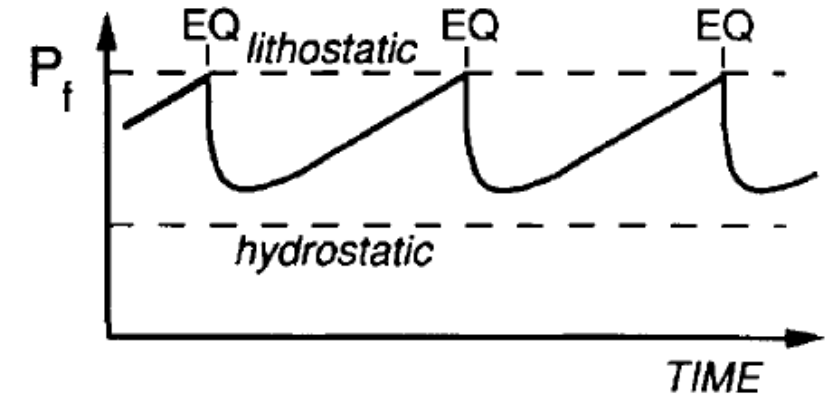
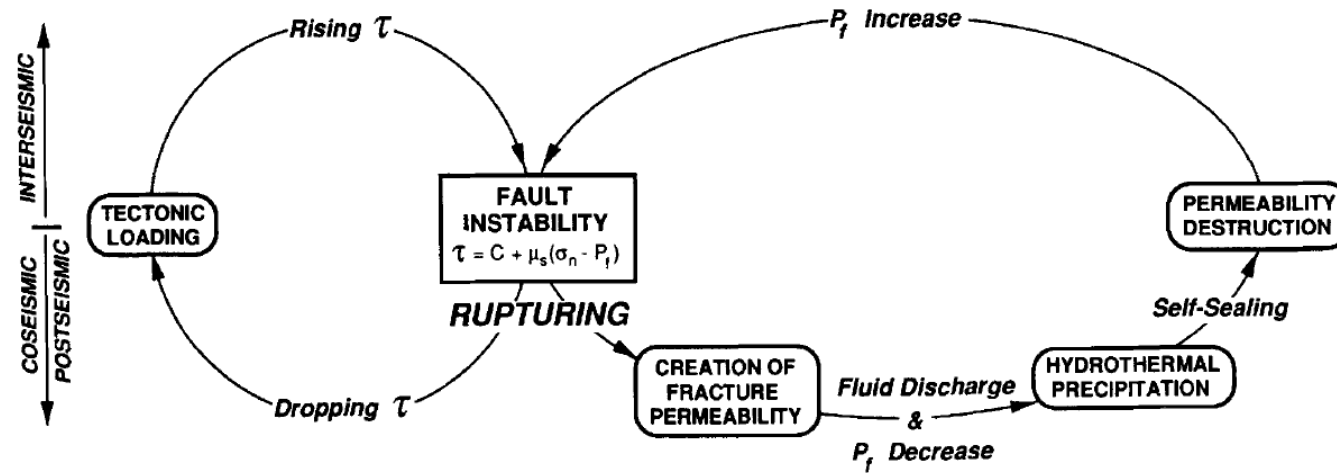


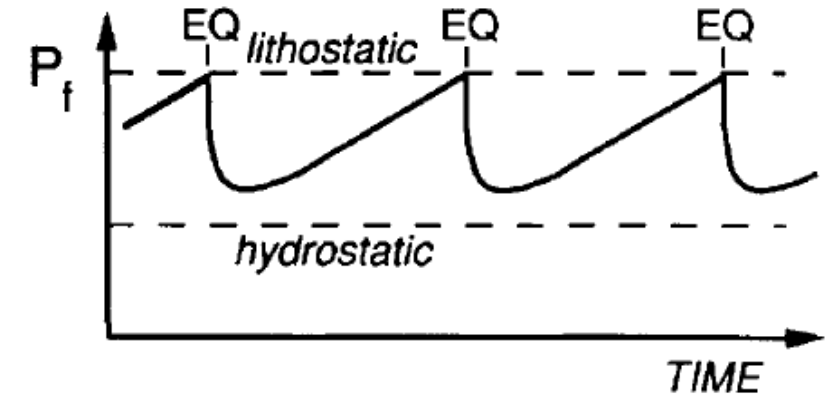
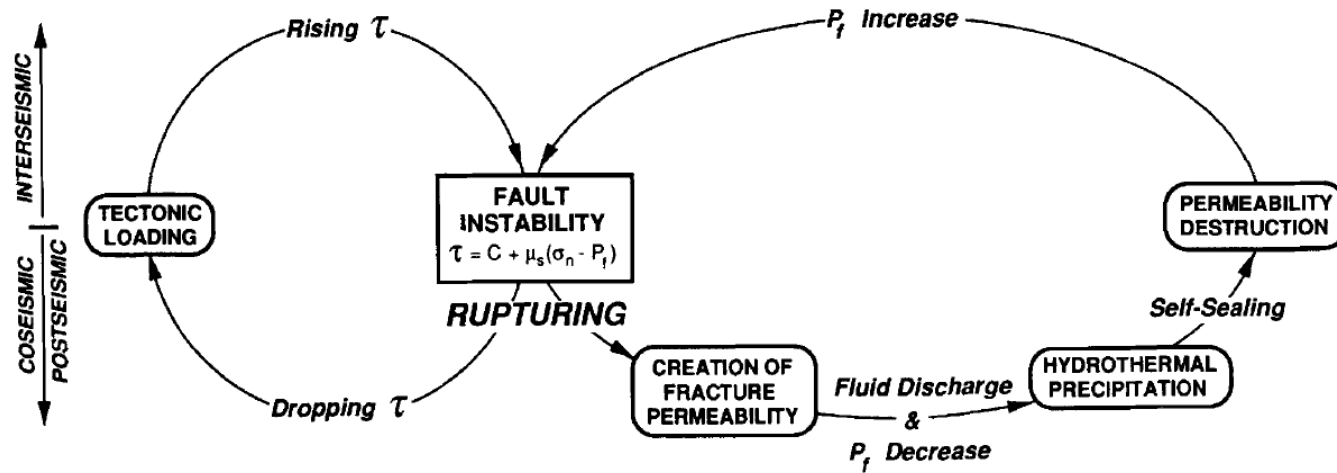
# Fluid pressure variations recorded by quartz vein geochemistry

Hugues Raimbourg, Vincent Famin, Kristijan Rajic, Saskia Erdmann, Benjamin Moris-Muttoni, Donald Fisher, Kristin Morell



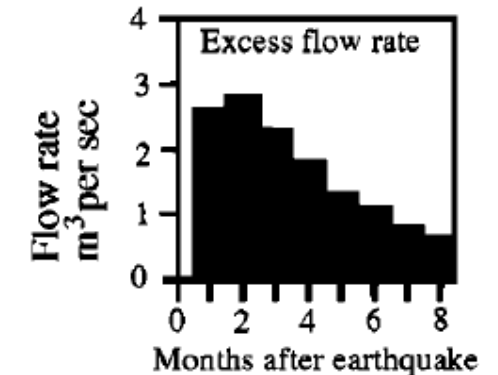
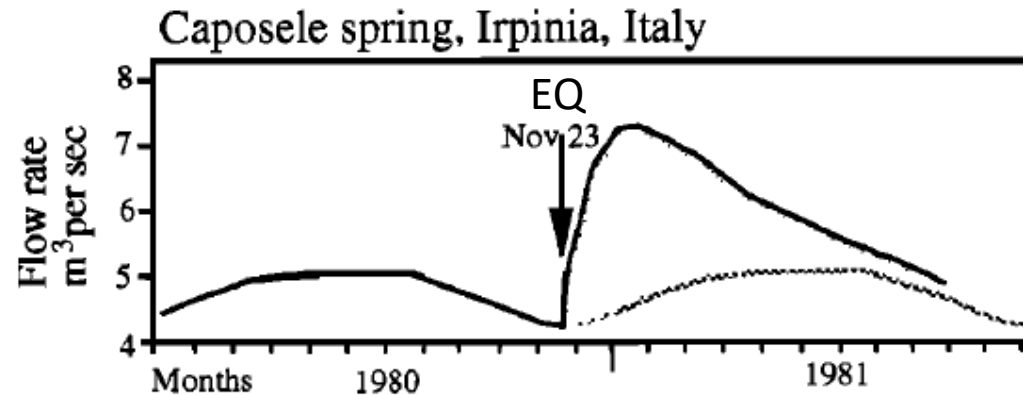
Fault-valve model (Sibson 1994): A widely model view that shows the large mechanical control of fluids on earthquakes

# Introduction



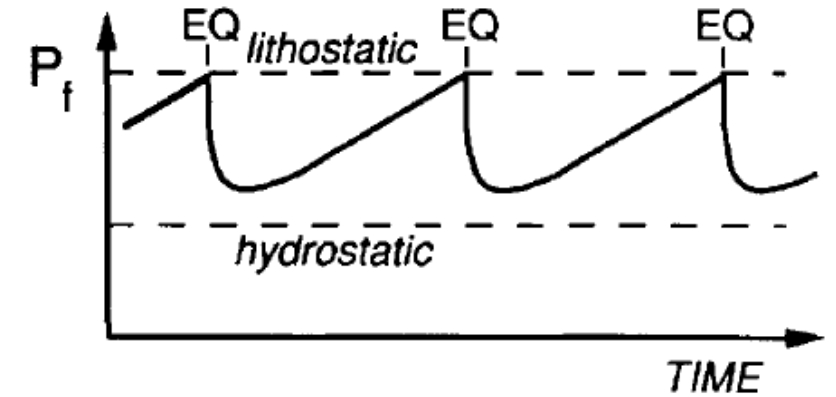
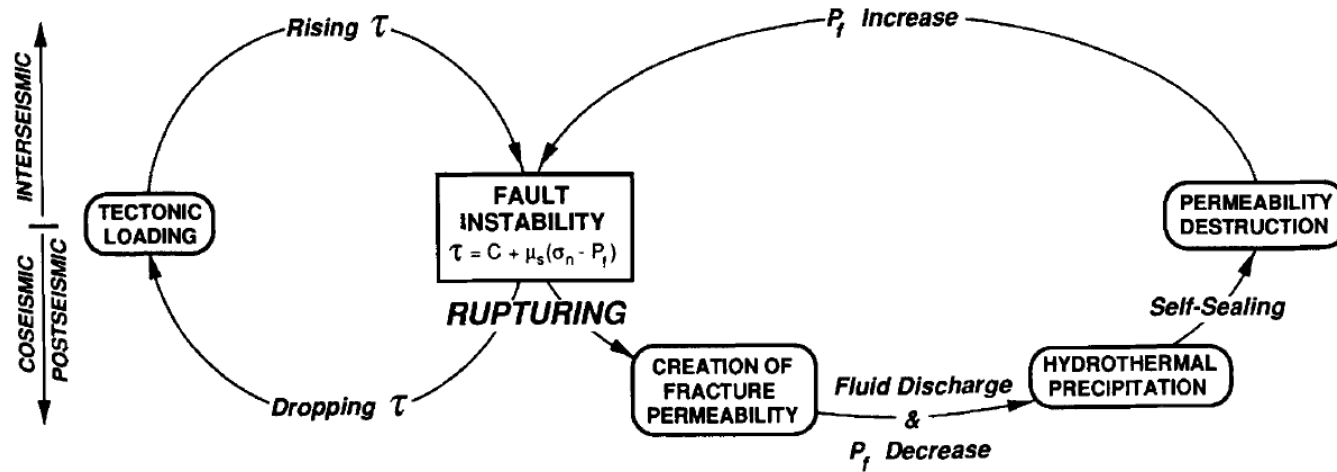
Fault-valve model (Sibson 1994): A widely model view that shows the large mechanical control of fluids on earthquakes  
**Supporting evidences for large temporal variations in fluid pressure:**

At the surface, increase in flow rate of spring as a response to earthquakes



Muirhead and King, 1993

# Introduction



Fault-valve model (Sibson 1994): A widely model view that shows the large mechanical control of fluids on earthquakes  
**Supporting evidences for large temporal variations in fluid pressure:**

-Large range of fluid inclusion density

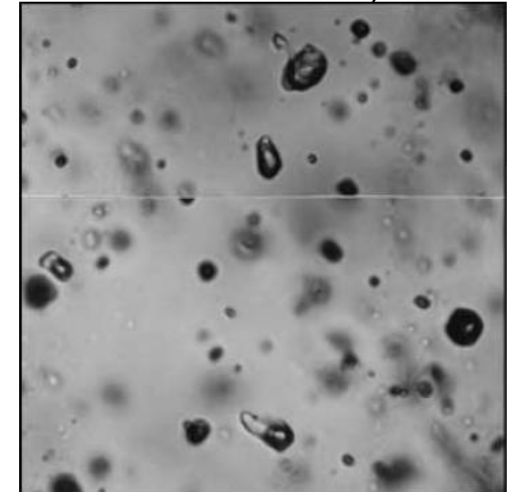
-Unmixing of a single fluid phase into two distinct fluid phases

