Unstable fault slip induced by lawsonite dehydration in blueschist: Implication for the seismicity in the subducting oceanic crusts

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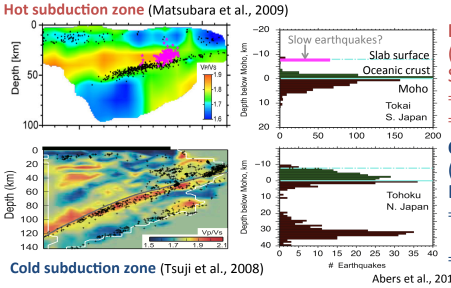
Intraslab seismicity in subduction zones

Hot subduction zone (Matsubara et al., 2009)



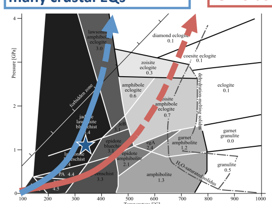
Cold subduction zone (Tsuji et al., 2008)

Hot subduction zones:
(e.g., Cascadia, SW Japan)
Single seismic zone
⇒few crustal earthquakes
⇒a number of slow EQs

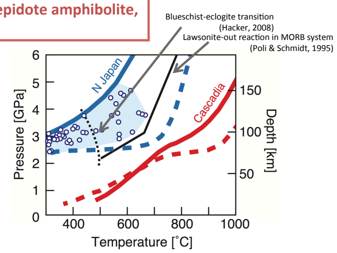
Cold subduction zones:
(e.g., NE Japan)
Double seismic zone
⇒a number of crustal earthquakes
⇒no slow earthquake

Cold subduction zones: Lawsonite blueschist, many crustal EQs

Hot subduction zones: Greenschist & epidote amphibolite, few crustal EQs



Hacker et al., 2003



modified from Abers et al., 2013

Can dehydration of lawsonite directly trigger seismic fault slip in the subducting oceanic crust?

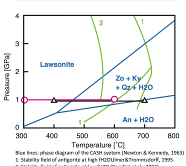
Sample and experiment

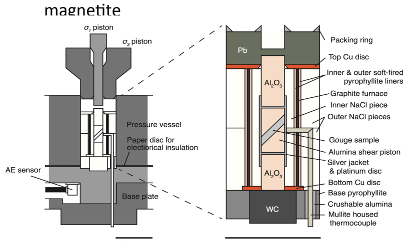
Sample 1: lawsonite, a common mineral in "cold" subducting crusts

- lawsonite vein within a lawsonite-blueschist block from the Franciscan Complex in CA, USA
- almost pure lawsonite (~98%), with minor staurolite and glaucophane

Sample 2: antigorite serpentine, stable frictional behaviour has been observed during dehydration (Chernak & Hirth, 2011; Proctor & Hirth, 2015)

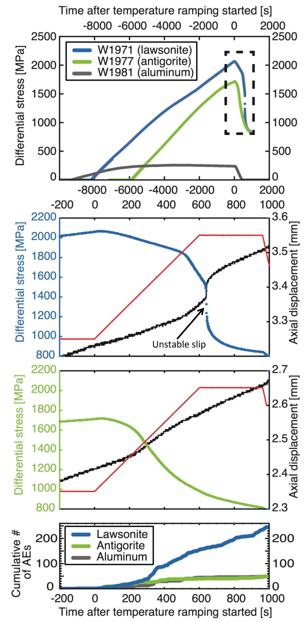
- from Nomo metamorphic rocks in Nagasaki, Japan
- predominantly antigorite (~98%) with minor diopside, spinel and magnetite





Experimental conditions:
Confining pressure (Pc): 1 GPa
Strain rate ($\dot{\varepsilon}$): 10^{-4} – 10^{-6} 1/s
(ca. 500 – 5 cm/yr)
Temperature ramping:
300˚C → 600˚C for lawsonite
400˚C → 700˚C for antigorite
Temp. ramping rate ($\dot{T}$): 0.05 – 0.5 ˚C/s

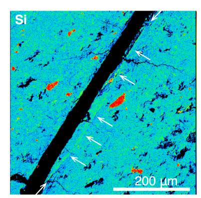
Temperature ramping experiments

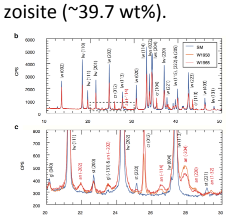


Recovered samples of lawsonite:
Strain is highly localised and the fault surface shows mirror-like slickensides with very little gouge.
→ similar to observations from high pressure faulting associated with the olivine-spinel transition (Schubnel et al., 2014).

