Investigation of the influence of fault strength on fault behavior for the shallow part of the fault by the dynamic rupture simulation

Today's Work, Tomorrow's Heritage
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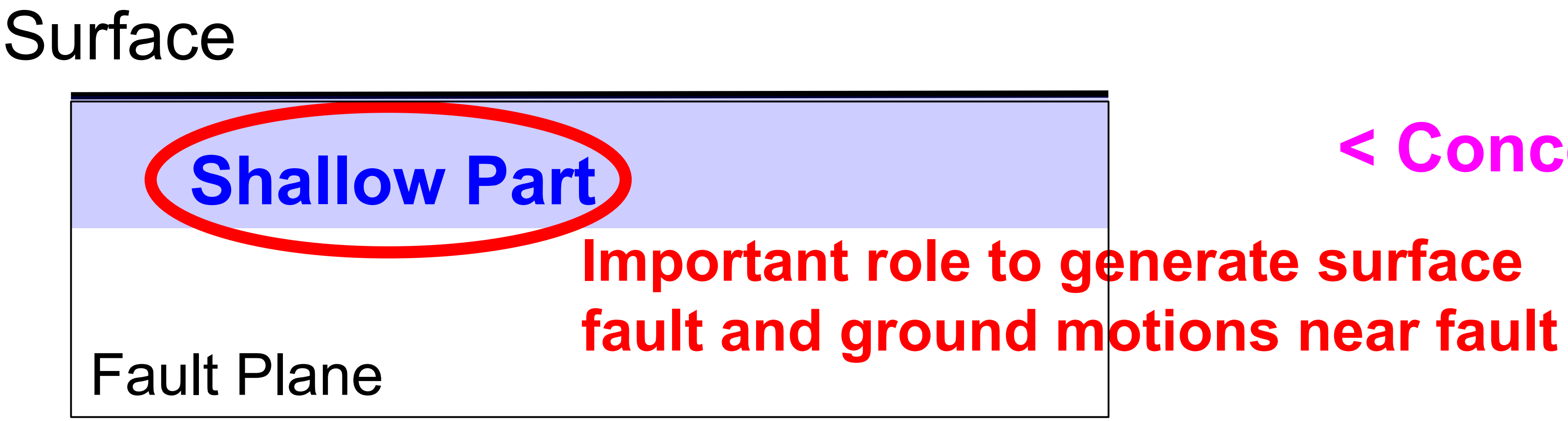
Introduction

■Modeling Fault behavior on the Shallow Part of the Fault



< Conceptual Figure >

< Points for Modeling Shallow Part of the Fault >

- Generating surface fault
  → **Step or Crack on the surface influence on the buildings**
- Modeling ground motions close to the fault
  → **Difference of the ground motion with (Surface/Buried) fault**

Introduction

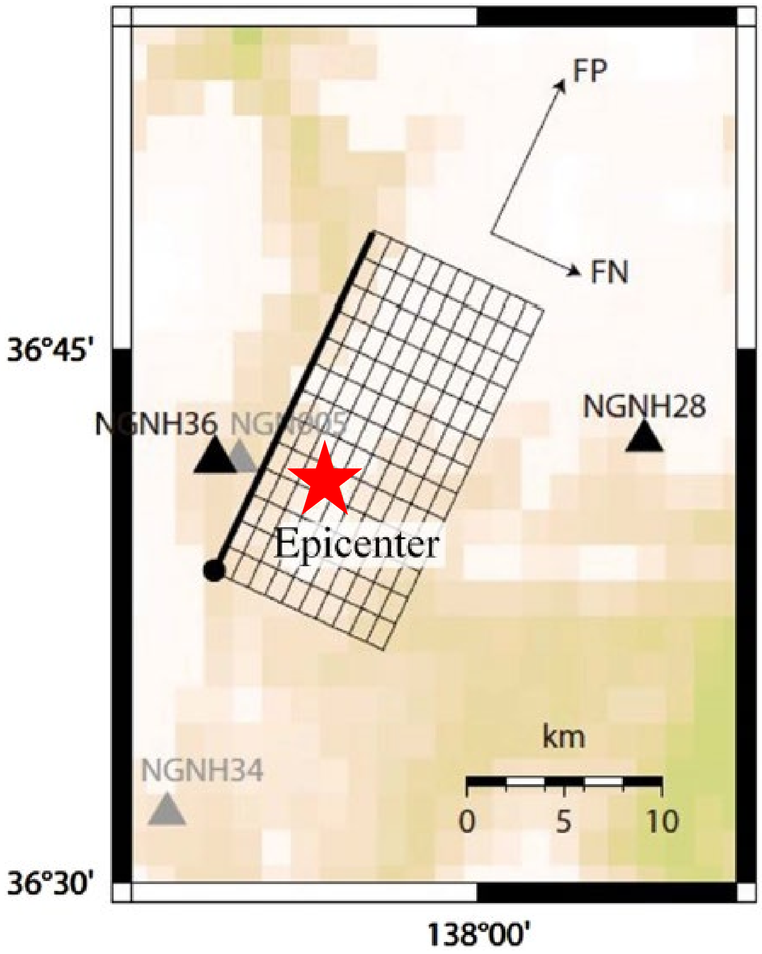
■Modeling ground motions for “Buried Fault” Earthquake

- ➢Strong Motion “Recipe” (Irikura and Miyake, 2001)

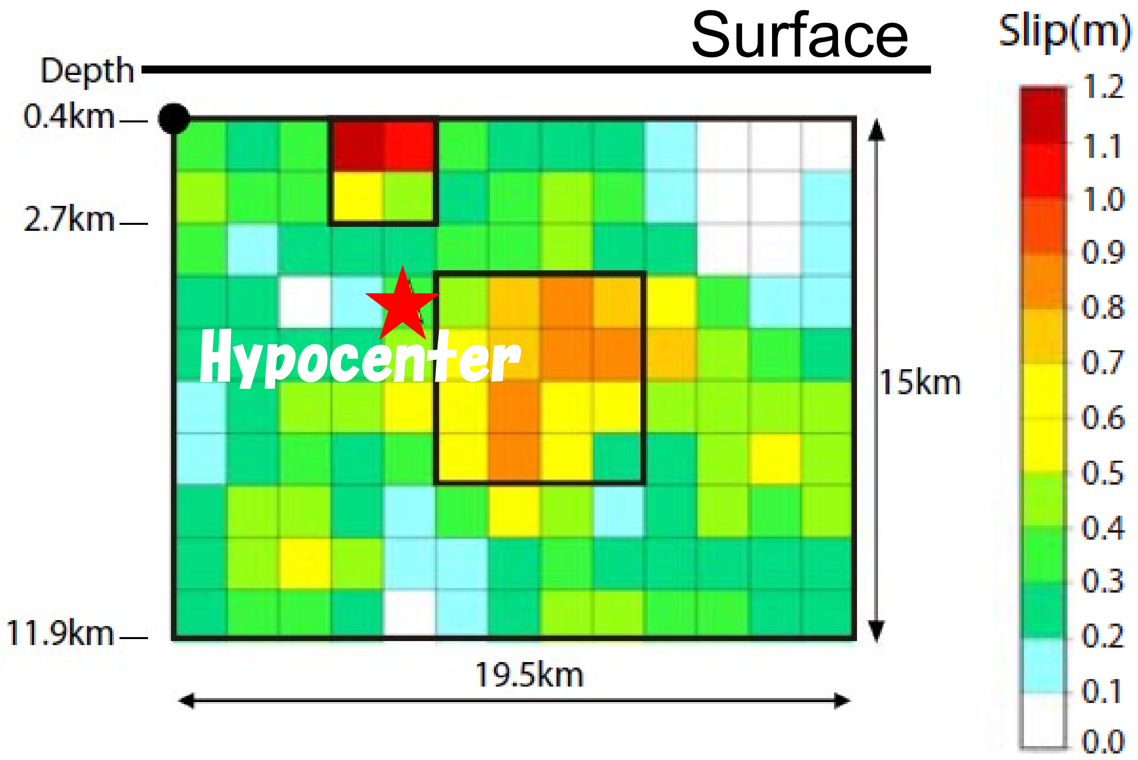
⇨ Not yet establishing the idea to model ground motions for “surface fault” earthquake

We have tried to model source behavior of the earthquake with “surface fault” and investigate the features of shallow part of the fault based on dynamic simulations.

Simulation Method



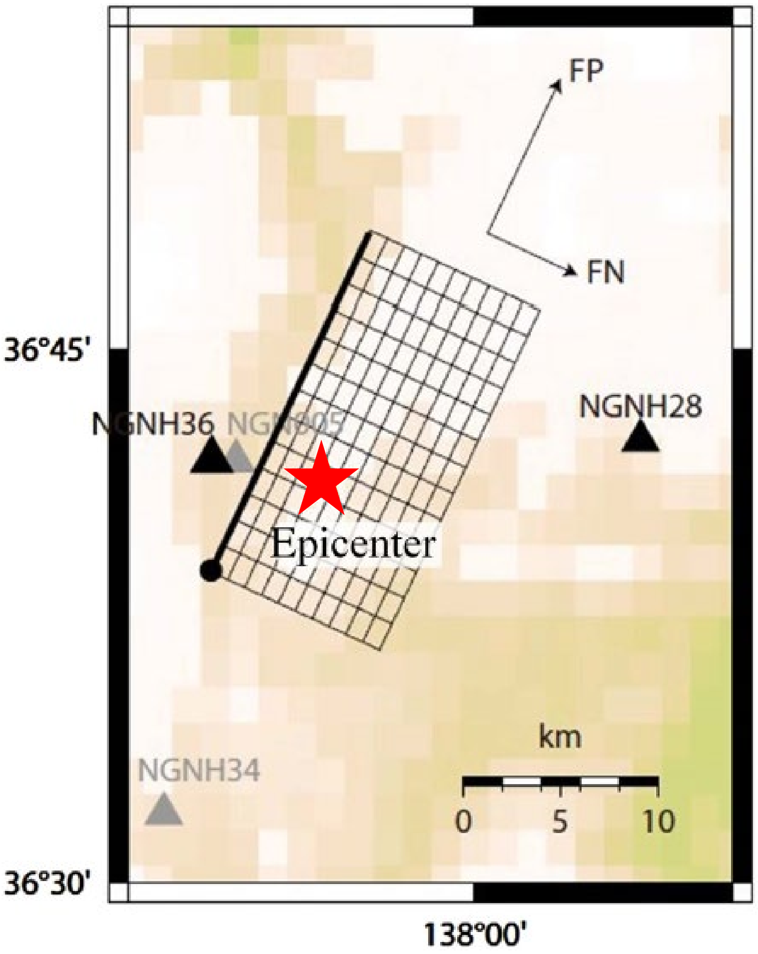
- **2014 Northern Nagano Earthquake (Mw 6.2)**
  (Breaking "Surface Fault" earthquake)

