Drilling the deepest offshore well in the world: what we learned from the Nankai trough seismogenic zone

Lionel Esteban – CSIRO-ESRE and the IODP science party 338 & 348
Outline

• Fundamental, internationally-coordinated basic research is necessary to improve knowledge and reliable input for future seismic hazard (and eventually risk) assessment; because earthquakes/tsunamis cannot (yet?) be precisely forecast as weather conditions forecast would do.

• Nankai represents one of the most studied areas in the world because:
  (i) strongest earthquakes in the world;
  (ii) megathrust and megasplay not “too deep”;
  (iii) extended width of the seismogenic area ruptures; and
  (iv) 1300 years historical record of tsunamigenic earthquakes.

  ▪ Nankai Trough: why, where, what, how?

  ▪ Low velocity zones (LVZ): seismic vs aseismic

  ▪ Fractures and faults detection: LWD, cores, vitrinite and locations

  ▪ Cuttings: Lithology, units, deformations, porosity, dielectrics and resistivity
Why Nankai trough?

Earthquakes map in the world

M ≥ 8
Why Nankai trough?

Earthquakes map in the world

$M \geq 8$
Why Nankai trough?

4.5 cm/yr

[Map showing the Nankai Trough and surrounding geological features]
Why Nankai trough?

Comparison of Sumatra and Japan
Why Nankai trough?
NanTroSEIZE project

A multi-stage effort to sample and instrument the plate boundary fault zone across the up-dip end of locking and rupture.
IODP Expeditions

Riser drilling @ C0002, 0-856-2000-3500 mbsf
Continuous cuttings recovery and mud gas analysis; and casing.
RCB Coring in various intervals
Extensive Logging While Drilling analyses (LWD)

Objectives:
Inner Wedge Package
*Structure, Lithology, Fluid composition, Deformation History, Pressure and Stress*
Assess transition from aseismic prism to seismogenic plate boundary
Establish framework for deeper drilling
NanTroSEIZE project

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Fujii-san

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RISER system

Upper section for 860 - 2300 mbsf
(12.25" x 20" section)

Under reamer to 20 inch
Stabilizer (16.375")
Some velocity (inner/VISION 8.20")
Direction, Inclination, Downhole weight on bit & torque (MWTD TeleScope 8.20")
Annular pressure & temperature (pet/VISION 8.25")
Radiodensity & image, natural gamma ray (pet/VISION 8.25")
Radiodensity At-Bit (12.25" bit)
RISER system
View of Nankai trough from seismic data

- **Megathrust Zone**: Fully-coupled, Increasing coupling, Decoupled
- **Slip Partitioning Zone**: 
  - Splay fault branching (200°C at ~55 km)
  - Décollement stepdown (150°C at ~30 km)
- **Aseismic Zone**: 
  - Décollement
  - Nankai Trough

**Eurasian Plate**: 
- Forearc basin
- Outer ridge
- Philippine Sea Plate

**Extensional**

**Strike-slip & Compressional, time-varying?**

- **Inner prism**: locked plate interface, seismogenic zone
- **Outer prism**: quasi-aseismic zone

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*Park et al., Science, 2002*

*Moore et al., 2009*
Low seismic velocity zones (LVZ) in Nankai trough

(Kinoshita et al, 2008)

Moore et al., 2009; Park et al., 2010
Low seismic velocity zones (LVZ) in Nankai trough

During subduction earthquakes, which way does the rupture follow?

Megathrust (plate interface) up to the sea floor or short cut along splay faults?

Deep LVZ (Kamei et al., 2012)
- ~10 km bsf
- Below megasplay fault

Shallow LVZ (Park et al., 2010)
- 2-4 km bsf
- >~120 km along strike
- Above décollement
Fractures and faults detection
# Fractures and faults detection

### Fracture and fault analysis for stresses

### Resistivity analysis for potential flow pathways

<table>
<thead>
<tr>
<th>Depth (mbsf)</th>
<th>Shallow button resistivity</th>
<th>Fractures</th>
<th>Fracture frequency (per 10 m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Conducive</td>
<td>Resistive</td>
<td>Undefined</td>
</tr>
</tbody>
</table>

**Image Logs**
Fractures and faults detection

Shear zone: Normal fault in its present-day position

Core 5R-4/58-92cm (2205.22 mbsf-2205.56 mbsf)
Vitrinite reflectance measurements suggest localized and rapid temperature elevation $\rightarrow$ rapid slip?

