Sounds of the subduction piping system?

How the dynamics of transient pore pressure diffusion in subduction zones could account for low-frequency earthquakes activity

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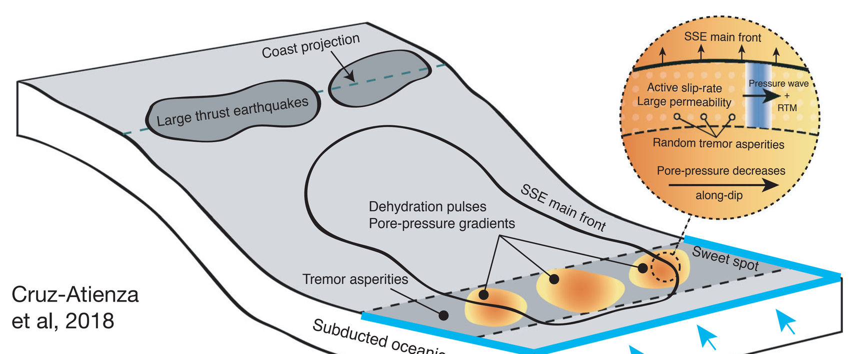
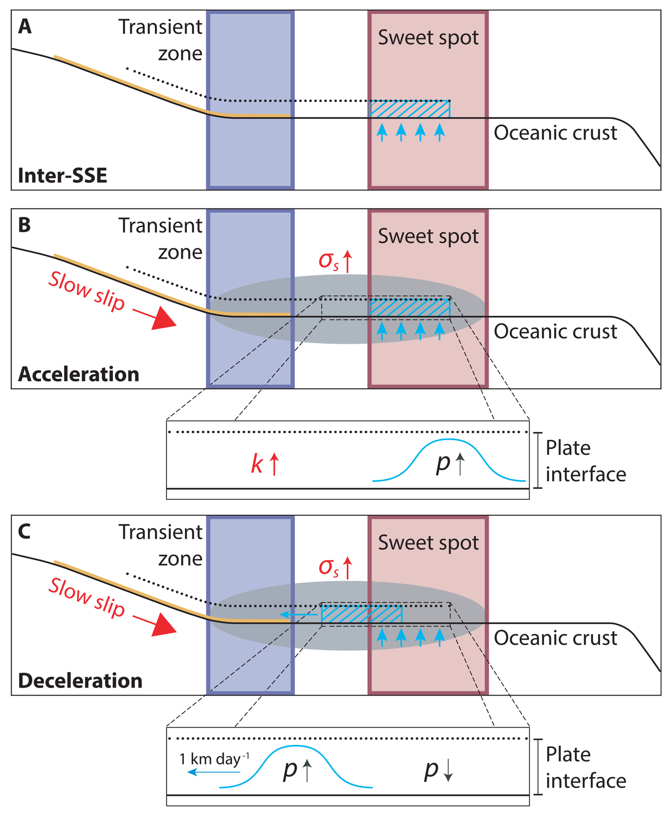
Fluid circulation is a key component of deeper subduction dynamics



Cruz-Atienza et al, 2018

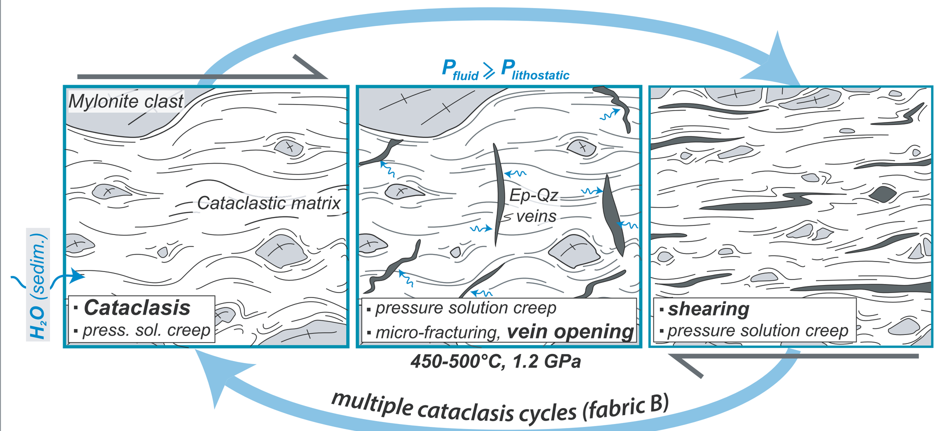
Over-pressured fluid originating from slab sediments dehydration saturates the regions of the plate interface where tremor occur.



