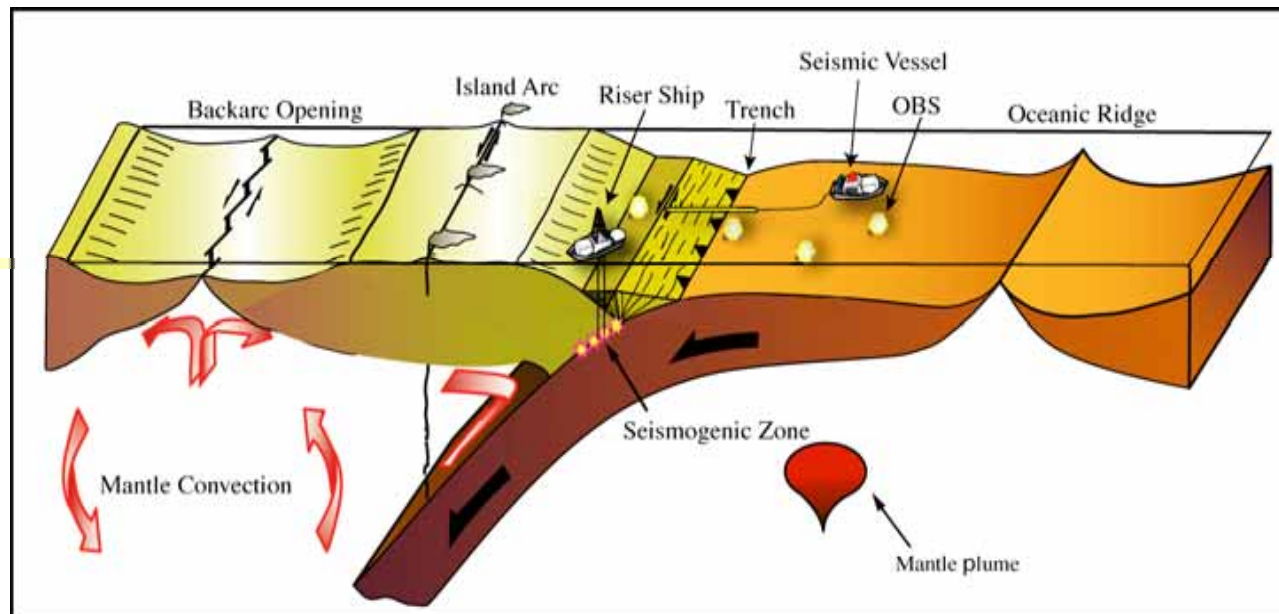


Outline of Plate Dynamics Research Program in IFREE / JAMSTEC



Institute for Research on Earth Evolution (IFREE)

Research Program for Plate Dynamics

Yoshiyuki Kaneda



Scope of Program -1-

The formation, evolution, and subduction of the lithospheric plates are the surface expression of cooling Earth the dynamics of these plates, which can be thought of as a cooling system for "heat engine" Earth, is responsible for the occurrence of internal and surface phenomena occurring over a wide range of spatial and temporal scales, from rapid events such as earthquakes and volcanic eruptions which can have a pronounced impact on our daily lives, to the formation of mountain ranges, island arcs and marginal seas which occur over geologic time scales of millions of years.



Scope of Program -2-

The important facets of plate behavior are the thermal and material structure of its comprising lithosphere (crust and upper mantle), rapid deformation at the plate boundaries and interior, and long-term plate deformation.

An understanding of these facets of plate behavior contributes to our knowledge of the phenomena governing viscous and visco-elastic flow, whose character is far removed from the strict rigidity used to define the lithospheric plates, but which are important for understanding phenomena that cannot be explained by simple plate tectonics, such as the uplift of mountain ranges and plateaus, the onset of subduction and the formation of back arc basins.



Scope of Program -3-

This programs are mainly focusing on subduction zones, where all aspects of plate structure and deformation are represented, including rapid processes such as large-scale rupture of plate boundaries in interplate earthquakes. Research into lithospheric structure, numerical modeling and material sciences will be integrated into a comprehensive understanding of plate dynamics.

The research in this program will be conducted in close cooperation with other research programs involved in related fields, such as the other programs of IFREE. Also, it will play an important role in promoting the scientific objectives of the

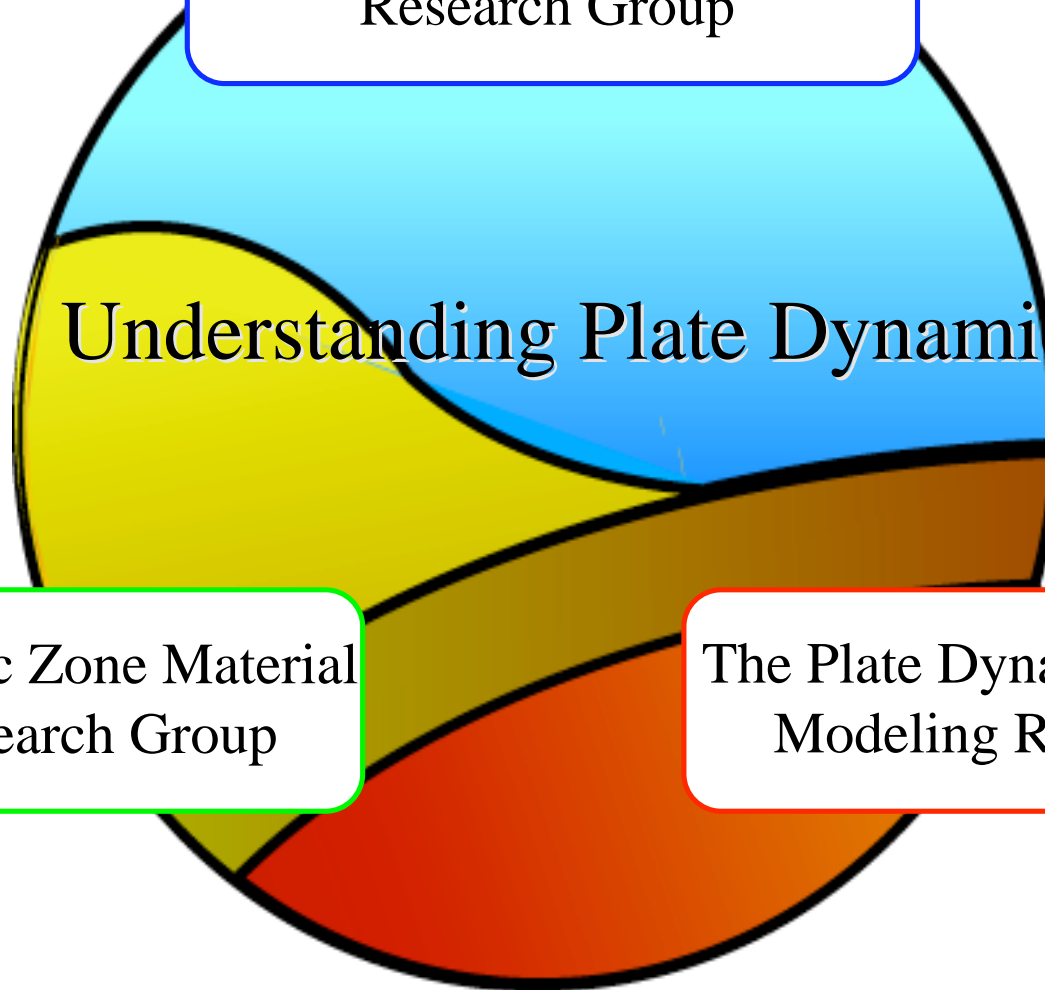
Research groups of this program

The Lithospheric Structure
Research Group

Understanding Plate Dynamics

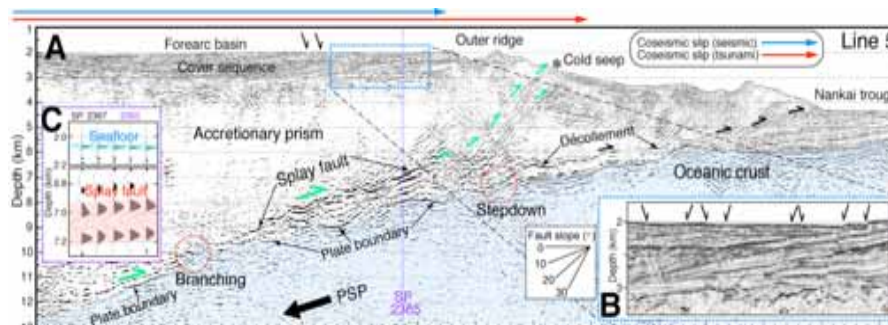
The Seismogenic Zone Material
Science Research Group

The Plate Dynamics Numerical
Modeling Research Group



Lithospheric Structure Research Group

- 1) The first theme is Quantitative determination of large scale plate structure in subduction zones.
- 2) The second theme is Quantitative determination of small-scale structure and its influence on interplate coupling.



Seismogenic Zone Material Science Research Group

- 1) Develop a quantitative understanding of the conditions important for the dynamics of subduction zones by experimental and theoretical methods
- 2) Understand the process of plate preparation, rupture, and rupture preparation, rupture, and rupture

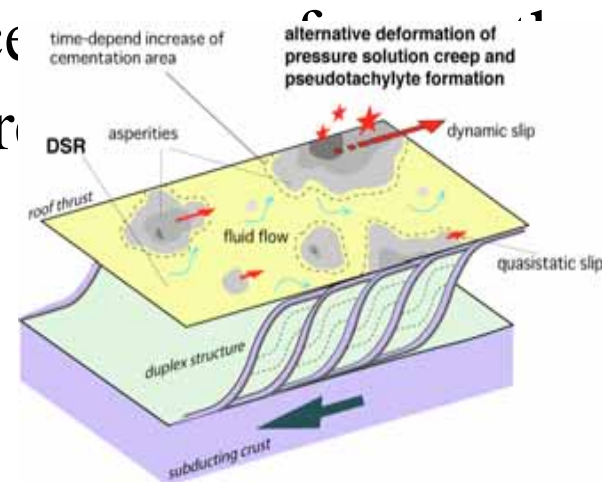
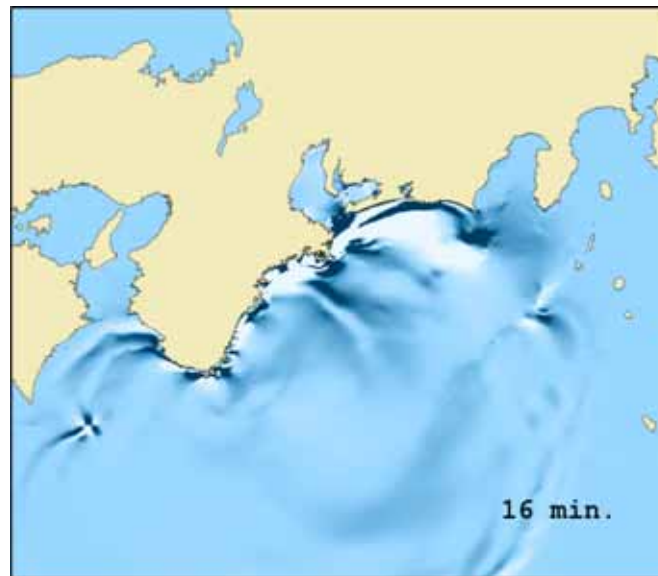


Plate Dynamics Numerical Modeling Research Group

1) Construct a model which provides an integrated description of subduction plate motion and associated crustal activity of various time scales.



Subduction Zone Structure Research - Survey Vessels -



R.V Kairei 4628 tons
Streamer Cable 156ch, 5000m
Airgun 200 liter



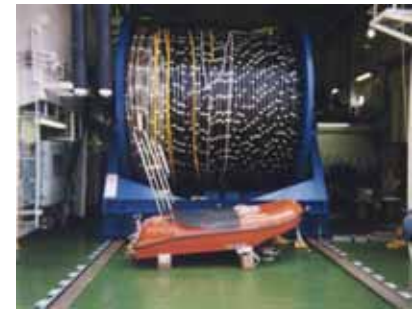
R.V Kaiyo 3176 tons
Airgun 200 liter
100 OBSs



OBS



Air gun



Streamer Cable

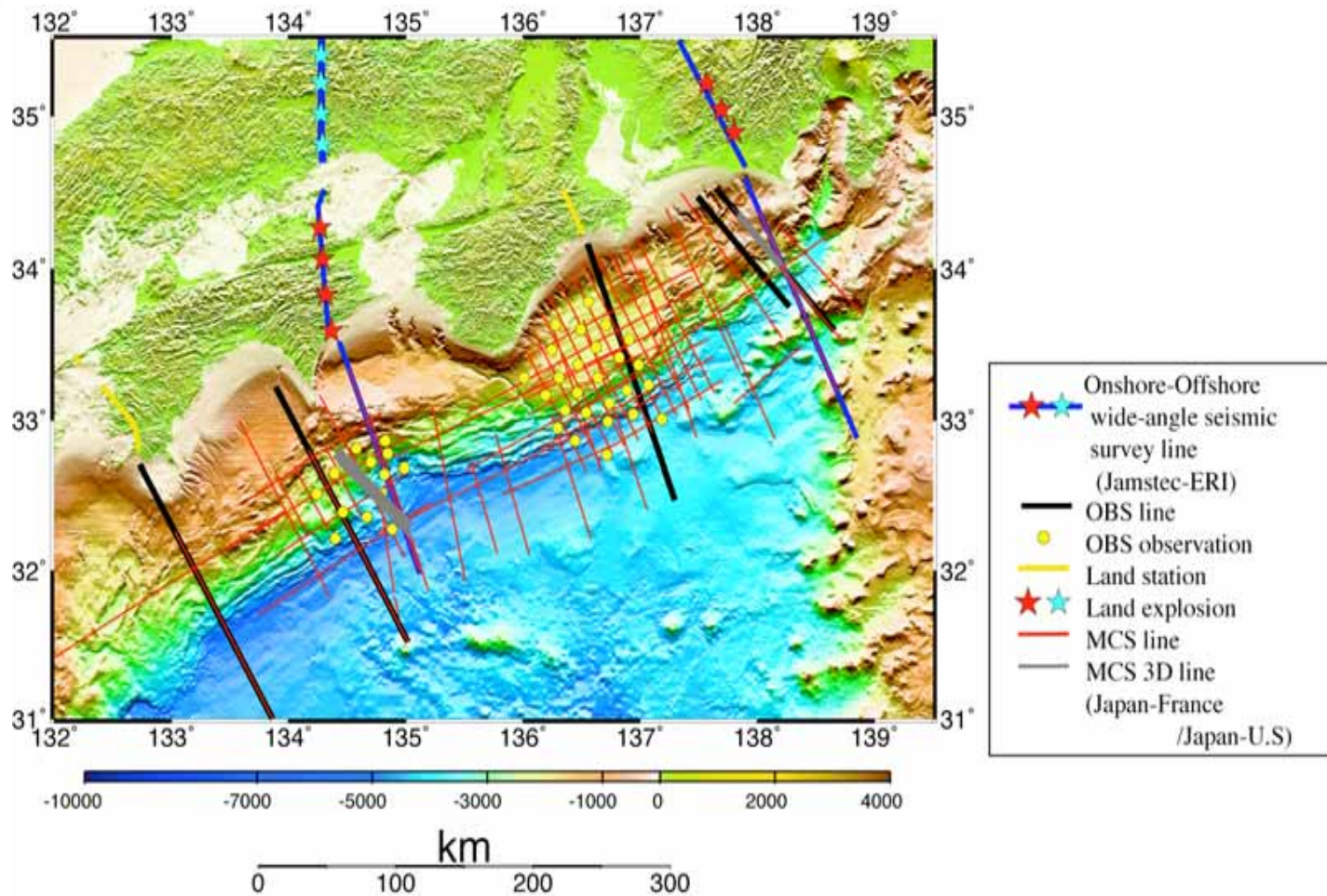


Research activity (1)

- Lithospheric structure research-

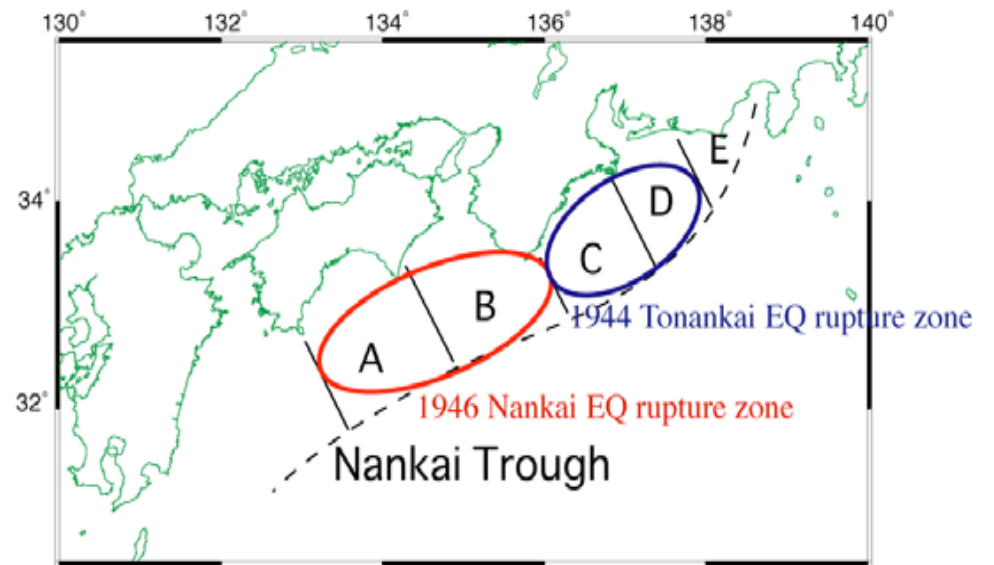
- 1) We proposed the hypothesis that the splay fault imaged off Kii Peninsula plays a role as a active fault in Tonankai megathrust earthquake system.
- 2) The seismic imaging of Paleo Zenisu and the deeper Paleo Zenisu Ridge off Tokai imply a cyclic ridge subduction system at a interplate locked zone off central Japan.
- 3) Onshore-Offshore seismic survey in SW Japan
- 4) IBM seismic survey
- 5) Seismicity observation using Ocean bottom Seismograph (OBS) to investigate the crustal activity off Kii Peninsula.

Nankai Trough seismic survey lines



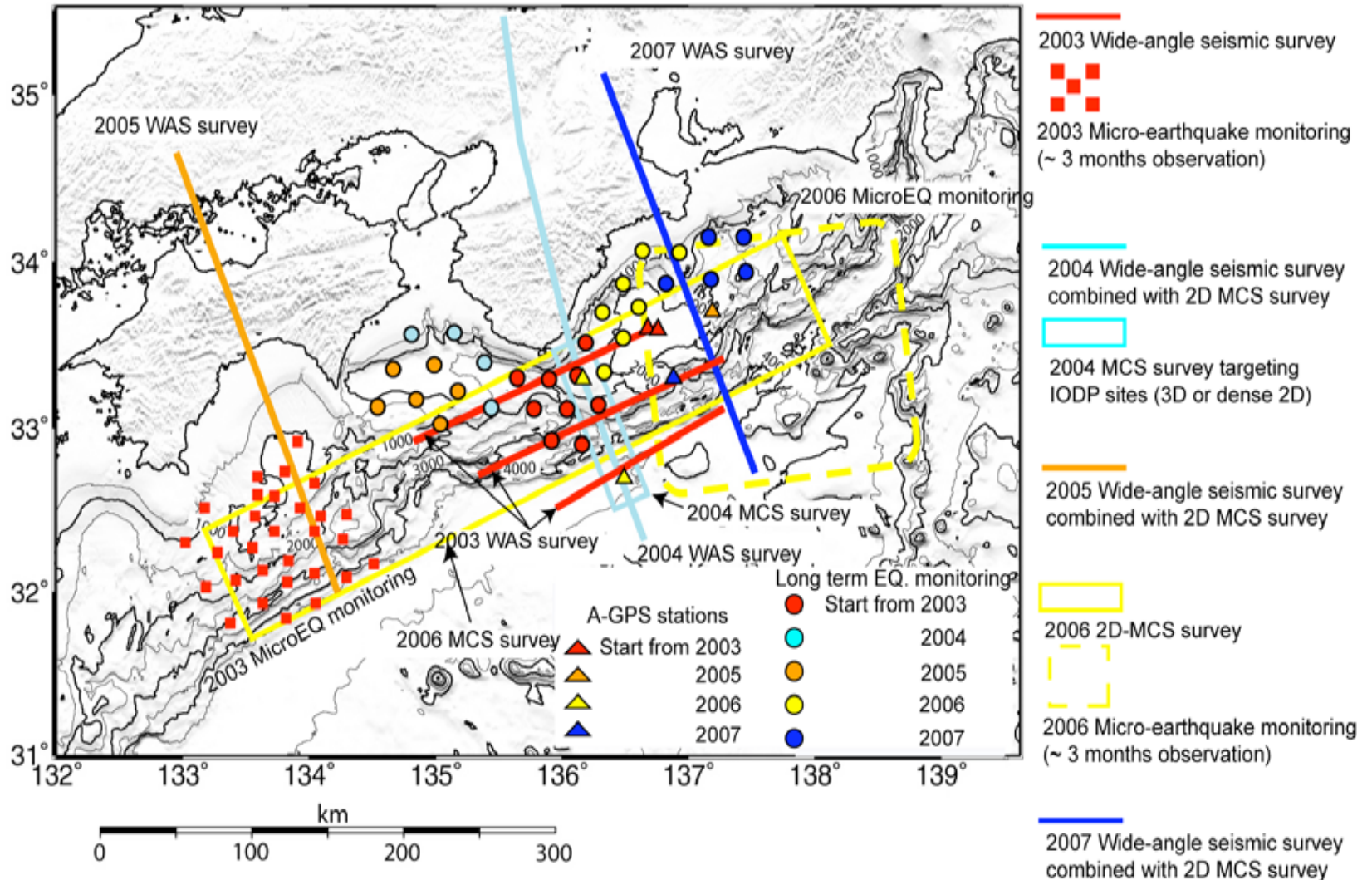
Megathrust Earthquake around Nankai Trough

Year	Rupture Zone	Interval
684	A B C D E	203年
887	A B	209年
1099	A B C D E	262年
1361	A B	137年
1498	A B C D E	107年
1605	A B C D	102年
1707	A B C D E	147年
1854	A B C D E	
1944	C D	90年
1946	A B	
	Nankai EQ Tonankai EQ Tokai EQ	



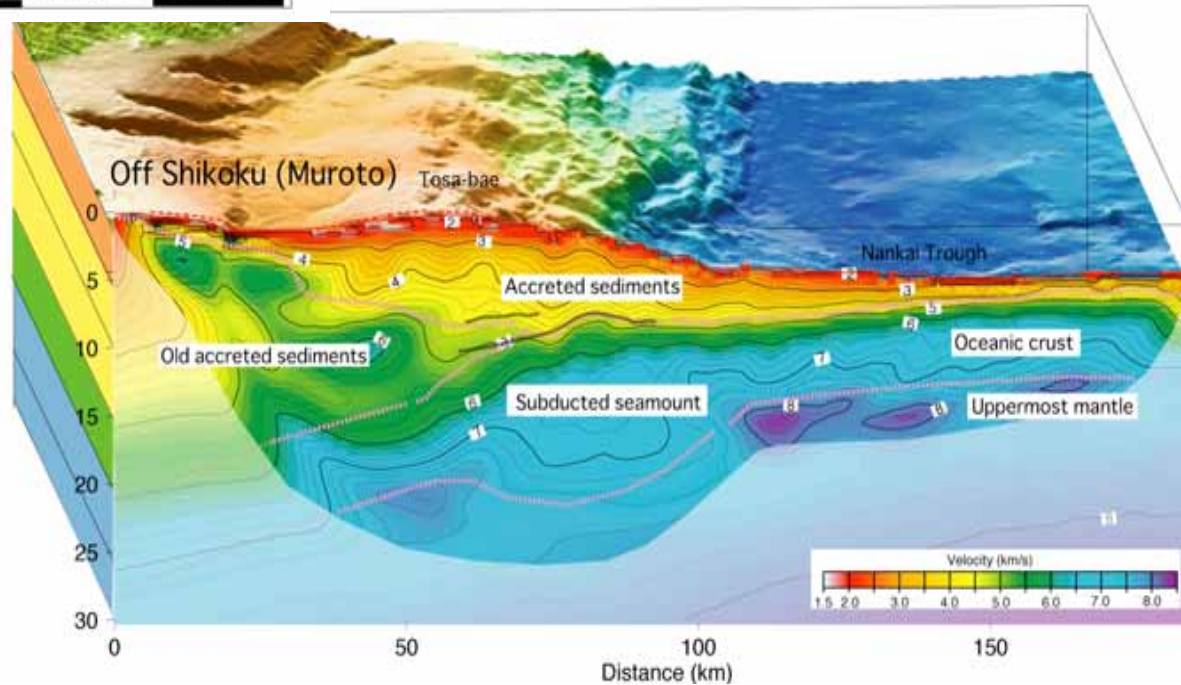
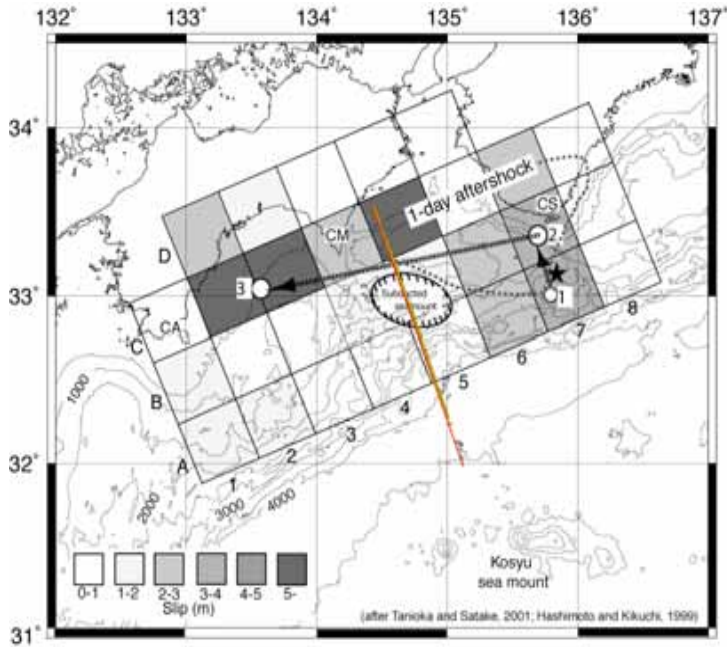
Tonankai - Nankai Research Project

Geophysical observation / survey mainly funded by the national project for the Tonankai, Nankai earthquakes



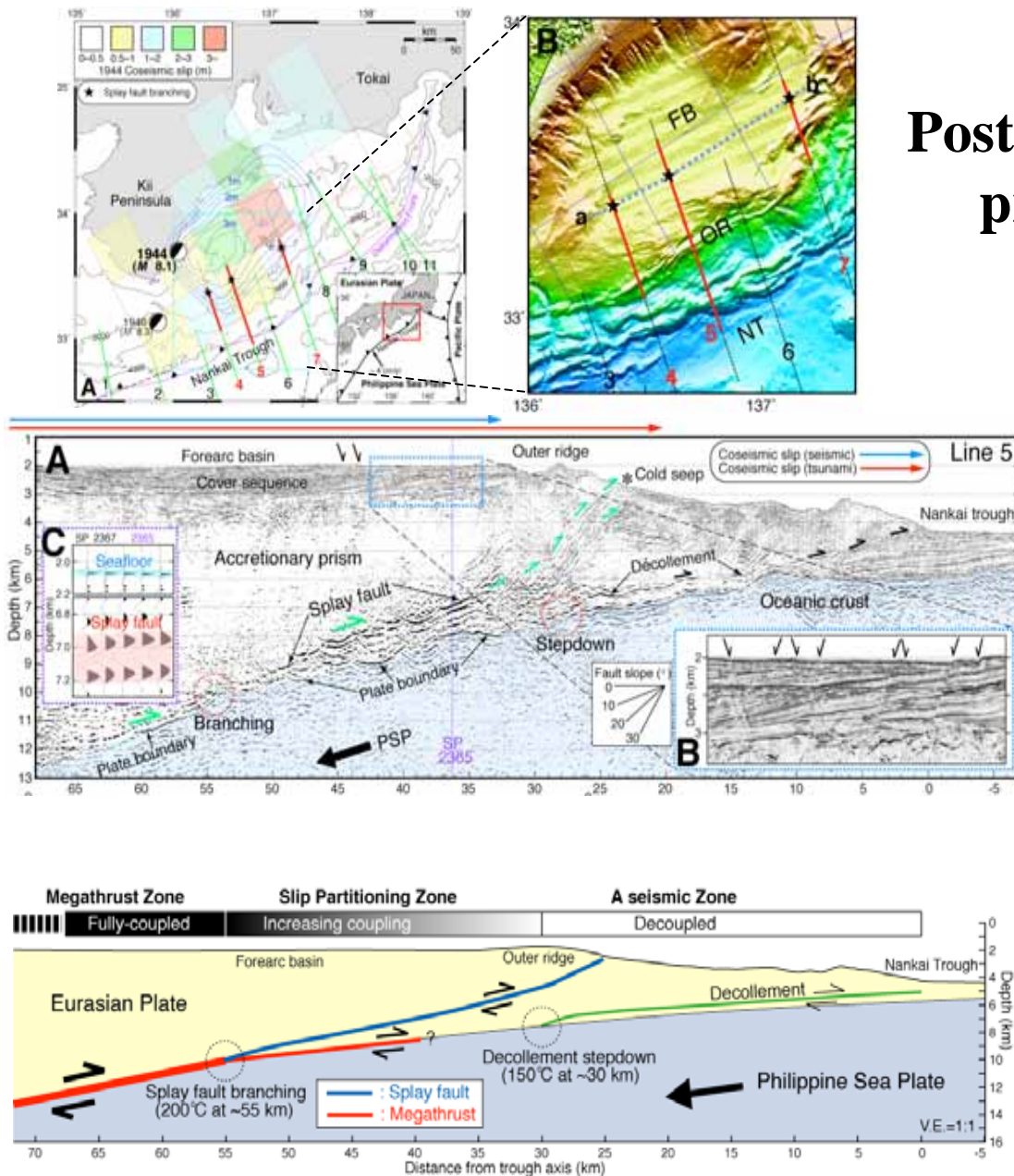
Off Muroto -Subducting Seamount-

Seismic velocity image (contour interval, $V_p=0.2\text{km/s}$) off Muroto, Shikoku Island. A lighter colored region shows no seismic ray sampled. Geological interpretation shown by dotted pink lines are superimposed. Black lines beneath the Tosa-bae represent interfaces interpreted from seismic reflection data.



