

## SZ4D Science Community Meeting

# Slow slip events driven by episodic fluid release from slab dehydration

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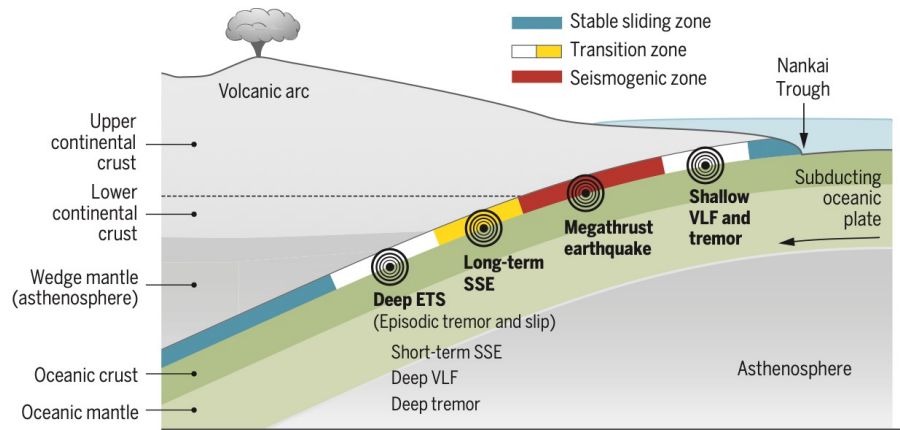
**Caltech**