Frank et al., 2015

With such strong spatial contrasts of pore pressure, slip-induced augmentation of permeability triggers a positive feedback: pore presure pulse starts propagating, favoring slip by reducing the effective normal stress.

Theoretical velocities of pore pressure pulses span the same range as various tremor migration regimes (1km/day – 50km/h).



Angiboust et al., 2015

A possible underlying geological process, observed on a smaller scale: veins and fractures cyclically opening, healing and being sheared.

A multiscale fault-valve system?

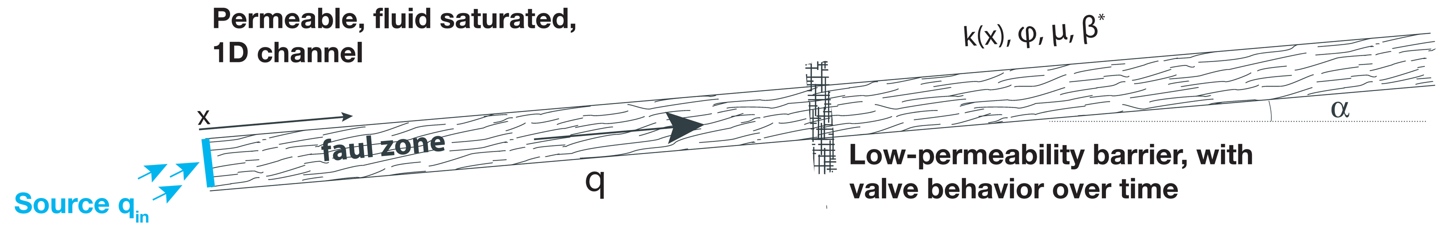
Can elementary low-frequency sources be integrated in a model of pore pressure propagation on the SSE scale and account for seismicity migrations and recurrence patterns ?

(Are LFEs the sound of creaking subduction pipes ??)

Model of a subduction "pipe": pore pressure diffusion in a permeable channel

We use a bimodal description of heterogeneous transport properties:

p(x,t)	pore pressure (Pa)
q(x,t)	surfacic flux ($kg.s^{-1}.m^{-2}$)
k(x)	permeability (~10^{-12} m^2)
φ	porosity (~0.05)
μ	fluid viscosity (10^{-3} Pa.s)
β*	fluide/pore compressibility (~1 GPa^{-1})
α	dip angle (~10°)



This system is described by a diffusion equation for pore pressure:

$$\begin{cases} q = \dfrac{\rho k}{\mu}\left[-\dfrac{\partial p}{\partial x} - \rho g \sin(\alpha)\right] \\ \dfrac{\partial p}{\partial t} = \dfrac{\partial}{\partial x}\left(D(x)\dfrac{\partial p}{\partial x}\right) \end{cases}$$

where:

$$D(x) = \frac{k(x)}{\mu \beta^* \varphi}$$

In diffusive systems, characteristic *time and length scales* are linked by:

$$D \sim L^2.T^{-1}$$

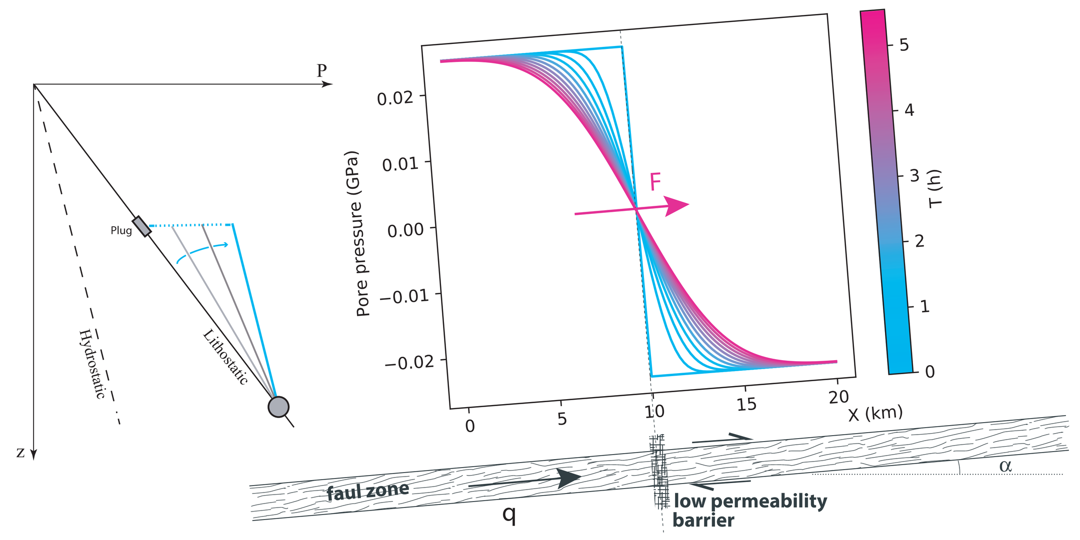
A numerical solution for this system of equations is calculated for each time step using a Crank-Nicholson final difference method, second order in time and space.

All numerical calculations are computed using a non-dimensional formulation of the previous equations.

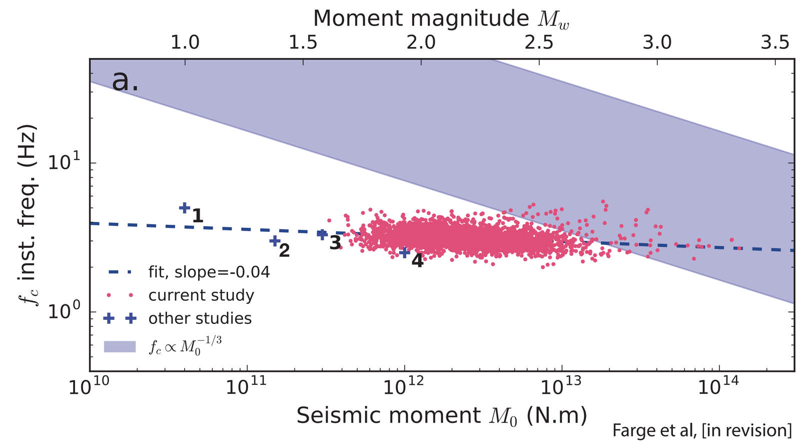
The elementary low-frequency source in this framework: a pore pressure valve

→ *Sources are loaded with pore pressure gradients*

Steep pore pressure gradients build up across low permeability barriers and are suddenly released when the barrier opens, corresponding to a low-frequency event in our model.



→ *Seismic source:*
simple force, constant duration / shear rupture?

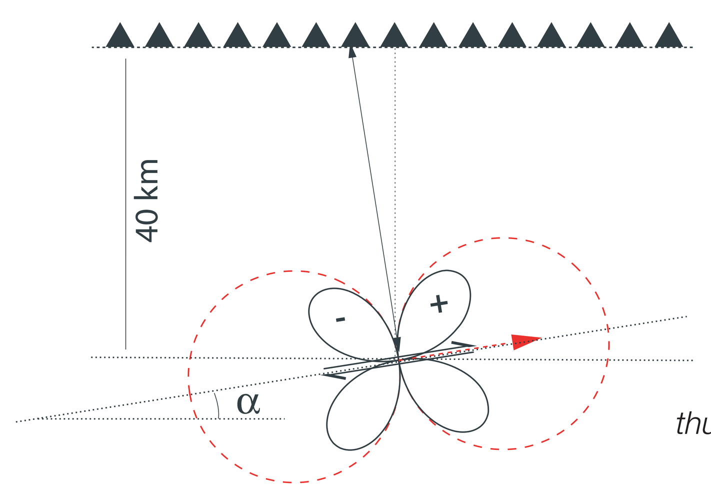


Farge et al, [in revision]

To reconcile the observation of an almost constant duration of low-frequency earthquakes in certain parts of the world, Shapiro et al. [2018] devised a simple force source mechanism.