→ Large range of fluid pressure conditions during trapping at depth

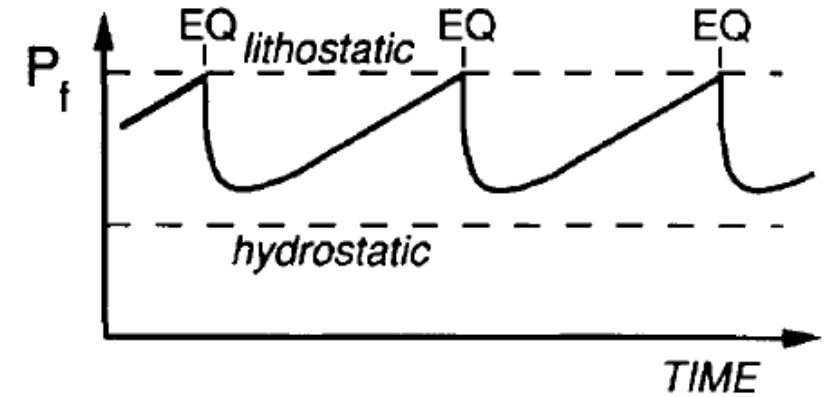
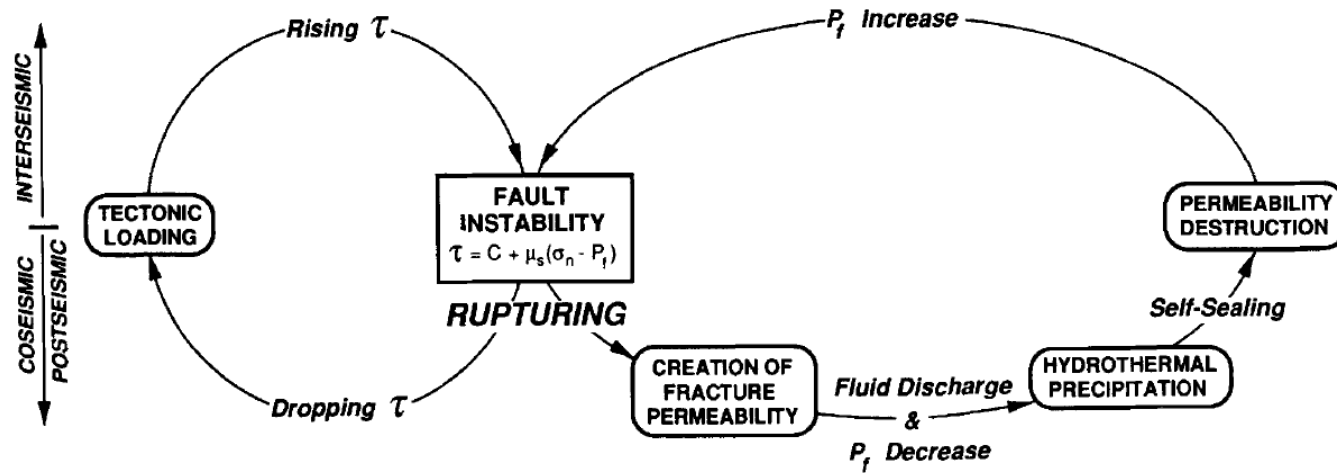
(e.g. : Wilkinson and Johnston, 1996, Robert and Boullier 1995)

At depth, evidences are much more limited and rely mostly on fluid inclusion studies:

Wilkinson and Johnston, 1996



# Introduction

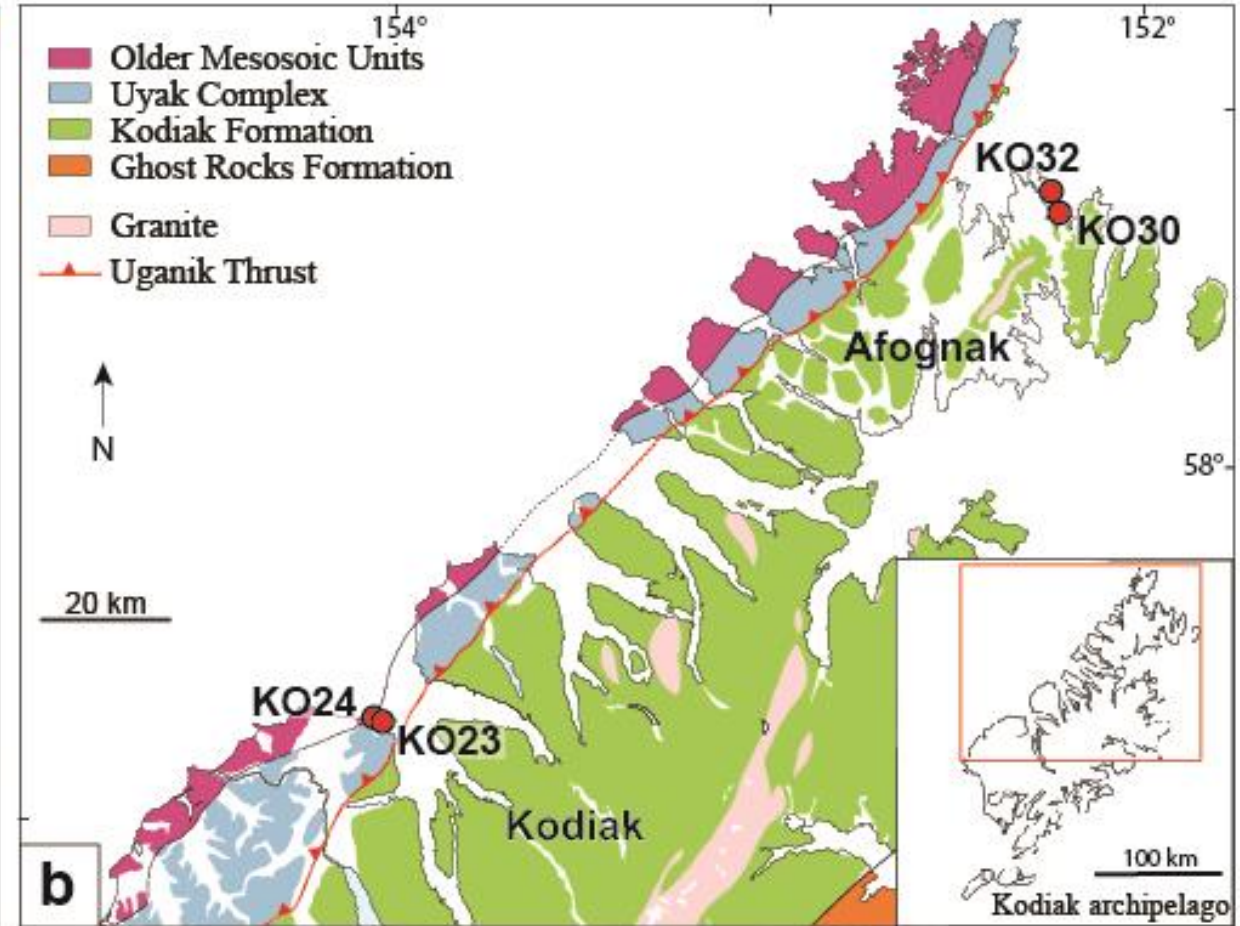
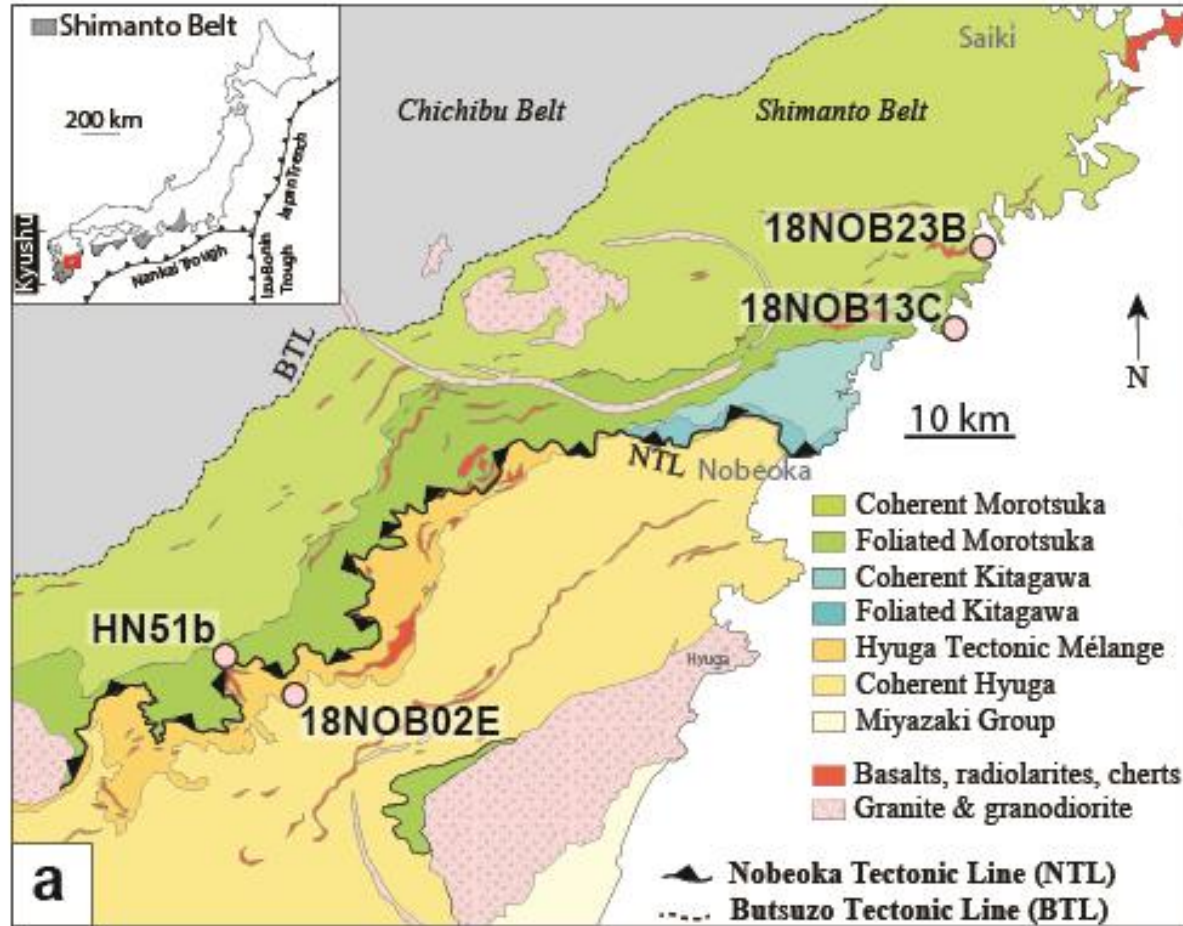


Fault-valve model (Sibson 1994): A widely model view that shows the large mechanical control of fluids on earthquakes  
Supporting evidences for large temporal variations in fluid pressure:

At depth, evidences are much more limited and rely mostly on fluid inclusion studies:

**Can one find other evidences of fluid pressure variations at depth?**

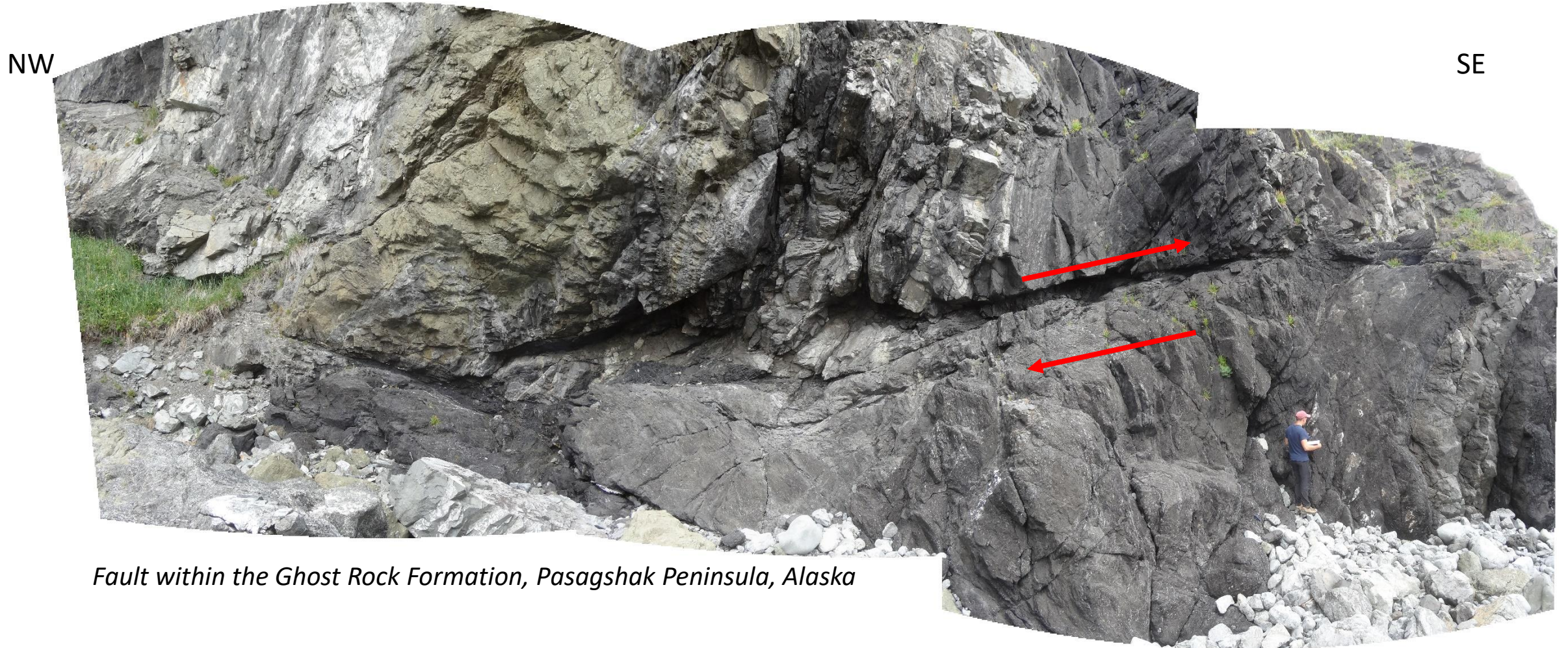
# Geological examples



Two examples chosen: accretionary complexes in Japan (Shimanto Belt) and Alaska (Kodiak Island)  
Classical examples of subduction margin, with well-constrained kinematics and geometry, as well as abundant evidences of localized deformation structures



# Geological examples



*Fault within the Ghost Rock Formation, Pasagshak Peninsula, Alaska*

Two chosen examples: accretionary complexes in Japan (Shimanto Belt) and Alaska (Kodiak Island)

Classical examples of subduction margin, with well-constrained kinematics and geometry

We focused here on zones of localized deformation, interpreted as reflecting plate interface, or intra-wedge, out-of-sequence thrusting, conditions.



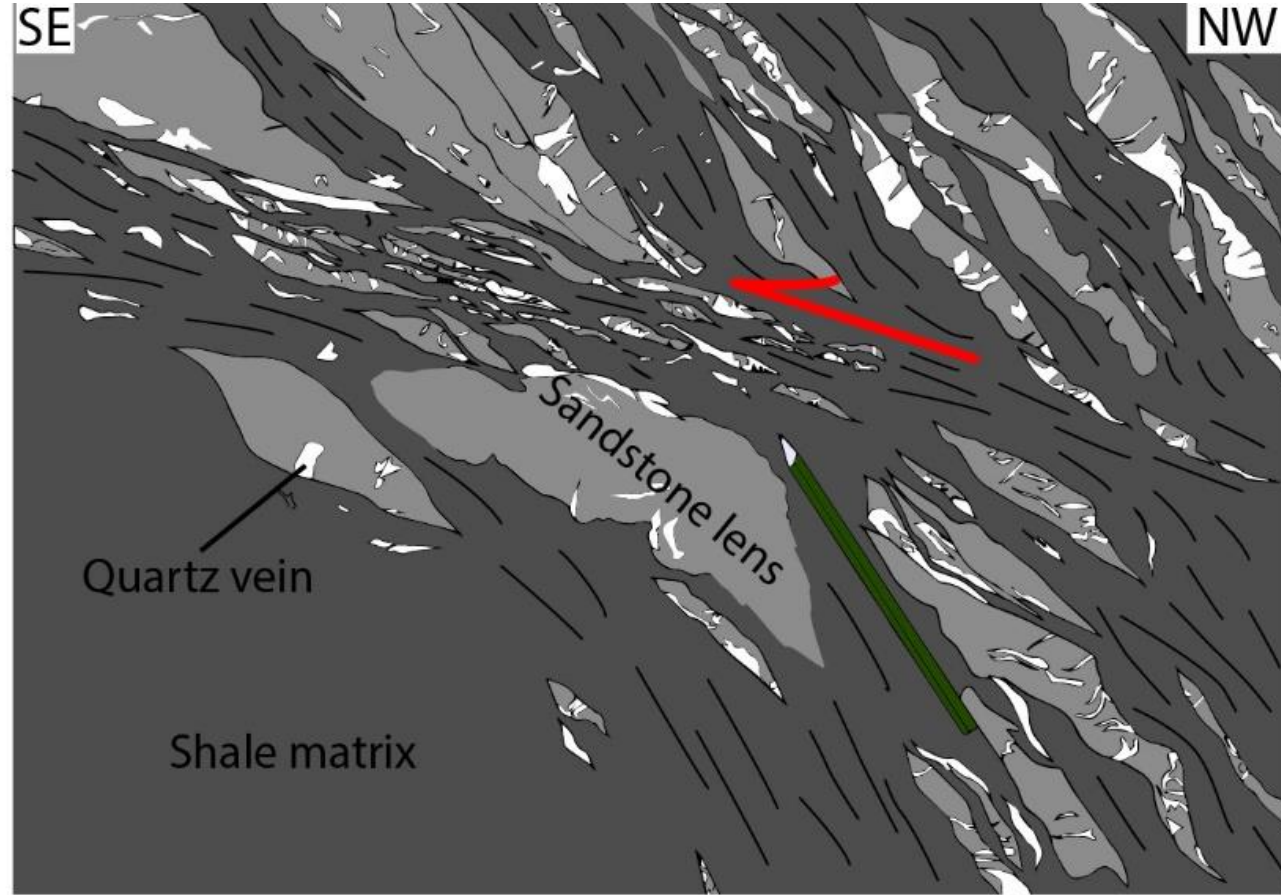
# Quartz veins at seismogenic depths: structures



Mode I cracks in the tails of sandstone lenses, formed in association with top-to-the-SE shear zones synkinematic with subduction deformation (Hyuga Coherent Formation, Japan)



## Quartz veins at seismogenic depths: structures



Mode I cracks in the tails of sandstone lenses, formed in association with top-to-the-SE shear zones synkinematic with subduction deformation (Hyuga Tectonic Mélange, Japan)

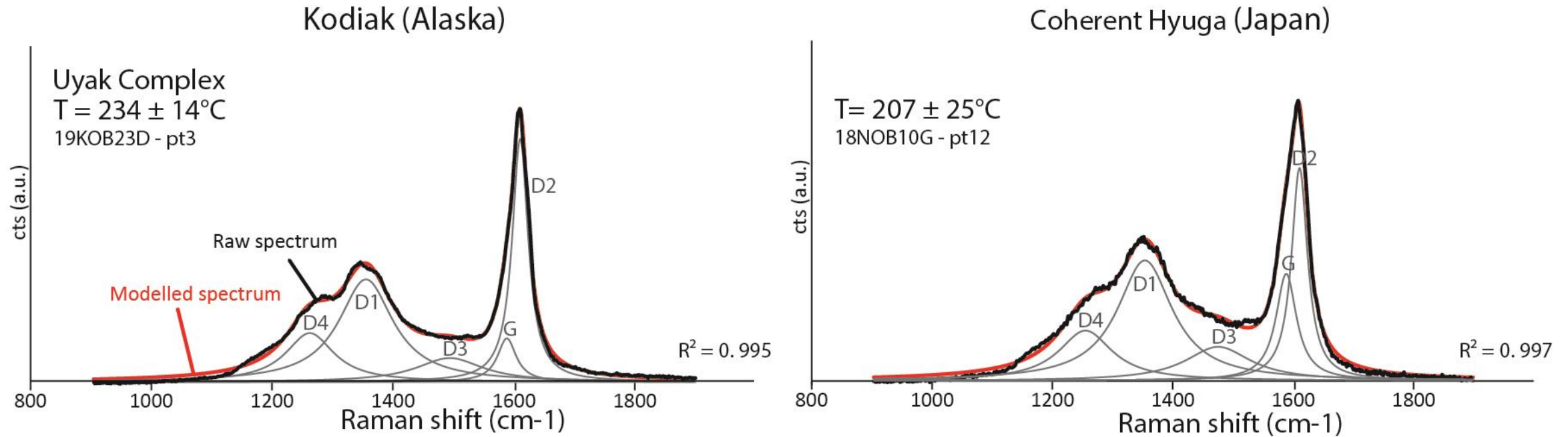


## Quartz veins at seismogenic depths: structures



Mode I cracks in the tails of chert lenses, during syn-subduction, layer parallel extension (Uyak Mélange, Alaska)

# Quartz veins at seismogenic depths: temperature of formation

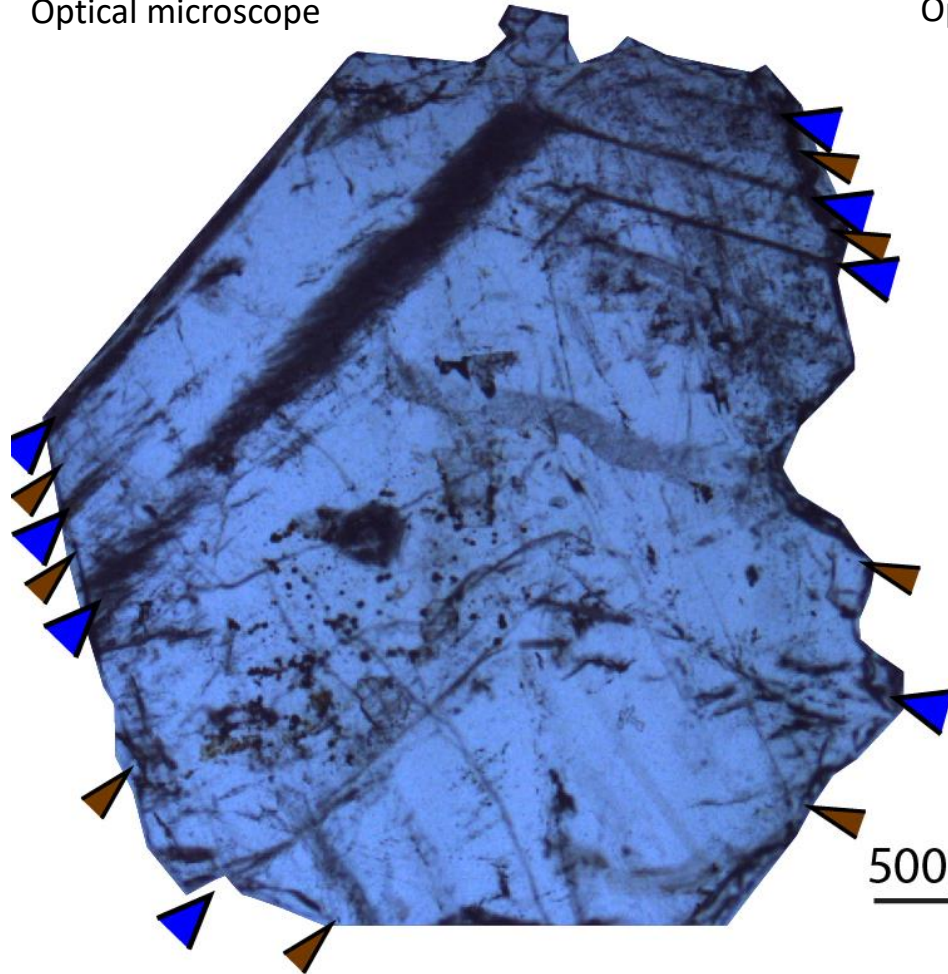


Conditions of deformation are constrained by Raman spectroscopy on carbonaceous matter, as  $T$  in the range  $200\text{--}250^\circ\text{C}$ , i.e. the  $T$  conditions of the seismogenic zone.