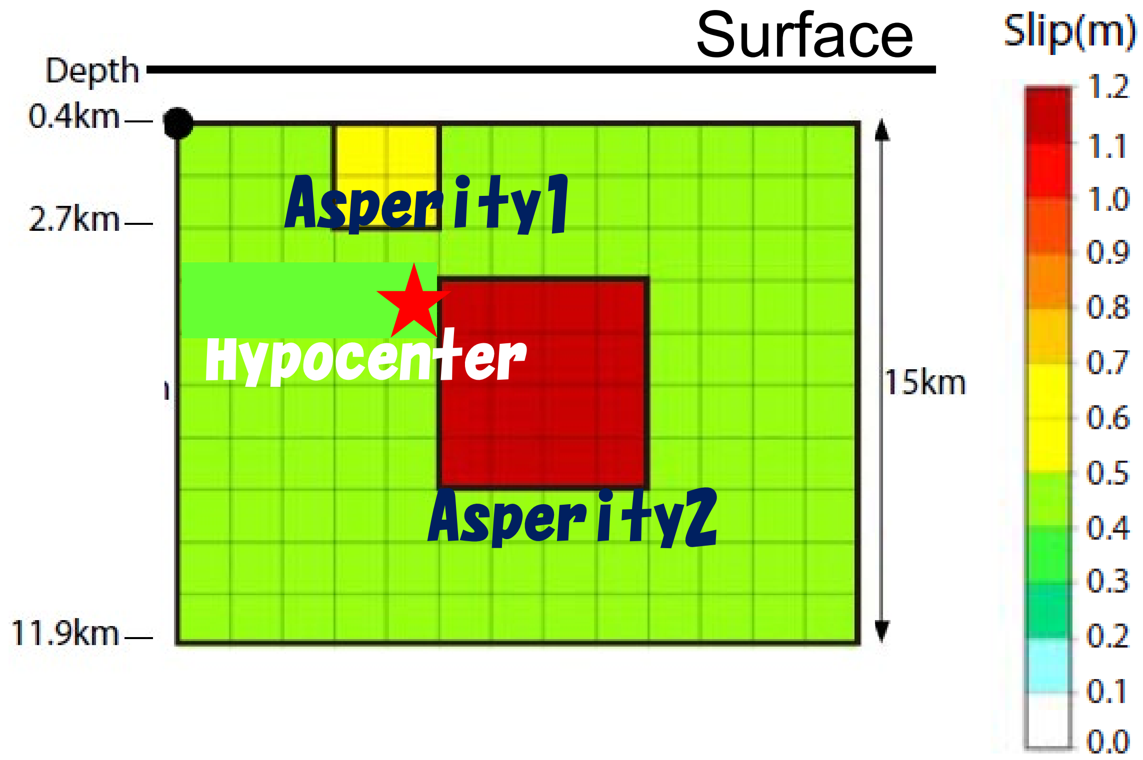


Slip distribution by kinematic source inversion
(Hikima et al., 2015)

Simulation Method

- 2014 Northern Nagano Earthquake (Mw 6.2) (Breaking "Surface Fault" earthquake)





Characterized source model (Tanaka et al., 2017)
→ 2 Asperities + Backgournd

Simulation Method

■ Simulation Condition

➢ Source parameter distribution

→ Based on characterized source model (Tanaka et al., 2017)

→ Assuming slip-weakening relation (Ida , 1972)

→ S-values for the Asperity is 1

➢ Method : SPECFEM3D (Galvez et al., 2014)

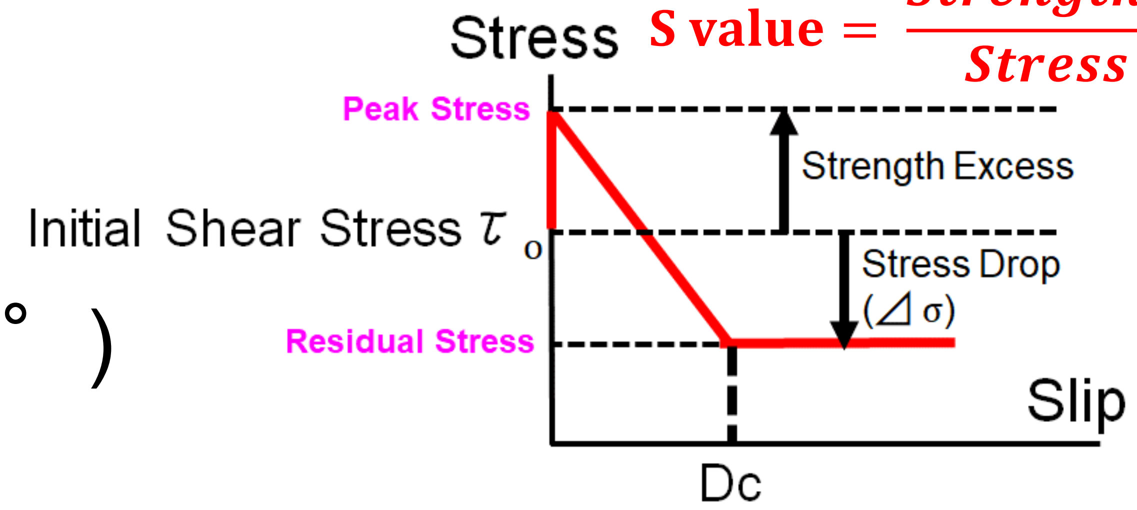
➢ Homogeneous Medium

Vs 3.4km/s, Vp 6km/s

(Hikima et al., 2015)

➢ Planar Fault (Dip Angle 50°)

$$\textbf{S value} = \frac{\textit{Strength Excess}}{\textit{Stress Drop}}$$



Model Construction Strategy

Assuming principal stress (σ1, σ3) as a function of depth

↓

Calcute $\tau_o \cdot \sigma_n$
(Aochi and Tsuda, 2023)

Setting stress drop and SE
(Assuming S =1 on Asperity)

↓

Calculating frictional coefficient(depth dependent)

↓

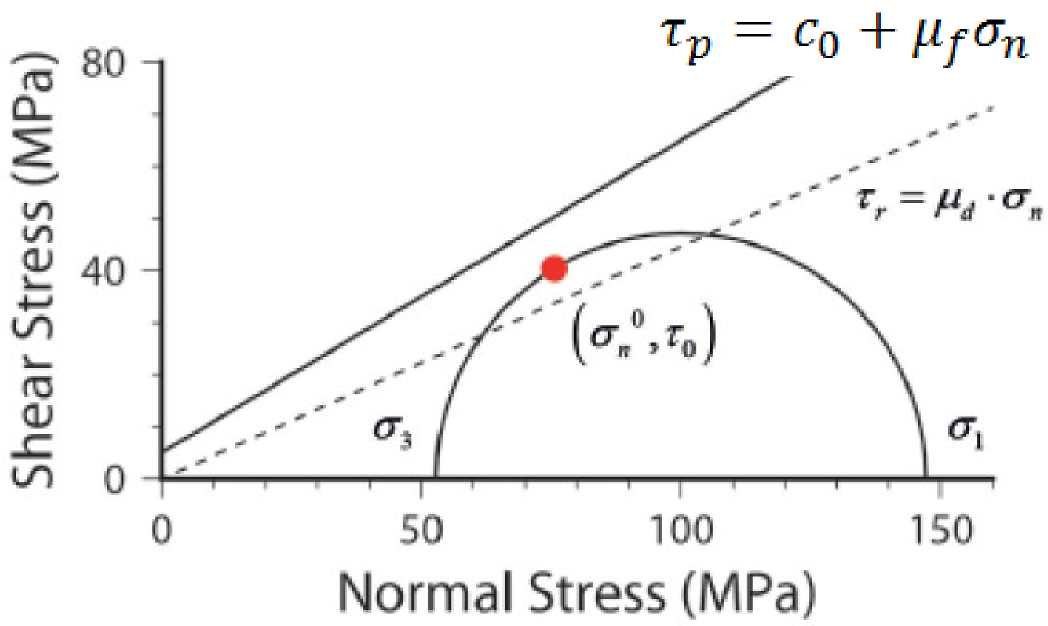
Setting slip-weakening relation ← Setting Dc*

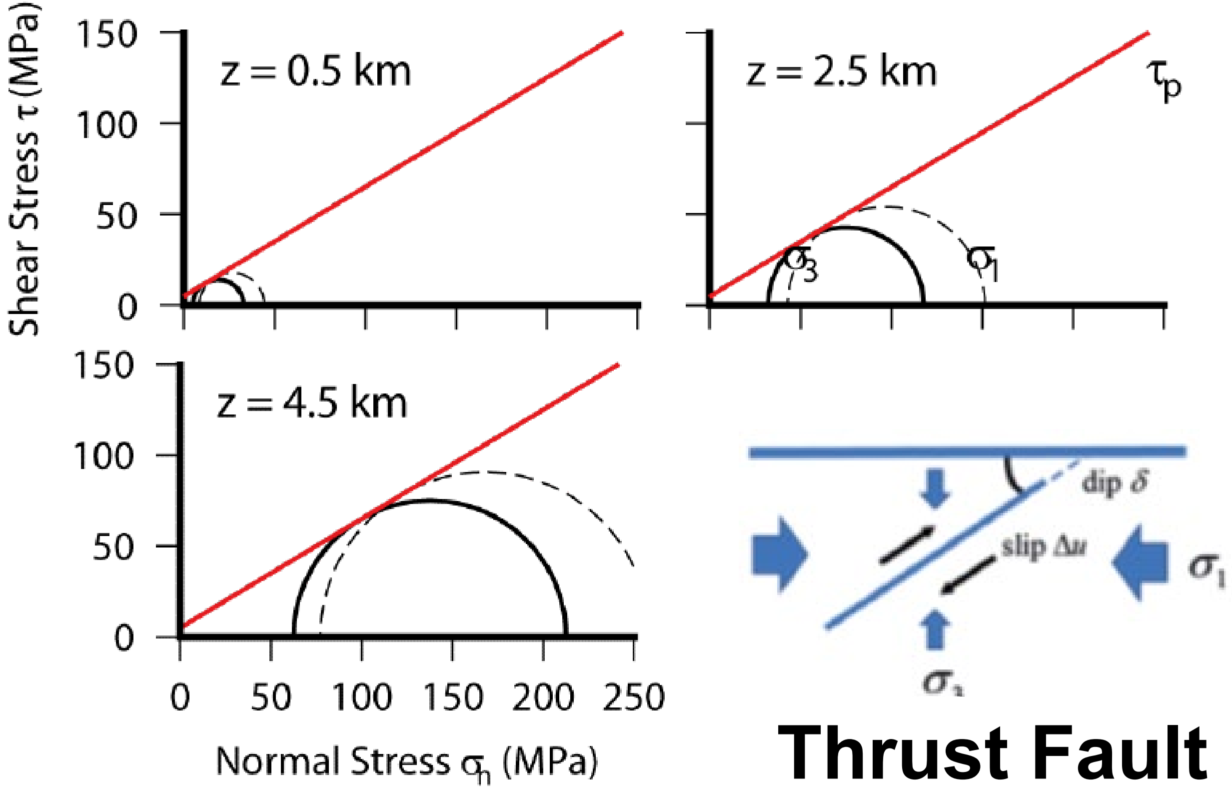
* Referring to Bizzarri (2014)

Aochi and Tsuda (2023)

Basic Assumption：Framework of Mohr-Coulomb Diagram

- Confining pressure increase with Depth
- Magnitude of principal stress changes with source mechanism