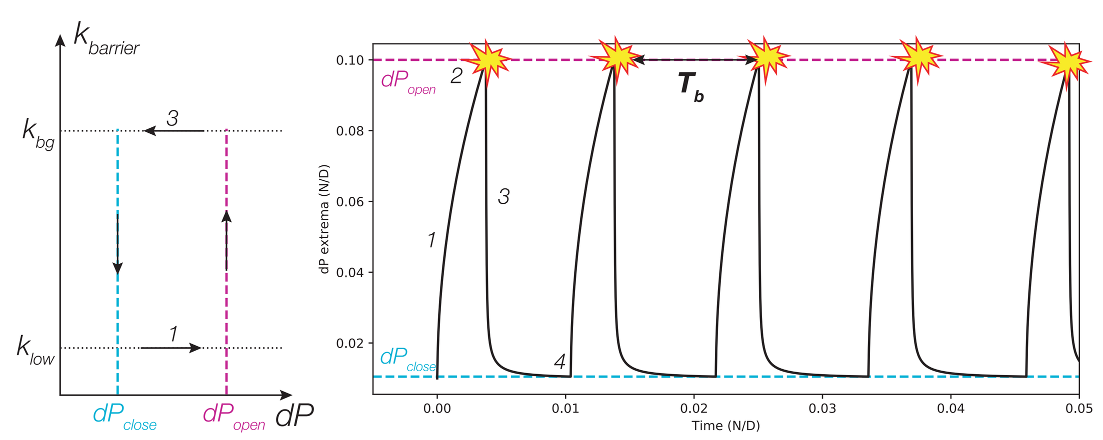
Duration only depends on the diffusivity of the medium .

$$\begin{cases} P(x,t) = \dfrac{\Delta P}{2}\,\mathrm{erf}\left(\dfrac{x}{\sqrt{4Dt}}\right) \\ u(t) = \dfrac{1}{4\pi\rho V_S^2 r}\,\Delta P\,|P^{norm}(t)| \end{cases}$$



Shear slip and simple force mechanisms are difficult to tell apart with the current state of their observation: such low SNR signals are mainly observed at short epicentral distances, thus with a low aperture angle.

→ *Time evolution of pore pressure at a valve: hysteresis behavior*



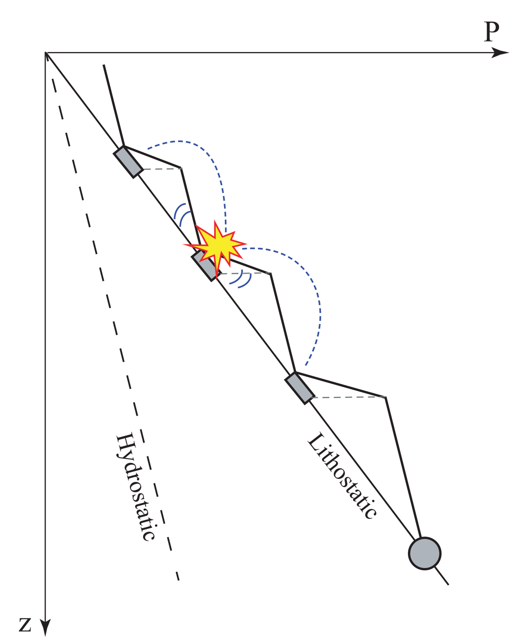
When a barrier is isolated, its opening and closing thresholds define the period of its cyclic activity T_b

A valve opens by instantaneous increasing the barrier's permeability to background levels.

The *opening* of a valve is controlled by a threshold of pore pressure differential across the barrier. The valve *closes* when the pore pressure differential is back close to the lithostatic gradient.