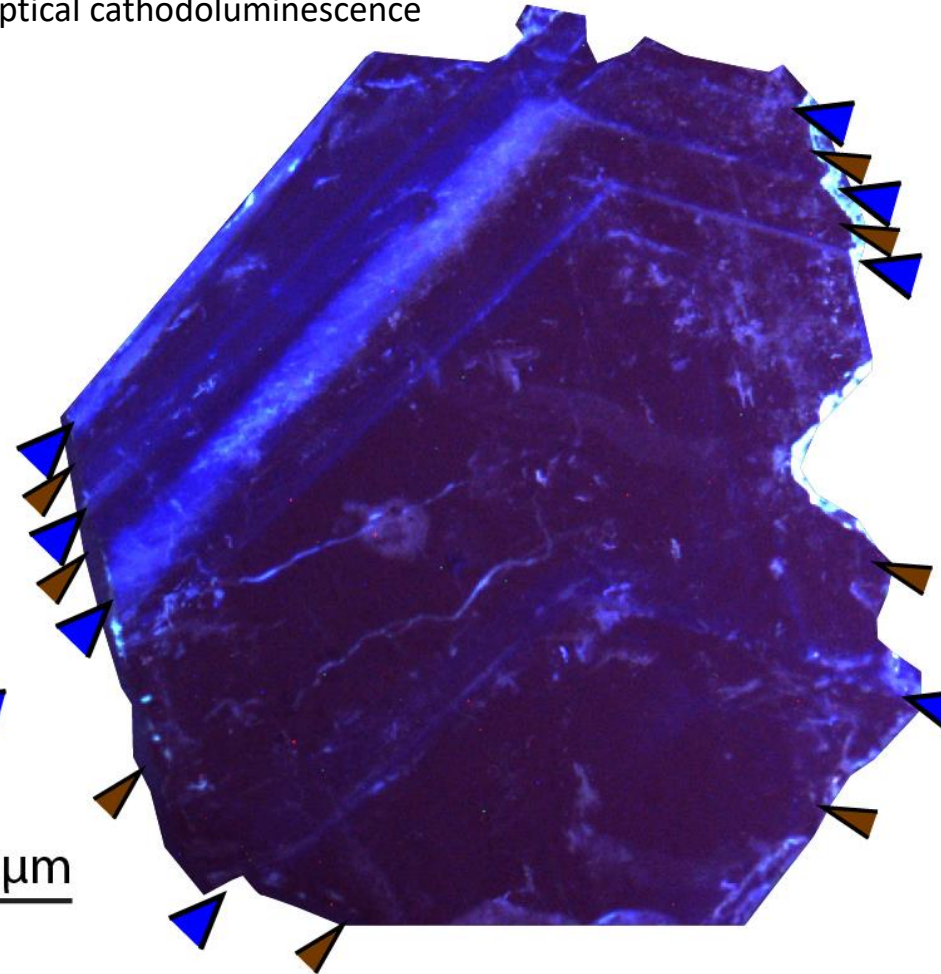


# Quartz veins at seismogenic depths: microstructures

Optical microscope



Optical cathodoluminescence



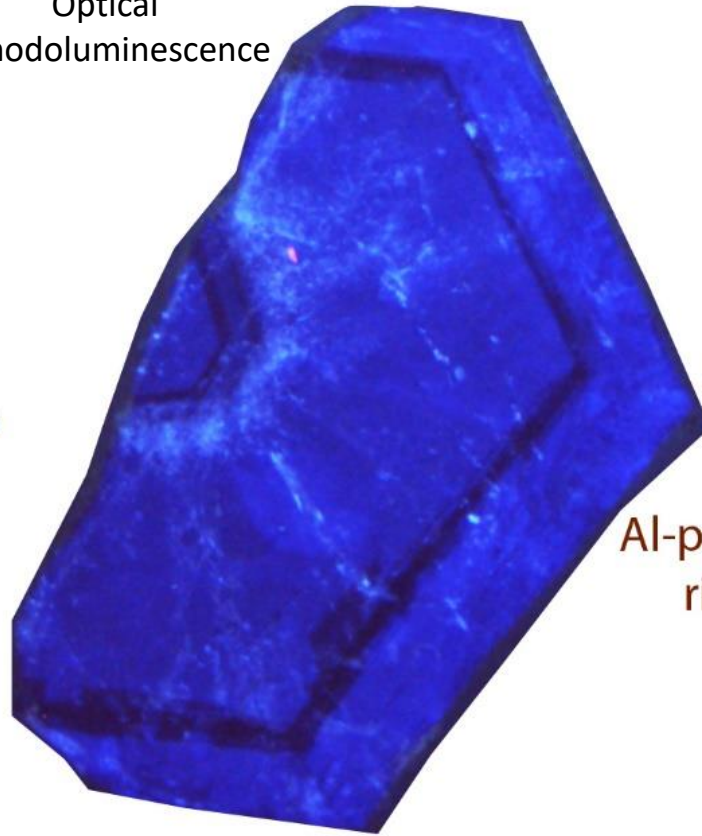
Mode I cracks contain often euhedral quartz crystals, with **growth rims** alternating (i) high, blue luminescence and high fluid inclusion density and (ii) low, brown luminescence and low fluid inclusion density.

# Quartz veins at seismogenic depths: geochemistry

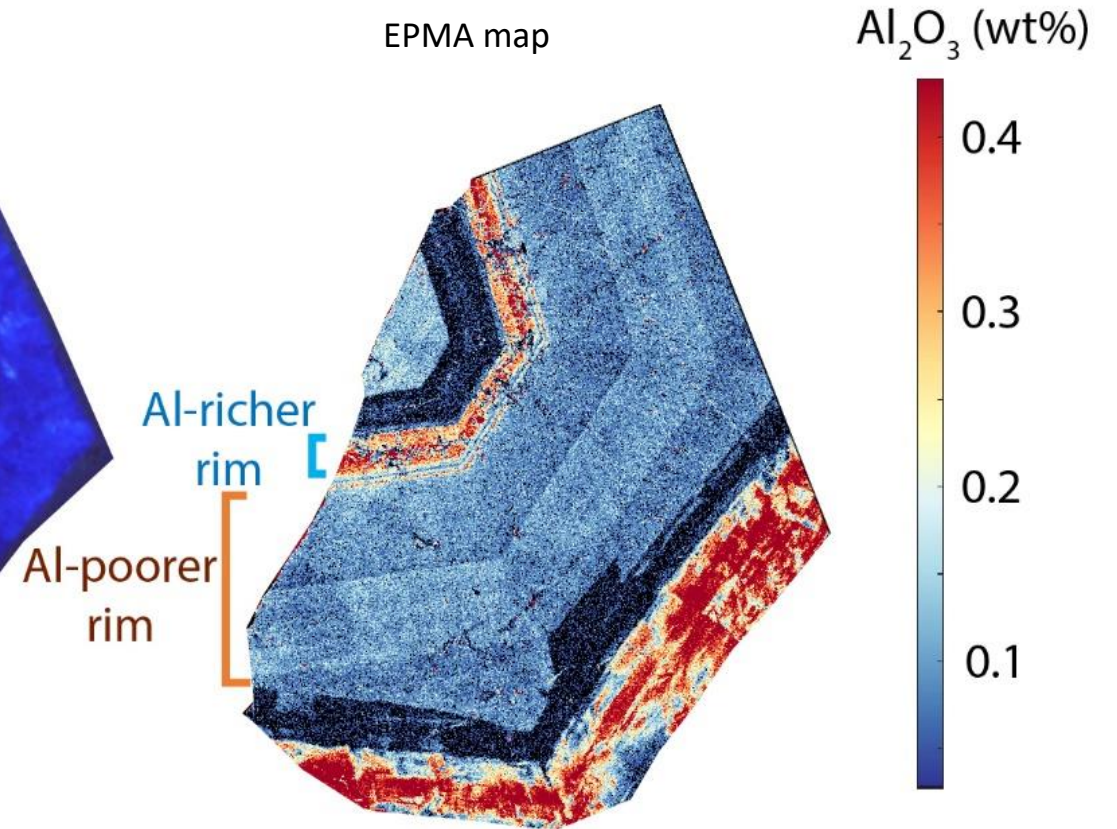
Optical microscope



Optical cathodoluminescence



EPMA map

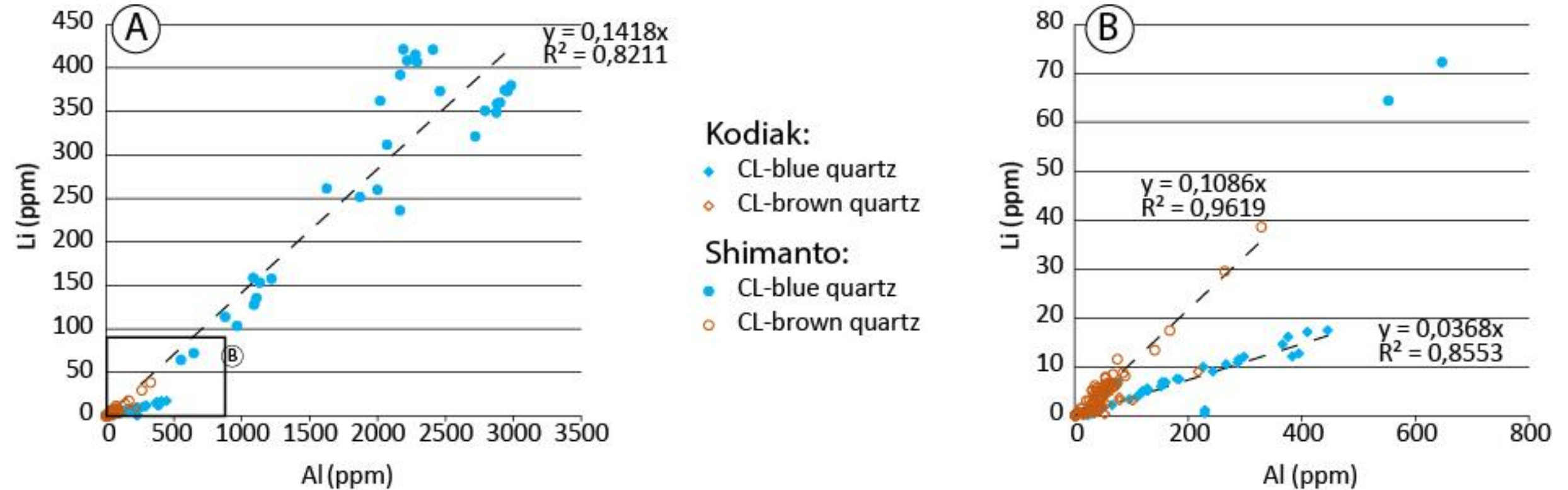


Quantification using XMapTools  
(Lanari et al. 2014, 2019)

**Growth rims** are also characterized by variations in Al content. The high luminescence/high fluid inclusion density domains correspond to **high Al content**.

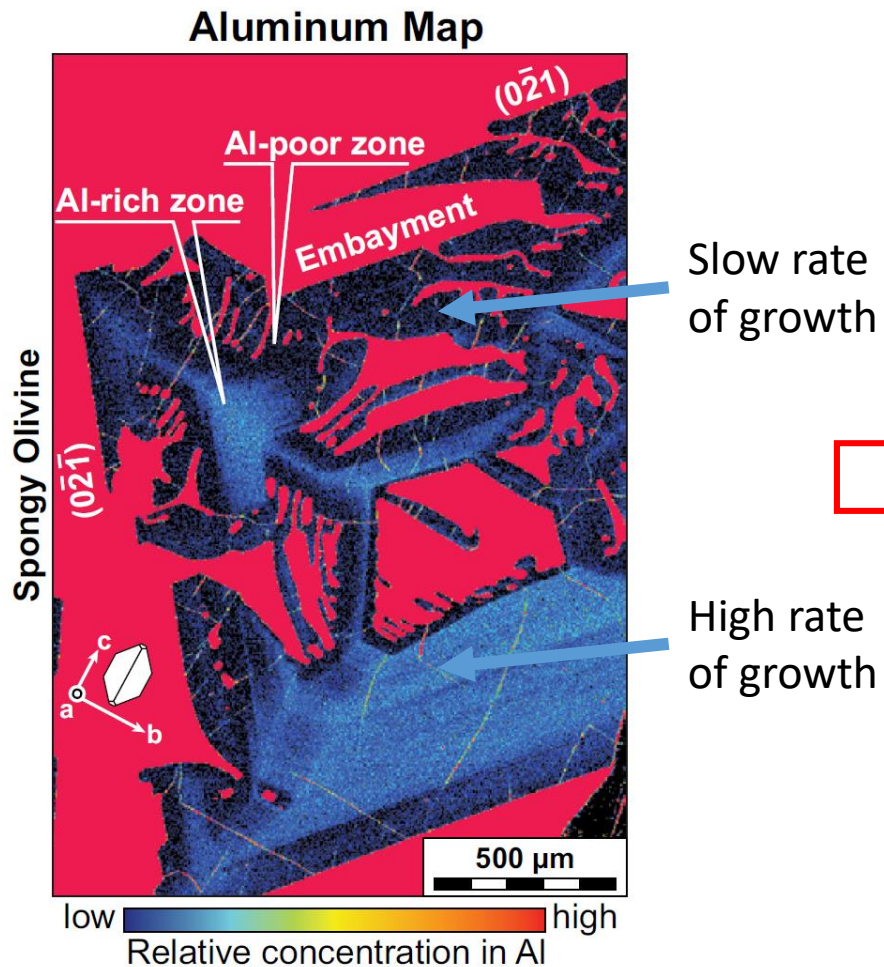


# Quartz veins at seismogenic depths: geochemistry



Al content is correlated with Li content → Li is the main charge-compensating cation for  $\text{Si}^{4+} \rightarrow \text{Al}^{3+}$  substitution