April 21, 2026  
Long Beach, California

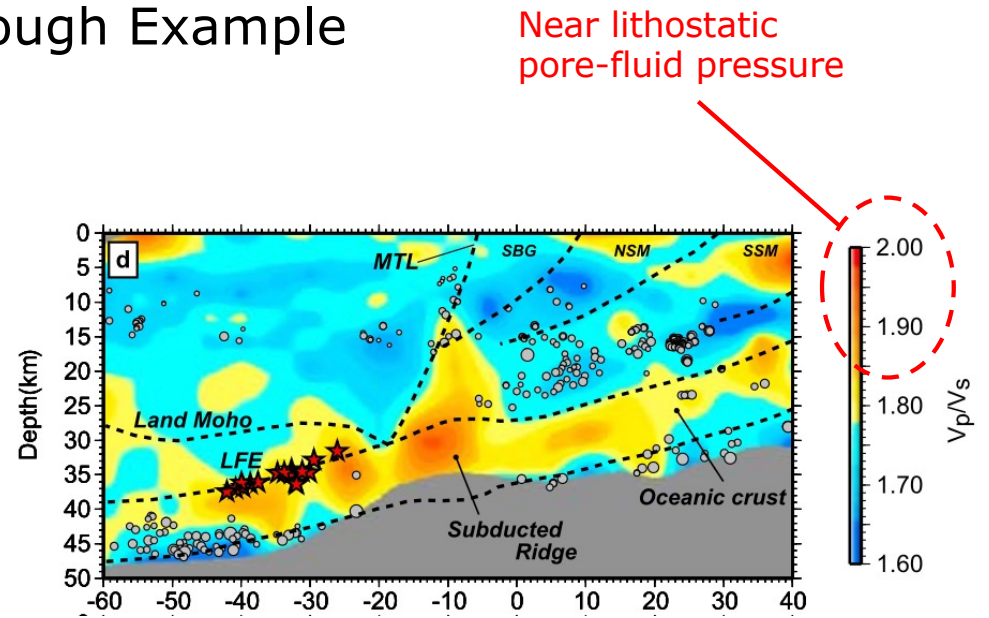


# Young and warm subduction zones

## The Nankai Trough Example



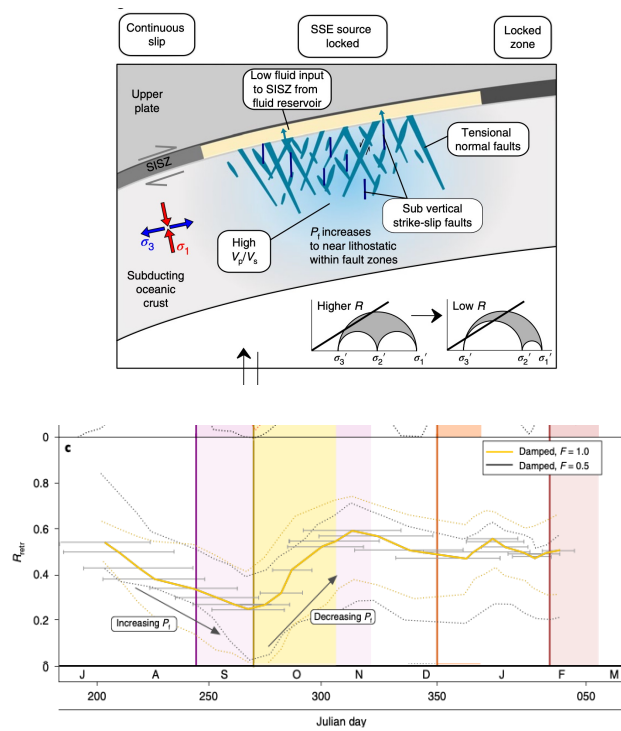
Obara and Kato, 2016, *Science*



Kato et al, 2010, *GRL*

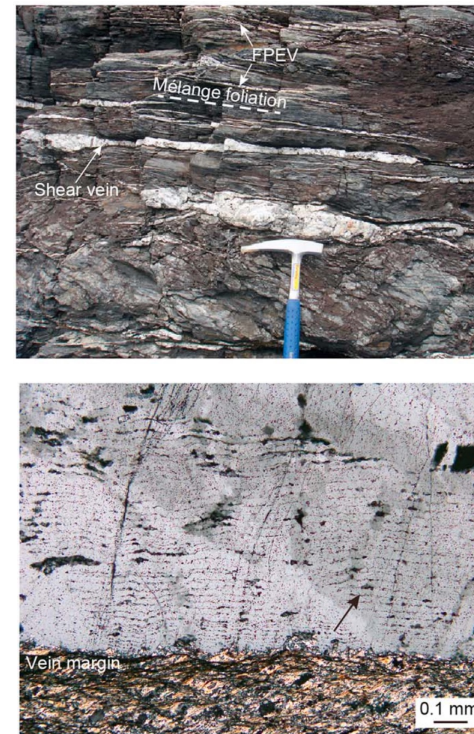
# Fluid pressure transients

- Geophysics (Hikurangi) Scale: ~ 10 km



Warren-Smith *et al*, 2019, *Nat. Geosci.*

- Geology (Southwest, Japan) Scale: ~ 10 cm



Ujii *et al*, 2018, *GRL*

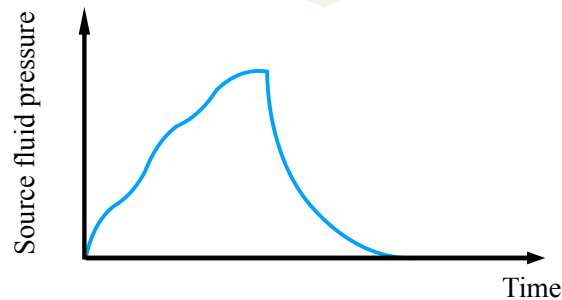
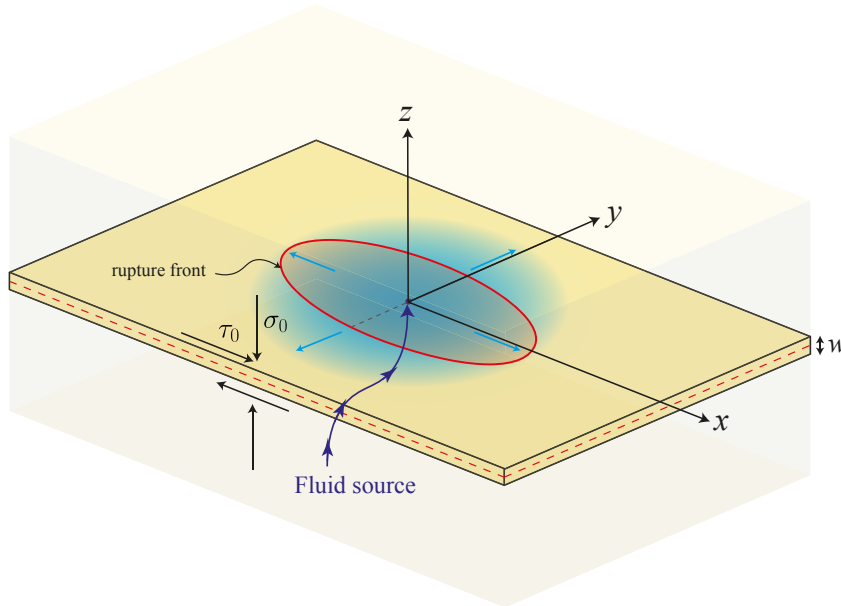
# Questions

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- 1) Can pore-fluid pressure transients trigger and sustain deep slow-slip events?
- 2) What fluid sources and transport mechanisms at depth are capable of generating such pressure transients?

# Fluid-driven slow slip events

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## Governing equations:

Fluid flow:

- $S \frac{\partial p}{\partial t} - \nabla \cdot \left( \frac{k}{\eta} \nabla p \right) = \delta_D(\vec{x}) H(t) q(t)$

Quasi-static elasticity:

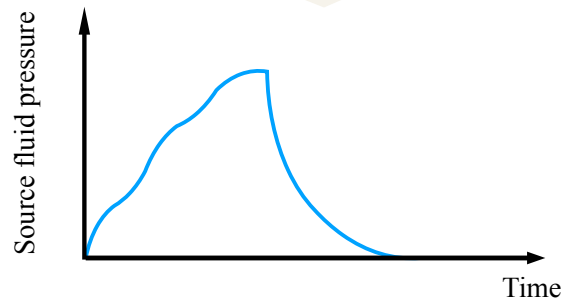
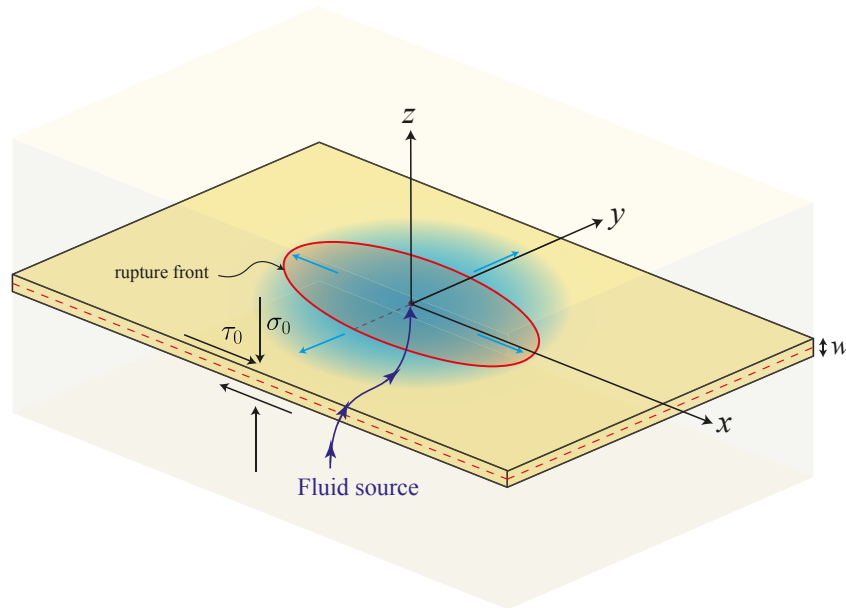
- $\boldsymbol{\tau} = \boldsymbol{\tau}_0 + \iint_A \mathbf{H} \cdot \boldsymbol{\delta} \, dx dy$

Friction:

- $\|\boldsymbol{\tau}\| = f \cdot (\sigma_0 - p)$

# Fluid-driven slow slip events

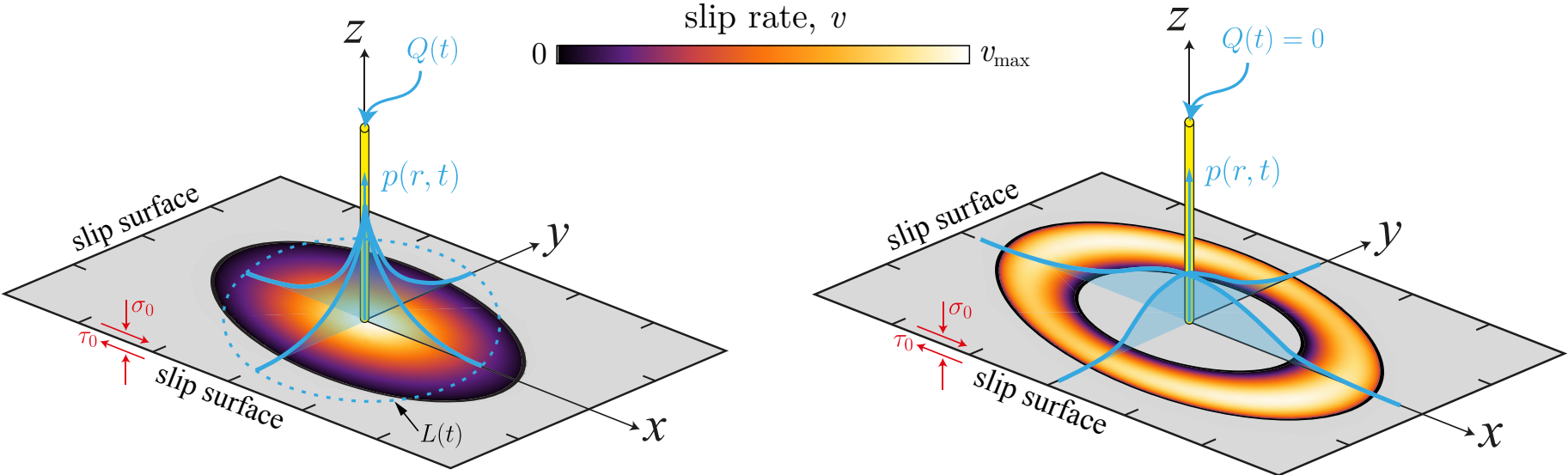
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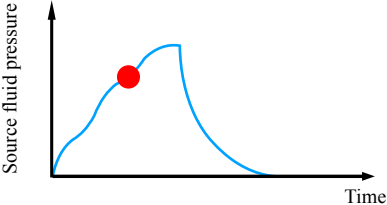
## Model assumptions:

- Along-fault fluid transport:
  - Conservation of mass and momentum for the fluid (equivalent porous media)
- Quasi-static linear elasticity for lithospheric deformation
- Plate-interface motion governed by a frictional regime

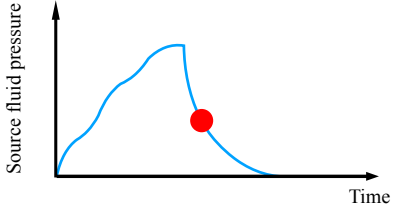
# Numerical simulations



Pressurization



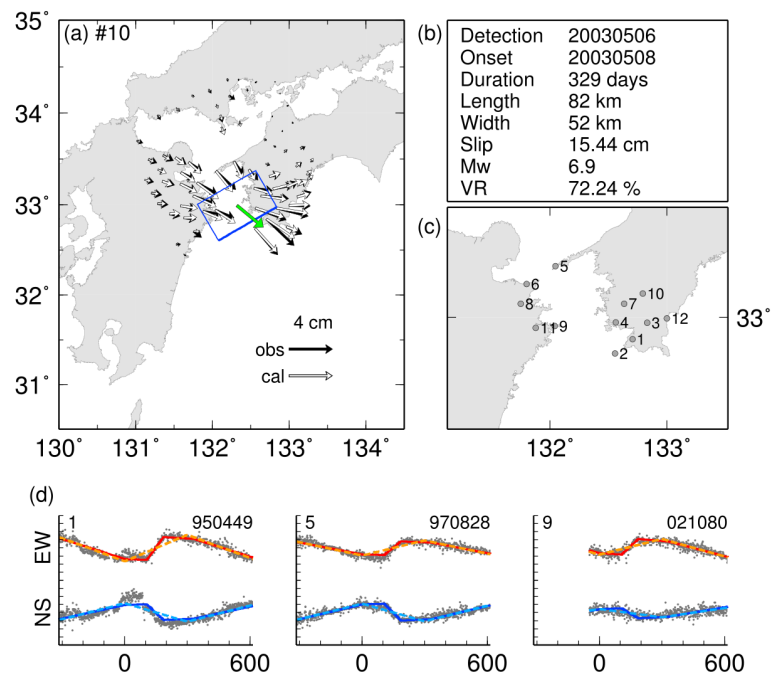
Depressurization



# Geodetically-inferred quantities depend on fluid source

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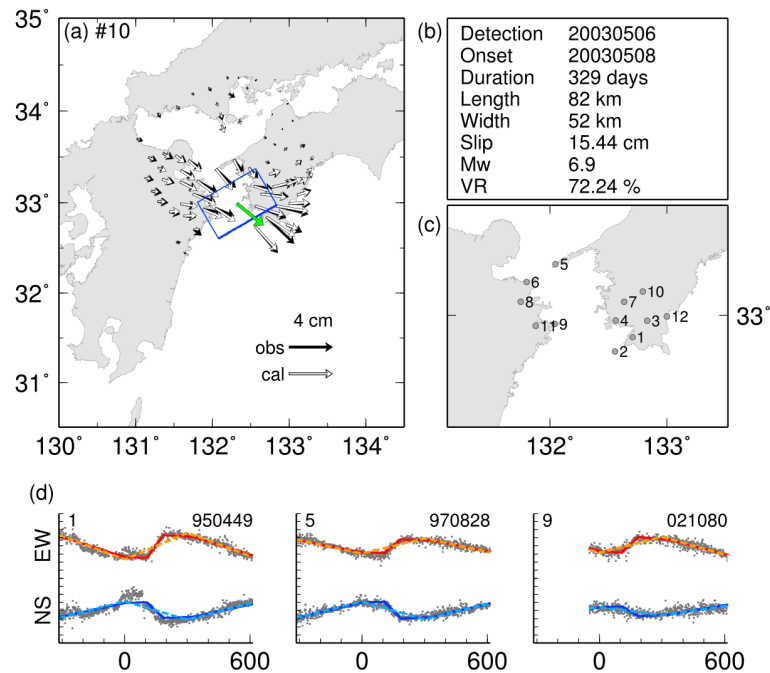
## SSE in Nankai - Example



