Drilling to the Fault of the 2011 Tohoku-oki Earthquake: Fault Friction and Energy

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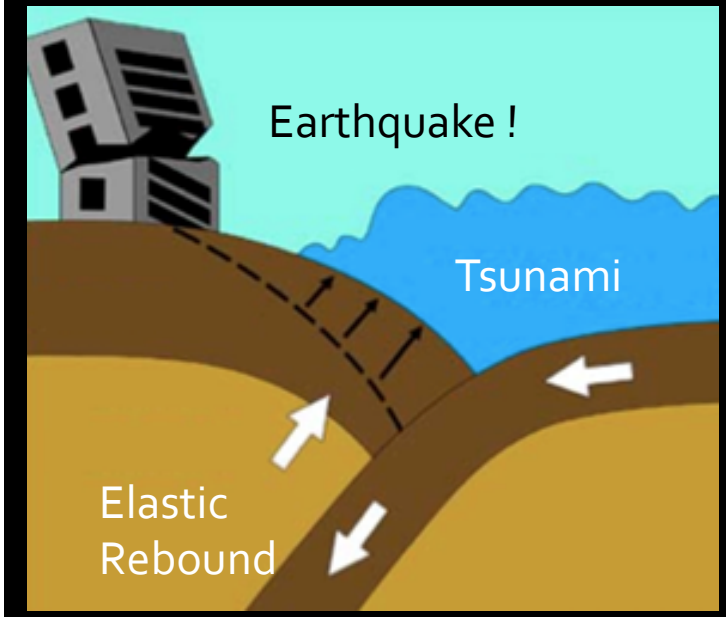


Largest slip ever recorded for an earthquake
maximum over 50 meters

Huge slip on shallow portion of megathrust
generated devastating tsunami

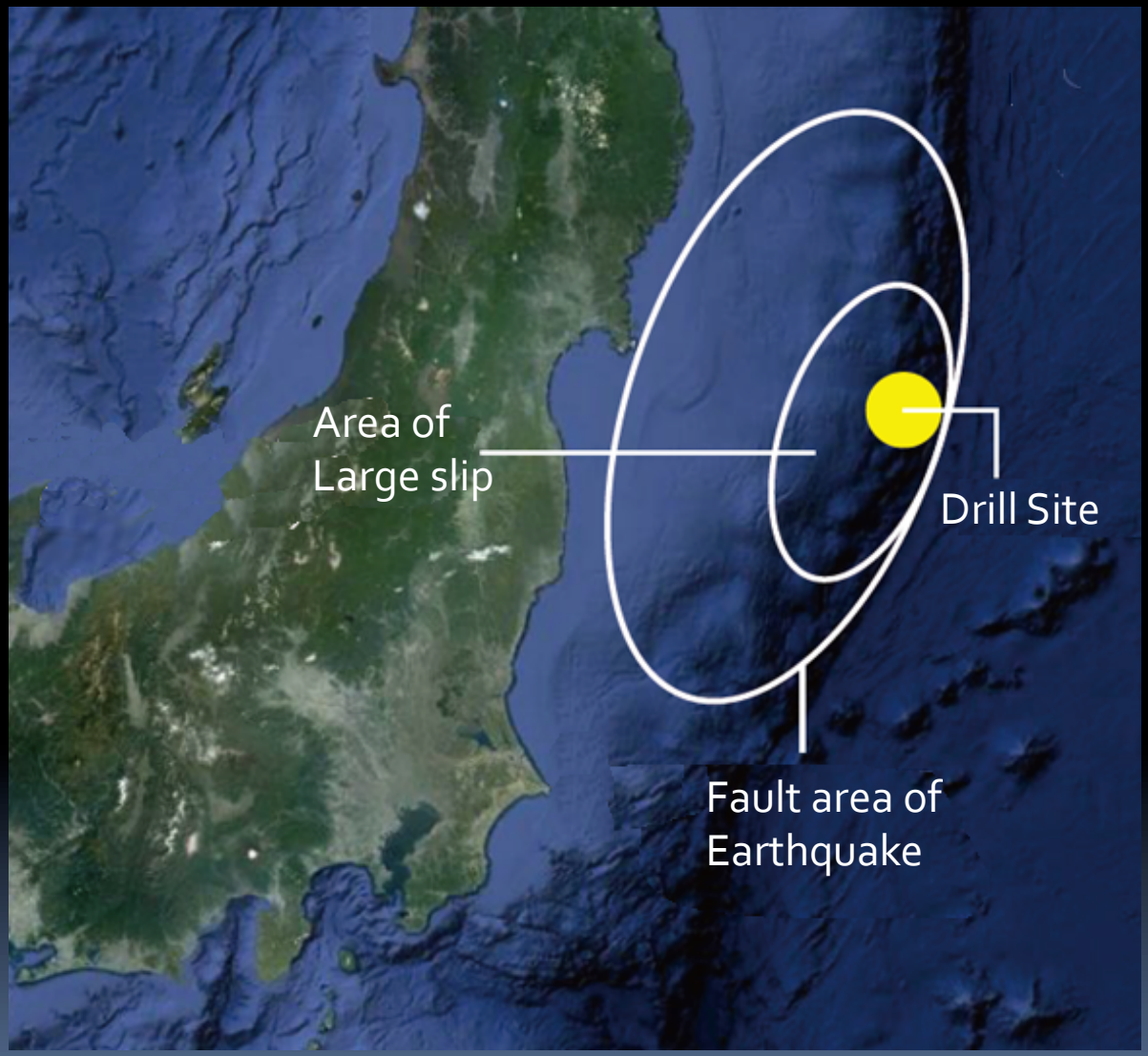
The goal of JFAST was to understand the huge slip that occurred on the shallow portion of the megathrust and caused the large tsunami