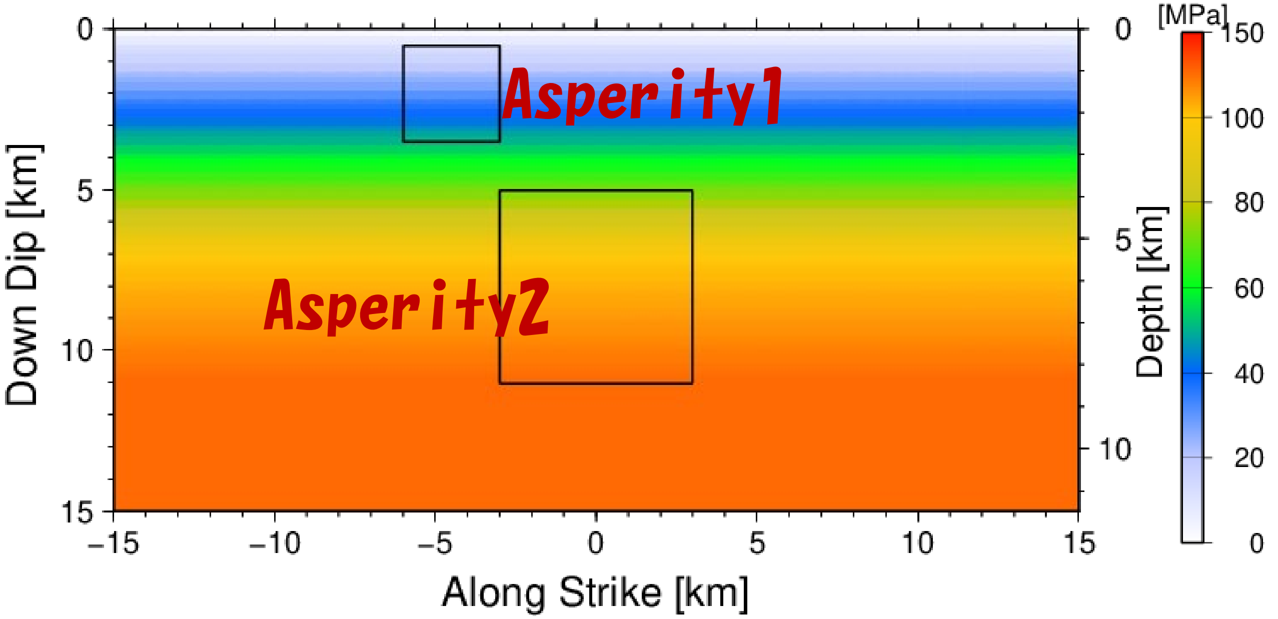


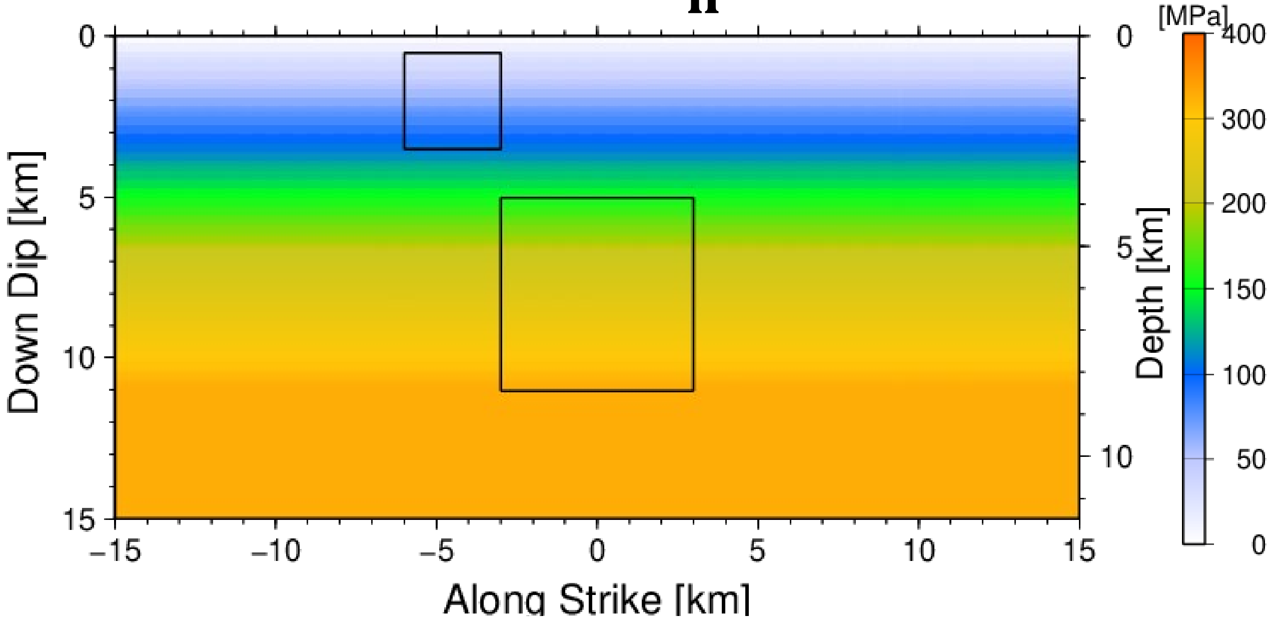
Thrust Fault

Stress Distribution

Shear Stress: τ_o

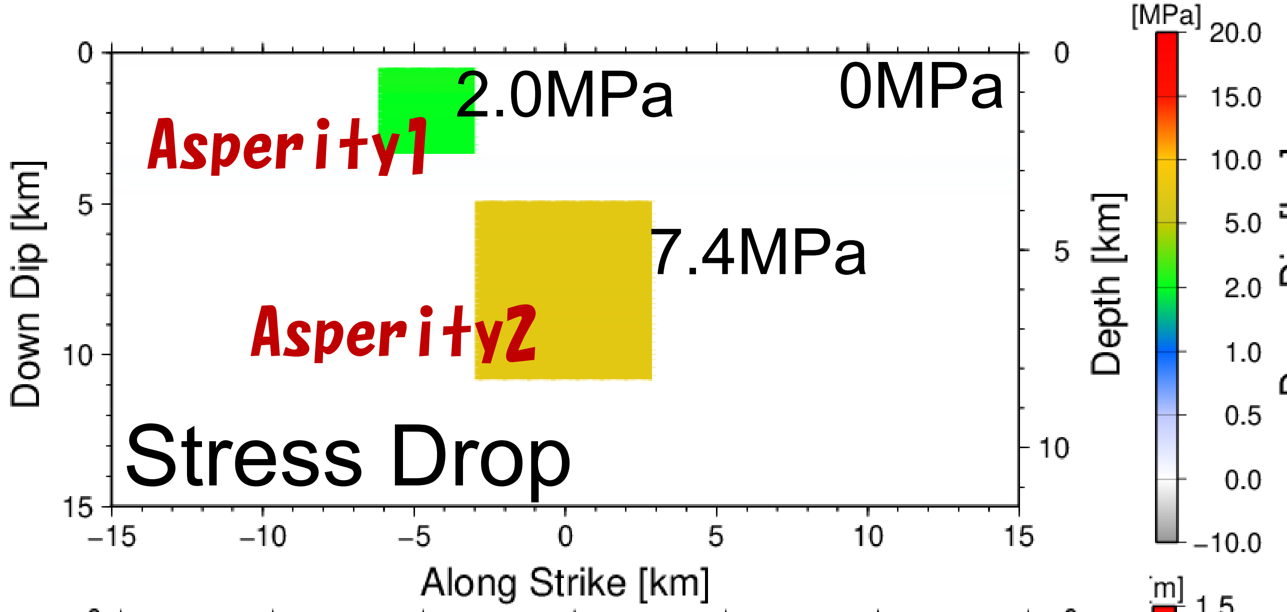
Normal Stress: σ_n

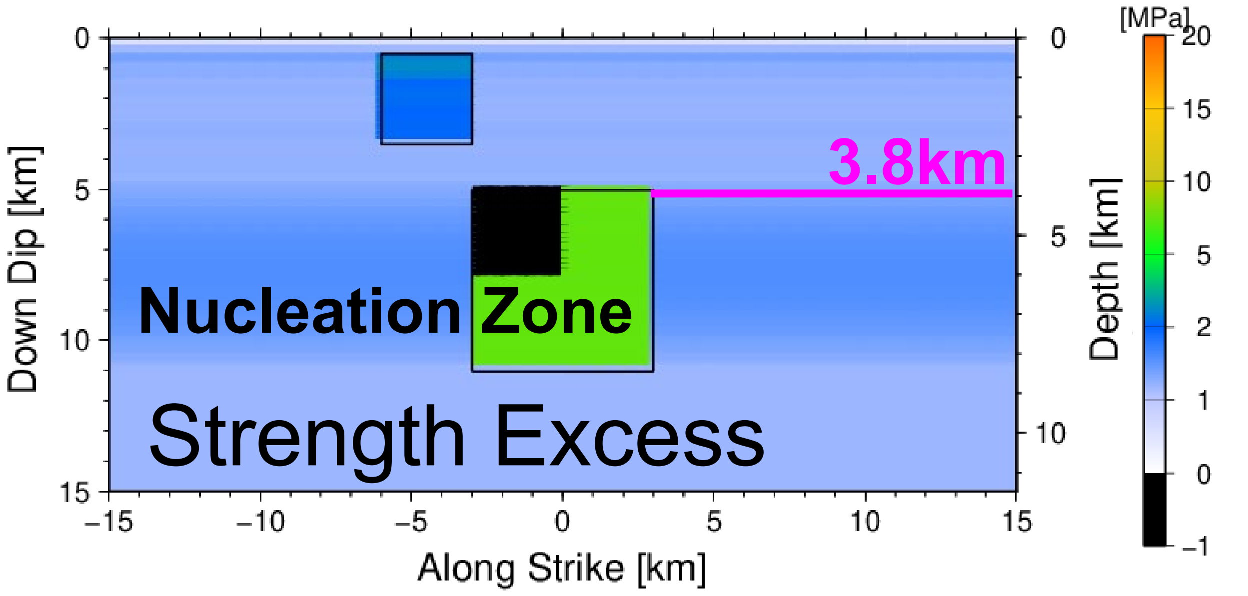


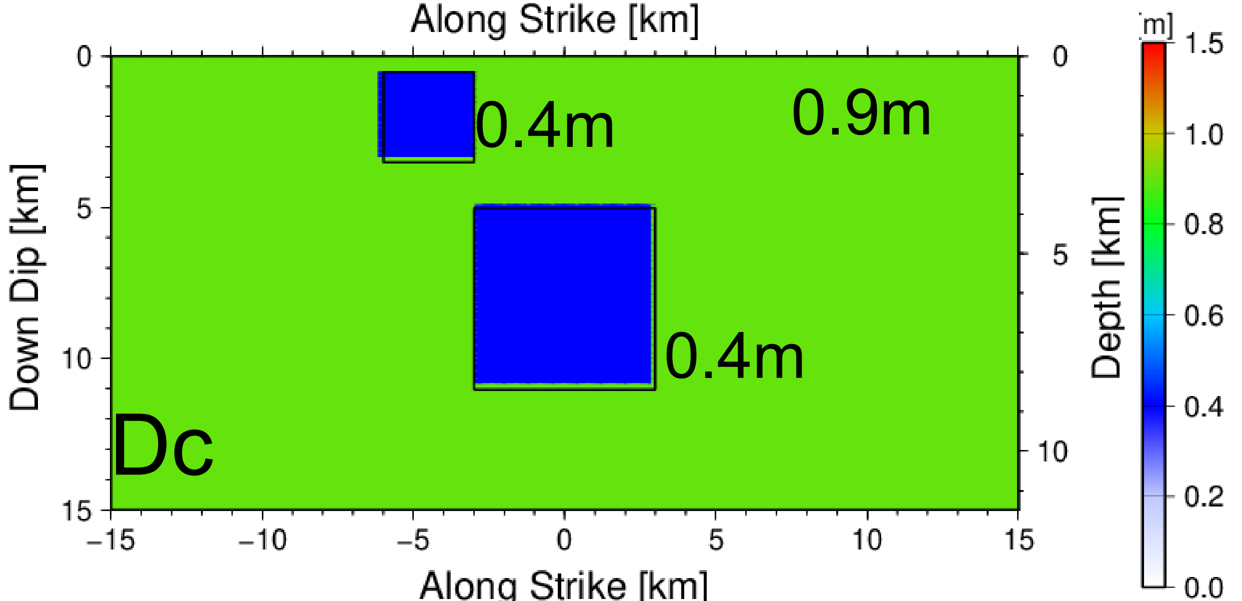


Depth-dependent distribution

