The landward normal fault of the Tohoku-Oki forearc: Mechanical conditions for its activation and estimation of its possible contribution to the tsunami

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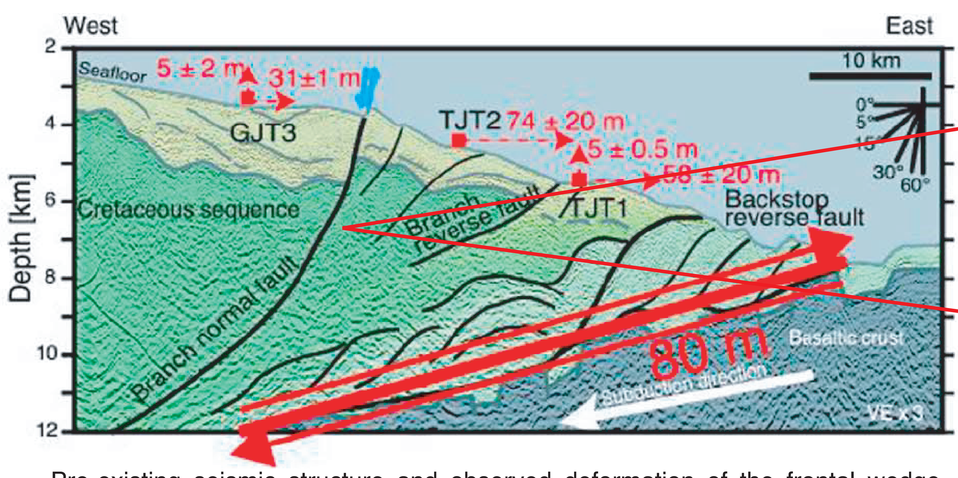
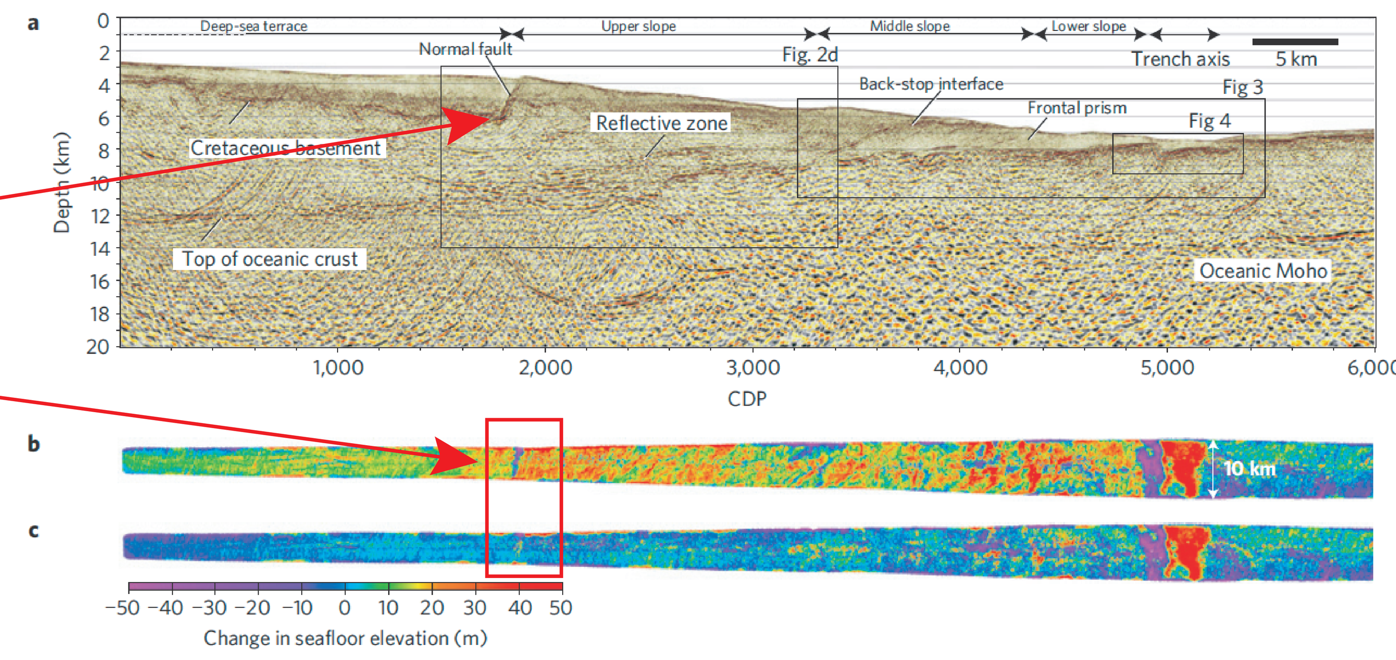
1. Objectives