- Determine the level of friction during the earthquake rupture from the heat on the fault. Done with temperature measurements. *Needs to be done quickly.*
- Sample the fault zone to directly observe the rock properties and physical conditions. *Fault zone of such large slip never been seen before.*
- Measure the local stress field with borehole breakouts

IODP Expedition 343
Japan Trench Fast Drilling Project – JFAST
1 April ~ 24 May 2012

Science Party

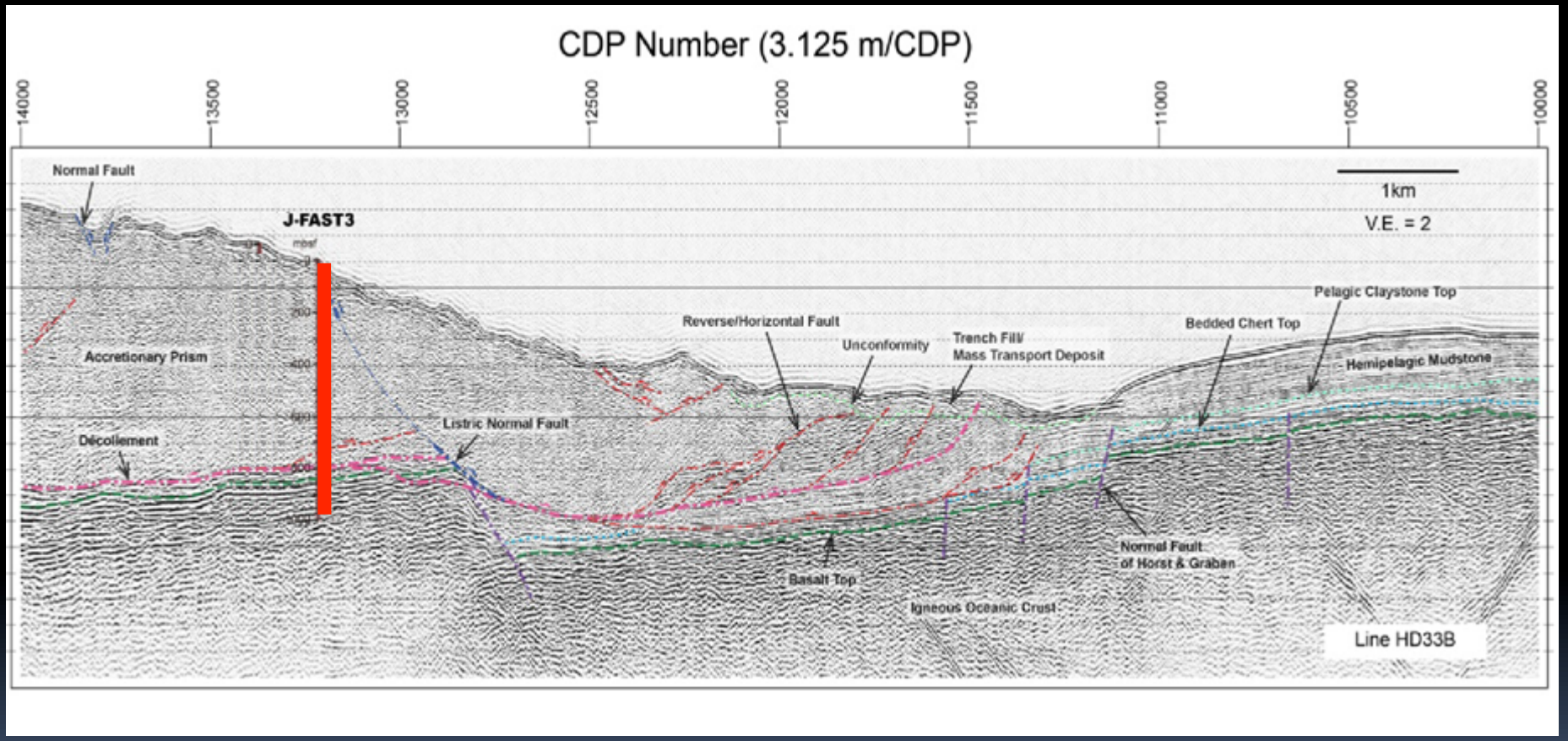
Geologists, Geophysicists, Geochemists, Biologist from 10 countries

