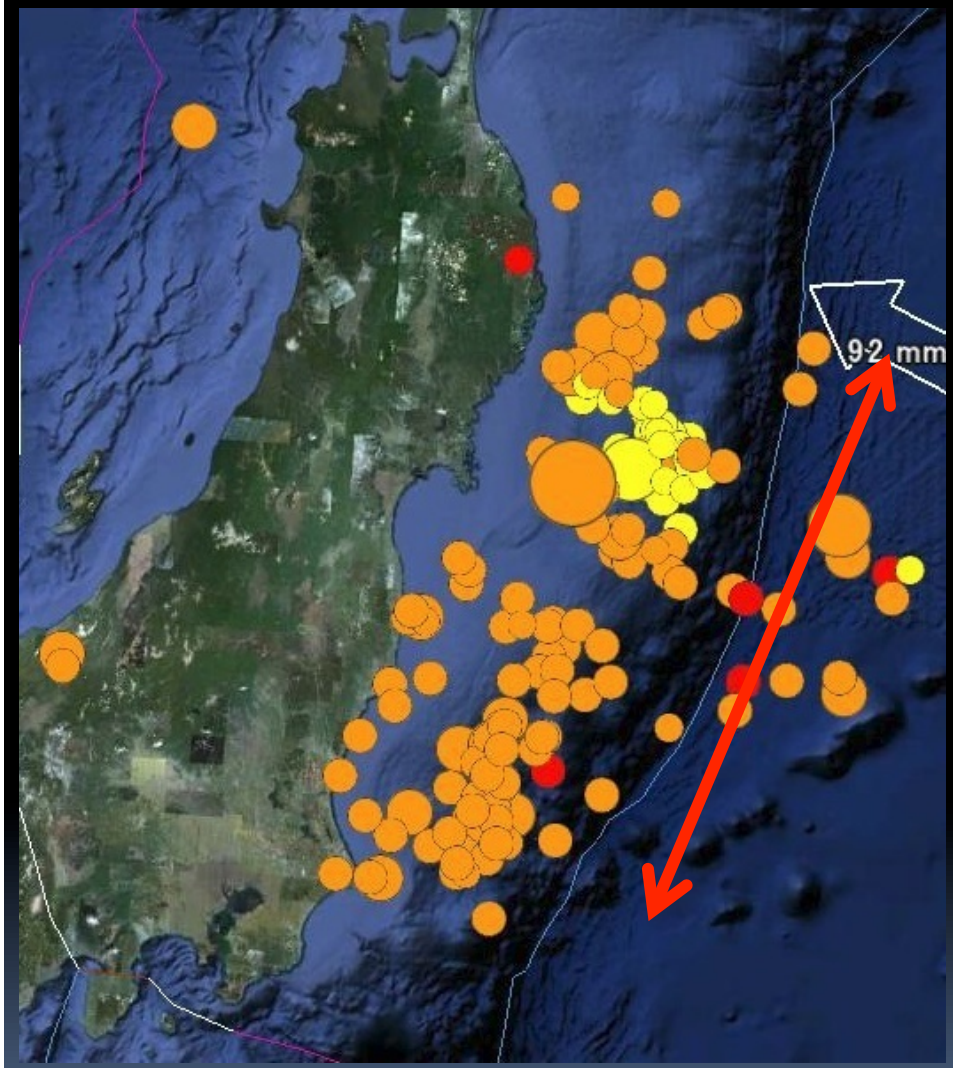
JFAST: Drilling to the Plate Boundary to Study Large Slip of the 2011 Tohoku-Oki, Japan Earthquake

James Mori, Fred Chester, Nobu Eguchi, Sean Toczko,
Emily Brodsky, Shuichi Kodaira, Expedition 343 Scientists

Science Party

Geologists, Geophysicists, Geochemists, Biologist from 10 countries

11 March 2011 Tohoku-oki Earthquake Mw9.0



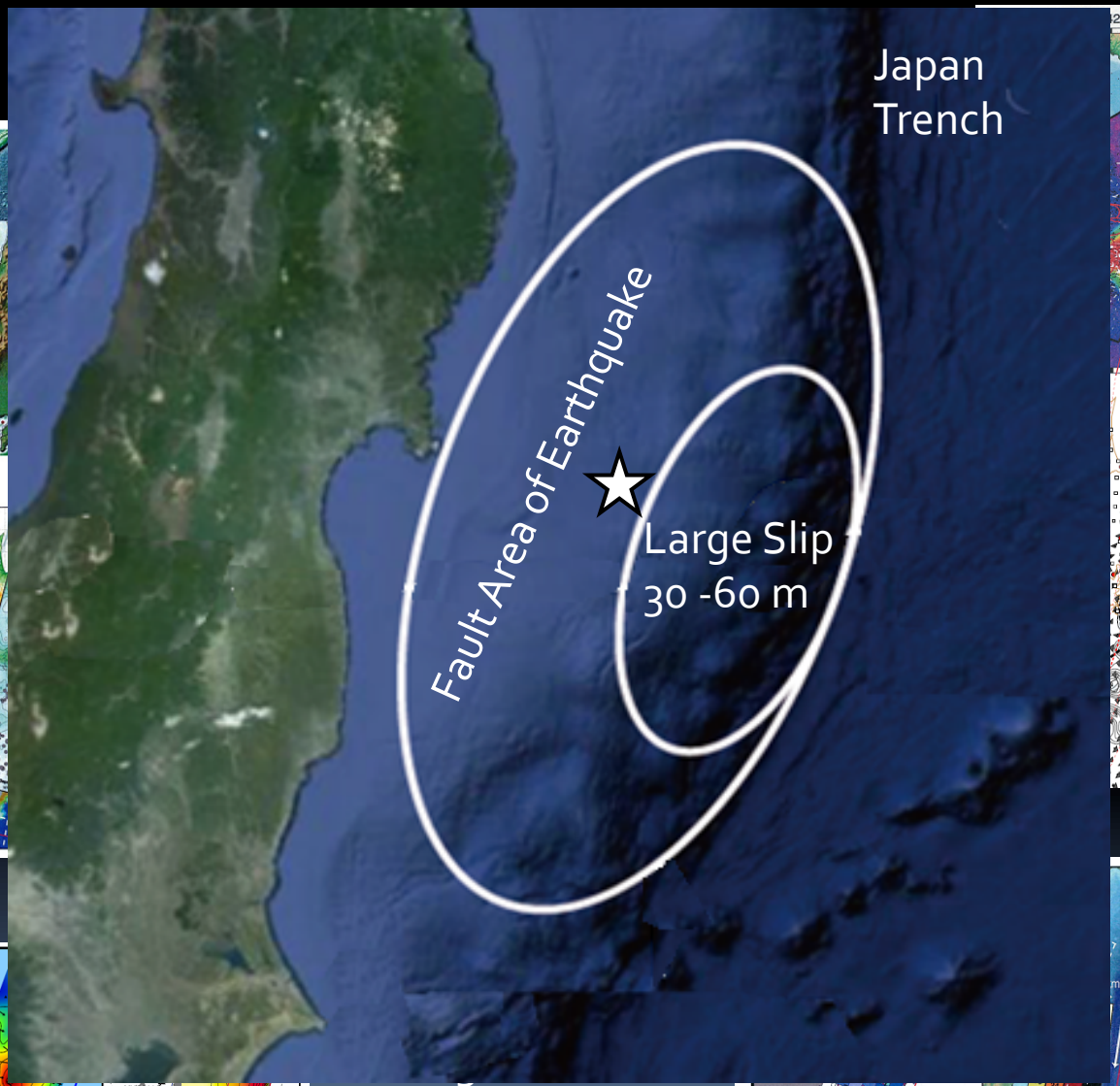
(Aftershock map from USGS)

- 400 x 200 km fault
- Over 18,000 people killed
- Damage and deaths mainly from tsunami, not shaking
- About ¥30 trillion damage (€230 billion)