Takagi *et al*, 2019, *JGR Solid Earth*

# Geodetically-inferred quantities depend on fluid source

## SSE in Nankai - Example



Takagi *et al*, 2019, *JGR Solid Earth*

Mean slip:

$$\langle \delta \rangle(t) = \frac{16}{3\pi} \frac{\Delta\tau_{r-0}^{1/2}}{\mu} \left( \frac{f_r}{2\pi w(S\Delta\tau_{r-0} + f_r\Delta\phi_p)} \right)^{1/2} \sqrt{V(t)}$$

Rupture area:

$$A(t) = \frac{f_r}{2w(S\Delta\tau_{r-0} + f_r\Delta\phi_p)} V(t)$$

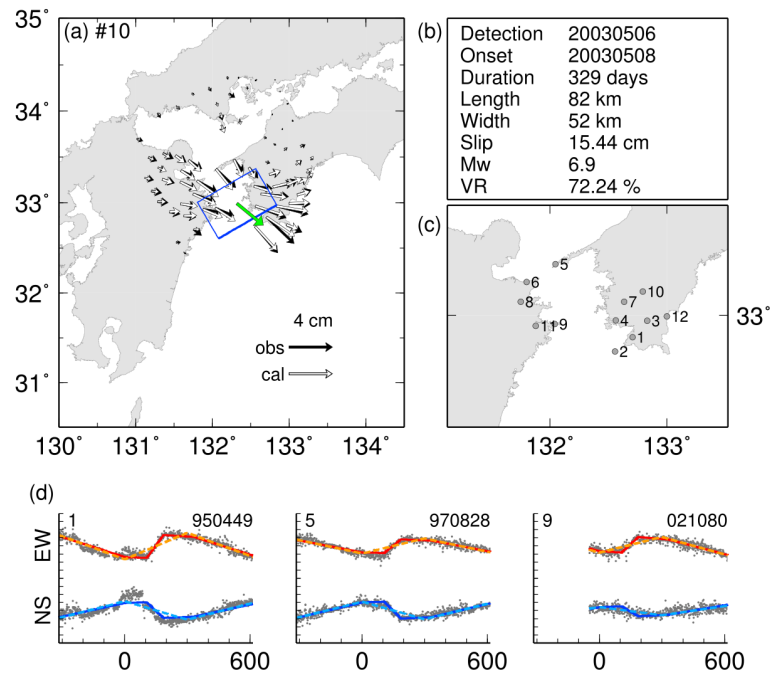
Moment release (not independent):

$$M_0(t) = \frac{16}{3(2\pi)^{3/2}} \frac{1}{\sqrt{\Delta\tau_{r-0}}} \left( \frac{f_r}{w(S\Delta\tau_{r-0} + f_r\Delta\phi_p)} \right)^{3/2} V(t)^{3/2}$$

+ Duration

# Geodetically-inferred quantities depend on fluid source

## SSE in Nankai - Example



Takagi et al, 2019, JGR Solid Earth

Mean slip:

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Rupture area:

$$A(t) = \frac{f_r}{2w(S\Delta\tau_{r-0} + f_r\Delta\phi_p)} V(t) \quad V(t): \text{injected fluid volume}$$

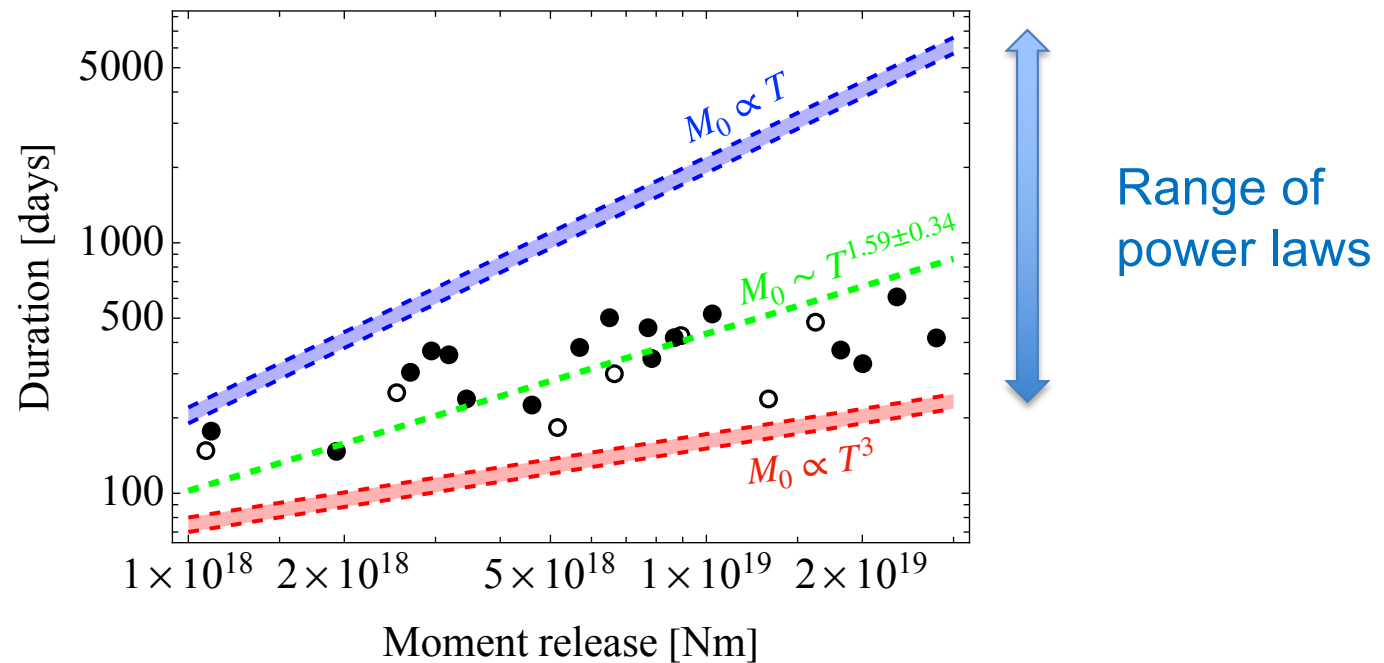
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+ Duration