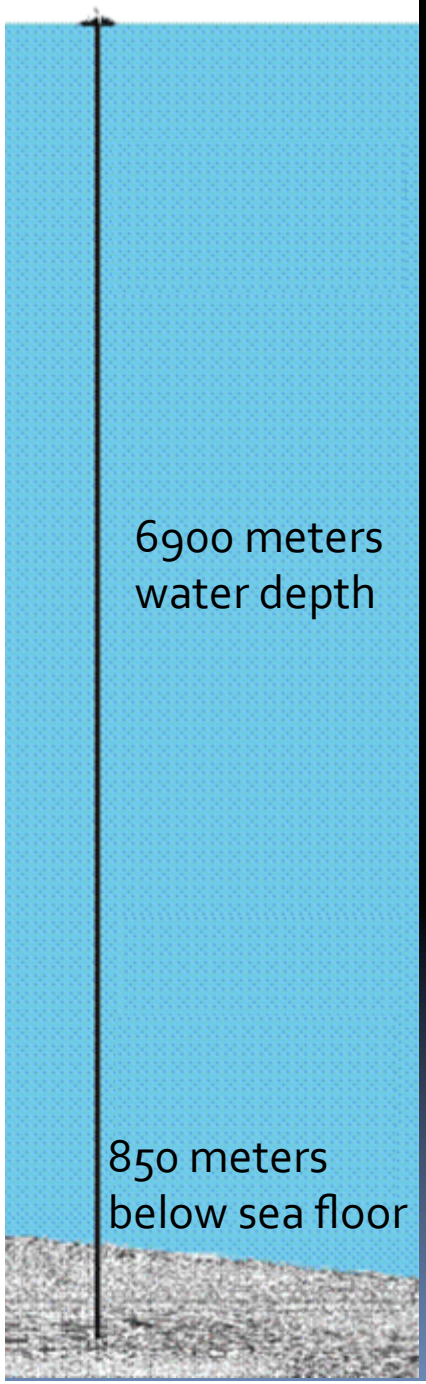


JFAST
Japan Trench
Fast Drilling Project

IODP Expedition 343

JFAST site


CDP Number (3.125 m/CDP)
14000
13500
13000
12500
12000
11500
11000
10500
10000
Normal Fault
J-FAST3
1km
V.E. = 2
Pelagic Claystone Top
Reverse/Horizontal Fault
Unconformity
Trench Fill/
Mass Transport Deposit
Bedded Chert Top
Hemipelagic Mudstone
Accretionary Prism
Listric Normal Fault
Décollement
Basalt Top
Normal Fault
of Horst & Graben
Igneous Oceanic Crust
Line HD33B



