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Gaspard Fargge, Claude Jaurart, Nikolai Shapiro

the intermittence and migrations of tremor
activity in subduction faults

emerges from cascades and interactions of un-clogging and
clogging in permeable channels

Intthismodel,



Background and motivation



Modeldesign



Results



conclusions

Clogging and un-clogging of the subduction plumbing system may generate tremor-like patterns

As seismic sources **interact through rapid fluid pressure transients**, events occur in cascades. Activity is **clustered** and **migrates** in the channel. **[+]**

The input flux in the fault zone controls if activity occurs, and shapes its intermittence. **[+]**

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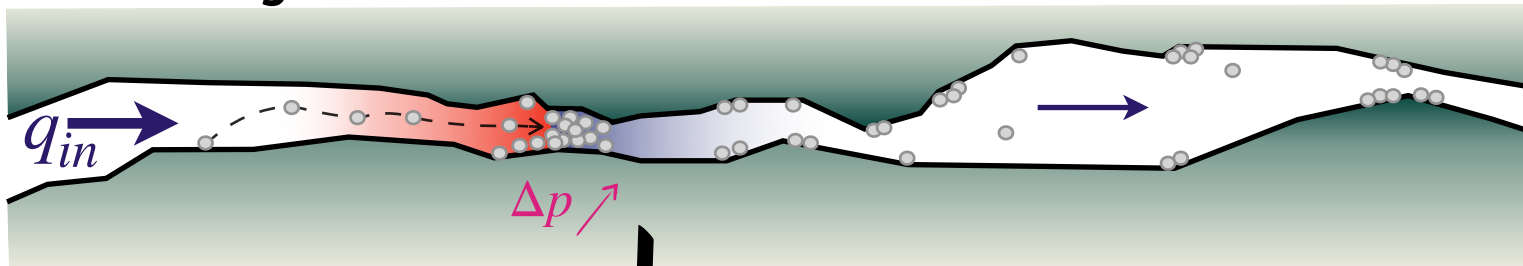
We solve for fluid pressure diffusion in a 1D, **dynamically permeable channel along-dip**.

Locally, several **permeability valves** open/close in response to the pressure gradient.

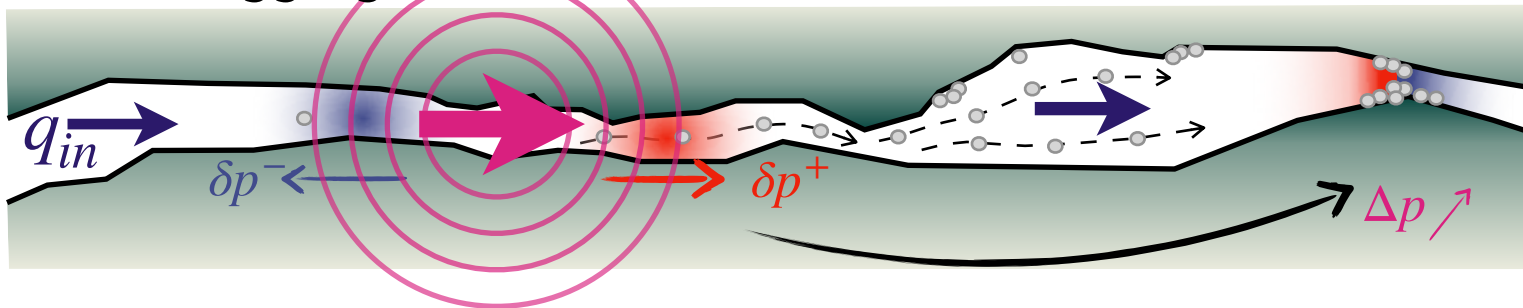
The strong, rapid pressure transient at **opening can act as (or trigger) a seismic source**.

This simple conceptual model shows how variable and realistic patterns of seismicity can be driven by dynamic permeability in a constantly fed fluid transport system.

1/ Loading



2/ Un-clogging



3-4/ Discharge and clogging

Variations of **fluid pressure** within subduction fault zones can **fuel fault-slip** events [\[1\]](#) and trigger the largest earthquakes [\[2\]](#).

In active subduction zones, fluid flow can be tracked through the activity of tremor and low-frequency earthquake (LFE) it seems to trigger.

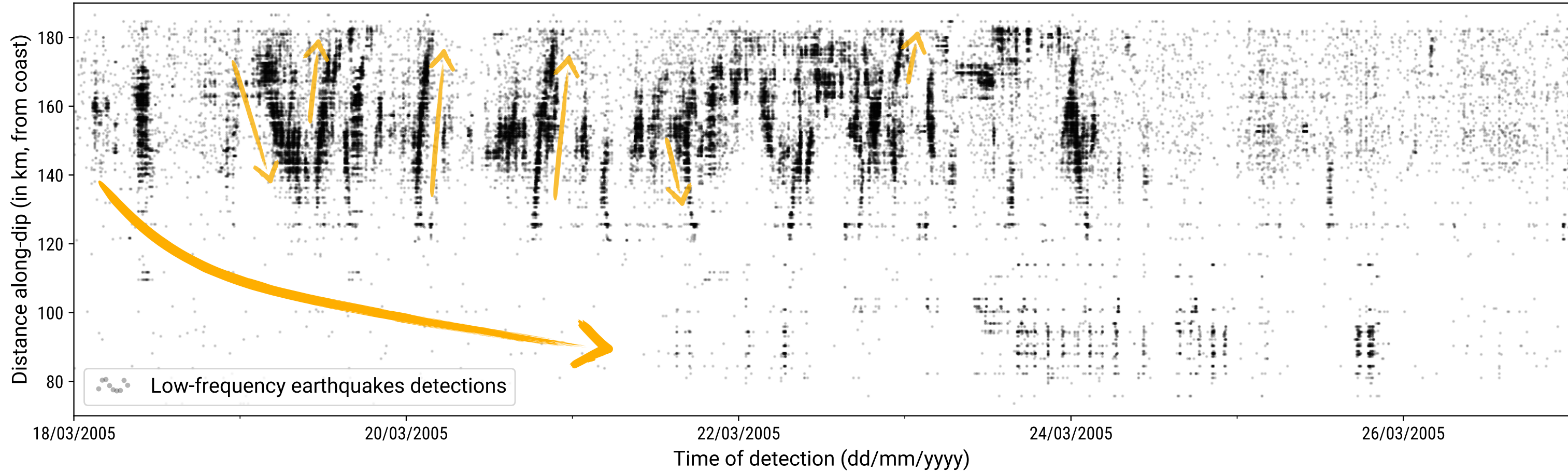
We build a model to **explore how fluid transport in a fault shapes its seismicity**.