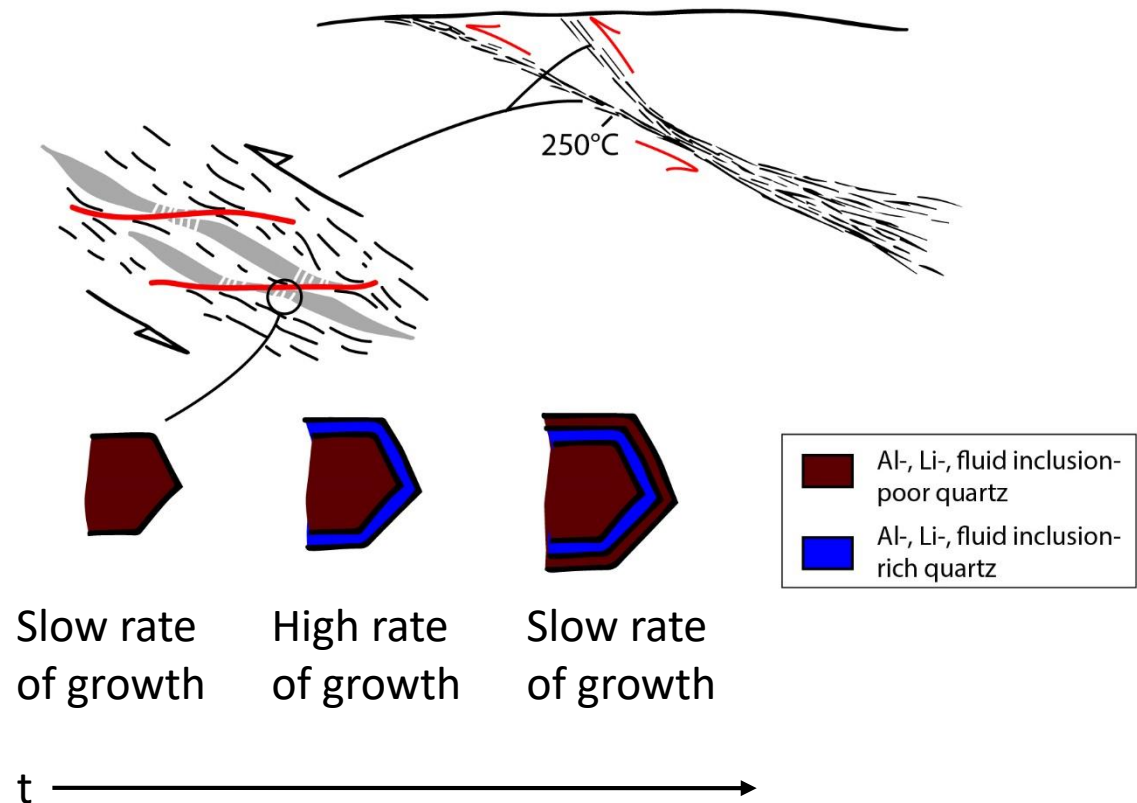
# Quartz veins at seismogenic depths: model of formation



Slow rate of growth

High rate of growth

## Model of quartz growth based on Al concentration

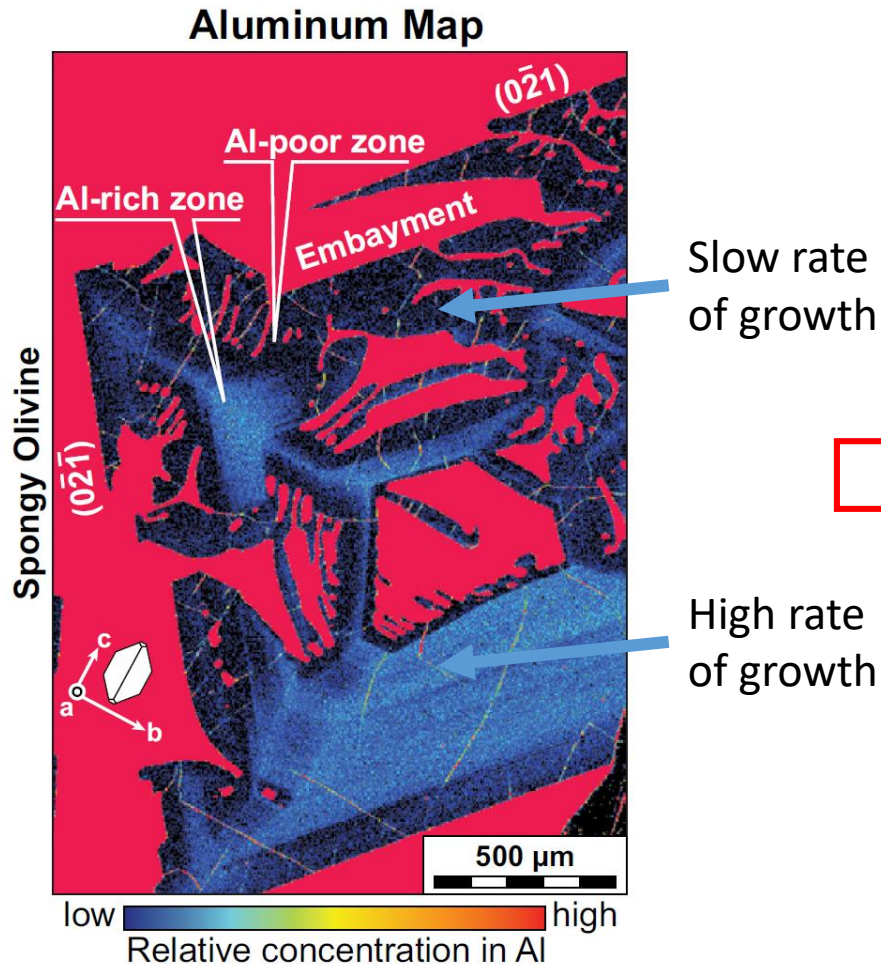


Incorporation of Al during experimental growth of olivine crystals (Welsch et al., 2014)

→ Al concentration is correlated with crystal growth rate



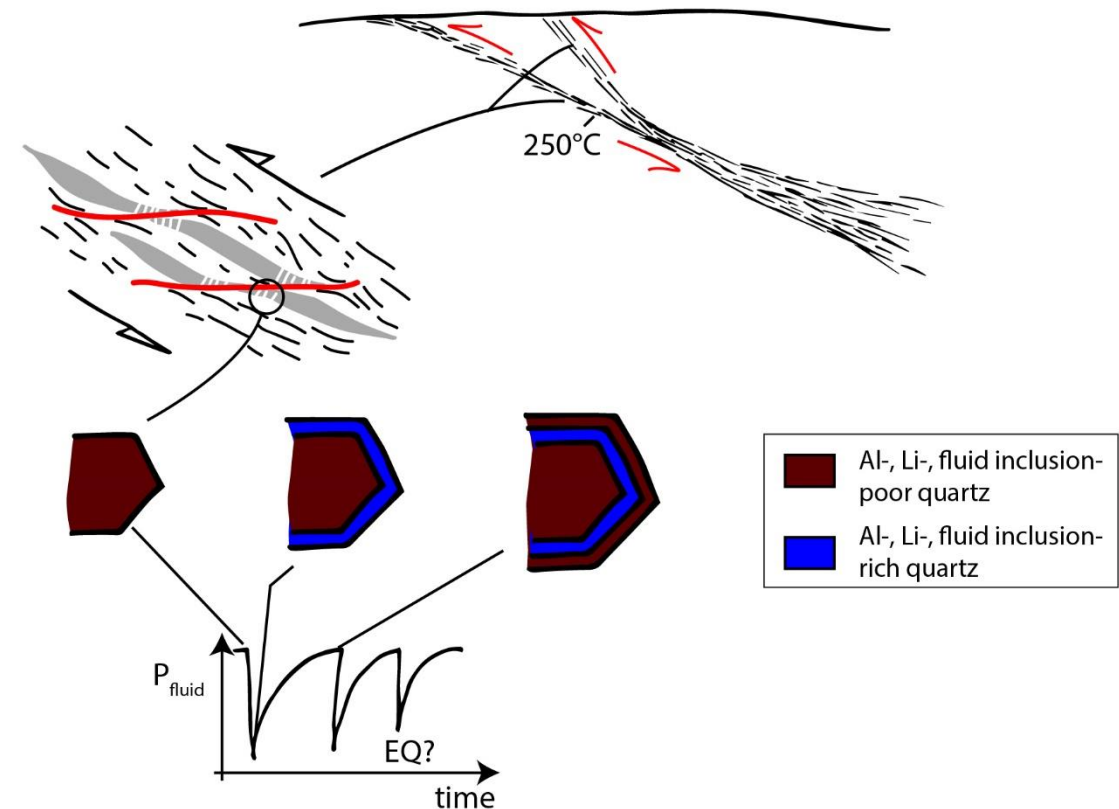
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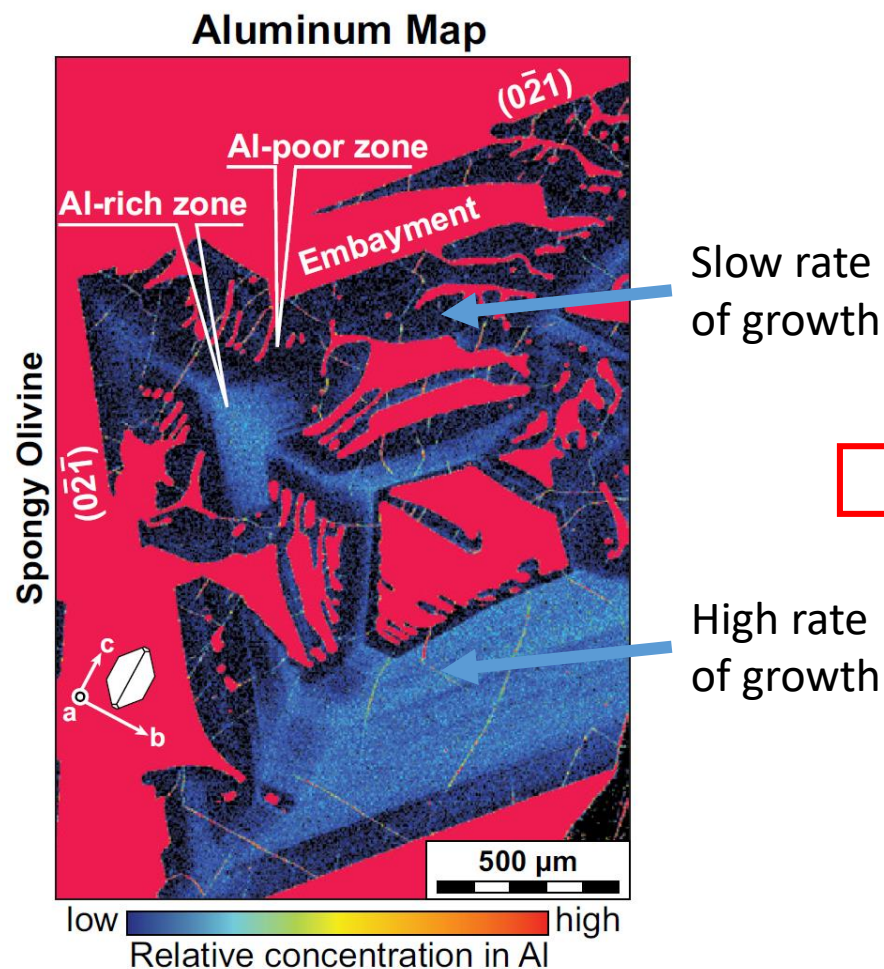
→ Al concentration is correlated with crystal growth rate