Very Deep Water Drilling
depth 6900 meters

Only *Chikyu* can handle the long (heavy) drill string

Many technical problems mainly due to deep water

- Strength of drill pipe
- Running tool release
- Broken drill pipe
- Underwater camera system
- Time constraints (seafloor round trip 3 to 4 days)

Set new drilling records research drilling.

Total pipe length below sea level (7740 meters)

Deepest core below sea level (7734 meters)

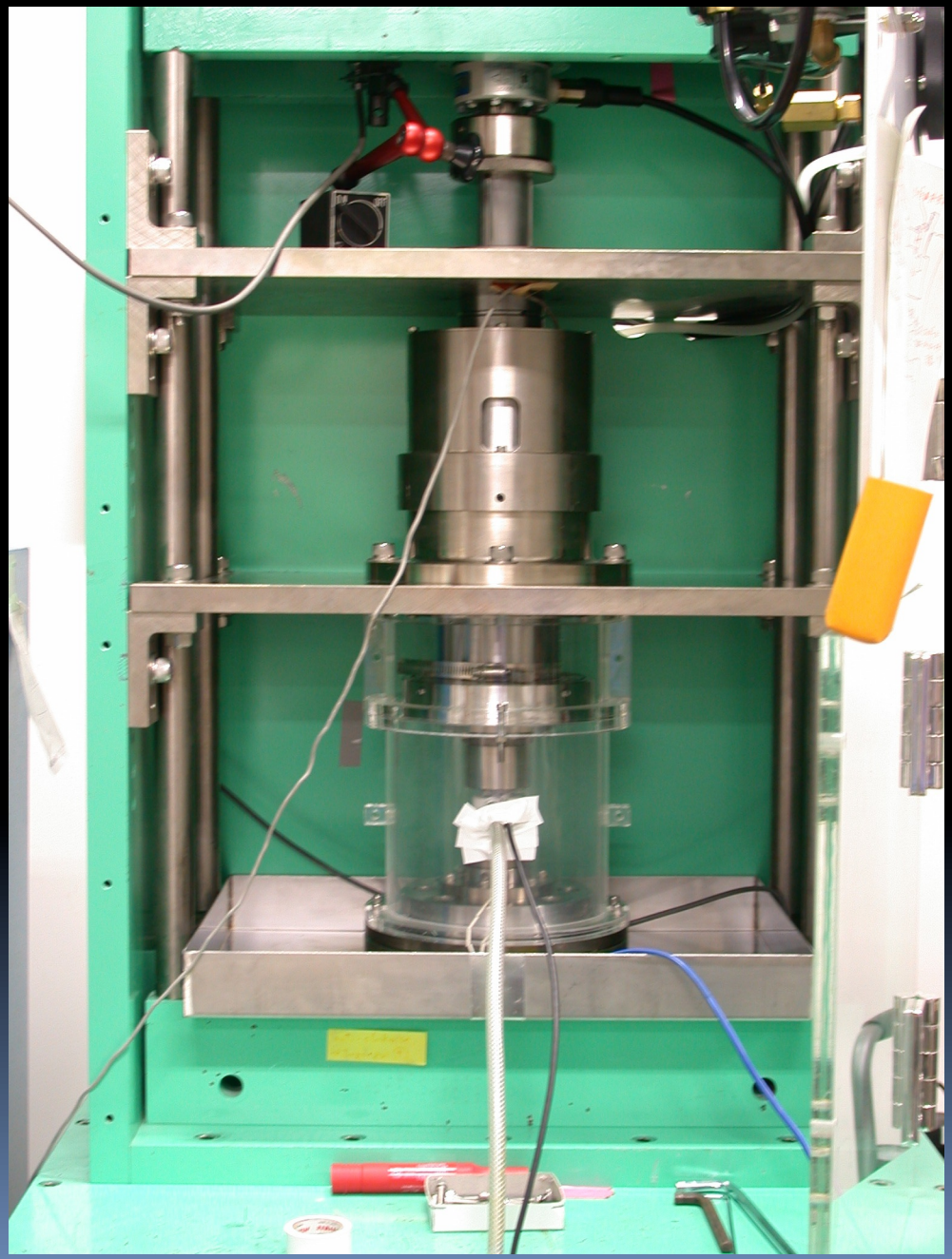
Core Sampling

- 21 cores from 648 to 845 mbsf
- Sampled small fault zone at 720 mbsf
- Sampled large fault zone at 820 mbsf