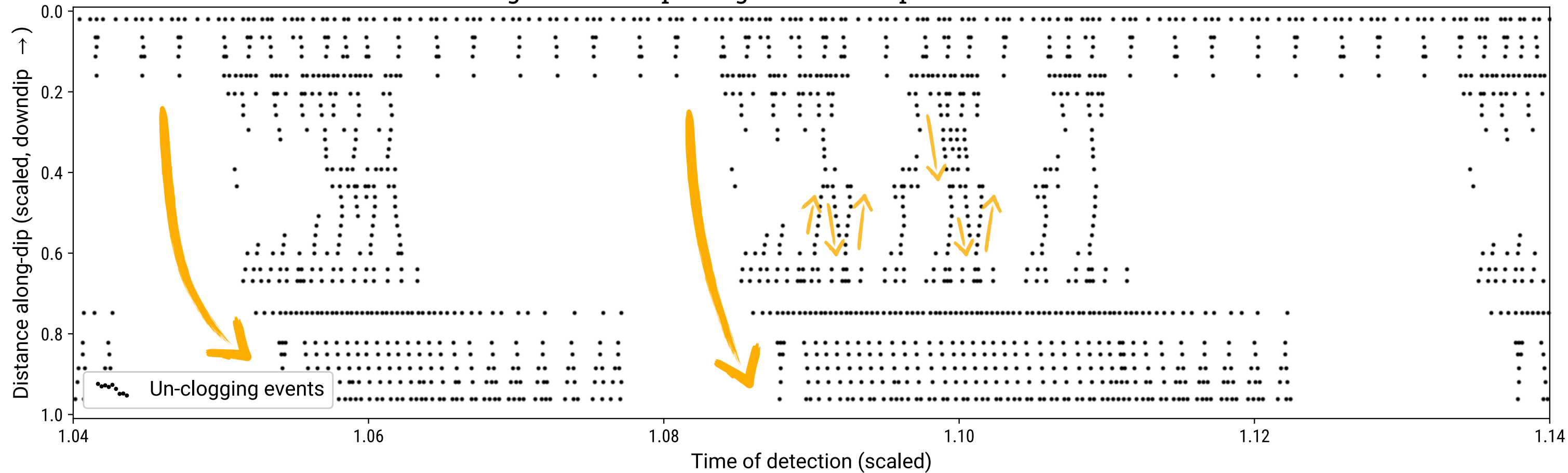


Bursts and migrations of low-frequency earthquake activity in Guerrero, Mexico





Bursts and migrations of opening events in a permeable channel with valves



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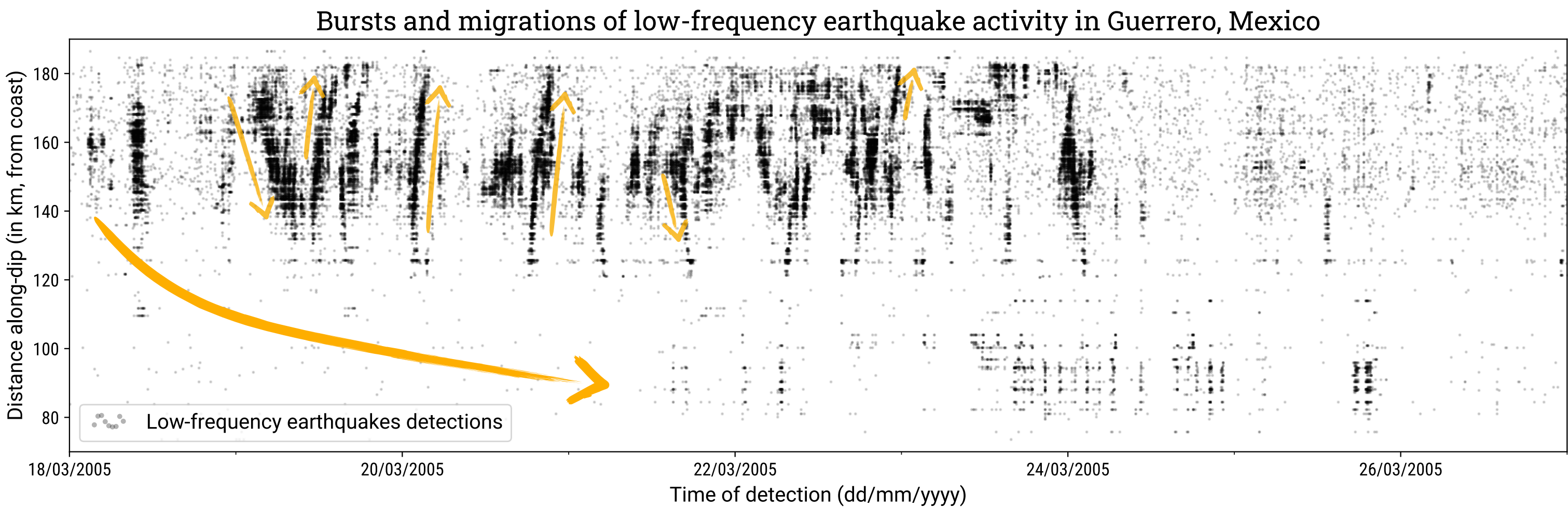
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the **intermittence** and **migrations** of tremor activity in subduction faults

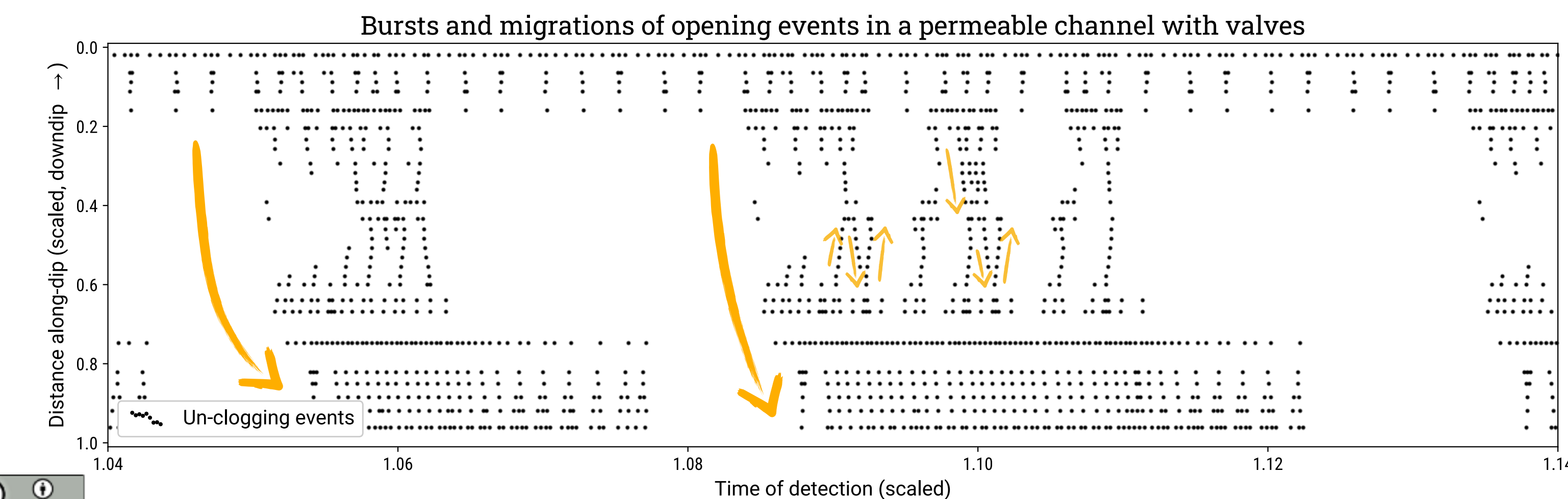
Clogging and un-clogging of the subduction plumbing system may generate tremor-like patterns

