Fluage permanent et épisodique

des failles actives

par dissolution cristallisation sous contrainte

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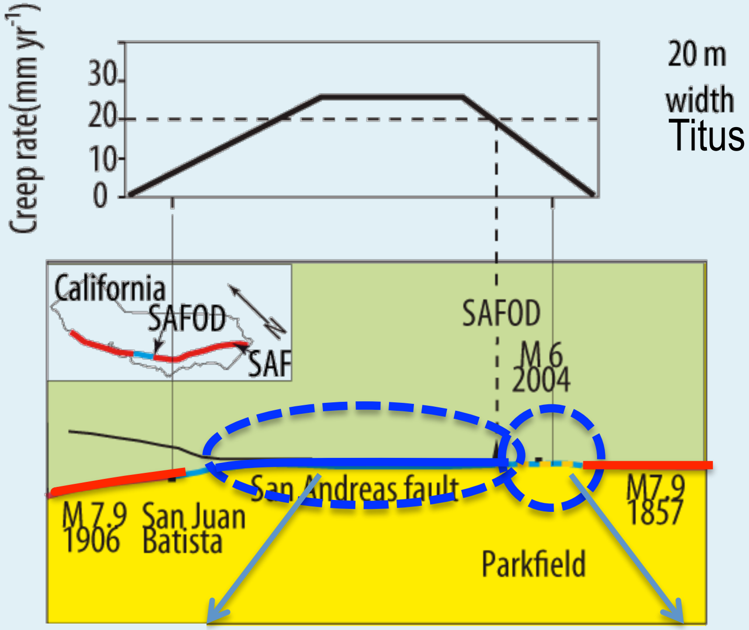
L. Jenatton, S. Mittempergher, F. Renard, J. Richard, F. Thouvenot, A. Tourette

Fluage permanent et fluage transitoire post-sismique

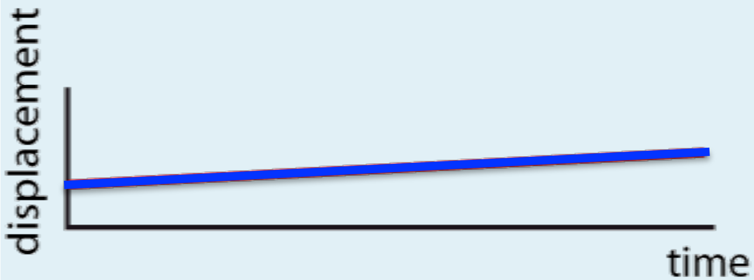
San Andreas fault (California)



Titus et al. 2006

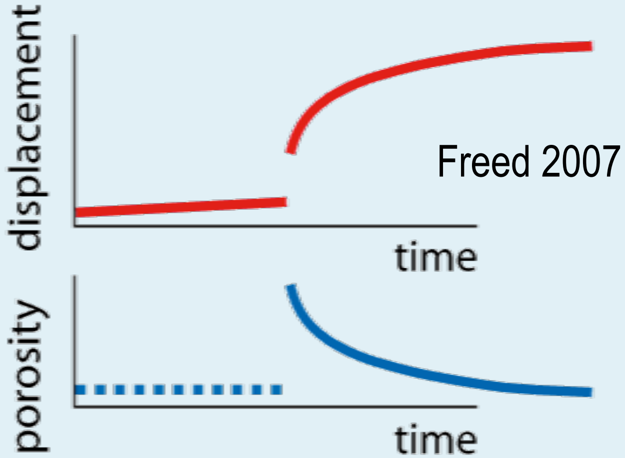
Steady creep with constant displacement rate

and microseismicity



Titus et al. 2006

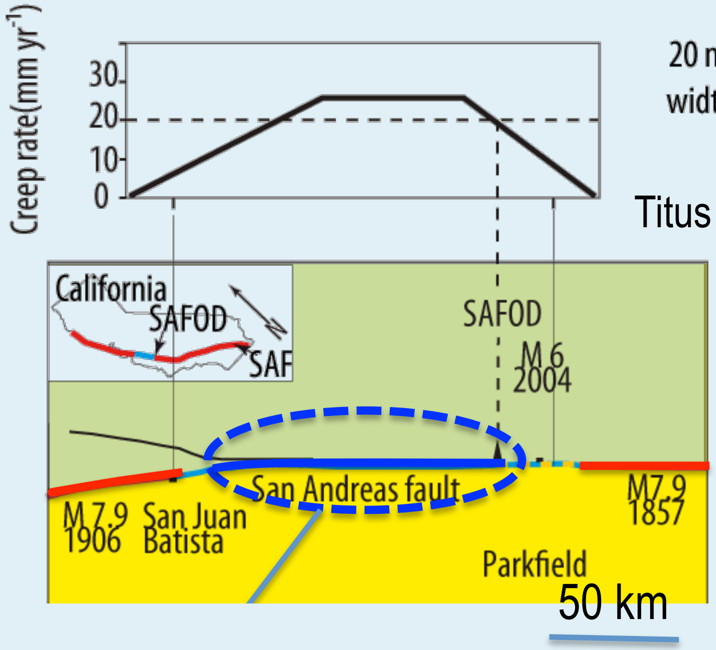
earthquake with post seisimic creep and healing



Brenguier et al. 2008

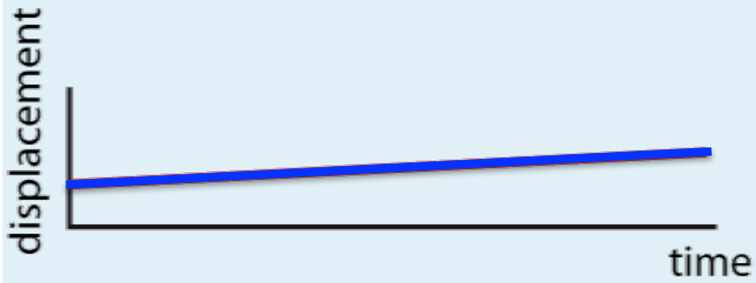
Fluage permanent des failles actives

San Andreas fault (California)



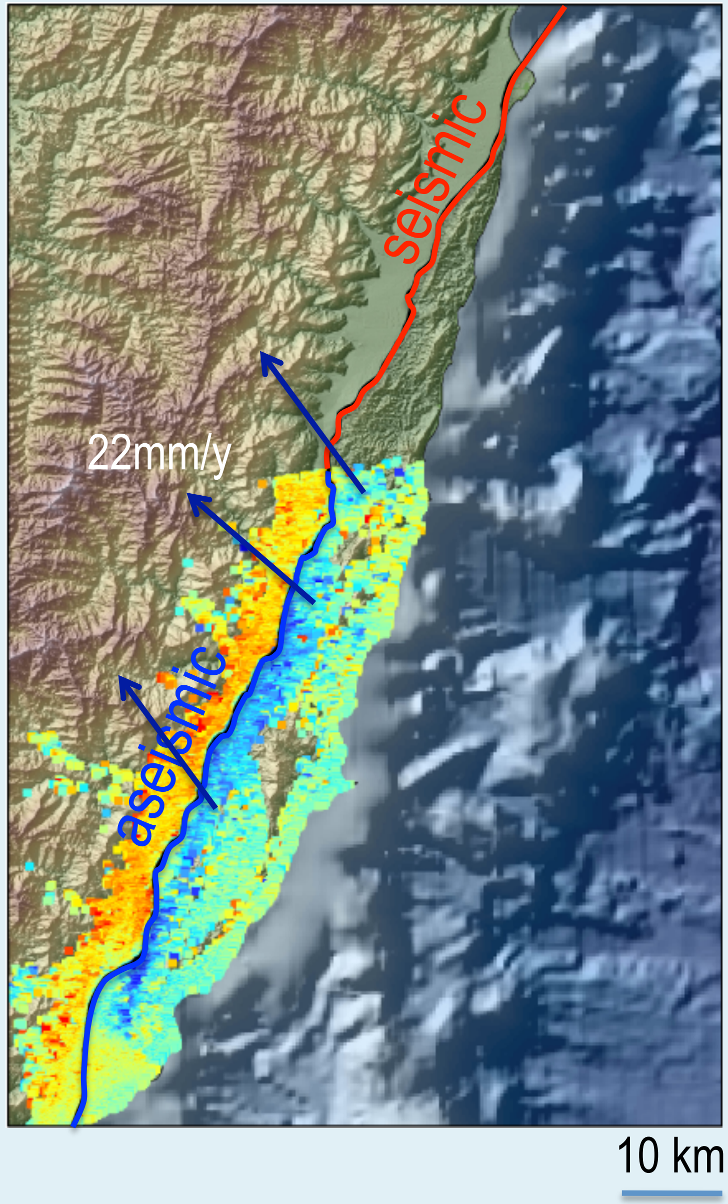
Steady creep with constant displacement rate

and microseismicity



Titus et al. 2006

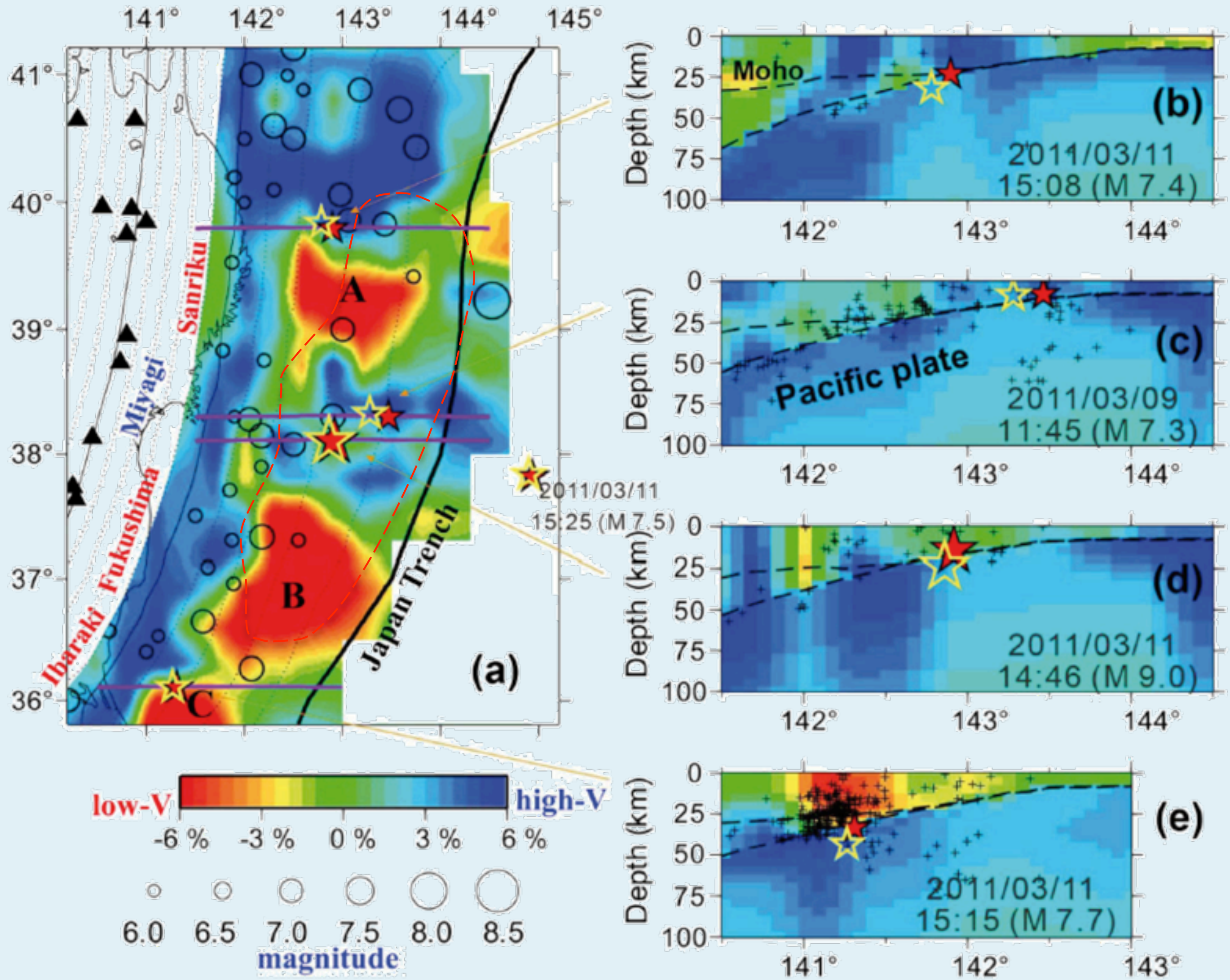
Long Valley fault (Taiwan)



Champenois et al 2012

Fluage permanent des failles actives

P-wave tomographic image in the megathrust zone of the M9 2011 Tohoku-oki earthquake (Japan)



Zhao etal 2011

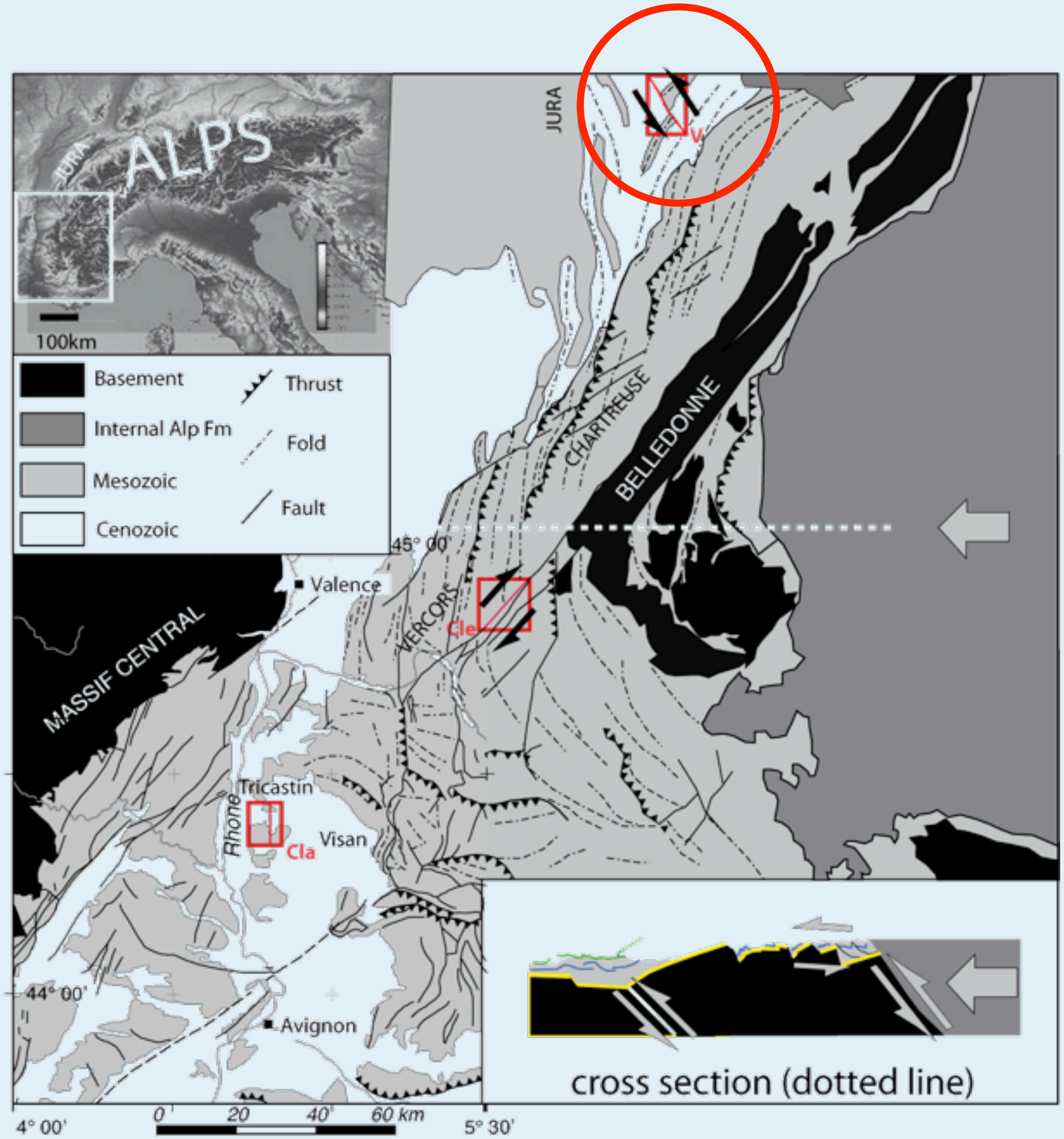
Questions et méthodes

Pourquoi est ce que certaines failles (ou portions de faille) fluent <u>en permanence</u> alors que d'autres failles (ou portions de faille) cassent en générant des séismes?