# Moment-duration scaling relation

Nankai Trough, Japan



Long-term SSEs: Catalog from Takagi et al, 2019, *JGR: Solid Earth*

# Connection between fluid source and $M_0 \propto T^n$

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Scaling relation

$$M_0 = BT^n$$

$$B = \frac{16}{3(2\pi)^{3/2}} \frac{1}{\sqrt{\Delta\tau_{r=0}}} \left(\frac{f_r A}{wS}\right)^{3/2}$$



Fluid source

$$V(t) = At^{2n/3}$$

$$Q(t) = \frac{2n}{3} At^{2n/3-1}$$

$$p(r, t) = \frac{2n}{3} \frac{A\eta}{4\pi kw} t^{2n/3-1} \int_0^1 \tau^{2n/3-1} \frac{e^{-\xi^2/(1-\tau)}}{1-\tau} d\tau$$

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Fluid source

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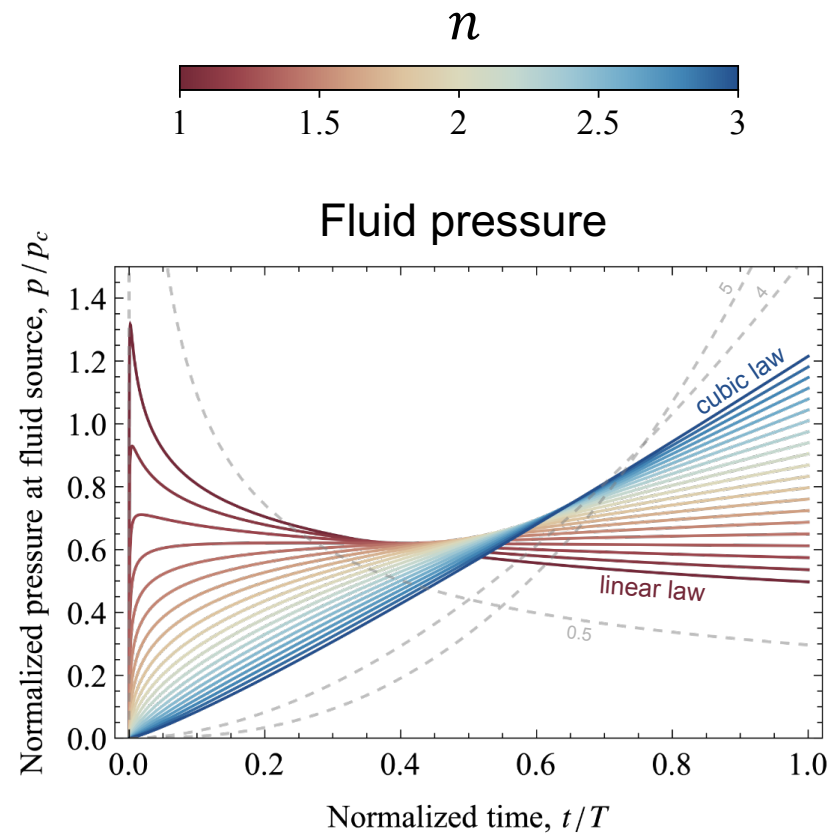
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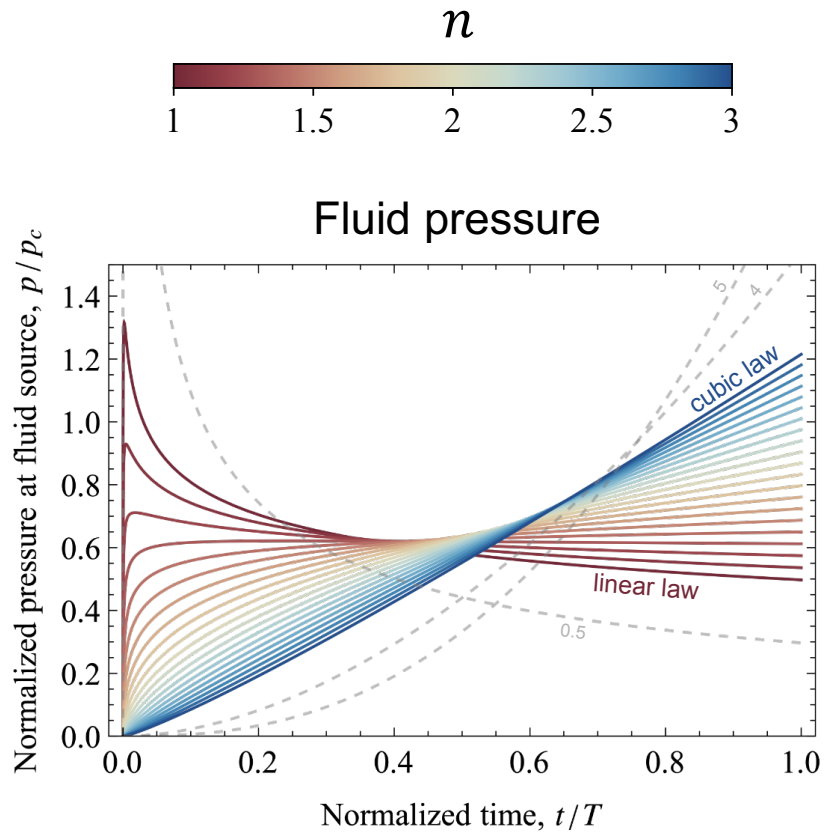
For a fixed  $n$ , there is a unique fluid-source solution.

# Family of solutions for a given $M_0 \propto T^n$

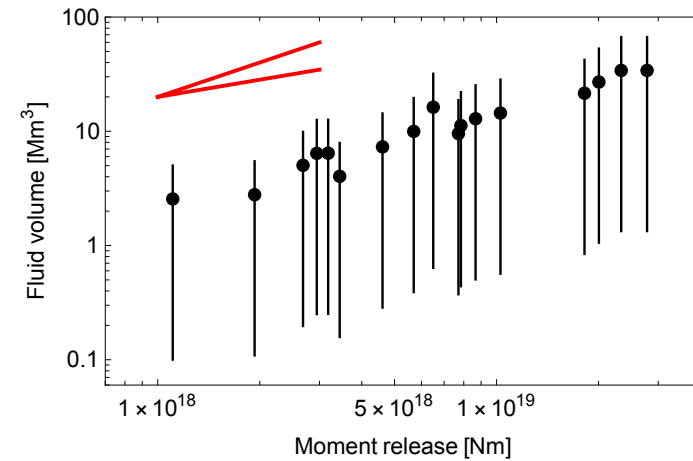
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# Time scales and volume scales