Gaspard Farge, Claude Jaupart, Nikolai Shapiro

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emerges from **cascades** and **interactions of un-clogging and clogging in permeable channels**



[Background and motivation](#) [\[+\]](#)

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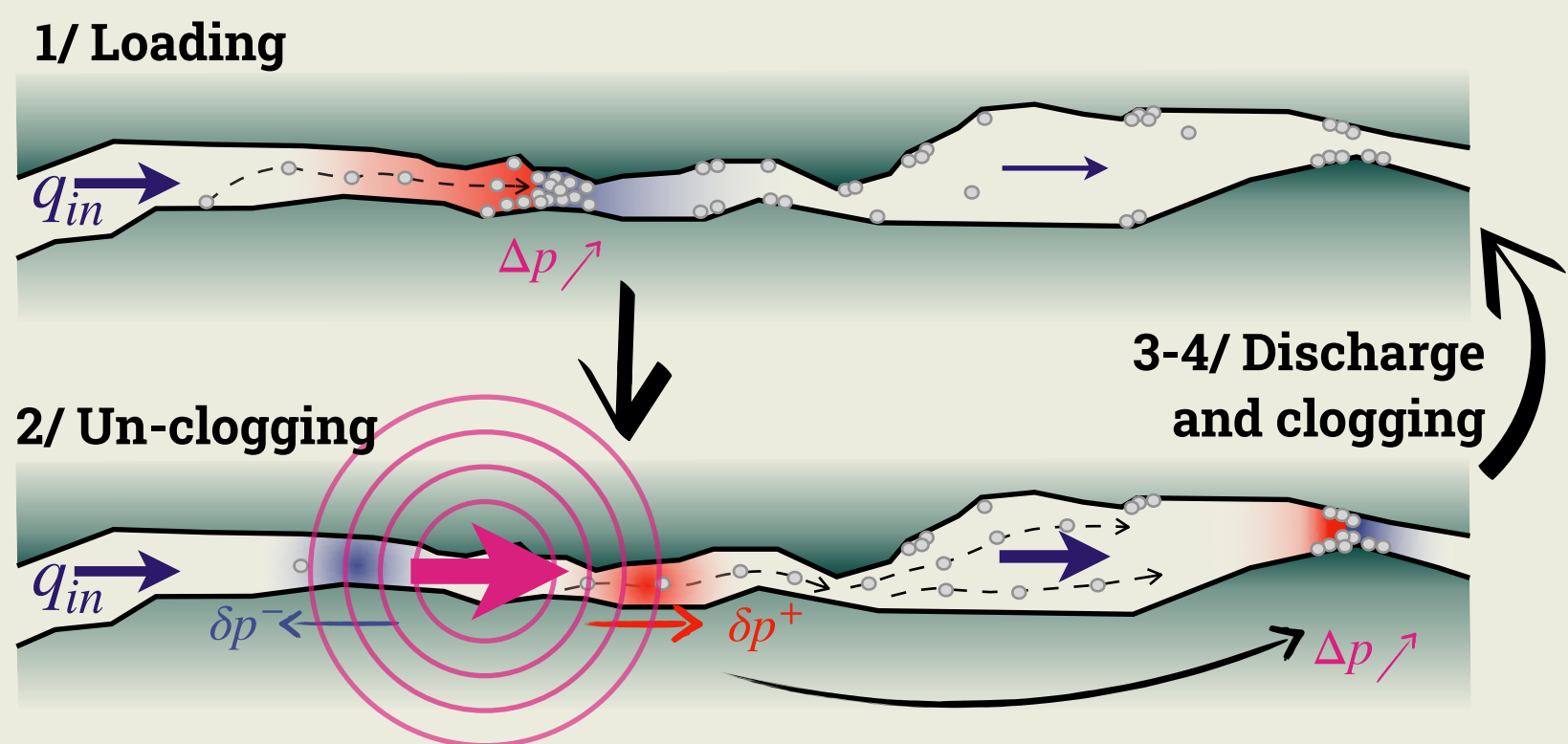
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As seismic sources **interact through rapid fluid pressure transients**, events occur in cascades. Activity is **clustered** and **migrates** in the channel. [\[+\]](#)

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[Conclusions](#)

This simple conceptual model shows how variable and realistic patterns of seismicity can be driven by dynamic permeability in a constantly fed fluid transport system.

Background and motivation

Fluid in subduction zones

As it is subducted, the downgoing slab dehydrates, and **free fluid then pushes its way towards the surface, at quasi-lithostatic pressures.**

At 40 km depth, the fluid preferentially follows the fault interface, whose **very anisotropic permeability** is a barrier to the upward flow, but **channels fluid along the fault plane.**

Variations of **fluid pressure** induced by variations in fluid flow within subduction fault zone can **fuel fault-slip** fast and slow slip events [1] and thus be a trigger for the largest earthquakes [2].

Tremor and LFE activity as proxy for fluid transport processes

Tremor **migrations** move **quickly on short distances**, and **slowly on larger distances**, leading us to think that sources interact through **diffusive interaction** mainly, perhaps through fluid pressure transients.