Est ce que des différences géologiques pourraient expliquer cette différence de comportement?

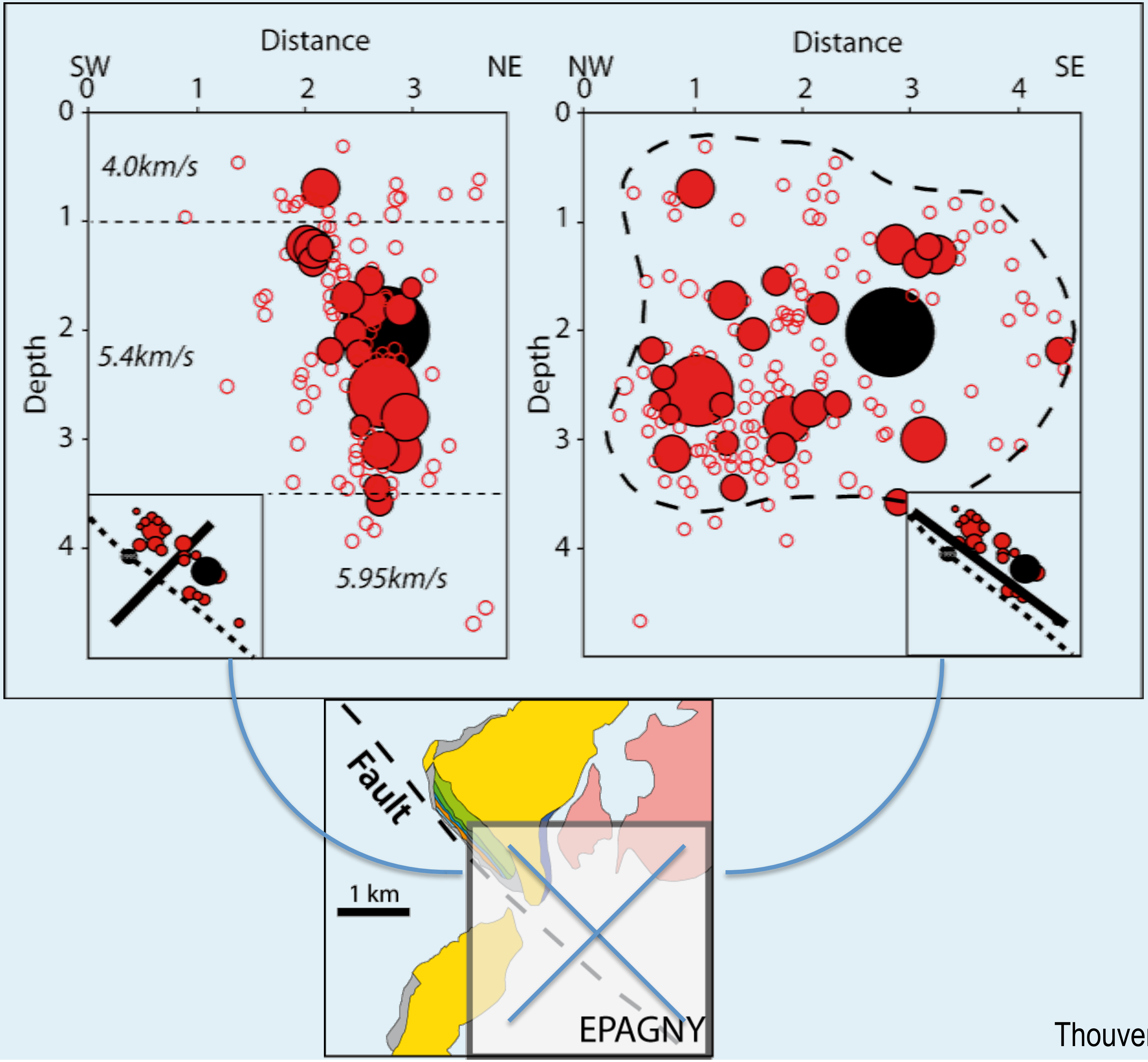
Nécessité d'une approche d'observation:
comparer la géologie
des zones avec ruptures sismiques
avec celles des zones de fluage permanent

Structural geology of the Western Alps



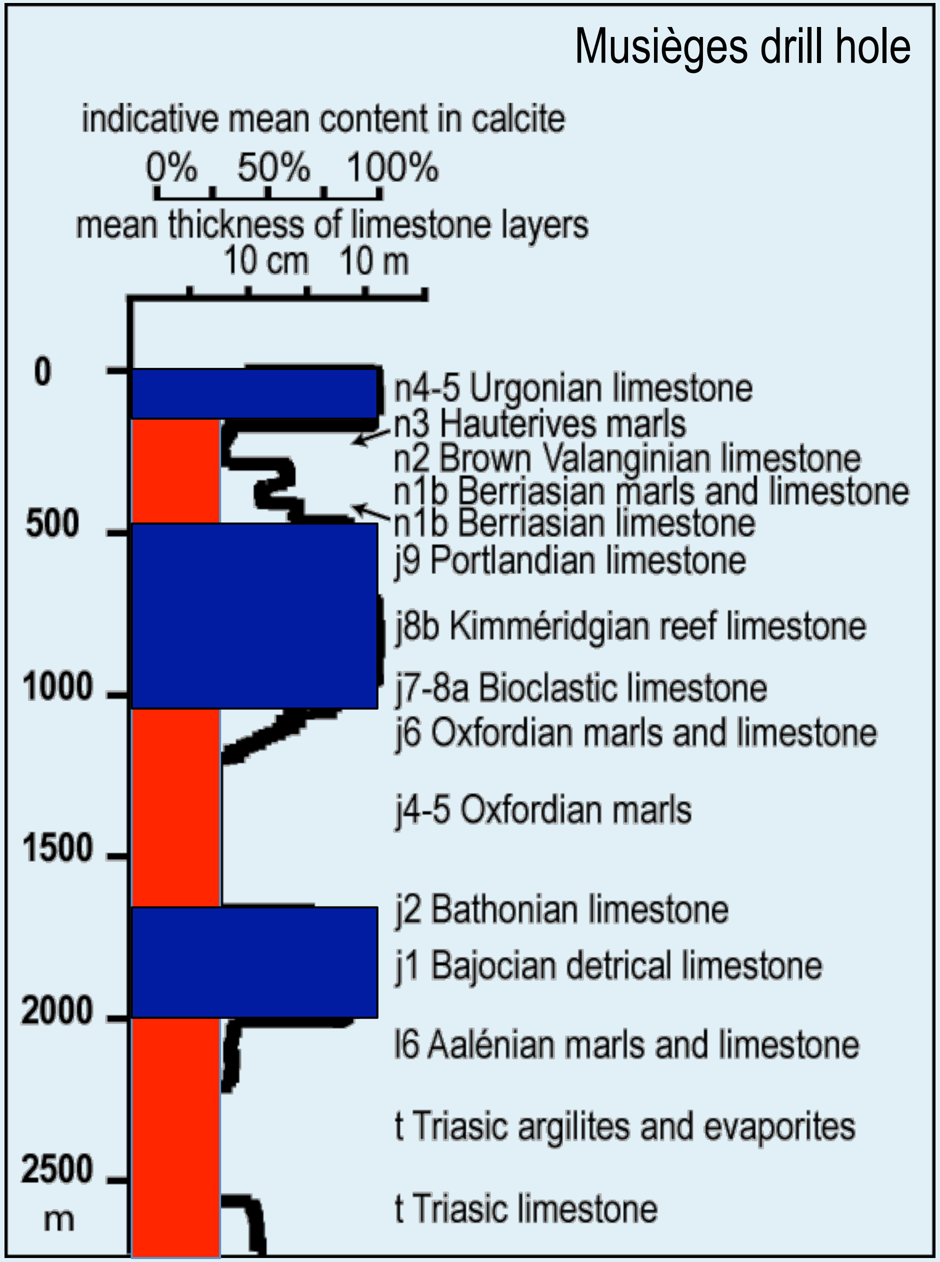
Gratier et al. 2013

Cross section: M5.3 Epagny earthquake and aftershocks



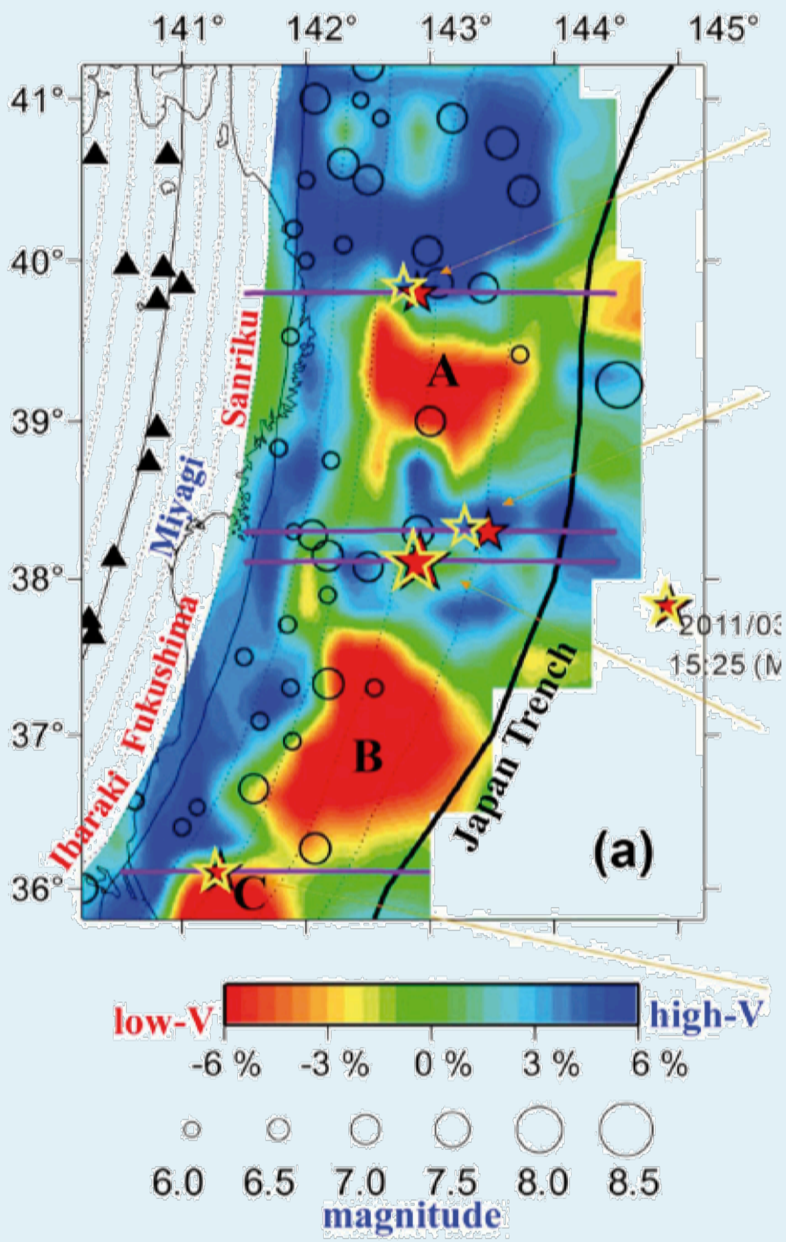
Thouvenot et al 2007

Lithology of the Epagny area



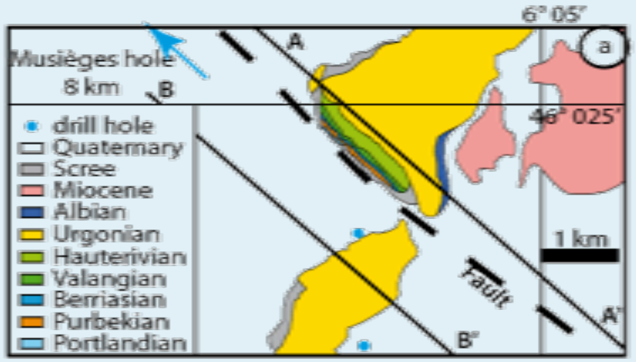
Gratier et al. 2013

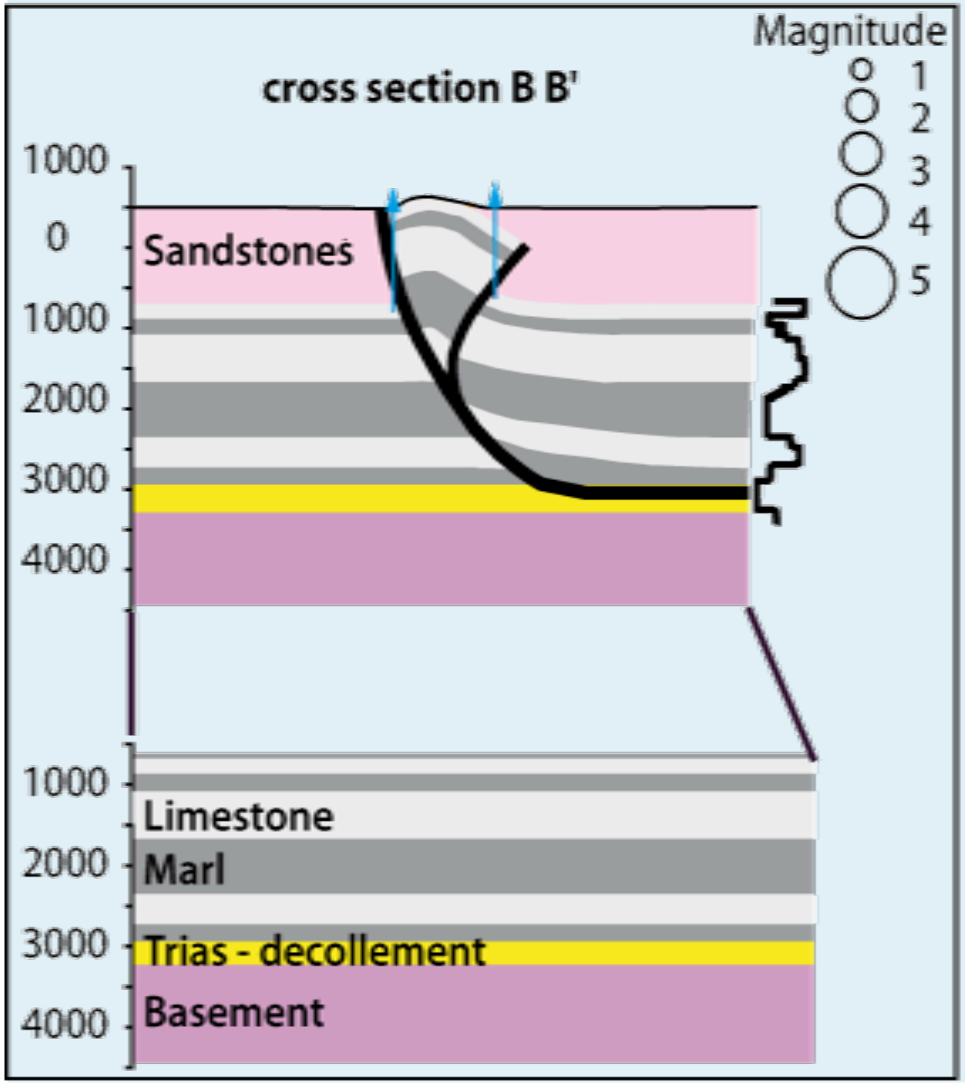
Tohoku-oki earthquake (Japan)