JFAST Core 17

- 821.5～824.0 mbsf, 0.97 m sample of 2.5 m length （38.8% recovery）
- Highly deformed scaly fabric fault zone
- Fault zone between subducting and overriding plate very thin (< 5 m)
- Contains fault zone for 2011 earthquake ?

JFAST Core 17
Fault zone of the 2011 Tohoku Earthquake

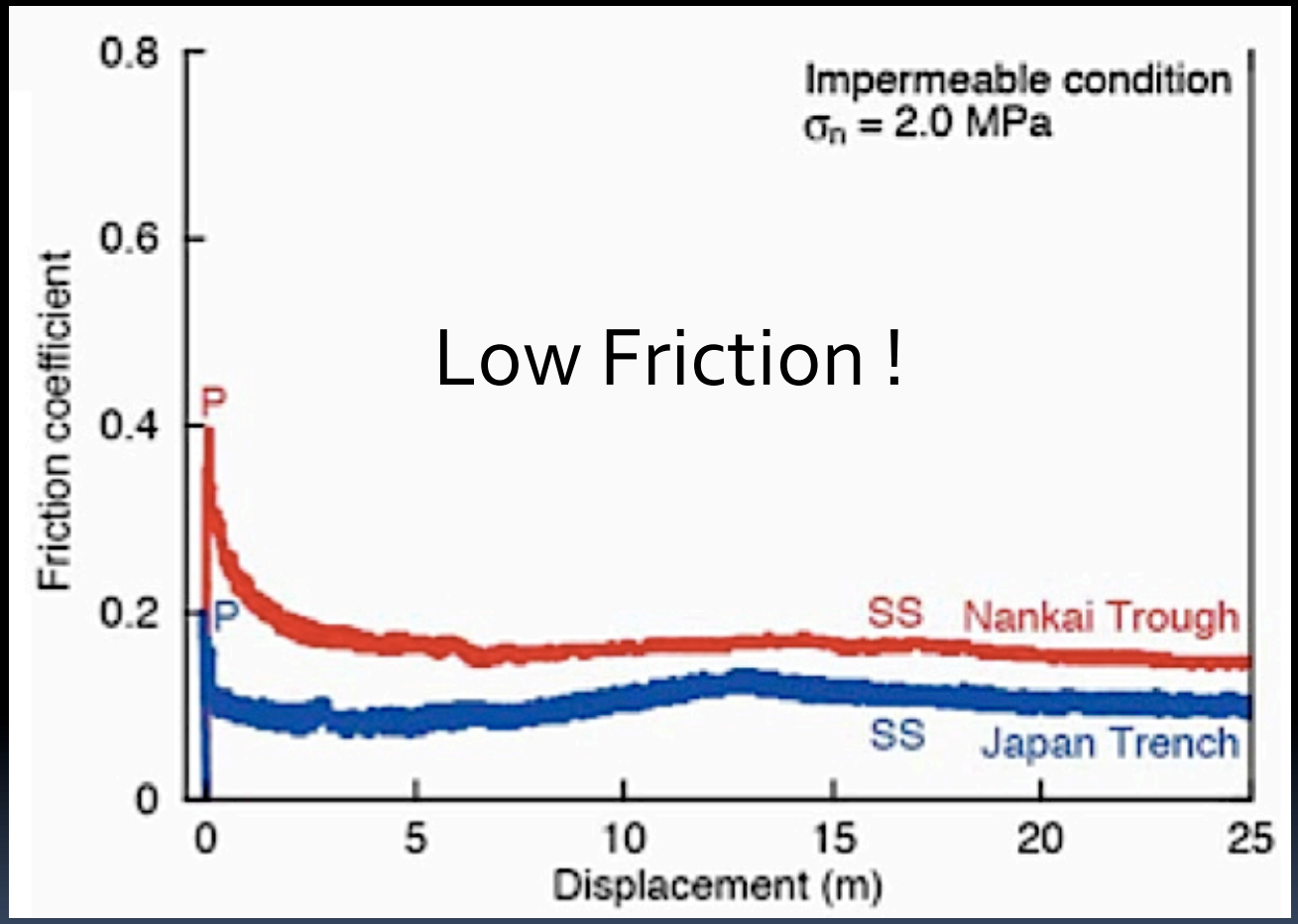


Friction Experiments on fault zone material

Ujiie et al., 2013

- High speed (1.3 m/sec, 60 m)
- JFAST-17 fault-zone sample

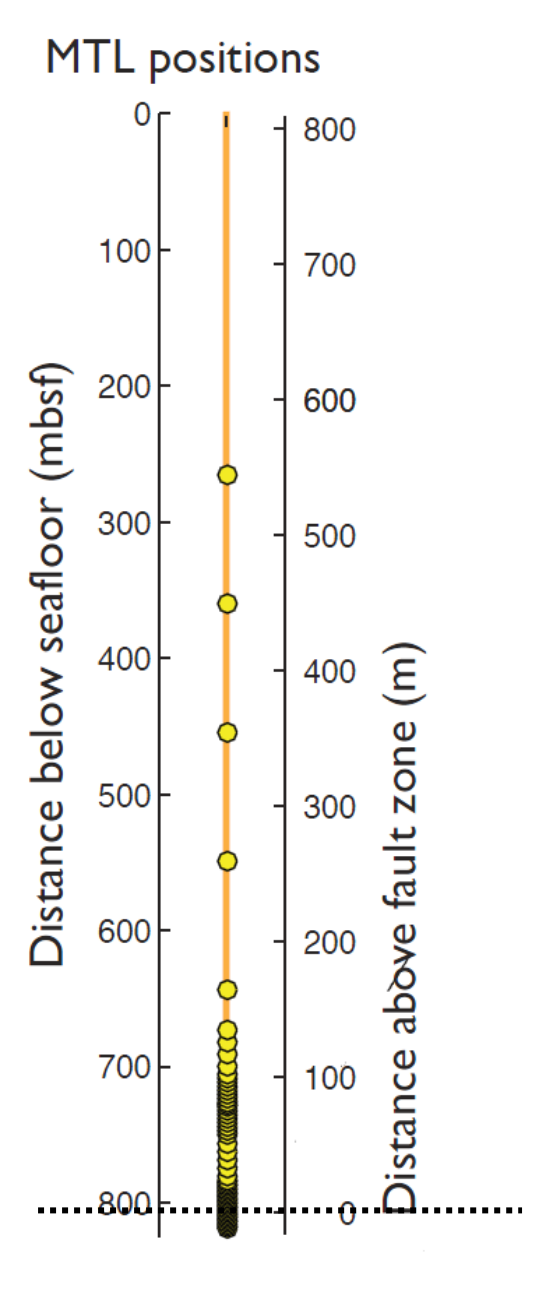
Laboratory Friction Experiments on Fault zone Material



