On the causes of brittle nucleation of shear zones: the example of Cap de Creus, Eastern Pyrenees (Spain)

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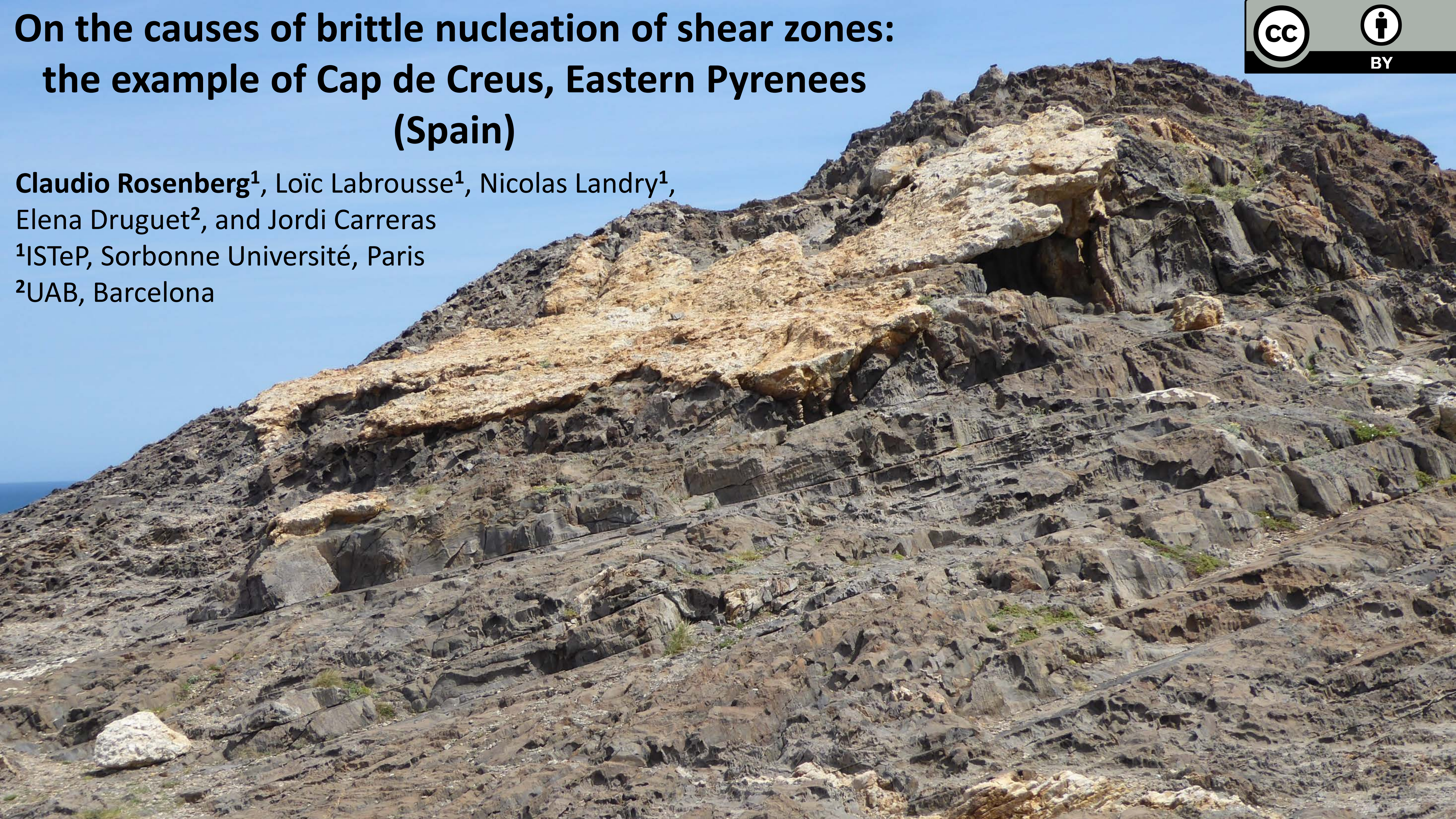


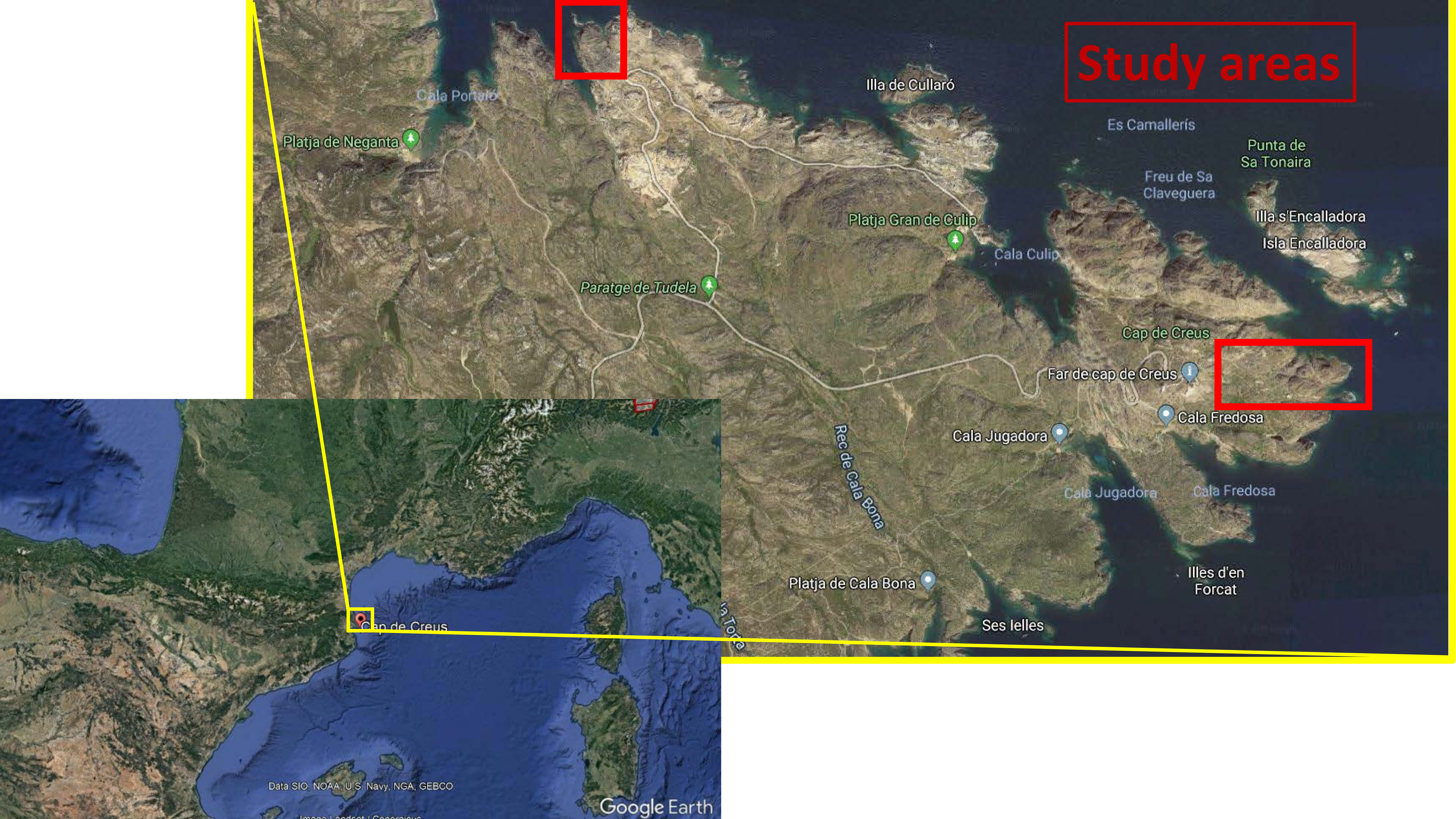
Large number of ductile shear zones were shown to initiate on brittle structures. Ductile localization on these brittle structures is often discussed (e.g., Mancktelow and Pennacchioni, 2005), and the main causes are inferred to be one or more of the following:

- Deformation at the brittle-ductile transition
- Strain rate increase
- Fluid overpressure

The classical examples of ductile shear zones of Cap de Creus (e.g., Carreras 2001) have also been interpreted as structures that nucleated on brittle faults (Fusseis et al. 2006; Fusseis and Handy 2008)

The present study investigates two selected areas of Cap de Creus, where the orientation, the spacing, and the length vs thickness ratios of the shear zones appear to be similar to those of the joints affecting the surrounding outcrops.

This study investigates under which T conditions the shear zones were active and why brittle fractures controlled their development.


Study areas
Cala Portaló
Platja de Neganta
Illa de Cullaró
Es Camallerís
Punta de Sa Tonaira
Freu de Sa Claveguera
Platja Gran de Culip
Illa s'Encalladora
Isla Encalladora
Cala Culip
Paratge de Tudela
Cap de Creus
Far de cap de Creus
Cala Fredosa
Cala Jugadora
Rec de Cala Bona
Cala Jugadora
Cala Fredosa
Illes d'en Forcat
Platja de Cala Bona
Ses Ielles
Cap de Creus
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Google Earth

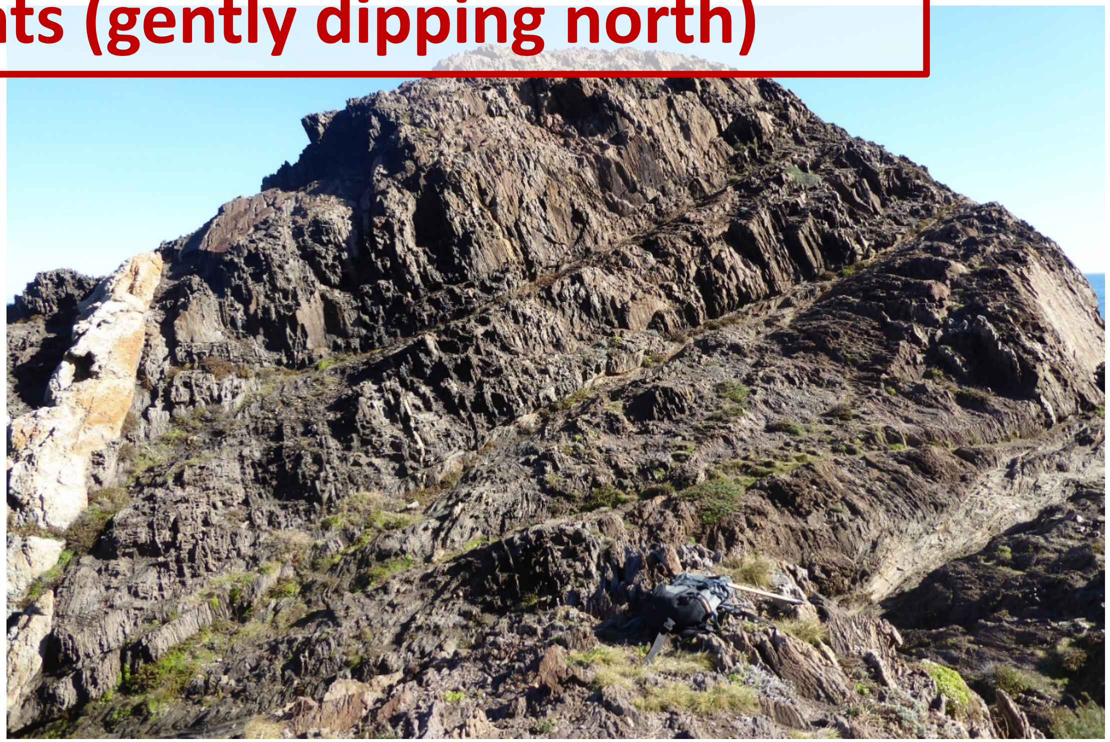
Systematic joints.

Red arrows indicate major joints.
Many more, of similar orientation are exposed on these outcrops.

Red arrows indicate major shear zones. Many more, of smaller size and similar orientation are exposed on these outcrops.