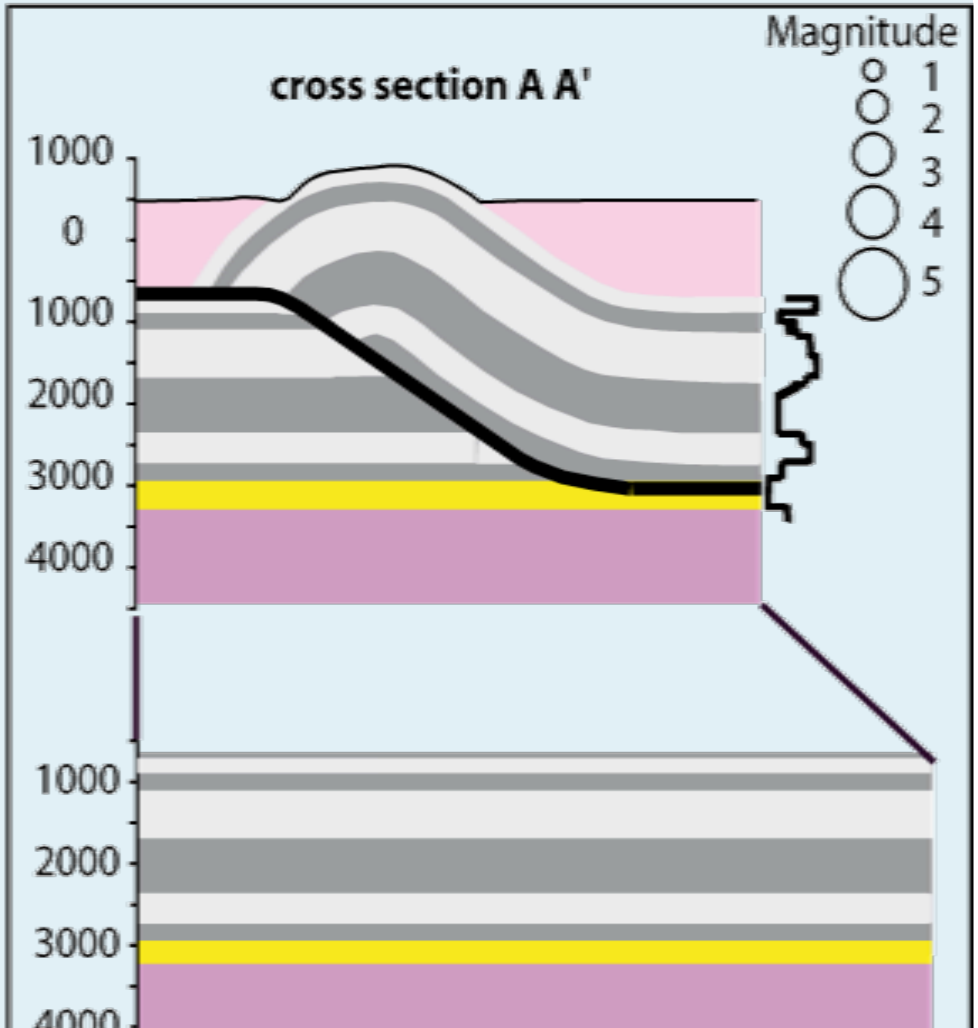


Zhao etal 2011

Geological cross sections in the Epagny area

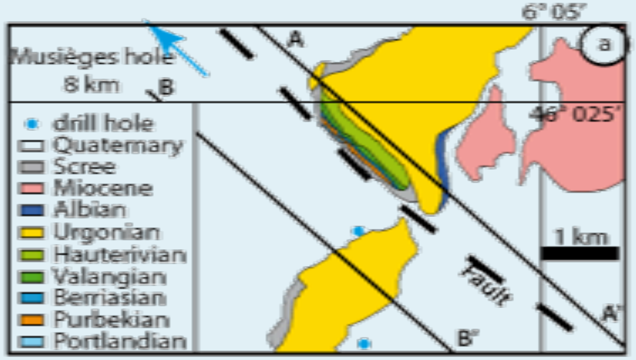


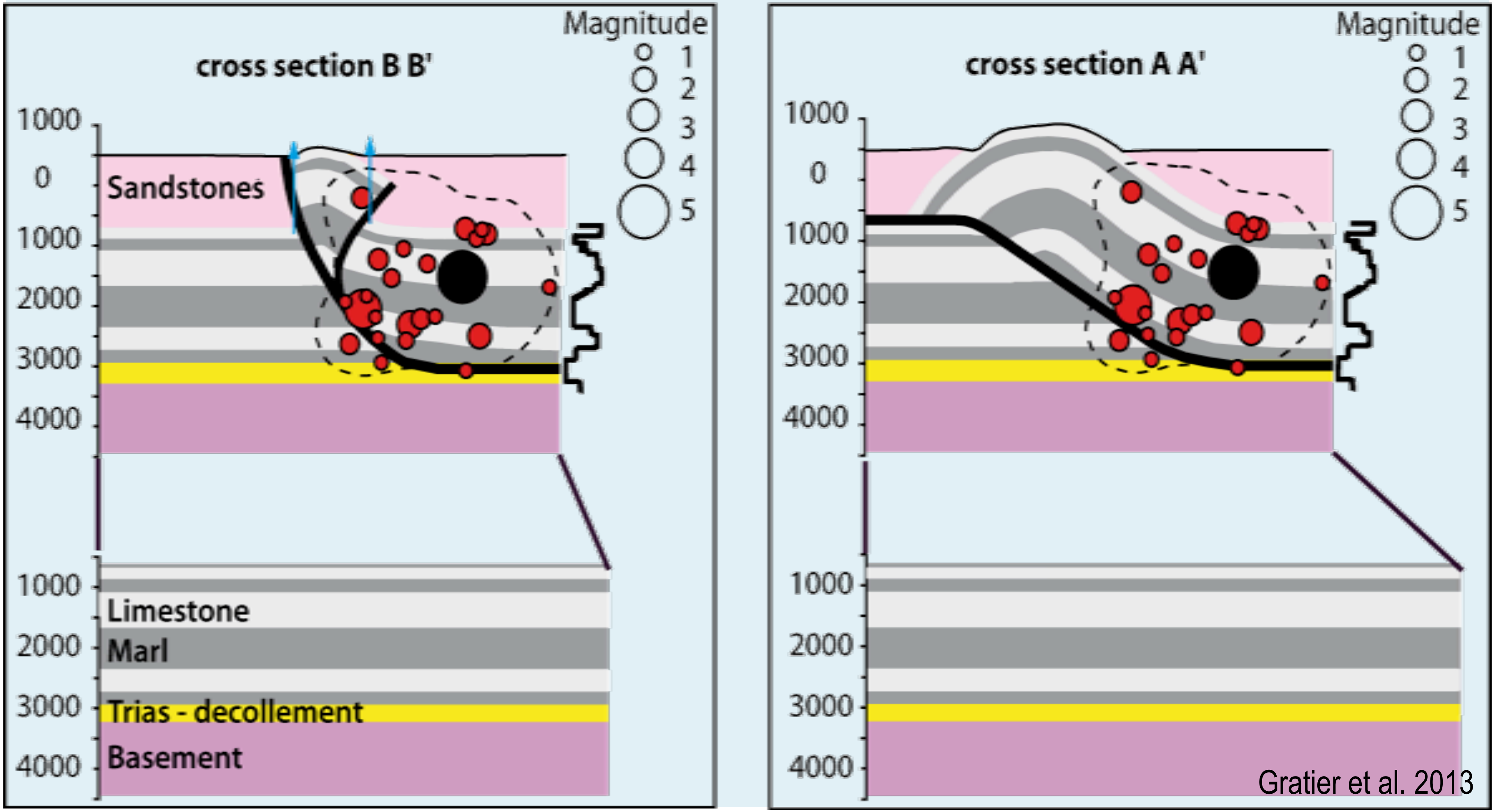




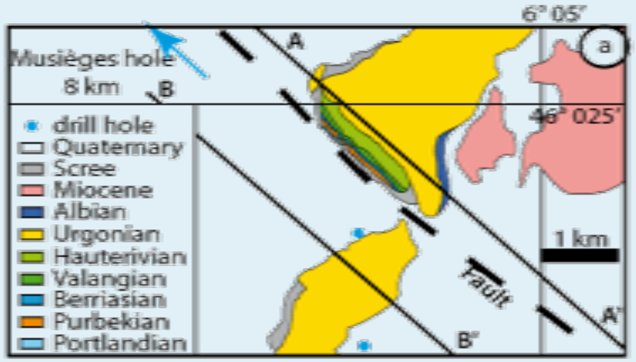
Gratier et al. 2013

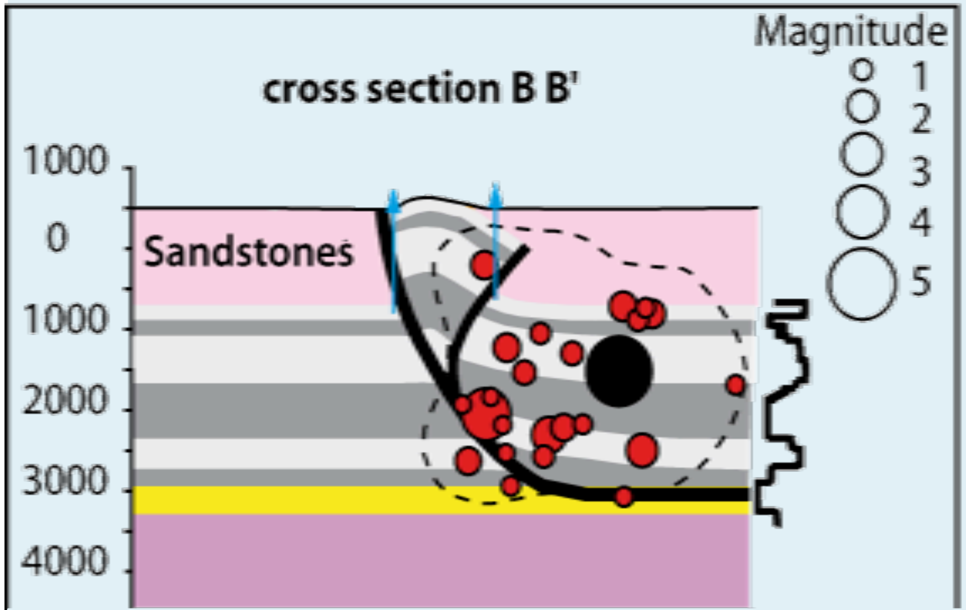
Geological cross sections in the Epagny area and location of the aftershocks ● and the main event ●

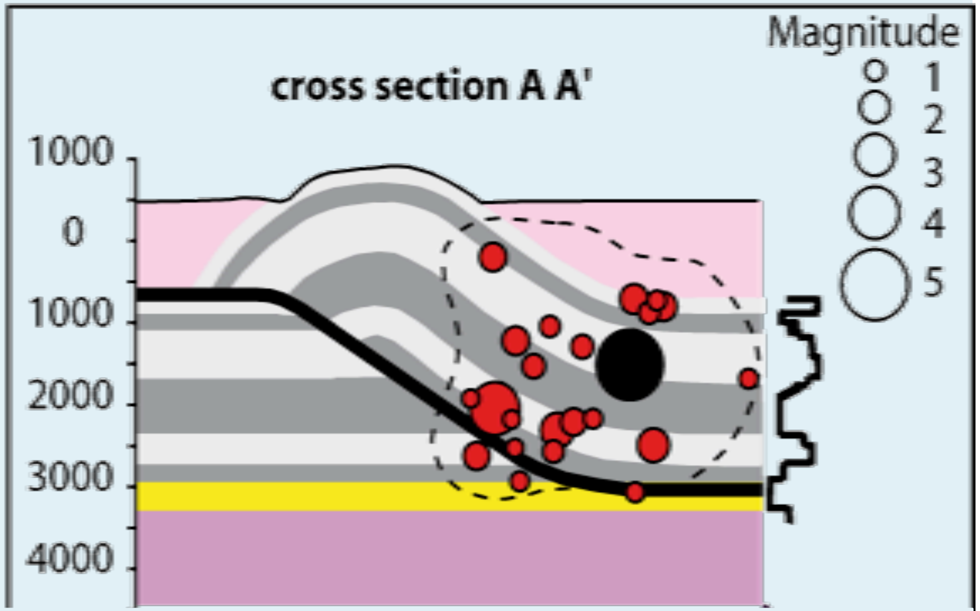




Geological cross sections in the Epagny area and location of the aftershocks and the main event