## Model of quartz growth based on Al concentration



**Al-rich growth rims reflect stages of rapid, out-of-equilibrium growth**

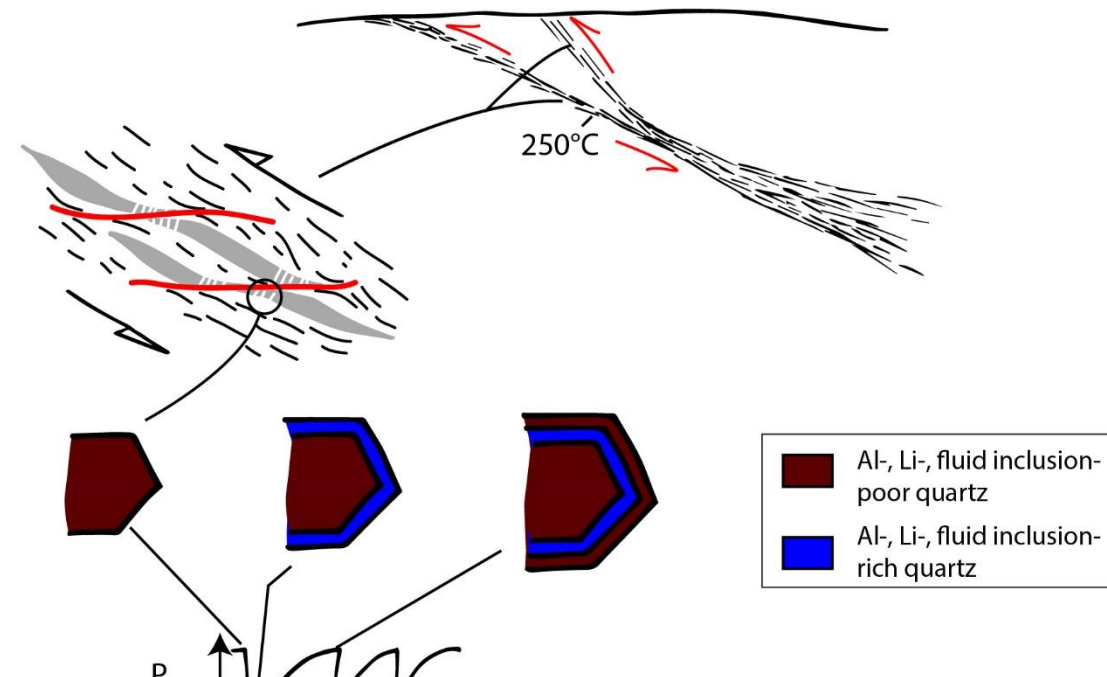
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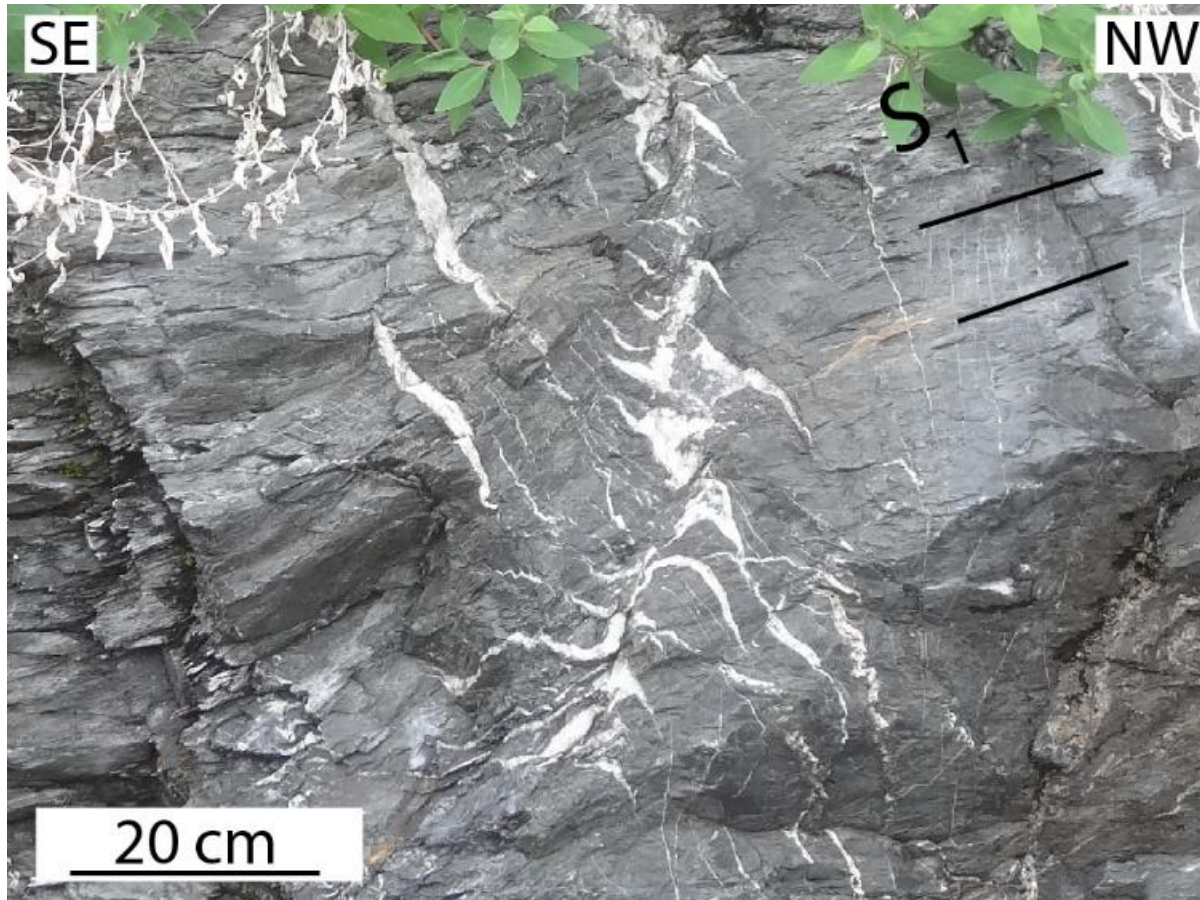
→ Al concentration is correlated with crystal growth rate

**At seismogenic depths, in zones of localized deformation, Al-rich growth rims records stages of large fluid pressure drop**



And what about the fluid conditions at higher temperature (brittle-viscous transition, i.e. the downdip limit of the seismogenic zone)?

# Quartz veins at the downdip limit of the seismogenic zone: structures



Kodiak Central Belt, Alaska

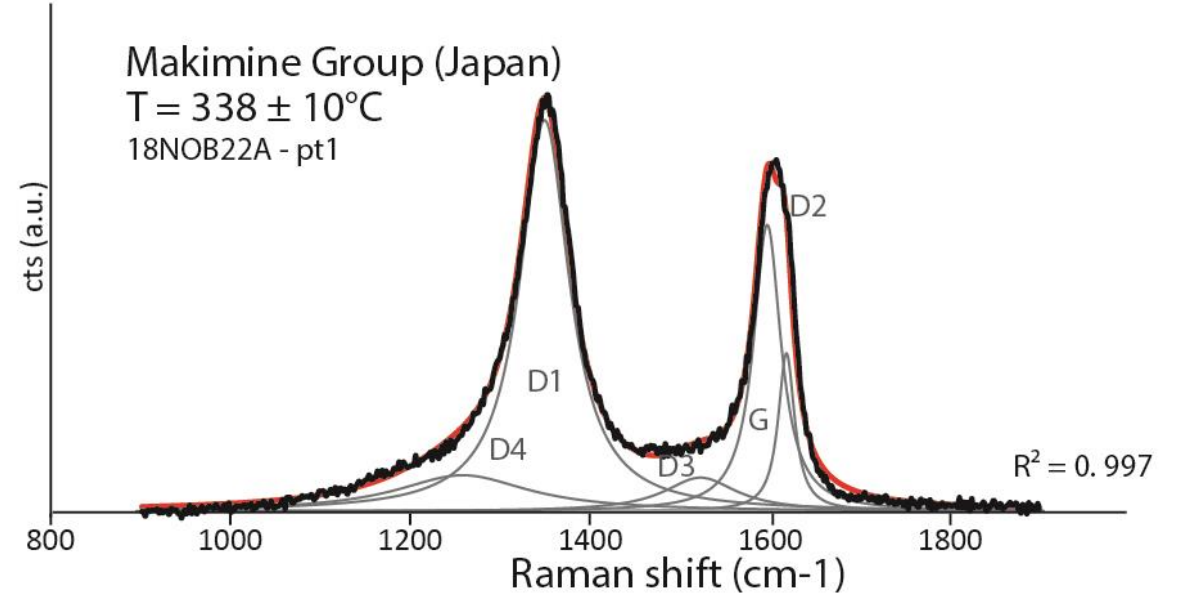
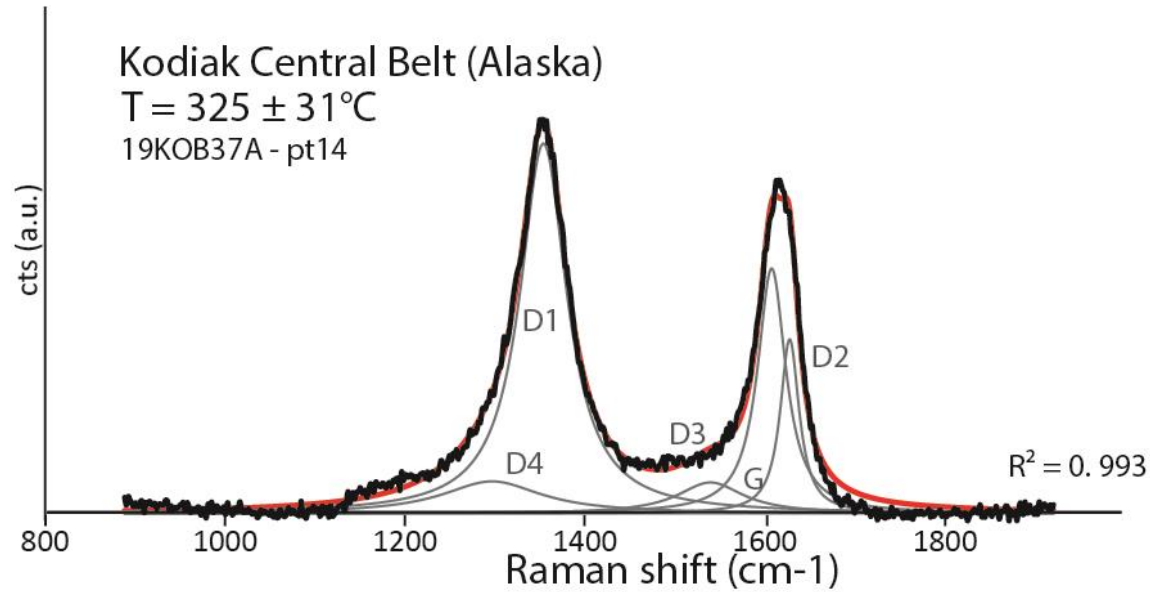


Makimine Group, Shimanto Belt, Japan

Mode I cracks, with en-échelon geometry, consistent with top-to-the-trench sense of shear, form contemporaneously with the metamorphic foliation.