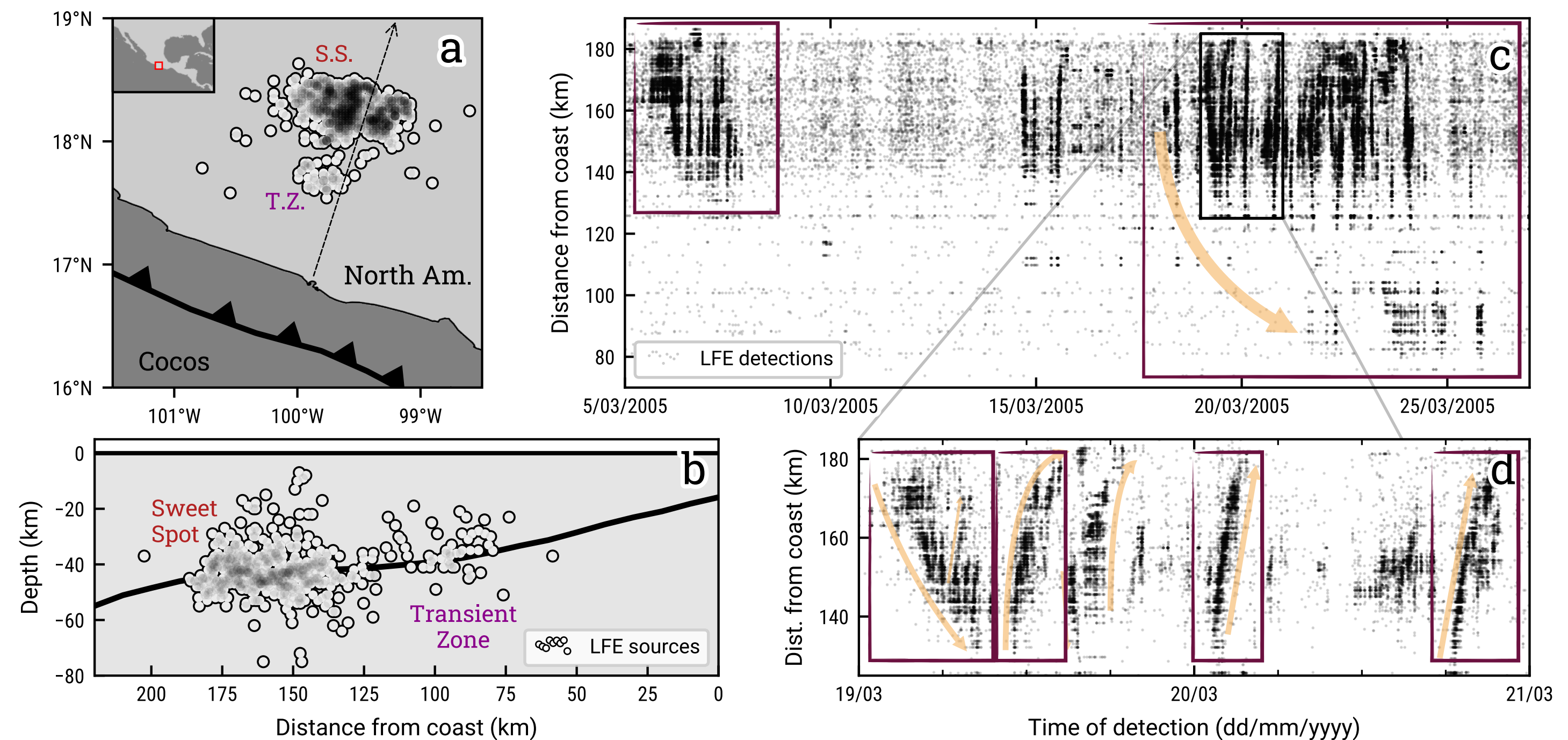
In active subduction zones, the activity of swarms of **low-frequency earthquakes (LFE)*** and **tremor** is often thought to be caused by **pulses of coupled slow fault slip and high fluid pressure** [1, 3, among others] in a mechanism akin to a **fault valve** [1, after 4].

Based on the hypothesis that **tremor activity reflects the dynamics of fluid transport processes in the fault,**

we build a model to explore how the **diffusion of fluid pressure** in a fault with **heterogeneous and variable permeability** could **shape its seismicity.**

* Here we assume that LFEs are elementary tremor sources, and that they are generated by the same underlying processes. "tremor activity" and "low-frequency earthquakes activity" are used as synonyms.

Anatomy of low-frequency earthquakes activity in Guerrero, Mexico



Tremor activity occurs is **intermittent** on **both short and large time and space scales**

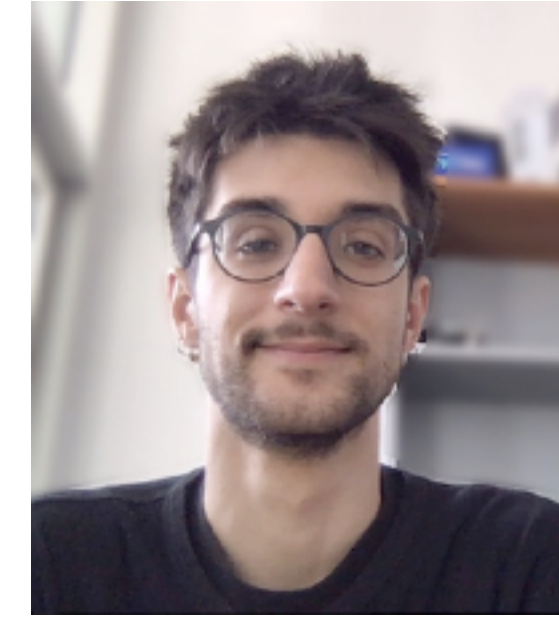
it occurs in **bursts** and **migrates**

How does fluid transport processes shape these patterns?

References

1. Frank, W. B., Shapiro, N. M., Husker, A. L., Kostoglodov, V., Bhat, H. S., & Campillo, M. (2015). Along-fault pore-pressure evolution during a slow-slip event in Guerrero, Mexico. *Earth and Planetary Science Letters*, 413, 135–143. <https://doi.org/10.1016/j.epsl.2014.12.051>
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5. Manga, M., Beresnev, I., Brodsky, E. E., Elkhoury, J. E., Elsworth, D., Ingebritsen, S. E., Mays, D. C., & Wang, C.-Y. (2012). Changes in permeability caused by transient stresses: Field observations, experiments, and mechanisms. *Reviews of Geophysics*, 50(2). <https://doi.org/10.1029/2011RG000382>
6. Shapiro, N. M., Campillo, M., Kaminski, E., Vilotte, J.-P., & Jaupart, C. (2018). Low-Frequency Earthquakes and Pore Pressure Transients in Subduction Zones. *Geophysical Research Letters*, 45(20), 11,083–11,094. <https://doi.org/10.1029/2018GL079893>