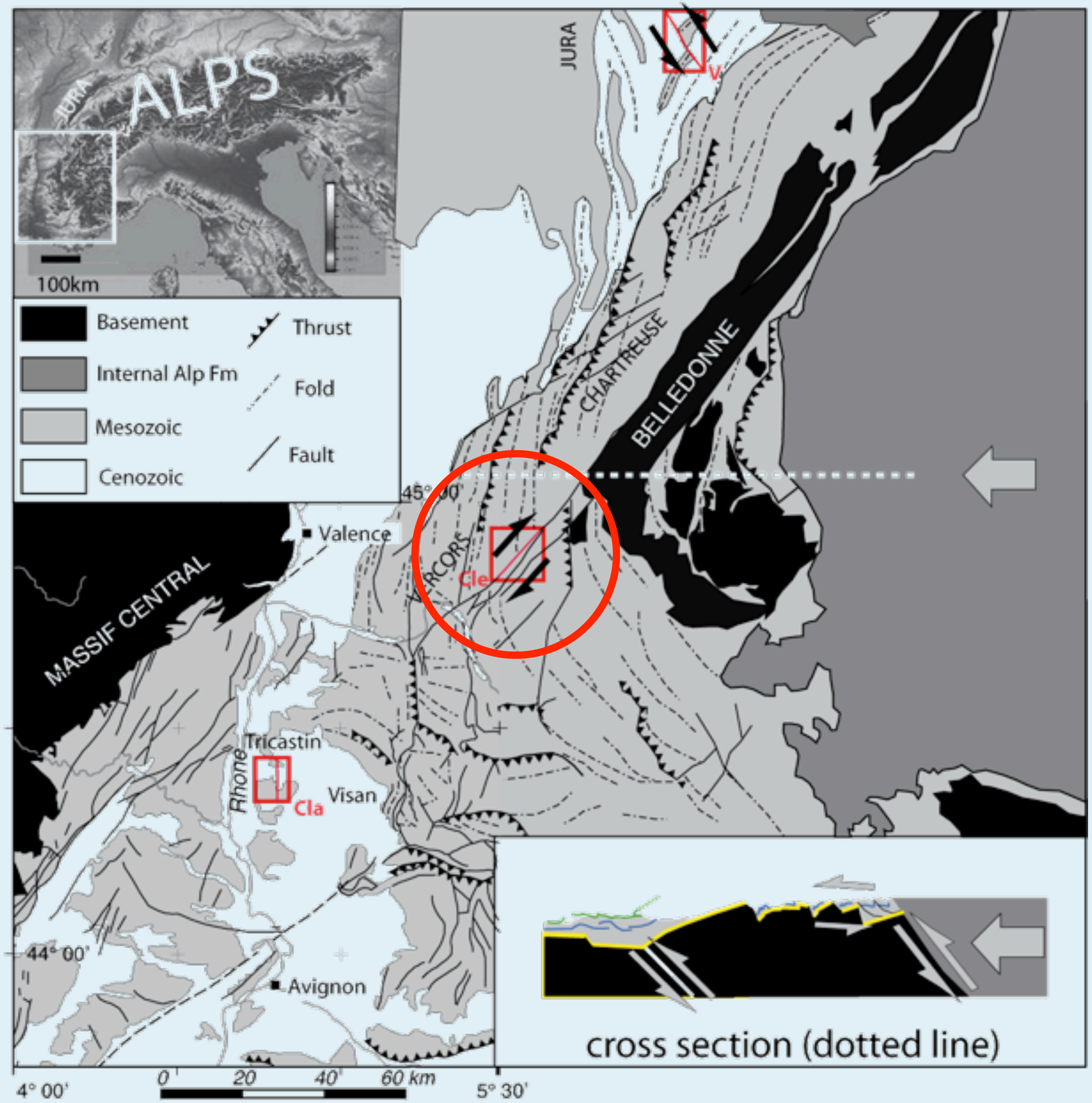
Le séisme principal et toutes les répliques s'initient dans les roches les plus dures (calcaires massifs)

Est ce que les marnes fluent? et par quel mécanisme?

Nécessité d'analyser les mécanismes de fluage sur des roches à l'affleurement

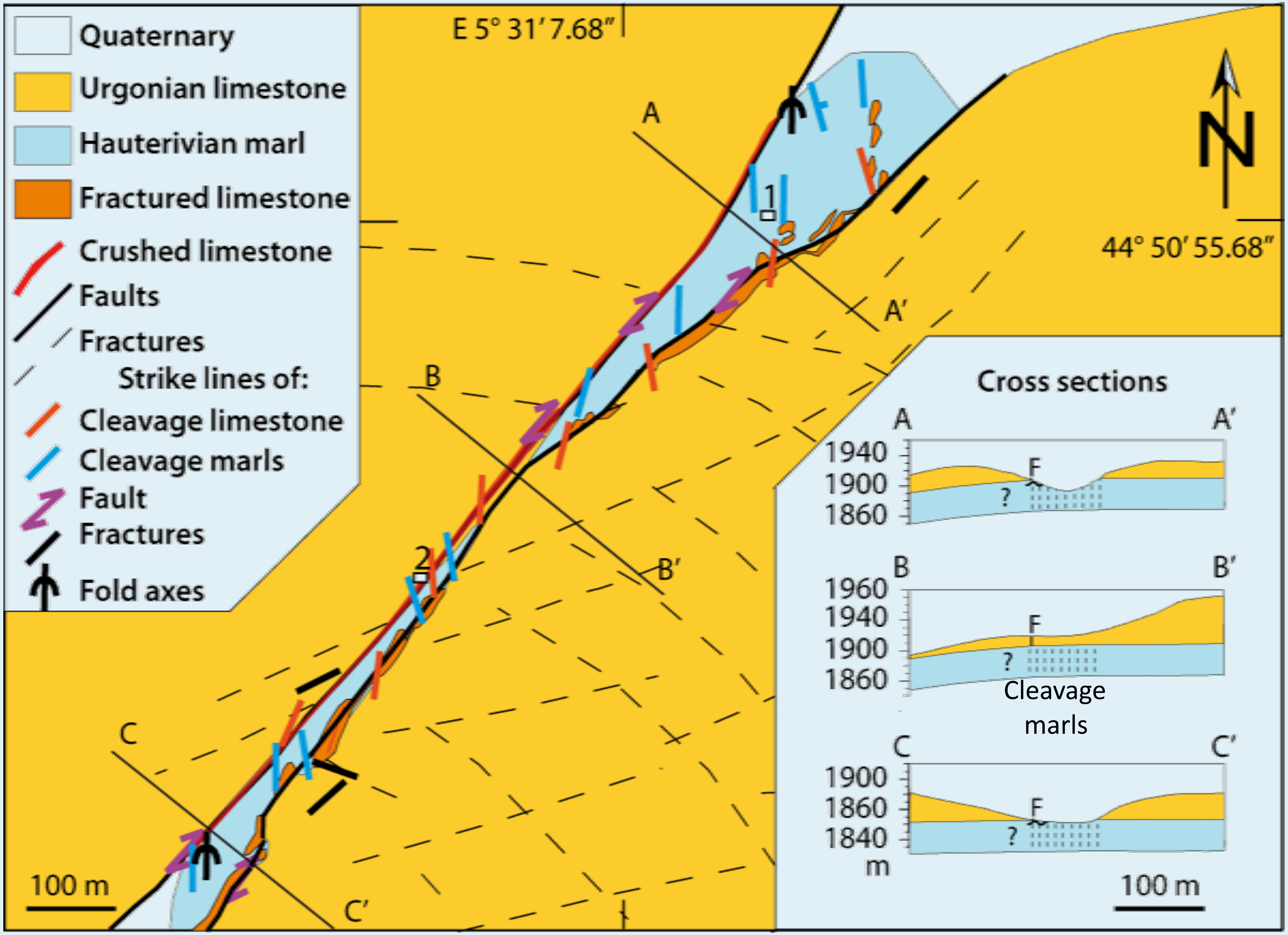
Gratier et al. 2013

Structural geology of the Western Alps



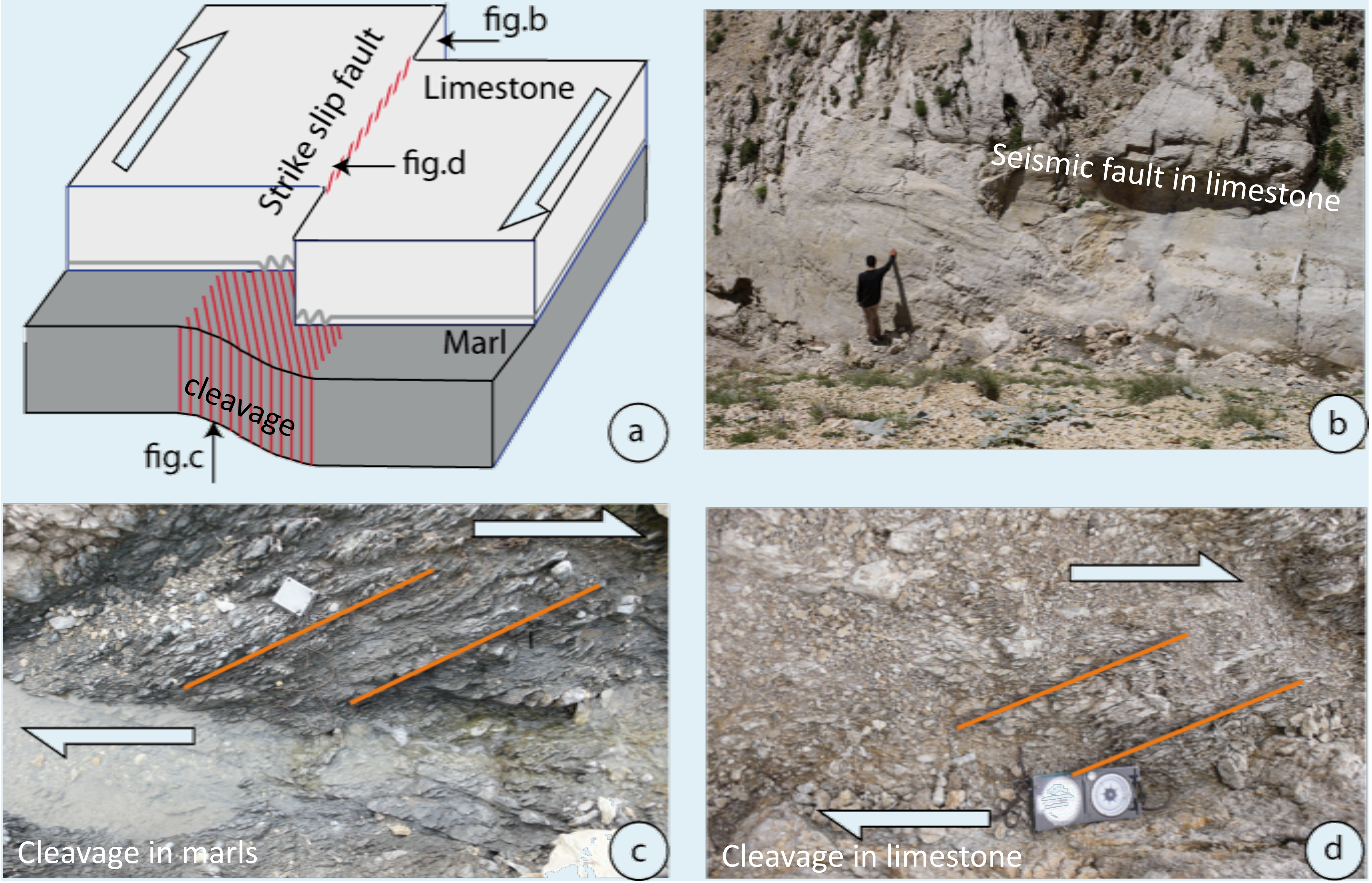
Gratier et al. 2013

Geological map and cross section of the Clery fault (Vercors)

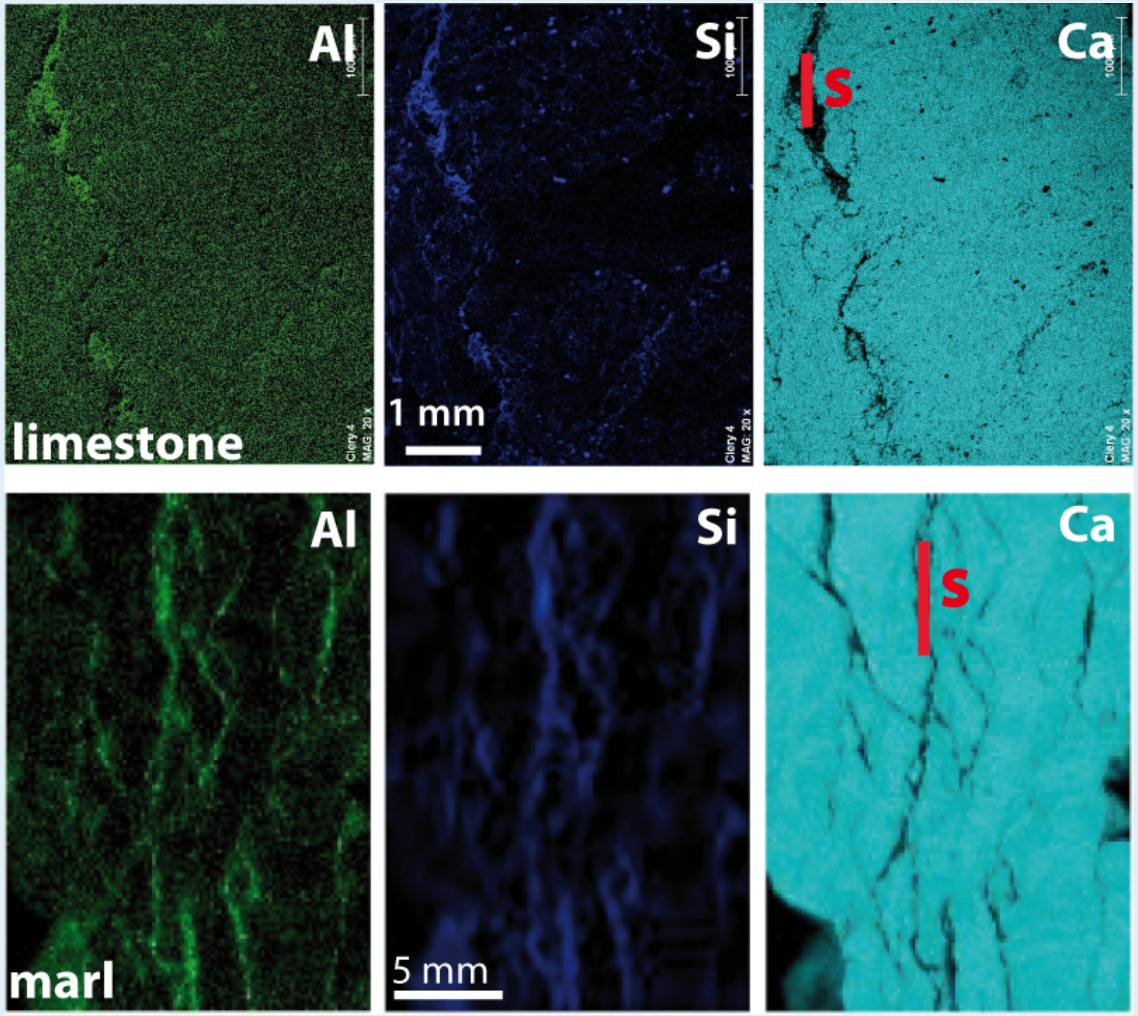


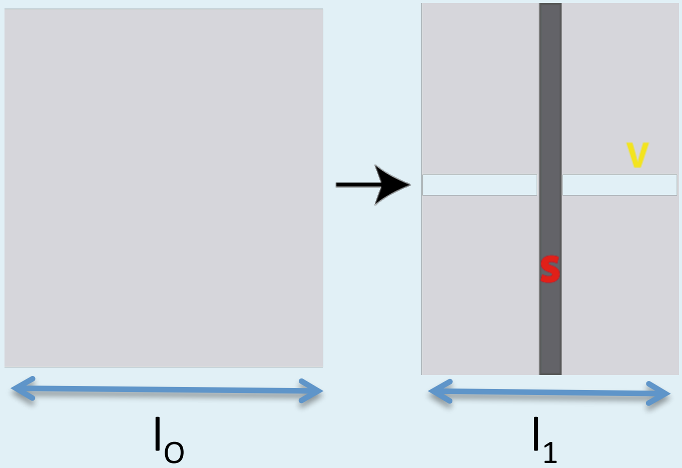
Gratier et al. 2013

Deformation structures near the Clery fault (Vercors)