Photograph from drone, of outcrops in previous slide.
Note the sharply defined and very large surface (red arrows) corresponding to a major shear zone

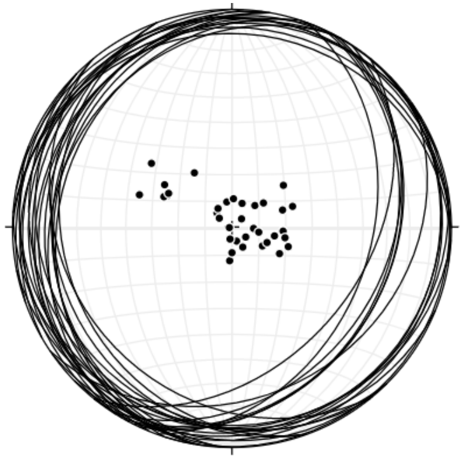
Within the study areas most shear zones are subparallel to one of the sets of joints (gently dipping north)



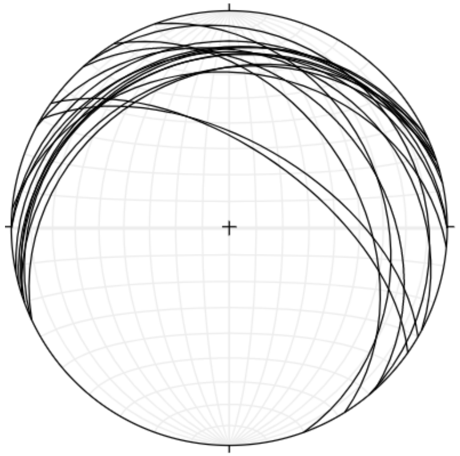
Joints

Set of gently dipping shear zones

N=35

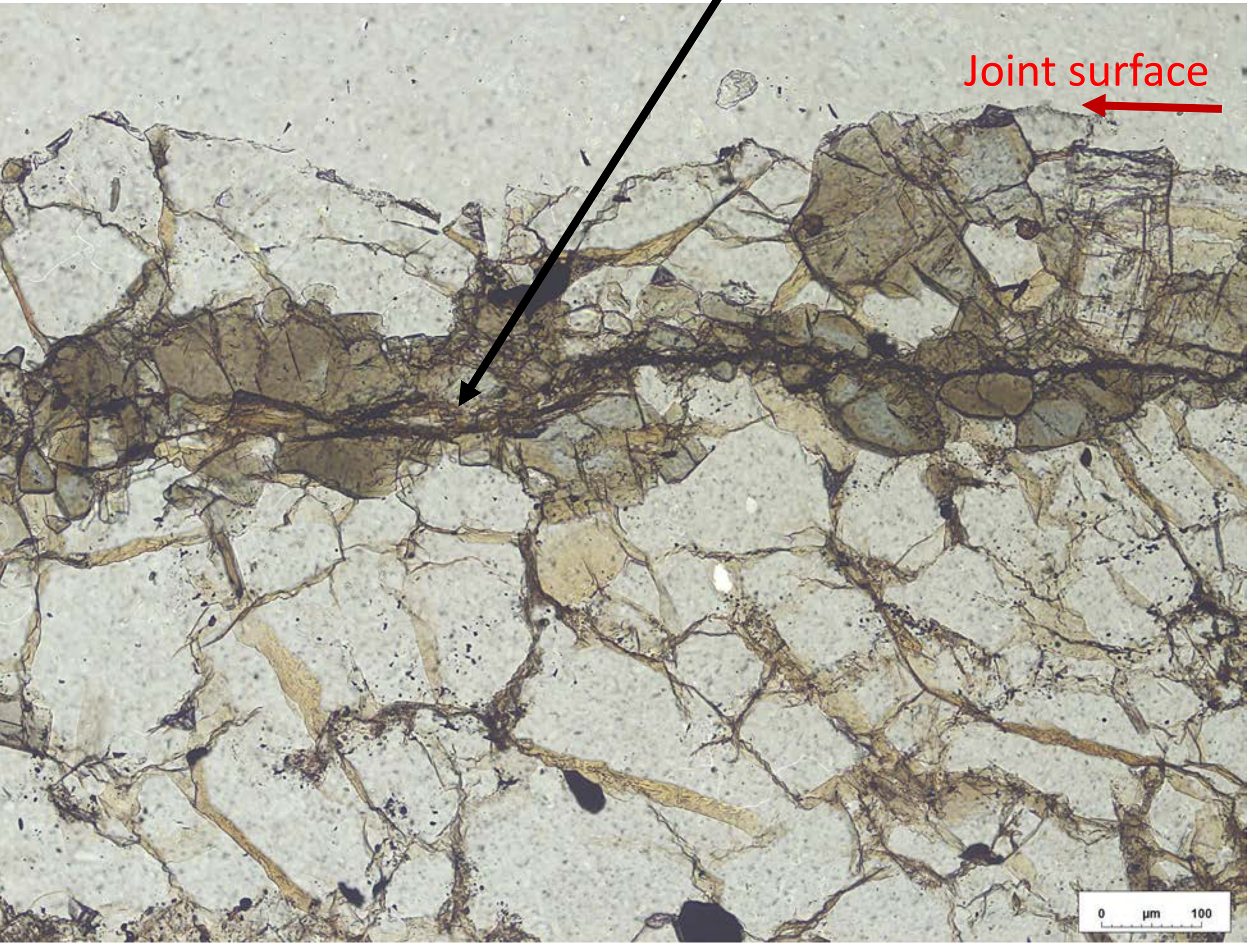


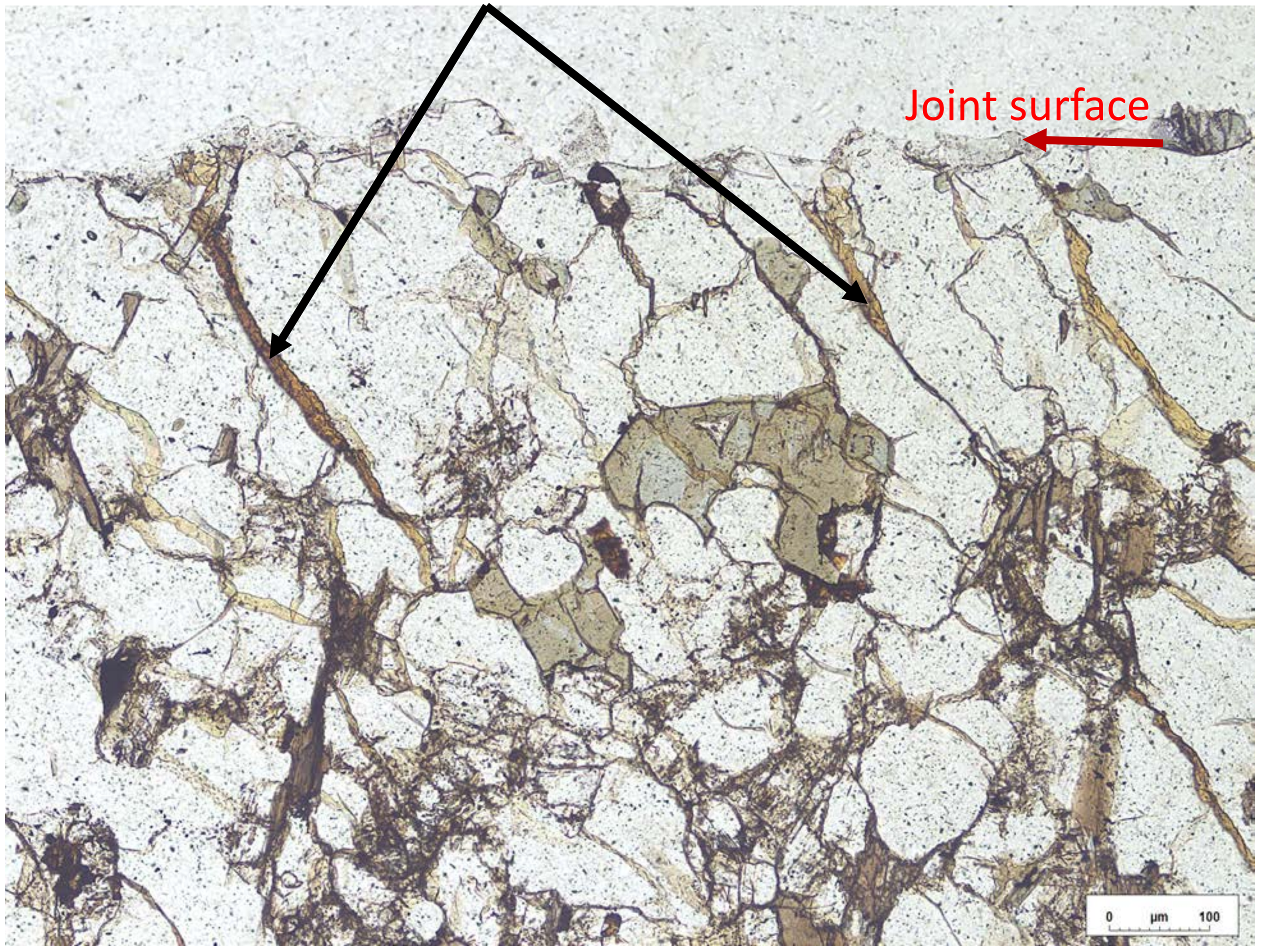
N=17

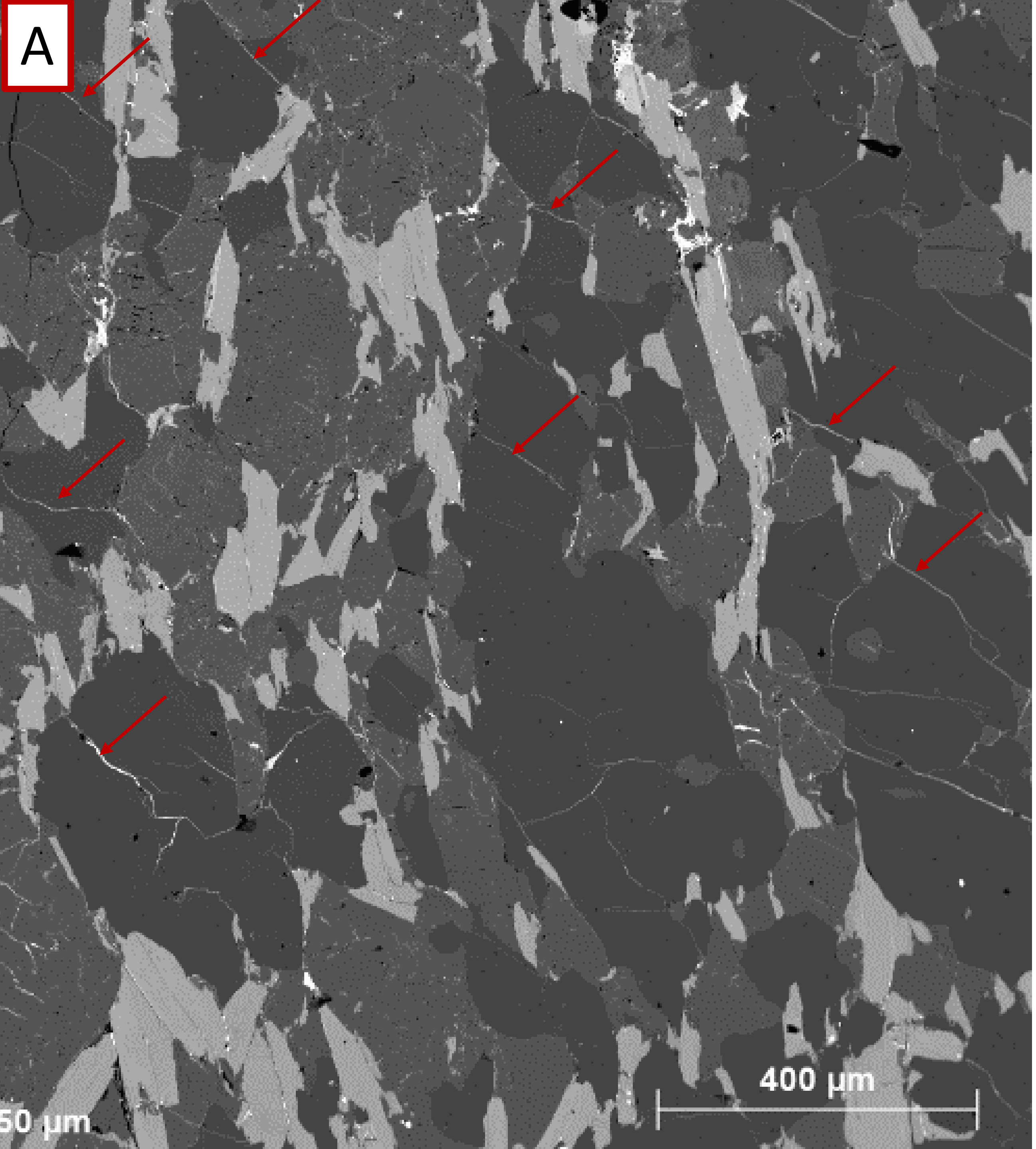



Joints are filled by laterally continuous, dark material
of approximately 1 cm thickness
Dark brown to wine-coloured filling
of joints

Metapelite in thin section, plane polarized light, cut perpendicular to the plane of a joint, showing ca. 1mm of thickness of country rock, immediately adjacent to the joint. Note the presence of tourmaline along joint-parallel microcracks and light brown minerals coating grain boundaries oriented at high angle to the joint, but mainly sub-parallel to each other.