Act as a barrier against

Poststack depth-migrated MCS profiles showing the splay faults off Kumano

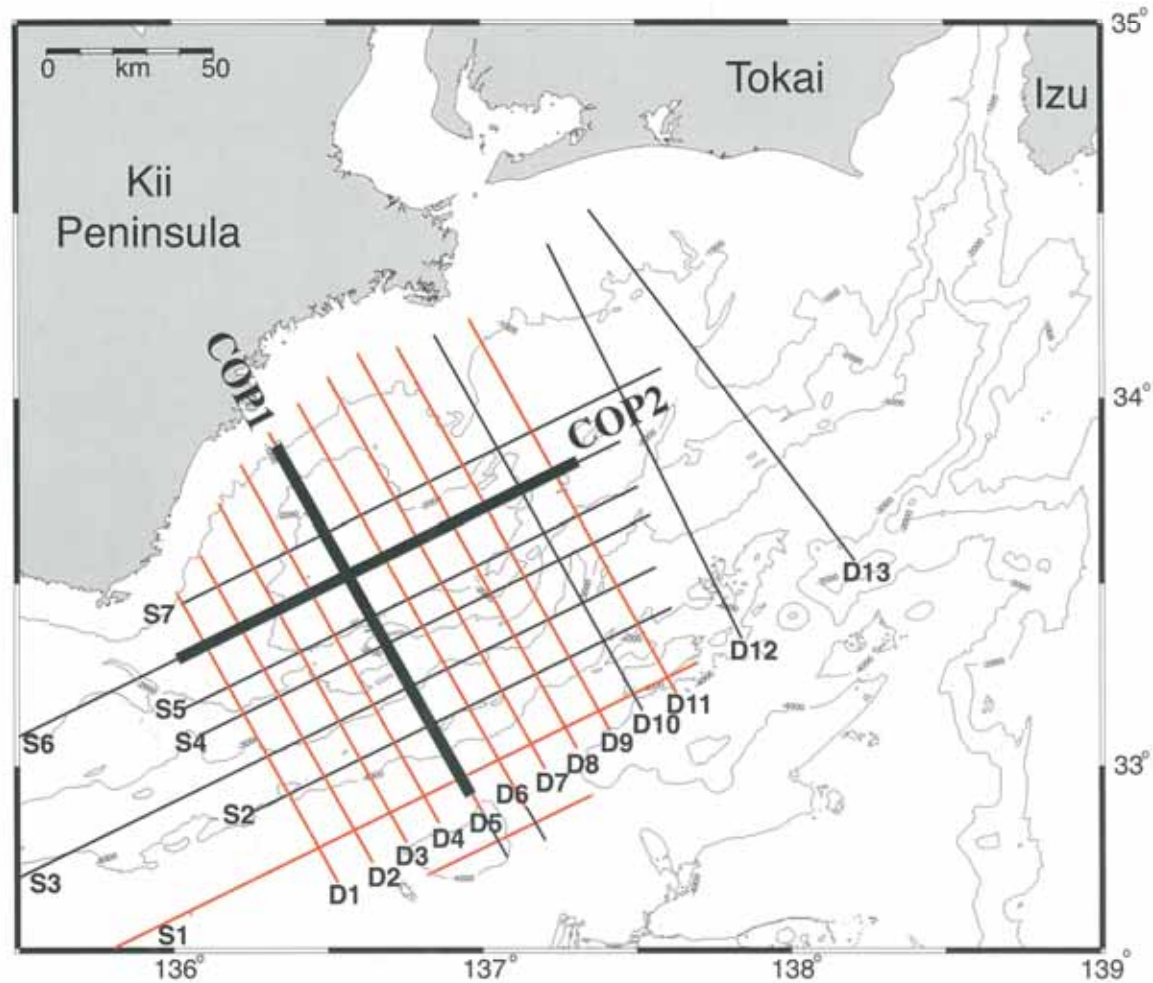


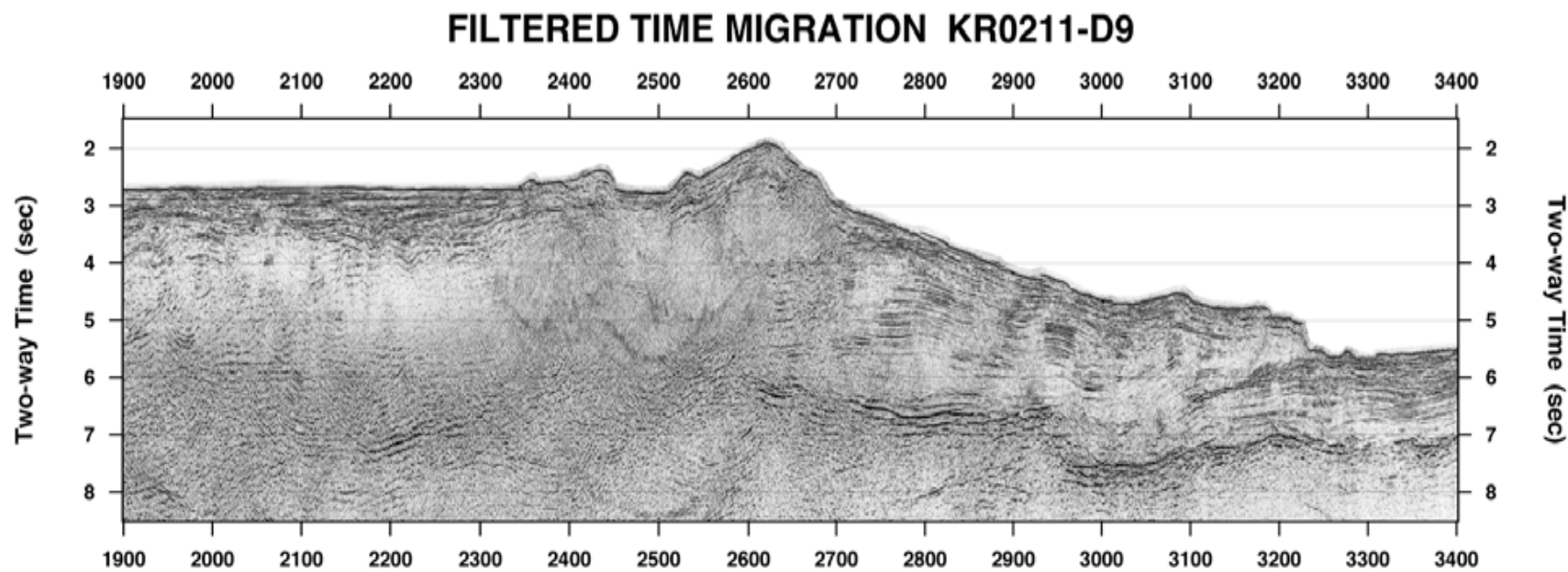
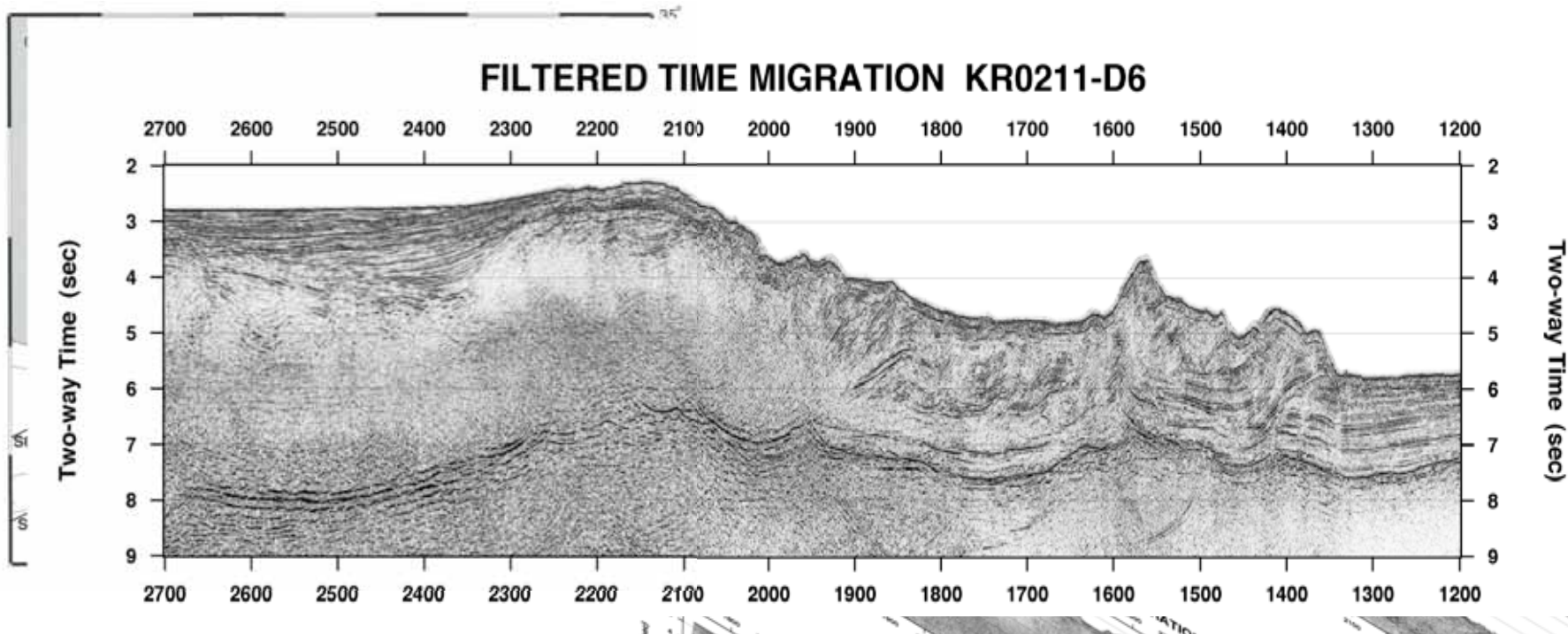
Schematic cross section of up dip portion of the Nankai subduction zone. Gradation in gray scale shows the degree of interplate coupling.

Temperature at the plate boundary is inferred from thermal modeling results.

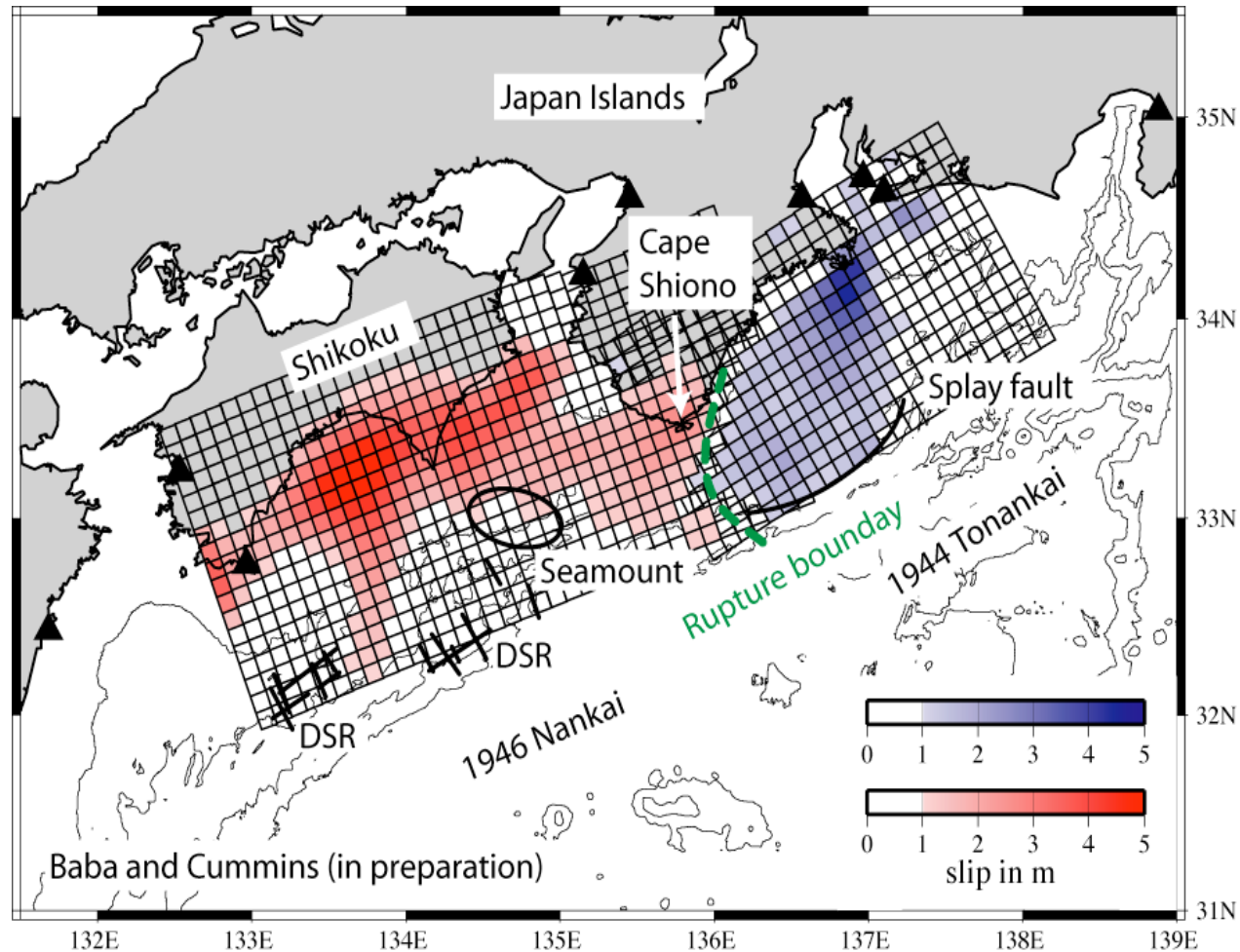
Control the rupture process at Tonankai EQ

Seismic survey lines off Kumano



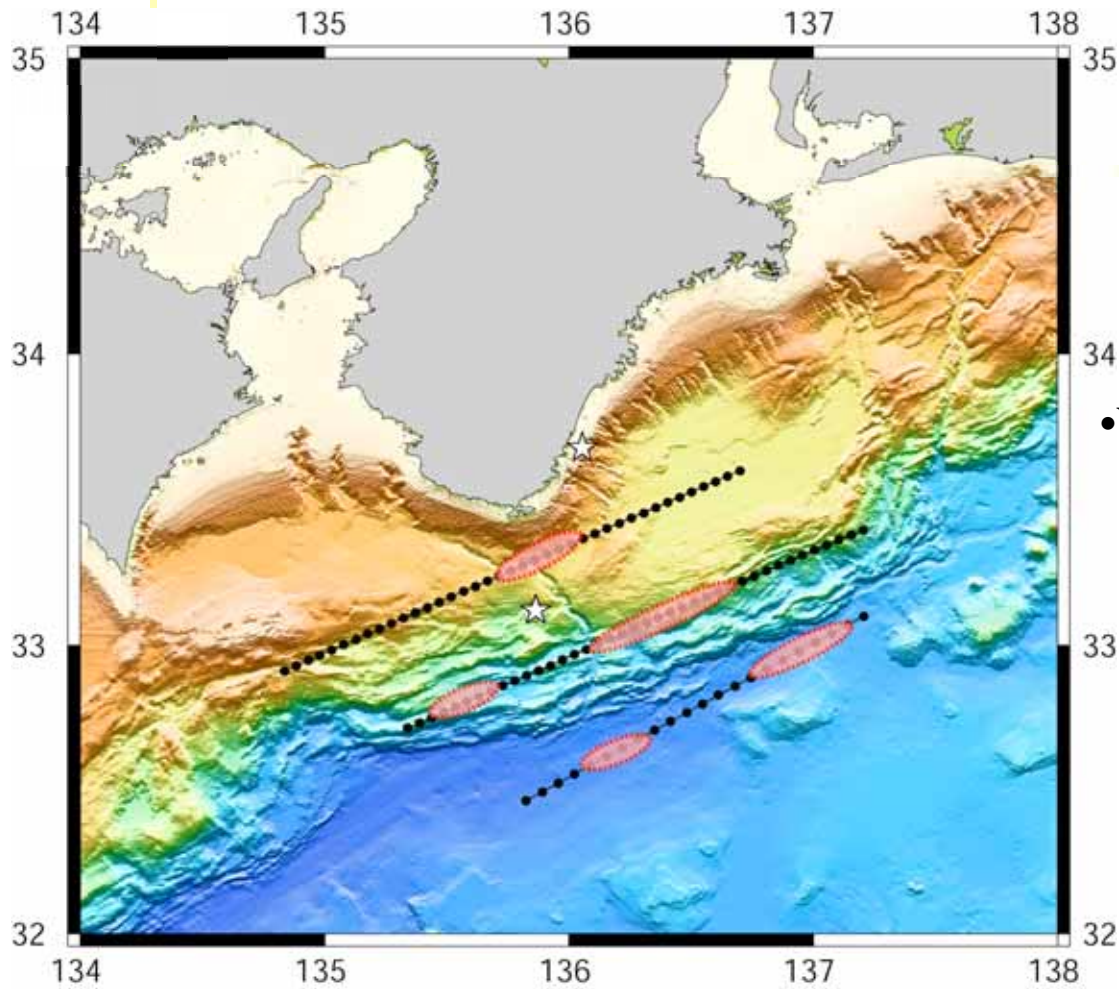


The obtained slip distributions of the 1944 Tonankai and 1946 Nankai earthquakes



Each slip distribution zones is not overlapped.

Structural anomaly along the segmentation boundary in Nankai Trough

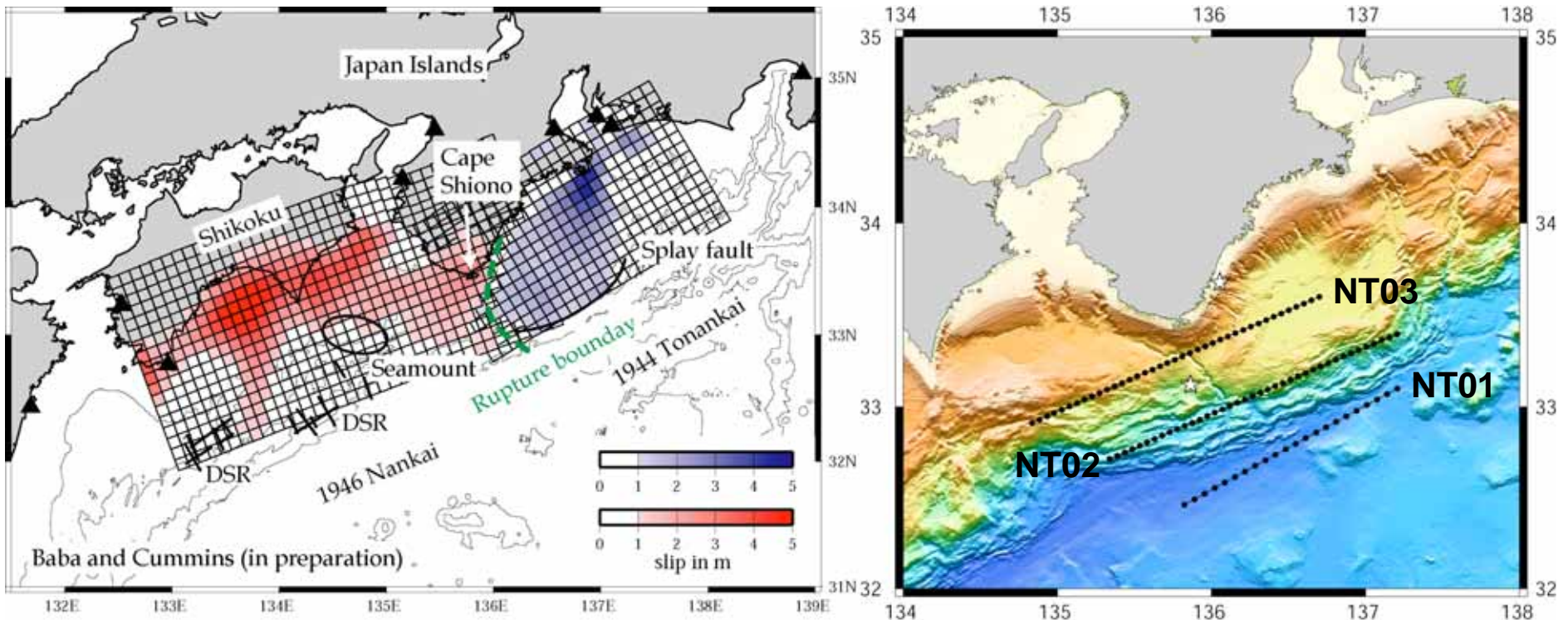


- Wide-angle seismic data
 - NT01: 22OBSs, 7 km spacing
 - NT02, NT03: 39OBSs, 5 km spacing
 - 12,000 cu. inch airgun, 200 m shot inter

Significantly low velocity uppermost mantle and/or sub-moho reflector are imaged in the segmentation boundary

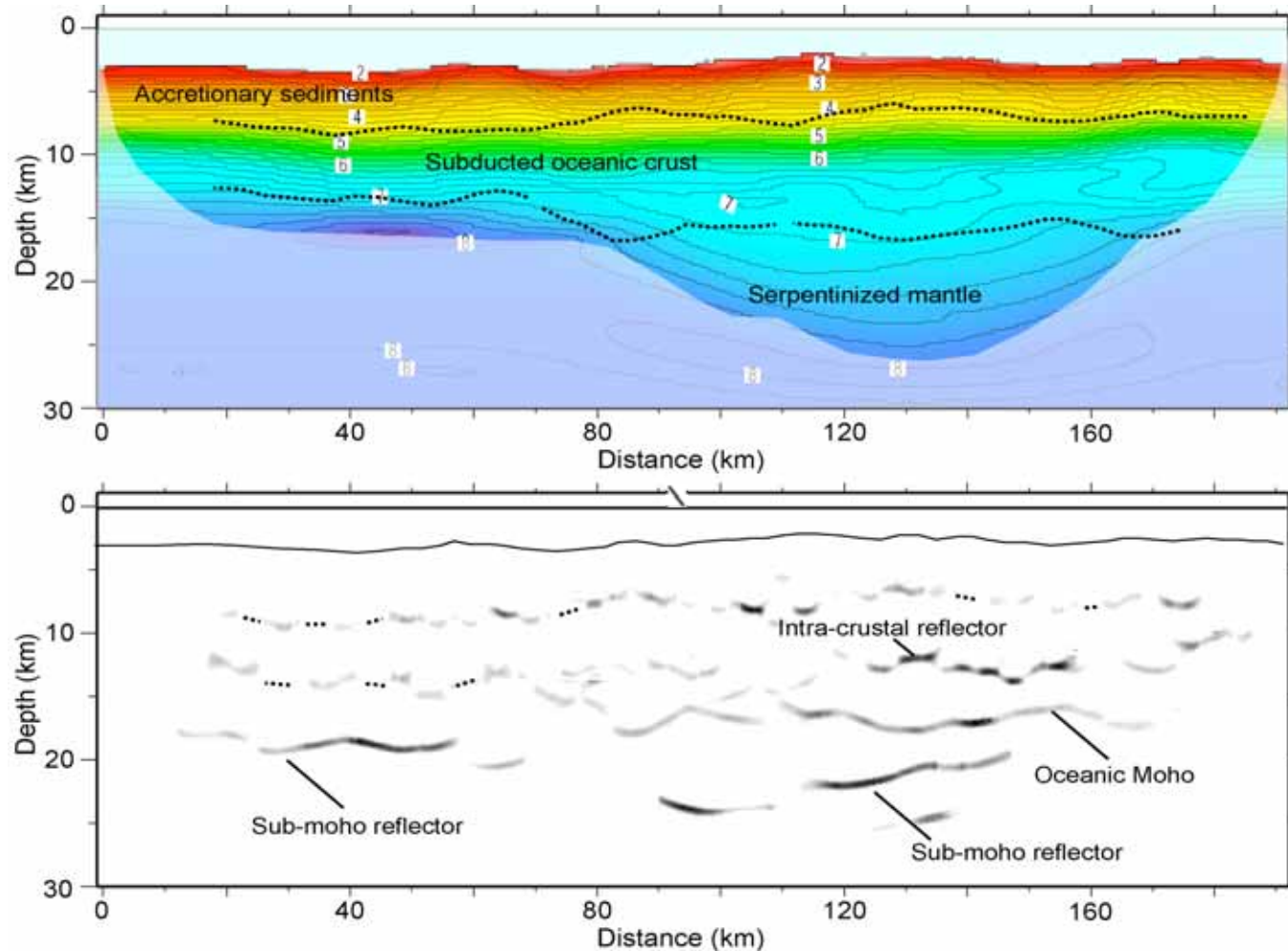
Nankai Seismogenic Zone

- co-seismic rupture segmentation -



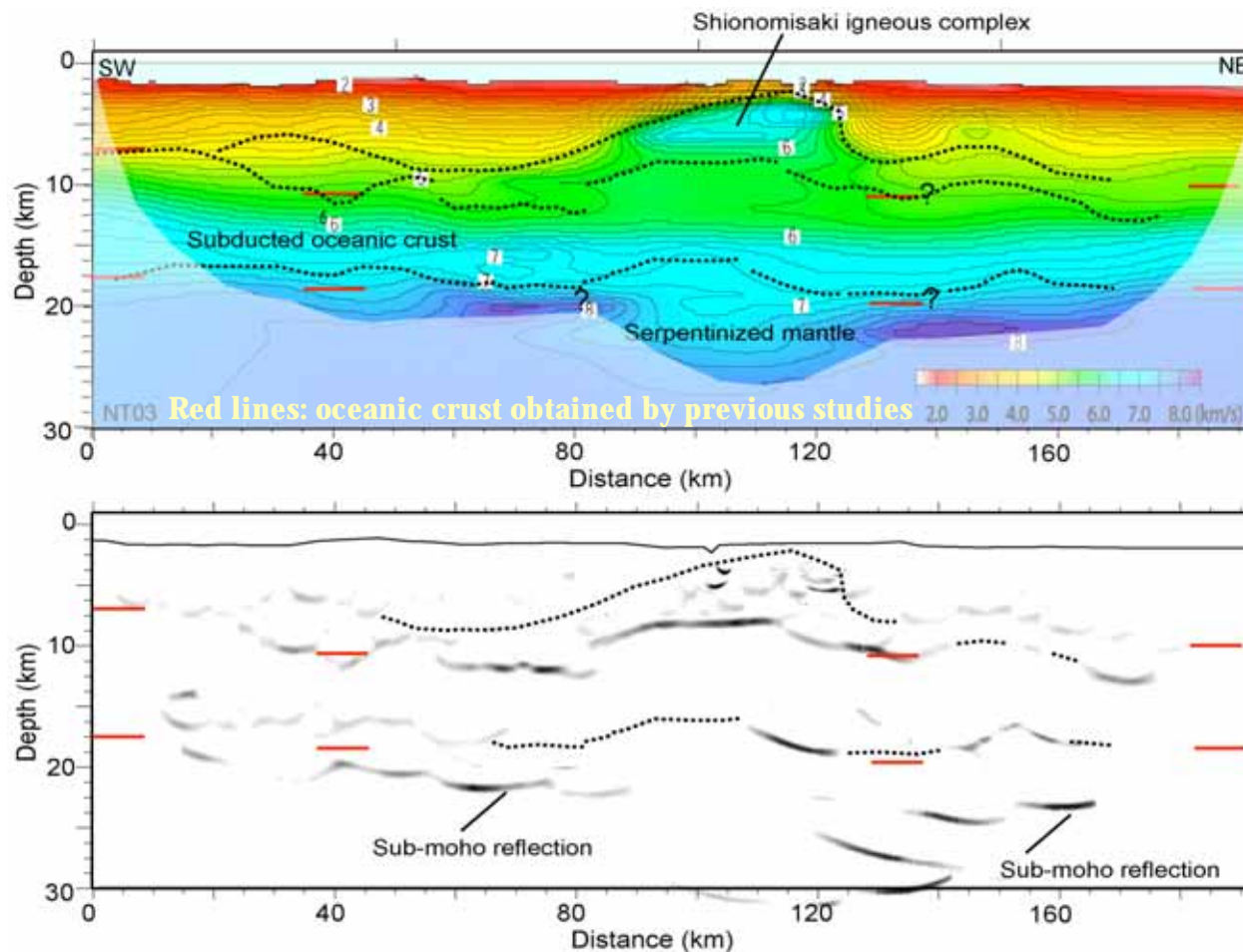
2004 Wide-angle seismic profiles crossing the segmentation boundary will provide a key information to solve this question

Seismic velocity / reflectivity images: NT02



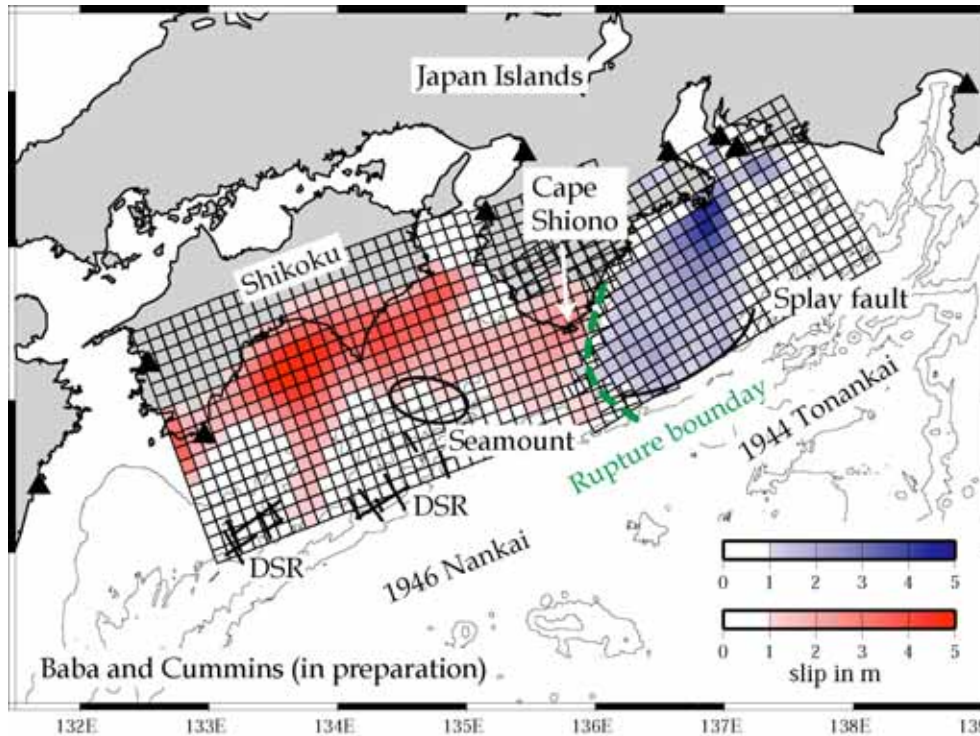
Significantly low uppermost mantle velocity ($V_p=7.4 - 7.6$ km/s) are imaged above sub-moho reflector.