Coefficient of Dynamic Friction about 0.1

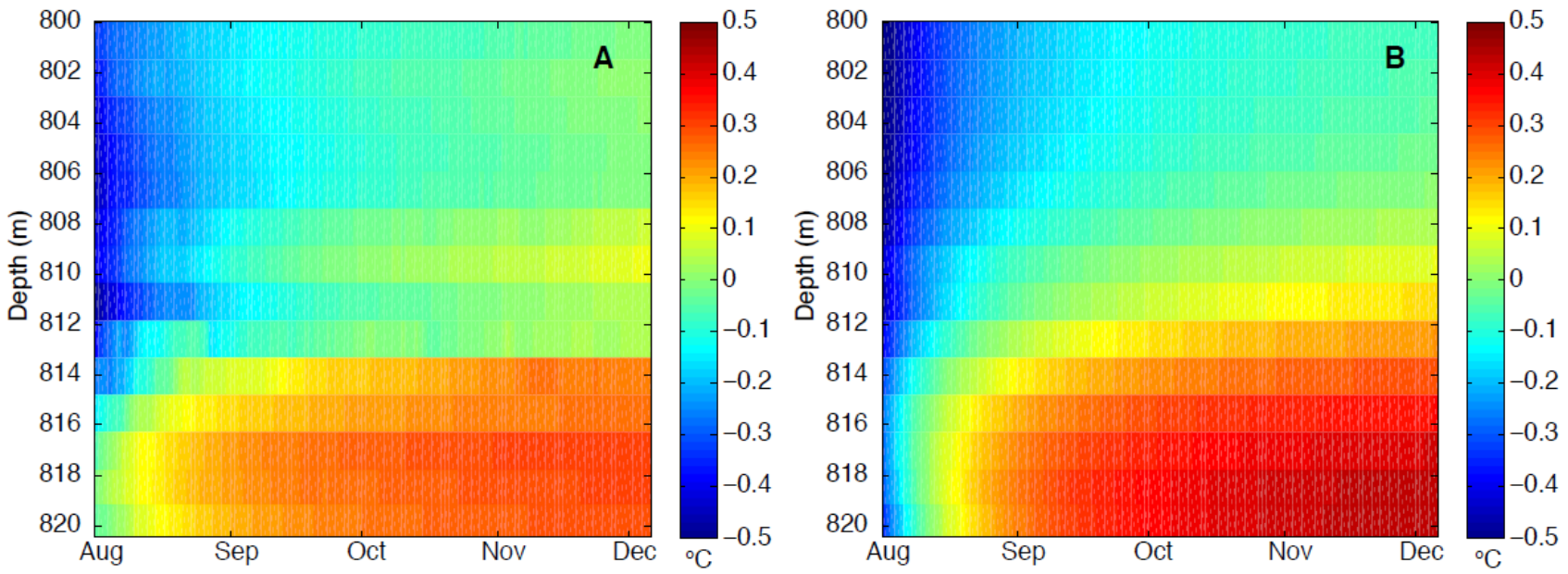
(Ujiie et al., Science 2013)

Temperature Sensors



Temperature Measurements across fault zone also used to determine the frictional heat