The landward normal fault in the forearc of NE japan has been the subject of several studies because of its potential contribution to the 2011 tsunami (McKenzie and Johnson EPSL 2012). From the displacement of ocean-bottom pressure gauges installed before the EQ, Ito et al., GRL 2011, have reported 60 to 80 meters of slip along the megathrust with more slip along the footwall of the normal fault. Comparison between images from seismic reflections taken before and after the EQ have confirmed a slip of 50 meters along the megathrust and a displacement along the normal fault.

The aim of this study is, first to determine the mechanical conditions for the activation of this landward normal fault. Anomalous or extreme mechanical conditions could reveal why the EQ reached the trench. Secondly, we propose to estimate the maximum vertical displacement that can be achieved along the fault in order to determine its potential participation to the tsunami.

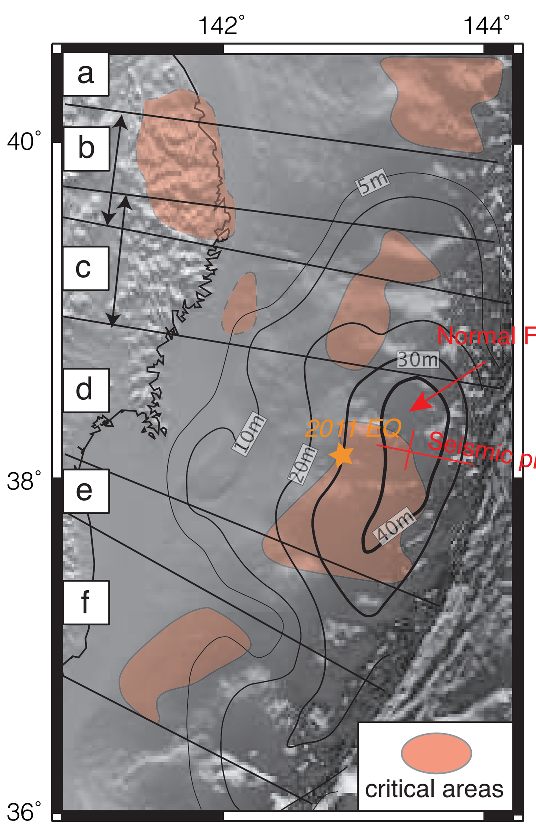


Pre-existing seismic structure and observed deformation of the frontal wedge (*Tsuji et al., EPS, 2011*). Red arrows indicate the observed displacements from *Ito et al, GRL 2011*.