Seismic velocity / reflectivity images: NT03

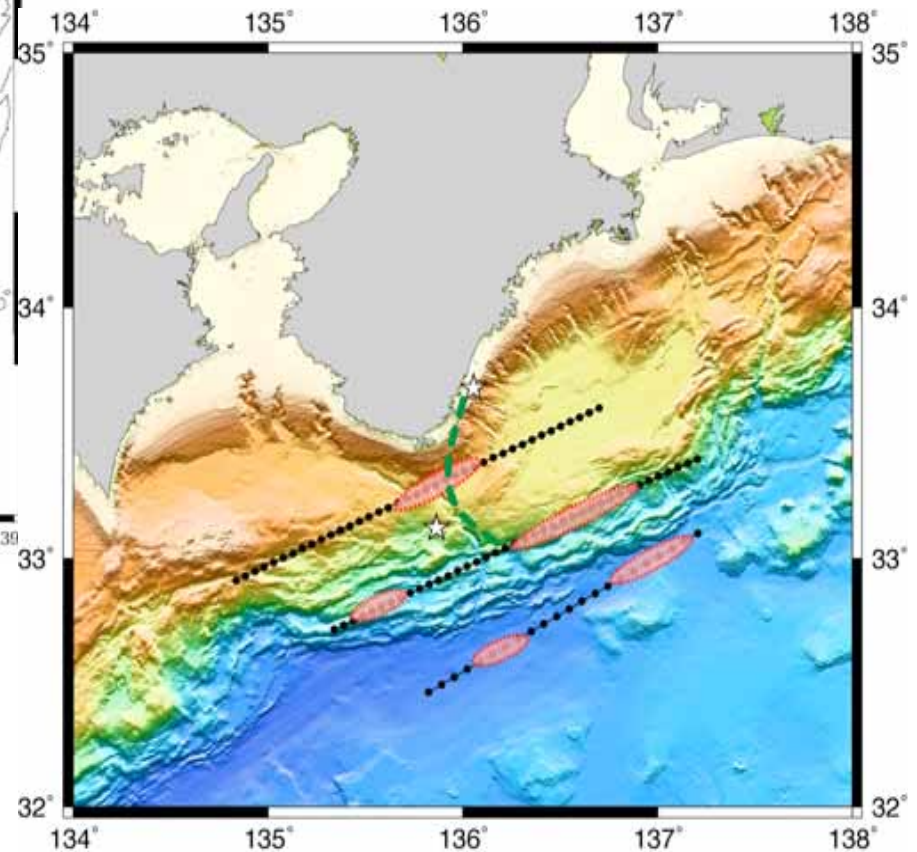


- Subducted oceanic crust is heavily deformed off the Shiono-misaki
- Anomalously low velocity uppermost mantle, which is similar to NT02, is imaged
- High velocity crustal body indicating the Shiono-misaki igneous complex is obtained immediately above the subducting oceanic crust.

Anomalous low velocity mantle and sub-moho reflectors along the segmentation boundary



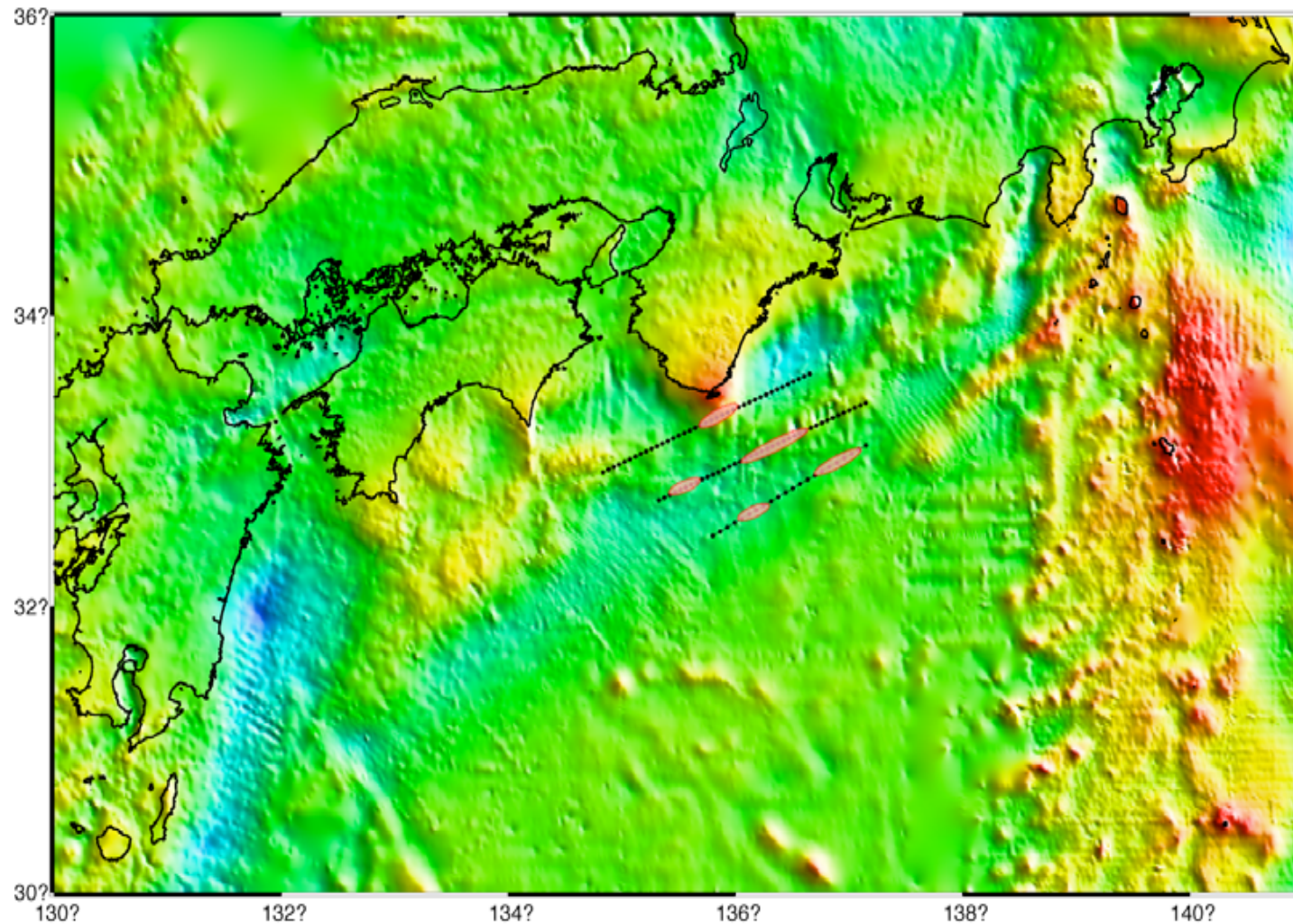
Locations of the anomalously low velocity uppermost mantle on the

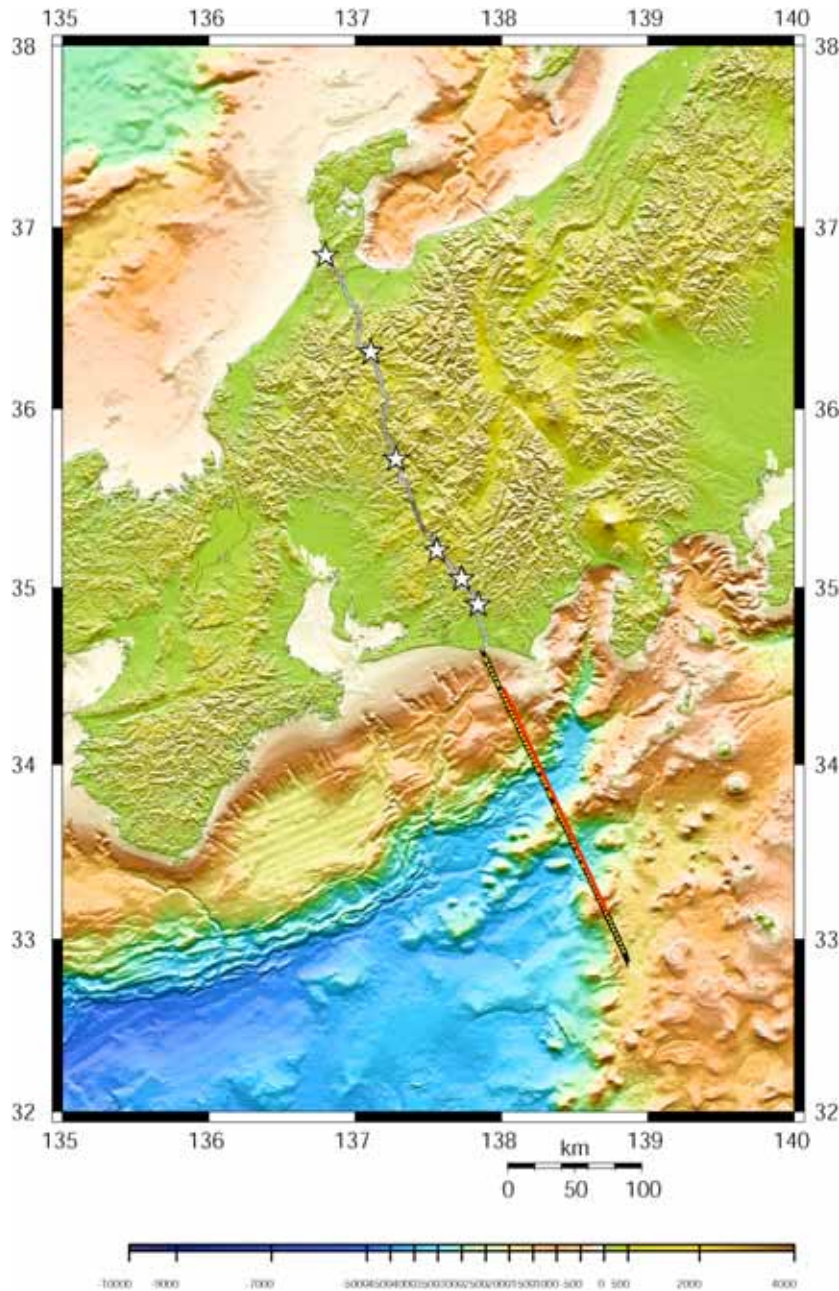


The low velocity uppermost mantle extending to southeast from the Shionomisaki may indicate 25-30 % partially serpentinized mantle

The presumed partially serpentinized mantle extremely reduced a strength of the

Free air anomaly off Kii Peninsula





Specification of onshore-offshore seismic survey

Onshore part of the profile

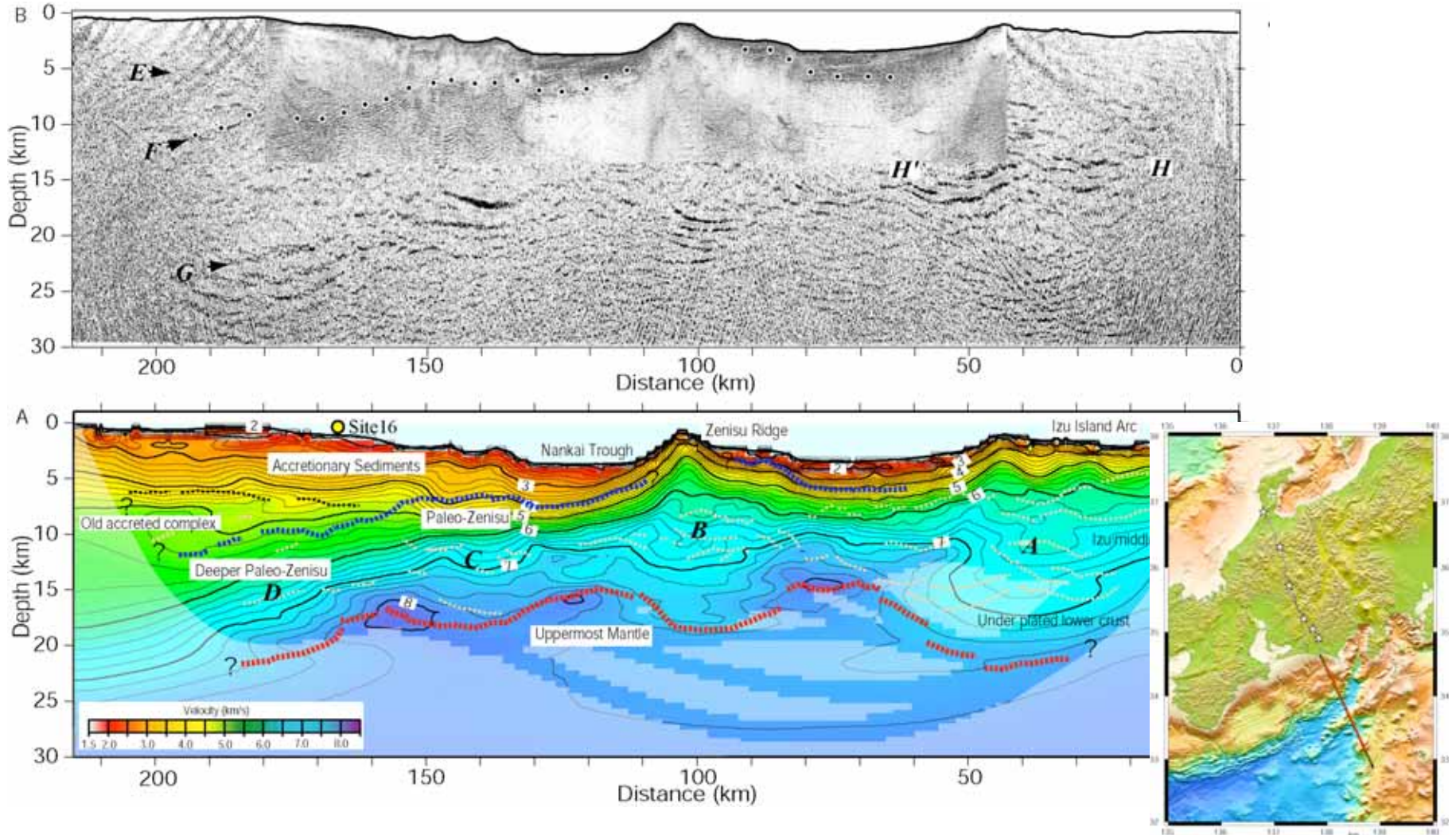
- 262 km long
- Six explosions
 - five 500 kg shots and one 100 kg shot
- 391 stations
 - 63 stations located at the southern part of the profile record both the onshore and offshore shots

Offshore part of the profile

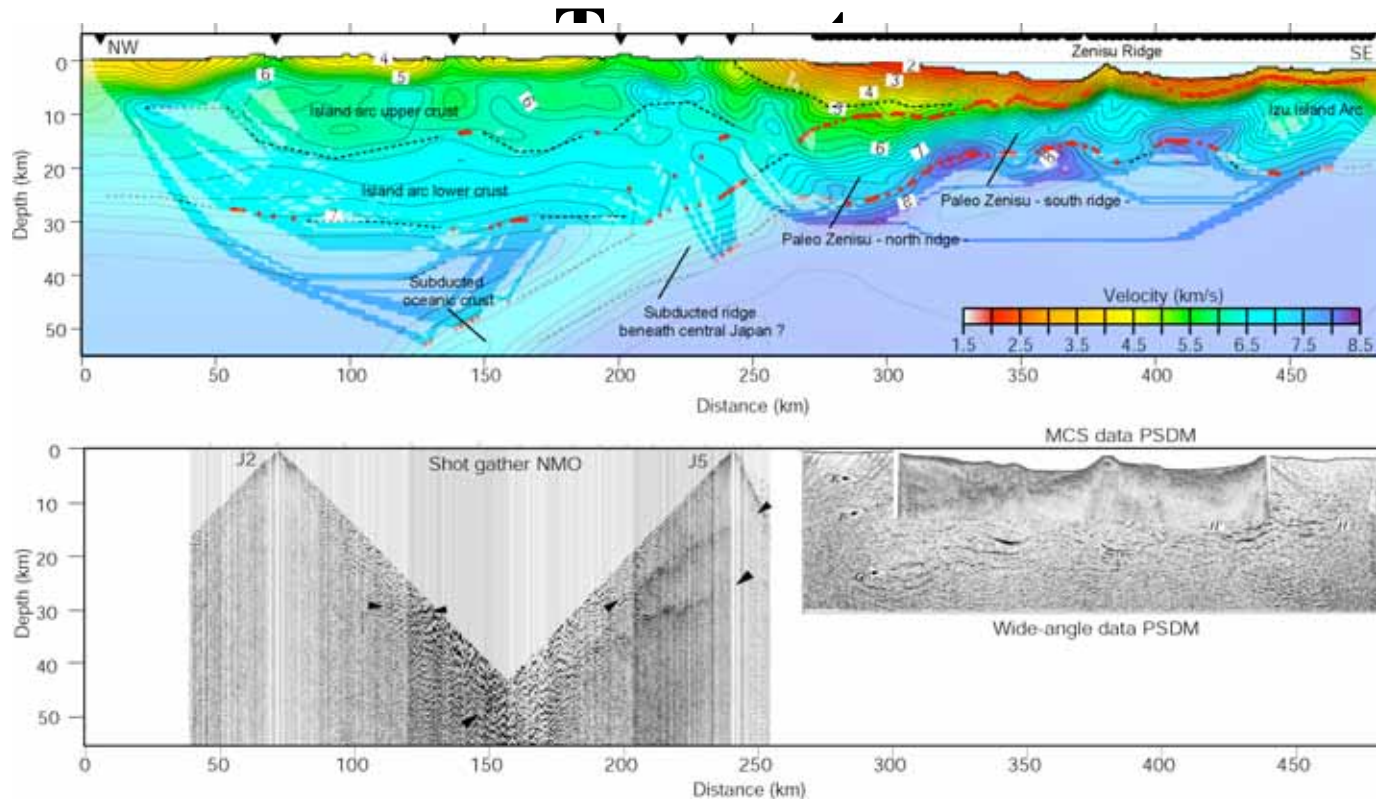
- 215 km long
- 2000 cu. inch air-gun shot at every 100 m interval
- 70 ocean-bottom stations deployed at about every 3 km spacing
- multichannel seismic reflection data were also acquired along a part of the profile

Cyclic ridge subduction off Tokai

- wide-angle seismic tomography and migration -

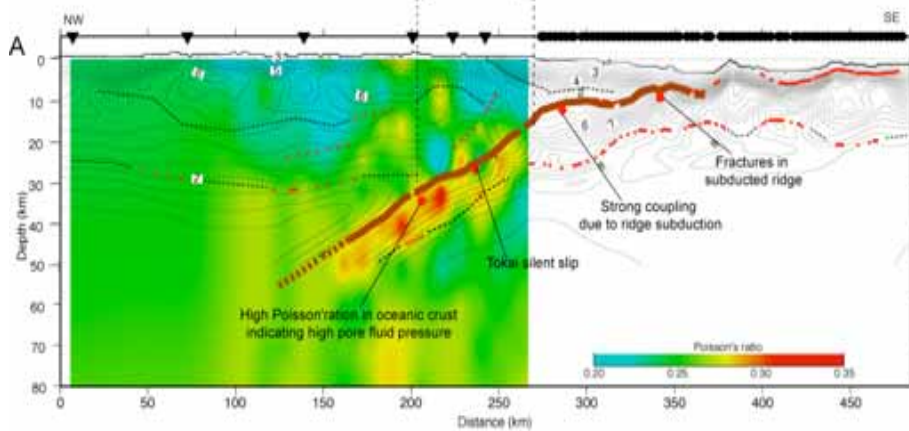
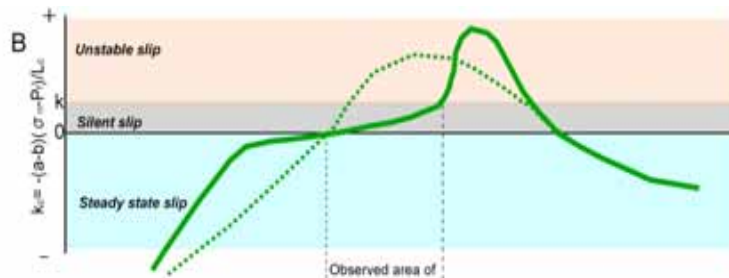
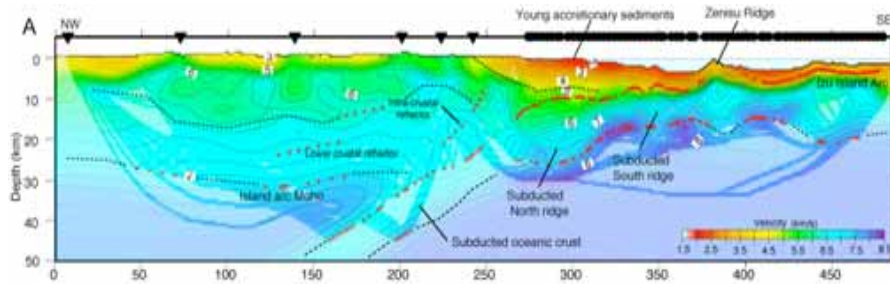


Central Japan Onshore-offshore Lithospheric

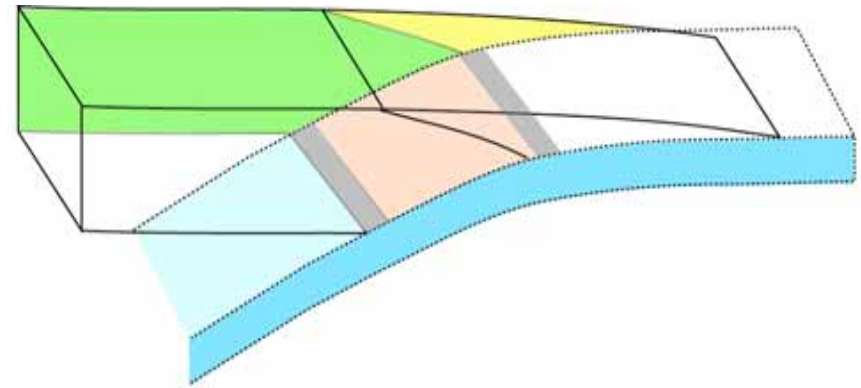


The seismic velocity / reflectivity images show several regions of crustal thickening down to 45 km depth, which are interpreted as subducted ridges. In the offshore part of the profile, we recognize subducting ridges at 300 km (the north ridge) and 350 km (the south ridge) with maximum thicknesses of 20 km and 12 km, respectively. The ridge structures in the Tokai segment support the rupture propagation of the 1944 Tonankai earthquake. GPS data suggest a strongly coupled region where the back slip rate is about 35 mm/yr in the Tokai segment. The north ridge is situated in the same area where the strong coupling is predicted.

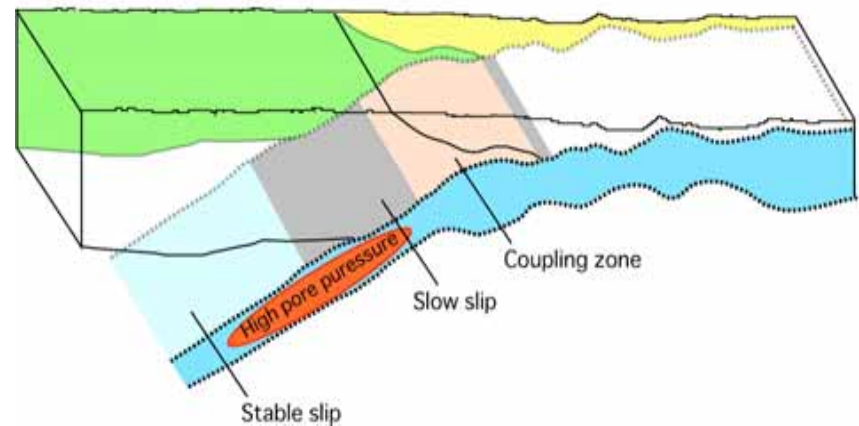
Tokai slow slip and its relation to the structure

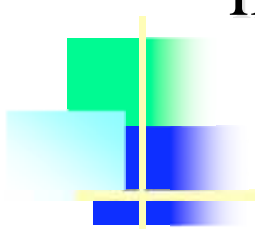


Typical subduction model



Narrow slow slip zone . Cyclic ridge subduction. Wide slow slip caused by high pore pressure.