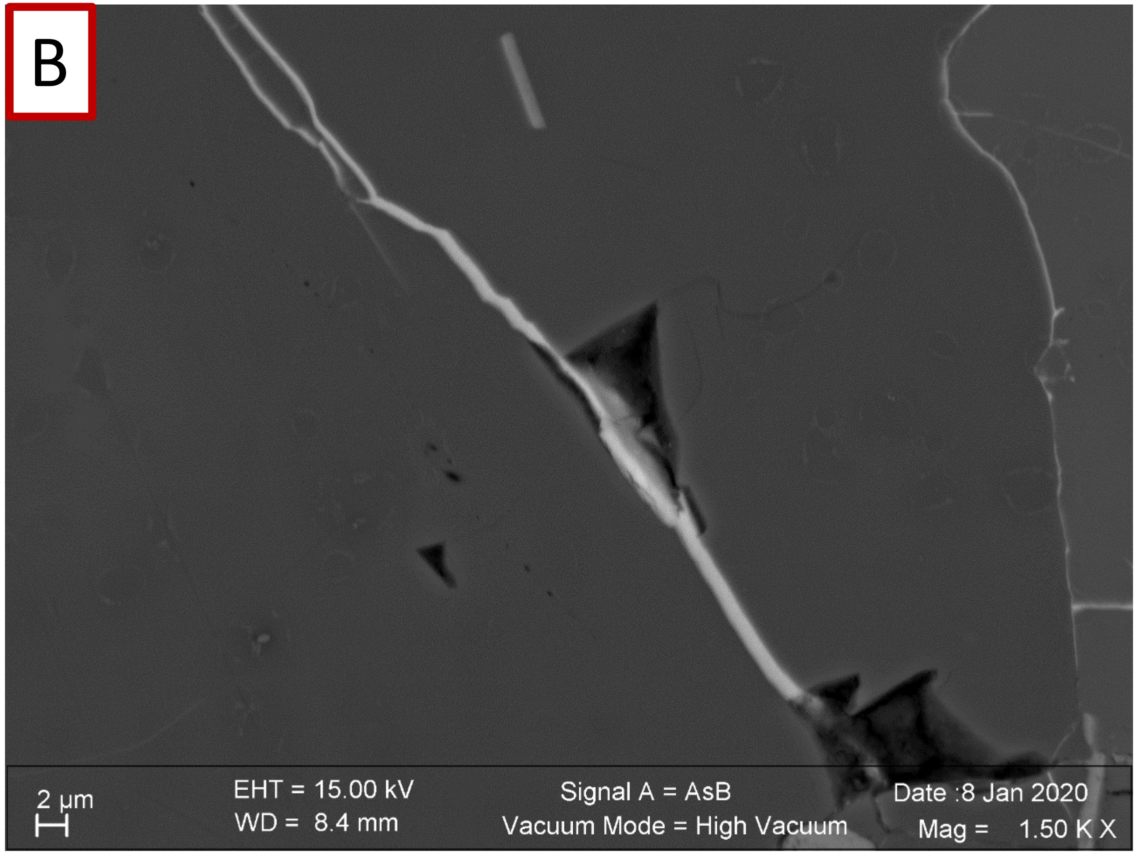






A) Micaschist, at 1 cm distance from large-scale joint that is oriented parallel to the long side of the microphotograph. Red arrows indicate microfractures. Due to colour contrasts, the more numerous intergranular fractures cannot be seen in this picture.

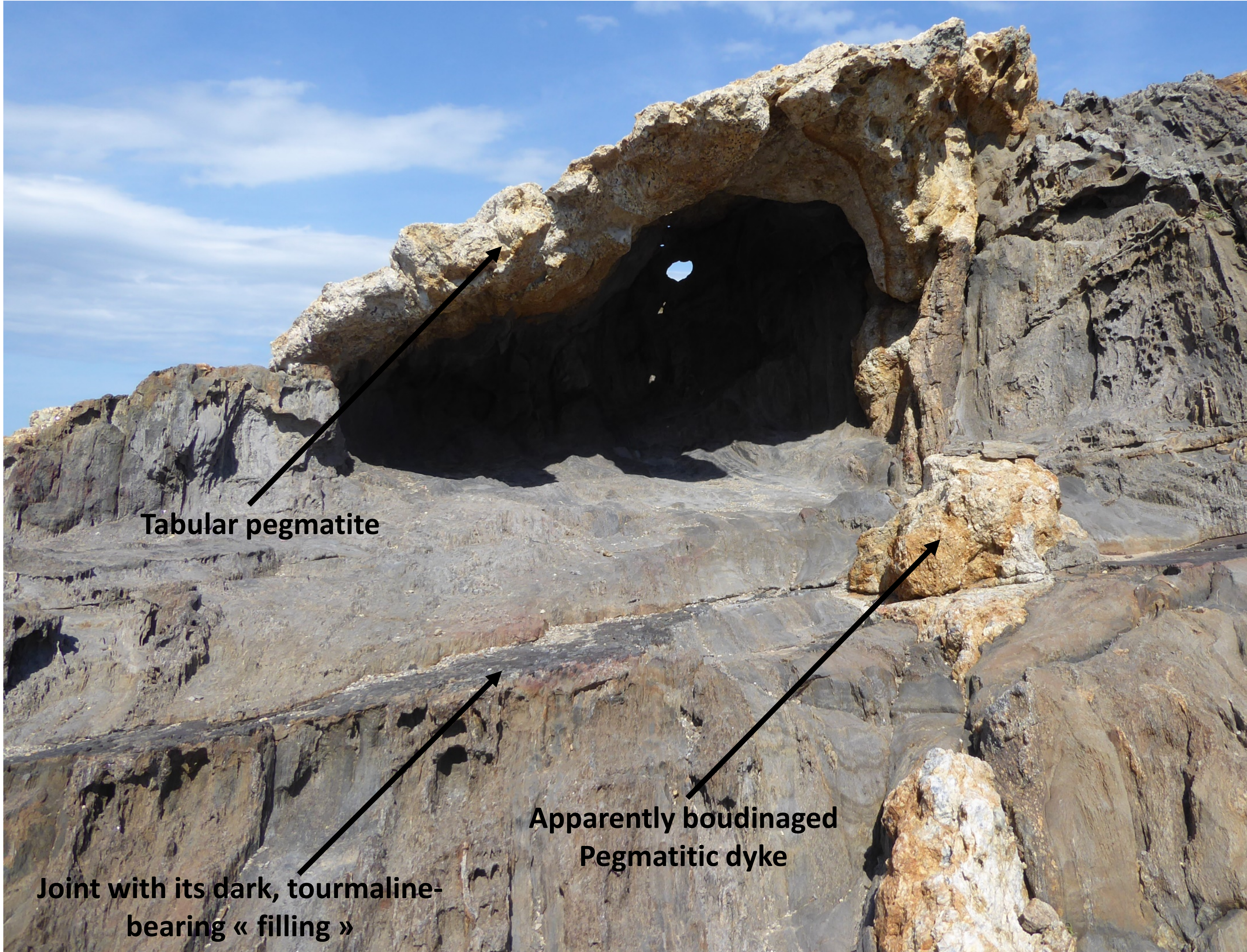
B) Detail of one microfracture and its filling. Note the thickness of less than 2µm. Based on SEM, the filling mainly consists of phosphates.