Parameter Settings

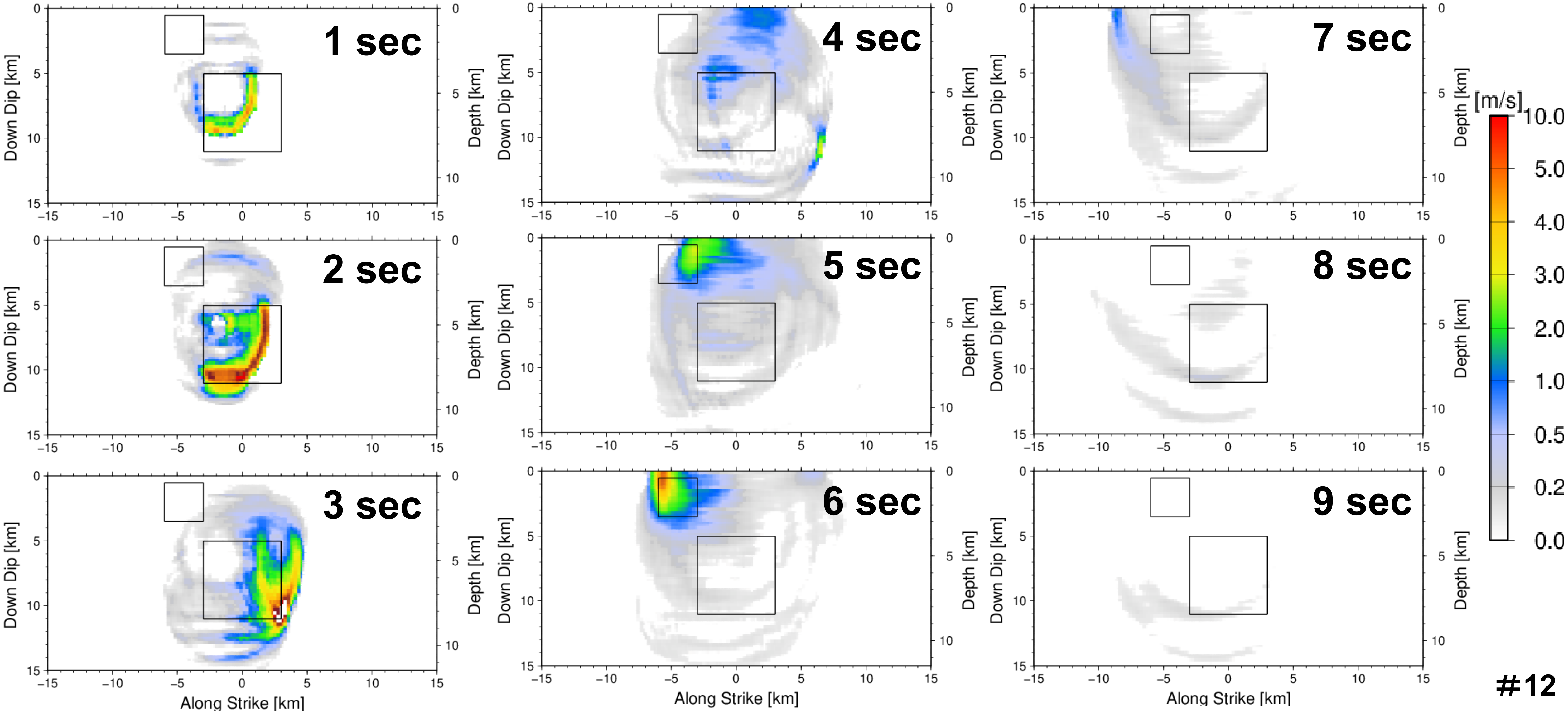




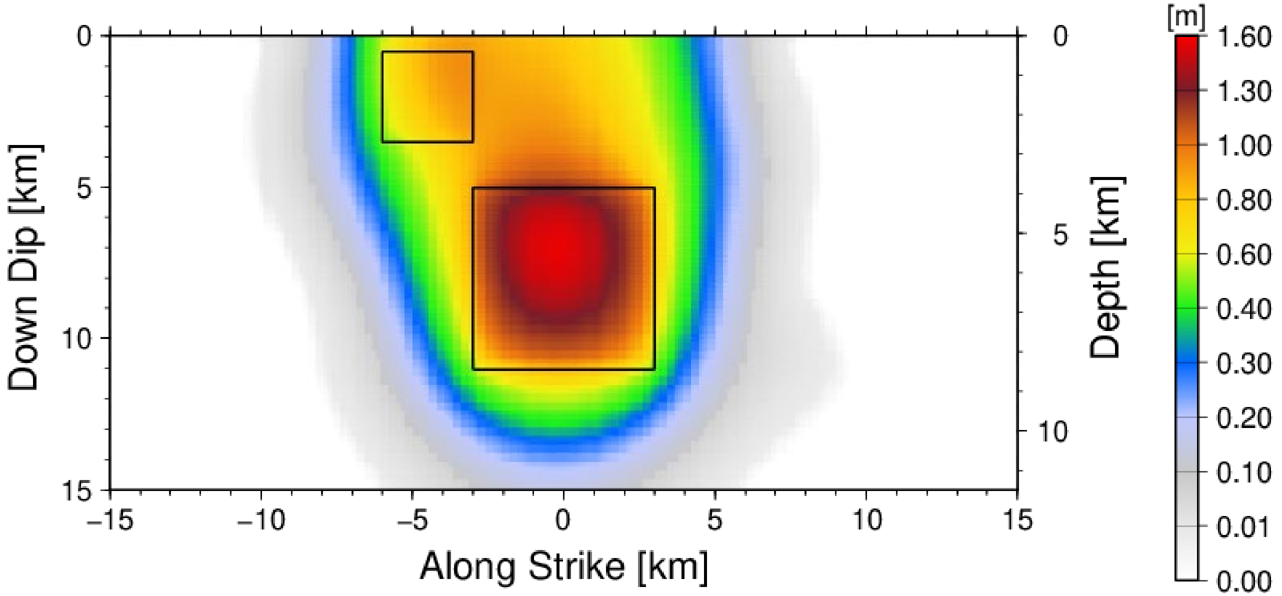


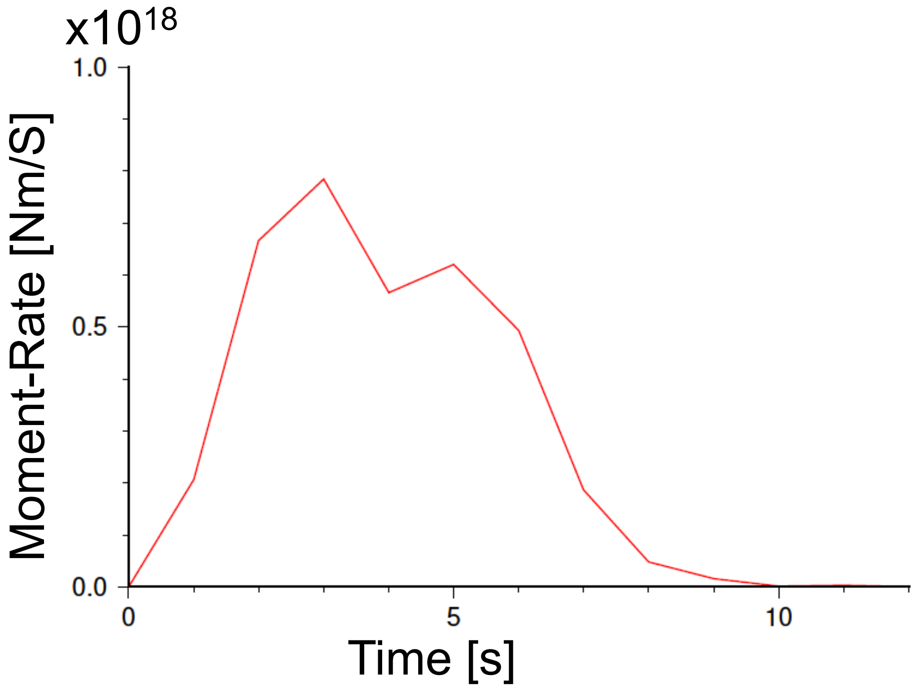
	Stress Drop [MPa]	Strength Excess [MPa]	Dc* [m]	Upper Depth [km]
Asperity 1	2.0	2.0	0.4	0.4
Asperity 2	7.4	7.4	0.4	3.8
Back Ground	0	1.2	0.9	-

