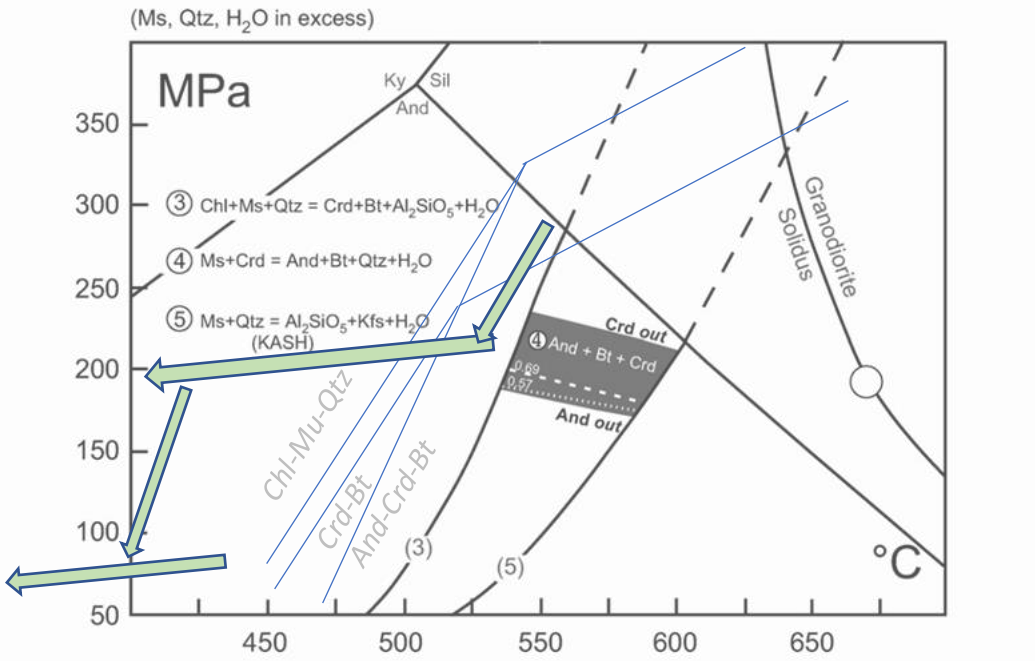
Spotting :
• the relationships with deformation need more attention

• the formation of spots does not imply necessarily the formation or cordierite (see Galan et al, in Betics) : serpentine , or biotite clusters ? Without reaching the cordierite field