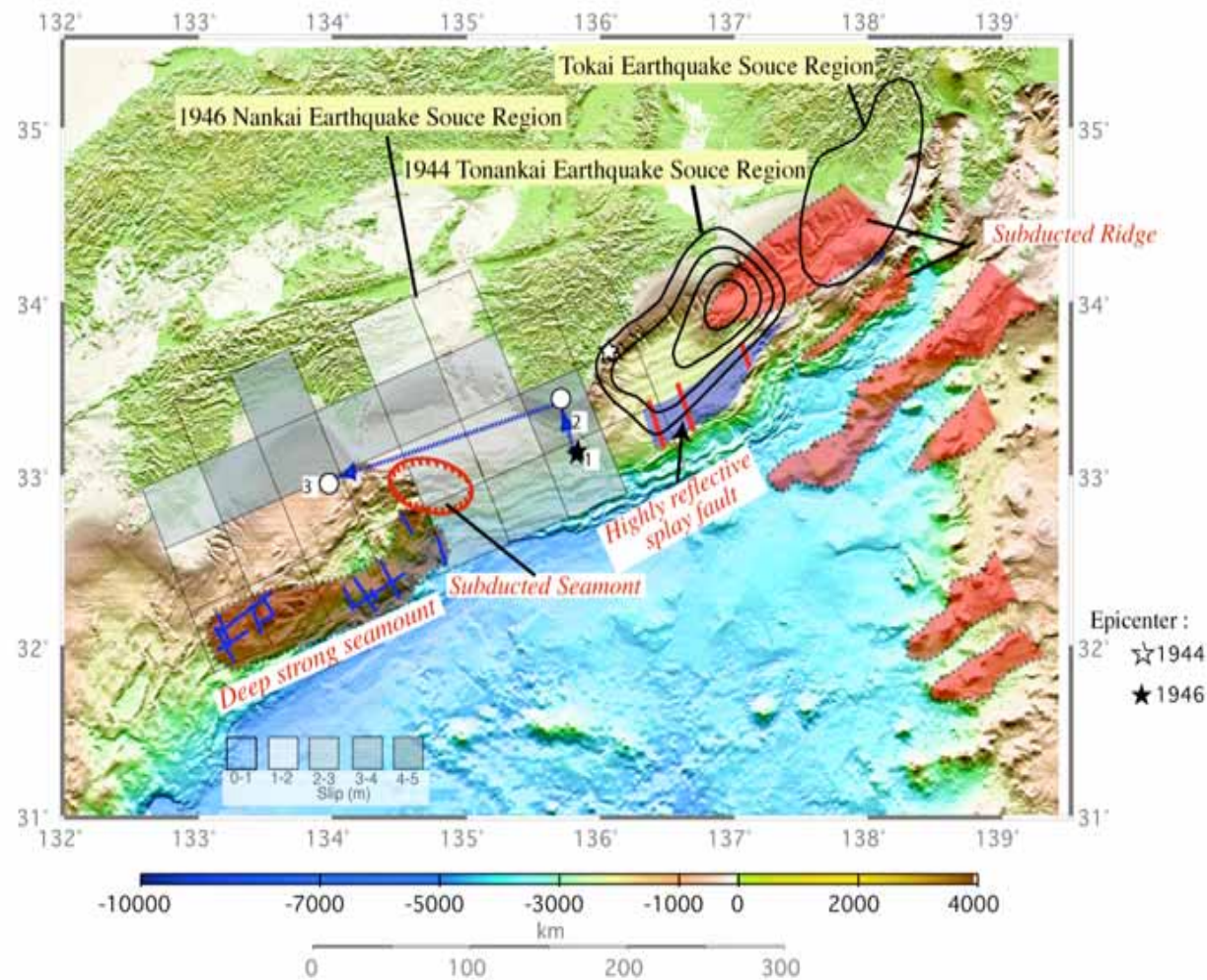




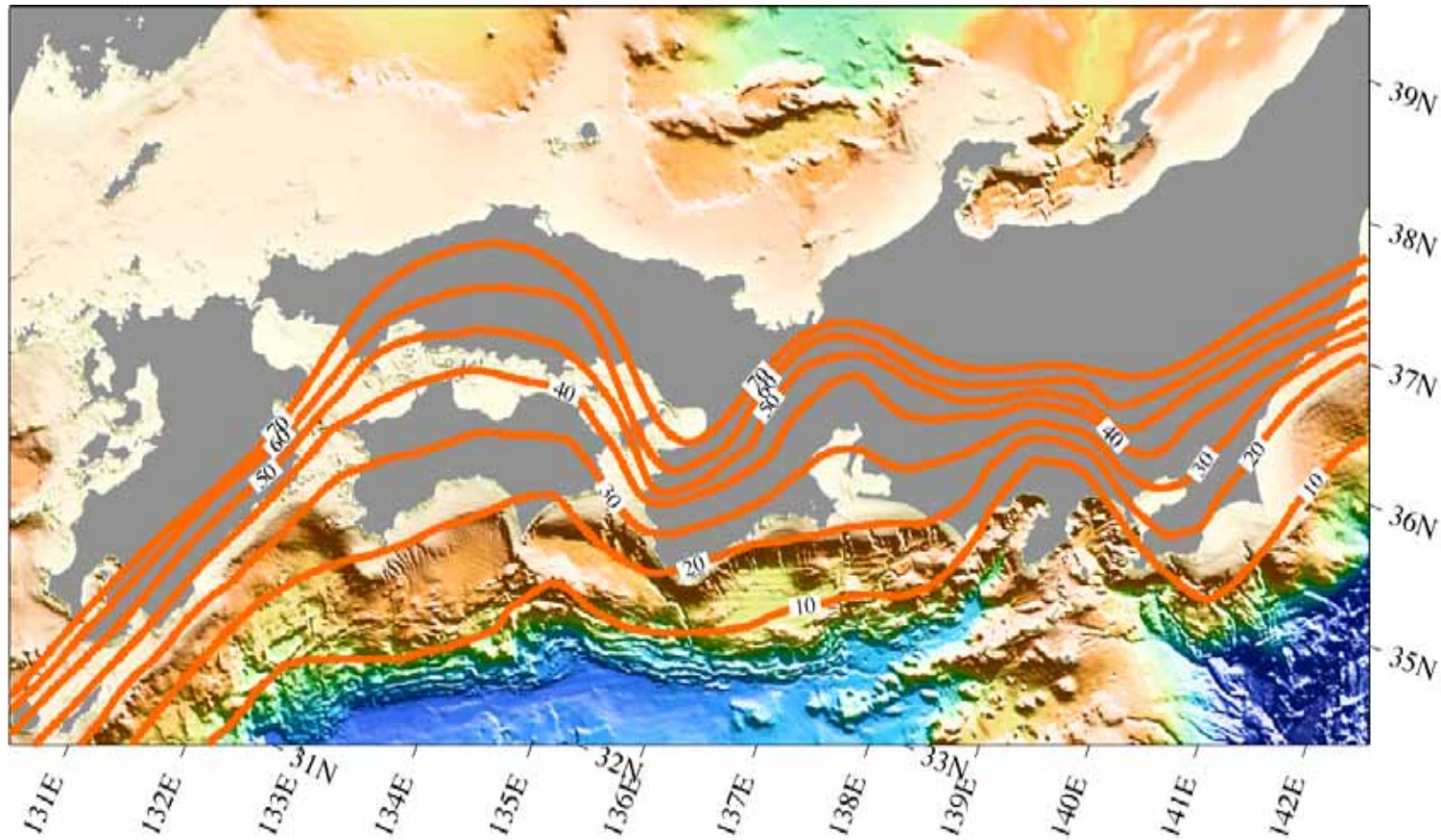
Structural factors controlling the rupture process of megathrust earthquake in the Nankai seismogenic zone

- 1) Subduction large seamount off Shikoku Island
- 2) Splay fault distribution off Kii Peninsula
- 3) Cyclic ridge subduction off Tokai

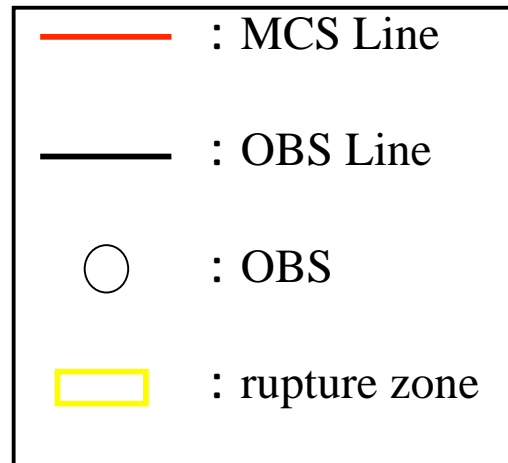
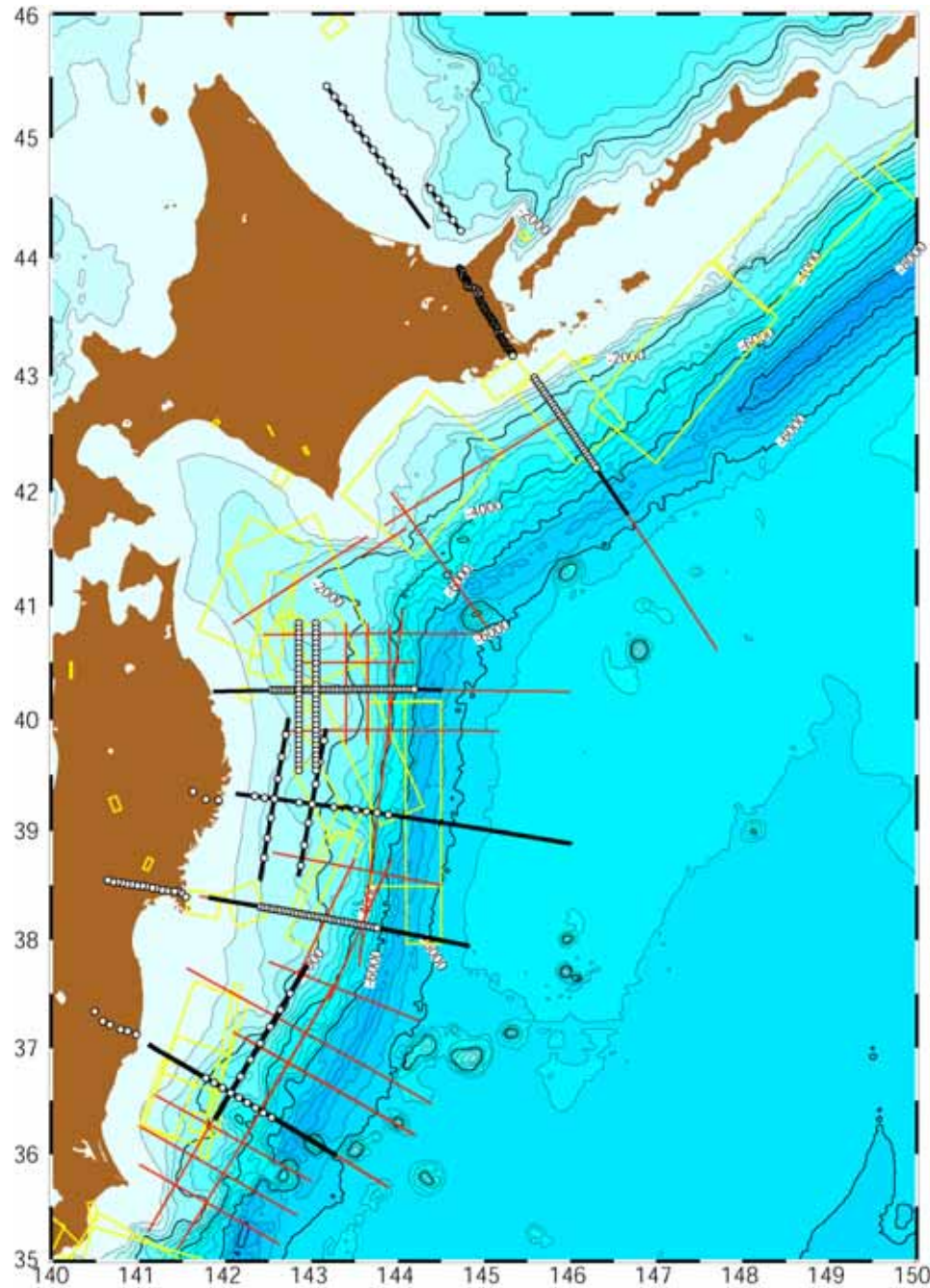
Structural factors controlling the rupture process of megathrust earthquake in the Nankai seismogenic zone



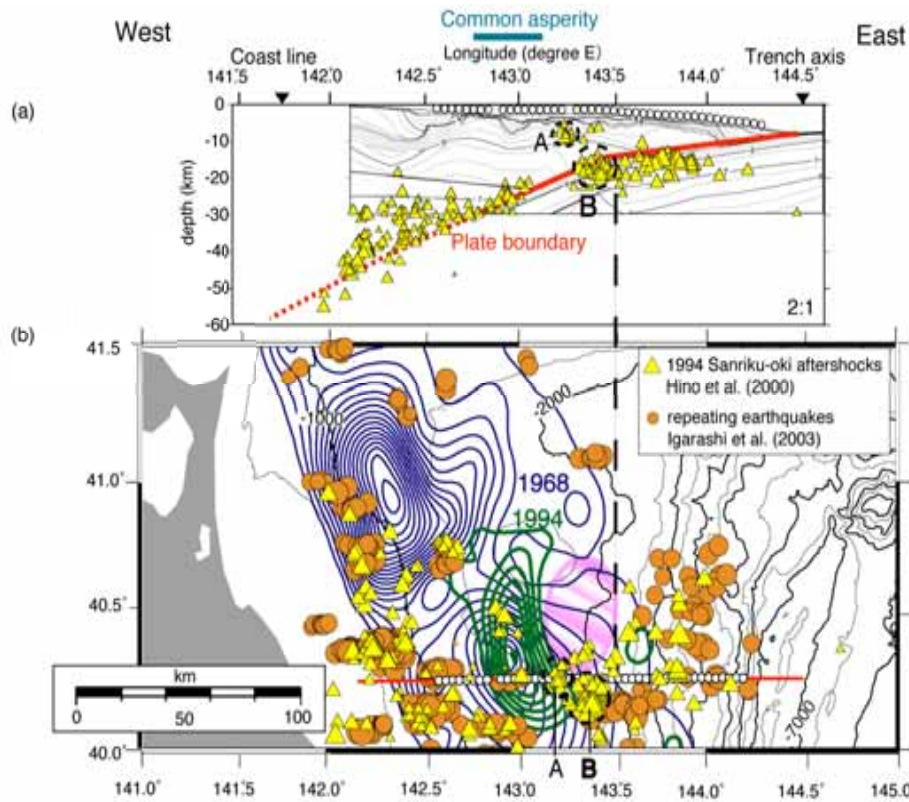
Philippine sea plate counter map



Seismic survey line in Japan Trench



Seismic survey off Sanriku



Model with iso-velocity contours as for Fig. 3a, superimposed on focal depths of aftershocks of 1994 earthquake projected onto the vertical cross section off Aomori forearc region.

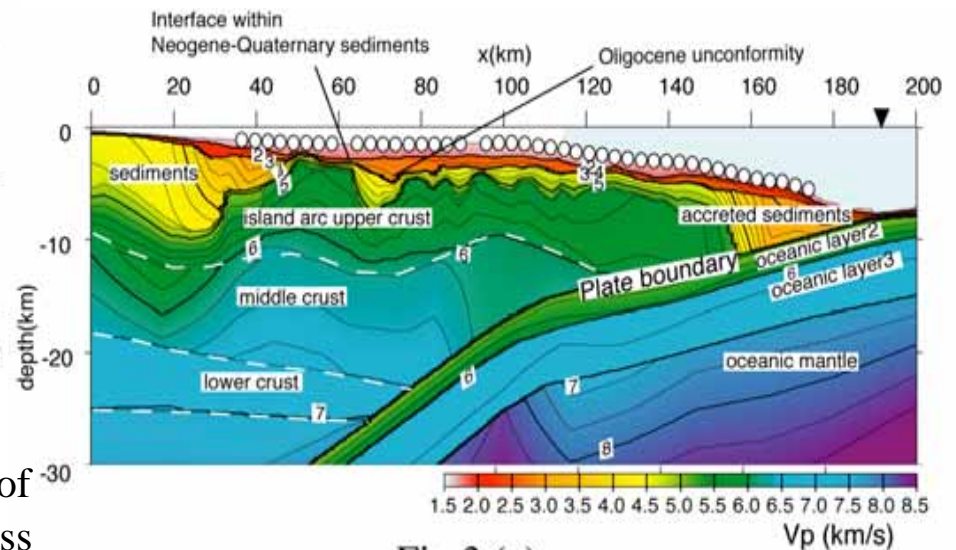


Fig.3 (a)

Spatial distribution of repeating earthquakes from Igarashi et al. Orange circles show the repeating earthquakes for the period from April 1992 to July 2000 ($M=3$ or larger). The red line indicates the location of the seismic refraction profile and white circles are OBS locations for this study.

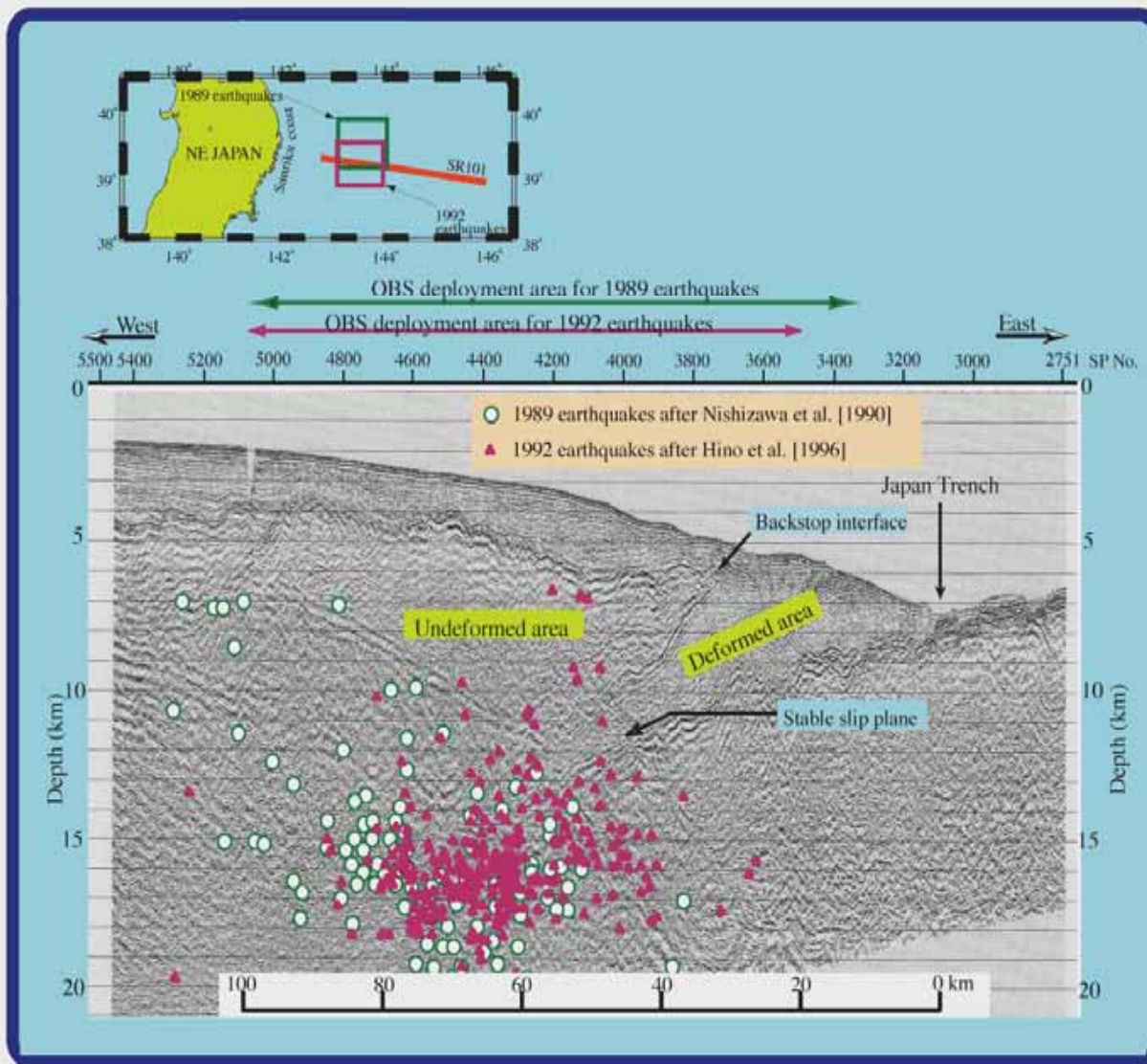
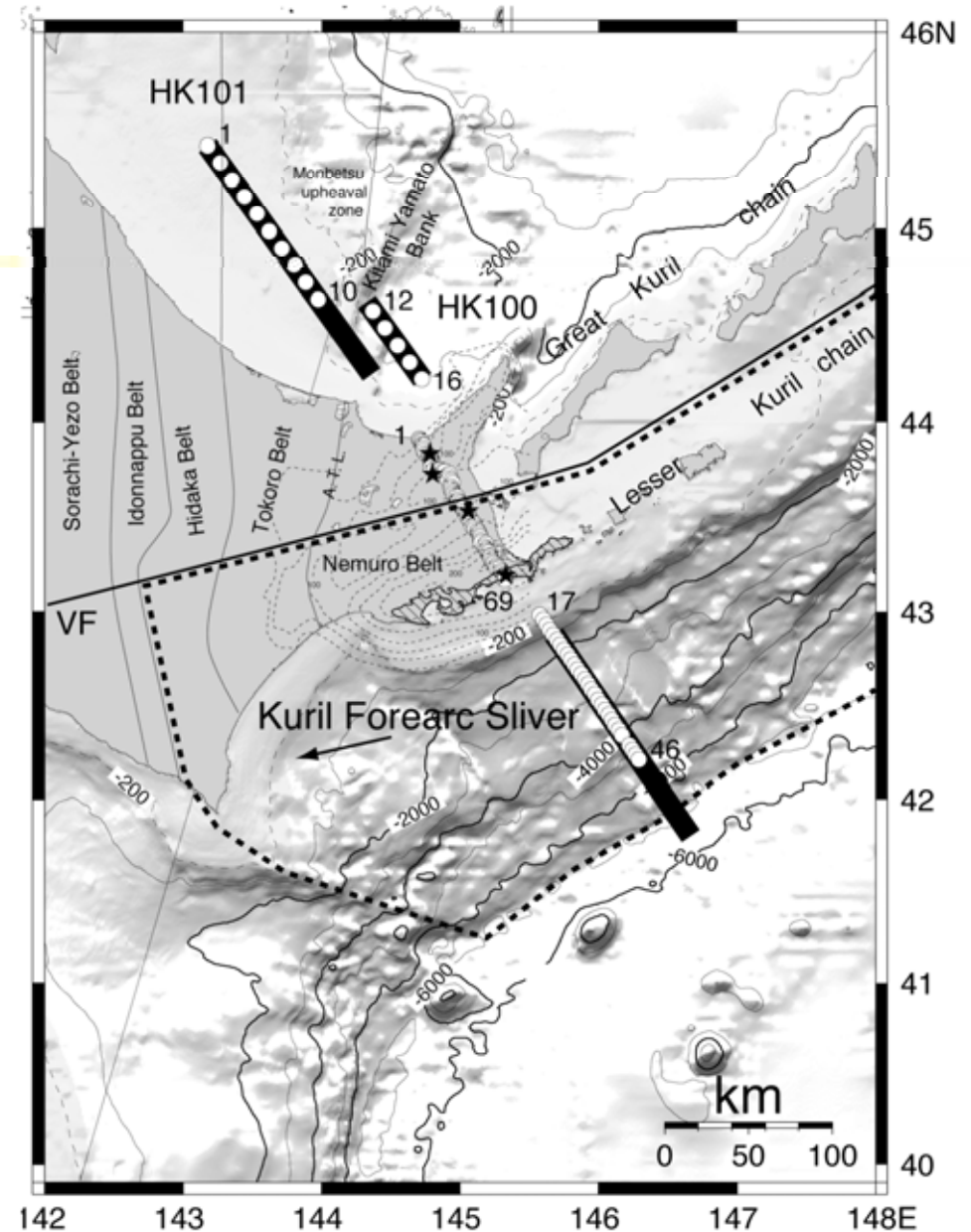


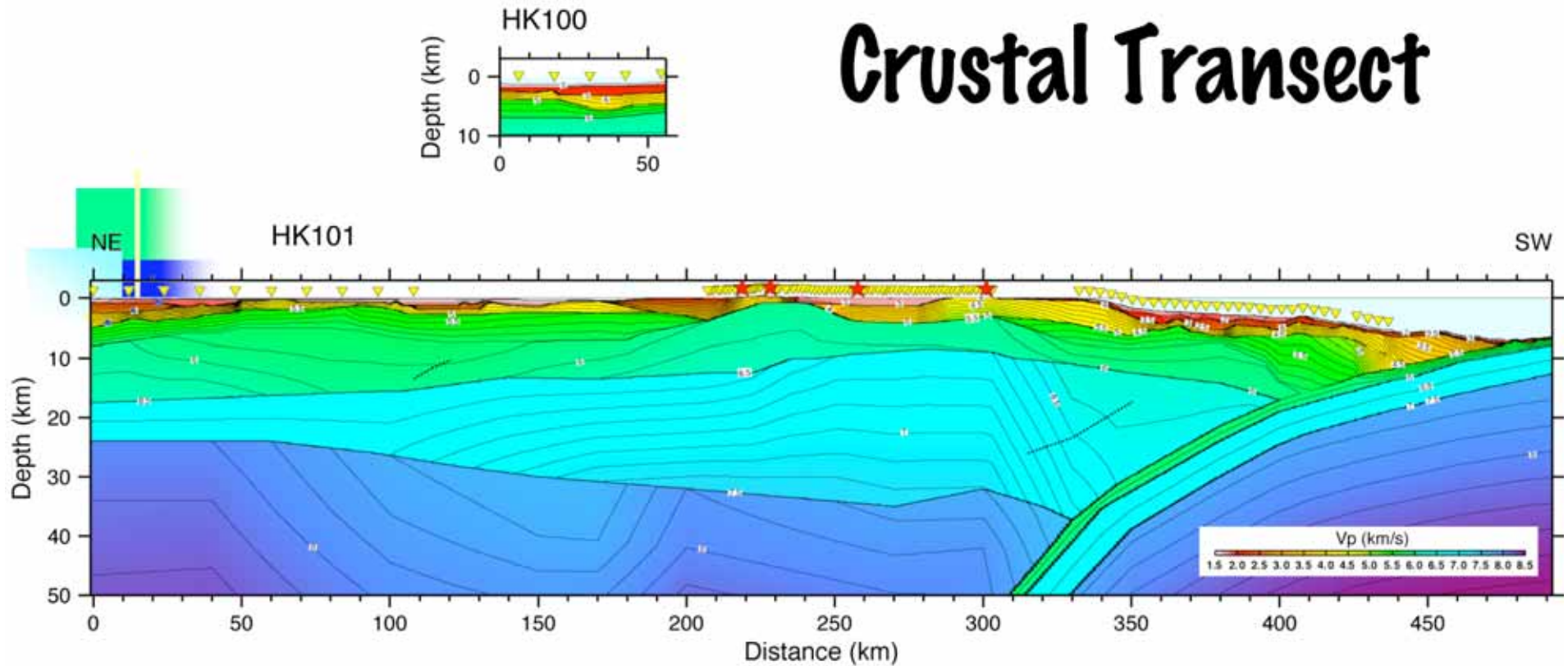
Figure 7 Comparison between the seismicity and the MCS reflection profile. Vertical exaggeration is 4 times. The seismicity rapidly increases landward from the location, where the deformed area pinches out landward and the stable slip plane becomes less obvious. Rectangles in the top location map show OBS deployment areas.