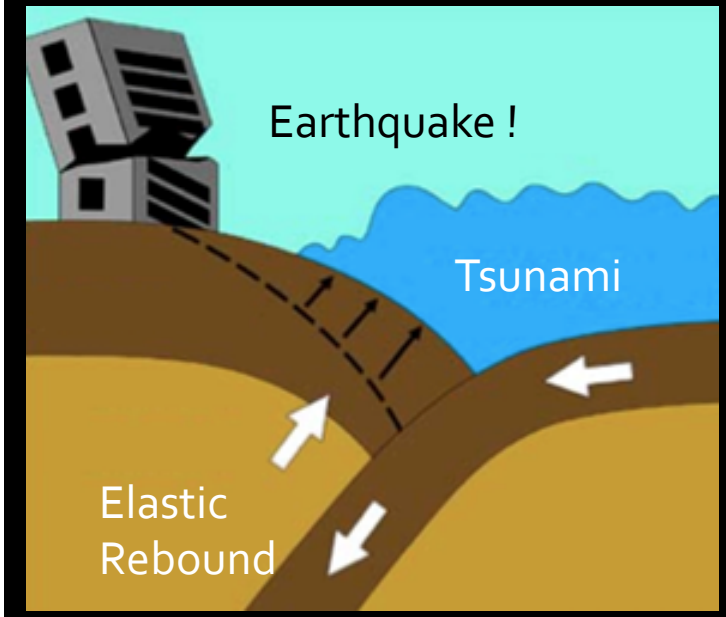
Earthquake Source Models

Teleseismic

Geodetic



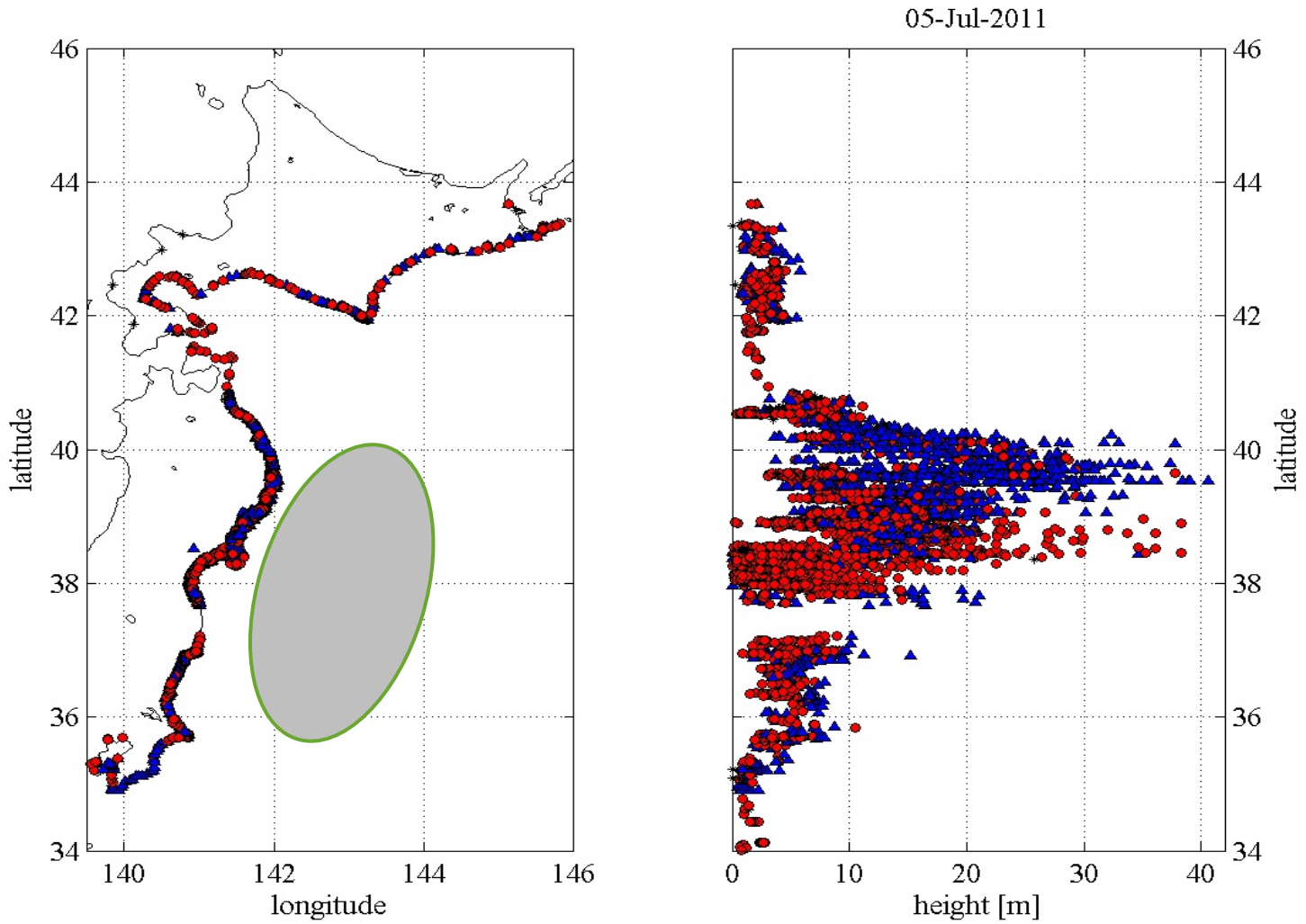
Tsunami



Largest slip ever recorded for an earthquake
maximum over 50 meters

Huge slip on shallow portion of megathrust
generated devastating tsunami

Tsunami Heights

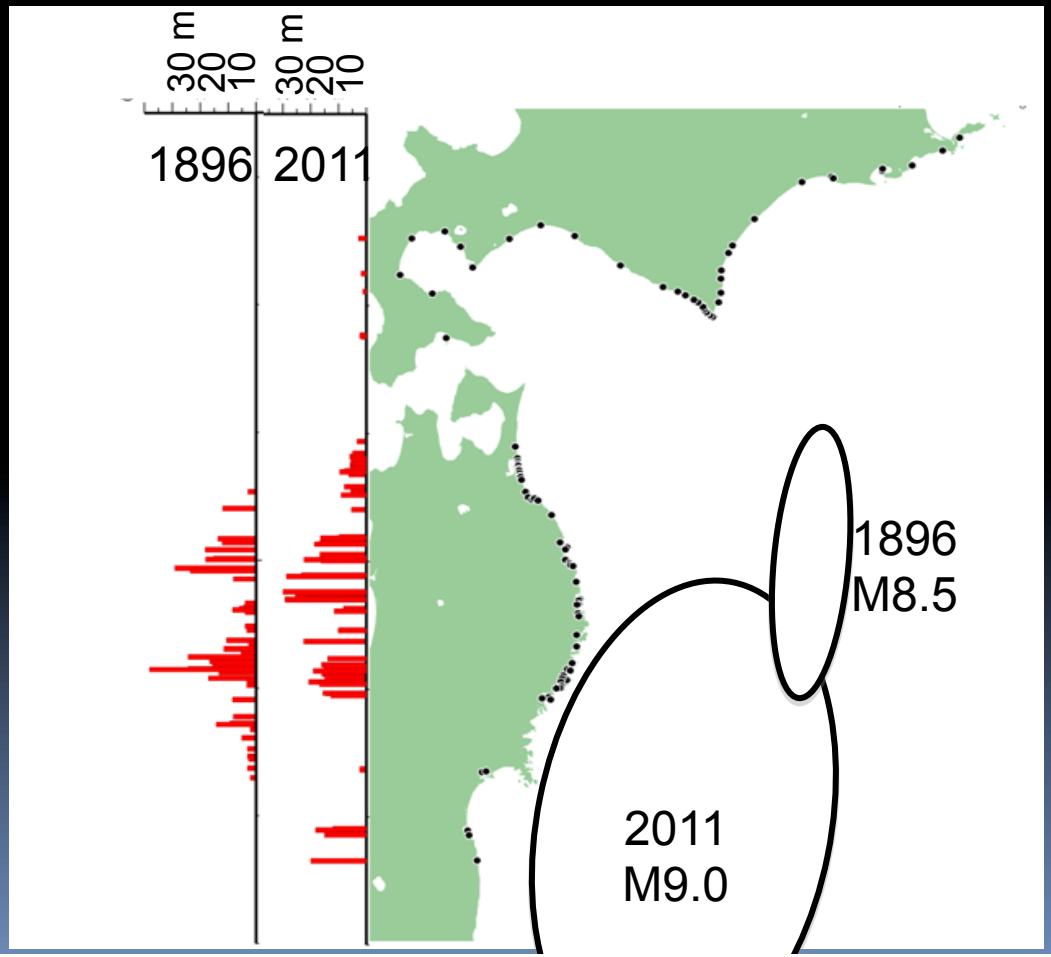


2011 Tohoku Earthquake Tsunami Joint Survey Group
http://www.coastal.jp/ttjt/


龍 泉 洞
Ryusendo Cave
6.5Km
三 王 岩
Sannoiwa Rocks
20Km
浄 土 ケ 浜
Jodogahama Beach
4Km
シートピアなあど
Seatopia Naado
5Km