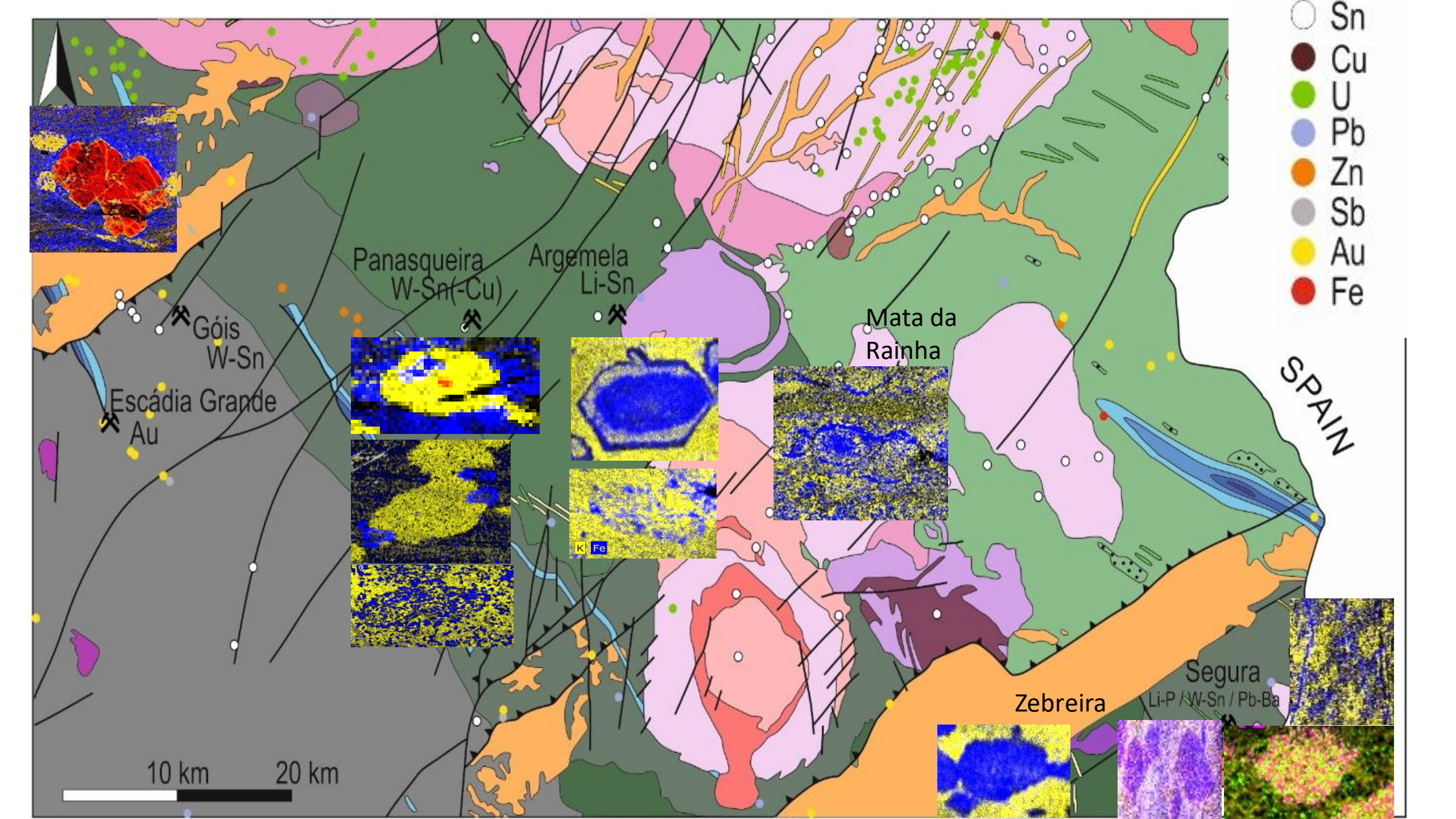
• the regional distribution of andalusite (preserved, multiple in the western part (Coimbra region), and potential cordierite spots areas with rare relics of andalusite (PNQ-Argemela, Segura) vs eastern part without andalusite and cordierite : no clear explanation (pressure ?)

• extension of muscovitisation related to late variscan fluids could be an interesting pathfinder (F, B, Li, Rb, Cs aureoles), (already proposed)

• the extension of tourmalinisation seem restricted to main contact zones, mais this needs checking



Overall retromorphosis: • the systematic retromorphosis to the chlorite zone (greenschist facies) implies large pervasive fluid circulation at the regional scale which need also explanations


Sn
Cu
U
Pb
Zn
Sb
Au
Fe
Panasqueira
W-Sn(-Cu)
Argemela
Li-Sn
Góis
W-Sn
Escádia Grande
Au
Mata da
Rainha
SPAIN
K
Fe
Segura
Li-P / W-Sn / Pb-Ba
Zebreira
10 km
20 km

Conclusions

•the schist host rock formation for granites and mineral deposits represent a significant source of information that has probably been underestimated in the past.
(despite a number of attempts)

• the exact nature of the spots remains a matter of debate
• zoning in the regional distributions of andalusite versus cordierite has no clear explanation
• absence of visible spots not always the case : microscopic and chemical evidences
• intense muscovitisation and tourmalinisation at the contact of the intrusions, visible and evident, have a wider distribution at least a hectometric scale
this could be more systematised in prospection stages
• very significant chemical redistribution on the scale of the sample, and pervasive fluid penetration over large volumes

>>> Could this be evidence of how metal sources work? B, W, Sn, Ti, … ?