- T: duration of slow slip event
  - 1 day to 1.5 years
- V: injected fluid volume per event



Long-term SSEs: Catalog from Takagi et al, 2019

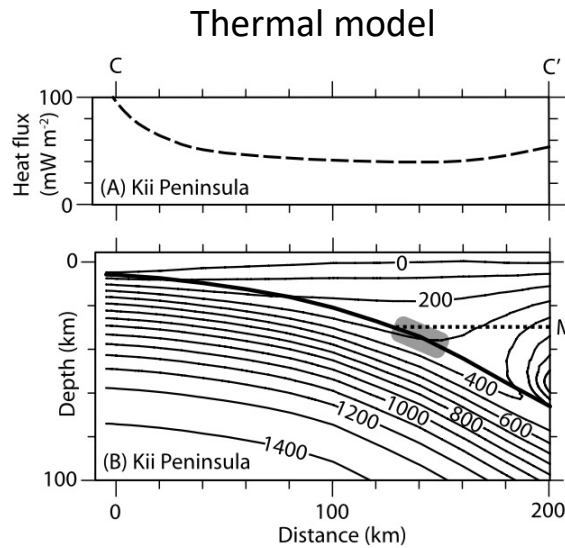
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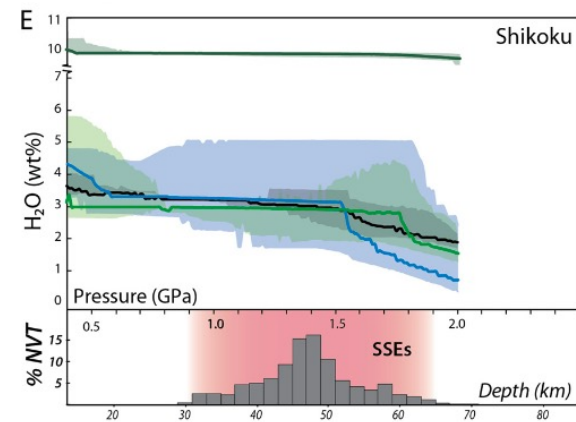
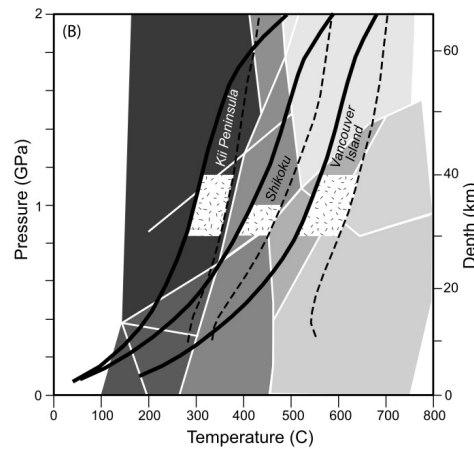
# Dehydration reactions of oceanic crust

## Nankai Trough, Japan



Peacock, 2009, *JGR Solid Earth*

**PT diagram for MORB**

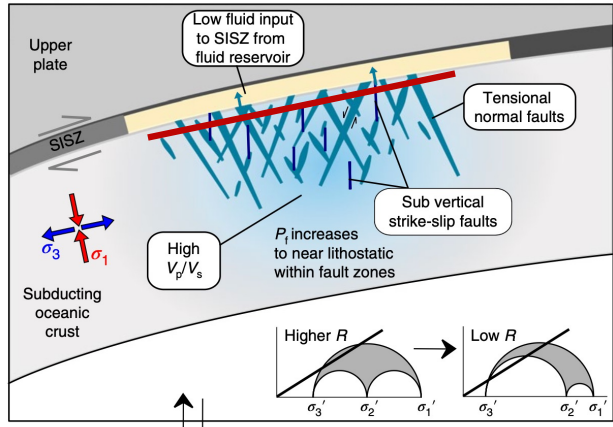
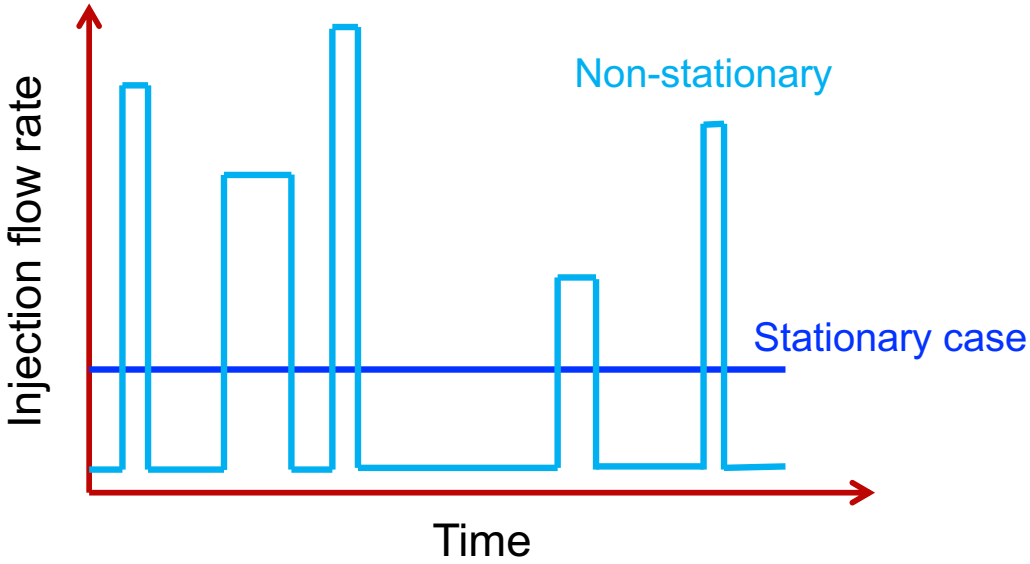


Condit et al., 2022, *EPSL*

Fluid production rates are too slow to account for the timescales relevant to SSEs

$$Q(z) = \frac{\rho_s}{\rho_f} \frac{dW}{dz} H \cdot \underline{V_{pl}} \sin(\theta)$$