Acquisition

- July-August 2000
- Offshore Survey
 - 492 km Profile
 - 46 OBSs
 - 150m Interval Shot
 - 200L Airgun (14MPa)
- Onshore Survey
 - ~100km Profile
 - 74 Stations
 - 4 Explosives

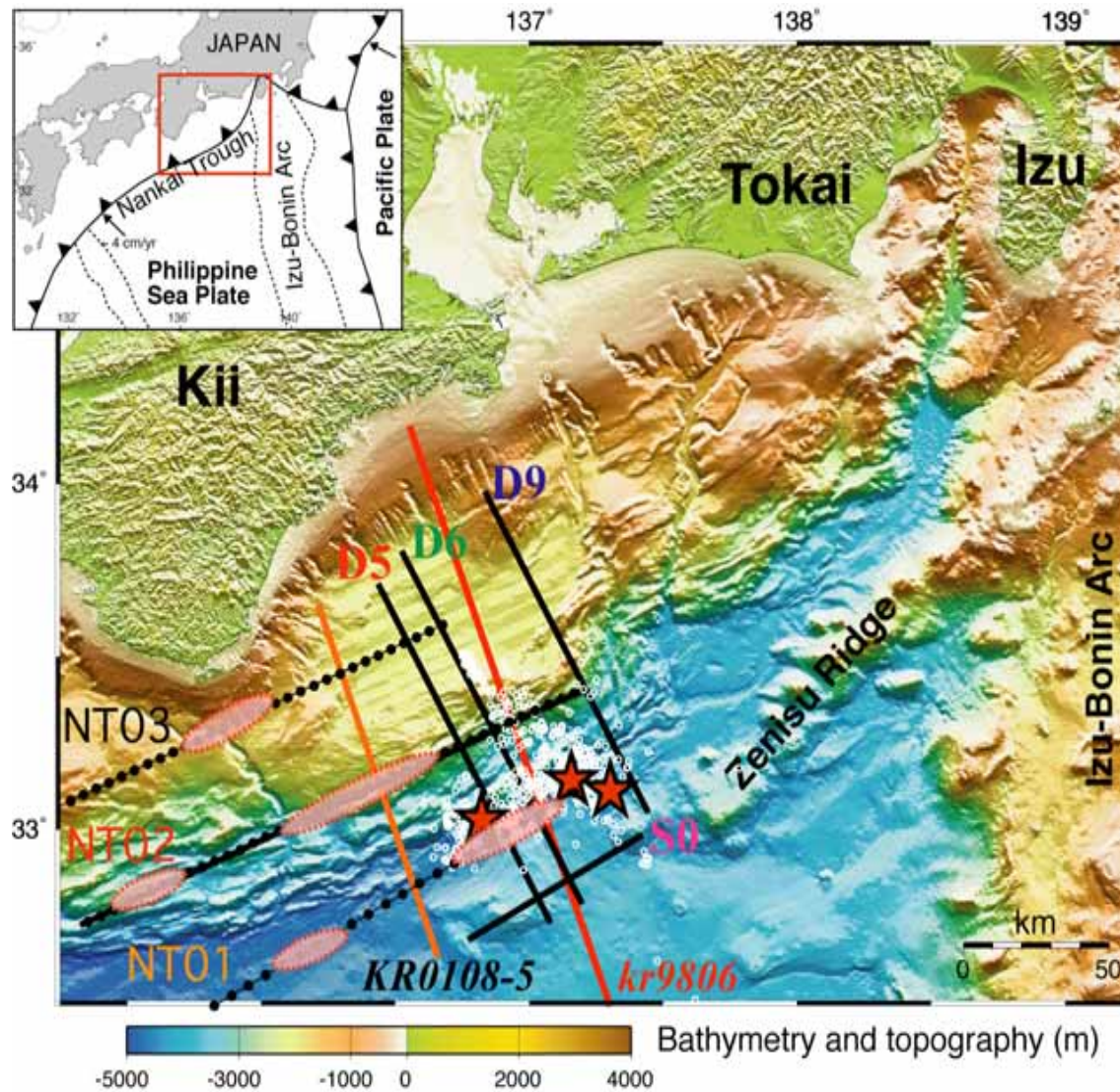


Crustal Transect



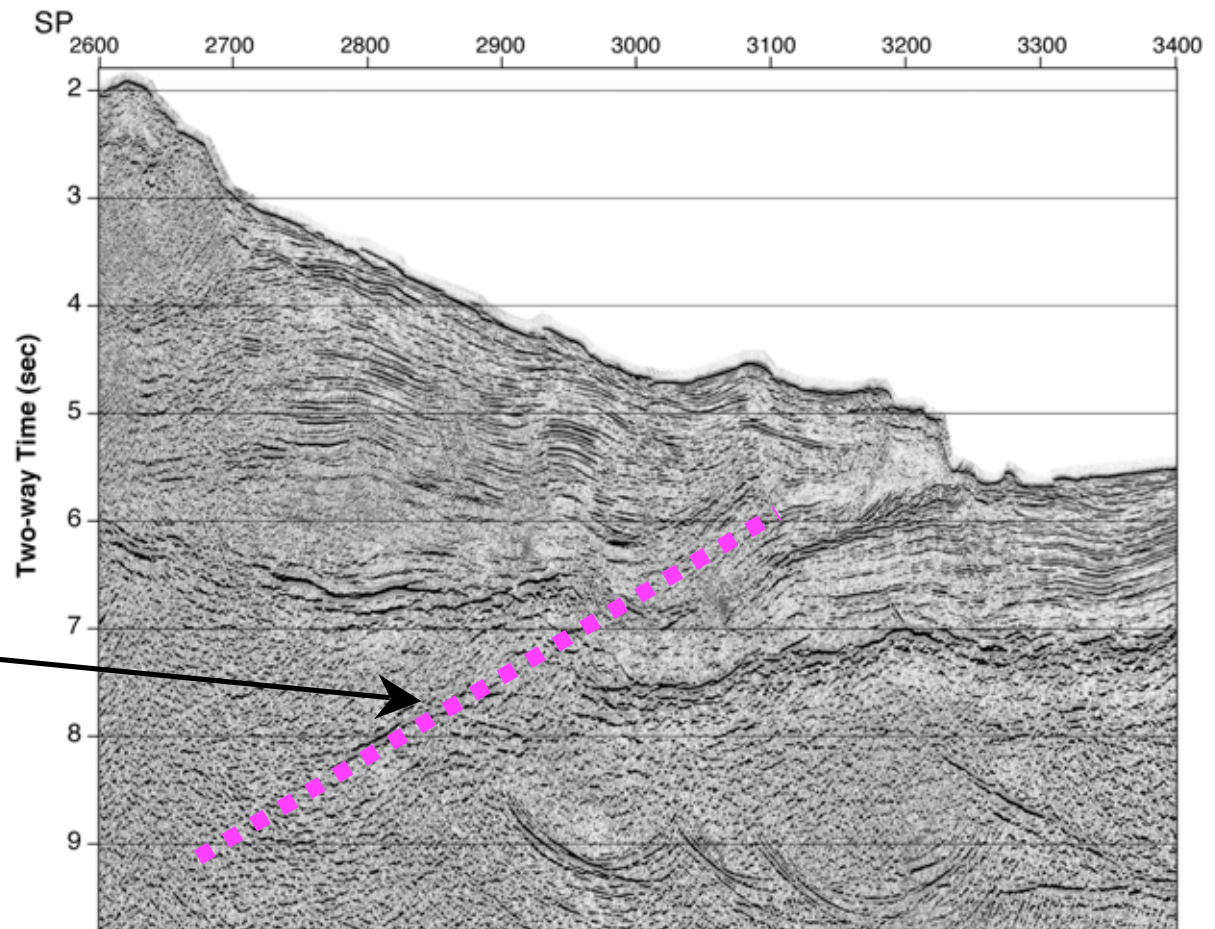
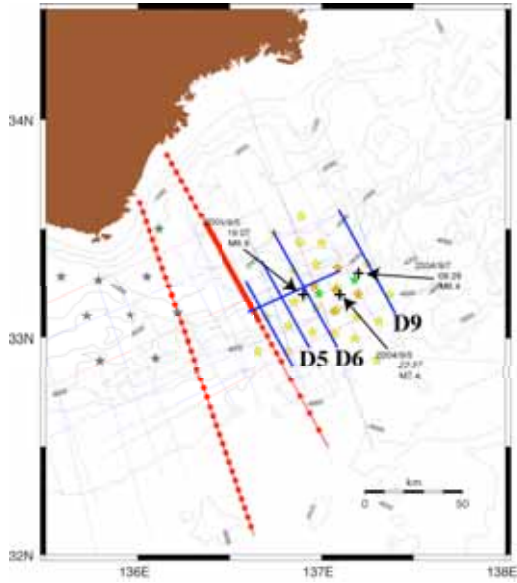
- Sea of Okhotsk
 - Thick upper crust and thin lower crust
- Transition zone
 - Slow uppermost mantle
- Kuril Arc
 - 6.0-6.2km/s layer
 - Thick and High Vp middle/lower crust

Off Kii peninsula Earthquake

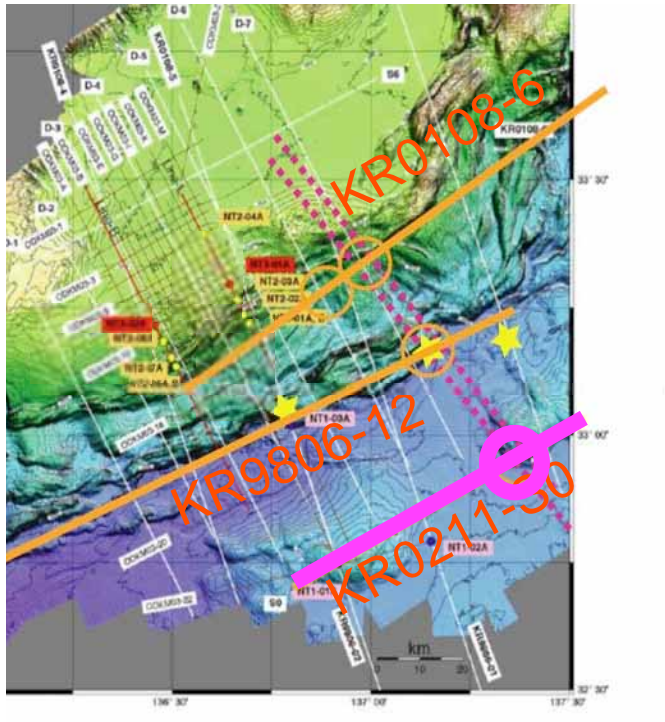


Seismic Section

KR0211-D9 Filtered Time Migration



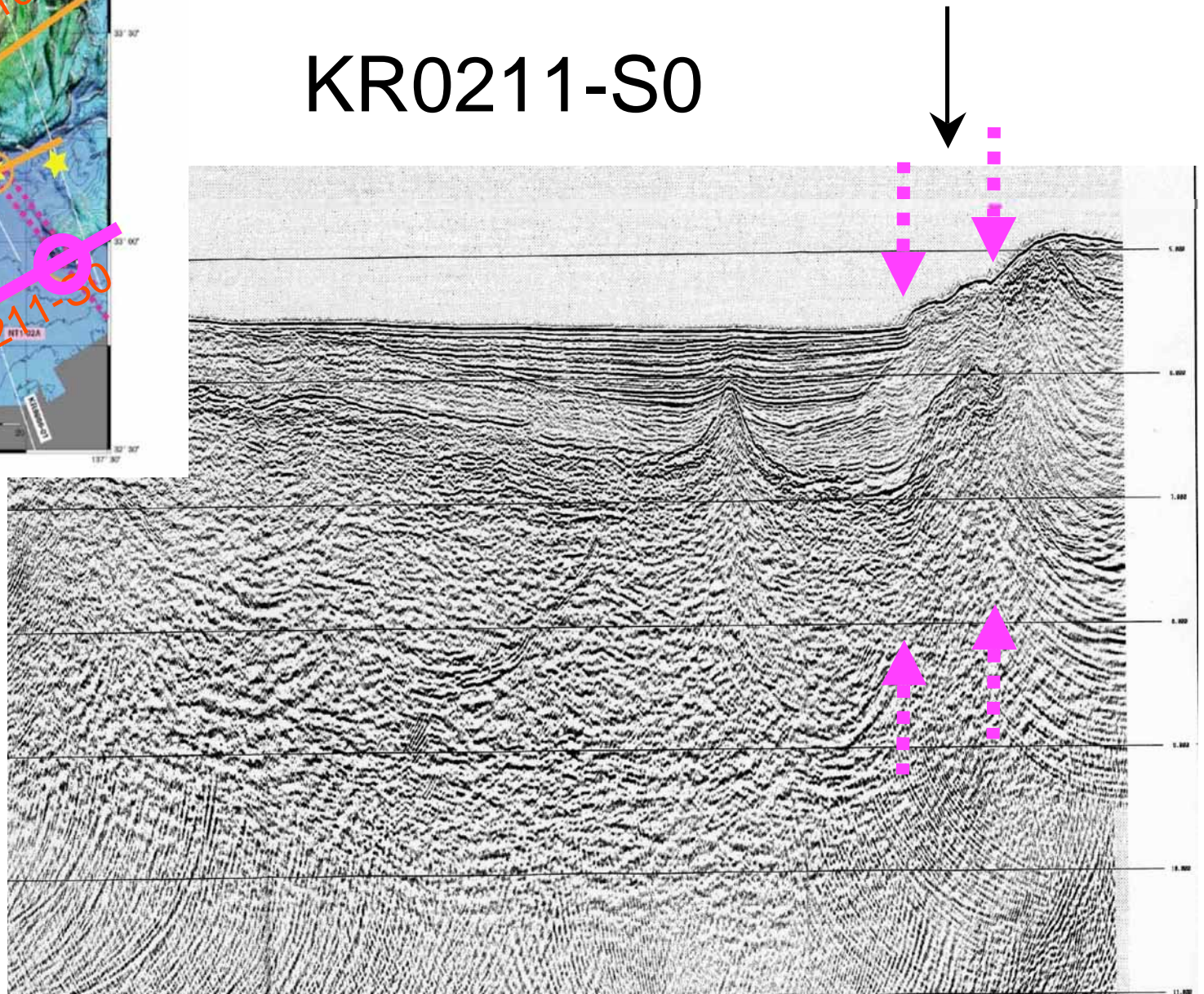
Reverse Fault ?



Seismic Section

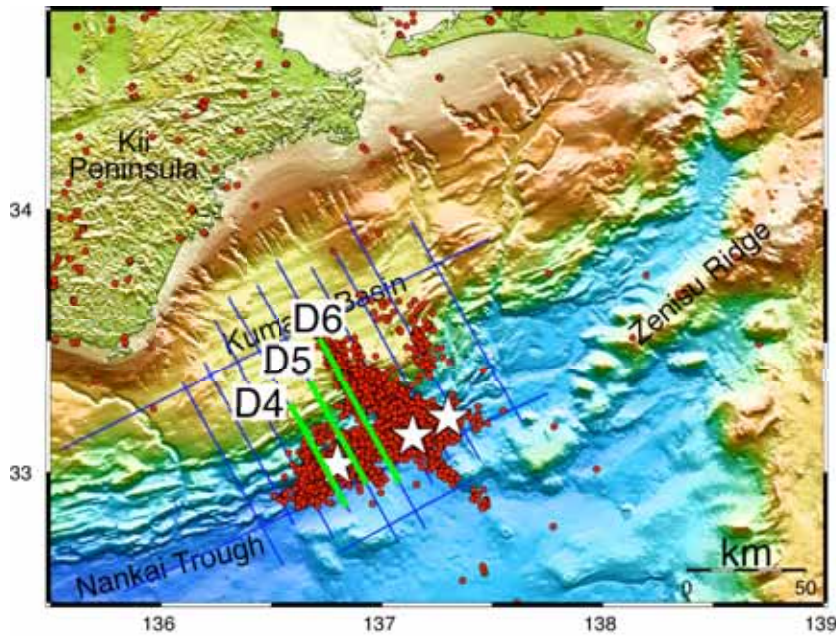
KR0211-S0

Strike Fault ?

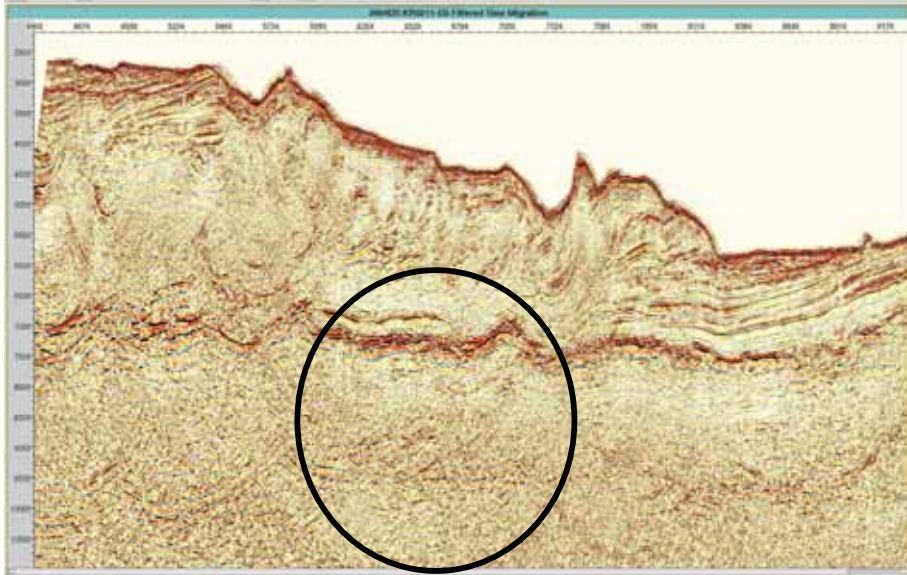


Deference seismic imaging between Before and After event

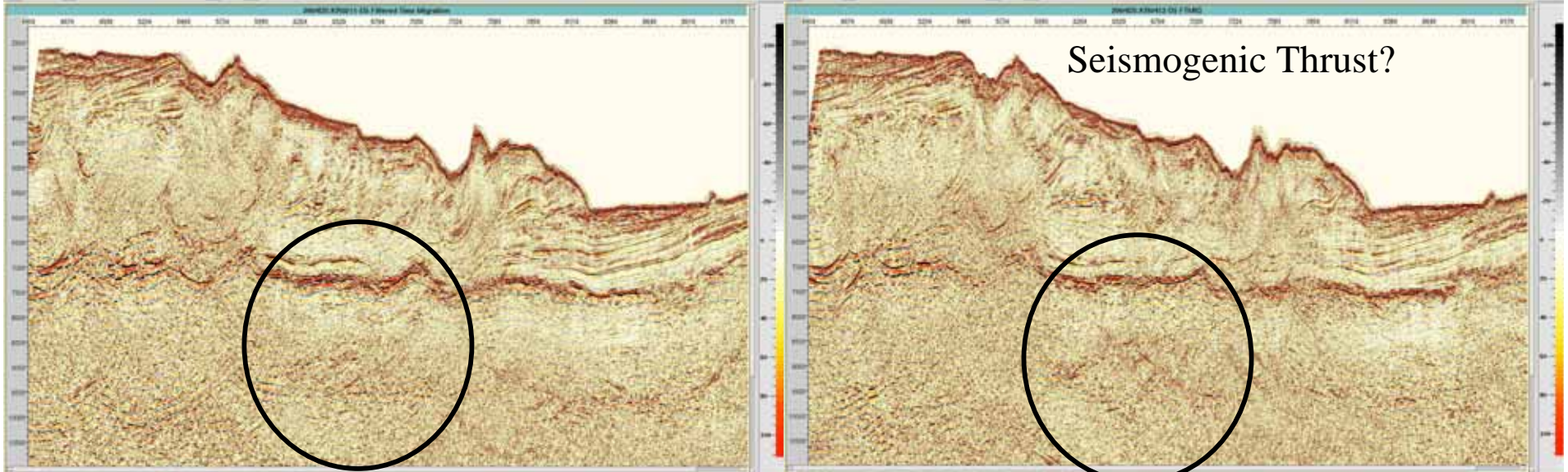
MCS Data Comparison:
Lines 2002 (Before Eq.) vs. Lines 2004 (After Eq.)



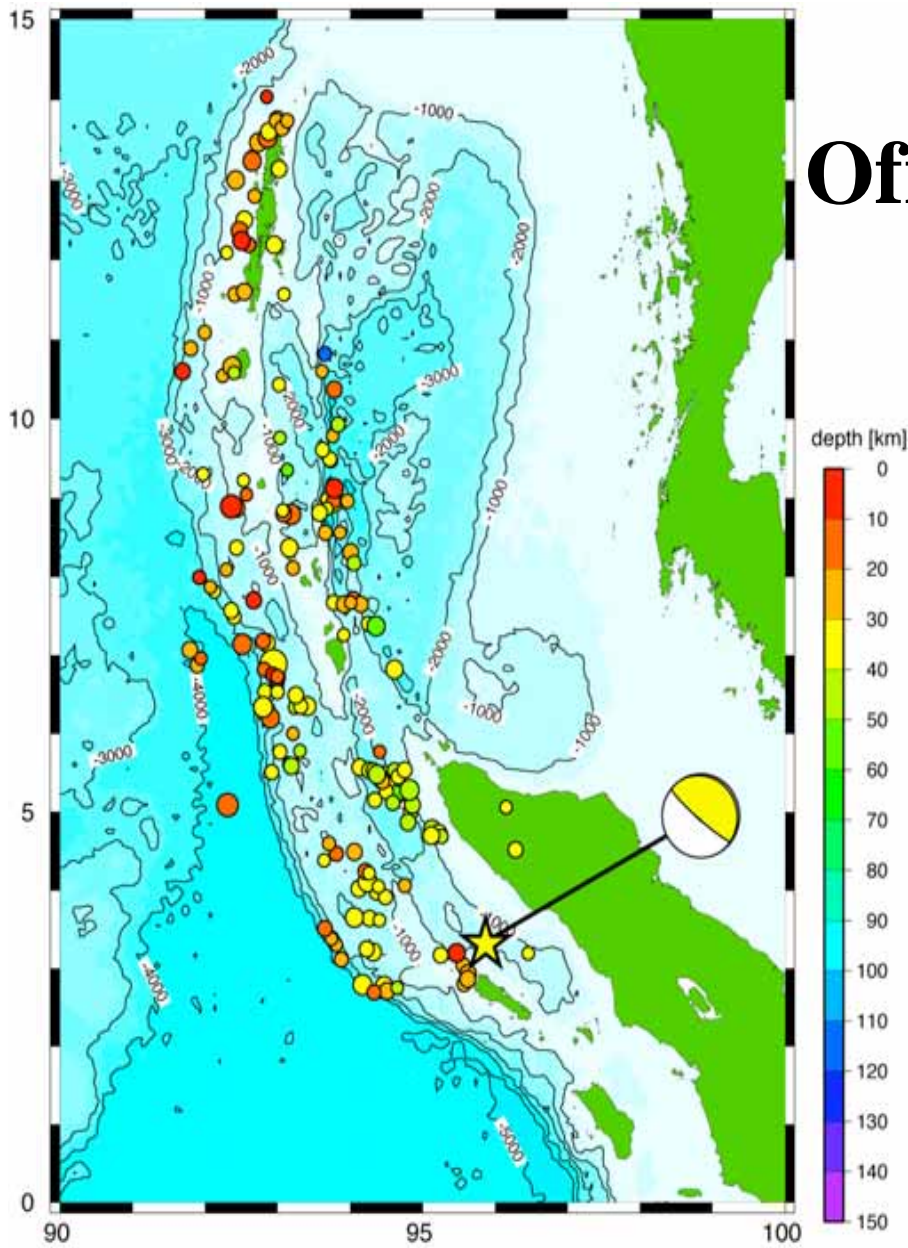
Line D5-2002 (Before Eq.)



Line D5-2004 (After Eq.)

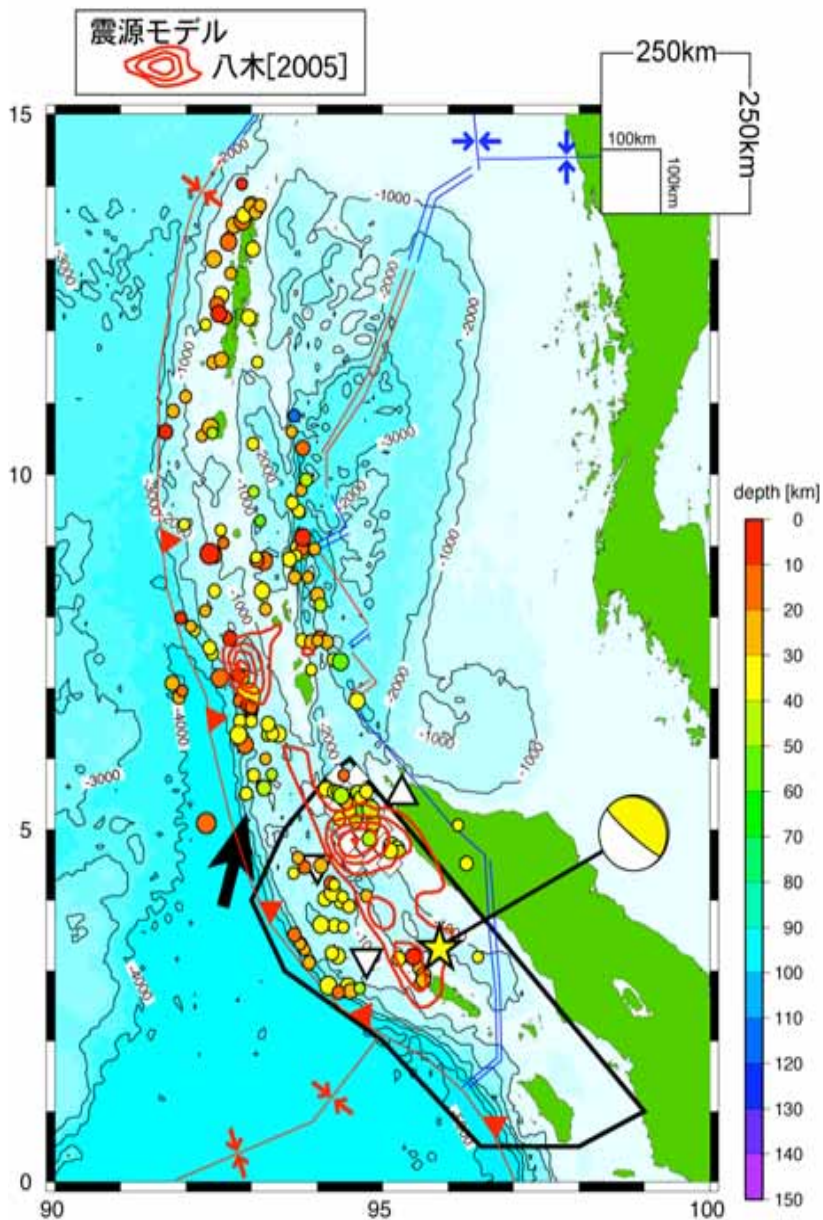


Off Sumatra Earthquake

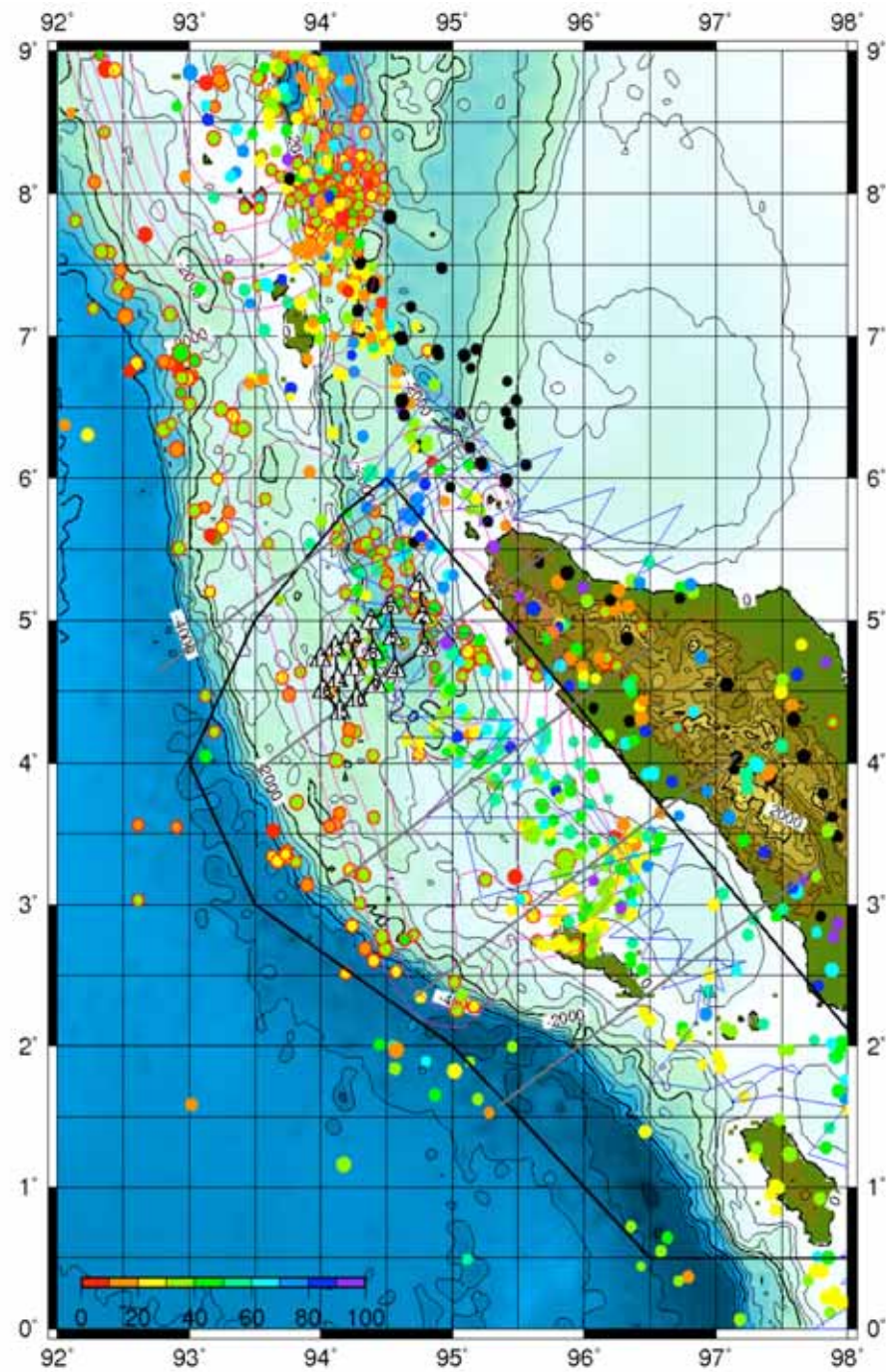


"The underwater survey of the SUMATRA earthquake source area"
The Research Vessel "Natsushima" of JAMSTEC passed across the Malacca Strait at midnight of February 18th. (Fri), 2005 (local time),

Bathymetric Survey

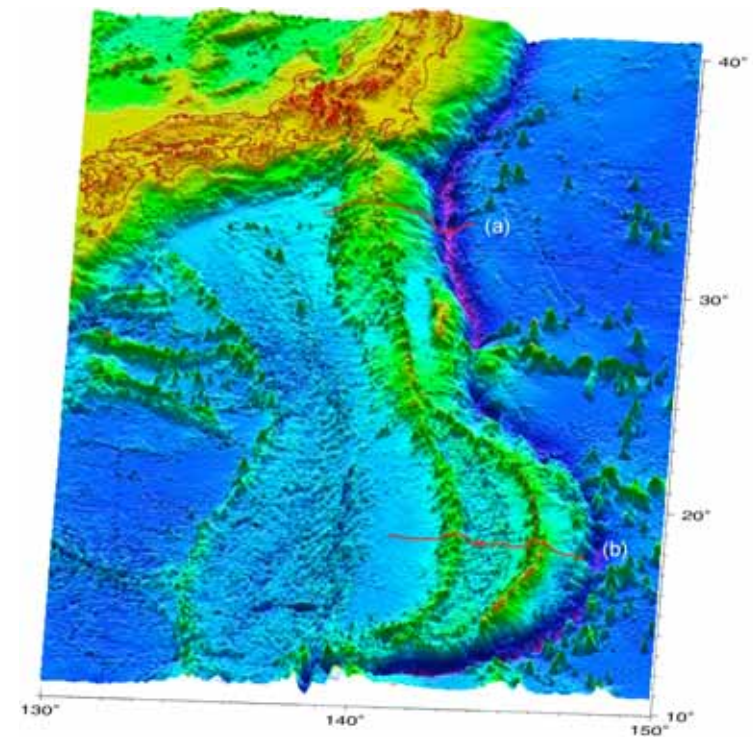
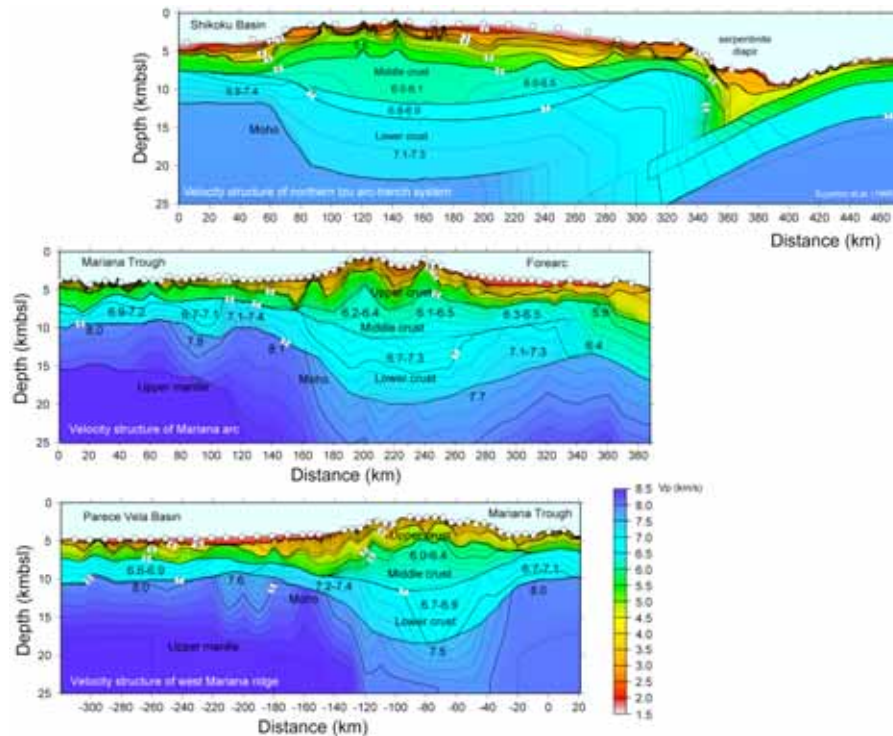


Seafloor topographic survey started
using
SEABAT 3000 system with a backscatter
imagery data acquisition.