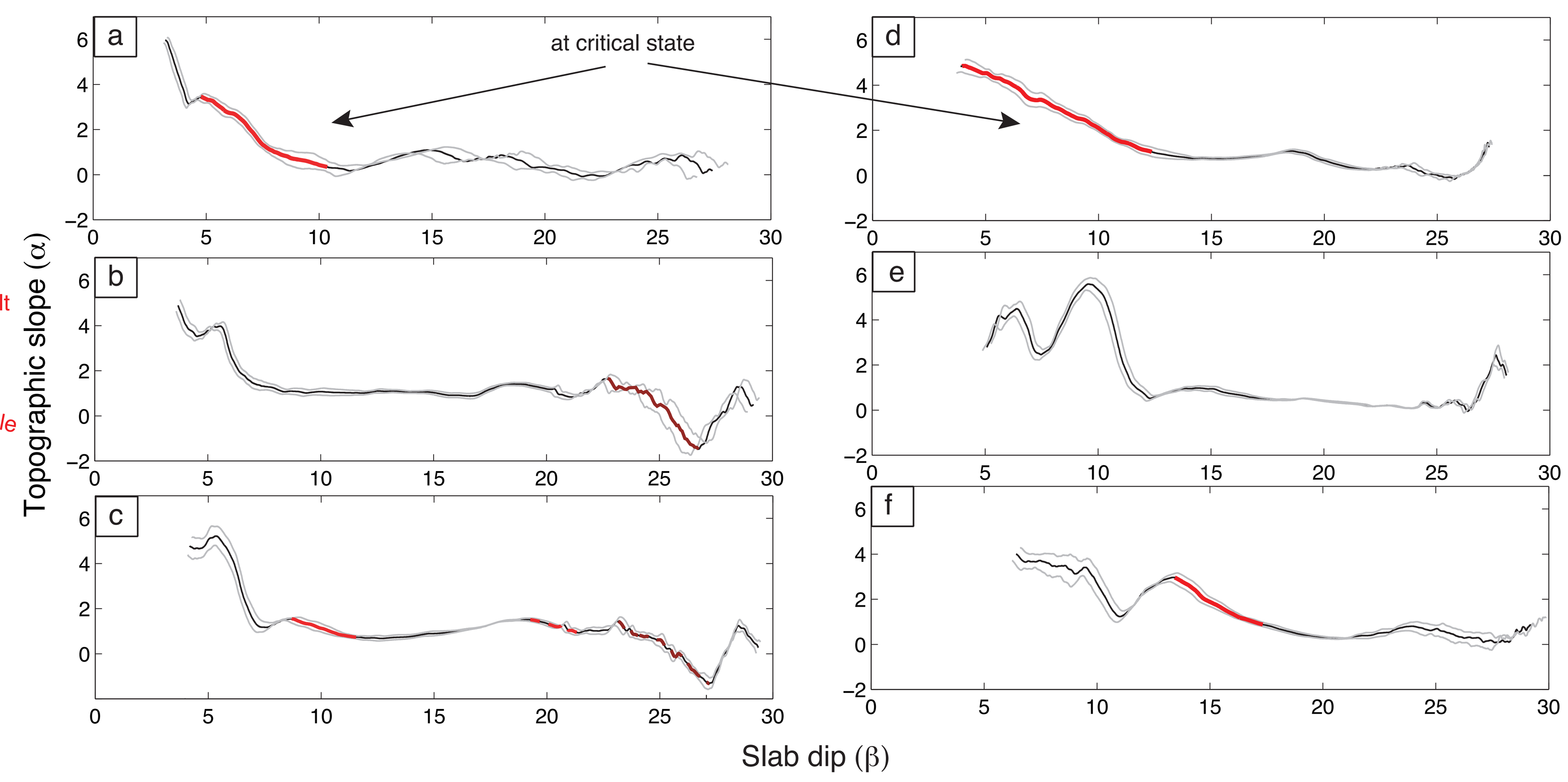


Kodaira et al., Nature 2012: Seismic reflection and differential bathymetric images seawards of the epicenter. a) seismic reflection after the Tohoku-Oki EQ. b) Differential bathymetry from seismic reflection obtained in 1999, c) differential with the 2011 image shifted by 50m landwards and 10 m downwards.