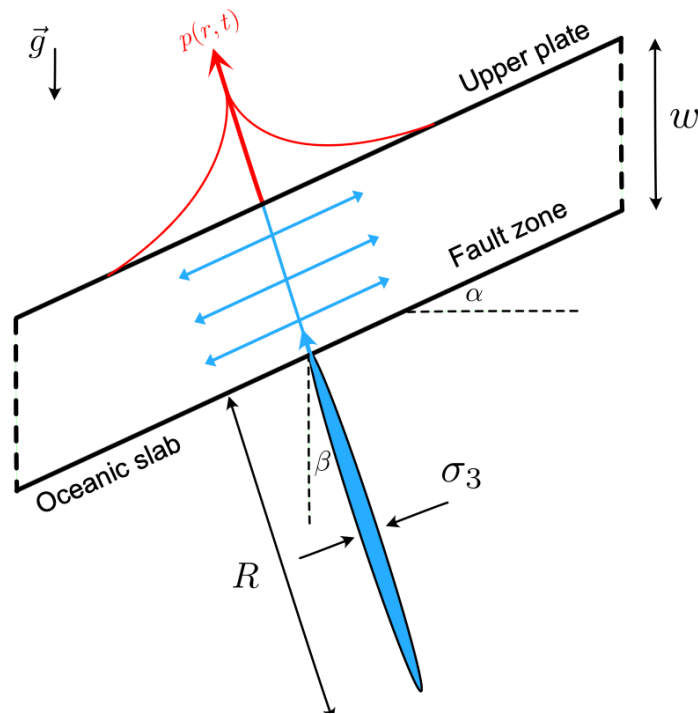
# Non-stationary fluid release



Warren-Smith *et al.*, 2019, *Nat Geo*

# Fluid-filled fracture in contact with the megathrust

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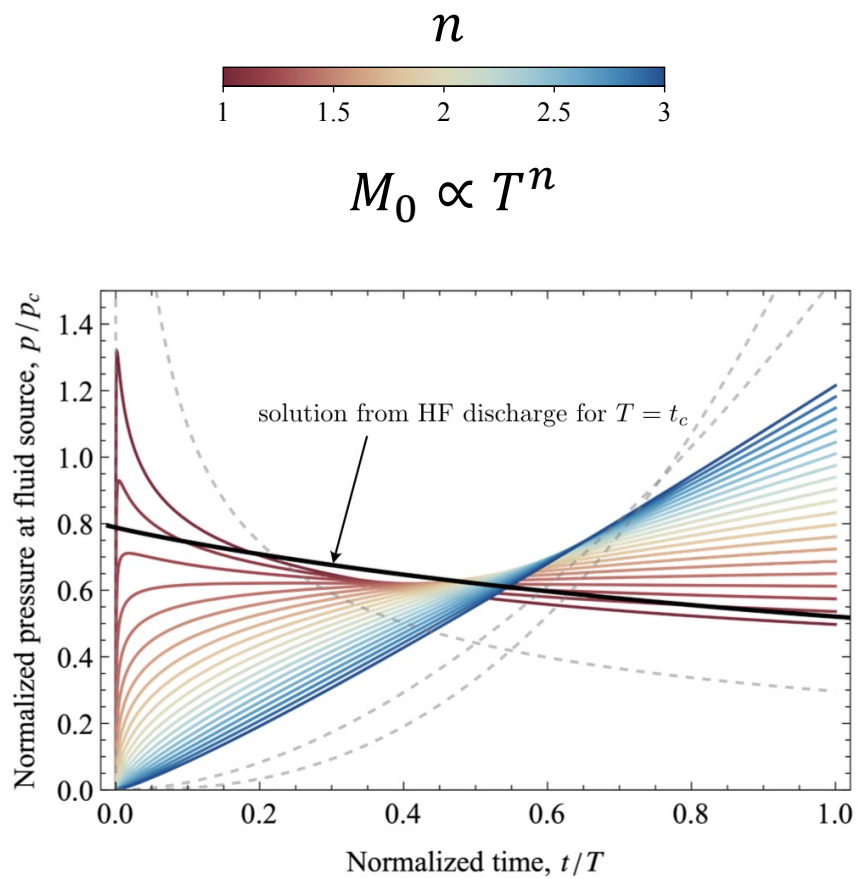


## Model assumptions:

- Fluid volume balance and elasticity for fracture
- Fluid transport along the plate boundary