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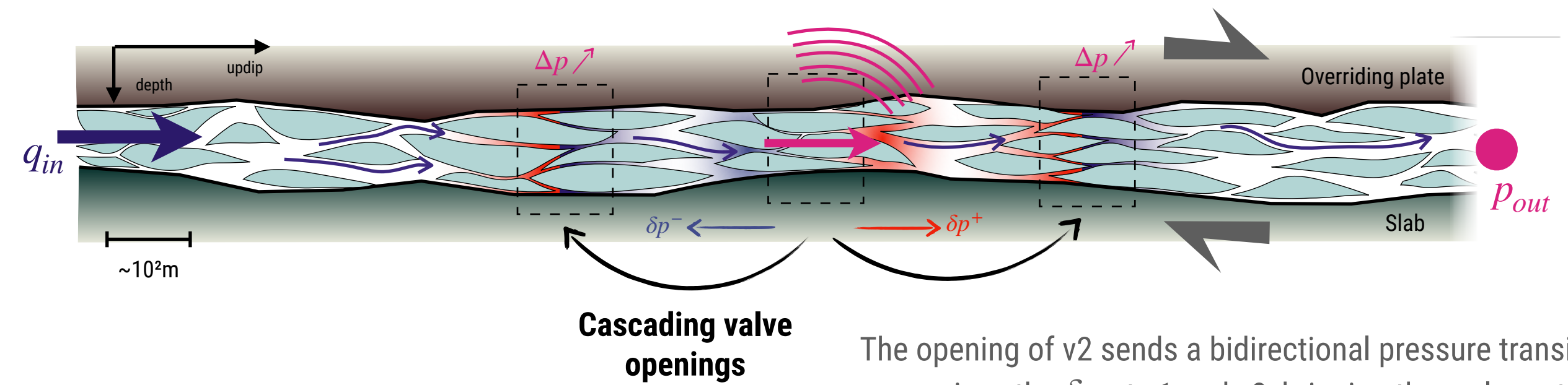
Results – (i)

Valve (source) interaction

The opening of a valve generates a strong **pressure transient that diffuses to neighboring valves**. Both updip and downdip valves are brought closer to failures as their δp increases. This mechanism is the **basis of constructive source interaction** in our model, and generates **fast cascades of valve openings**, and therefore of seismic events.

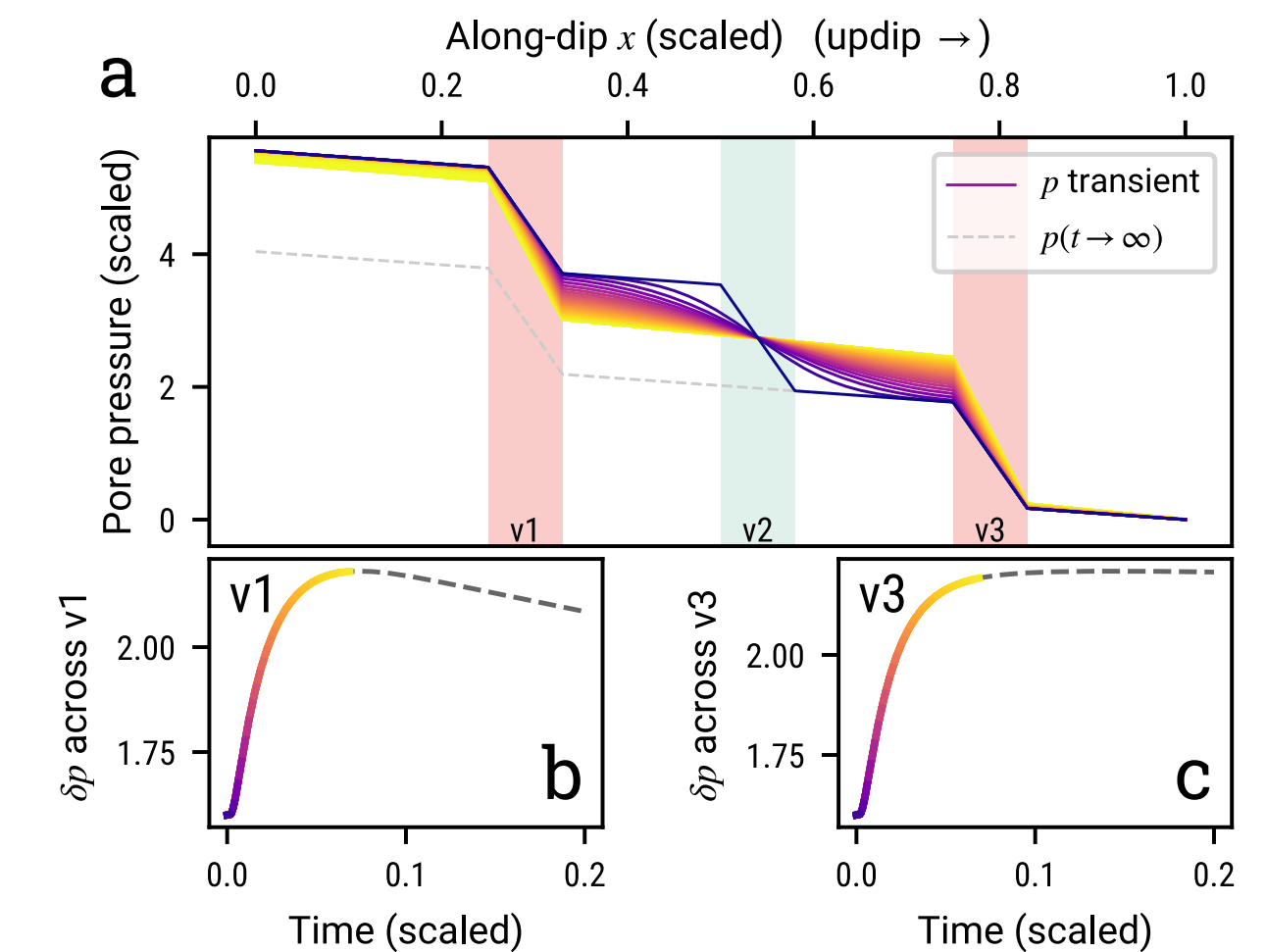
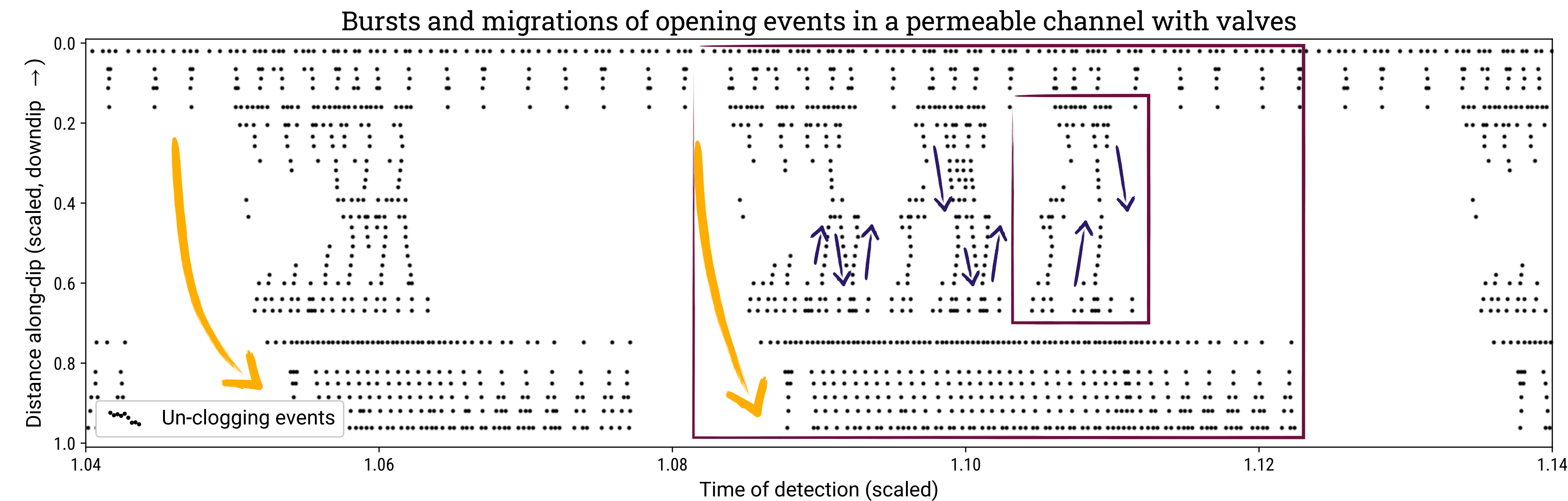
Patterns of clustering and migration