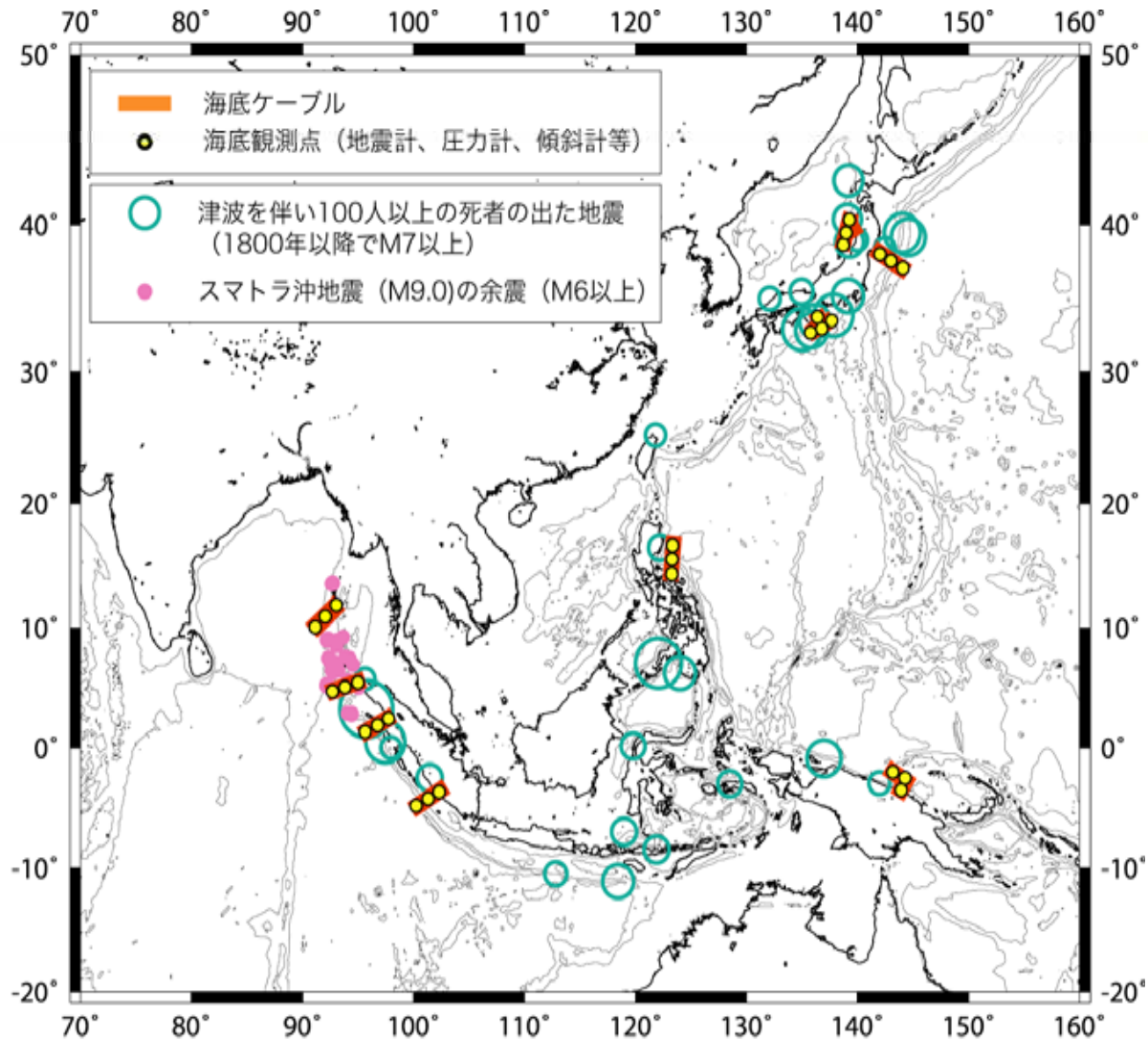
IBM research program in coming 5 years.

Results of seismic survey in IBM.



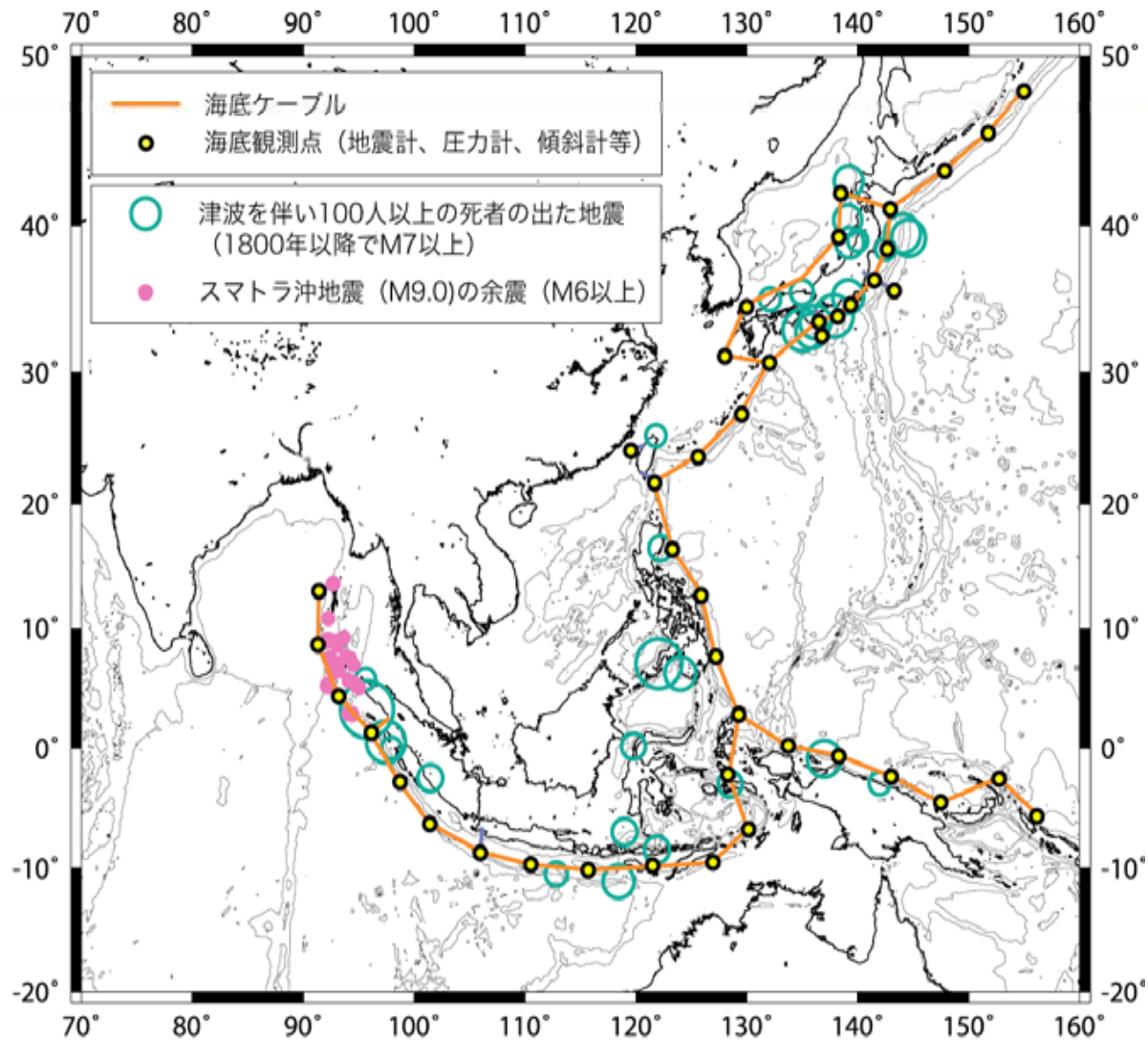
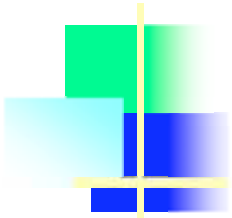
Mitigation System against the Earthquakes and Tsunamis

-1-



Mitigation System against the Earthquakes and Tsunamis

-2-



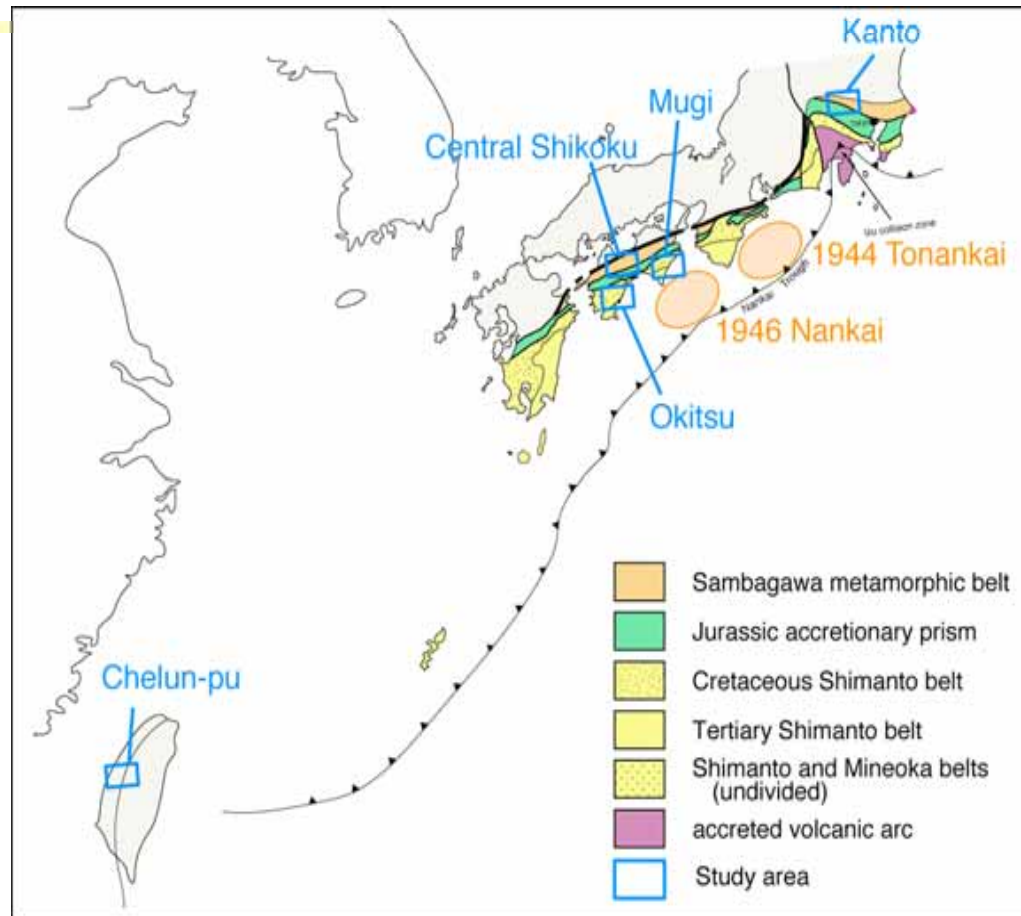
Research activity (2)

- Seismogenic zone material science research-



- 1) Sample and analyze exhumed fault rocks at Shimanto accretionary complex SW Japan and the accreted sediment at an evolved portion of the Nankai accretionary prism for elucidating the micro dynamic system in seismogenic zone.
- 2) The results of analyses confirms typical evidence for the seismic slip by the discovery of pseudotachylyte in Shimanto accretionary complex.
- 3) Experiments for reproduction of fault slip at Chi-Chi earthquake

Location Map of Field



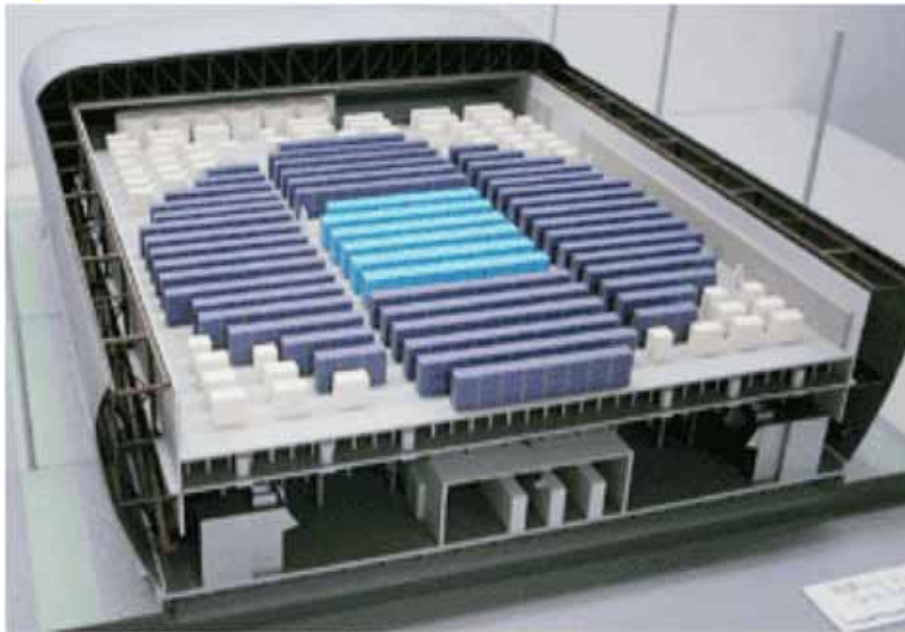


Research activity (3)

-Plate dynamics modeling research-

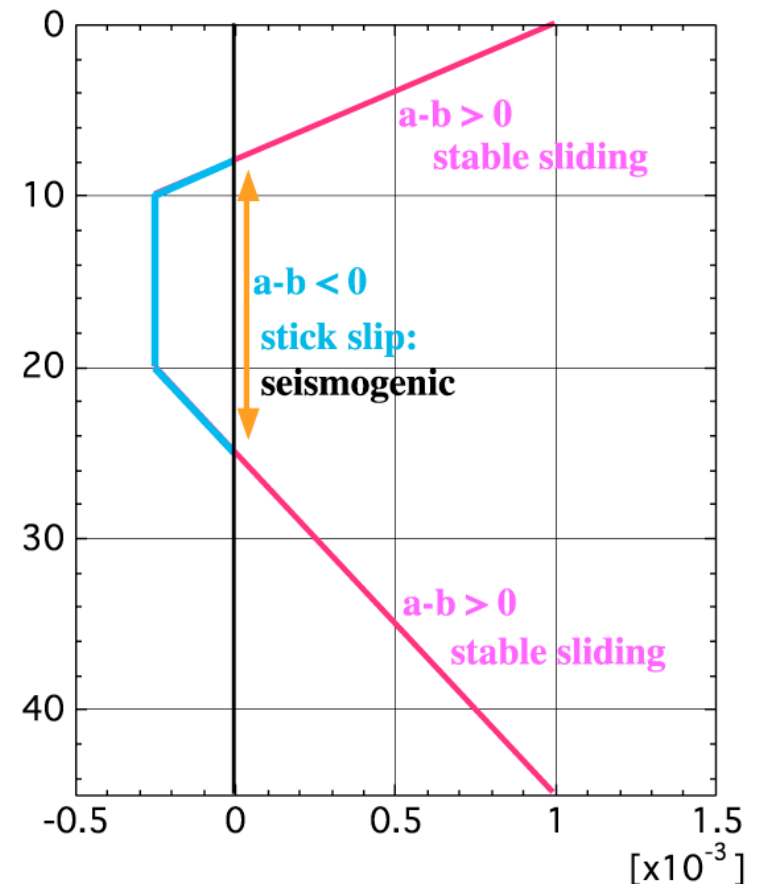
- 1) Develop the modeling software such as megathrust EQ recurrence cycle simulation using ES.
- 2) Obtained results include a detailed 3D Philippine sea plate interface, S-wave anisotropy within the subducting plate and analysis of the source process of the 1946 Nankai earthquake.
- 3) Slip distribution of the 2003 Tokachi-oki EQ

Results of ES utilization

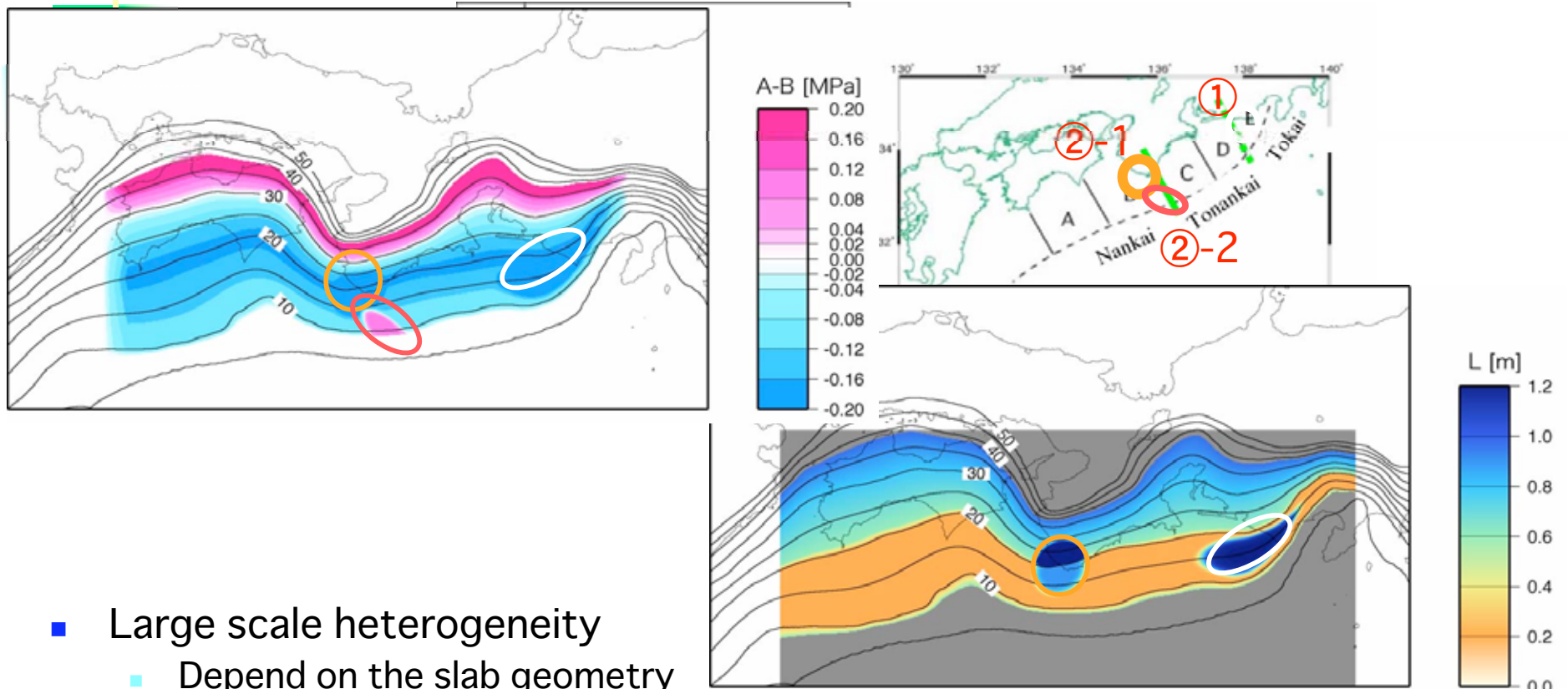


Model settings

- depth dependence of frictional parameters
 - $a-b$: depth dependent
 - L : const (0.1 m)
- normal stress:
 - depth dependent
 - some anomaly
 - seamount/ridge

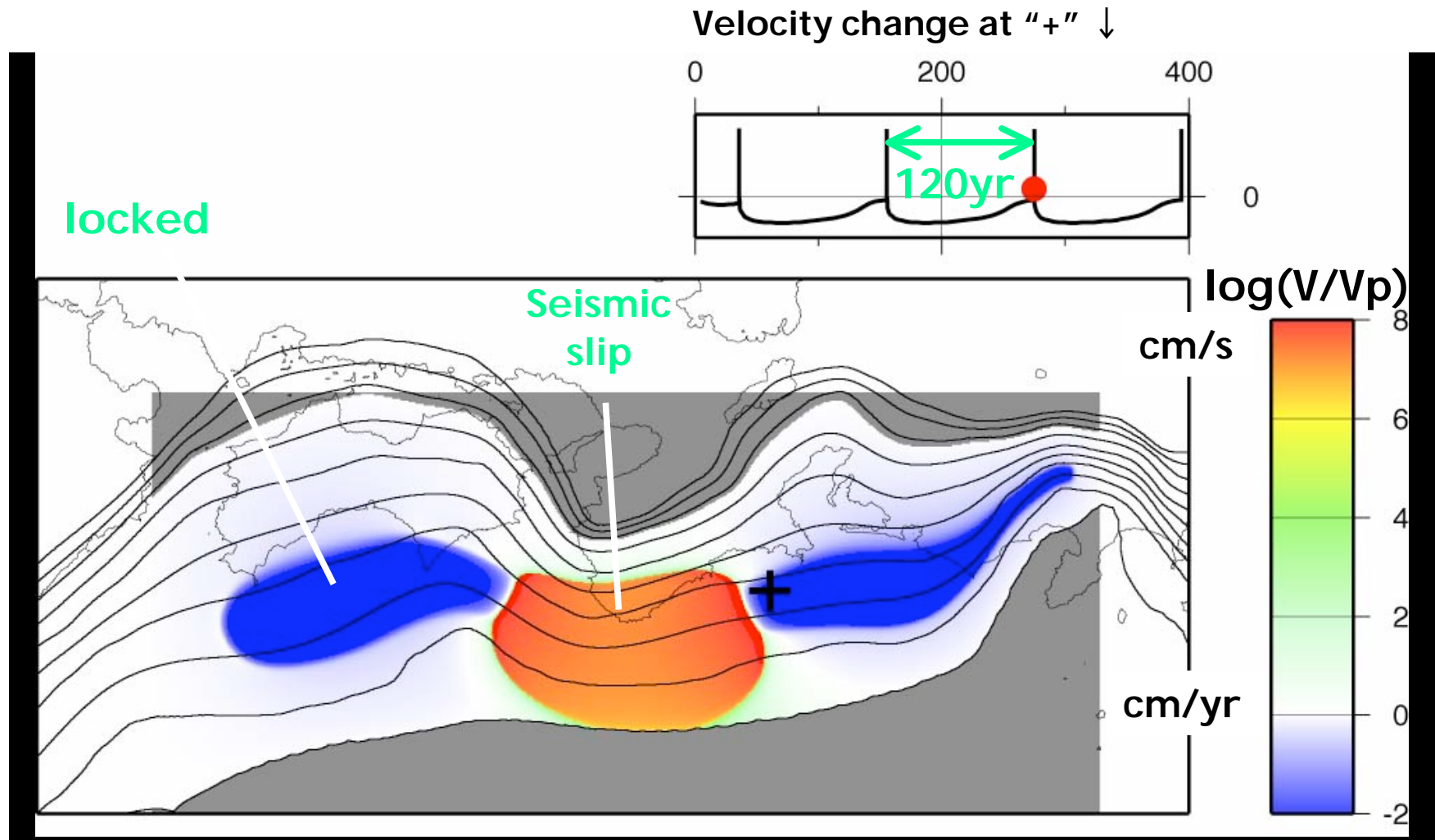
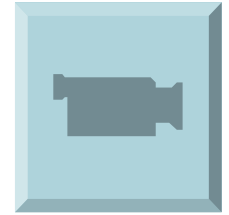


Frictional property



- Large scale heterogeneity
 - Depend on the slab geometry
 - Shallower than 10km (deformable backstop): stable sliding
- Small scale heterogeneity
 - High fracture energy area
 - Effective normal stress (+200MPa) & L (max: x 5.0)
 - Stable sliding area
 - $b=0.0$

Simulation result



Slip velocity

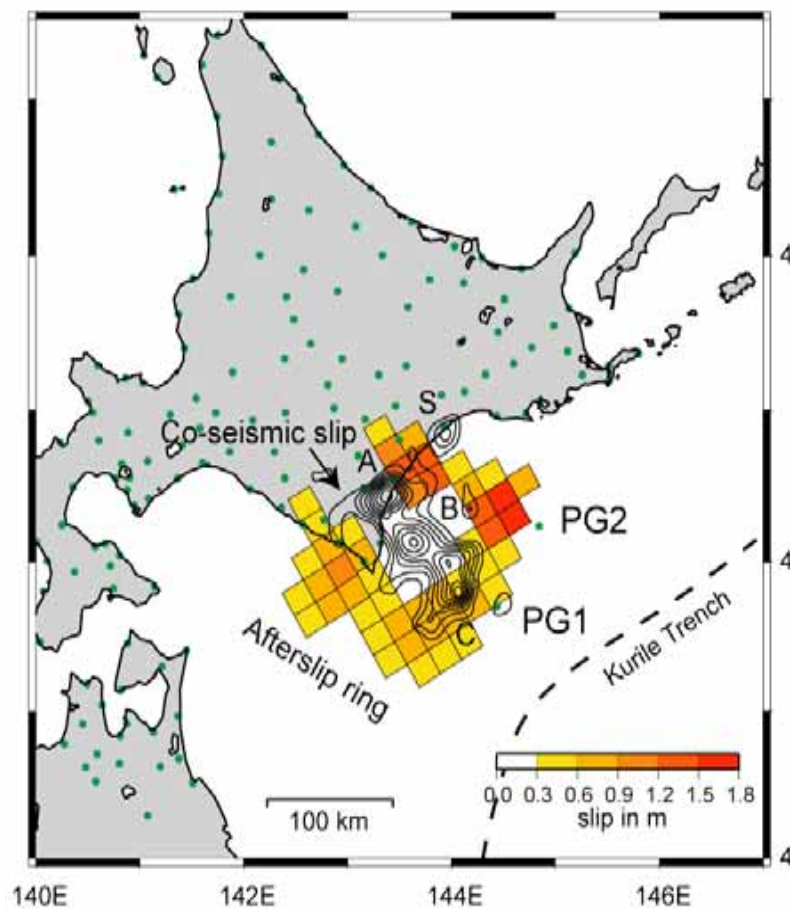
Wave propagation generated by megathrust EQ 1944 Tonankai EQ - 1946 Nankai EQ



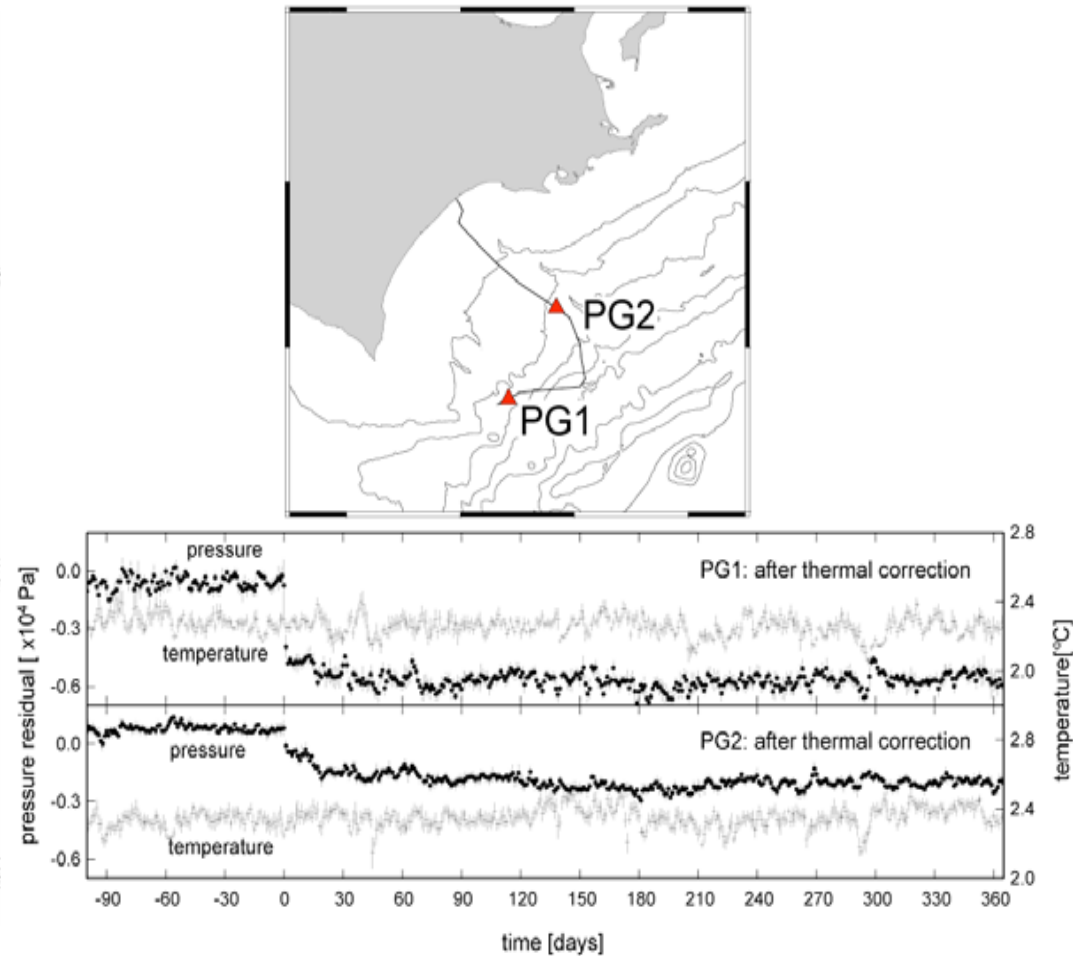
The result of computer simulation for the Tonankai, Nankai hypothetical earthquake demonstrating large ground shaking radiating from the source region, and propagating to east along the fault rupture.