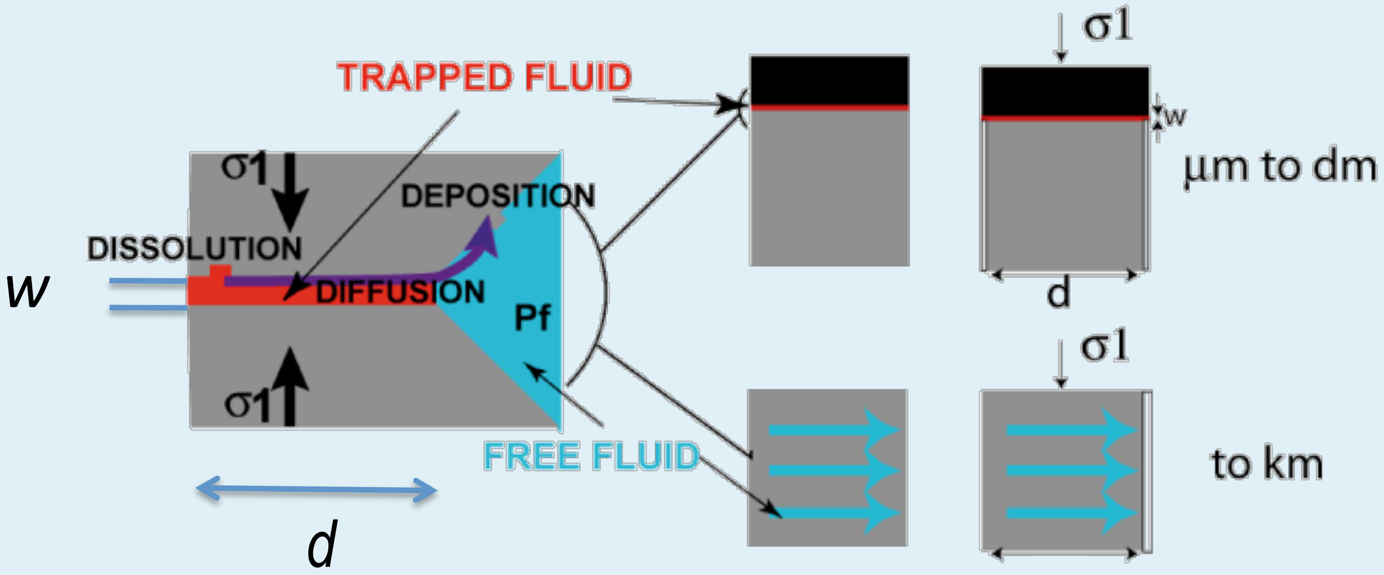
Deformation structures near the Clery fault (Vercors)
Pressure solution cleavage:
dissolution of soluble species (calcite), passive concentration of insoluble species (phyllosilicate)





Gratier et al. 2013

Basics concepts for pressure solution creep



Quantitative analysis of natural structures + Thermodynamics & Kinetics + Experiments > Creep laws

Strain rate $$\dot{\varepsilon} \approx Dw \ \mathrm{c} \ \Delta\sigma^{n} / d^{3}$$

Dw = Diffusion coefficient x thickness of the fluid phase trapped under stress

$\Delta\sigma$ = Normal stress difference = $\sigma_n - P_f$, $1 < n < 1.7$

d = Distance of mass transfer by diffusion

c = Solubility of solid in solution

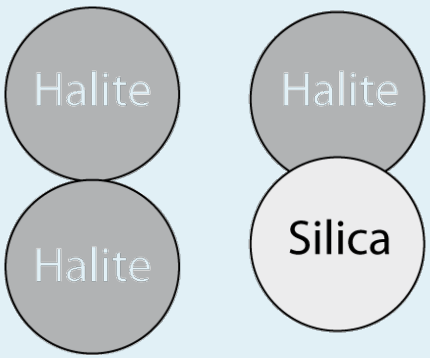
depends on PT conditions: - low temperature (20°C) the more soluble: Calcite > Feldspar > Quartz

- high temperature (350°C) the more soluble: Quartz - Feldspar > Calcite

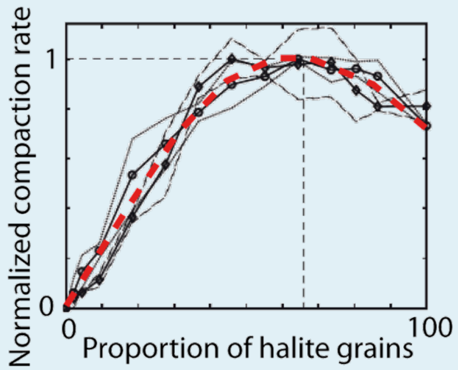
What is the difference between limestone and marl for pressure solution

- Solubility : same mobile mineral (calcite) NO DIFFERENCE
- Stress: ALMOST NO DIFFERENCE may be higher in limestone?
- Distance of diffusive mass transfer = grain size almost the same: ALMOST NO DIFFERENCE

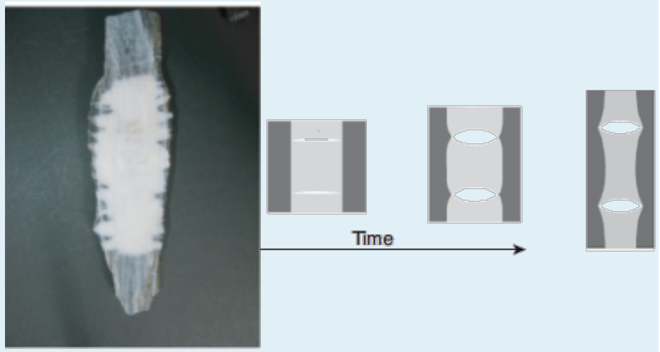
- Diffusion coefficient x thickness: here THERE IS A DIFFERENCE: pressure solution kinetics is much higher at contact between different minerals than at contact between same mineral



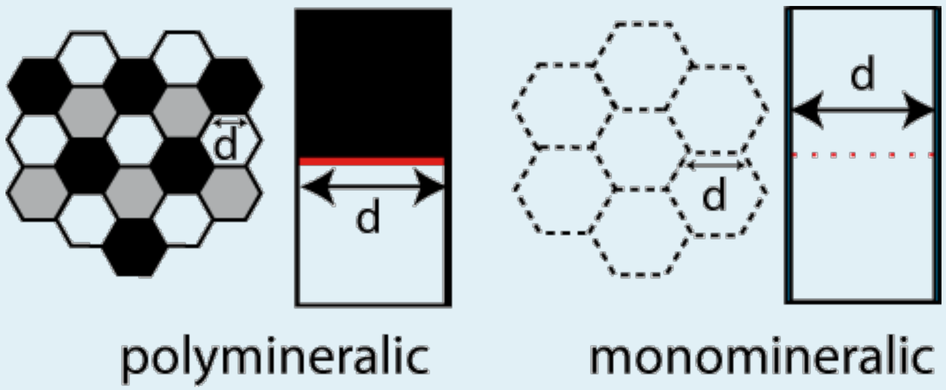
Hickman & Evans 1991



Zubtsov et al 2004



Gratier 2011

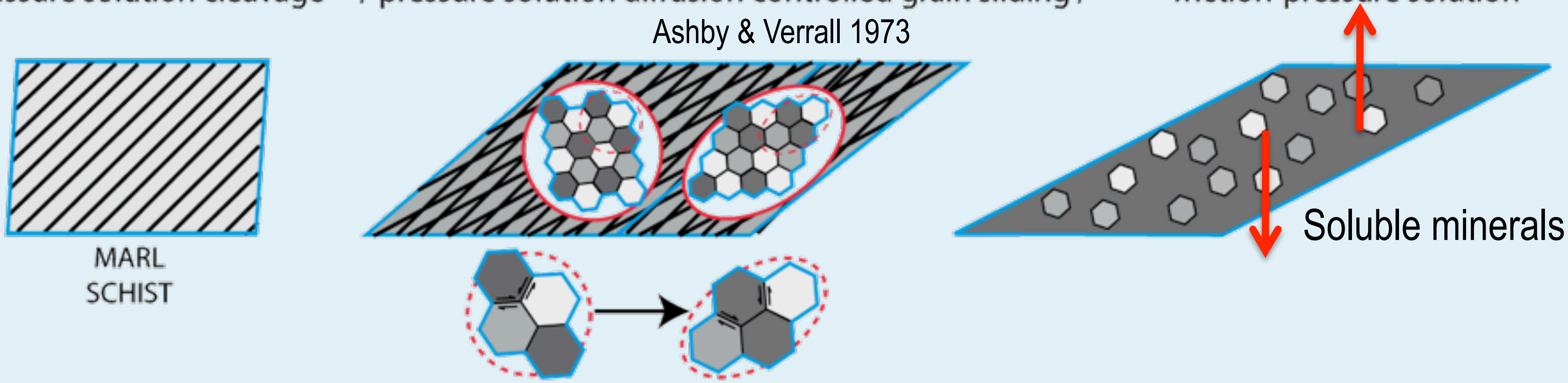


Gratier et al. 2013

Evolution of pressure solution creep structures in shear zones

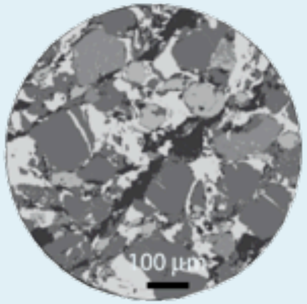
Pressure solution cleavage / pressure solution diffusion controlled grain sliding / friction-pressure solution

Ashby & Verrall 1973

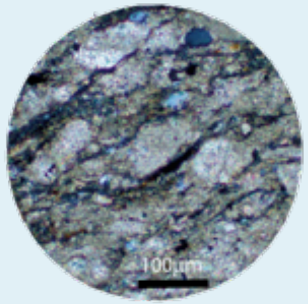


$\gamma<1$, $l_1/l_0>0.4$

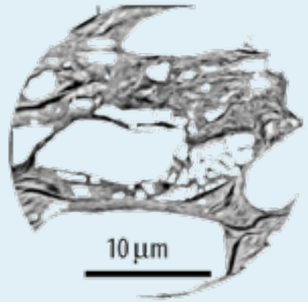
$\gamma>10$, $l_1/l_0<0.1$



Boundary of the SAF active creeping zone



Vercors creeping zone



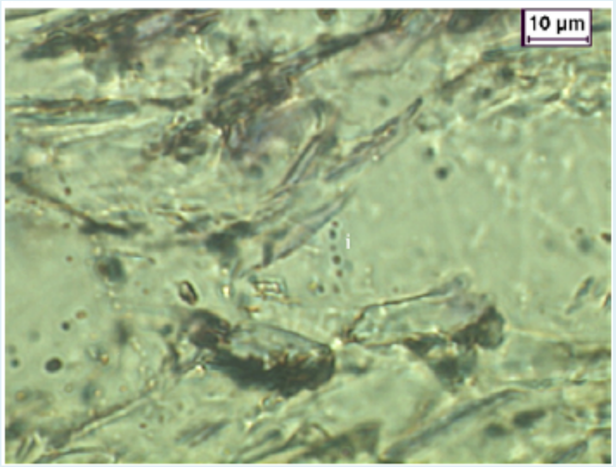
Middle of the SAF active creeping zone

Gratier et al. 2011, 2013

Competition between steady state pressure solution creep and friction

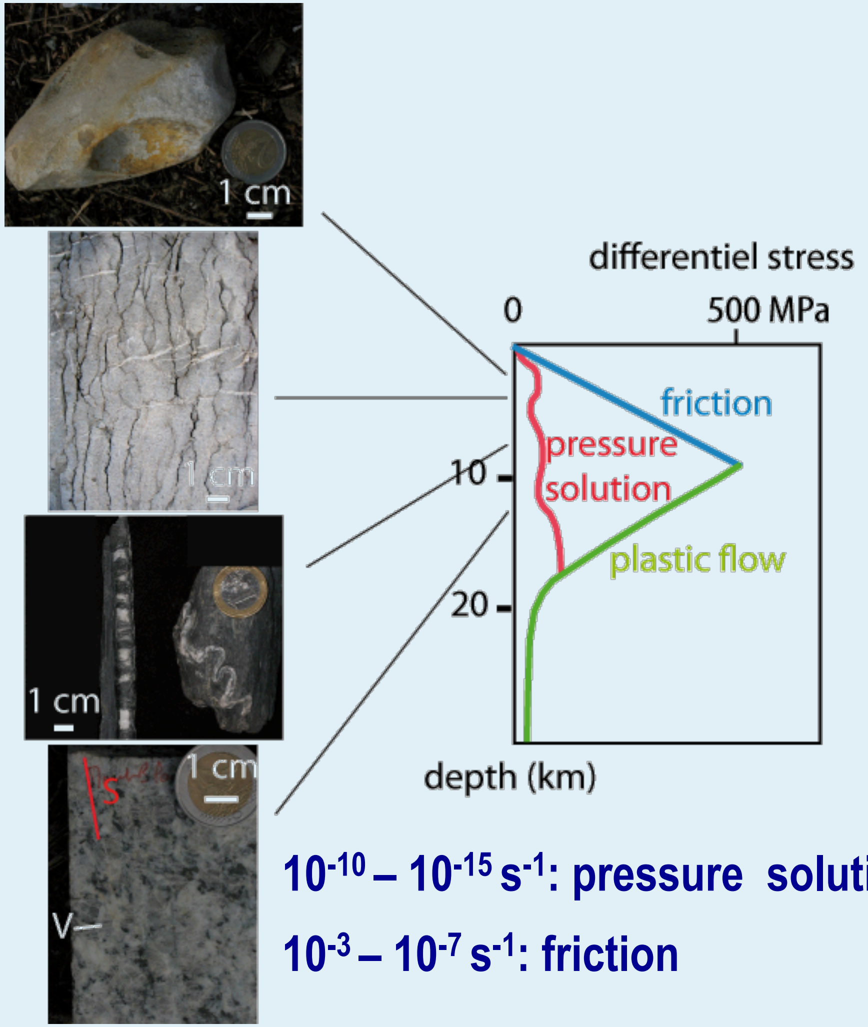
Effect of strain rate

Experimental shear deformation
rotary shear apparatus
Mixture of mica and halite



At low velocity (<1µm/s) pressure solution (viscous)
At high velocity (>1µm/s) friction

Effect of geology



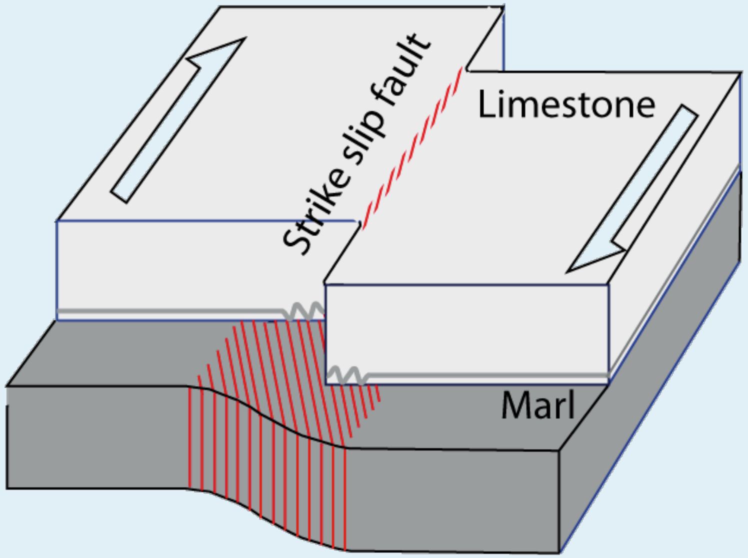
10^{-10} – 10^{-15} s^{-1}: pressure solution

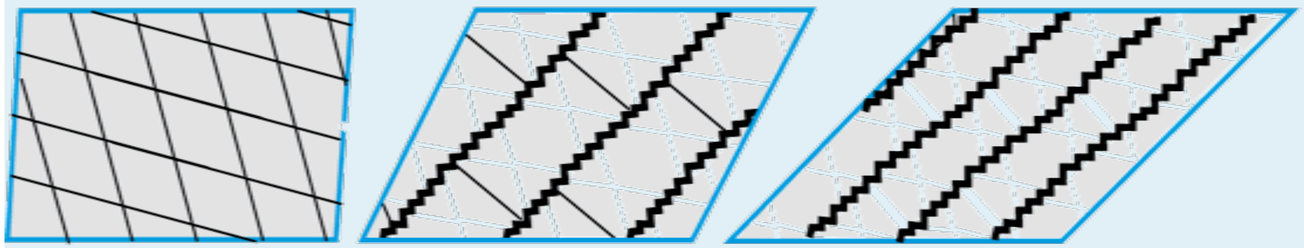
10^{-3} – 10^{-7} s^{-1}: friction

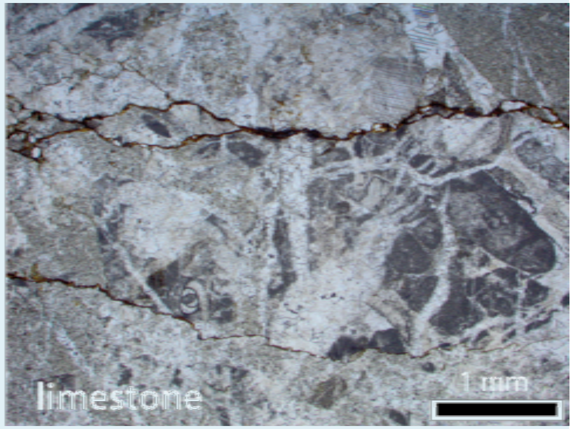
Niemeijer & Spiers 2006

Gratier et al 2013b

What is activating pressure solution creep in limestone?