The synthetic seismic activity (opening activity) organizes around those rapid cascades of events. They are the building blocks of larger bursts and migrations, on both short and longer time and space scales.



The opening of v2 sends a bidirectional pressure transient that raises the δp at v1 and v3, bringing them closer to failure

In the model, seismic sources **interact** with each other through **pressure transients**



patterns of **clustering** and **migration** emerge from these **elementary cascades**

Results – (ii)

Input flux controls the activity

In a range of input flux – depending of the valves' sensitivity to the pressure gradient and permeability – **valves can both open when closed and close back when open**. In this flux range, activity is permanent and variable.

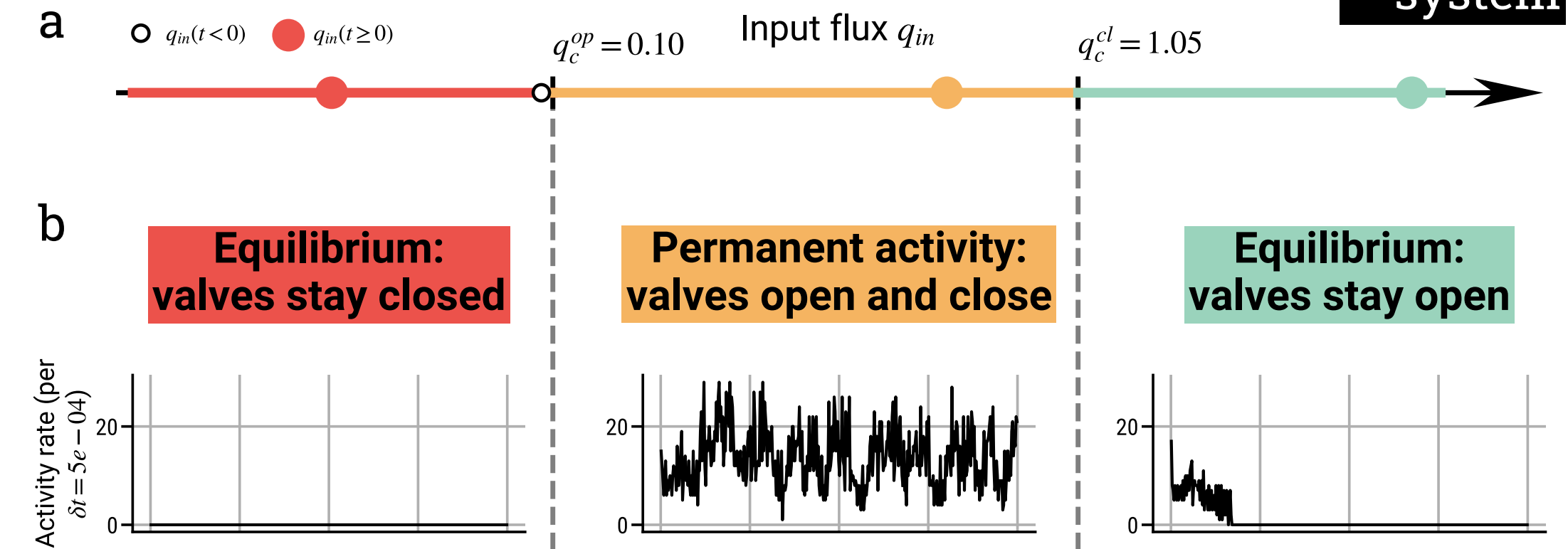
Within the domain of flux allowing permanent activity, different regimes can be observed:

- Low flux, valves are mostly closed, and open in bursts: **activity is low and time-clustered**
- Intermediary flux, valves open and close rapidly, randomly but at a constant rate: **activity is high and Poisson-like**
- High flux, valves are mostly open, and when they close large bursts occur as they impede the flow: **activity is low, and quasi-periodic**

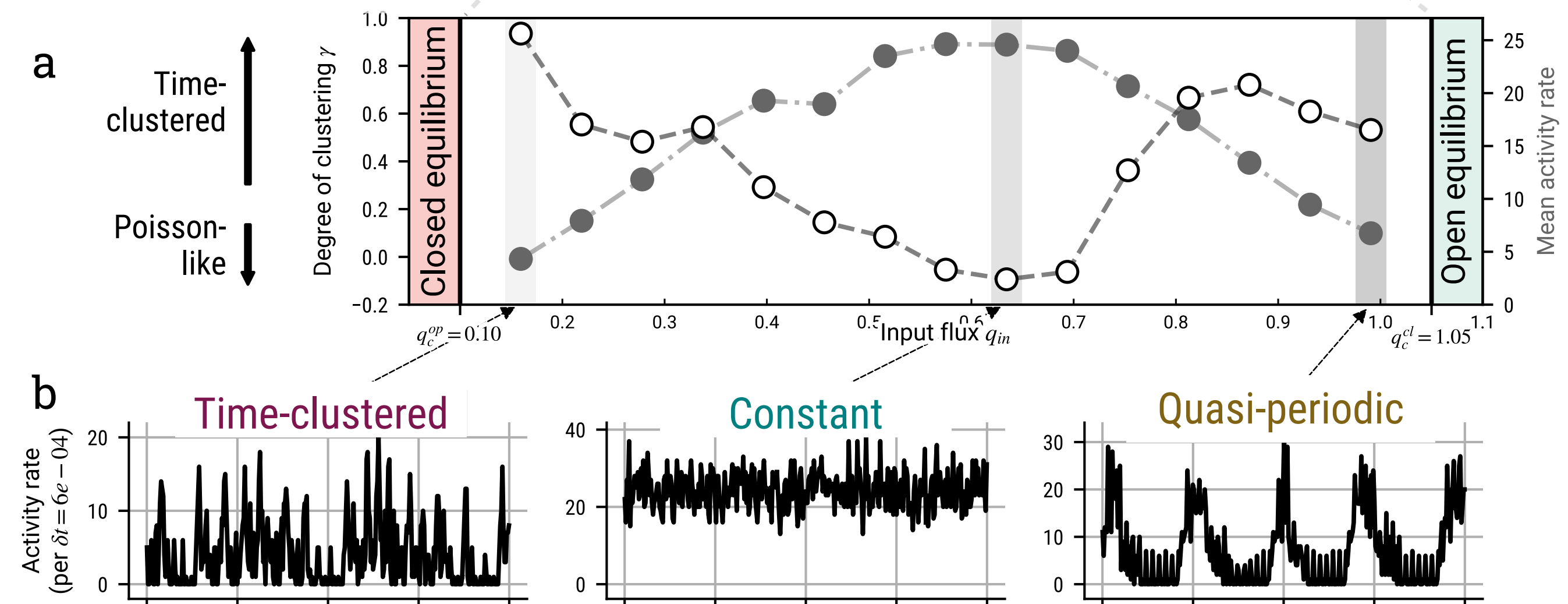
Under a **constant source** of fluid pressure,
the proposed fluid transport processes,
generate and sustain