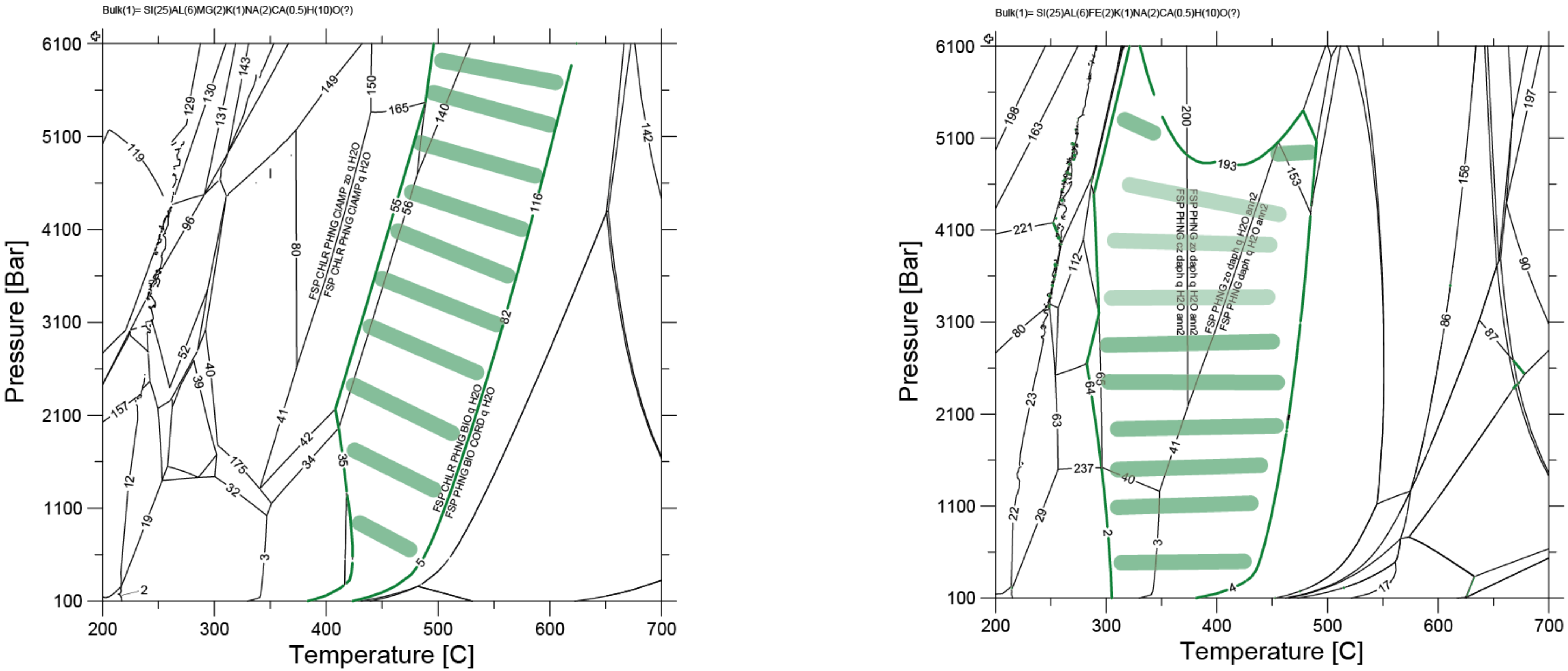
Tourmaline is very common in pegmatite dykes , some of which feed tabular sheets dipping at low angle and cross cutting the main schistosity of the country rocks.

Pegmatite tabular bodies have orientations similar to the joints described above.

The numerous tourmaline grains observed in the material filling the joints possibly derive from pegmatite-related fluids, hence a high-T, regional anatectic event.