Snapshot for Slip-Rate Function



Slip Distribution





<Source Parameter>

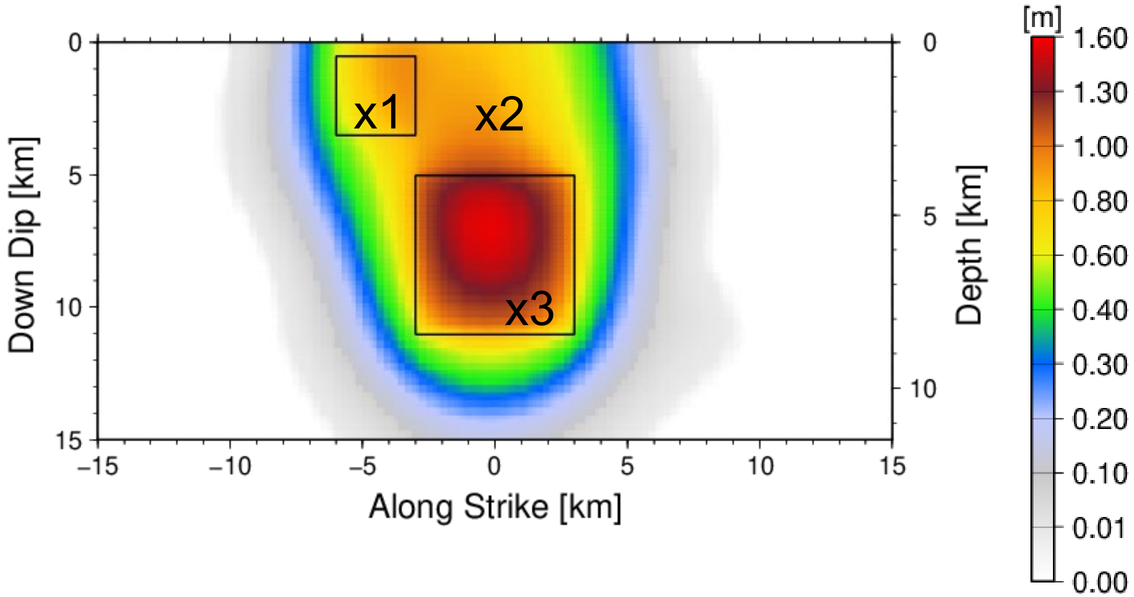
Mo 3.88 E+18 [Nm] → Mw 6.32

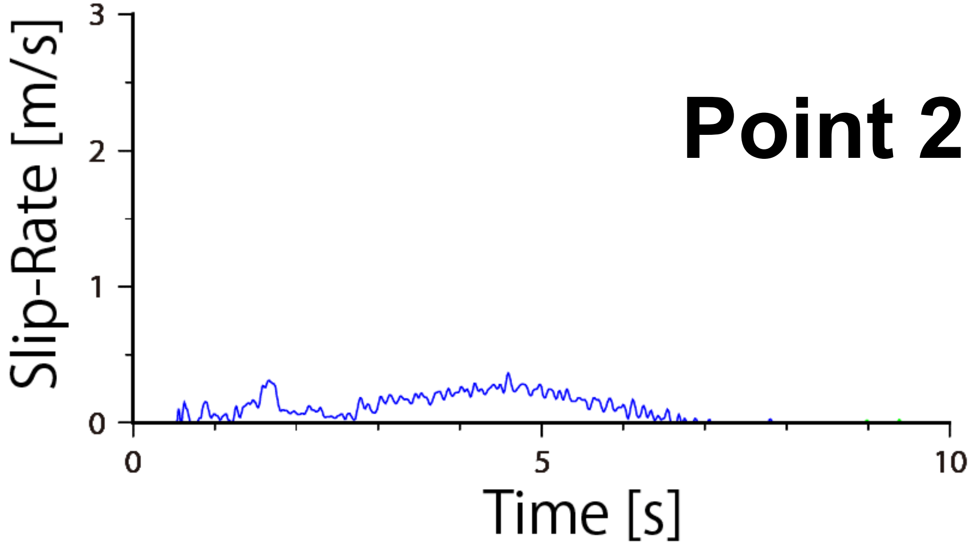
Fault Surface 272 [km^2] → Somerville et al(1999)'s criteria

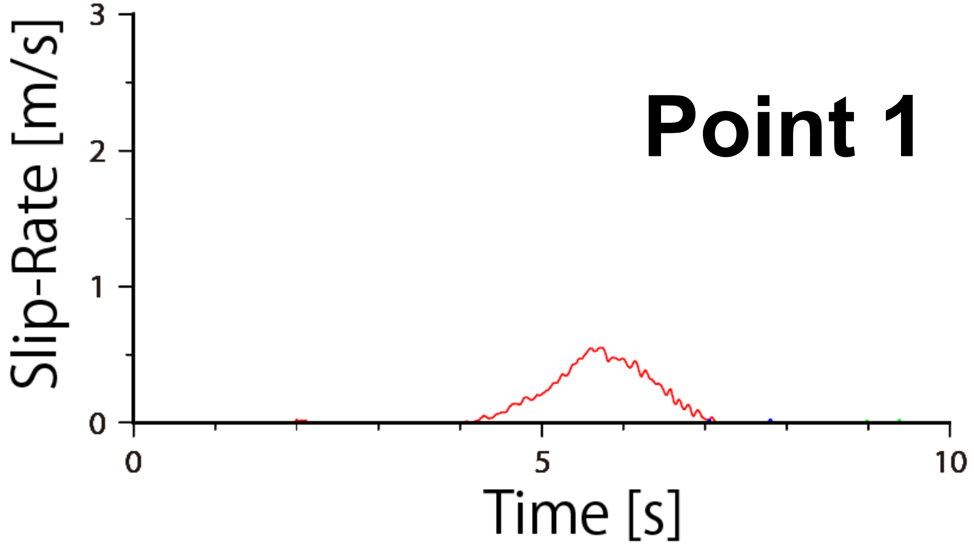
Maximum Slip 1.48 [m]

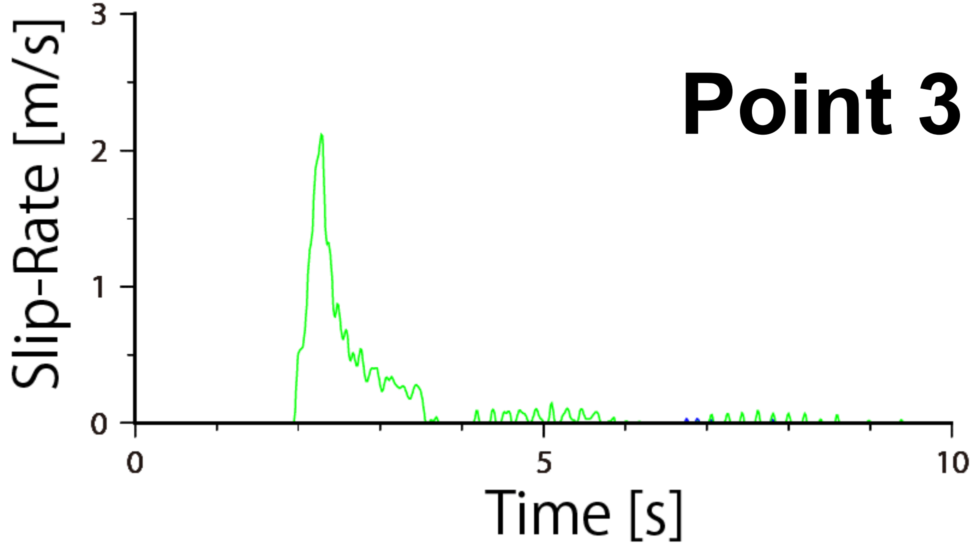
Average Stress Drop 1.1 [MPa]