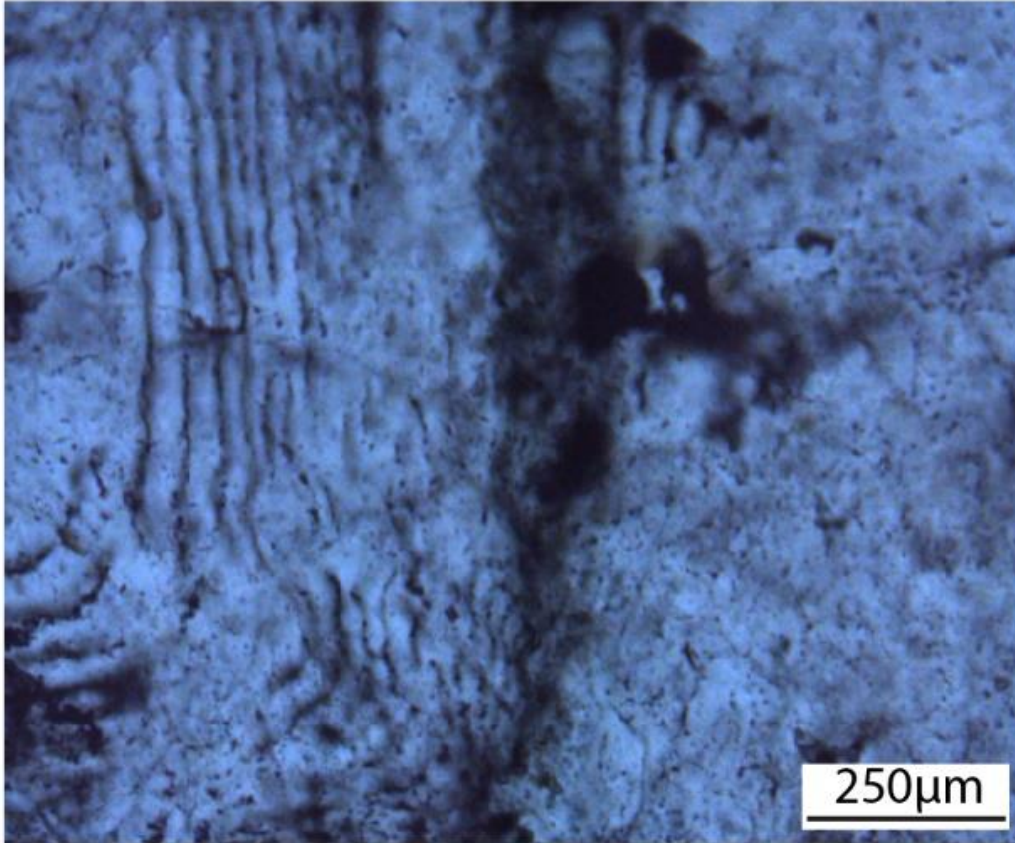
# Quartz veins at the downdip limit of the seismogenic zone: temperature of formation



Mode I cracks, with en-échelon geometry, consistent with top-to-the-trench sense of shear, form contemporaneously with the metamorphic foliation. Temperature of deformation and veining is in the range 320-350°C.

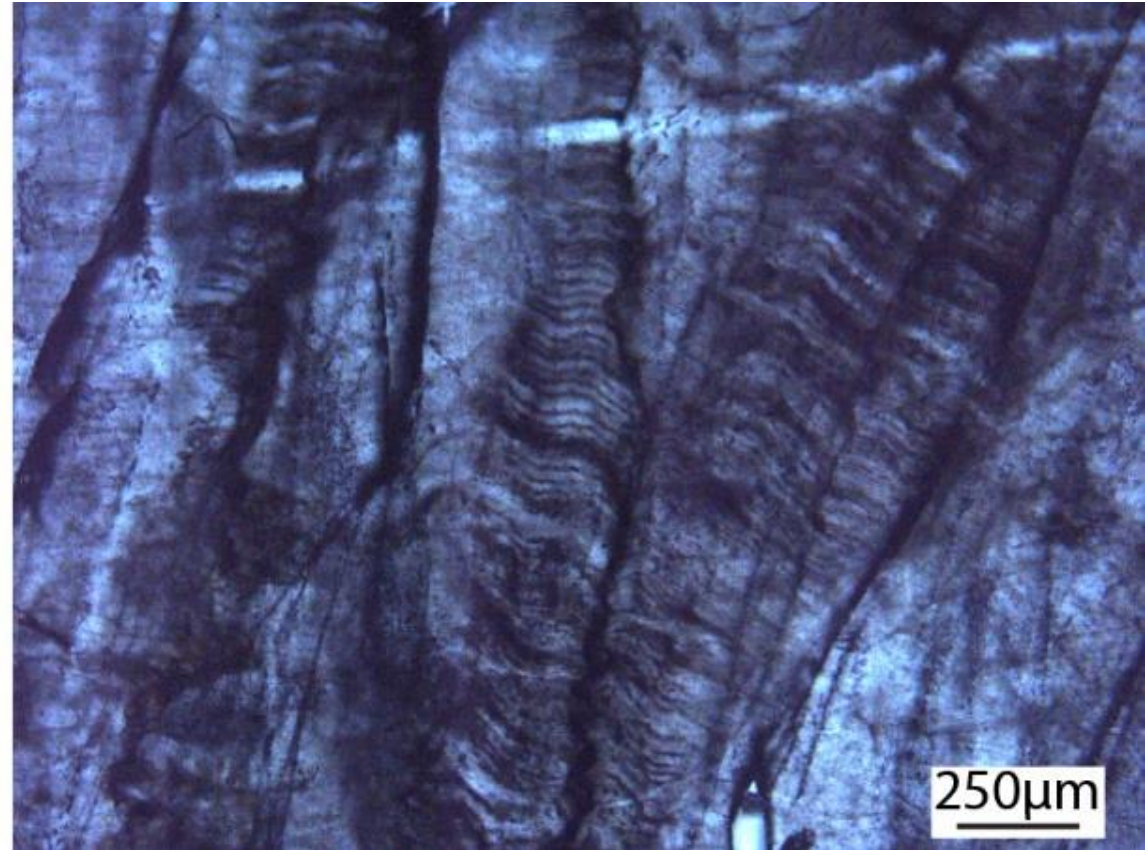
# Quartz veins at the downdip limit of the seismogenic zone: microstructures

Optical microscope



Kodiak Central Belt, Alaska

Optical microscope



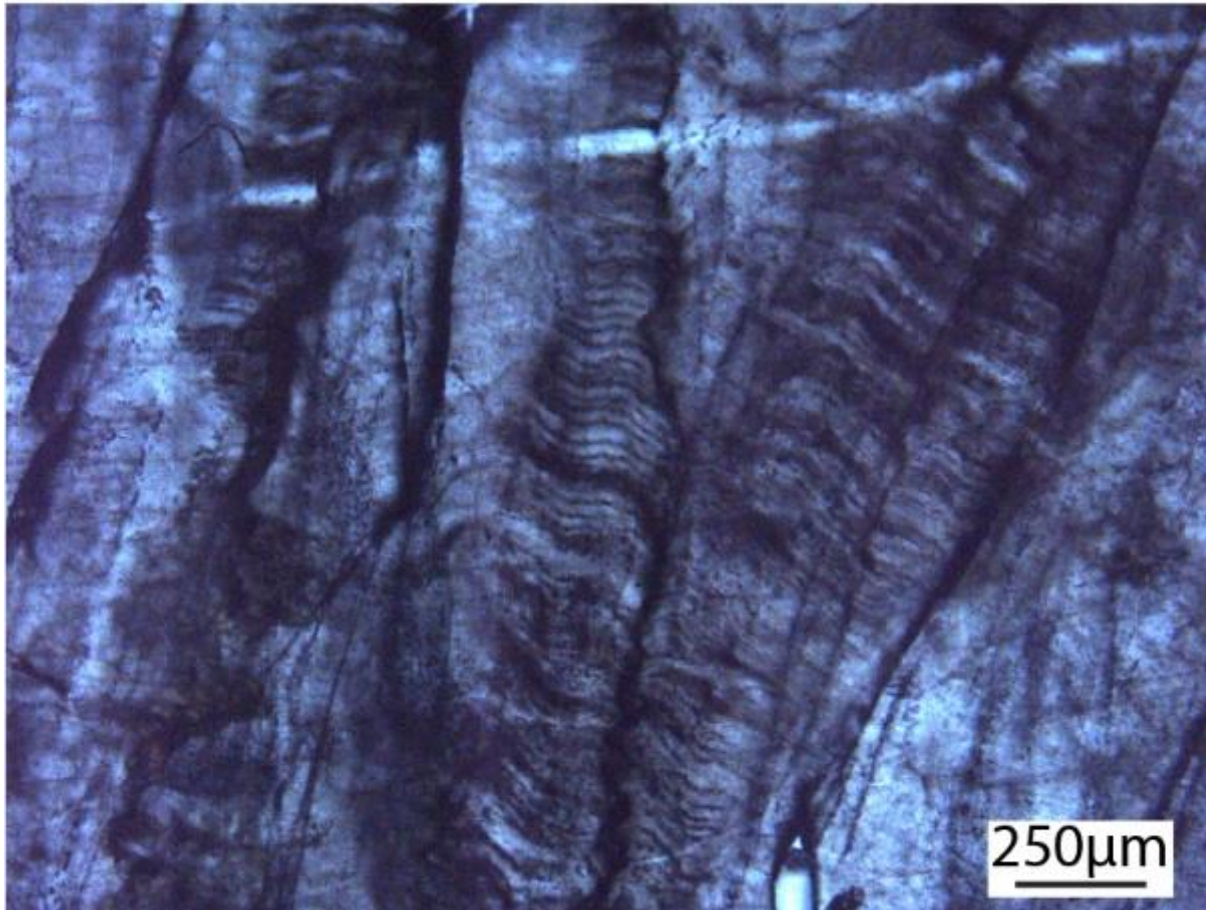
Makimine Group, Shimanto Belt, Japan

Mode I cracks, with en-échelon geometry, consistent with top-to-the-trench sense of shear, form contemporaneously with the metamorphic foliation. Temperature of deformation and veining is in the range 320-350°C. Crack-seal microstructures within the veins reflect pulses of deformation during ETS at the base of the seismogenic zone (Fisher and Brantley 2014, Ujiie et al. 2018)