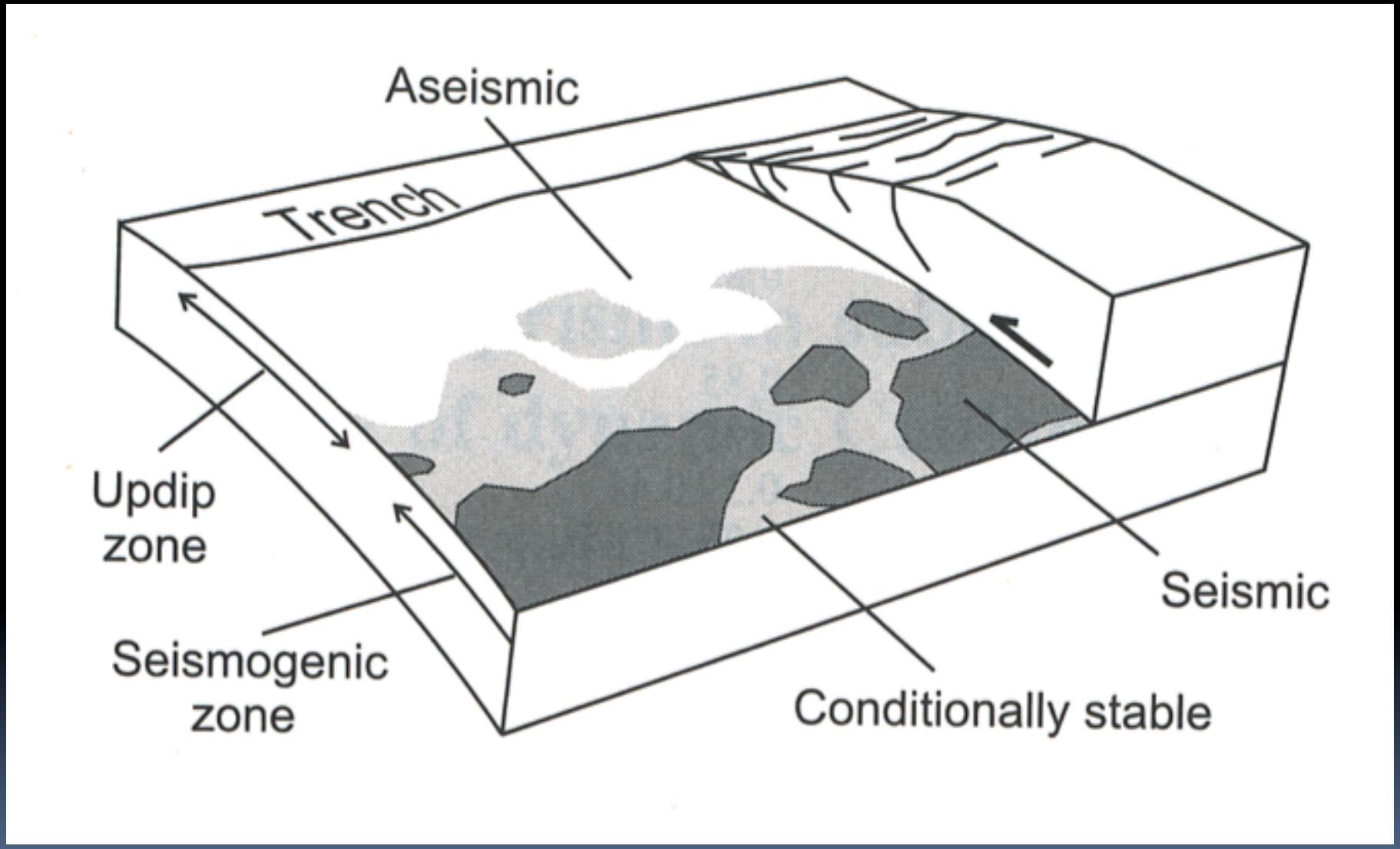
Large Tsunami from Smaller Past Earthquake

M8 can also produce 20 - 30 m tsunami.
For tsunami hazazrds, important point is not magnitude but amount of slip on shallow portion of megathrust



Data from
Hokkaido Univ.

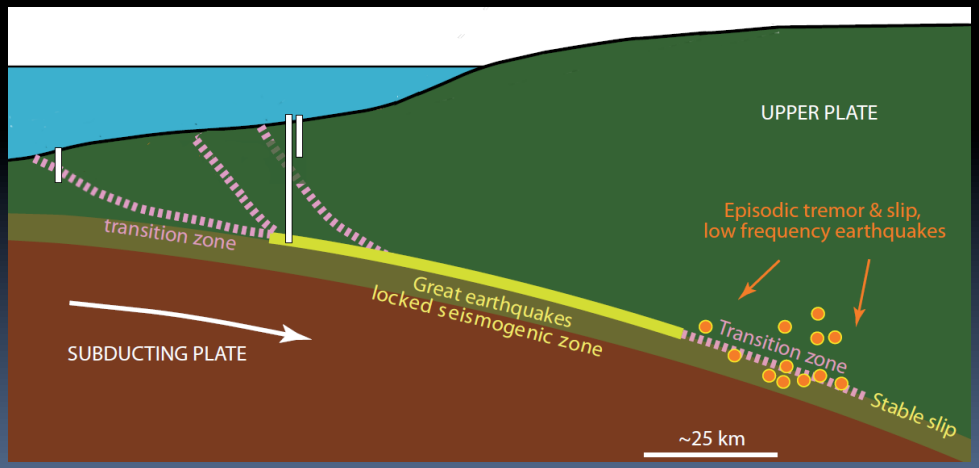
Slip on Shallow Portion of Subduction Zone



Wang and Hu, 2006

Integrated Ocean Drilling Program (IODP)

Challenge 12 of the IODP Science Plan for 2013-2023,
'*What mechanisms control the occurrence of destructive earthquakes, landslides, and tsunami?*'



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

- What are the physical mechanisms of the slip ? (stress and friction on the fault)
- What are the rock properties and fluid conditions that allow such slip ?
- Can such large slip occur at other subduction zones ?

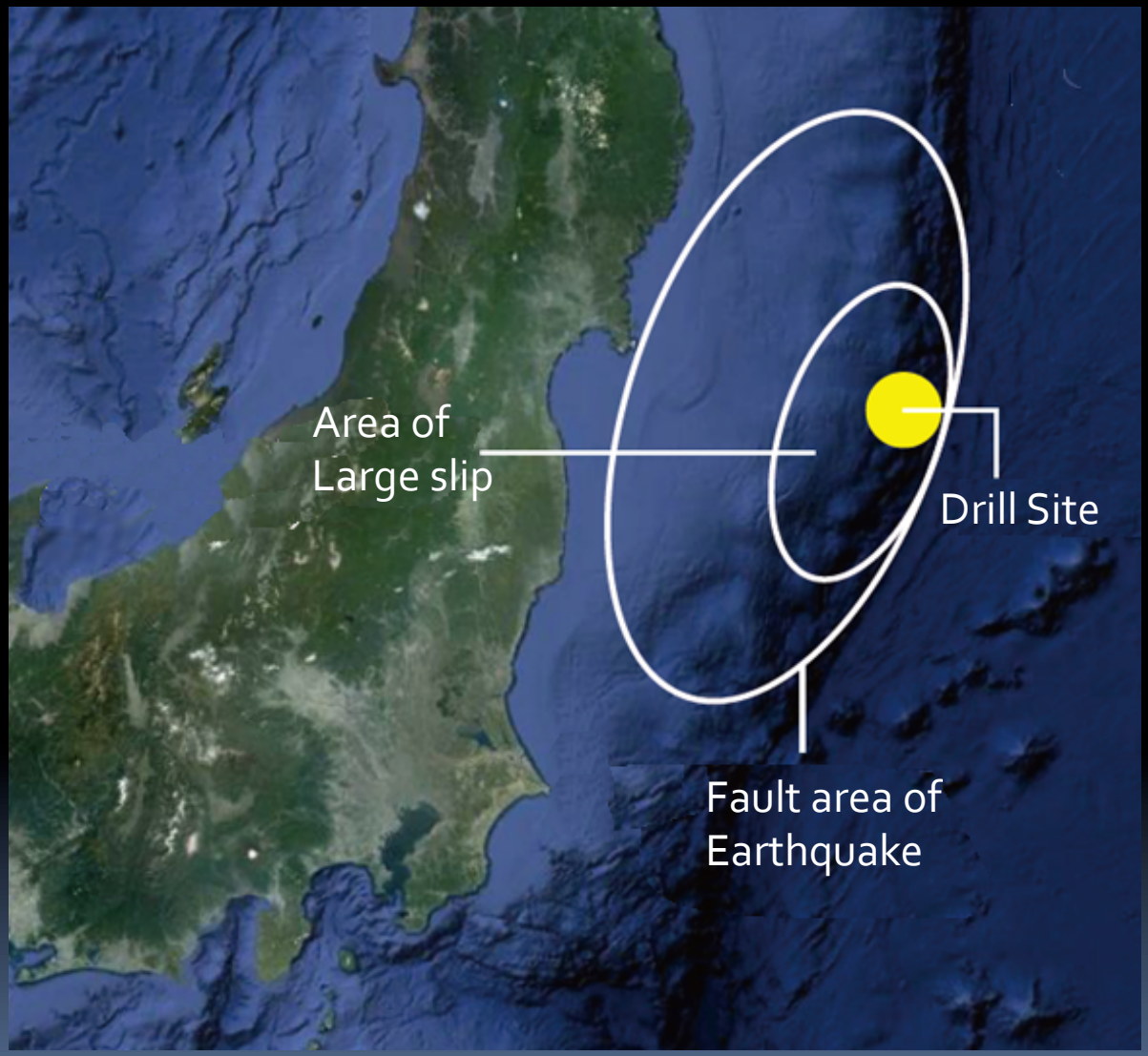
JFAST Timeline

2011 Mar. 11	Tohoku-oki earthquake
2012 April 01 ~ May 24	Expedition 343 - JFAST - LWD and Coring
2012 July 5 ~ 19	Expedition 343T - JFAST - Installation of temperature sensors
2013 February 11~21	Kairei/Kaiko Cruise KR13-04
2013 April 21~ May 9	Kairei/Kaiko Cruise KR13-08