Distributions of Slip-Rate Function

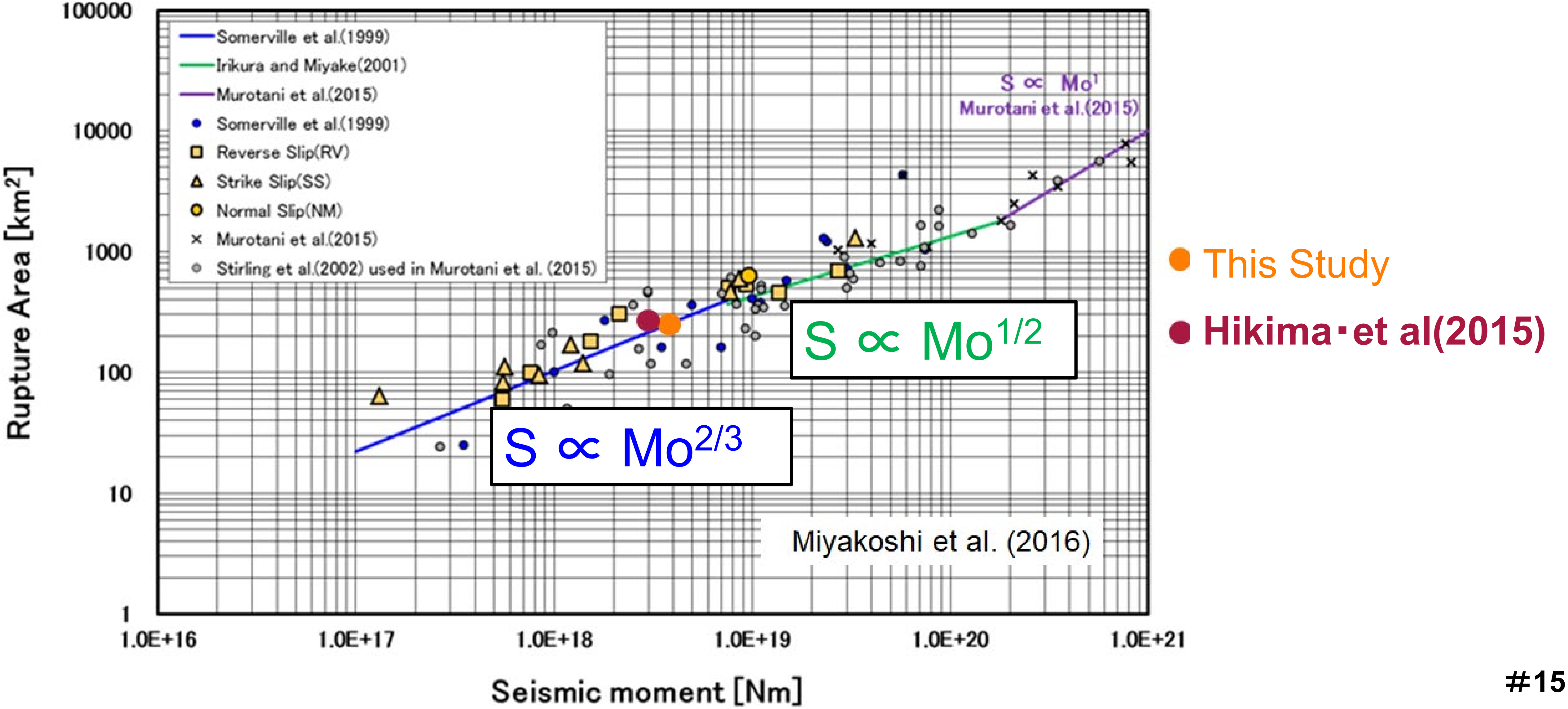






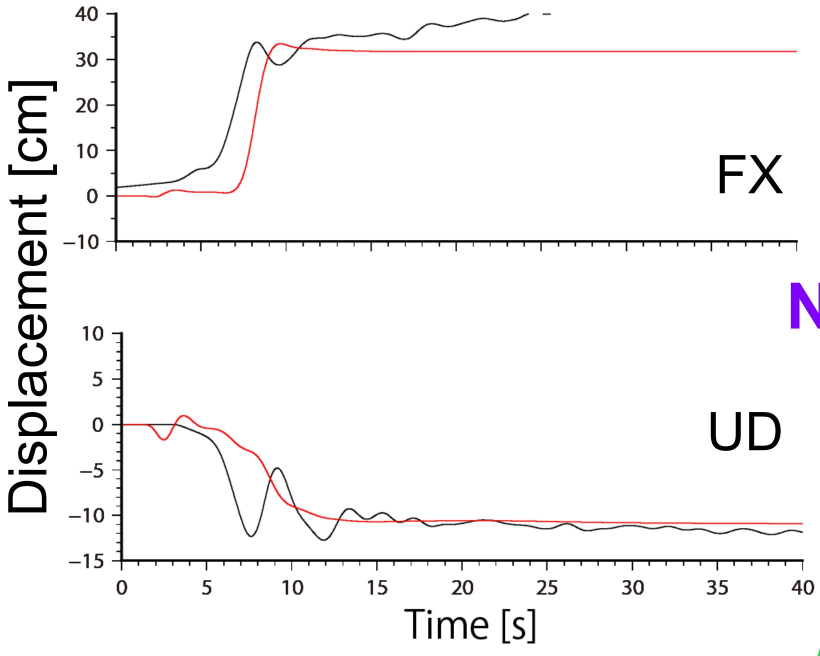


Compare with Scaling Low



Surface displacement and Ground Motion

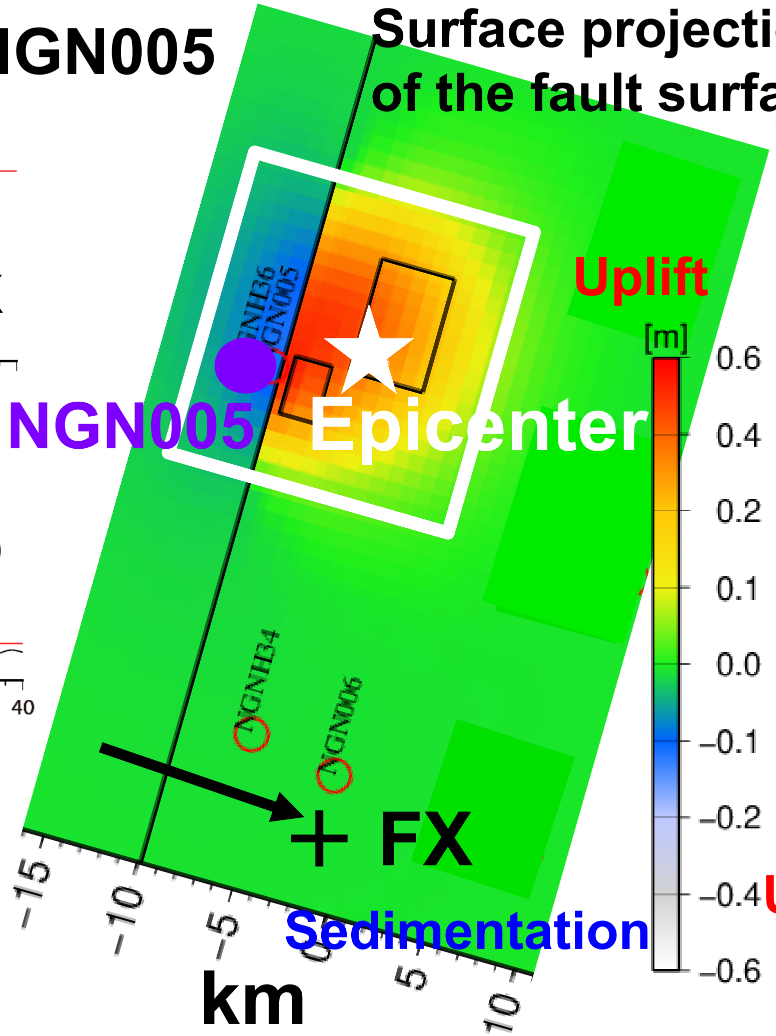
Displacement Waveform@NGN005

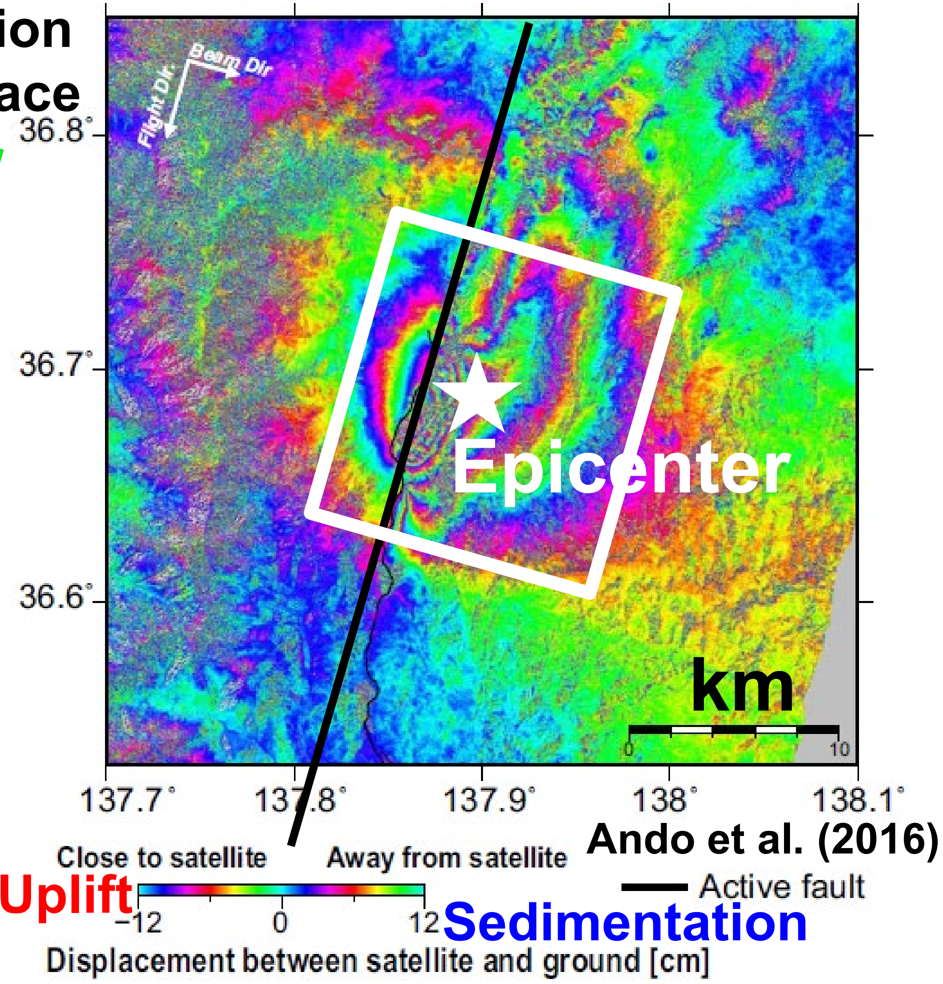


—：Observation

—：Simulated Results

(Longer than 2 sec)



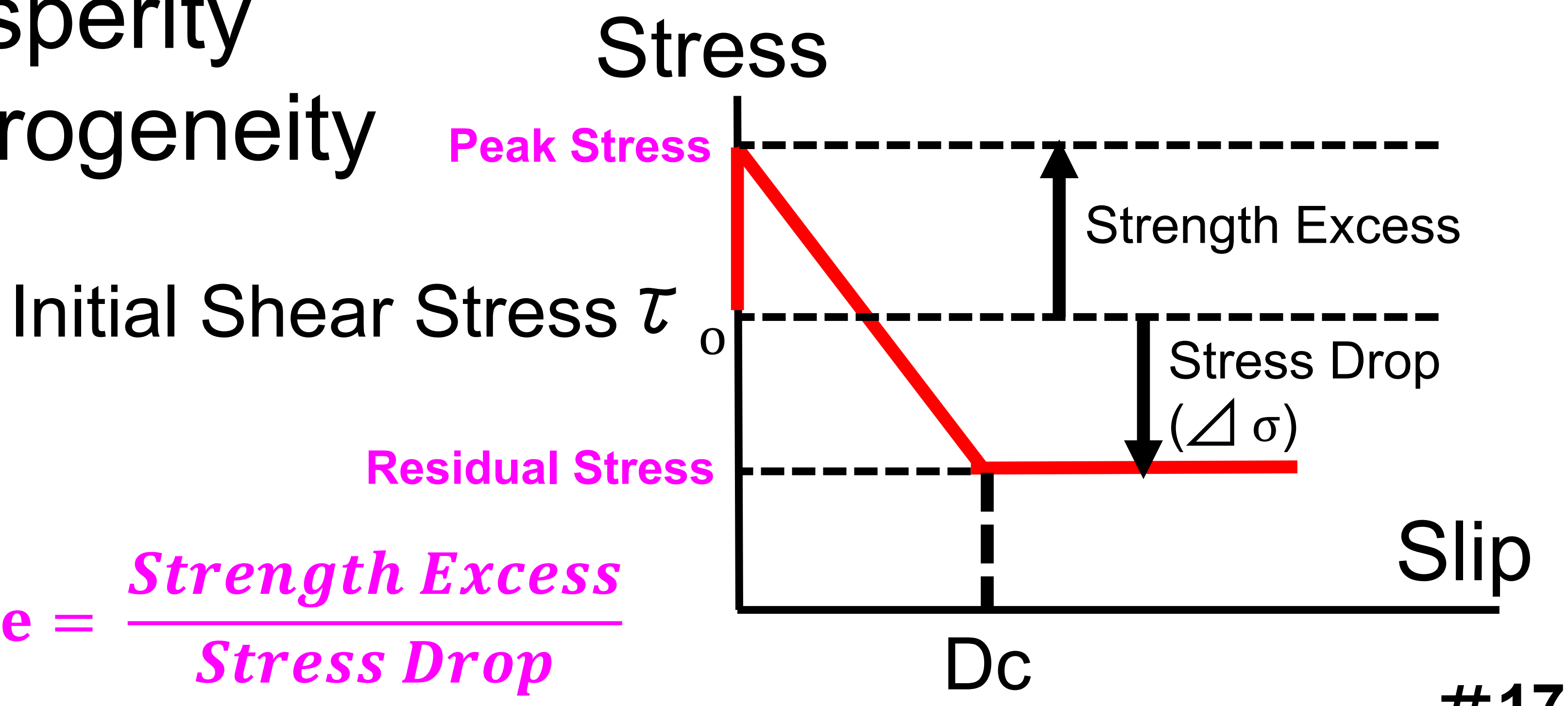


Vertical Displacement

(Left：Simulation, Right：InSAR datsa)

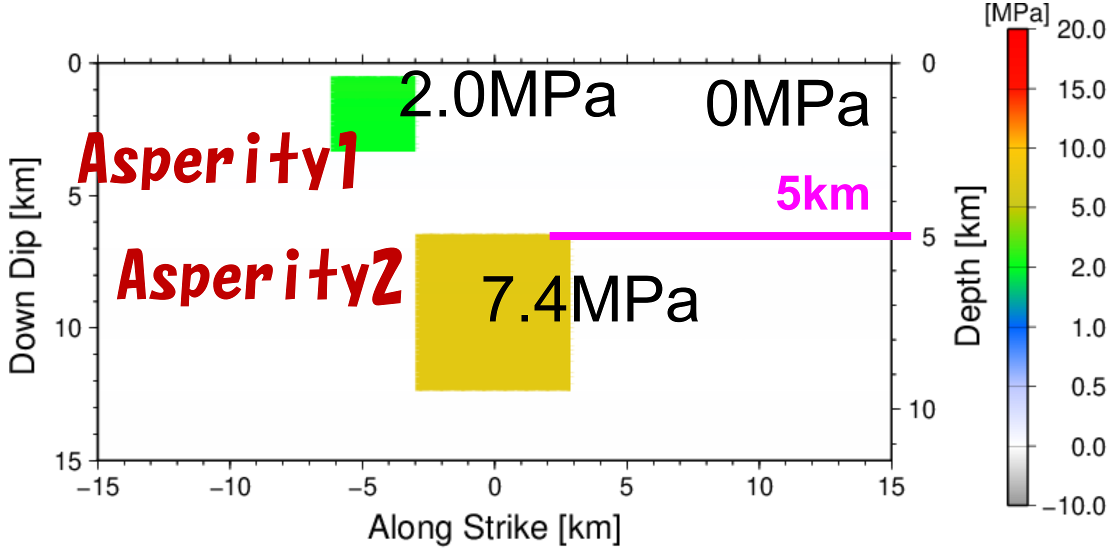
Investigate Fault Behavior for the Shallow Part