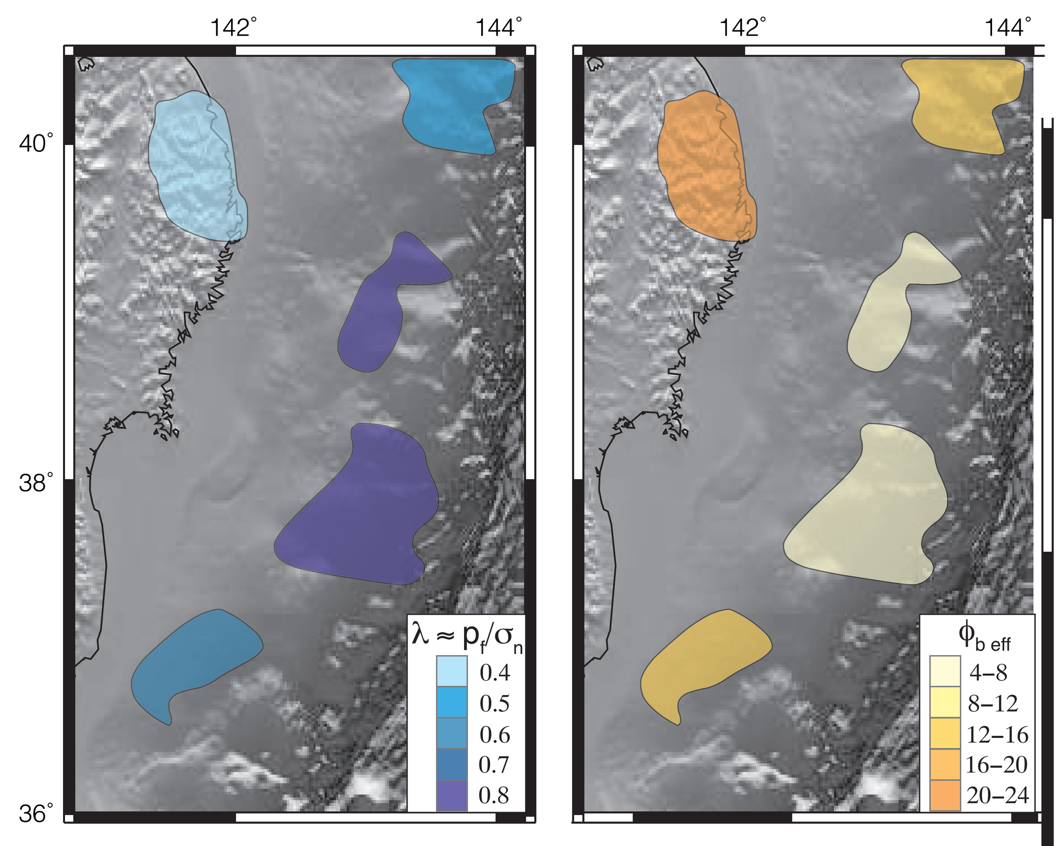
2. Background mechanical properties from the critical taper theory



Pink: Critical areas. Black: contour lines of *Wei et al, EPSL 2011* co-seismic slip model. Red: Location of the seismic reflection profile and position of the landward normal fault.



Topographic slope versus slab dip of each morphological segment along the NE Japan forearc. Back: mean, grey: ± standard deviation, red: at critical state.

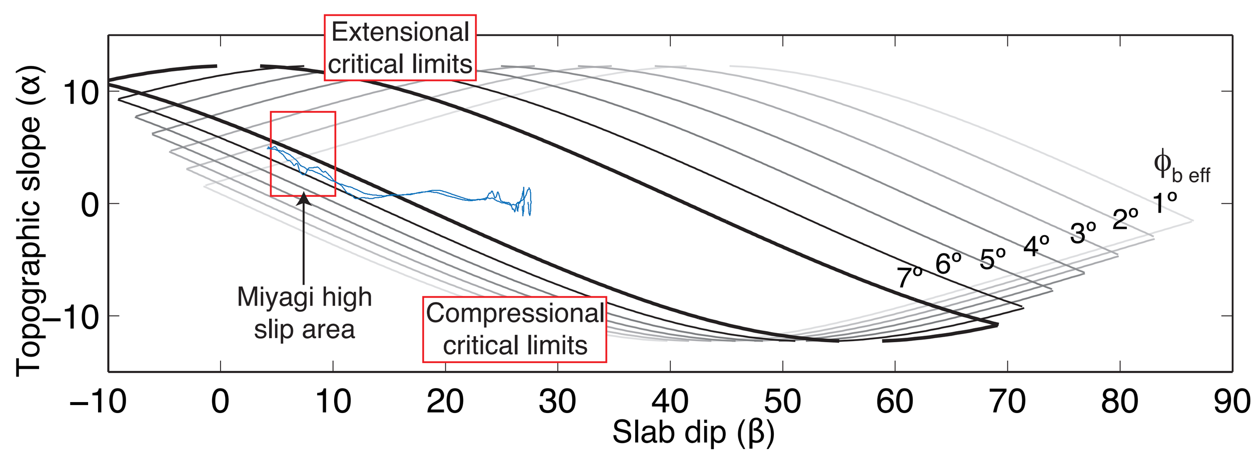


Pore pressure in the wedge and effective basal friction along the megathrust estimated from the fit to theoretical critical tapers.