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

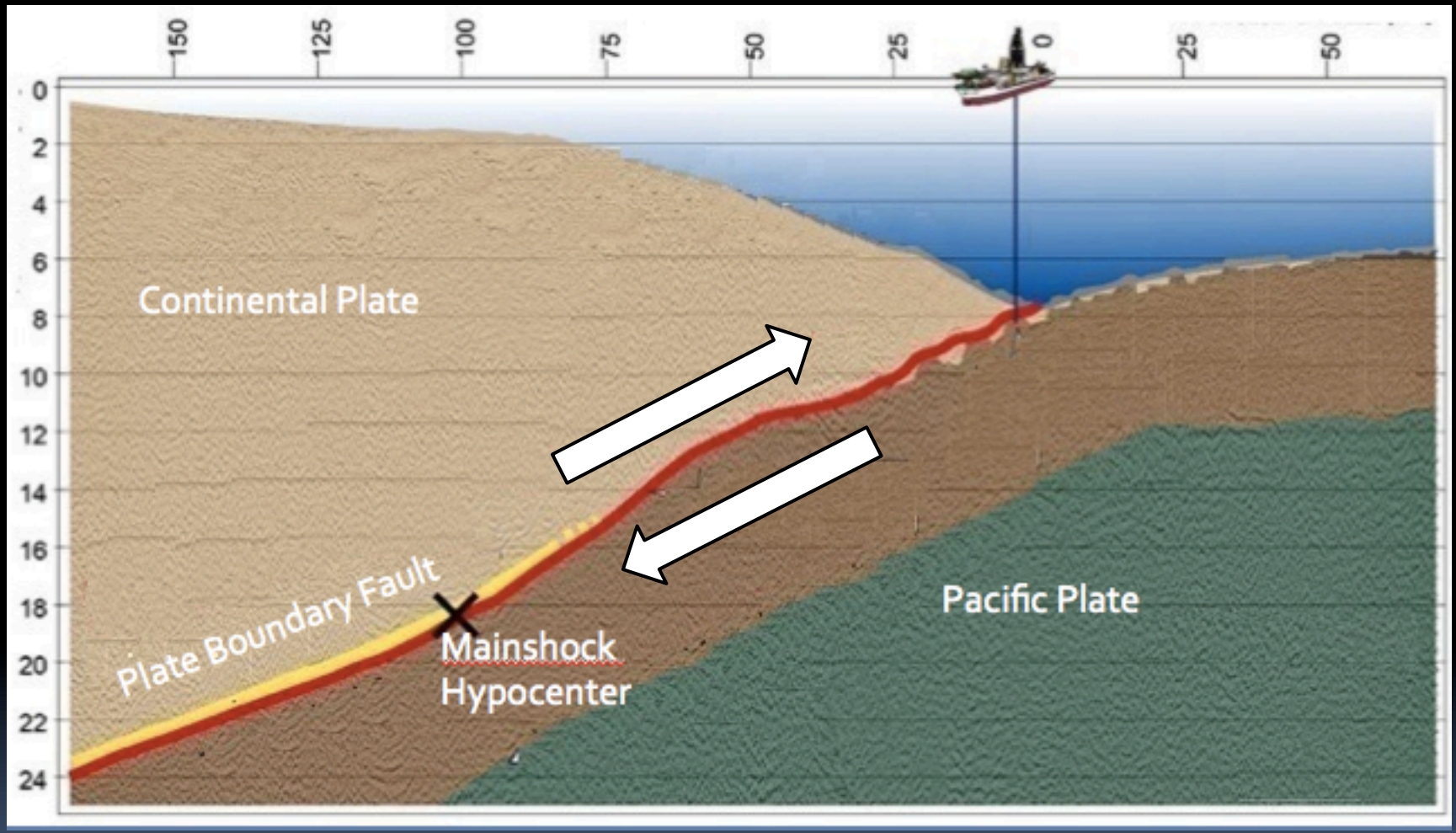
DV Chikyu operated by JAMSTEC (Japan Agency for Marine Earth Science and Technology)

210 m long 130 m height 56,752 tons
6 thrusters 150 people



JFAST
Japan Trench
Fast Drilling Project

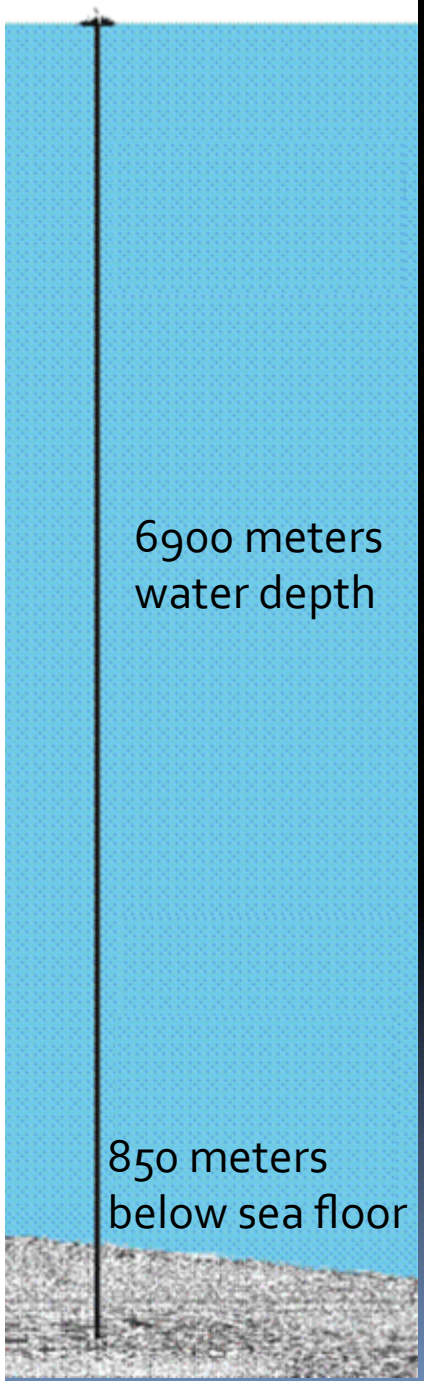
IODP Expedition 343


150
125
100
75
50
25
0
25
50
0
2
4
6
8
10
12
14
16
18
20
22
24
Continental Plate
Plate Boundary Fault
Mainshock
Hypocenter
Pacific Plate

Science Objectives

- 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.*

Very Deep Water Drilling



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

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)

New drilling records for total length below sea level (7740 m)

Stands of 36 m pipe

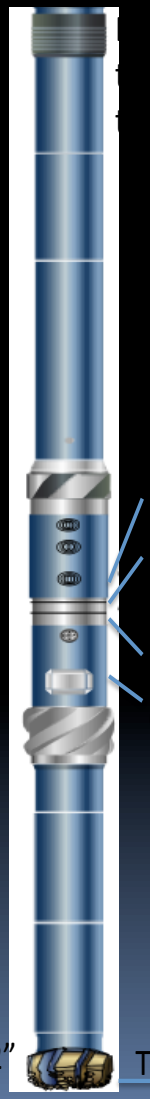
Observations and Measurements

1. Logging while Drilling （LWD）
2. Core Sampling
3. Temperature Measurements

Logging While Drilling (LWD)

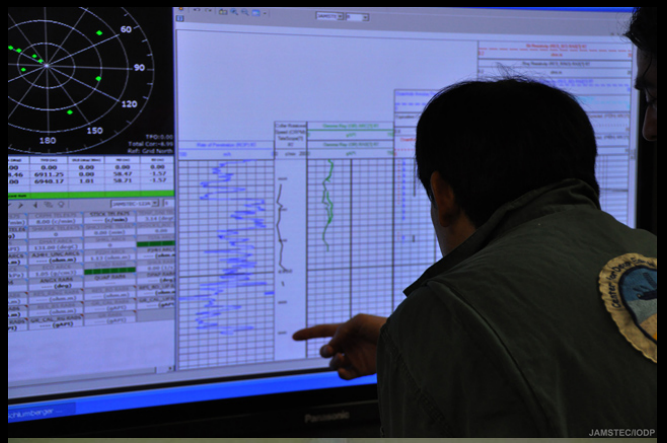
- Geophysical Measurements
  - Density
  - Resistivity
  - Natural Gamma