- Possible parameters to control fault behavior
  - Stress Drop (Assume S value → Strength Excess)
  - Critical Distance (Dc)
  - Location of Asperity
  - Medium Heterogeneity



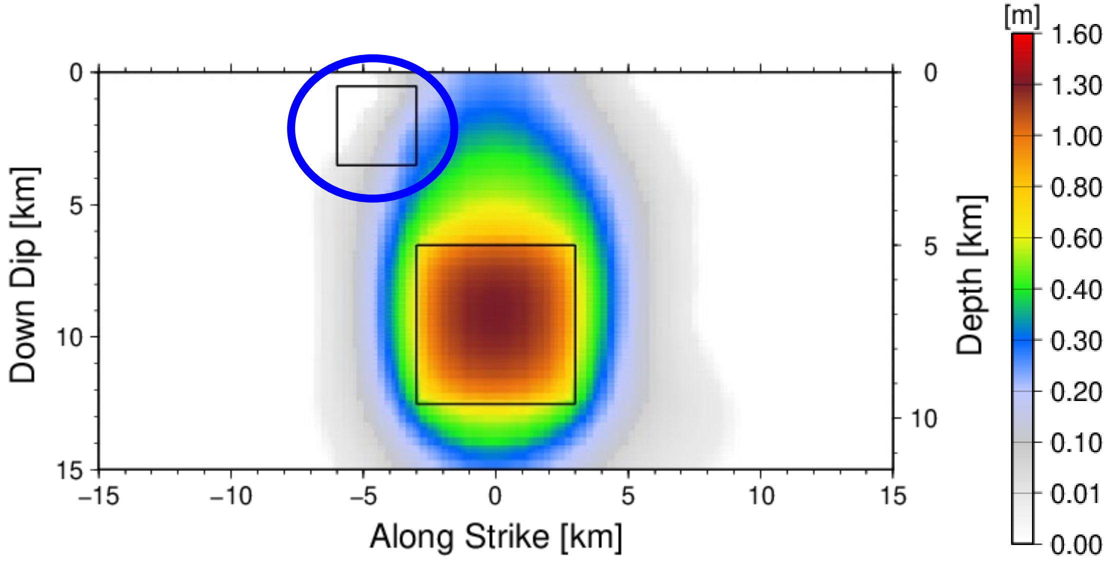
$$S\ value = \frac{Strength\ Excess}{Stress\ Drop}$$

Changing Location of Deep Asperity2



■Simulation Condition

- Separating two Asperities
  (Deepen the Asperity 2)
  3.8km → 5km from surface
- Other parameters are same as original

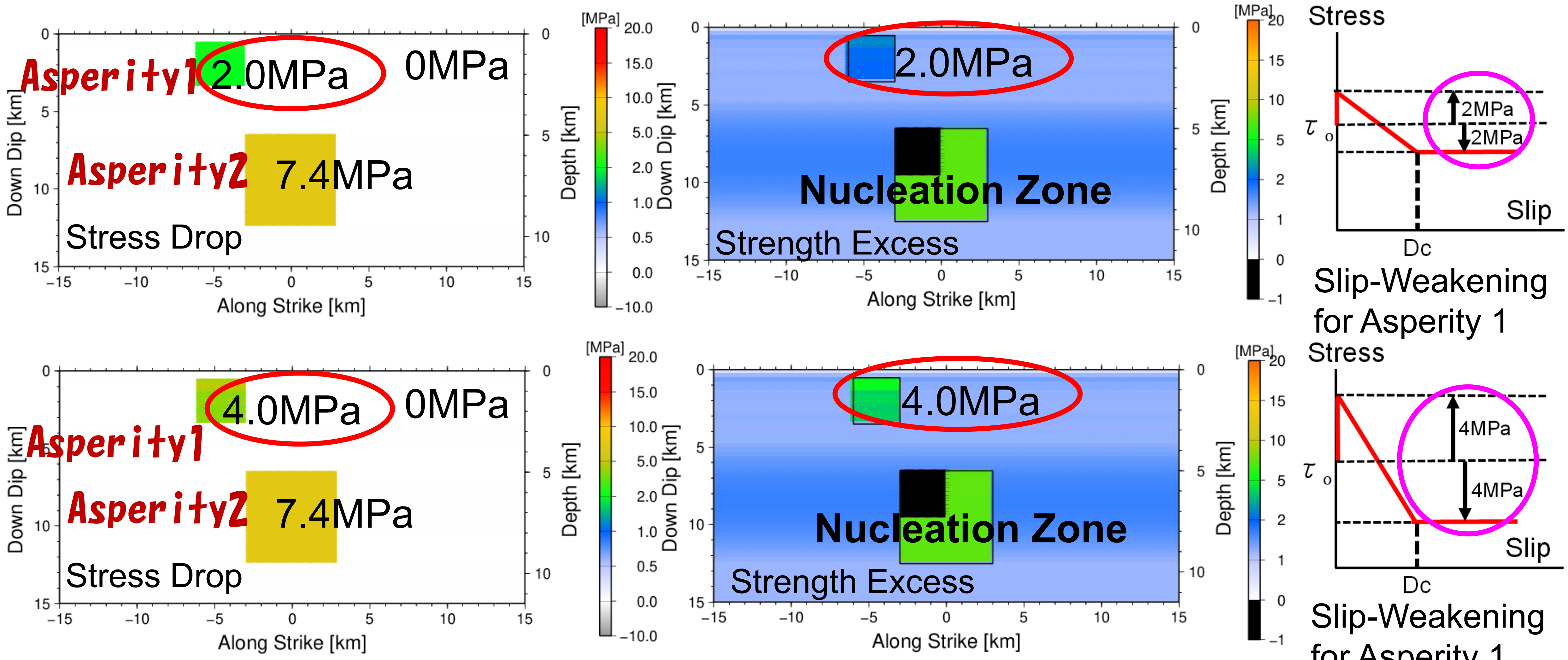


Simulation Results

Not sufficiently rupture of Asperity 1

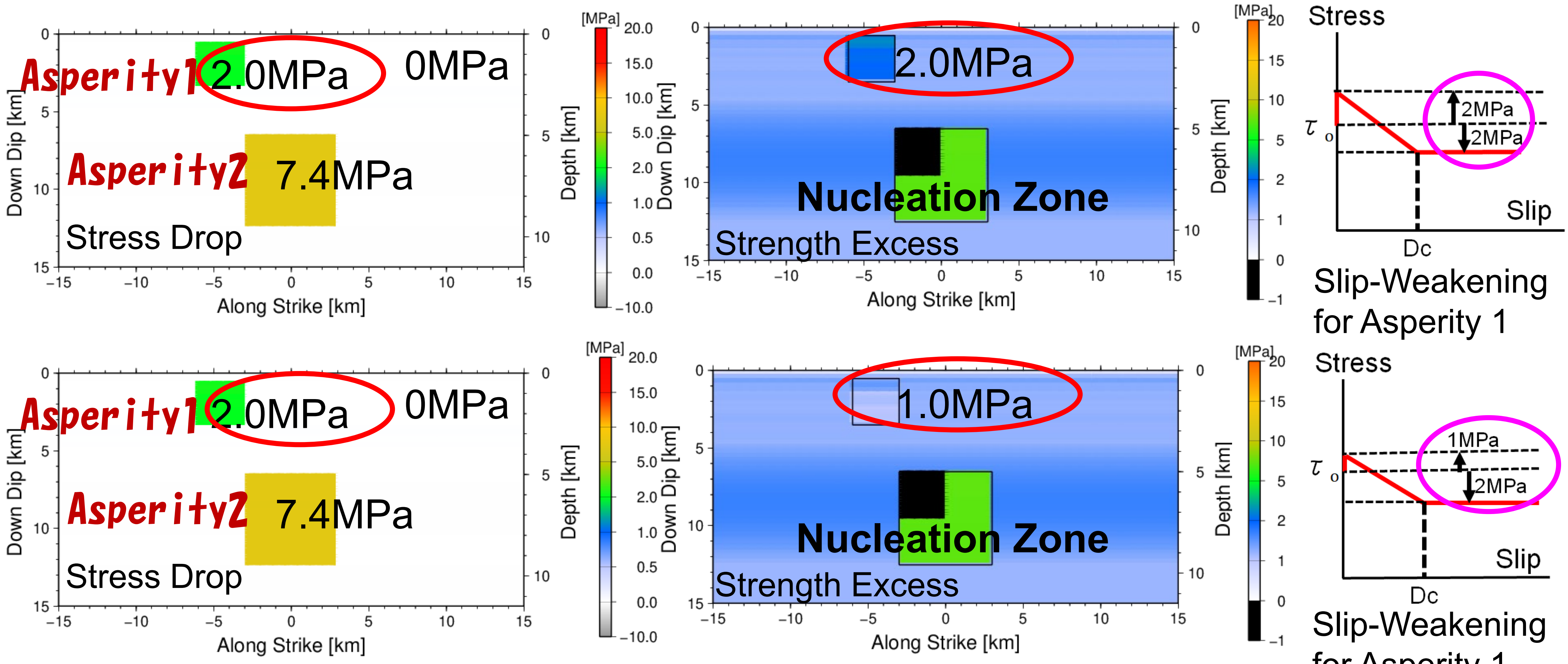
➡ **Changing stress conditions of shallow Asperity 1**