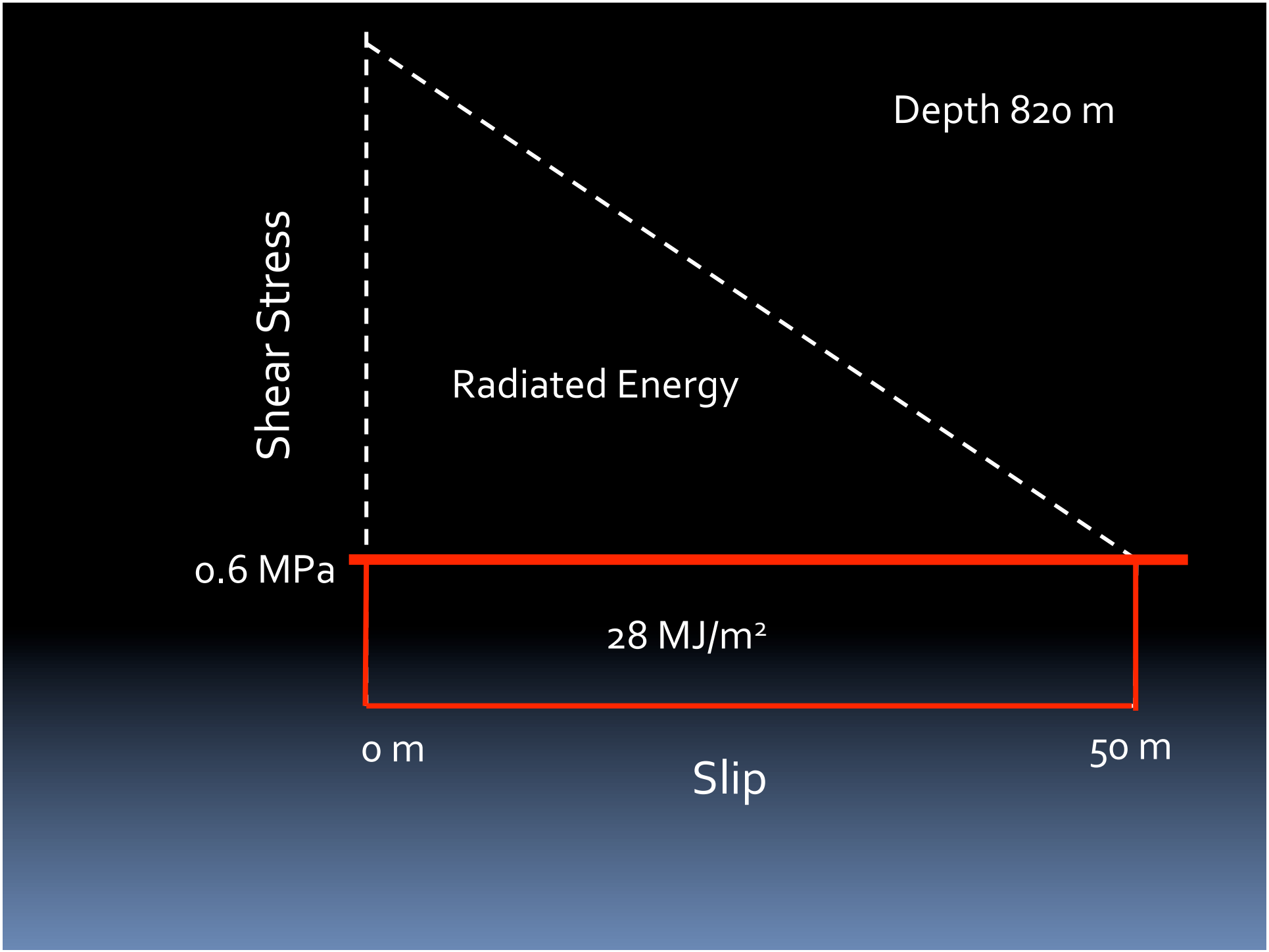
TemperatureData Model μ~0.08



Low Friction !

Result similar to friction experiment

Fulton et al., Science 2013


Depth 820 m
Shear Stress
Radiated Energy
0.6 MPa
28 MJ/m²
0 m
50 m
Slip

Science Results

- Narrow plate boundary fault zone (< 5 meters)
  Very localized deformation in brown clay

- Very low dynamic friction (lower than Nankai)
  - Laboratory experiments
  - Temperature measurements

- Horizontal Stess nearly zero
  -> Complete stress drop

How to explain huge slip of Tohoku-oki earthquake

- Very low dynamic friction during rupture.
  Once rupture starts friction can drop to very low level.

- Plate boundary material has relatively high
  static friction, so stress can accumulate.
  Does not slip aseismically.

- Very low friction means that there will be a complete
  stress drop.

- Large low-friction slip will localize fault zone.

- Low friction due to the pelagic brown clay (smectite).

Remote Operated Vehile (ROV) Kairei used to retreive temperature sensors

References

Fulton, P. M. et al., Low Coseismic Friction on the Tohoku-oki Fault Determined from Temperature Measurements, *Science*, 342, 1215-1217, doi: 10.1126/science.1243641, 2013

Chester, F.M. et al., Structure and composition of the plate-boundary slip-zone for the 2011Tohoku-oki earthquake, *Science*, 342, 1208-1211, doi: 10.1126/science.1243719, 2013.

Lin, W., et al., M. Conin, Stress State in the Largest Displacement Area of the 2011 Tohoku-Oki Earthquake, *Science*, 339, 687-690, doi:10.1126/science.1229379, 2013.

Mori, J., et al., Investigation of the huge tsunami from the 2011 Tohoku-Oki, Japan Earthquake using ocean floor boreholes to the fault zone, *Oceanography* 27, 132-137, 2014.

Ujiie, K., et al., Low coseismic shear stress on the Tohoku megathrust determined from laboratory experiments, *Science*, 342, 1211-1214, doi: 10.1126/science.1243485, 2013.