Earthscope Institute on the spectrum of fault slip behaviors

The mystery of fault tremor; where, when, how, and why?

They say there's nothing new under the sun. But under the ground...

TREMORS
Range of talks

- Review
- Seismic and geodetic observations
- Lab and geological observations
- Theory and models
- The path ahead
Locked, slipping, and bizarre

Numerous subduction zones and other faults

Figure from Steve Malone
Several reasons for public to care

- Are locations of intra- and inter-plate quakes illuminated by tremor geometry?
- Crustal earthquakes distribution?
- Does tremor pattern change before megaquakes?

*Megaquake closer to Seattle?*

Early studies suggested the Cascadia Subduction Zone would rupture no closer to Seattle than line “A.” But new research suggests the rupture could extend to line “B,” which would mean more shaking and destruction in urban areas.

More information: [www.ponga.org](http://www.ponga.org)

Source: Tim Melbourne, Central Washington University

Reporting by SANDI DOUGHTON
Graphic by MARK NOWLIN
/THE SEATTLE TIMES

Nov. 17, 2009 in Seattle Times

Abers et al., Geology, 2009
Related to big earthquakes?

Abers et al, 2009

Tremor locations
Tremor and slow slip coincide in space

Wech et al., 2009

Hirose & Obara, JGR, 2010
Two kinds of quakes

old
$M \sim \text{duration}^{\text{cubed}}$

new
$M \sim \text{duration}$

Ide et al., Nature, 2007
High water -> More tremor

more stress -> more tremor
also seen for Japan, Vancouver Is

Rubinstein et al., 2007
Maps showing where tremor and slow-slip events have been observed (Peng and Gomberg, NGEO, 2010)
Episodic Tremor and Slip schematic

Dragert et al., 2004
Long-dip-direction ETS in Japan, soon to be published in Science
Tremor triggering earthquakes
Multiple segments with regular recurrence intervals

Brudzinski & Allen, 2007

Color is ETS recurrence interval
Locally Amplified Shear Strain Rates in Mélange Shear Zones Inducing Distributed Brittle Failure

- after Fagereng & Sibson, 2010: Geology 38, 751-754

- length scale imposed by phacoid dimensions
Easier to find ETS

Survival depth of basaltic oceanic crust (blue) and depth range of intraslab earthquakes (purple)

Model-predicted peak dehydration depth (blue) and serpentine stability in subducting slab (purple)

Wada and Wang, 2009
Smaller events between major ETS episodes between two Cascadia ETS events, projected along strike

Wech et al., in press, GRL
Tremor more irregular than previously mapped?

Beam-located tremor

Cross-correlation tremor

Ghosh et al., 2009
RTR’s - Rapid Tremor Reversals

Houston, Delbridge, et al., in review
Characteristic migrations

Obara, JGR, 2010
A hierarchy of tremor migration patterns and their relation to slow slip

- Long term migration driven by slow slip front
- Rapid tremor reversals back into the slow slip pulse
- Streaks along the leading edge of the slow slip front

**Tremor migration speed**
- 10 km/day
- 100 km/day
- 1000 km/day

**Slow slip rate**
- 1 cm/yr
- 100 cm/yr

⇒ Tremor migration speed correlates with slow slip rate

Pablo Ampuero -- Tectonic tremor
LFE vs tremor

Obara, JGR, 2010
All LFEs

short vs long LFEs

Duration

Sensitivity to tides

Ide, Nature, 2010
Tremor stripes vs geology

Ide, Nature, 2010
Tremor fills Cascadia

Courtesy Mike Brudzinski
Along Strike Migration and Segmentation

Kao et al., 2007

✴ Steady movement, halting, jumping

✴ 2008 event occurred over nearly the entire margin

Brudzinski, pers. comm.
Parkfield Tremor Locations

- 88 stacked LFE templates
- Located by P and S arrivals on stacked waveforms, using a 3D velocity model.
- Sources extend 75 km both NE and SW of Parkfield

*Shelly and Hardebeck, GRL, 2010*
Amplitude potential

- Characterize source amplitude as peak ground velocity of 20th largest event during 2001-2010.
- Avoids bias from large amplitude outliers (EQs/noise) and large number of small amplitude events.

*Shelly and Hardebeck, 2010*
Shallower sources have larger, less frequent bursts

Shelly, in prep.
Parkfield precursors?

Families 1 and 4

San Simeon

Parkfield

HRSN Network Changes

Migration from the north

Migration from the south

Shelly, GRL, 2009
Activity migration
- Along strike ~10 km/day,
- Reversing pulses ~100 km/day
- Down-dip 10s of km/hr,
- Flickering by the second,
- Repeating patches, and
- Perhaps jumping 100s of kms.

Progress will come from further observations
- ETS relation to earthquakes,
- ETS relation to geology, and
- ETS fine-scale spatiotemporal evolution.

Imagination fails me here.