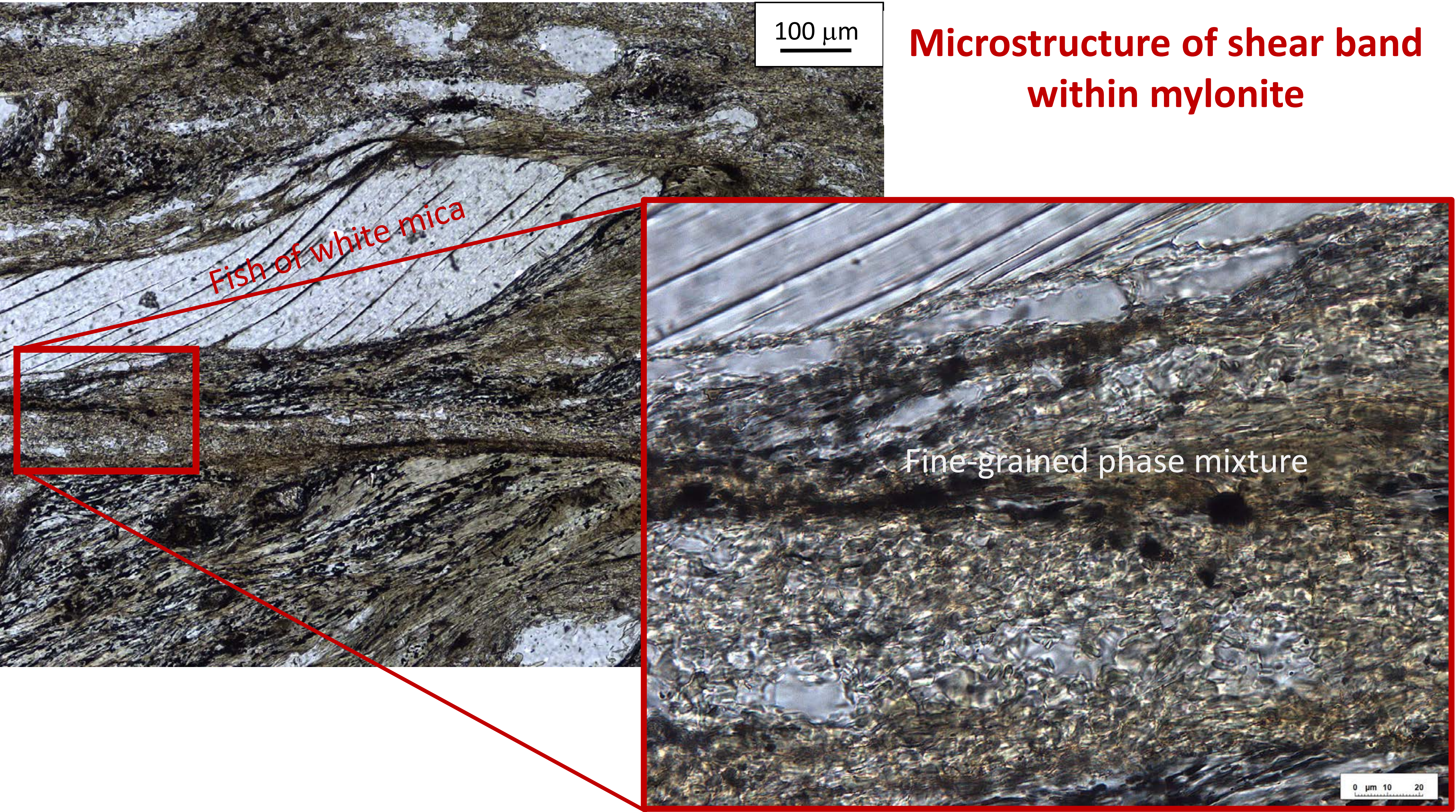
Pseudosections constructed on the base of the bulk chemistry of mylonites from the shear zones described above



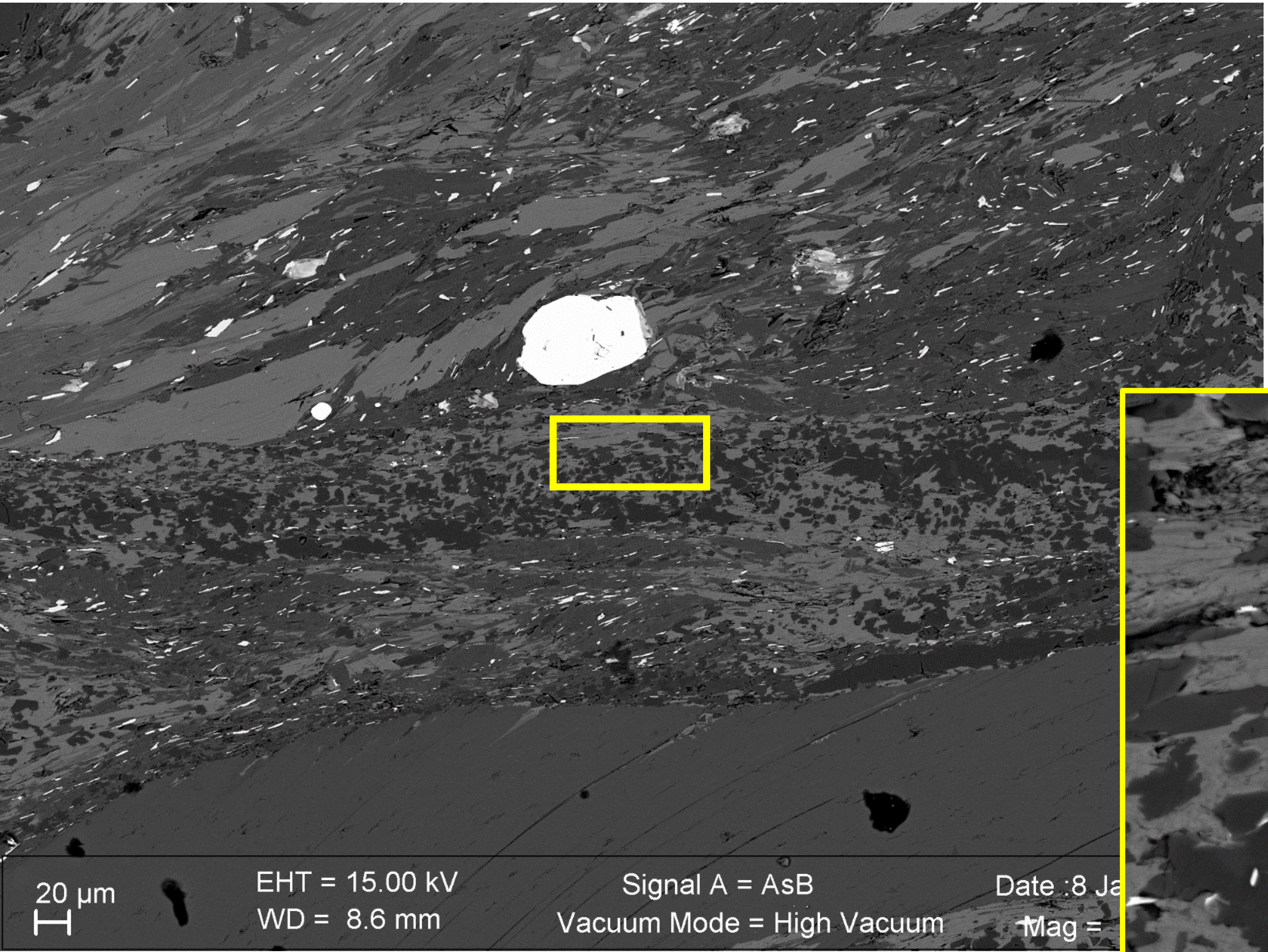
Left: NCKMASH system. Right: NCKFASH system. Green areas represent P-T stability field of mylonites

