Geologic Context of the Biggest Earthquakes

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• Sediment Influx and Biggest Earthquakes
• Consequent Accretionary Prisms
• Thermal Structure of Kumano Prism, Japan
• Probable Deformation Mechanisms
• Role of Solution Creep in Traditional Locked Zone
• Silica Mobility Hypothesis
• Quartz in Faults
• Porosity, Rigidity and Development of the Hanging Wall
• Anisotropy of Rock Strength
• Large Area of Seismogenic Zone
Biggest Earthquakes and Sediment Influx

Nankai Trough Earthquakes

Ruff 1989

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Underthrusting of Thick Sediment Blanket

(After Lay, Schwartz, Bilek…..)
1944 M 8.1 Earthquake

Baba and Cummins (GRL 2005)
Crustal Transect

(Kikuchi et al., 2003)

Site C0011
Site C0012

VLF Earthquakes (Obara and Ito, 2005)
Where is the Fault Slip?

1944 M 7.9-8.1 (e.g. Kukuchi et al., 2003; Baba and Cummins, 2005)

VLF Earthquakes & Tremor (Obara and Ito, 2005; Ito et al, 2006, 2009; Obana & Kodiara, 2009)

1944 M 7.9-8.1 (e.g. Kukuchi et al., 2003; Baba and Cummins, 2005)

ETS (e.g. Obara, 2002)

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Large Sediment Influx Grows Prisms

G.Moore et al. (2009)

Park et al. (2010)

Splay Faults

Offscraping

Deep Underthrusting

Underplating

Park et. al. (2010)
Materials at Depth

- Upper Tertiary Prism
- Quaternary Prism

Diagram showing geological features and processes at depth, including Cretaceous-lower Tertiary Accretionary Prism, Seismogenic Rock Production, and particulate flow and cataclasis. The diagram also highlights solution creep, 1944 rupture, and various mineral zones such as the seismogenic zone, lawsonite-chlorite, pumpellyite-actinolite, and amphibolite.
Materials at Depth

Cretaceous- lower Tertiary Accretionary Prism

Upper Tertiary Prism

Quaternary Prism

Seismogenic Zone

Pressure (GPa)

Temperature (°C)

Seismogenic Rock Production

Solution Creep

Particulate Flow and Cataclasism

ETS

1944 Rupture
Materials at Depth

P-T-time path of subduction, accretion and uplift

Upper Tertiary Prism

Quaternary Prism

Cretaceous-lower Tertiary Accretionary Prism

Particulate Flow and Cataclasism

Solution Creep

Seismogeic Creep

ETS

Crystal Plasticity

Seismogenic Zone

Temperature (°C)

Pressure (GPa)
Temperatures for Décollement form Spinelli and Harris (G3 Submitted)

Limits of Solution Creep (aka Pressure Solution) as Dominant Ductile Deformation Mechanism from Field Examples

Interval of Solution Creep Lies in 1944 Slip Zone
Does Solution Creep Affect the Seismogenic Behavior of Rocks?

1) Examples of Solution Creep
2) Quartz in Fault Zones
3) Increasing Shear Modulus

Progressively Veined Fault Zone from the Kodiak Accretionary Complex, SW Alaska
Rocks from the paleoseismogenic zone

Line of cross section

1964 Rupture

Kodiak Accretionary Complex, SW Alaska

100 km

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Kodiak Islands, Alaska

Modern Decollements

Probable Subduction Thrusts at Depth: 1) Similar in thickness to surface decollements, 2) finer grained material cross cutting mélange fabric
Cataclasite
Mélange
Solution Creep (Pressure Solution)
Dissolution of Mineral Phases, esp. Quartz: ~ 250°C, 13 km SW Alaska

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Solution along Foliation

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1) Estimates of solution creep rates would accommodate plate convergence in observed thickness of cataclasite shear zones. **Not true because big earthquakes occur.**

2) If seismogenic zone is completely locked rocks would never become foliated during interseismic interval.
Fluid Migration Up Splay Fault:

Shear Zones in Footwall with Abundant Quartz Veins (Rowe et al., 2009)
Velocity Weakening of Quartz and other Framework Silicates (Granite)

Seismogenic Zone

After Blanpied, Lockner, & Byerlee, 1995
Quartz Precipitation in linked Extensional and Shear Veins Chrystalls Beach Accretionary Complex, New Zealand (Fagereng, Remitti, and Sibson, 2010)
Cataclasite

Mélange

Frictional Melt (Pseudotachylyte)

Cataclasite

solution fabric
Cataclasite

Mélange

Frictional Melt (Pseudotachylyte)

Frictional Melt = High Velocity Slip

But, absence of major quartz shear veins along failure surface

Some other aspect of rock also fosters stick-slip
“Solution creep” cements and rigidifies the sandstones and shales of the accretionary prism to produce a stiff rock that can accumulate elastic strain.
Crustal Transect

(Kikuchi et al., 2003)

Site C0011
Site C0012

VLF Earthquakes
(Obara and Ito, 2005)
Increasing Velocity of Upper Plate Indicates Increasing Rigidity and Density

NGANISHI ET AL.: STRUCTURE OF NANKAI TROUGH SPLAY FAULT

(a)

Depth (km)

NW Site40 Outer ridge Deformation front SE

(b)

Depth (km)

Backstop interface Splay fault

Young Accreted Sediments

Old Accreted Sediments Subducting Oceanic crust

Uppermost mantle

Sub-Moho Reflectors

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Increasing Velocity of Upper Plate Indicates Increasing Rigidity and Density

(JGR, 2008)
Rigidity and Stress Drop Rise Dramatically with Prism Consolidation and Cementation

Porosity = 2-5%
Density ~ 2.7 Mg/m³
P-Wave Velocity ~ 5.5 km/sec
Stress Drop = 2100 kPa
Estimated Rigidity ~ 30 GPa

Porosity ~ 30%
Density ~ 2.2 Mg/m³
P-Wave Velocity ~ 3 km/sec
Stress Drop < 10 kPa
Estimated Rigidity 1.6-6.4 GPa

(Sources: Ito and Obara, 2006; Expedition 319 Scientists, 2010; Brodsky et al., 2009; Kikuchi et al., 2003)
Progressive Shear Through Solution Creep and Higher Velocity Slip Progressively Rotates Planar Fabric Parallel to Subduction Thrust
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Progressive Shear Through Solution Creep and Higher Velocity Slip Progressively Rotates Planar Fabric Parallel to Subduction Thrust

Through-going Planes of Weakness Encourage Slip Propagation
Low Dip of Subduction Thrust Increases Area in Seismogenic Zone Therefore Increases Potential Size of Earthquakes

crustal strike-slip fault e.g. San Andreas
Very Shallow Subduction Thrust in SW Alaska: Large Sediment Supply, Broadens the Prism
Summary

- Limits of solution creep matches much of the rupture zone of large thrust earthquakes
- Deposition of quartz in faults can foster velocity-weakening slip
- Consolidation and cementation by solution creep substantially increases the rigidity of upper plate and creates a volume of rock prone to stick-slip failure
- Planar fabrics due to creep and high velocity shear along the plate boundary form an anisotropy favoring slip propagation
- Accretionary prism growth lengthens the potential seismogenic zone of subduction thrusts, leading to large earthquakes.