=>> A very high pore pressure in the wedge and a low effective basal friction are estimated in the area of maximum slip and in the hanging-wall of the landward normal fault.

3. How to activate the normal fault?

Hypothesis 1: Dynamic overshoot

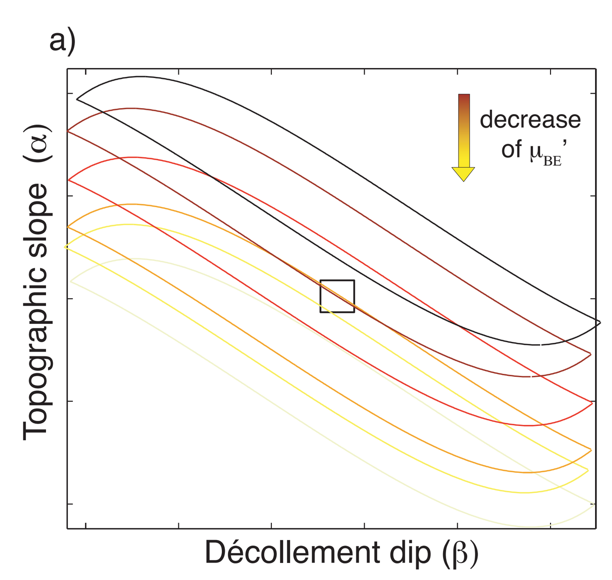


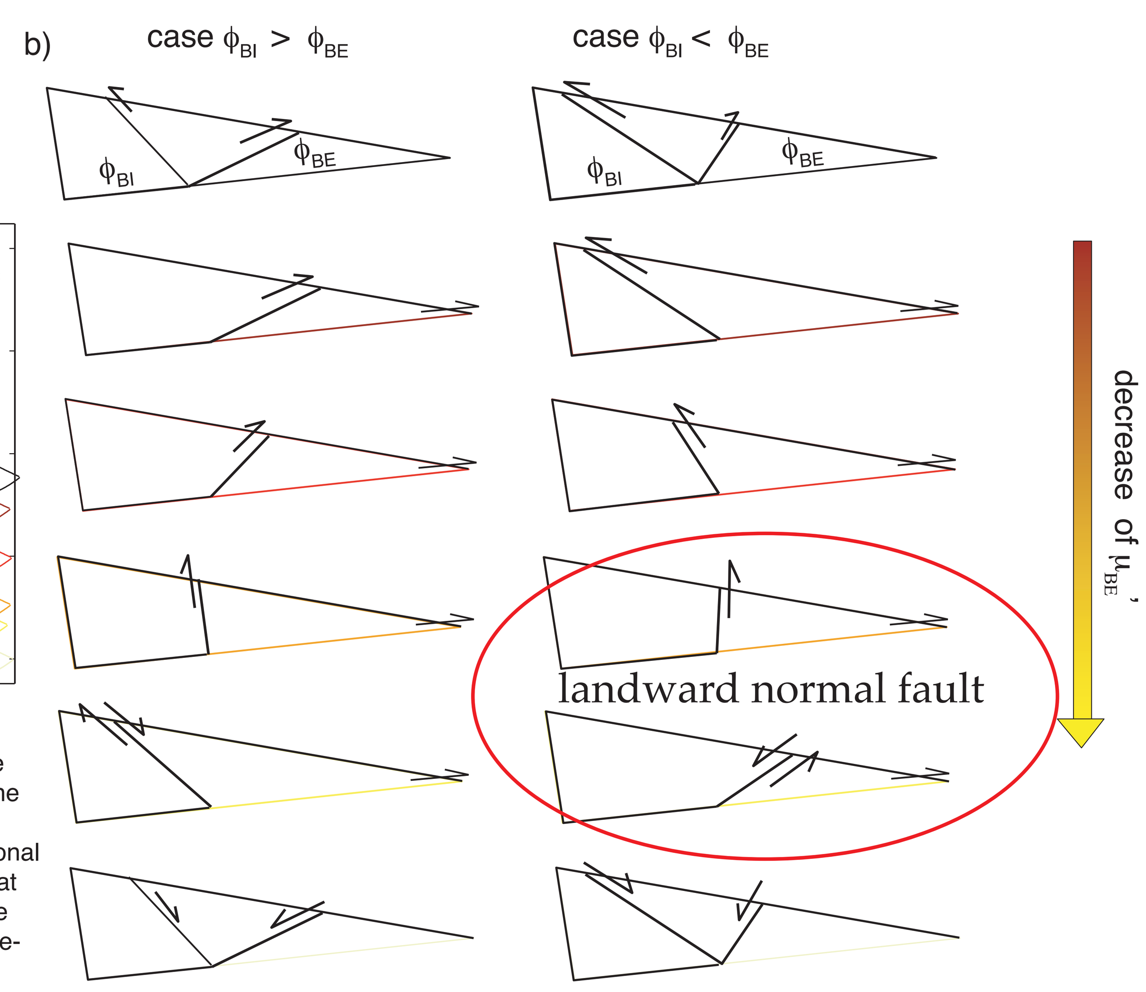
Critical envelops matching the Miyagi high slip patch taper. To reach the extensional critical envelop, a strong decrease of effective basal friction is needed.