# Solution and characteristic time

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Characteristic time

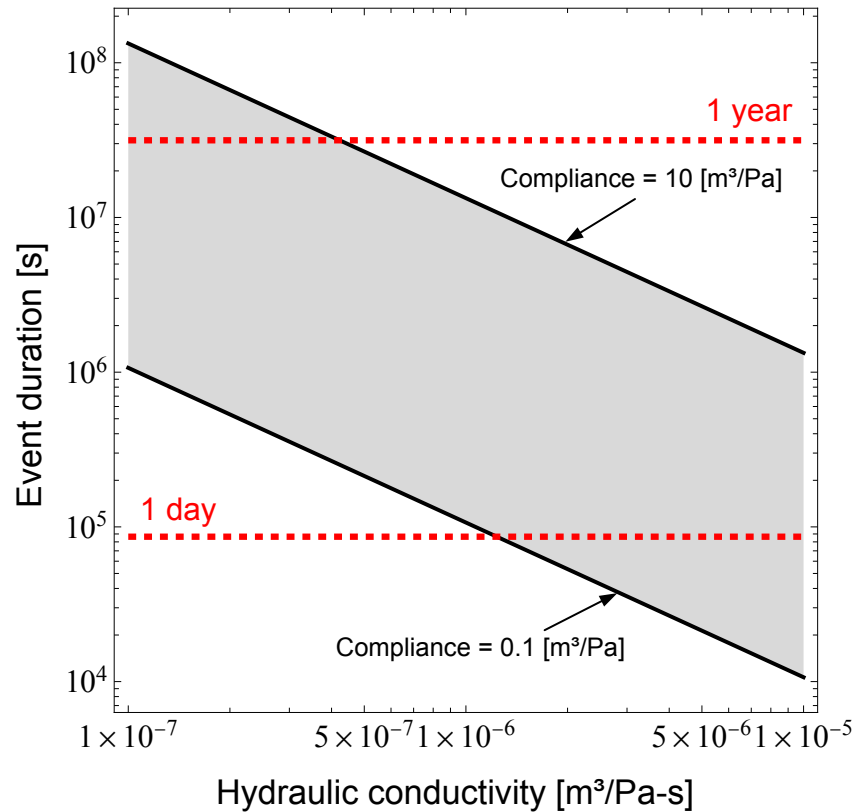
$$T \sim \frac{c}{kw/\eta}$$

# Delivery time scale versus duration

$$T \sim \frac{c}{K}$$

$$c = \frac{16 R^3}{3 E'} \quad \text{Fracture compliance}$$

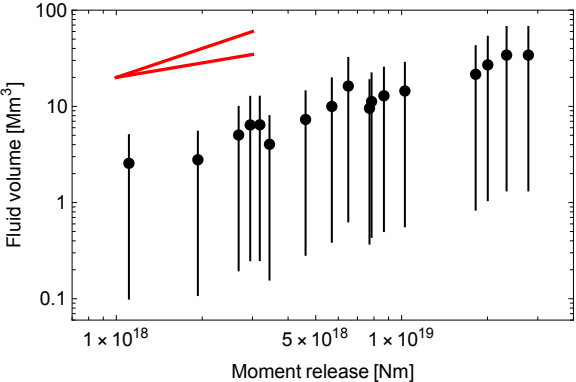
$$K = \frac{k w}{\eta} \quad \text{Hydraulic conductivity}$$



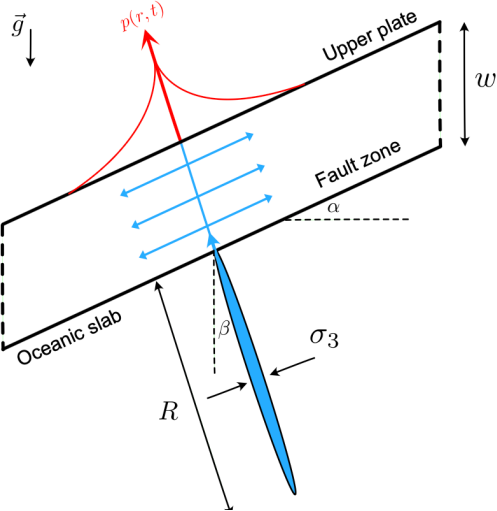
# Fluid volume budget

## Nankai Trough, Japan

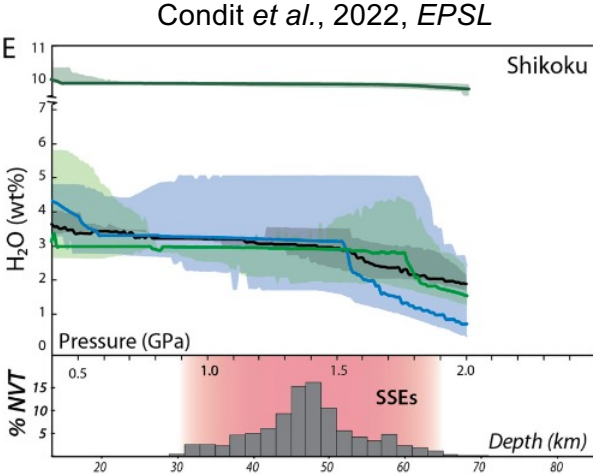
M-T from geodesy



Fracture size (slab)



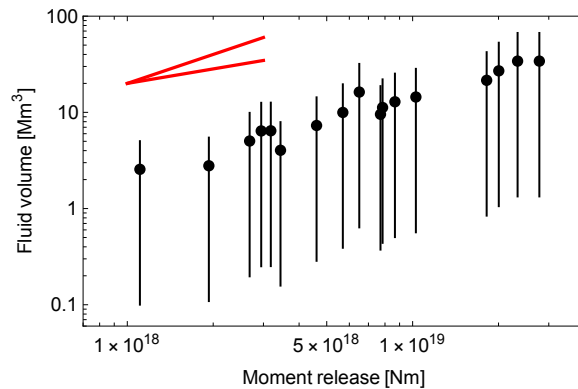
Dehydration reactions



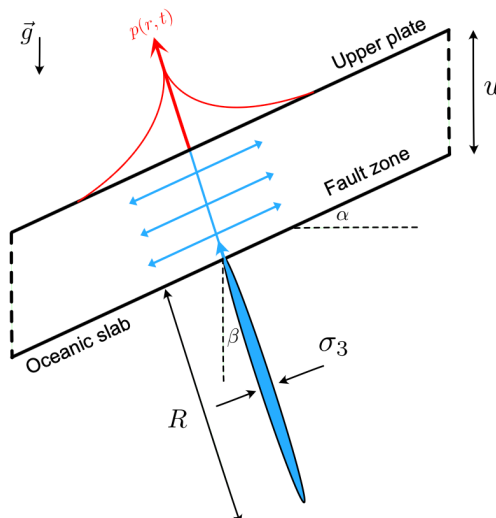
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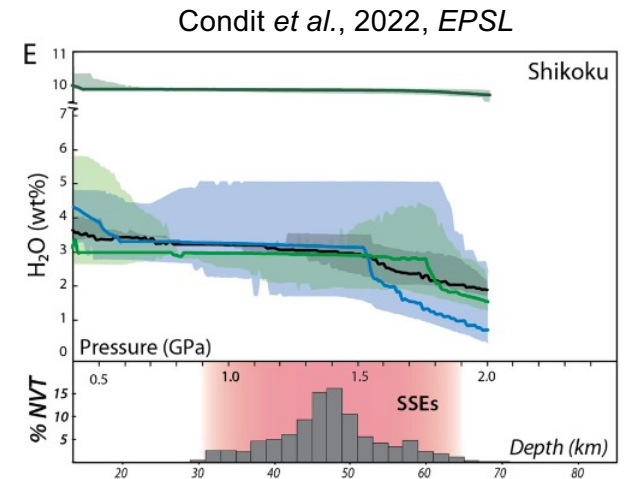
M-T from geodesy



Fracture size (slab)



Dehydration reactions



$$V \sim 1 - 100 \text{ Mm}^3$$

Over ~ 20 years in Nankai

# Summary

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- SSEs can be fluid-driven
  - Tested against geodetic, seismological, thermal, and petrological studies/observations
- Release of metamorphic fluids can be non-stationary (transient hydraulic fractures)
- Hydraulic fractures can account for the time- and volume-scales required for slow slip events
- Although the volume budget is tight