Furumura et.al

Co-seismic and 1-year post-seismic slip distributions of the 2003 Tokachi-oki earthquake



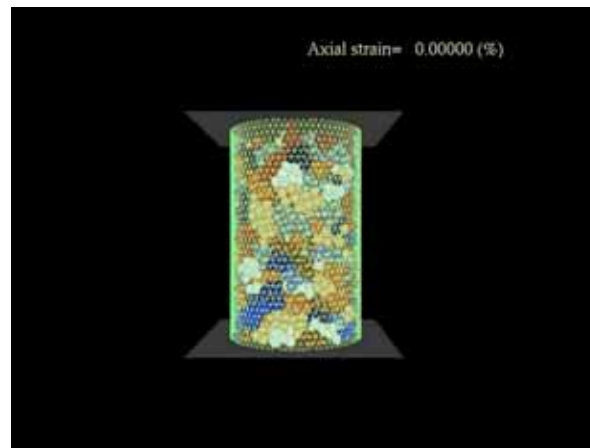
Co-seismic slip : Yagi (2004)



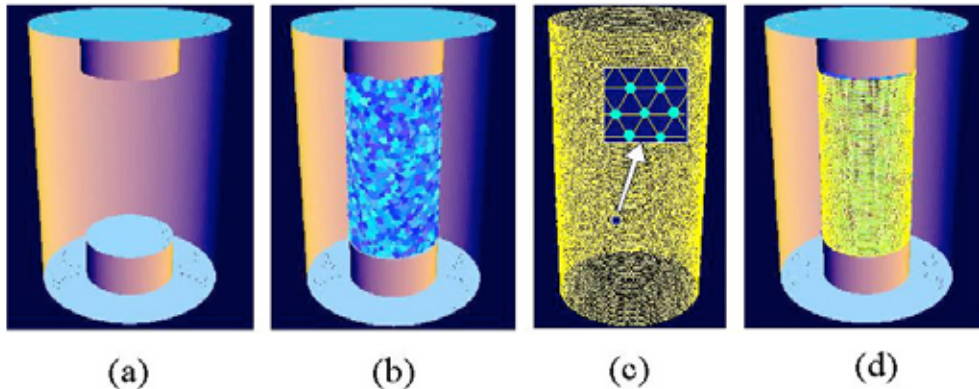
Seafloor vertical displacements observed by ocean-bottom pressure gauges

Microscopic/Macroscopic modeling for Deodynamic (FEM DEM etc)

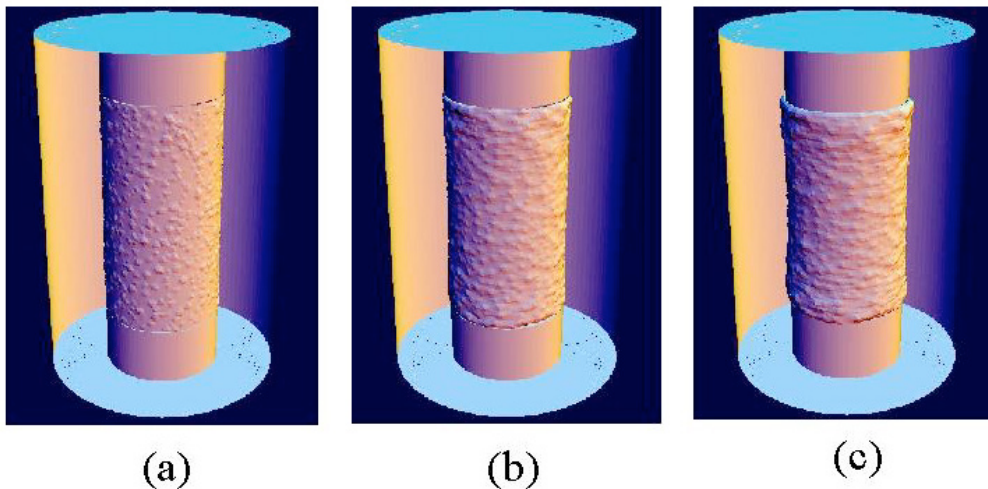
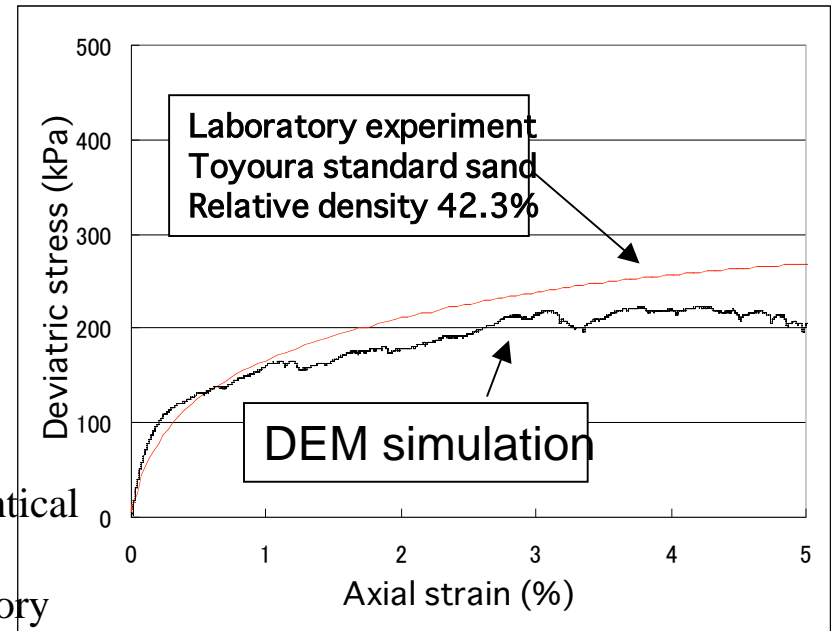
Development of new analytical methods based
on the Discrete Element Method



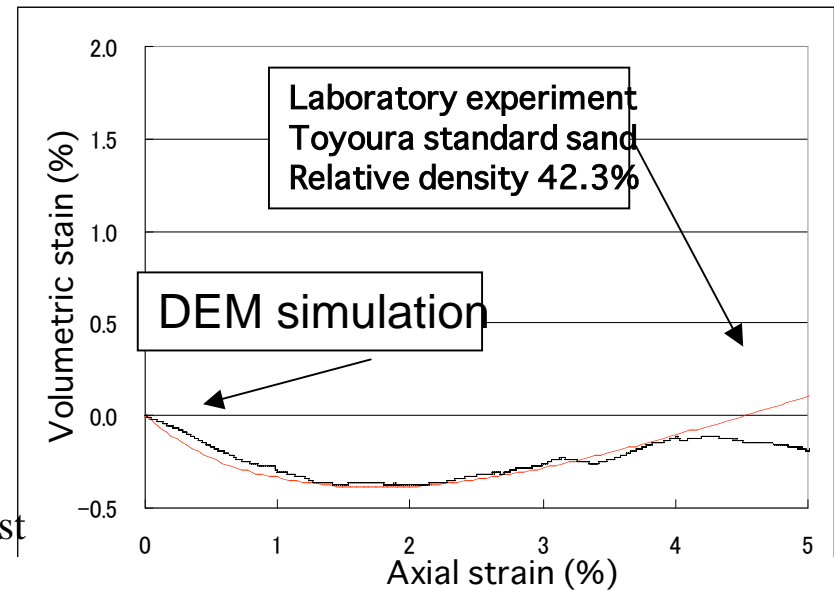
Virtual tri-axial compression testing simulation using DEM



The experimental method, condition, procedure are all identical to those of real laboratory tri-axial compression tests. Idealized conditions which are impossible to see in laboratory experiments can be realized.



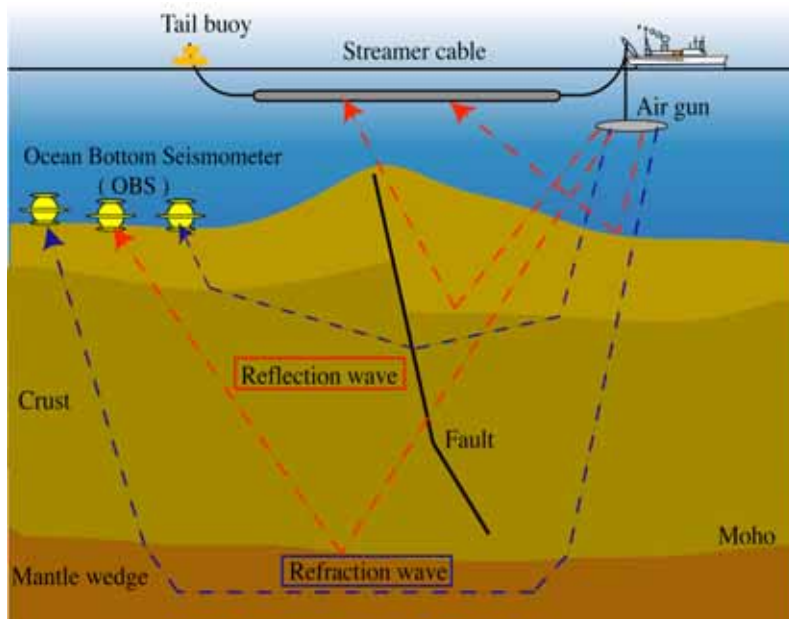
Snapshots of deformation during a tri-axial compression test



Multiscale approach to understand Geodynamics

1) Lithospheric Structure Research

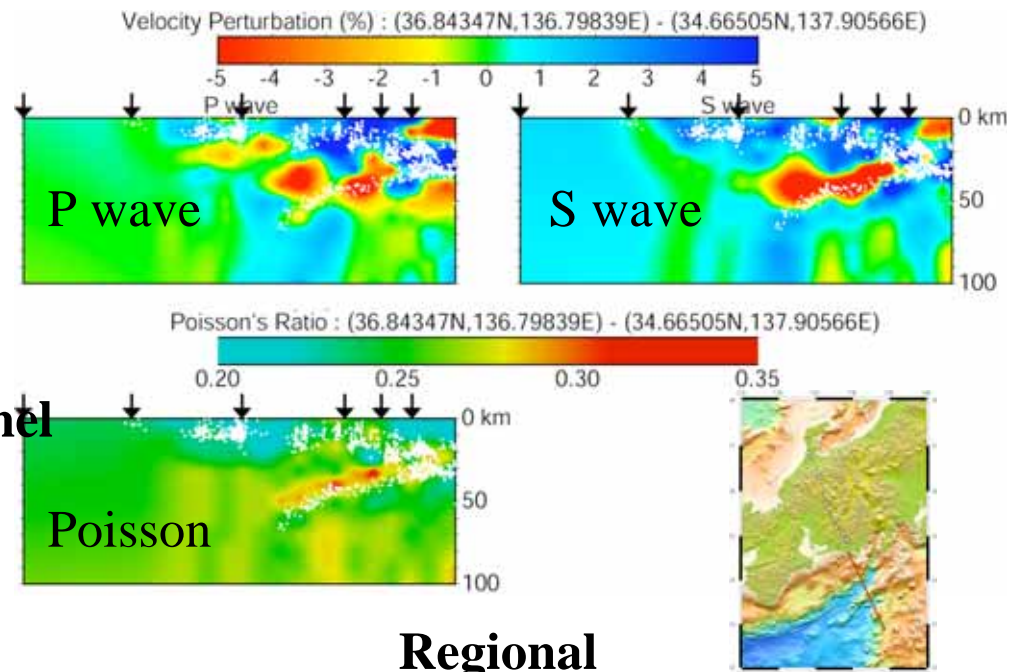
- Wide angle refraction and Multi channel reflection seismic survey



nography

Seismic Tomography

V_p, V_s and Poisson's ratio structure (Kamiya and Kobayashi, 2003)



Wide angle refraction and Multi channel reflection seismic survey

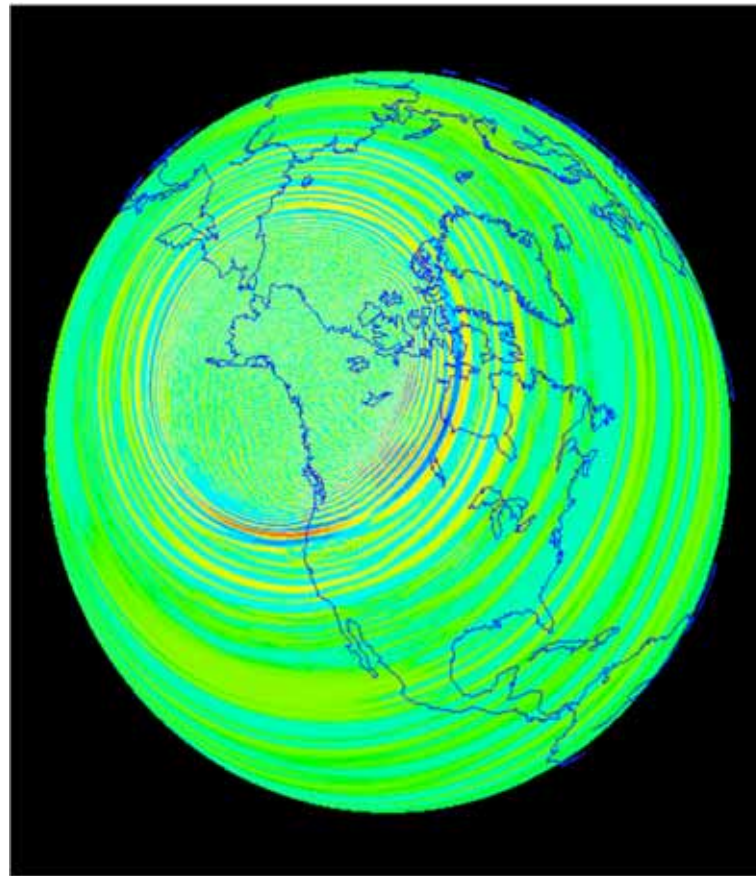
Local

Regional

Multiscale approach to Geodynamics

2) Modeling Research

- Forward modeling to determine the structure
- Microscopic/Macroscopic modeling for Geodynamic (FEM DEM etc)



Regional

Snapshot of the vertical component of the synthetic seismic waveform



Multiscale approach to understand Geodynamics

Integration

3) Physical and Material science approach

- Experimental research to elucidate micro process
- Geological research to understand micro/macro process

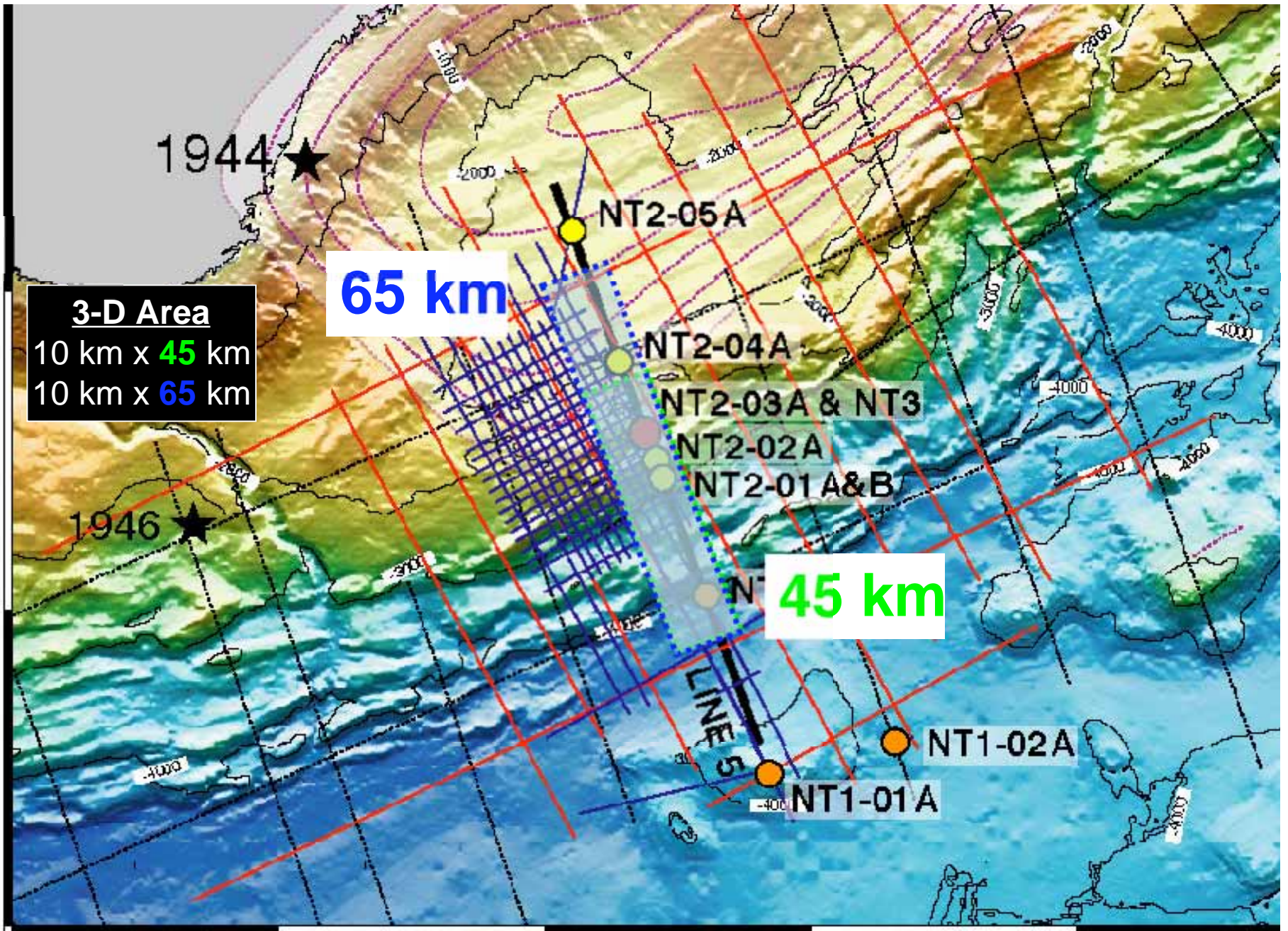
4) Integrate to results from structural /physical /material / and analytical researches

The deep-sea drilling vessel CHIKYU



Length Overall: 210m
Gross Tonnage: 57500ton
Max. Complement: 150persons

Operation Capability for Water Depth:
Riser Drilling 4000m (2500m at 1st Stage)
Riser less Drilling 7000m
Maximum Drill String Length:
12000m (10000m at 1st stage)