=>> Long-term effective basal friction: 7.5° ($\mu = 0.13$)

=>> Dynamic effective friction for extension: 1° ($\mu = 0.017$) => lithostatic pore pressure

Hypothesis 2: Splay faults as markers of transition of frictional properties:





a/ Evolution of a schematic critical envelop for the up-dip part of the wedge. The square represent the taper of this study.

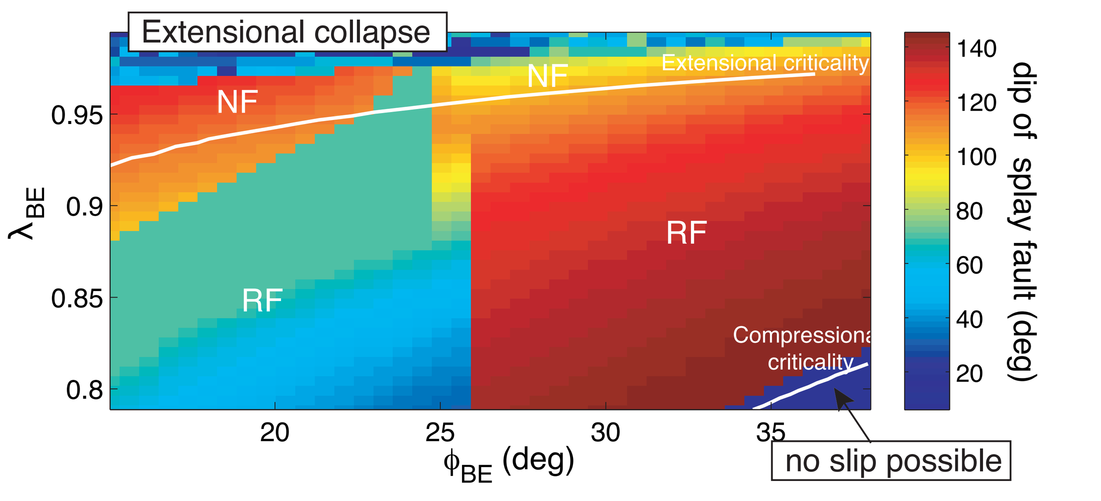
b/ Different faults obtained from transition of frictional properties. The downdip part of the wedge is set at mechanical state. Properties (friction and effective friction) are varied in the updip part with their corresponding critical envelop in a).

=>> From the limit analysis method, we have learned that transition of frictional properties will create some deformation in the upper plate (Cubas et al., in prep., Pons et al., JM, 2011). The motion along the fault is controlled by the difference in friction whereas the dip depends on the effective friction.