Important for setting of temperature sensors and for coring fault zone

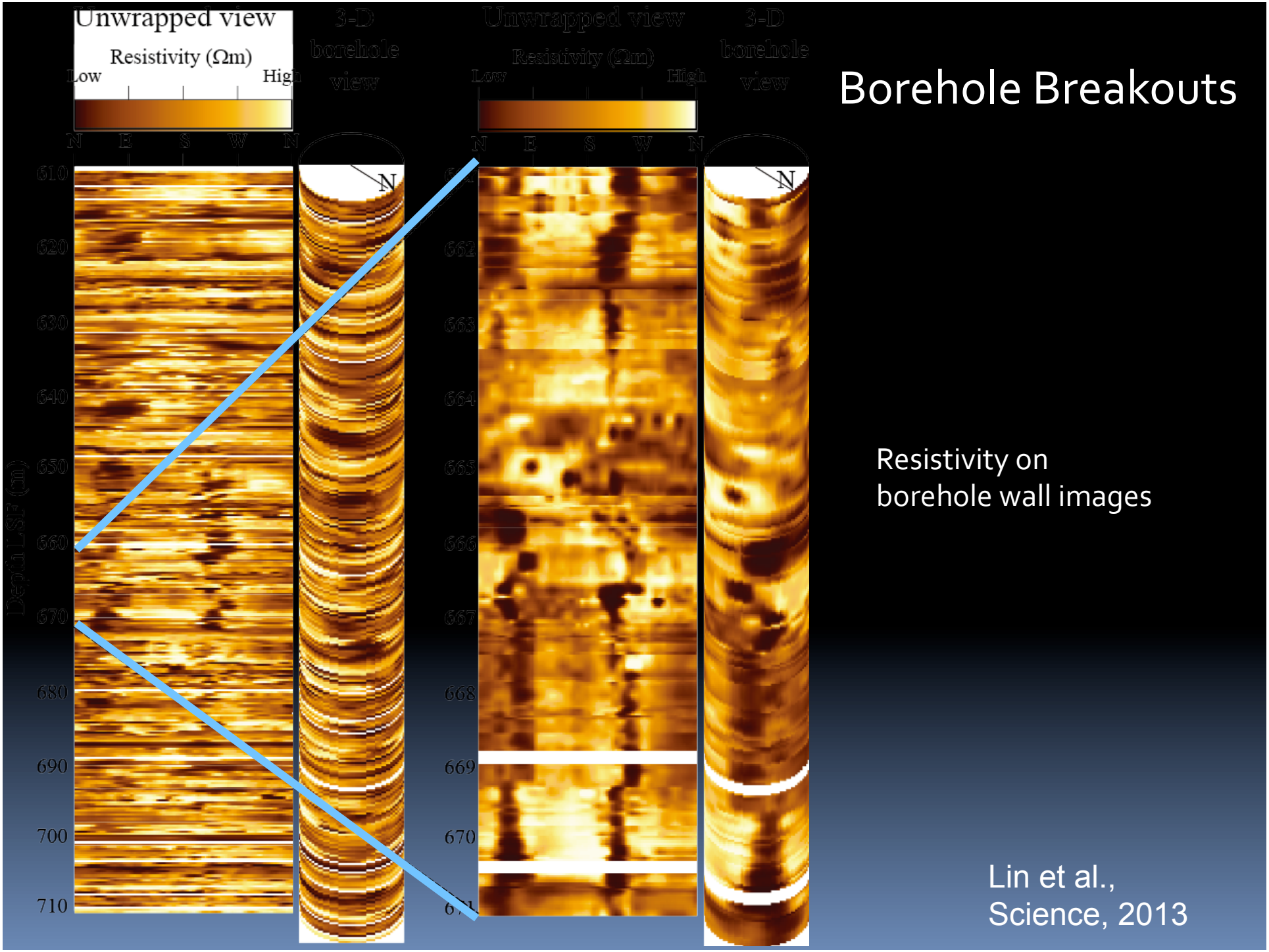


Logging While Drilling (LWD)

- Observed changes dips and azimuth of bedding
- Changes in lithology
  - 820～835 mbsf clay
  - 835 mbsf chert layer
- 2 possible fault zones at
  - 720 mbsf
  - 820 mbsf

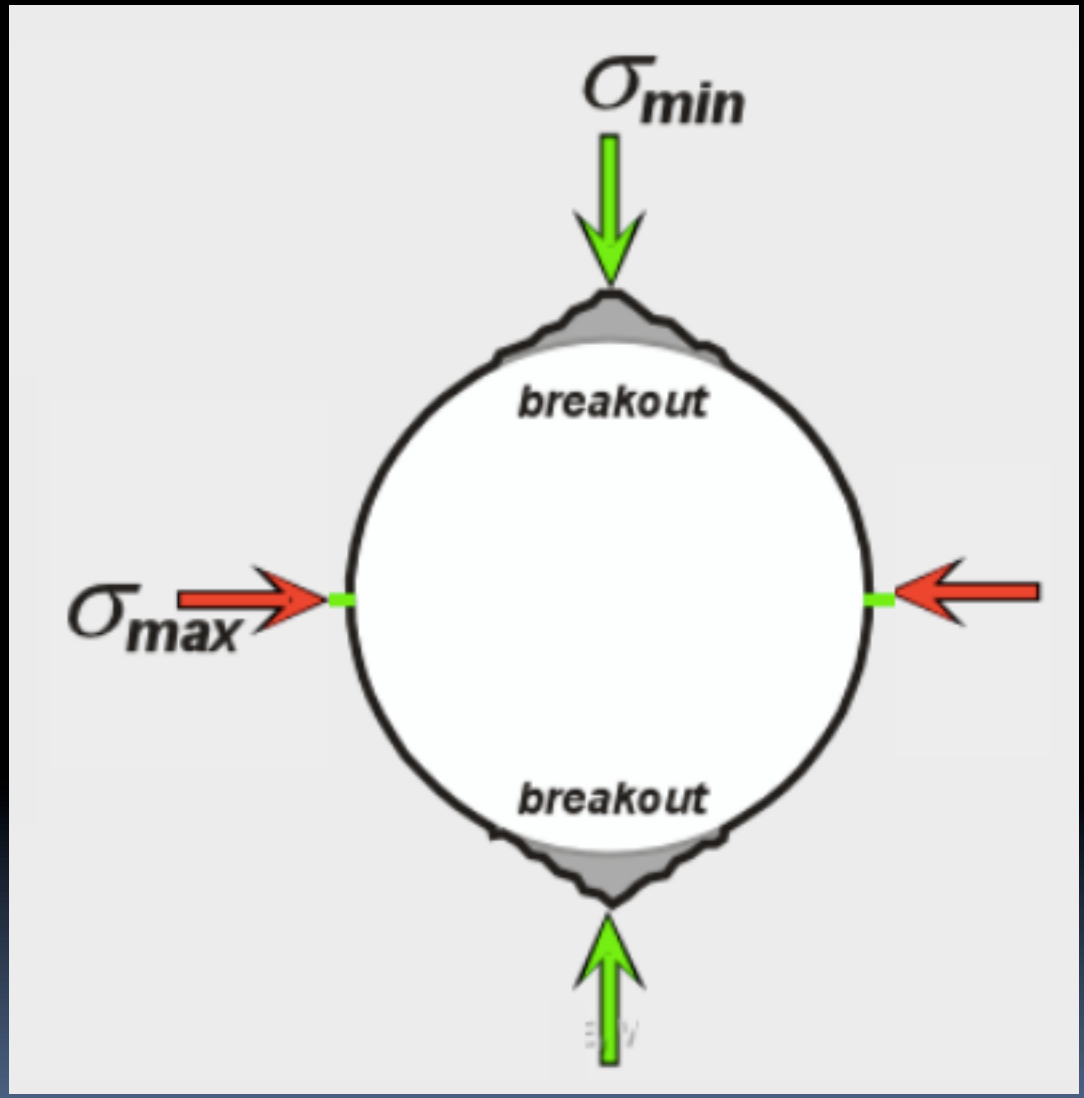


Borehole Breakouts

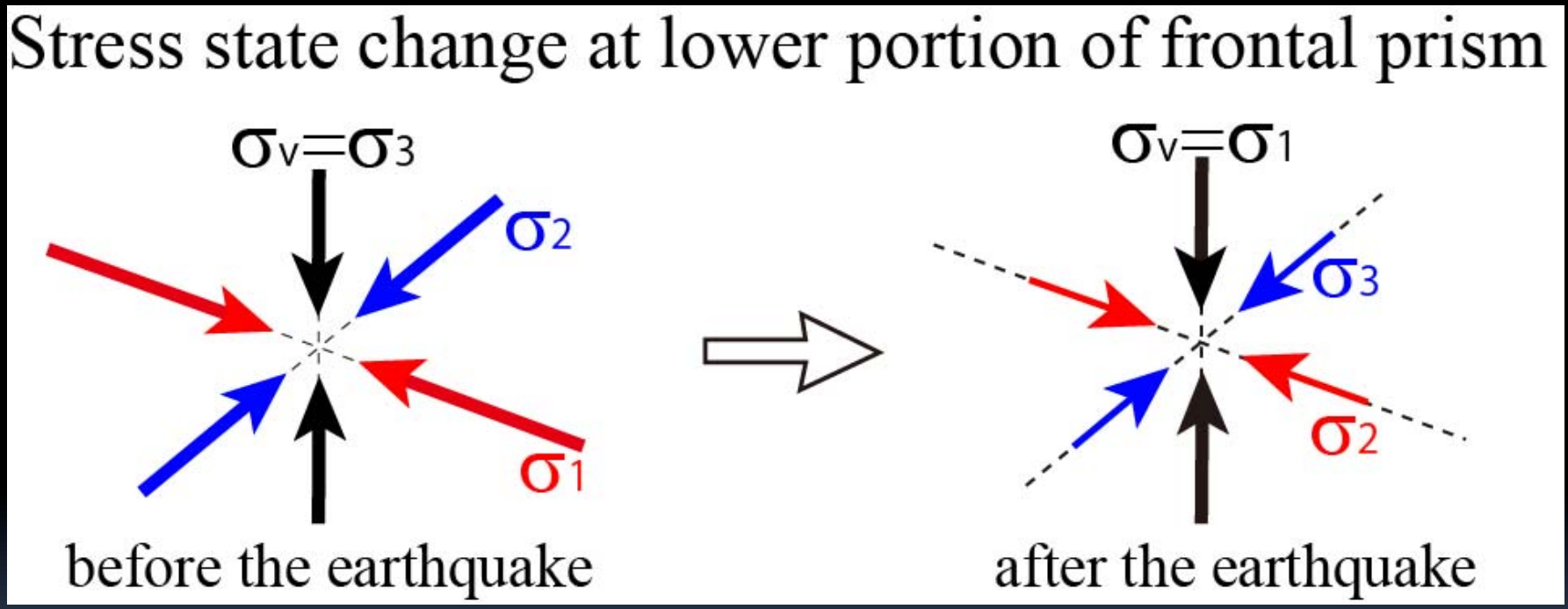


Resistivity on borehole wall images

Lin et al., Science, 2013


σ_{min}
breakout
σ_{max}
breakout

Change of local stress directions before and after earthquake. Close to zero horizontal stress after earthquake.