3-D Area
10 km x 45 km
10 km x 65 km

65 km

45 km

136°

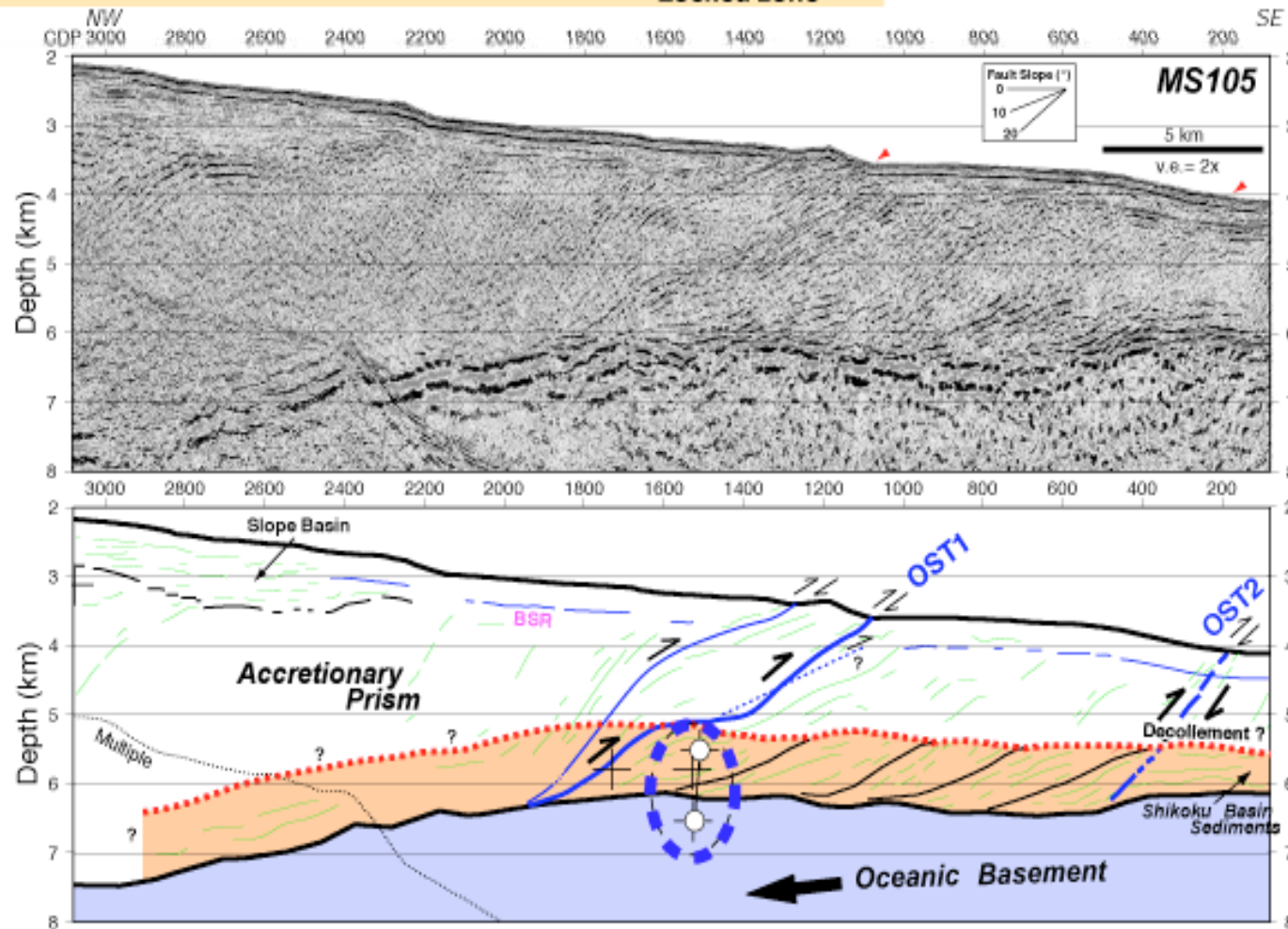
137°

Roof Thrust and Identical Waveform Earthquake

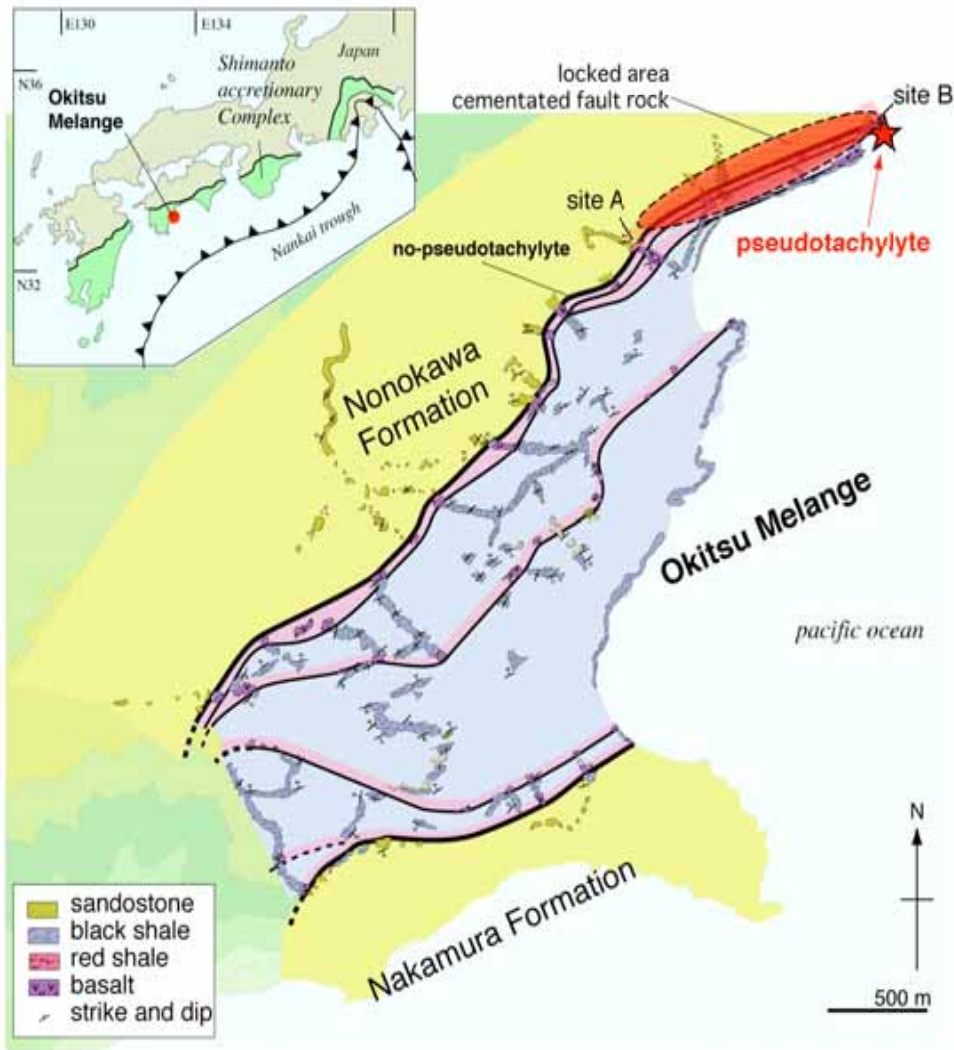
1946 coseismic rupture area

150° C

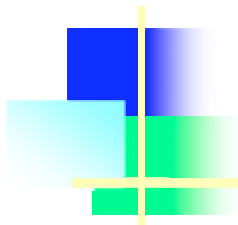
Locked zone



Seismogenic fault along the roof thrust

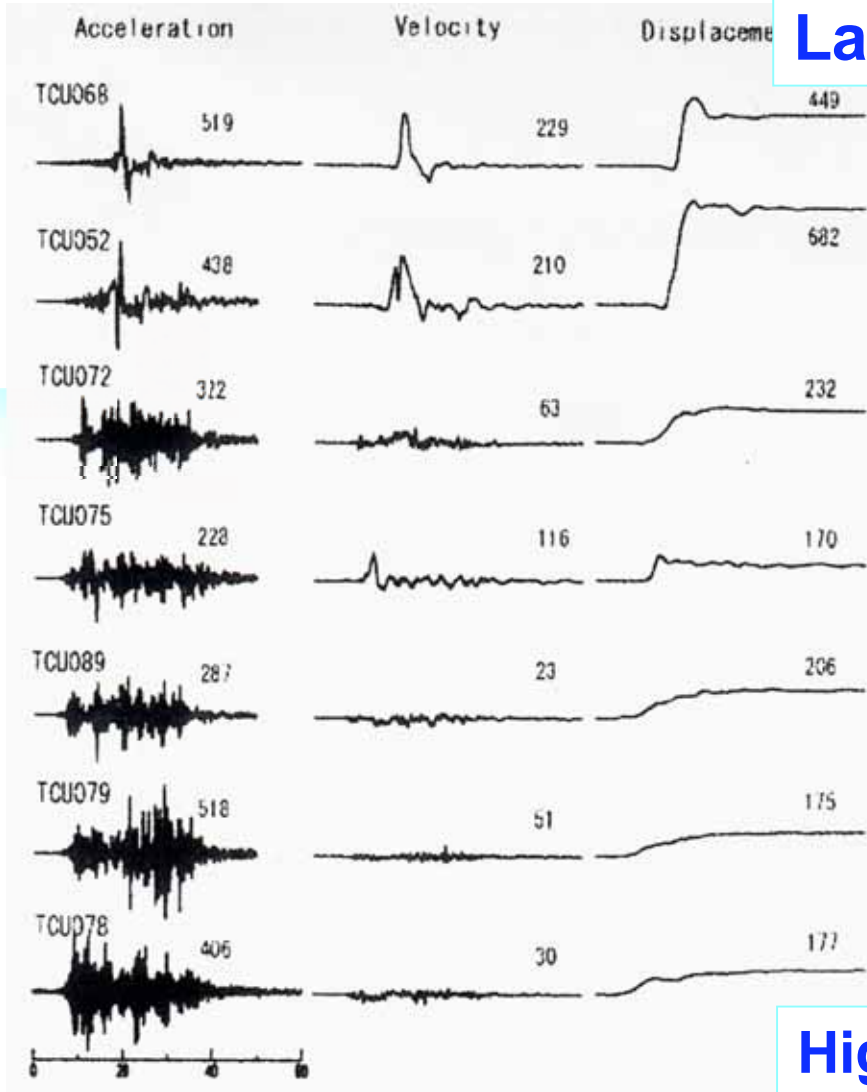


Reproduction of fault slip in northern part Chi-Chi earthquake in 1999



Chi-Chi earthquake in 1999

North

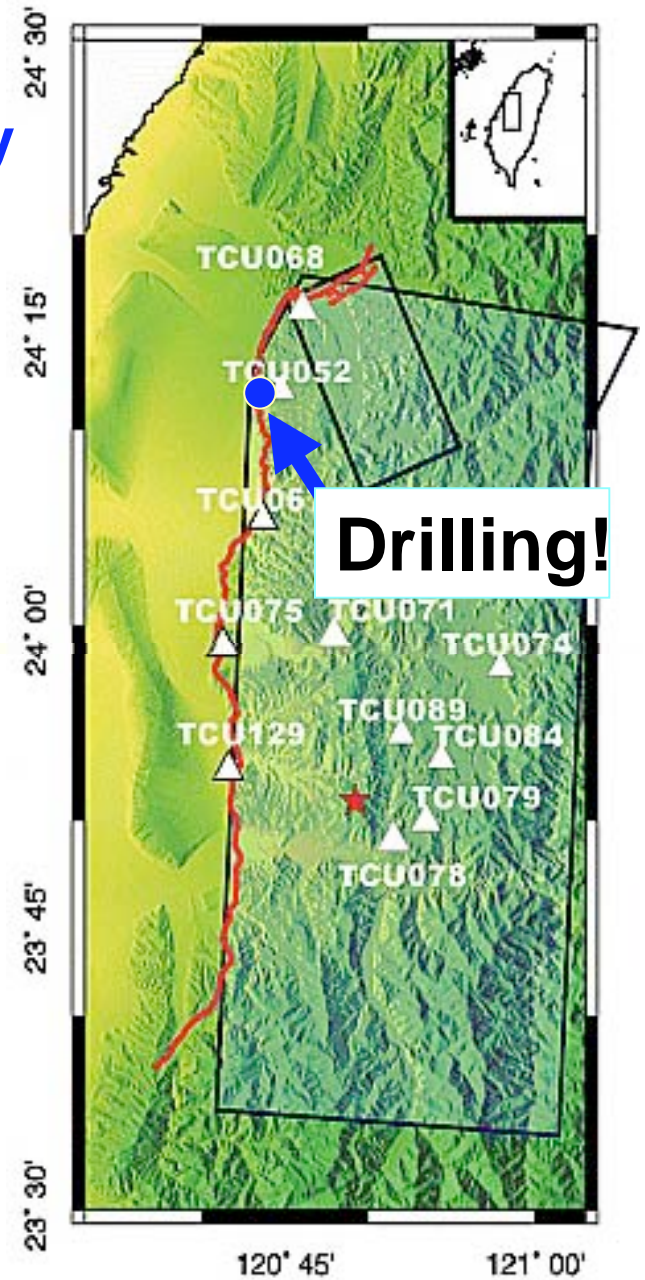


Low frequency
Large slip



High frequency
Small slip

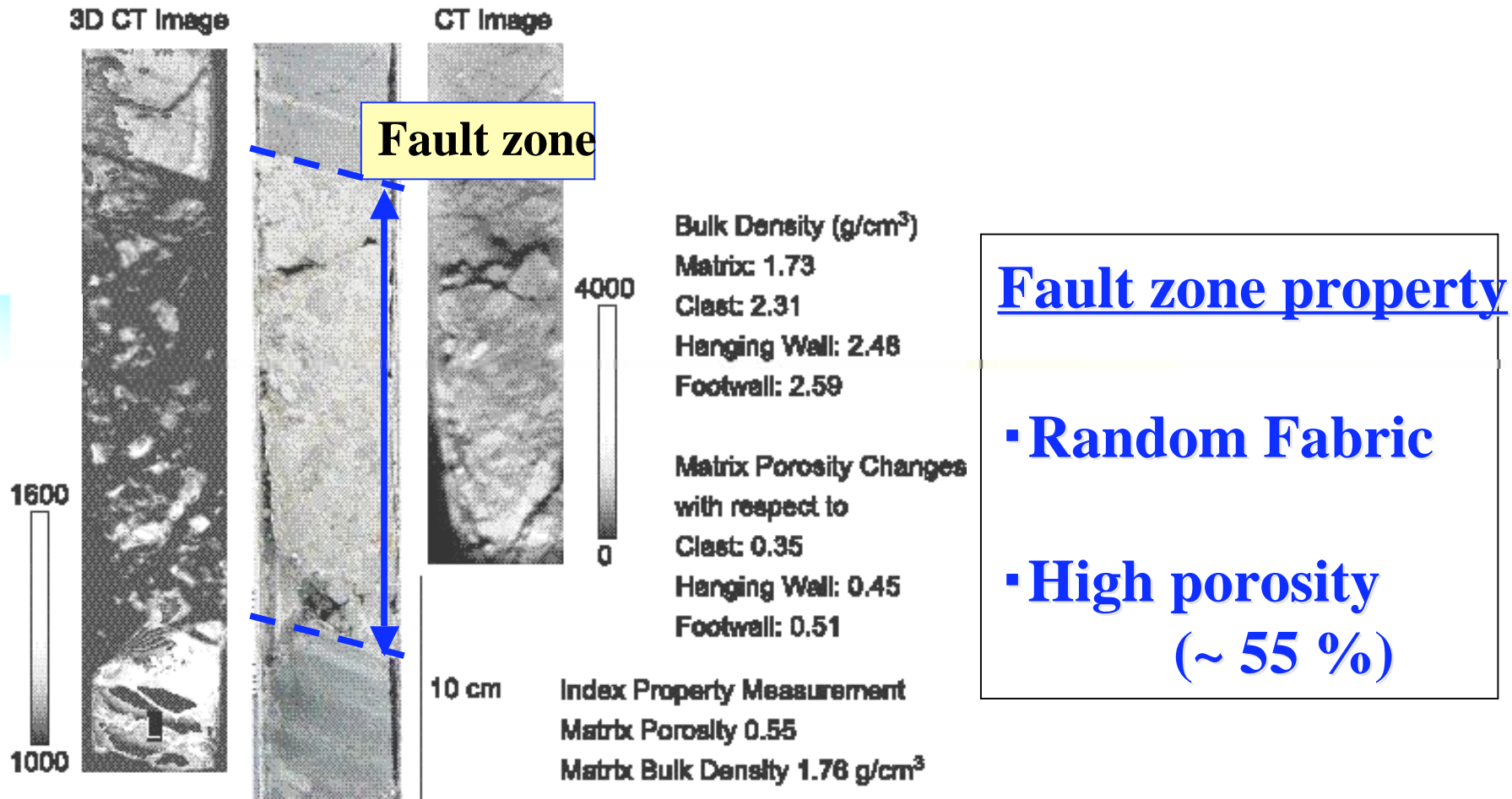
South



Ma et al (2002)

Core collected at fault zone of Chi-Chi earthquake

Fault Zone at 224.55-224.75 m (Vertical Depth: 172.02-172.17 m)





Observed & Core data

Fault slip properties in northern part

① The ground motion is dominated by large low frequency displacements with relatively small high-frequency accelerations.

② Fault zone

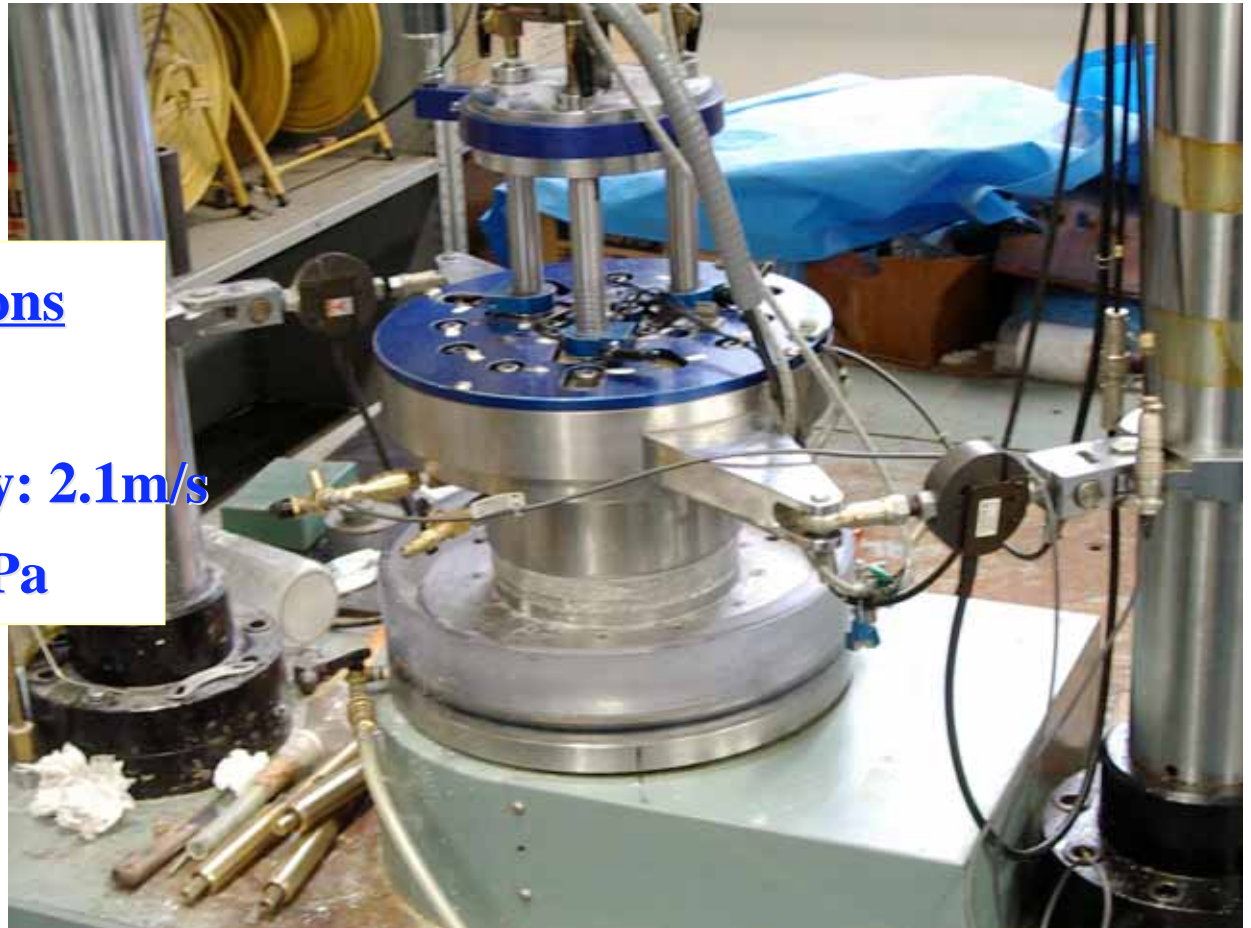
- Random fabric (20cm-width) without discrete slip surfaces
- High porosity (~ 55 %)

[Why were such anomalous properties observed?](#)

Experiments : Reproduction of fault slip in northern part

Environmental conditions

- Pore water pressure
- Maximum slip velocity: 2.1m/s
- Normal stress: 0.5 MPa

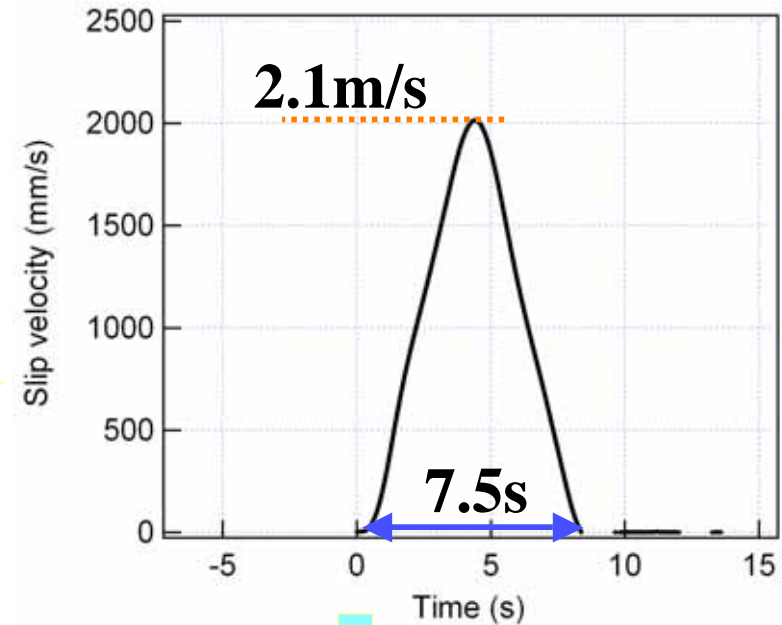
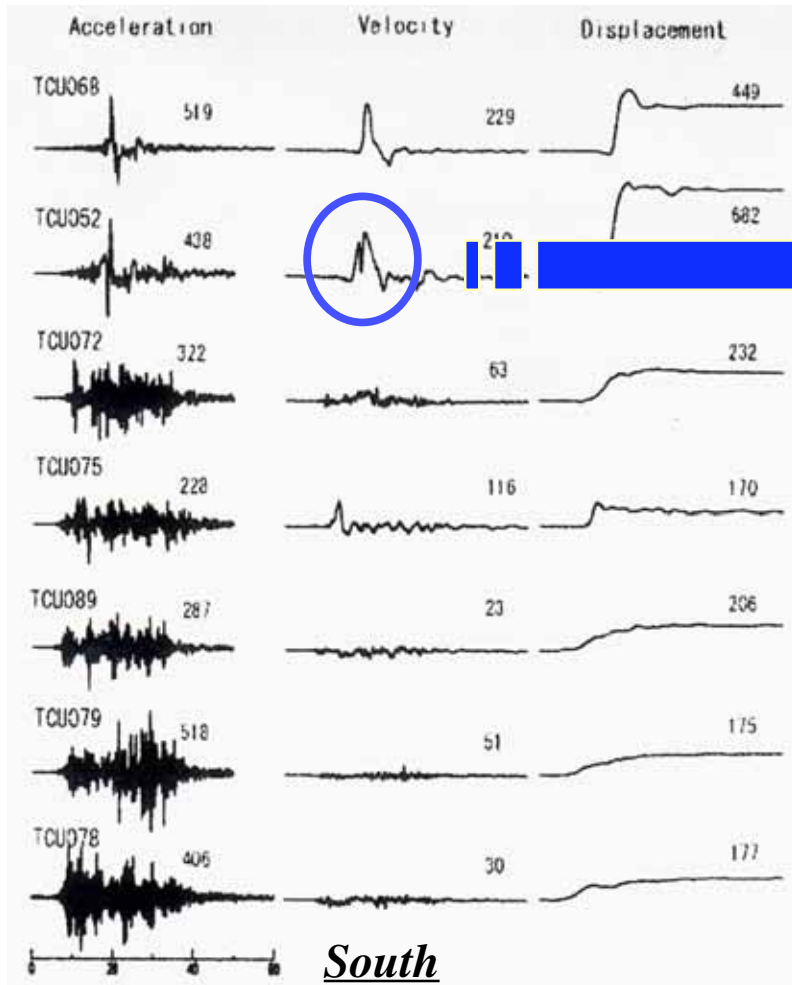


Ring shear apparatus

Disaster Prevention Research Institute, Kyoto University
—Landslide Section

Reproduction of fault slip

North



Input signal for experiment

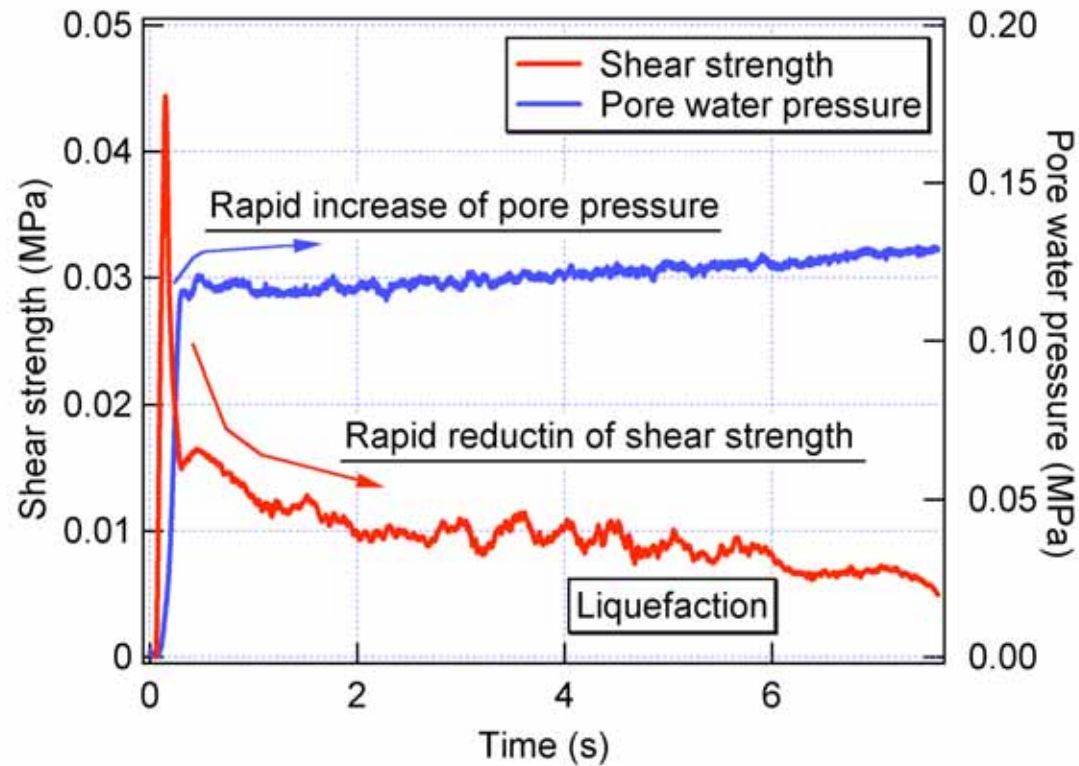
We know ...

**Response of shear strength
and pore pressure !**

Sample: Toyoura sand (similar to sand of the fault zone)

σ_n : 0.15 MPa (Undrain)

Experimental Results (Loose sample: Porosity 47 %)



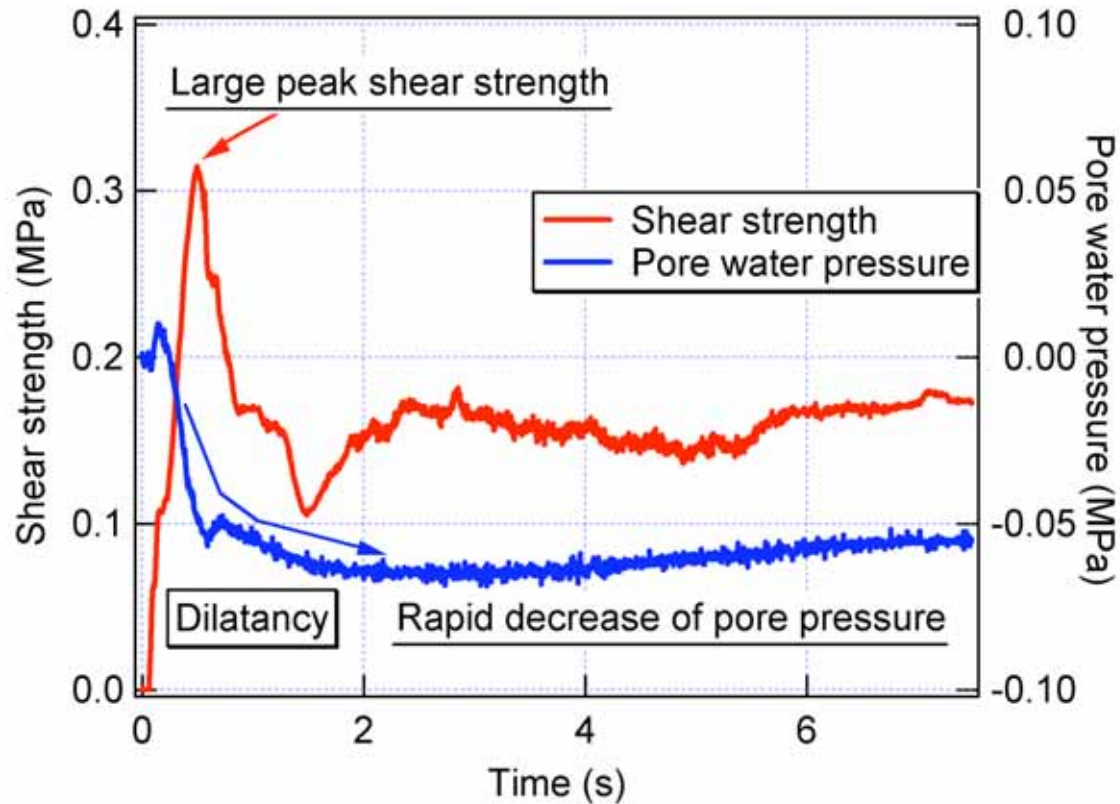
*Rapid reduction of shear strength
and increase of pore pressure*



•Lubrication of fault slip !

•Enhancement of shear rupture propagation !

Experimental Results (Dense sample: Porosity 40 %)

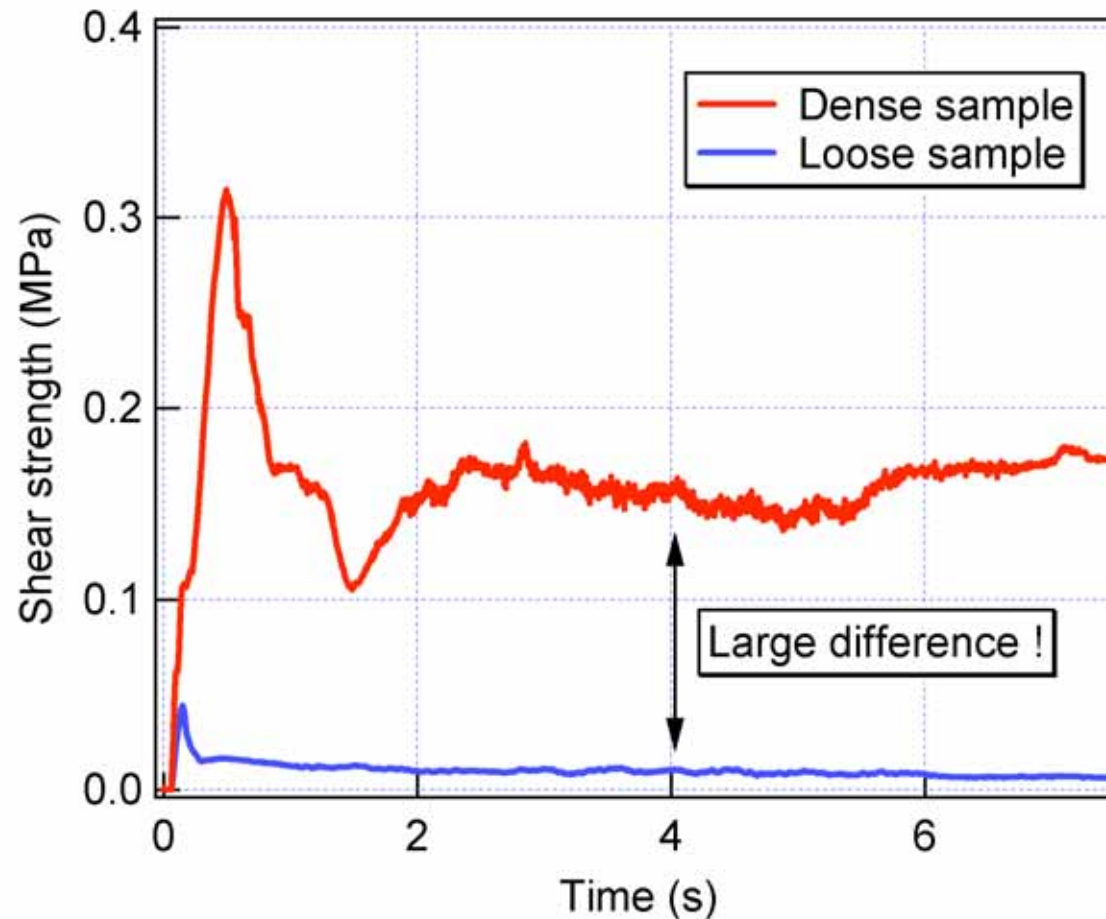


Large increase of shear strength
and reduction of pore pressure



•Suppression of shear rupture propagation

Comparison between loose and dense samples



Initial condition significantly affects the shear strength.

Mechanism of reduction in shear strength

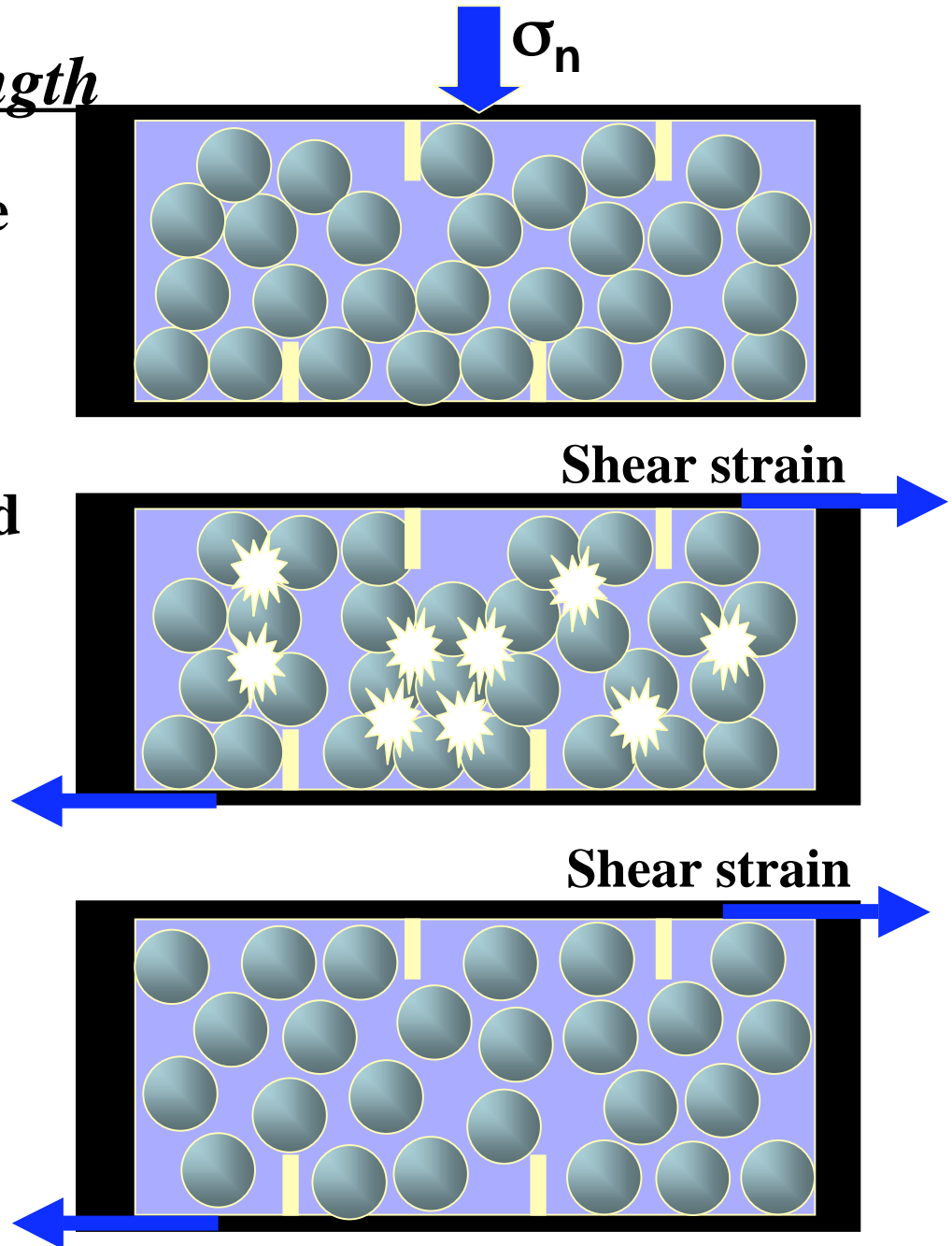
Apply the shear strain to the
Loose sample.



Each grain is compacted, and
the pressure of pore water
between grains increases.



Due to the rapid increase in
pore pressure, grains are
separated, which leads to the
reduction of friction between
grains and whole shear
strength decreases.



Mechanism of
increase in shear strength

Apply the shear strain to the
Dense sample.



Each grain is squeezed, and
will override other grains.



Dilatancy occurs, and pore
pressure decrease which
leads to the increase of whole
shear strength.