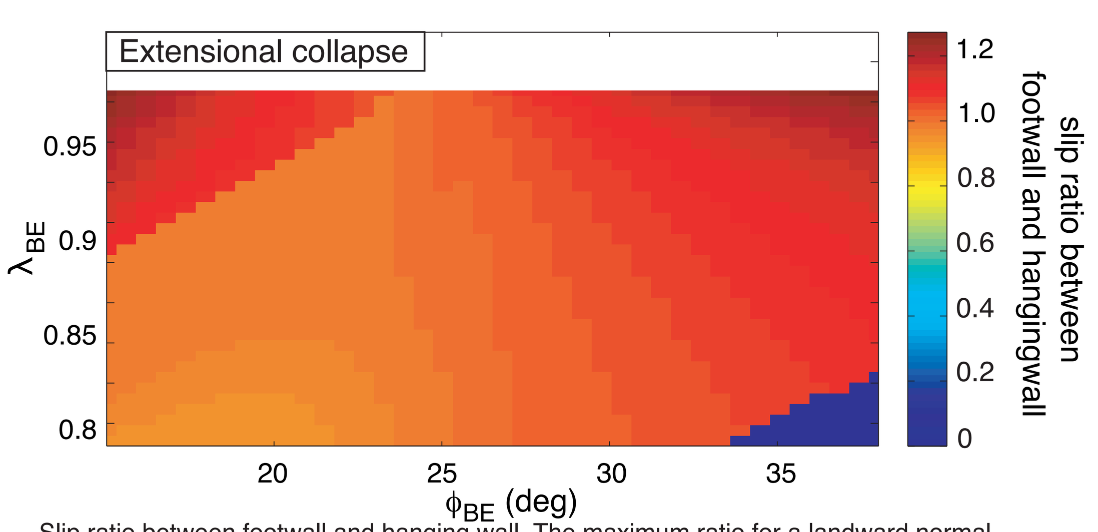
To activate a landward normal fault, a higher friction but lower effective basal friction is required up-dip along the footwall.

4. Estimation of the frictional properties and maximum amount of slip

If no preexistent normal fault

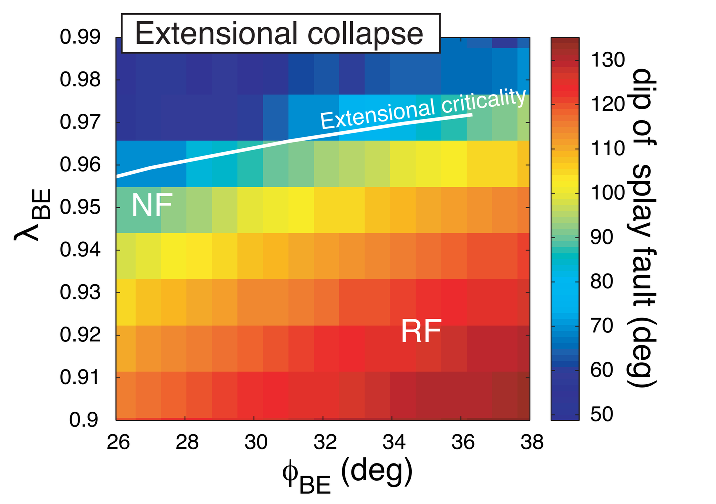


Dip of splay fault in function of the pore pressure and the basal friction obtained with limit analysis in case of transition of frictional properties. $\alpha = 4.8°$, $\beta = 6°$ values at the landward normal fault, internal friction = 38.75°, $\lambda_{wedge} = 0.8$, $\phi_{BI} = 25°$ from critical taper results above. Bulk properties along the fault. NF: Normal fault, RF: reverse fault.



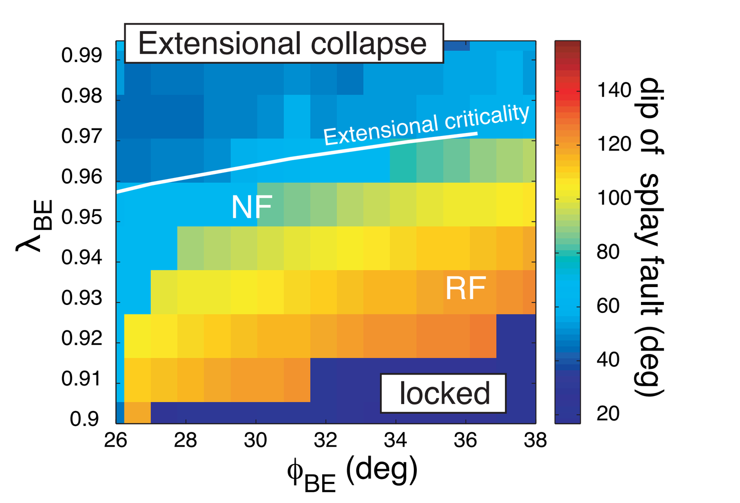
Slip ratio between footwall and hanging wall. The maximum ratio for a landward normal fault is about 1.1. For a slip of 50m of the footwall, the slip of the hangingwall would be 45m, and 5 horizontal m of slip have to be accomodated by the normal fault.