Changing Frictional Features of Shallow Asperity1



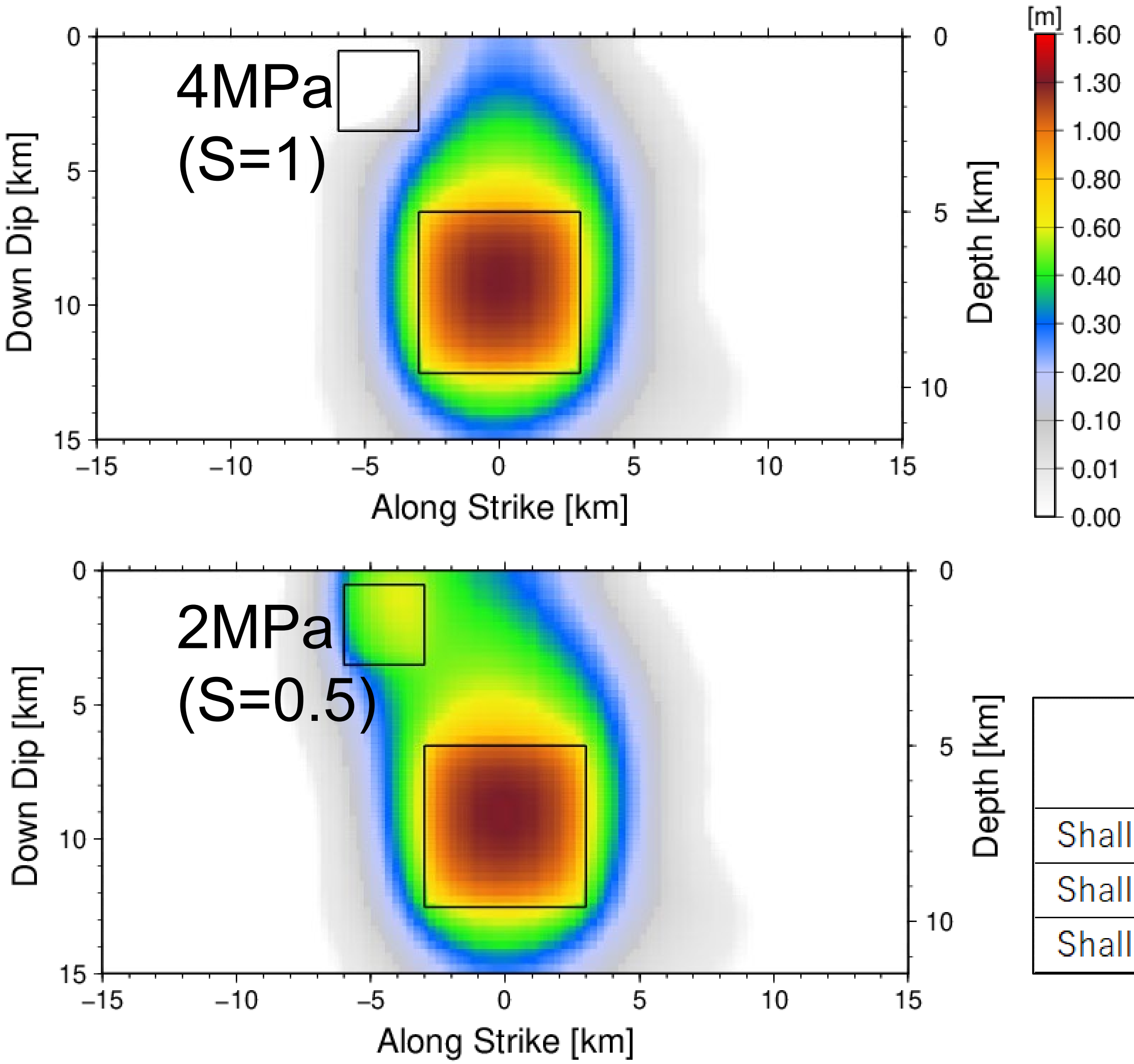
τ_o: dependent on depth

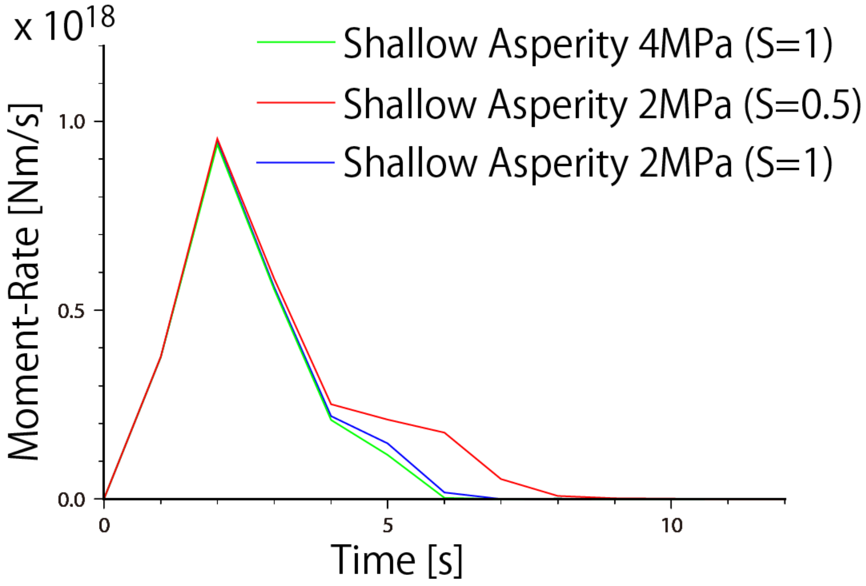
Changing Frictional Features of Shallow Asperity1



τ_o: dependent on depth

Changing Frictional Features of Shallow Asperity1



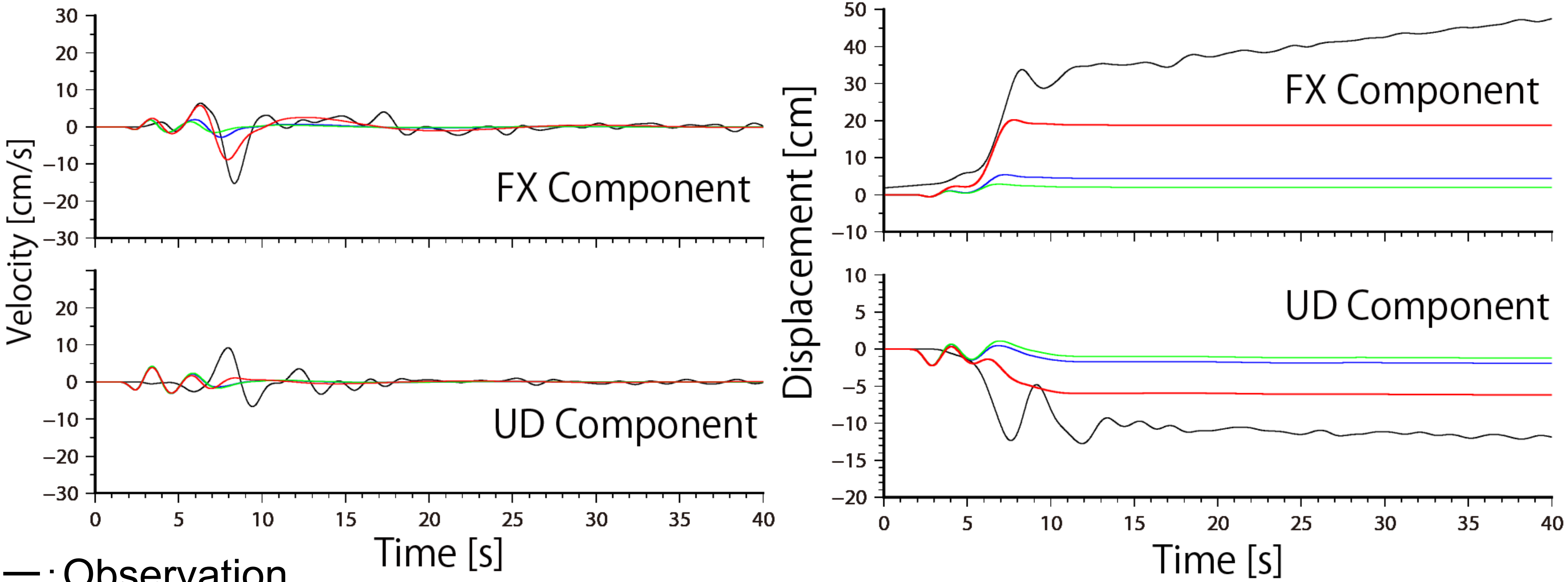


Resultant Source Parameters

	Fault Surface [km^2]	Mo [Nm]	Mw	Maxium Slip [m]
Shallow Asperity 4MPa (S=1)	241.4	2.52E+18	6.20	1.30
Shallow Asperity 2MPa (S=1)	264.9	2.95E+18	6.25	1.31
Shallow Asperity 2MPa (S=1)	248.4	2.59E+18	6.21	1.31

Changing Frictional Features of Shallow Asperity1

■ Simulated Ground Motions on NGN005 Station



—: Observation
—: Shallow Asperity1 (2MPa, S=1.0) —: Shallow Asperity1 (4MPa, S=1.0)
—: Shallow Asperity1 (2MPa, S=0.5)

(Longer than 2 sec)

Summary and Future Work

- We have constructed the dynamic source model compatible with the observations for the 2014 Northern Nagano Earthquake with surface faults.

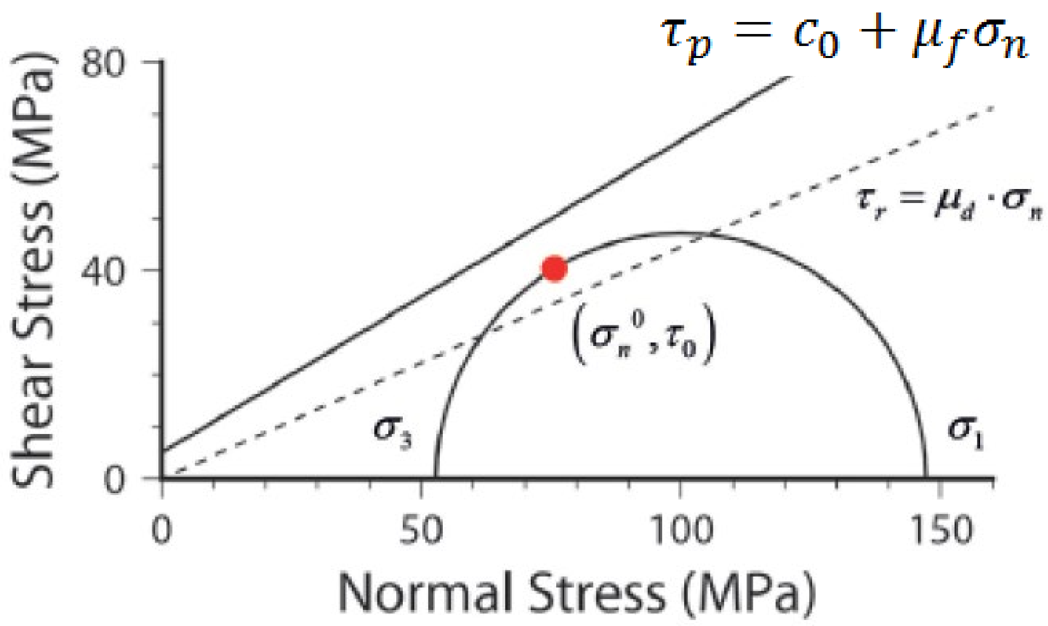
- Small strength drop could generate larger ground motions, indicating that the stress ratio (S values) might play important role to model ground motions like stress drop.

- Incorporation of soft sediment layers and heterogeneous Dc distribution into simulations is next step to model ground motions with surface fault more quantitatively.

Depth-Dependent Stress Setting

■ Framework of the Mohr-Coulomb Diagram

- ➢Confining pressure increase with Depth
- ➢Magnitude of principal stress changes with source mechanism



$$\Delta\varepsilon \equiv \frac{\Delta\sigma}{G} = \frac{(\sigma_1 - \sigma_3)/2}{G}$$

G = Rigidity of the Meduim

$$\tau_o = \Delta\sigma \sin(2\theta)$$

$$\sigma_n = \frac{\sigma_1 + \sigma_3}{2} - \Delta\sigma \cos(2\theta)$$

θ: Dip Angle

Stress dependent on depth and medium

APPENDIX

Rupture velocity: $v_r \propto v_s$

Slip velocity: $\dot{D}_{\max} \propto \dfrac{v_r}{C(v_r)} \dfrac{\tau_p}{\mu} \propto \dfrac{v_s}{C(v_s)} \dfrac{\tau_p}{\rho v_s^2} \propto \dfrac{1}{C(v_s)} \dfrac{\tau_p}{\rho v_s}$

τ_p : peak stress

μ : rigidity

ρ: density

Ohnaka and Yamashita (1989)