→ *The rationale for source interactions in this model*

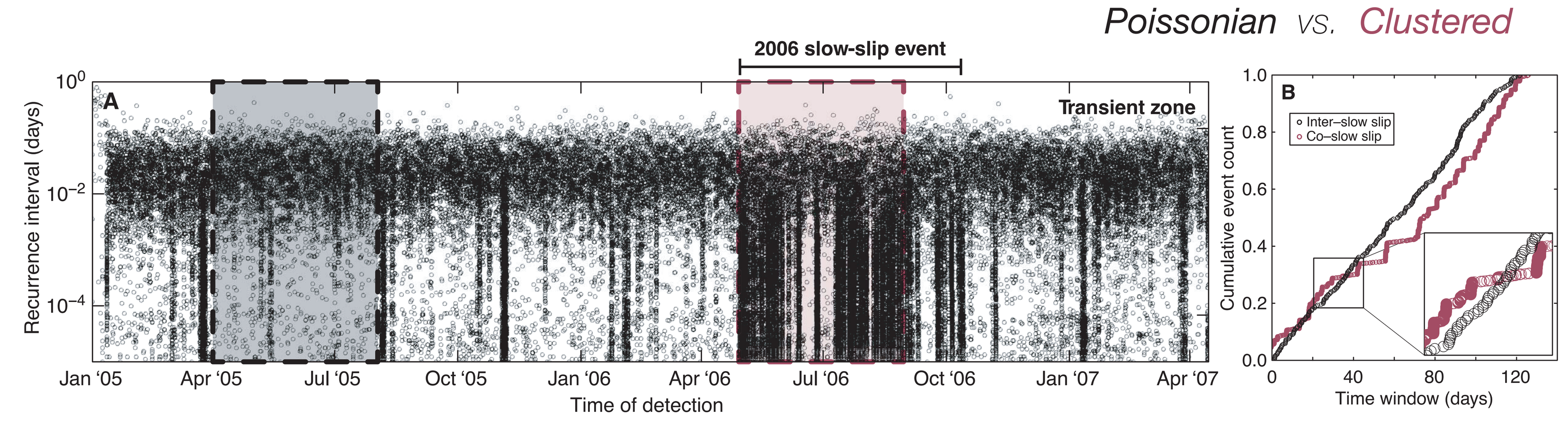
The activation of a source thus triggers a short scale pore pressure transient, increasing the pressure updip and lowering it downdip.



This is the basis of the interactions in the model, each source has the potential to trigger other sources at a characteristic distance and with a characteristic velocity, depending on the valve strength, the pressure state and the transport properties of the medium.

Elementary sources interact through pore pressure transients diffusion

→ *Low-Frequency earthquake observed activity:*
Poissonian vs. Clustered



Frank et al., 2016

Two regimes of activity of LFEs are observed in various subduction zones:

Poissonian activity, constant rate of seismicity — observed in between slow slip events : sources do not interact

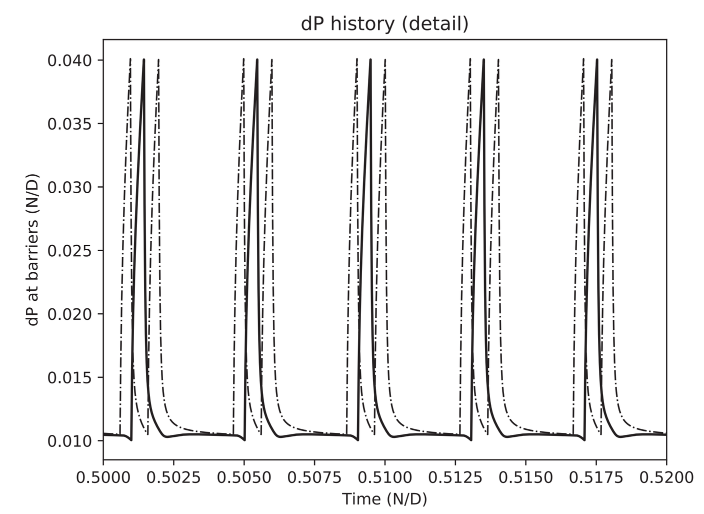
Clustered activity, LFEs occur in burst — observed during slow slip, bursts can be used as a proxy of small slow slip events: sources interact in cascades