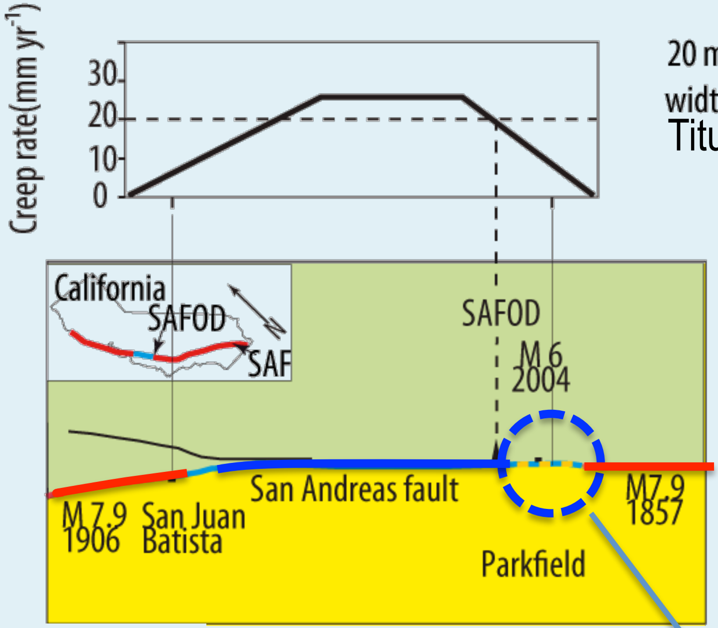


Effect of fracturing?

Gratier et al. 2013

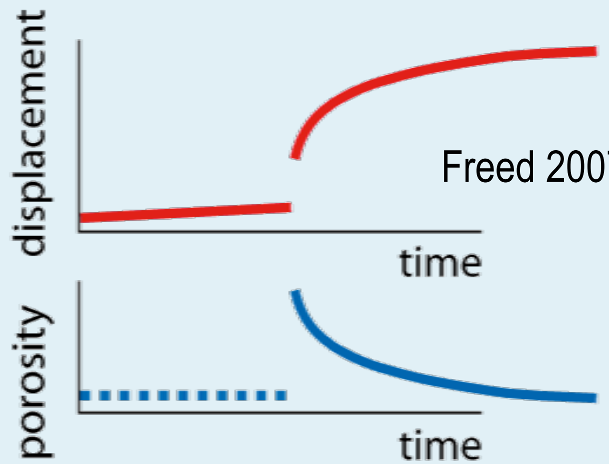
Fluage transitoire post-sismique

San Andreas fault (California)



20 m width
Titus et al. 2006

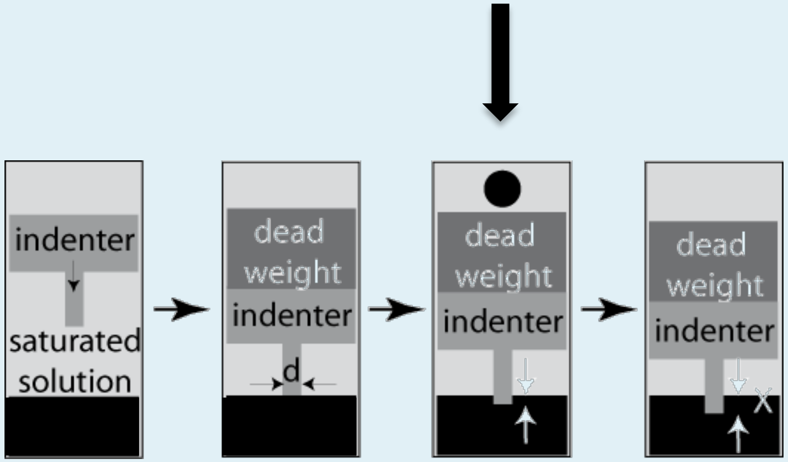
earthquake with post seisimic creep and healing



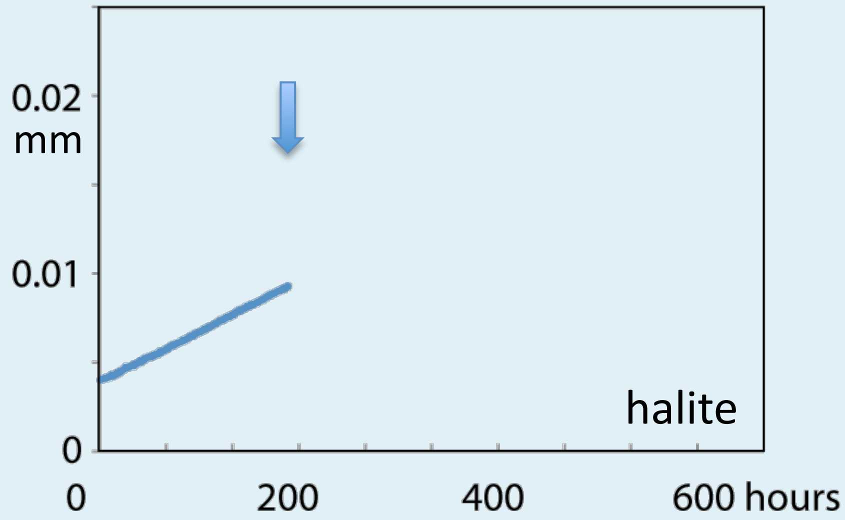
Freed 2007

Brenguier et al. 2008

Pressure solution experiment: dynamic indenting



indenter = 0.3 – 2 mm

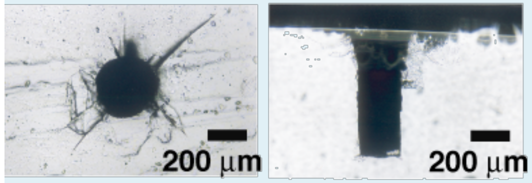


halite, plaster, calcite, 40°C

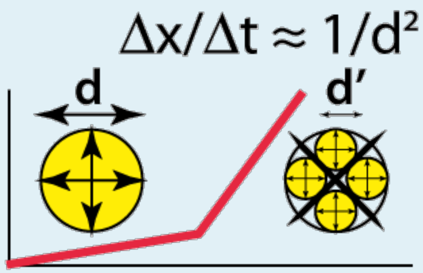
(indenting occurs only in presence of the solution)

Gratier et al 2012

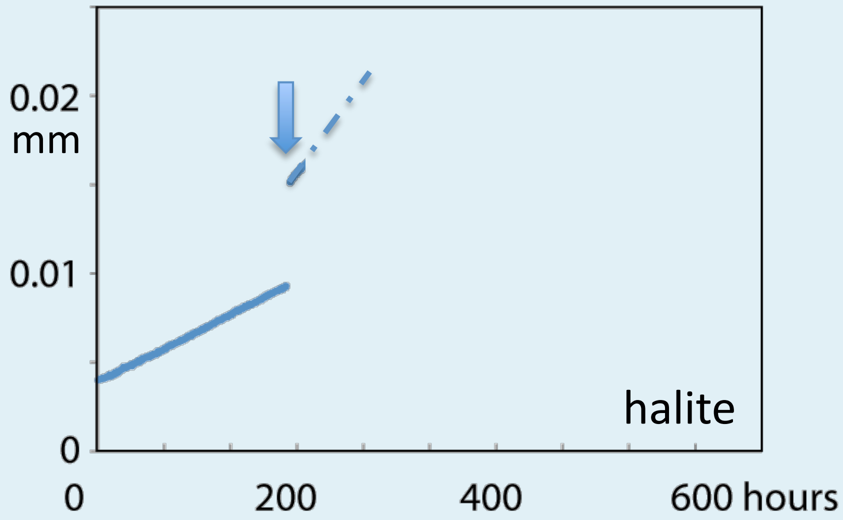
Pressure solution experiment: dynamic indenting