realistic **patterns of intermittence** and
migration of seismic activity

In a range of input flux q_{in} , activity is **permanent and intermittent**



within this range, q_{in} governs the activity style: **time-clustered, constant, or quasi-periodic**



Model design

A permeable fault channel

We model the ascent of fluid along the permeable fault zone in a **high permeability, 1D channel along the dip of the fault**.

The channel is fed **by a constant fluid flux q_{in}** at its downdip end, from the dehydration of downdip slab segments.

At its updip end, the channel is connected to a highly permeable area (fractured continental crust), and the **pressure is fixed to hydrostatic levels**.

A valve mechanism

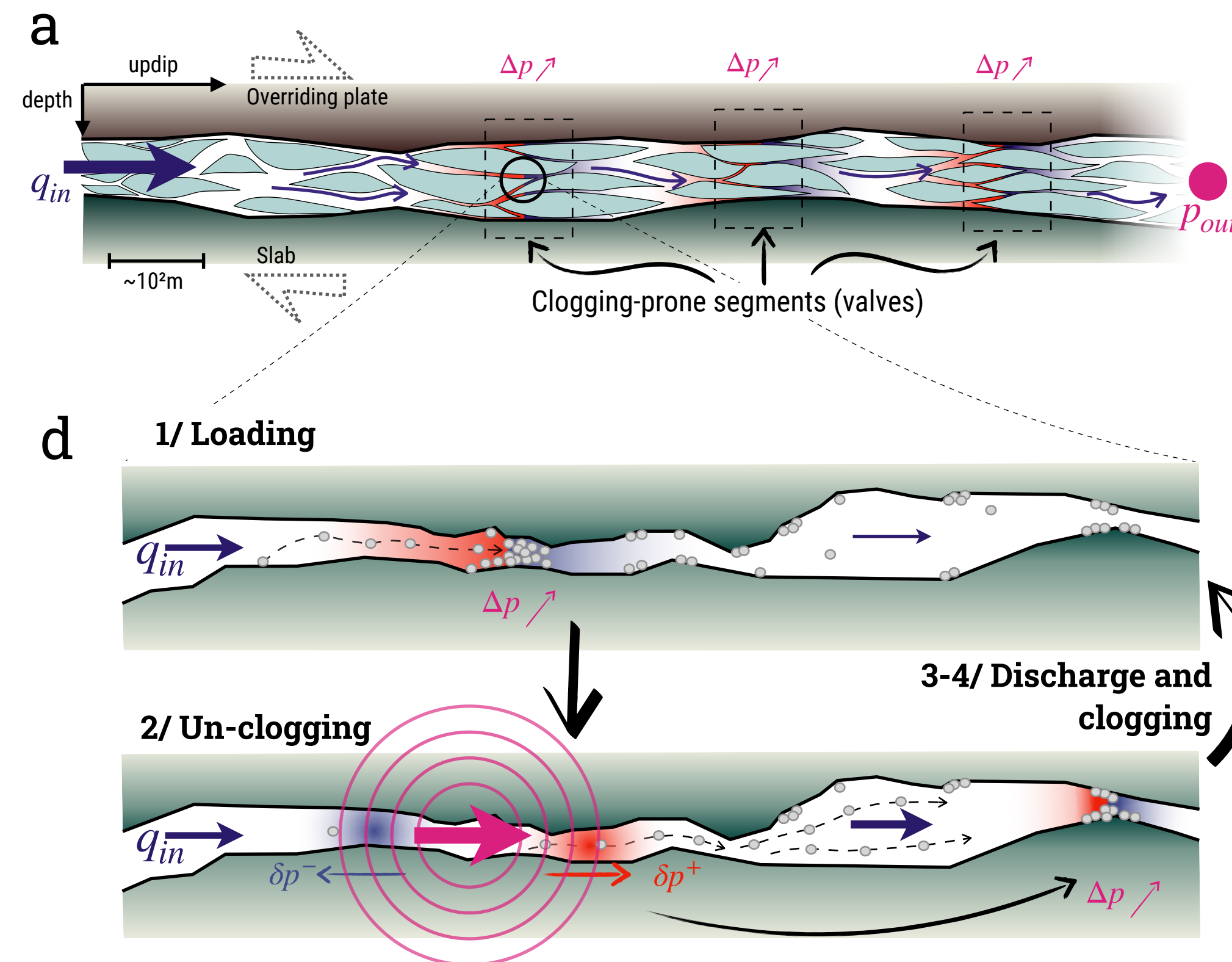
Fluid flow in the fault zone carries fine material (silica colloids or material eroded from the permeability walls) [5], that is subject to erosion and deposition processes, in response to the local velocity of the flow.

We model this phenomenon as permeability valves. In fixed locations, the permeability can open and close in response to the local pressure gradient: **δp is high, then the valve opens, and δp drops, allowing the valve to close**, with an hysteresis (e).

When a valve opens, it releases a strong fluid pulse because of the local pressure gradient build up while the valve is closed. This strong, rapid, localized pressure gradient can act as **a source of seismic waves [6]**, or trigger seismic slip in local asperities.