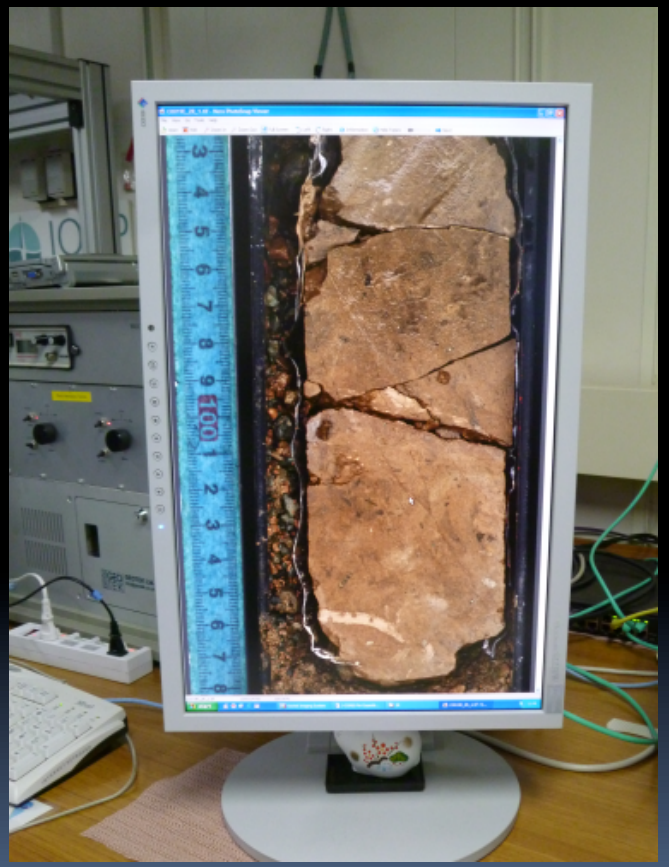


Lin et al., Science 2013

Core Sampling

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

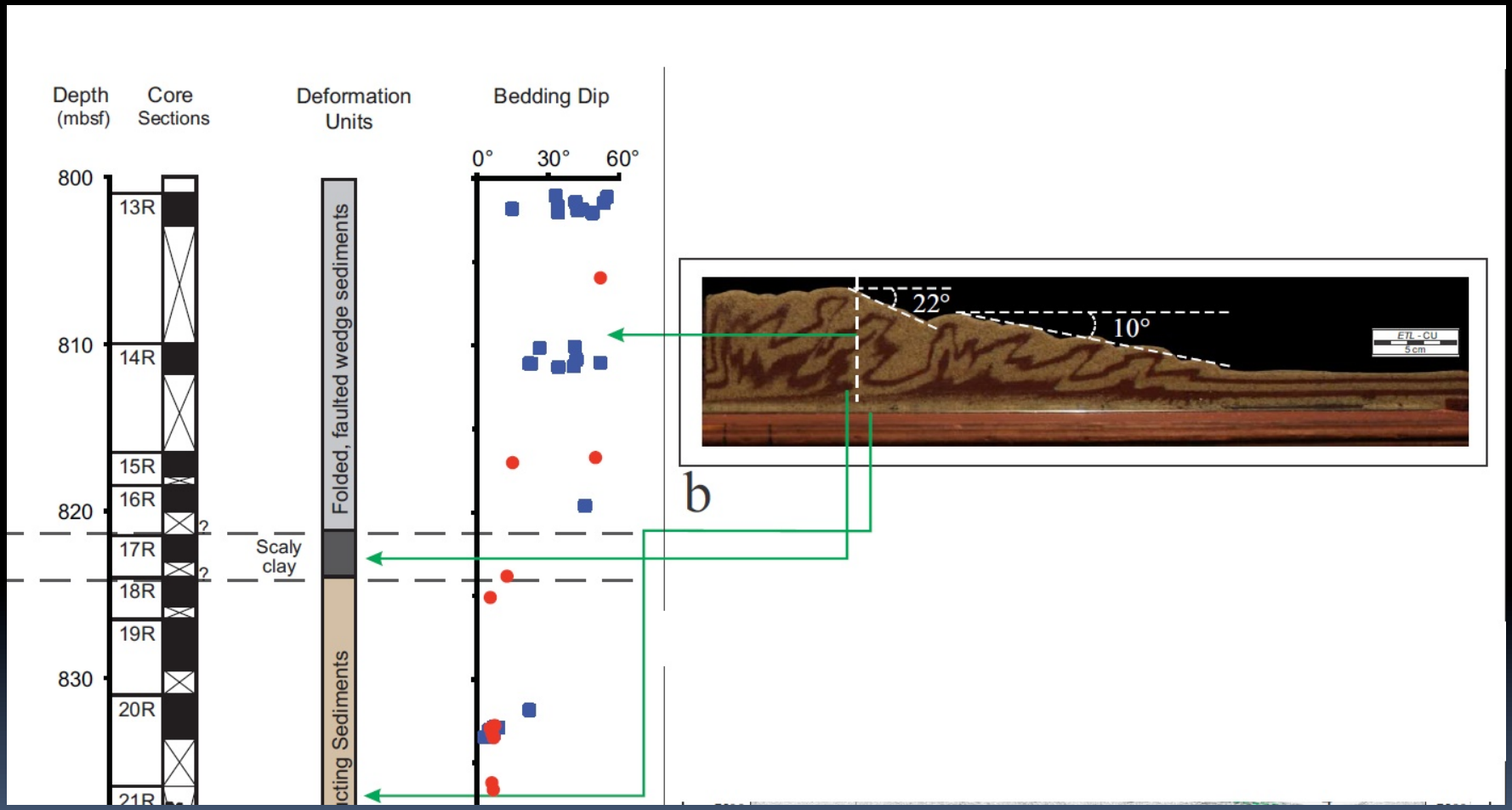
Core Flow



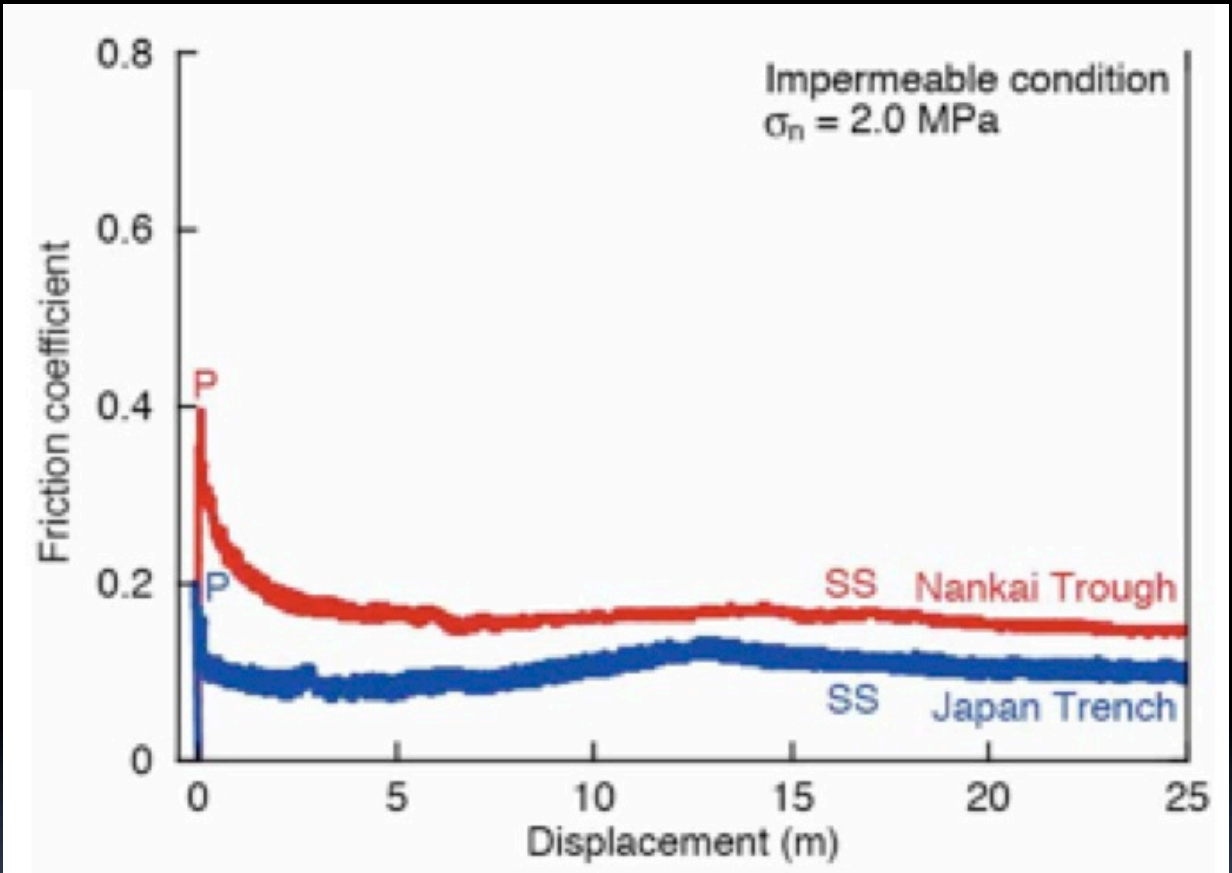
JFAST-17

- 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-17


Depth
(mbsf)
Core
Sections
Deformation
Units
Bedding Dip
0°
30°
60°
800
810
820
830
13R
14R
15R
16R
17R
18R
19R
20R
21R
Folded, faulted wedge sediments
Scaly
clay
cting Sediments
22°
10°
b