If preexistent normal fault

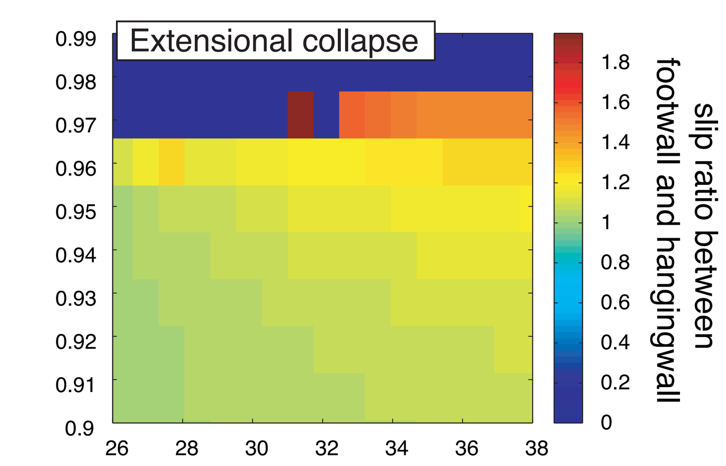


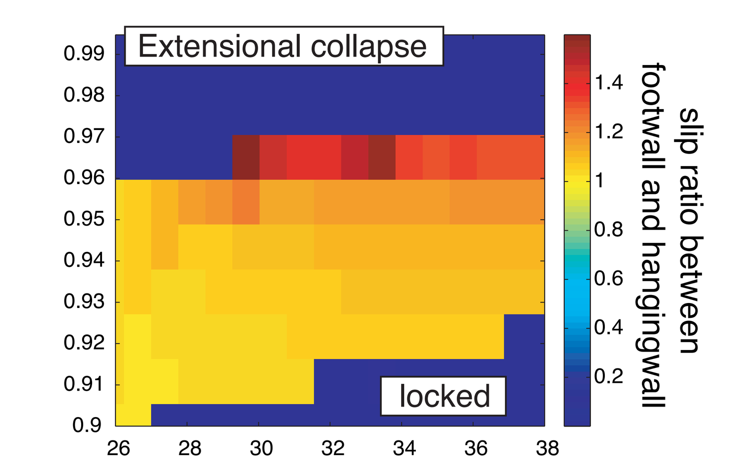
Dip of splay fault if its friction equals the downdip megathrust friction (25°)

If weak fault



Dip of splay fault if its friction is lower than the downdip megathrust friction (15°).





Slip ratio between footwall and hanging wall. The maximum ratio for a landward normal fault is about 1.2.For a slip of 50m of the footwall, the slip of the hangingwall would be 41.6m, and 8.4 horizontal m of slip have to be accomodated by the normal fault.

=>> The landward normal fault can be activated for a downdip basal friction of 25° with a basal λ of 0.8 ($\mu_{BI} = 0.09$), if the up-dip friction is larger than 26° with a basal λ of 0.94 ($\mu_{BE} = 0.04$).

=>> In that case the maximum horizontal displacement accomodated by the normal fault is about 17% of the horizontal up-dip displacement. If we consider a 60 degrees dipping normal fault, for an up-dip displacement of 50m, then the vertical displacement is about 14m.

Conclusion

A landward normal fault can be activated by a sudden increase of static friction with an increase of pore pressure leading to a low effective friction.

In that case, the maximum vertical displacement would be about 30% of the updip horizontal slip. In conclusion, the fault could have participated to the tsunami but can not be the principal cause.