halite,

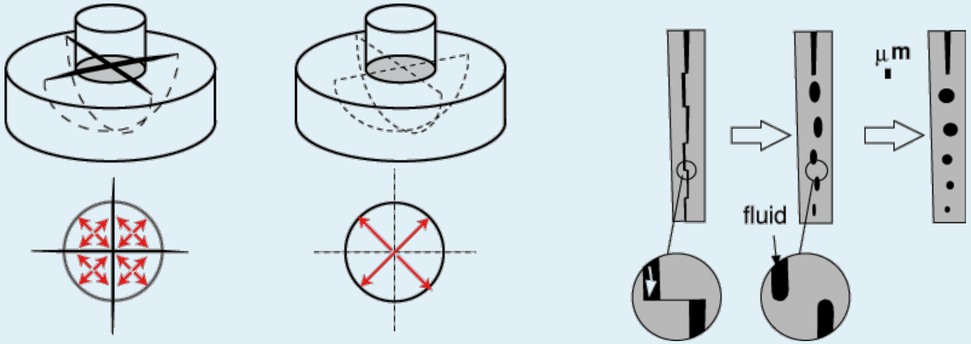


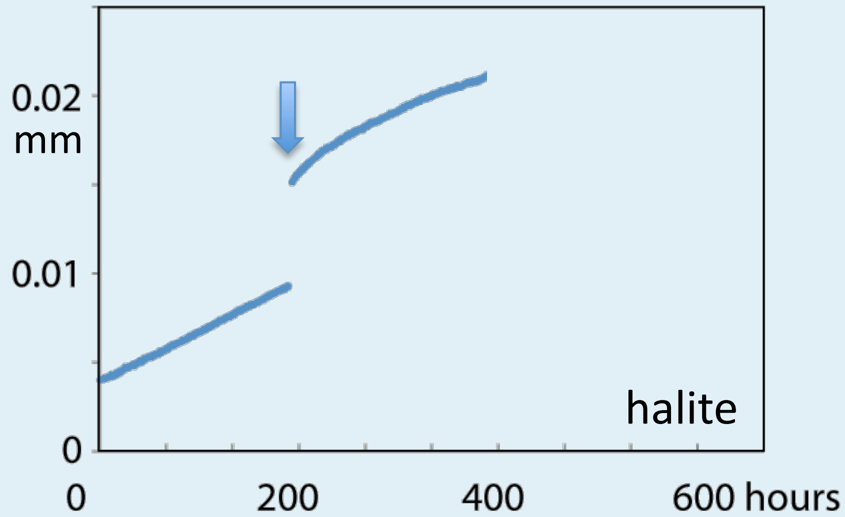
40°C

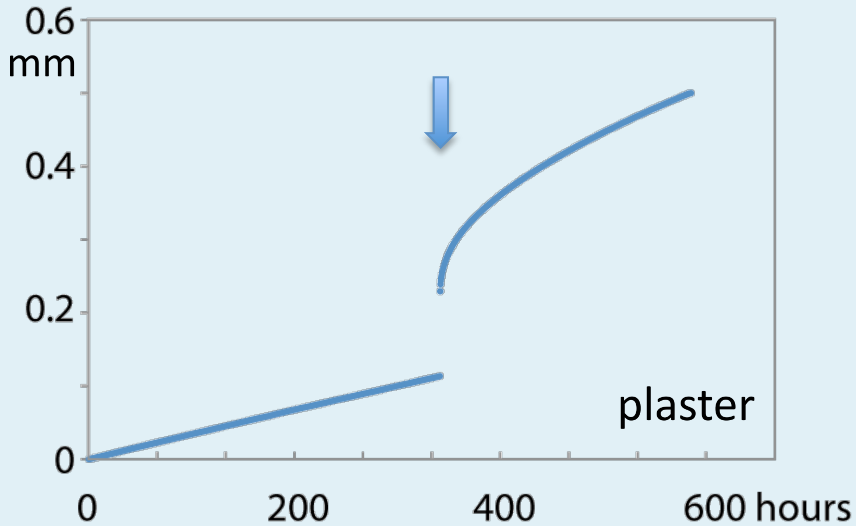


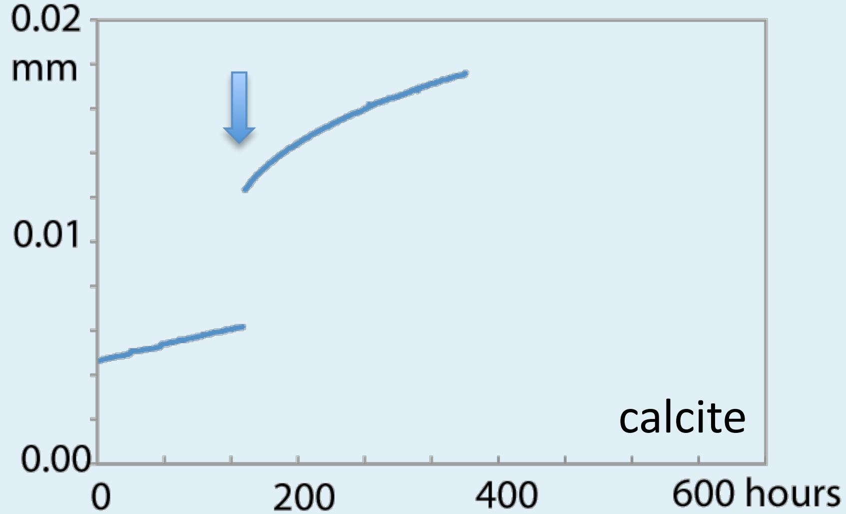
Gratier et al 2012

Pressure solution experiment: dynamic indenting



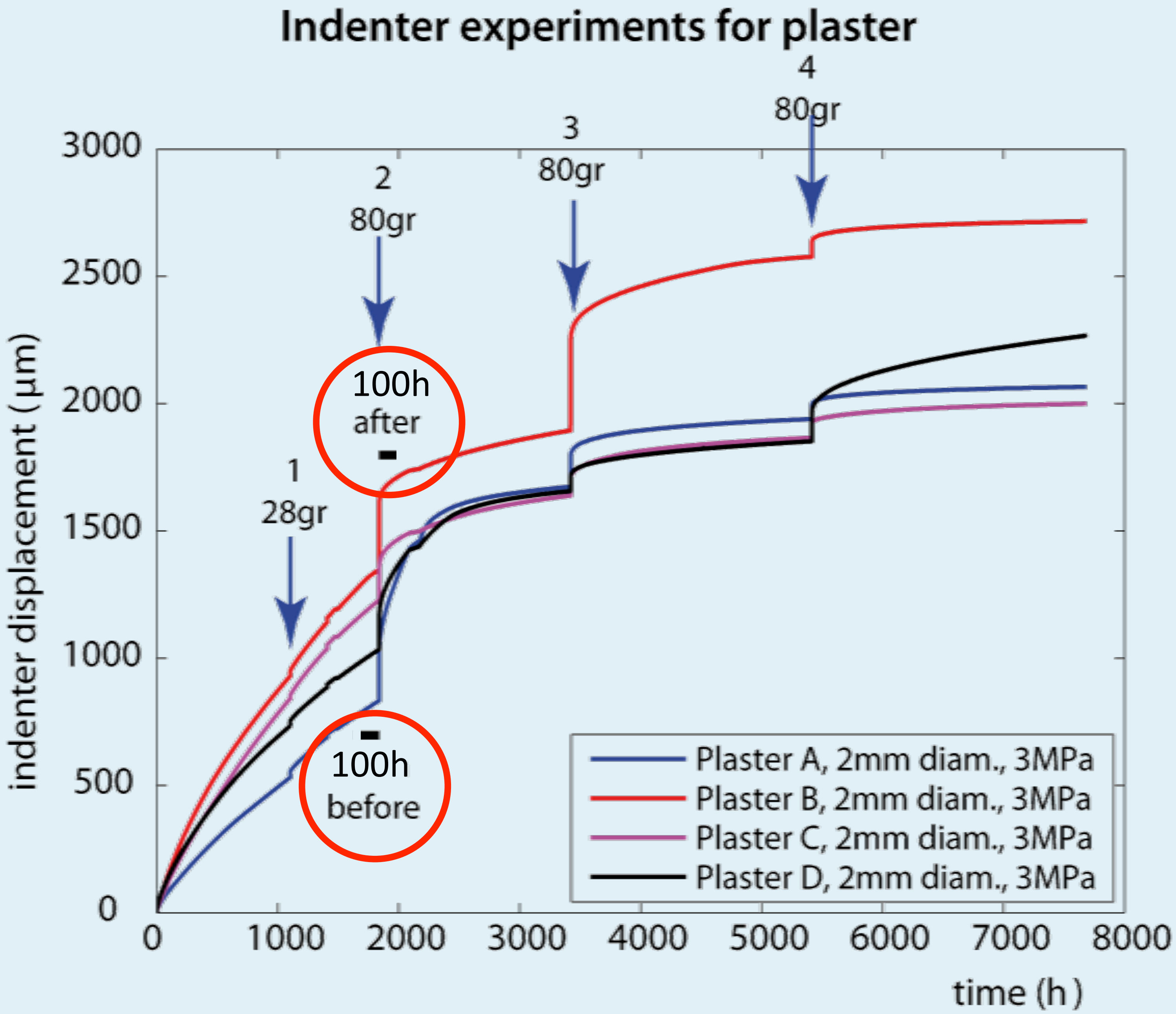






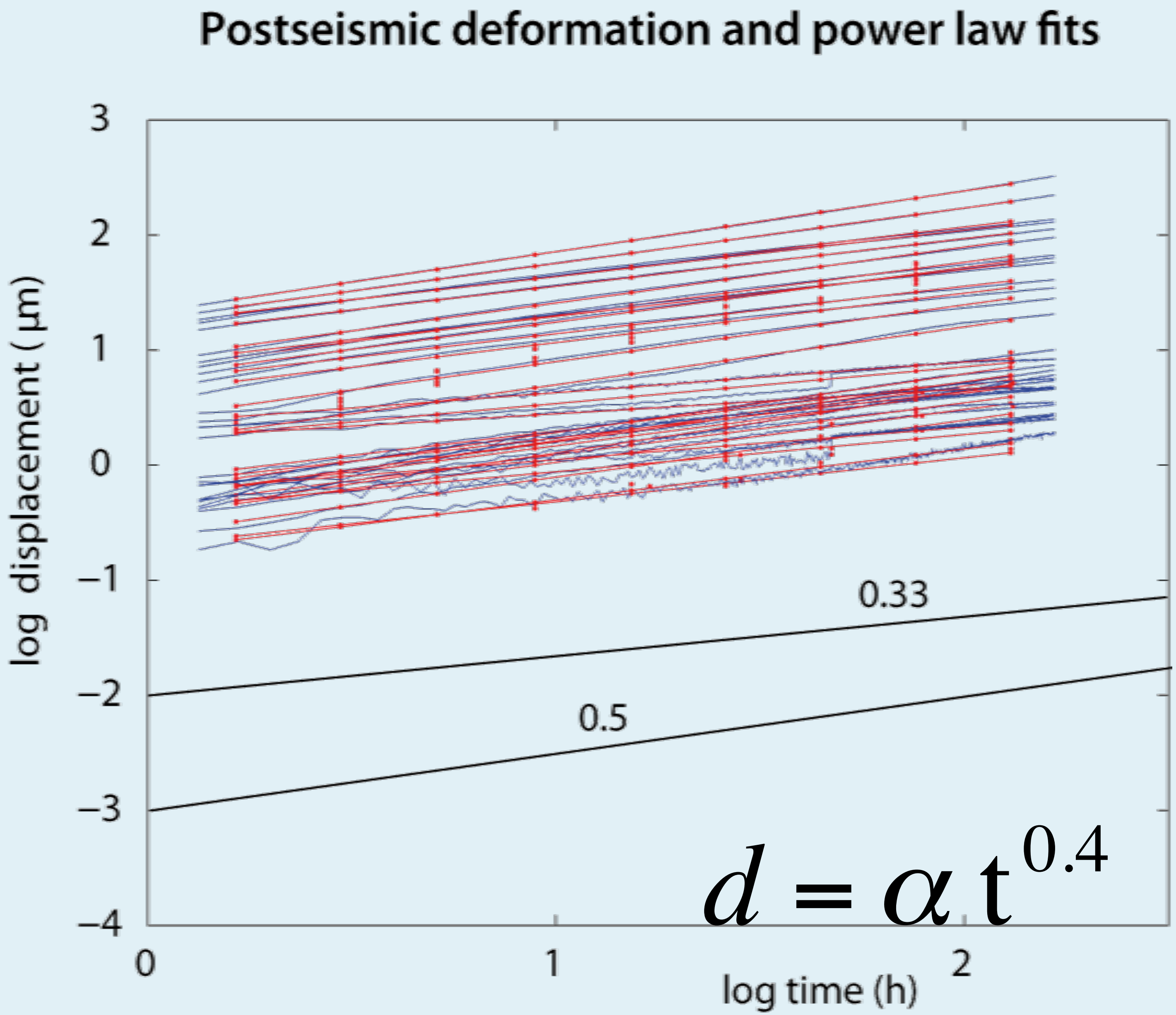
Laboratory simulation of the rheological evolution during seismic cycle Gratier et al 2012

Pressure solution experiment: dynamic indenting



Gratier et al 2012

Pressure solution experiment: dynamic indenting



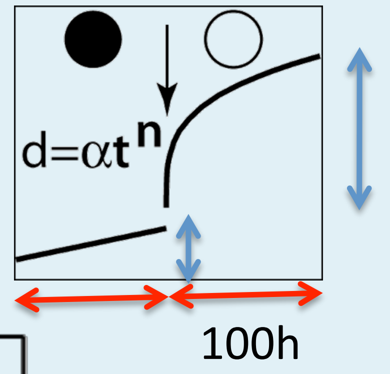
$$d = \alpha\, t^{0.4}$$

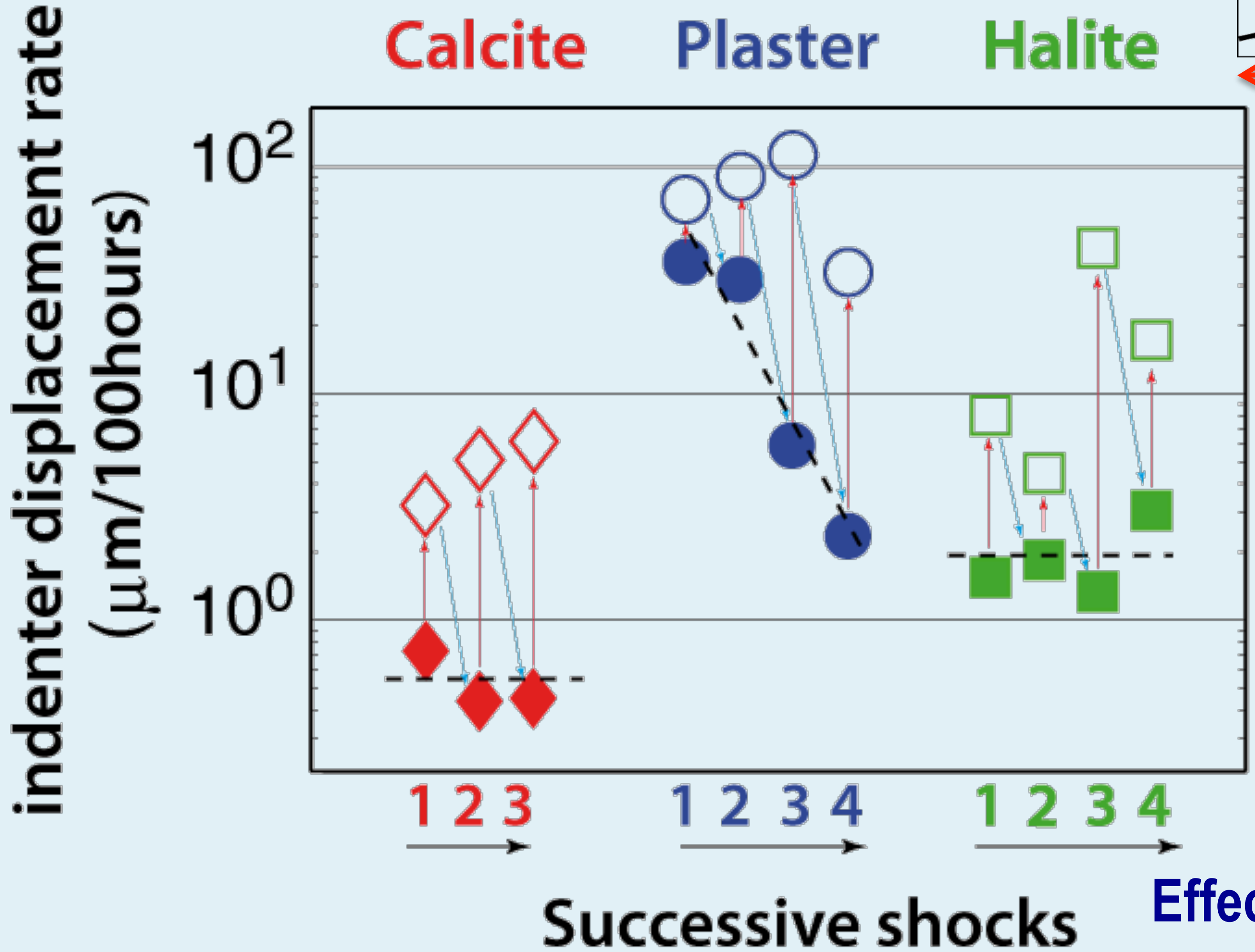
halite
plaster
calcite

Gratier et al 2012

Displacement rate: displacement / 100 hours before and after the shocks

Full symbol = pre-shock (stabilized displacement rate)
Open symbol = post-shock (transitory displacement rate)



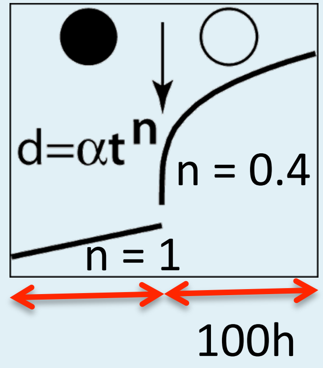


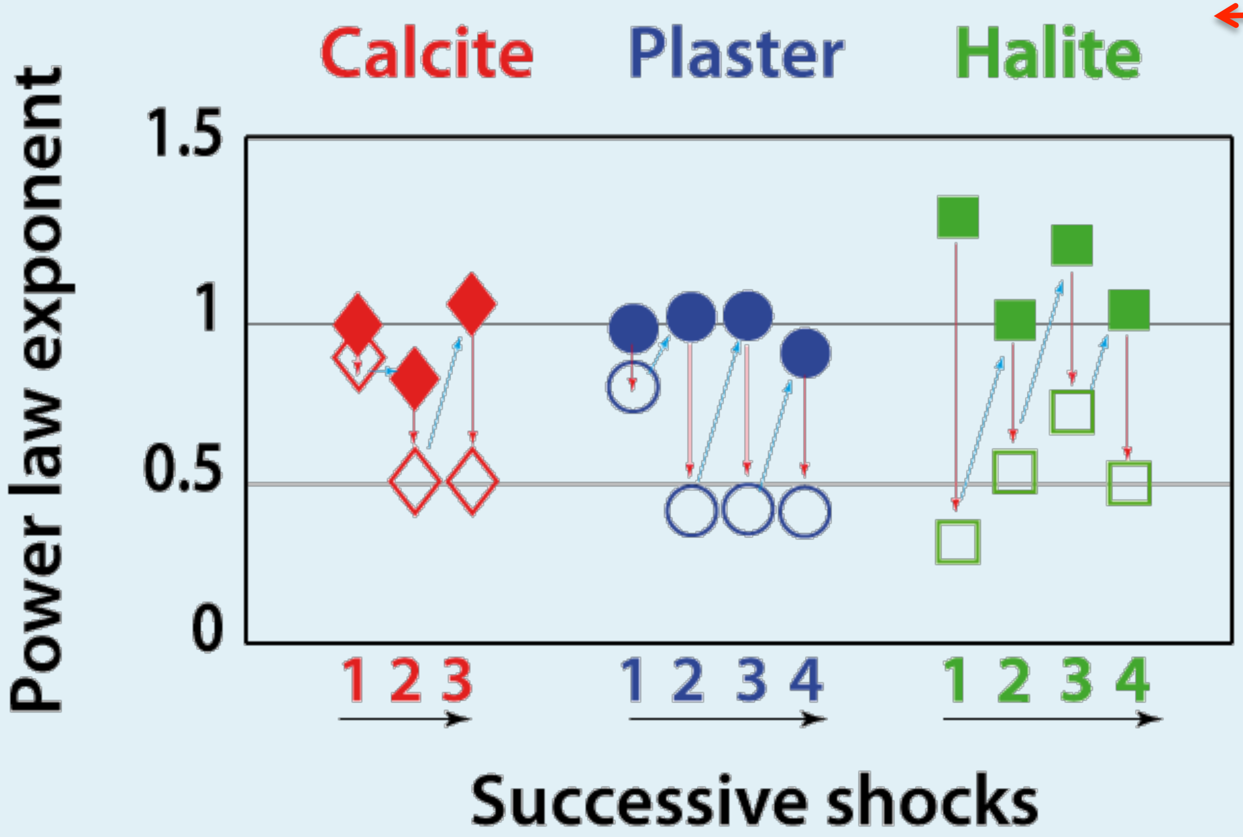
Effect of porosity

Gratier et al 2012

Exponent of the power law fit 100 hours before and after the shocks

Full symbol = pre-shock (stabilized displacement rate)
Open symbol = post-shock (transitory displacement rate)