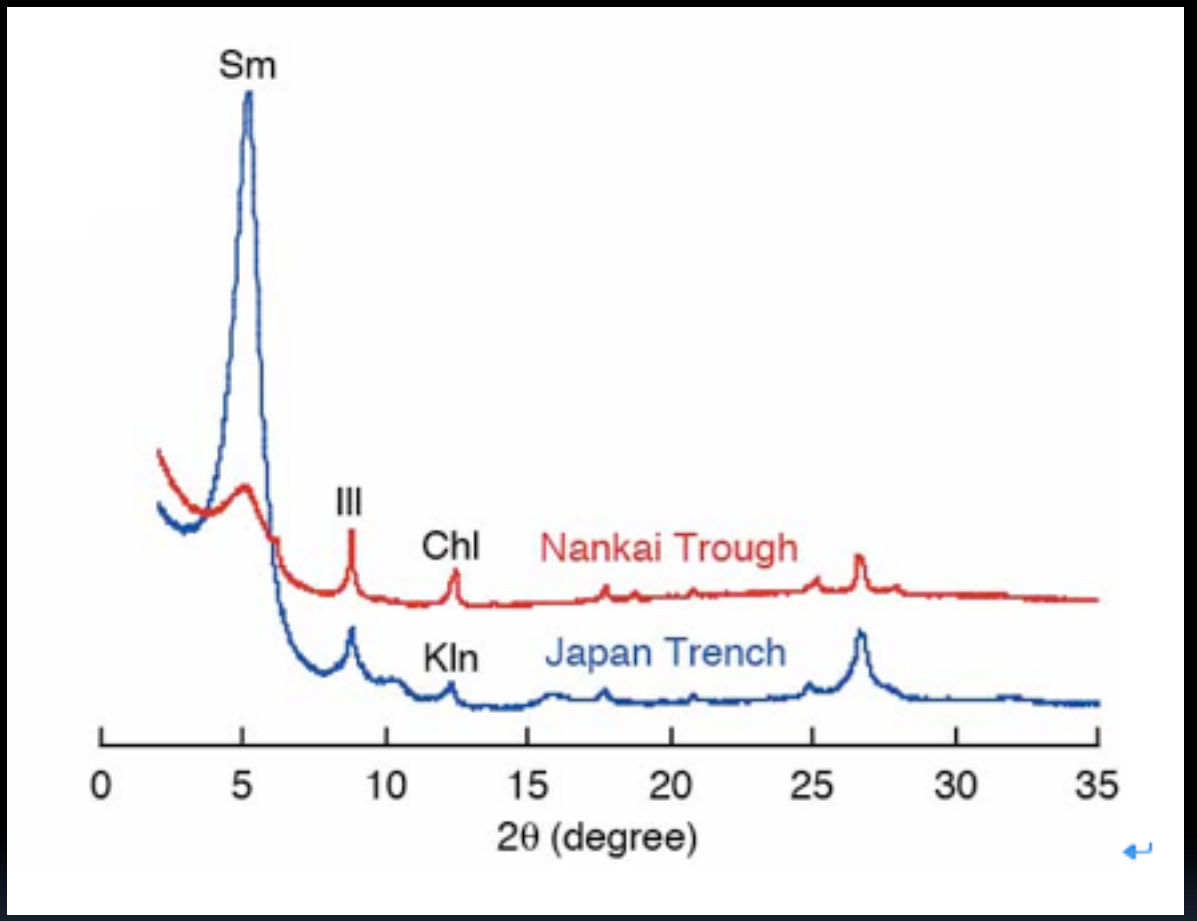
Laboratory Friction Experiments on Fault zone Material



Coefficient of Dynamic Friction about 0.1

(Ujiie et al., 2013)

Fault zone sample used
X-ray diffraction analyses



High smectite content in *brown pelagic clay*

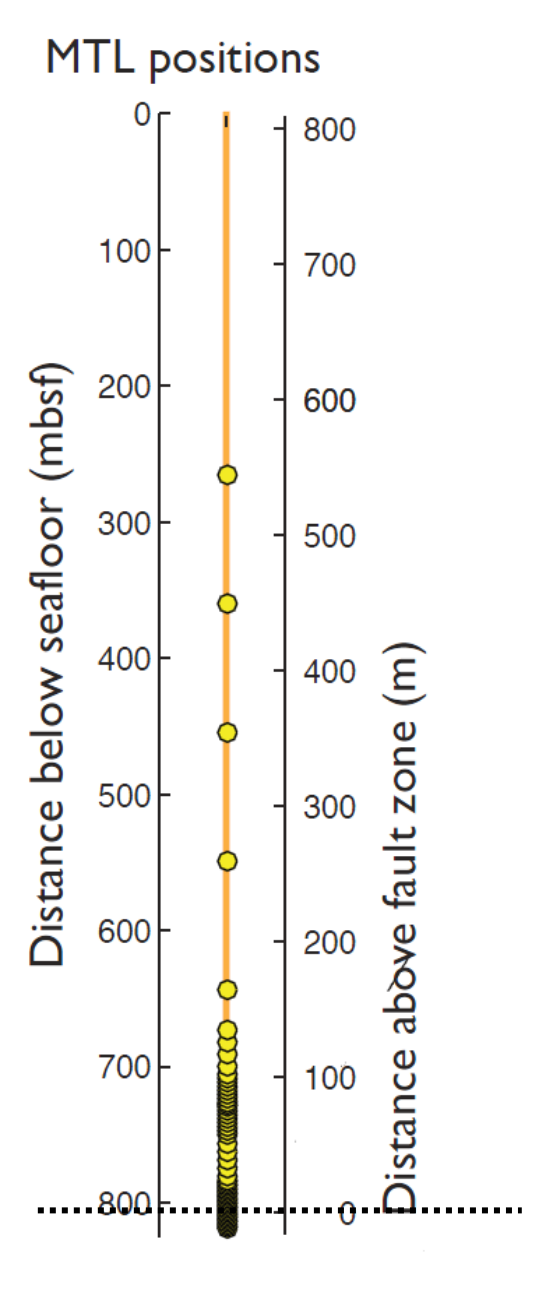
(Ujiie et al., 2013)

Fault Zone Temperature Measurements

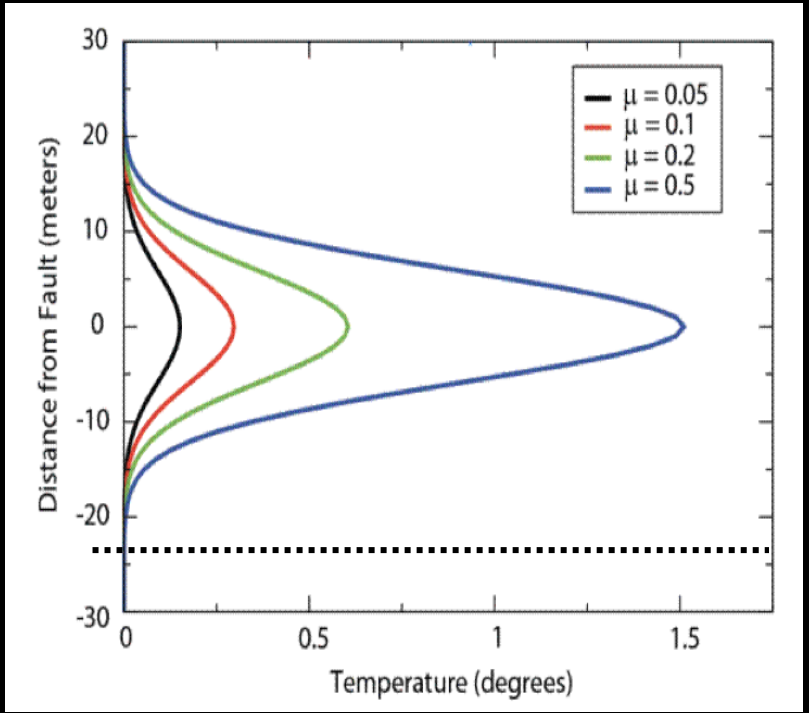
- Unable to install temperature sensors during main expedition during April and May 2012.
- Successful deployment during second chance in July 2012

Installation of temperature observatory on 16 July 2012.
Water depth of about 6900 meters.