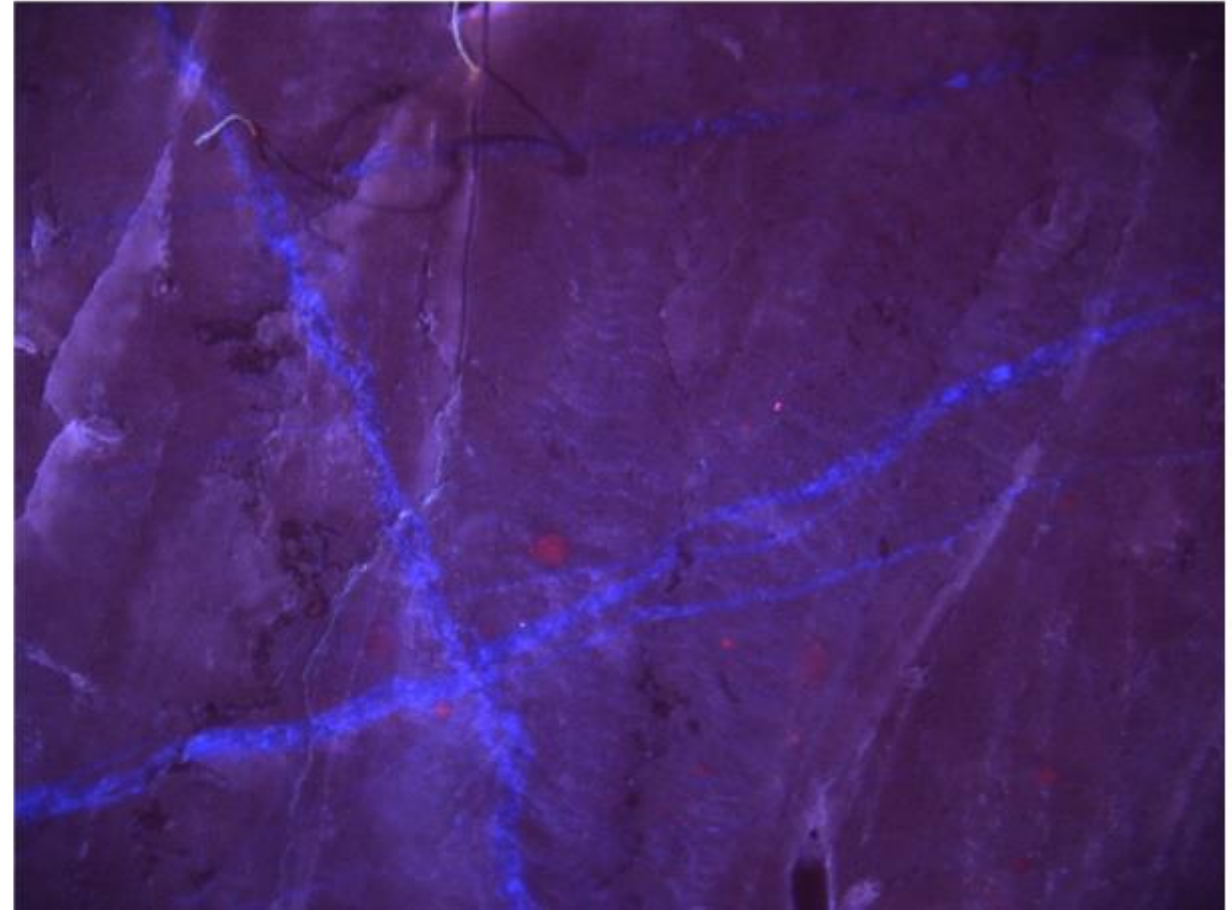


# Quartz veins at the downdip limit of the seismogenic zone: geochemistry

Optical microscope



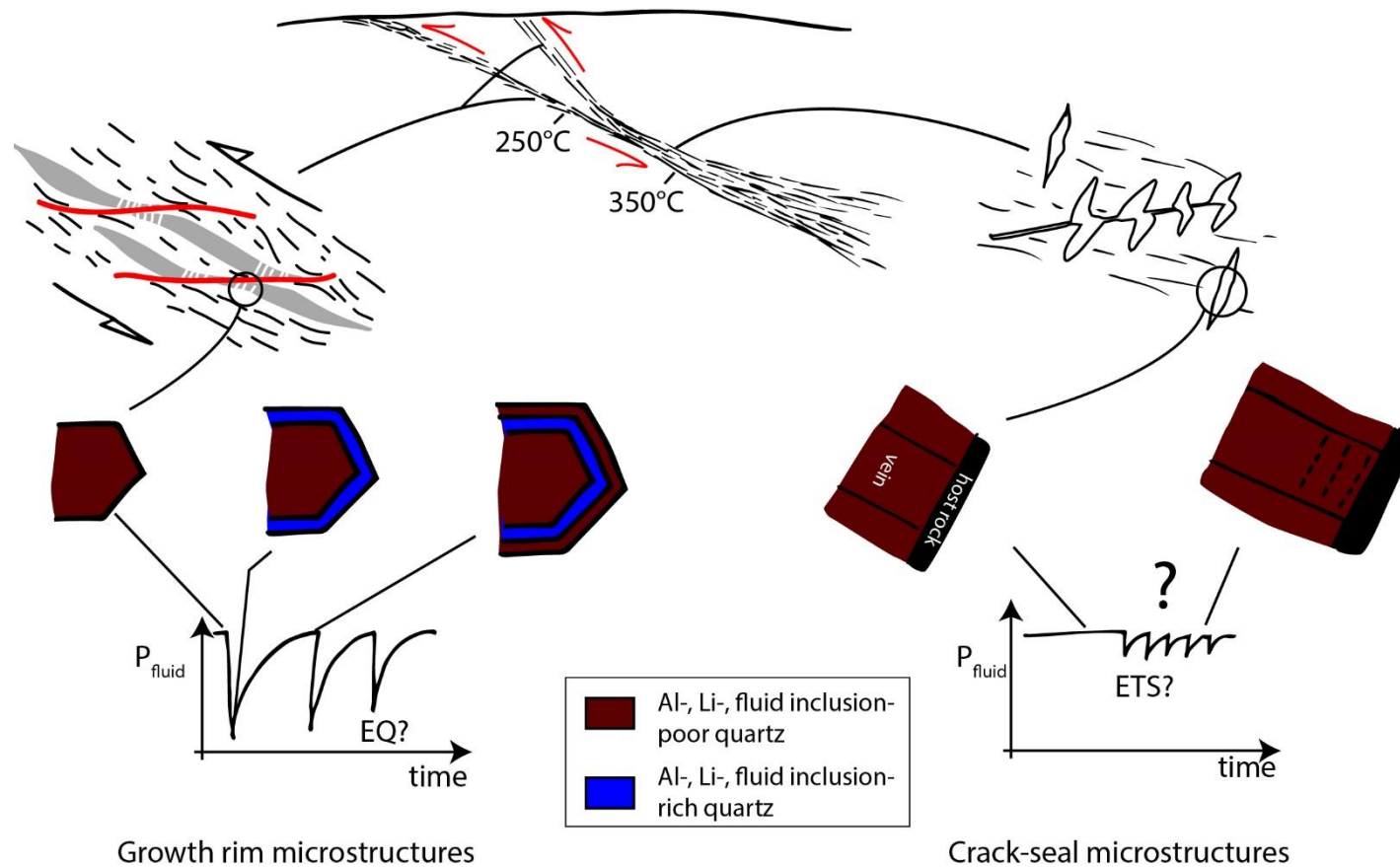
Optical cathodoluminescence



The crack-seal domains, similarly to other vein quartz from the same temperature range, have a low luminescence and accordingly a low content in Al.

Contrarily to the lower temperature samples, there is **only a single type of quartz** (in terms of Al concentration and luminescence)

# Conclusions

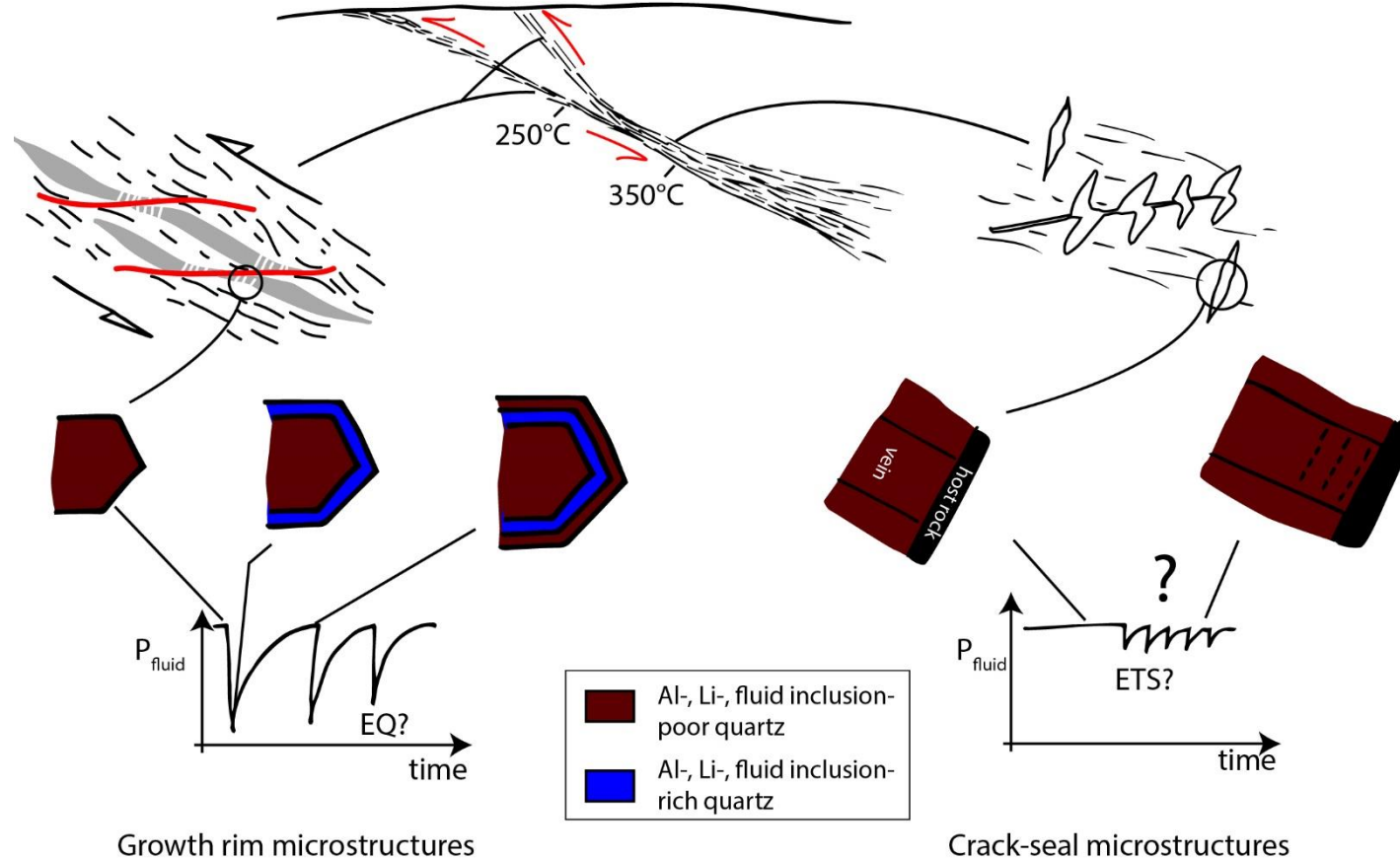


Following our interpretative scheme, we propose the following model about the record by quartz geochemistry of the variations in fluid pressure across depths:

- At the temperature of the seismogenic zone ( $T < 300^\circ\text{C}$ ), quartz growth rims enriched in Al are the record of stages of fluid pressure drops, possibly after earthquakes
- At the higher temperatures of the brittle-viscous transition ( $T > 300^\circ\text{C}$ ), deformation pulses are reflected by crack-seal microstructures, but the associated variations in fluid pressure have a much more limited amplitude



# Conclusions

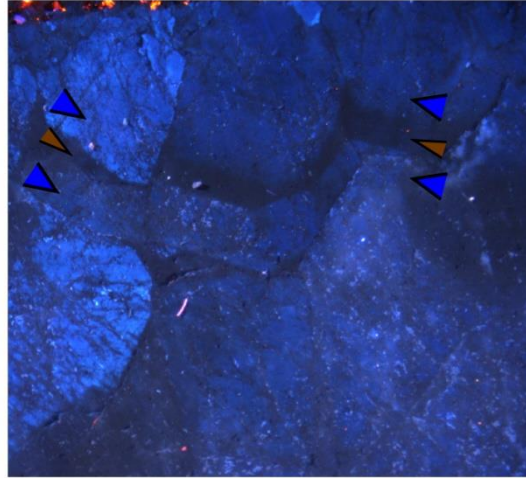
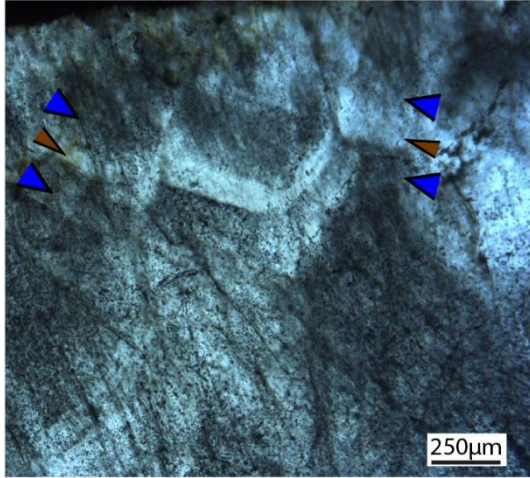


Get more information on these results:

Raimbourg, H., Rajic, K., Famin, V., Moris-Muttoni, B., Palazzin, G., Fisher, D. M., Morell, K., Erdmann, S., Di Carlo, I., and Montmartin, C., 2021, Quartz vein geochemistry records deformation processes in convergent zones: G-cubed, v. 22, no. 4, p. 1-35.

# Application to other case studies

Helminthoides Flysch, low-grade metasediments, Alps

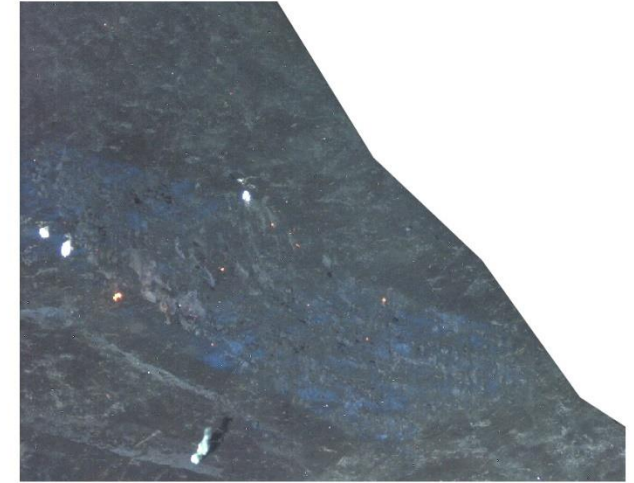
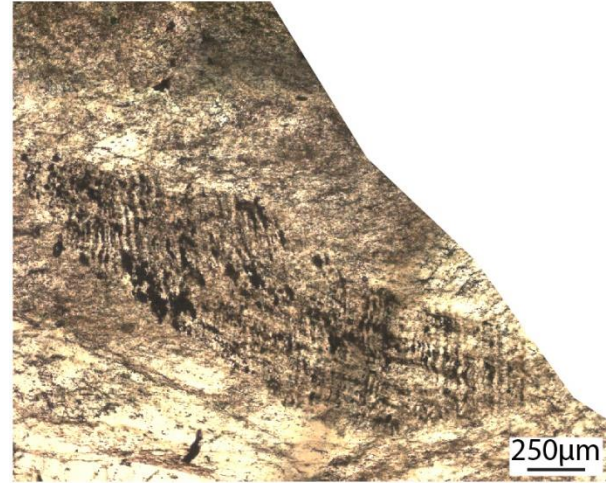


Montagne noire External Flank, variscan belt, France

$T < 300^{\circ}\text{C}$  |  $T > 300^{\circ}\text{C}$

Brittle-Plastic Transition

Montagne noire External Flank, variscan belt, France



Other examples of quartz show similar geochemical features across metamorphic grades