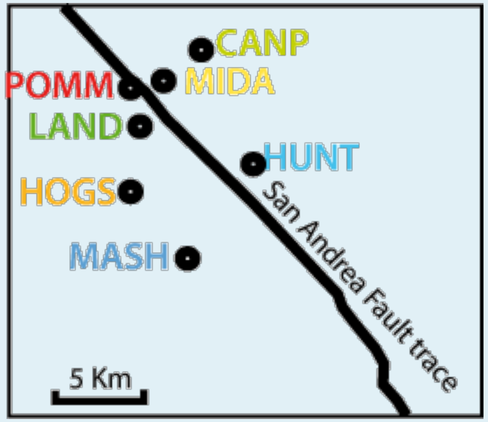




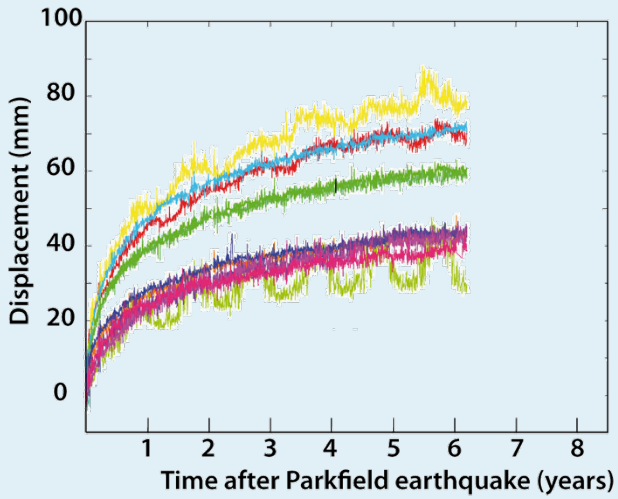
Post shock power law (n = 0.4) then linear evolution (n = 1)

Gratier et al 2012

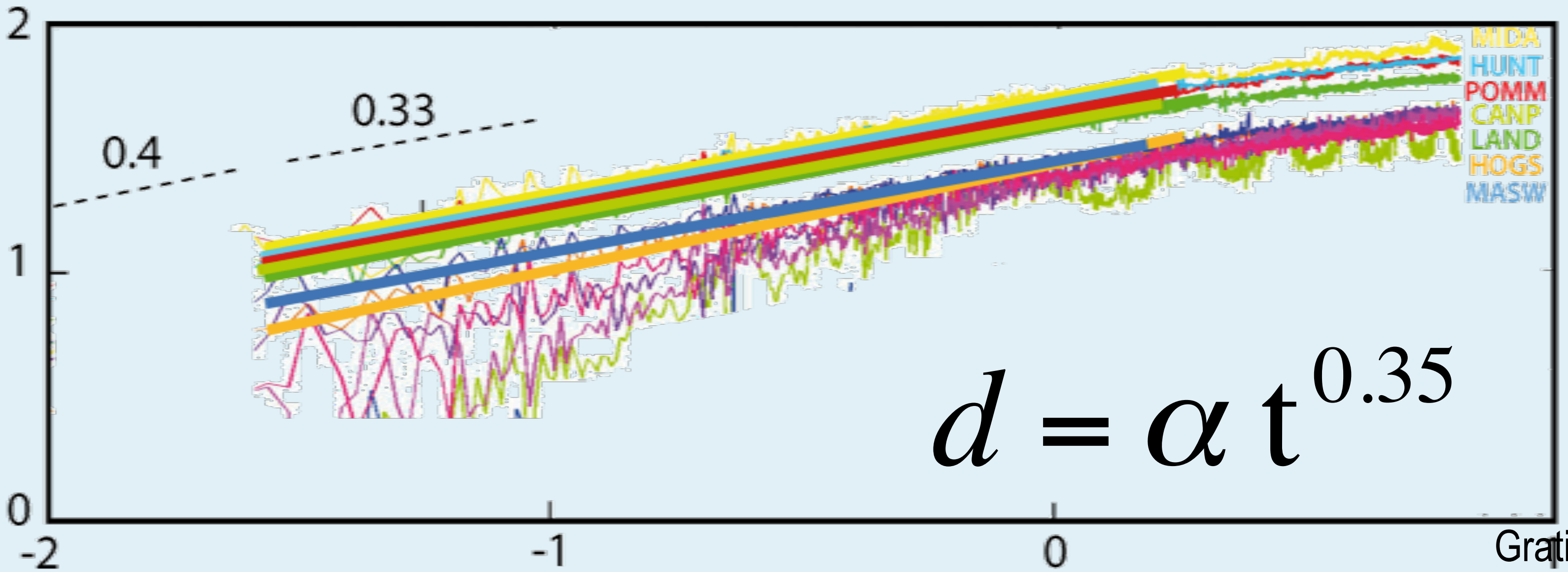
Power law fit of post-seismic displacement after 2004 M6 Parkfield



USGS data



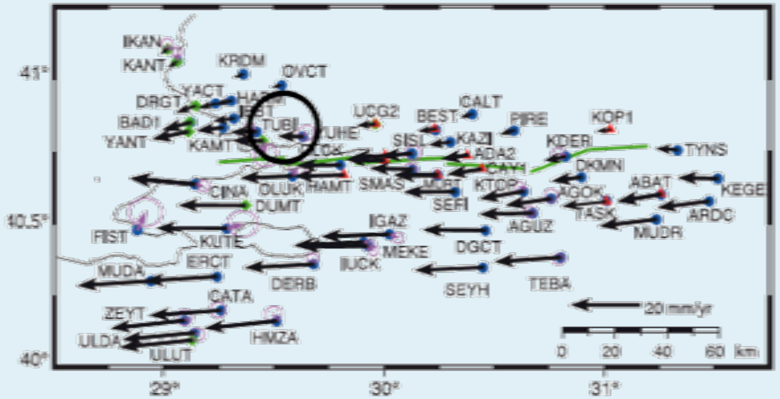
displacement versus time following the 2004 Parkfiel earthquake (California)

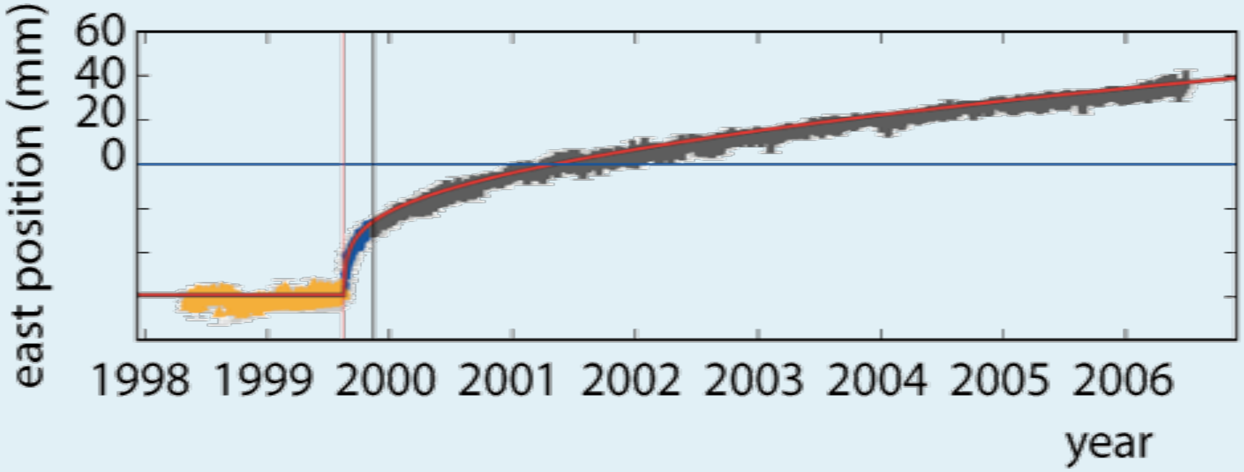


$$d = \alpha\, t^{0.35}$$

Gratier et al 2012

Power law fit of post-seismic displacement after 1999 M 7.2-7.4 Izmit (Turkey)





Ergintav et al JGR 2009

$$d = \alpha\, t^{0.3}$$

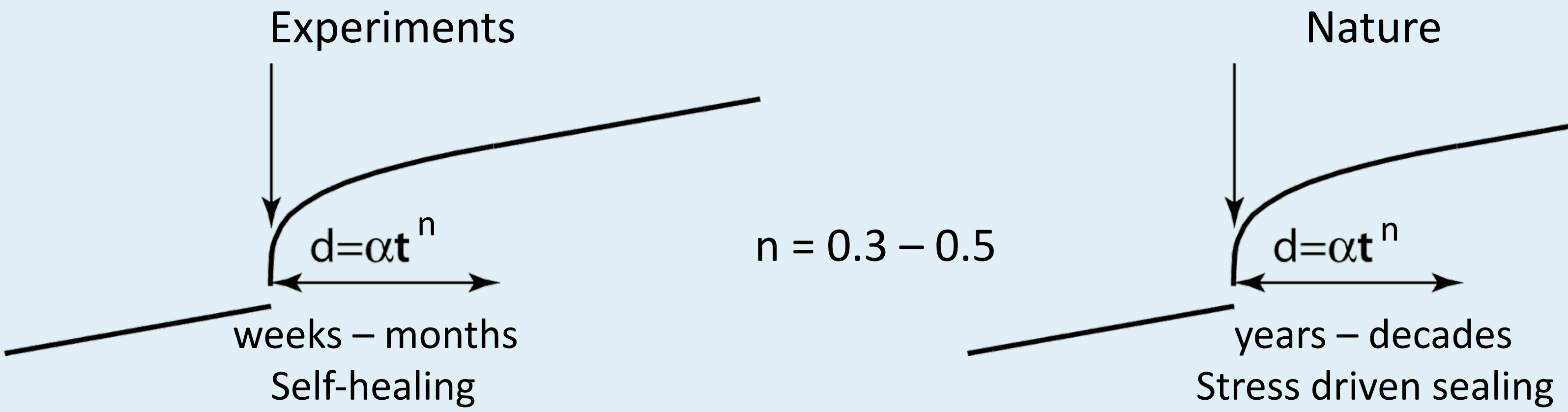
Gratier et al 2012

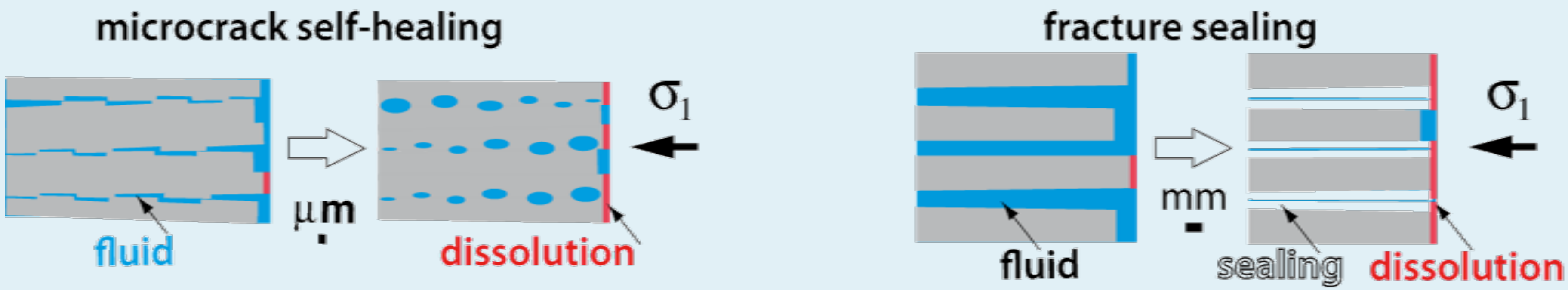
Conclusion for post-seismic pressure solution creeping processes

- Pressure solution is accelerated by fracturing and then is slowed down by fracture healing both in the lab and possibly in nature

- The same post-seismic displacement power law is founded : $d = \alpha\, t^{n}$ **(0.3 < n < 0.5) then a linear evolution.**

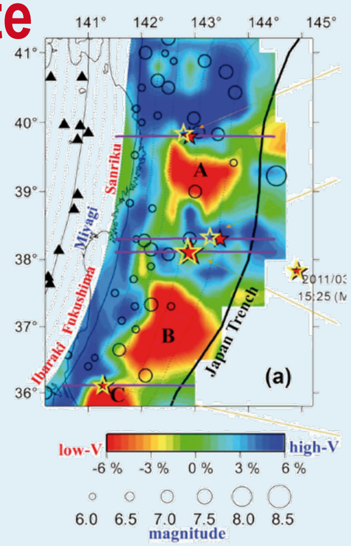
- However the characteristic times of healing are different in nature and experiment due to the difference in the healing mechanisms.



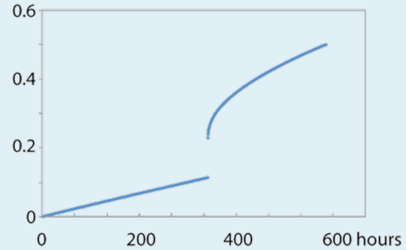


Evolution of the roughness of the dissolution surface can explain the power law (work in progress)

Conclusions générales: fluage permanent et transitoire des failles actives par dissolution cristallisation sous contrainte

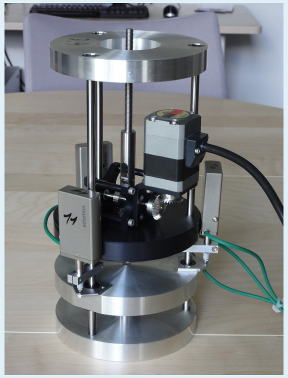


<u>Géologie des zones sismiques et asismiques</u>: la possibilité de fluage permanent par dissolution cristallisation sous contrainte dépend de la nature des minéraux et des roches et leur microstructure: une roche composée de minéraux solubles et insolubles (marnes, schistes...) se déforme plus facilement par dissolution cristallisation sous contrainte qu'une roche monominérale soluble (calcaire, grès..)



Même les roches qui cassent dans la croûte supérieure peuvent montrer <u>un fluage transitoire</u> par dissolution cristallisation activé par la fracturation et limité par la cicatrisation de ces fissures

Des éléments clé à approfondir:
<u>Fluage permanent:</u> connaissance des propriétés des fluides piégés sous contrainte (contacts mixtes minéraux soluble / insoluble) et comparaison tomographie – sismicité échelle régionale
<u>Fluage transitoire:</u> compétition entre propagation des fractures (rapides & lentes) et leur processus de cicatrisation > effet fréquence chocs



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