Temperature Sensors



Calculated Temperature Anomaly

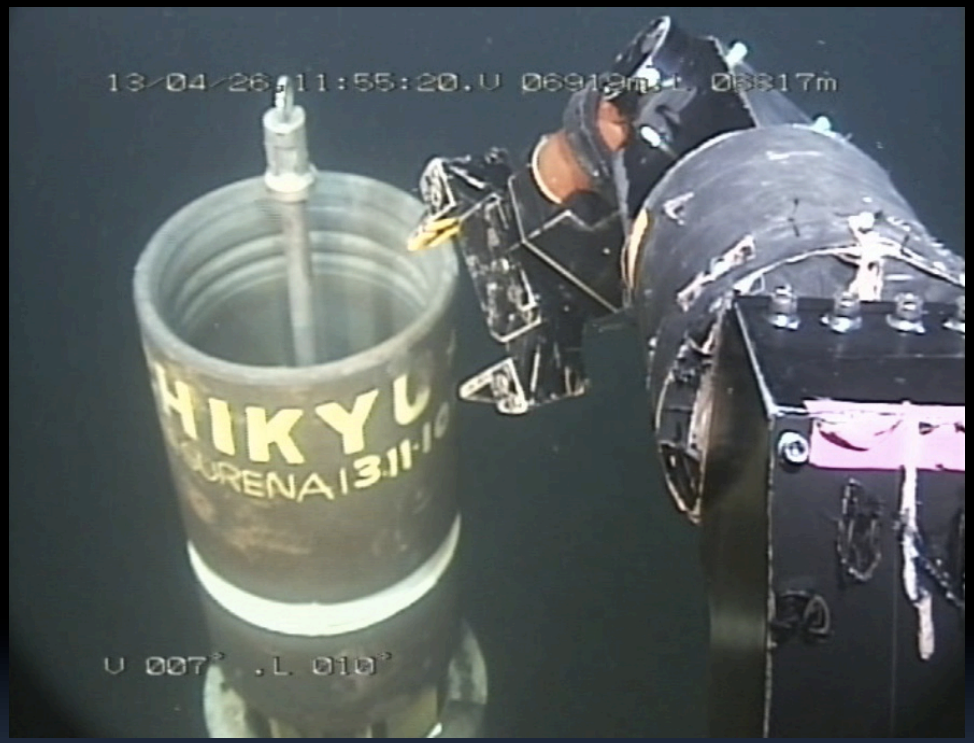



IMO 9165920
かいれい
KAIREI


かいこう
KAIKO
JAMSTEC


6765
6768
6740
0.00150264°N
0.00046199°E
17.3°
173.714m

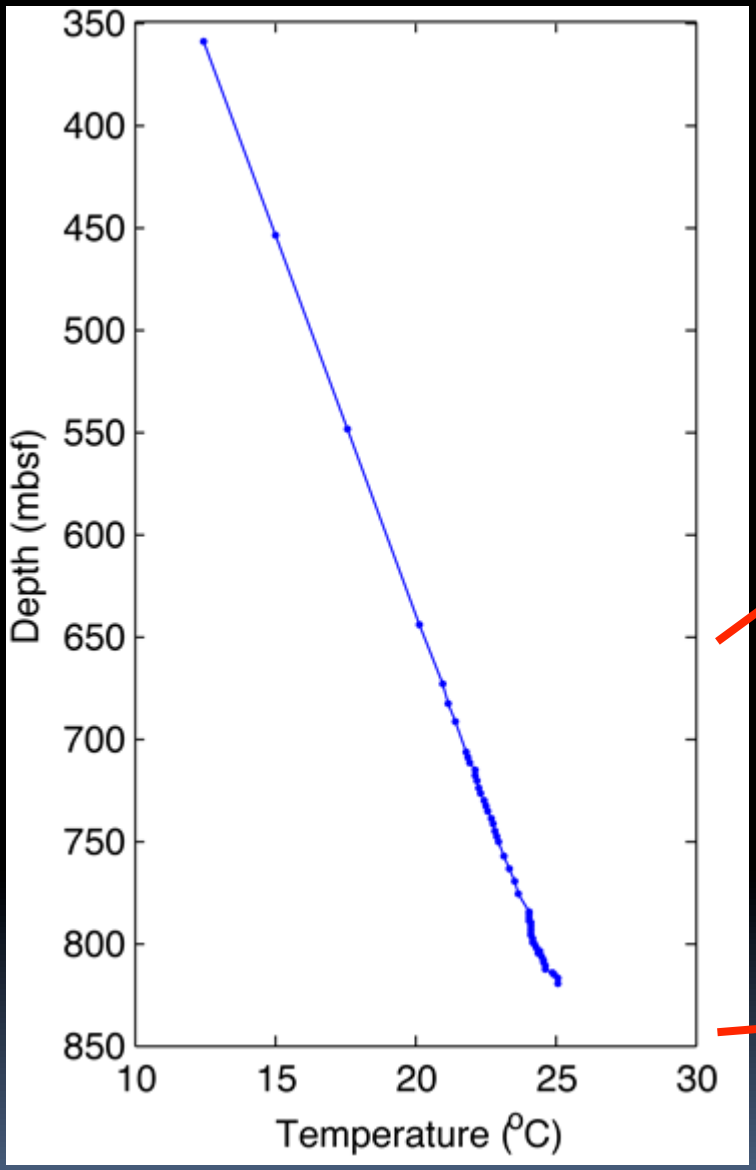
Fault Zone Temperature Measurements

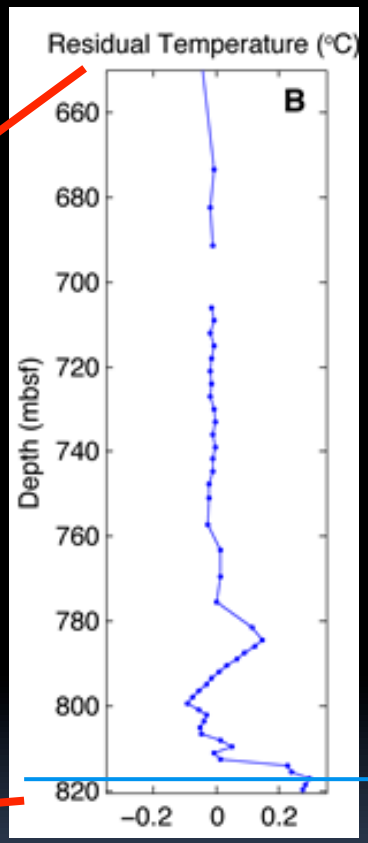


Retrieval of temperature sensors on 26 April 2013.

- Unable to retrieve sensors in February 2013
- Successful retrieval in April 2013 ！

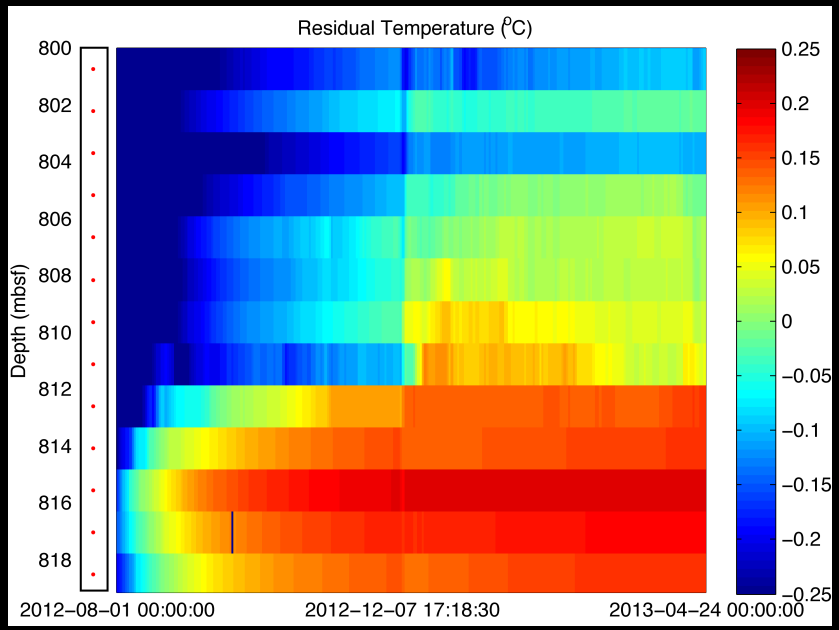
Temperature Data





Fault

Fulton et al., 2013



Temperature signal about 0.2°C across fault zone

Fault zone

Low amount of frictional heat on fault zone
Apparent coefficient of friction of about 0.1

Preliminary Results

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

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

- Complete stress drop

How to explain huge slip of Tohoku-oki earthquake ?

- Plate boundary material has relatively high static friction, so stress can accumulate. Does not slip aseismically.
- Material with very low dynamic friction. Once rupture starts friction can drop to very low level.
- Very low friction means that there will be a complete stress drop.
- Large low-friction slip will localize fault zone.
- These may be properties of the pelagic brown clay.

Summary

- JFAST was a rapid scientific response to a natural event with huge societal impact
- Expedition 343 was planned and carried out very quickly by the scientific community and JAMSTEC
- Extreme technical challenges for the deep water drilling
- Successful completion of Science objectives to obtain temperature data and sample the fault zone