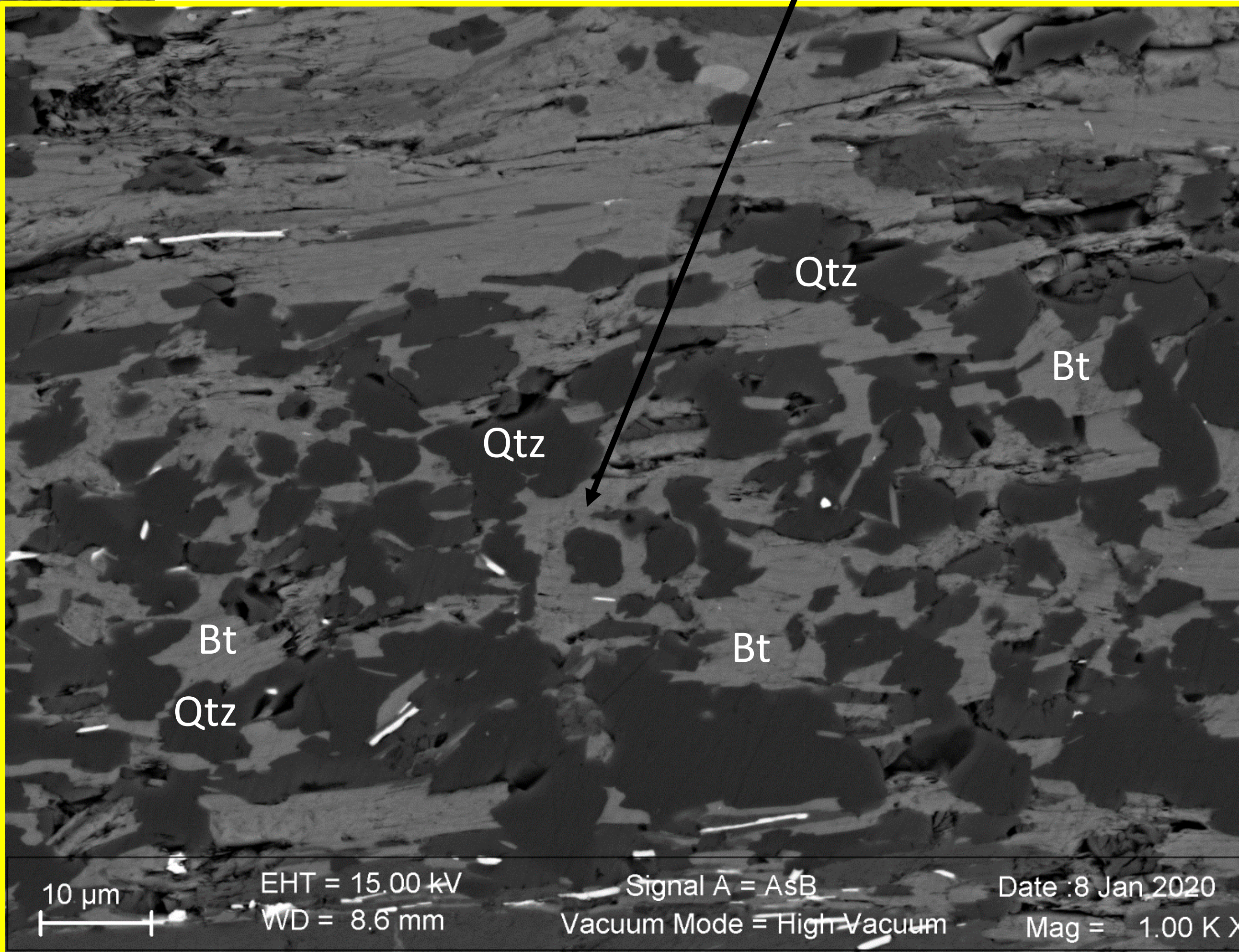
Based on the bulk Fe/Mg ratio of 0.5 a value intermediate between the T fields of the diagrams above would be appropriate: hence about 400° C +/- 50°

Microstructure of shear band within mylonite



SEM photos showing that biotite is stable within fine grain-size (ca. 5 µm) aggregates of mixed phases (quartz and biotite), where deformation is localized and accommodated by granular flow.





The presence of stable biotite in the deforming aggregate suggests **T ≥ 400° C** during deformation, hence well above the brittle-ductile transition

Conclusions

Joints sub-parallel to shear zones must have formed at high T, when fluids related to the emplacement of pegmatites could precipitate tourmaline within them. Only small parts of the joints, within areas of limited extent are reactivated as shear zones. Nucleation of shear zones on previous joints explains the highly localized character of this ductile deformation event.

Deformation within the shear zones must have taken place at T of 400° C, hence well in the ductile field. The spatial association between shear zones and joints cannot result from deformation taking place at the brittle-ductile transition.

The reason for the inferred development of shear zones along previous joints appears to be the weakening effect of the joints and their damage zones on the country rocks. First, the joints provide continuous planes of anisotropy with cm-thick fillings sharply separated from the country rock over several thousands of square meters. Second, the damage zone of the joints is transformed, over a thickness of more than 1 cm on each side of the joint, by the presence of μm thick phosphate-bearing seams, along grain boundaries oriented obliquely, and at high angle to the plane of the joint.

References:
Carreras, J., 2001. Journal of Structural Geology, 23, 1457-1486.
Fusseis, F., Handy, M.R., Schrank, C., 2006. Journal of Structural Geology 28, 1228–1243.
Fusseis and Handy, 2008, Journal of Structural Geology 30, 1242–1253.
Mancktelow and Pennacchioni, 2005, Journal of Structural Geology 27, 645–661.