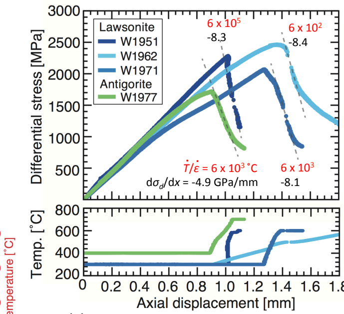
XRD analysis:
A small amount of anorthite (<5 vol%) formed as a result of dehydration during experiments.

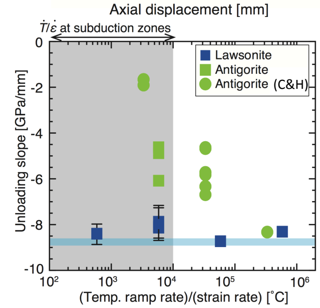
EPMA chemical analysis:
Slightly higher concentration of Si along the shear zone, subparallel to the slickenside surface; anorthite has a somewhat higher Si content (~44 wt%) than lawsonite (38.3 wt%) and zoisite (~39.7 wt%).





Stress-displacement curves



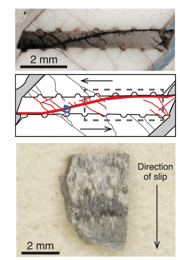


Lawsonite: unloading slope is similar to the effective unloading stiffness of the apparatus (~280kN/mm, 8.8 GPa/mm for the sample dimension used in this study) over the entire range of T/ε tested.
→ **unstable fault slip**

Antigorite: the unloading slope is controlled by the temperature ramping rate and strain rate.
→ **reaction-controlled stable sliding**

These observations indicate dehydration induced unstable fault slip in lawsonite (i.e., stick-slip) but stable slow slip in antigorite, consistent with the differences in AE.

Time-independent thermal-mechanical factor $\dot{T}/\dot{\varepsilon}$
If we assume:
Thermal gradient = 10 ˚C/km,
subducting velocity = 10 cm/year,
subducting angle of 45˚,
range of strain rate from 10^{-13} to 10^{-15} 1/s,
$\dot{T}/\dot{\varepsilon}$ in natural subduction zone systems will range from ~10^2 to 10^4 ˚C.
→The values of $\dot{T}/\dot{\varepsilon}$ imposed in our experiments (6 × 10^2 to 6 × 10^5 ˚C) cover the range expected for subduction zone systems.



Stiffness of the natural fault system:
$K_f = G/2/(1-\nu)/L$ (Scholz, 2002)
G: the shear modulus (~30GPa),
ν: the Poisson's ratio (~0.25),
L: the length of the slipping region.
If we assume L≈ 10 m (i.e., for a M1 earthquake, the stiffness of the natural systems K_f ~2 MPa/mm.
Unstable slip resulting from dehydration of lawsonite will occur even more easily in natural subduction zones than in the laboratory.

Summary:

1. Unstable fault slip (i.e., stick-slip) occurred during dehydration reactions in the lawsonite gouge layer and AE signals were continuously observed under the differential stress.
2. The unloading slope during the unstable slip follows the stiffness of the apparatus at all experimental conditions, regardless of the strain rate and temperature ramping rate. A thermal-mechanical scaling factor for the experiments covers the range estimated for natural subduction zones.
3. Lawsonite is one of the few minerals that exhibit brittle deformation resulting in unstable fault slip at high pressure and temperature conditions.
4. Dehydration of lawsonite can directly trigger unstable fault slip in the subducting oceanic crust.