Sakaguchi et al. 2011, geology
Vitrinite reflectance measurements suggest localized and rapid temperature elevation → rapid slip?

Sakaguchi et al. 2011, geology
Vitrinite reflectance measurements suggest localized and rapid temperature elevation → rapid slip?

Sakaguchi et al. 2011, geology

In site C0002F, detected faults at 1590.5 mbsf and 1790.5 mbsf record R0 < 0.30, near detection limit => < 40°C. NO evidence of rapid slip (i.e. HT)
Major/minor element analysis suggest enhanced smectite-illite transformation for C0004 shear zone → localized temperature elevation → rapid slip?

after Yamaguchi et al., 2011
What about in site C0002

Sedimentology, Deformation and Mineralogy – identify the boundary

[Diagram showing depth and mineral composition with layers labeled III and IV.]

First occurrence of Unit IV lithology

Possible interval of mixing of discrete fragments of materials from Units III and IV.
What can we learn from cuttings

Drilling induced cohesive aggregates

Pillow cuttings

Intact cuttings

Deformed and scaly fabric

Moisture and Density (MAD) measurements

- Bulk cuttings (1-4 mm)
- Bulk cuttings (> 4mm)
- Handpicked intact cuttings (> 4mm)
What can we learn from cuttings

**Cuttings** – extensive lithologic description through Unit IV and into V

<table>
<thead>
<tr>
<th>Cuttings lithology</th>
<th>X-ray diffraction</th>
<th>Structural geology</th>
<th>Physical properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silty claystone vs. sand/sandstone</td>
<td>Total clay minerals (wt%)</td>
<td>Deformed grains &gt;4 mm (%)</td>
<td>Bulk density (g/cm³)</td>
</tr>
<tr>
<td>Lith. unit</td>
<td>Calcite (wt%)</td>
<td>1-4 mm (%)</td>
<td>Deformed grains 1-4 mm (%)</td>
</tr>
</tbody>
</table>

- **Coarser mean grain size** (~ 1 mm)
- **Deeper parts more deformed**;
  apparition of scaly fabric > 2320 mbsf
What can we learn from cuttings

Site C0002
What can we learn from cuttings

Cuttings – NGR analyses indicate mixing zone of cuttings up to 100m

Underreamer = 20”
(cutting 42.8m above bit)

Bit = 12.25”
(recorded depth)

Yunsun, 2014
What can we learn from cuttings

The Problem: Porosities from cuttings are too high

- Soaking (+ time) in seawater: not helpful
- Drying: Good
- Cuttings size: better when > 4 mm size
What can we learn from cuttings

DIELECTRICS
Ability to load/discharge charges=> polarizability
Also called: electric permittivity
What can we learn from cuttings

![Graph showing correlation between electrical resistivity and pore fluid salinity]

- Cuttings - C0002F
- Electrical resistivity (ohm.m) at 300 MHz
- Pore fluid salinity (g/L)
- Symbols: 
  - Marl
  - Shaly-Sand
  - Schlattingen carbonates
  - Schlattingen marl
  - Schlattingen shales

Equations:
- \( y = -0.076x + 2.8 \)
- \( y = -0.079x + 2.2 \)
What can we learn from cuttings

Clay - water change intervals
Dielectric constant at 3 MHz

Sand layers picking
Electrical resistivity at 10 MHz (ohm.m)

Gamma-ray Resistivity Sonic - Vp900

CUTTINGS

LWD LOGS

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Summary

Nankai Trough is an excellent place to work on megathrust and megasplay fault mechanisms. Over the last 6-7 years, since NanTroSEIZE project started (OPD and IODP), several aspects of this seismogenic zone have been discovered:

- System works as lock and rupture
- 2 LVZ: (1) shallow at 2-4 km deep (above decollement); (2) deep at 10 km below megasplay fault. This deep LVZ is marked by an extensional system area and very seismic while the shallow LVZ is the opposite.
- Several faults ± permeable have been detected from LWD resistivity images and confirmed from cores.
- The vitrinite detects fast slip (HT) at the tip of the thrust fault which is not visible in the site C0002 fault systems.
- Cuttings became a very useful material for: lithology, unit boundaries, deformations, porosity, resistivity and dielectrics despite the mixing intervals. The cuttings depth recovery and mixing intervals seem to be detected from dielectrics results with the help of LWD resistivity and sonic.
Questions?