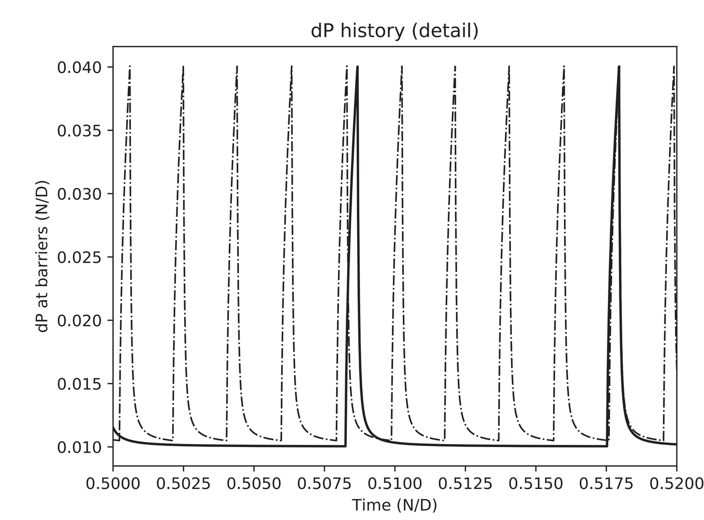
→ *Characterizing interactions in synthetic catalogs created with the pore pressure model*

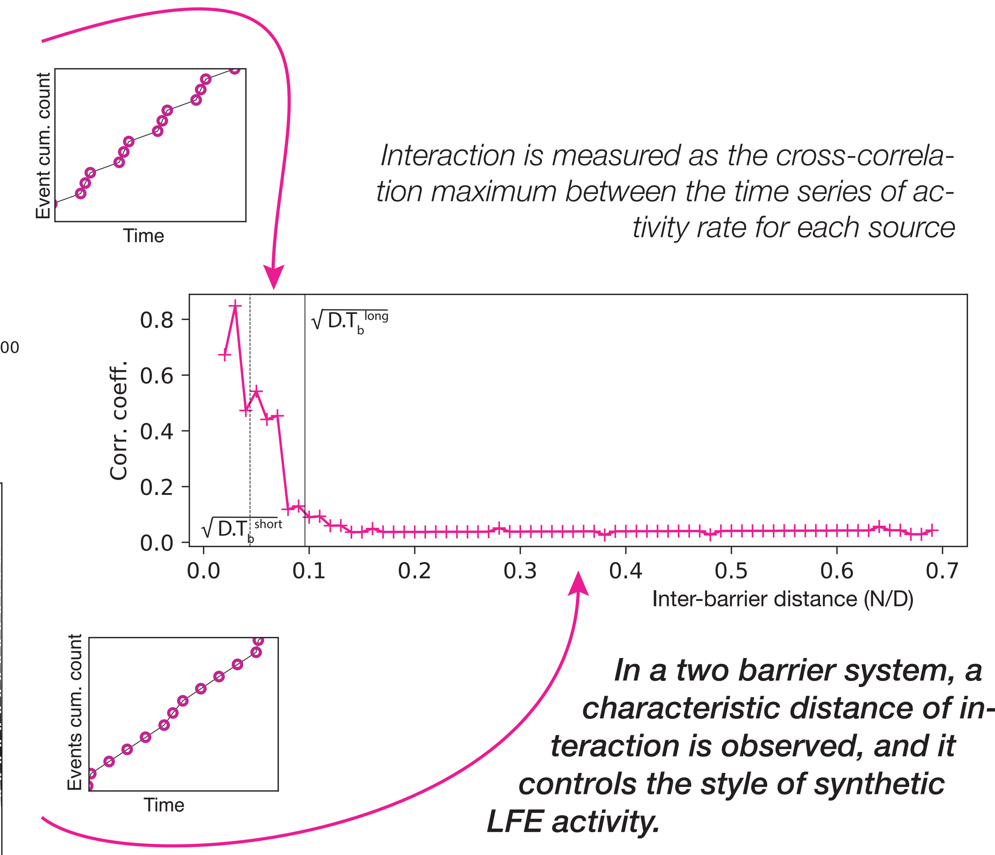
Interactions between sources is driven by pore pressure transients created by the opening/closing cycles of each valve.

In this diffusive system, pore pressure transients of a period T_b should be significantly felt at a distance of :

$$L \sim \sqrt{D.T_b}$$







Interaction is measured as the cross-correlation maximum between the time series of activity rate for each source

In a two barrier system, a characteristic distance of interaction is observed, and it controls the style of synthetic LFE activity.

Whereas simple diffusive systems do not exhibit any characteristic velocity, defining thresholds of pore pressure for an event to occur will allow for a velocity of interaction to be characterized.

→ *This model allows us to explore the conditions for the generation of complex seismicity patterns*