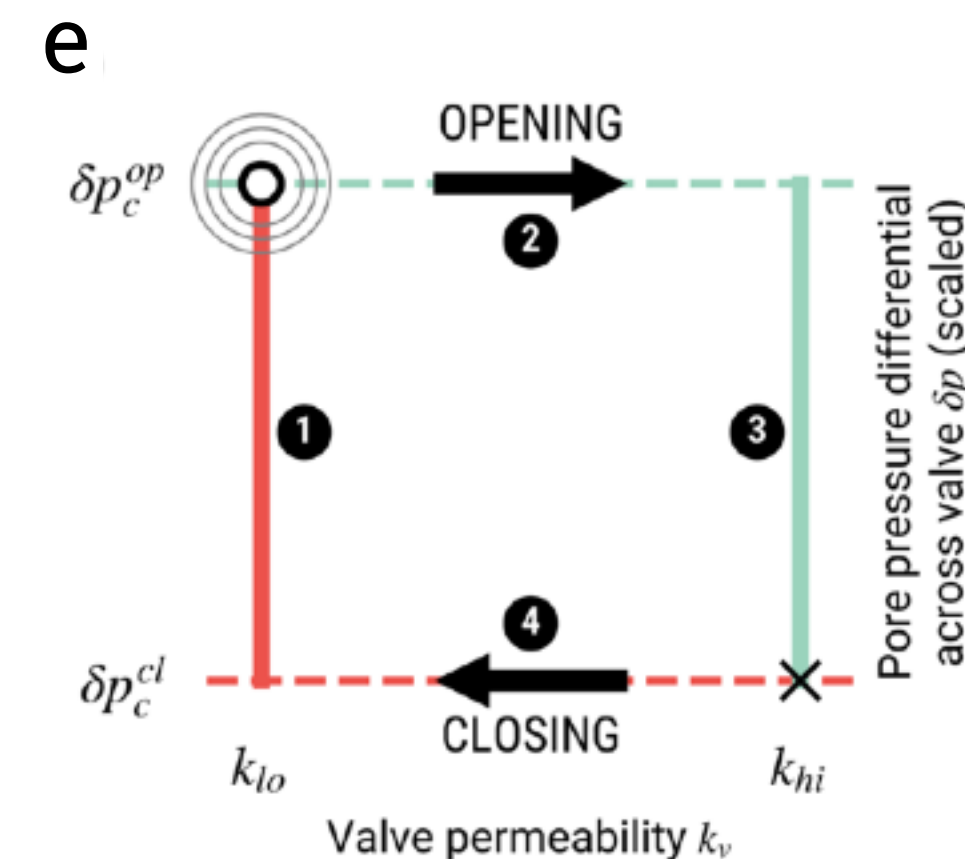
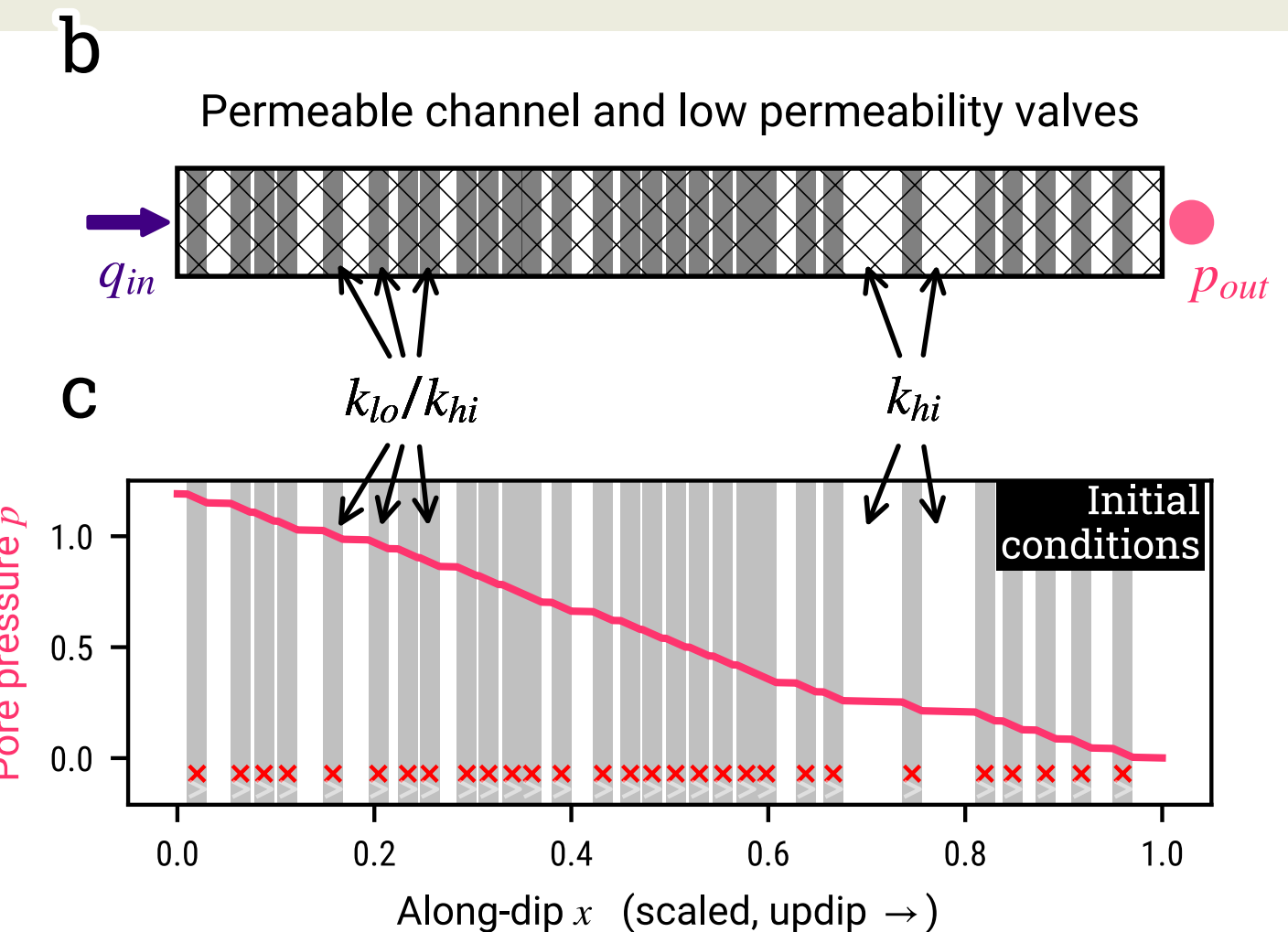
We therefore consider that each opening is accompanied by an LFE-like seismic event.

We solve for fluid pressure diffusion in a permeable channel with valves



A 1D permeable channel, with valves, along the dip of the fault

Schematic (a) and physical (b) representations of channel and permeability valves. (c) shows the initial fluid pressure conditions in a channel.



Valves: permeability heterogeneity and variability on an elementary scale

(d) Schematic representations of a valve cycle. (e) shows the hysteretical cycle that valve permeability follows in response to the pressure diff. across the valve.