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

mostly review

Earthscape Institute on the spectrum of fault slip behaviors
The mystery of fault tremor; where, when, how, and why?

mostly review
Empirical talk

- Tremor
  - Tectonic setting
  - Appearance
  - Sensitivity to weak stresses
  - Regularity and irregularity
  - Magnitude-frequency
  - Migration
  - more ...

- Bold Speculation will follow later
Locked, slipping, and bizarre

Figure from Steve Malone
Locked, slipping, and bizarre

Figure from Steve Malone
Locked, slipping, and bizarre

Numerous subduction zones and other faults

Figure from Steve Malone
Global studies generally find tremor occurring at the plate interface

Autocorrelation location of low-frequency quakes that comprise tremor

Brown et al., 2008
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Autocorrelation location of low-frequency quakes that comprise tremor.

Brown et al., 2008
Episodic Tremor and Slip schematic

Dragert et al., 2004
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Dragert et al., 2004
Episodic Tremor and Slip schematic

Dragert et al., 2004
central Japan cross-section

Locked

ETS region

Stable Slip

Hirose et al., 2008, Shelly et al., 2006, Audet, 2009, Abers et al., 2009

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Periodic (14.5 mo) Cascadia recurrence

Rogers and Dragert, 2003
Multiple segments with regular recurrence intervals

Brudzinski & Allen, 2007

Color is ETS recurrence interval
Tremor vs earthquake

Gomberg et al., GSA Bull., 2009
Tremor vs LFE vs earthquake

Gomberg et al., GSA Bull., 2009
Two kinds of quakes

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

new
$M \sim \text{duration}$

Ide et al., Nature, 2007
Two kinds of quakes

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

*new* $M \sim \text{duration}$

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

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

Rubinstein et al., 2007
Tremor is modulated by surface wave stresses

Rubinstein et al., 2007
Tremor is modulated by surface wave stresses

Rubinstein et al., 2007
Widespread tremor from 2002 Denali

7 spots along SAF

Gomberg et al., 2008
Smaller events between major ETS episodes between two Cascadia ETS events, projected along strike

Wech et al., in press, GRL
Gutenberg-Richter Power-Law Distribution of Tremor Swarms

(assuming moment is proportional to duration)

Wech et al., in press, GRL
Tremor and slow slip coincide in space

Wech et al., 2009

Hirose & Obara, JGR, 2010
Tremor and slow slip coincide in time

Maeda & Obara, 2009
Every 14 months we check figure * BS Array

Wech figure
2008 dense-array pilot study

Time (days)

1 km
2008 dense-array pilot study

84 sensors in a km$^2$, 

Time (days)
2008 dense-array pilot study

84 sensors in a km²,
Caught 8 days with light tremor in March,
2008 dense-array pilot study

84 sensors in a km$^2$
Caught 8 days with light tremor in March, then 17 days of heavy tremor passing directly underneath in May

Time (days)
2008 dense-array pilot study

84 sensors in a km$^2$, Caught 8 days with light tremor in March, then 17 days of heavy tremor passing directly underneath in May
Tremor source spectra not so simple

Zhang, Gerstoft, Shearer, Yao, Vidale, Houston, Ghosh, *in prep*
Tremor source spectra not so simple

Zhang, Gerstoft, Shearer, Yao, Vidale, Houston, Ghosh, *in prep*
Tremor source spectra not so simple

No ultraviolet catastrophe, but what’s going on?

Zhang, Gerstoft, Shearer, Yao, Vidale, Houston, Ghosh, *in prep*

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Tremor more irregular than previously mapped?

Beam-located tremor

Cross-correlation tremor

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Ghosh et al., 2009
Notable tremor streaks

Ghosh et al., G3, in revision

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RTR’s - Rapid Tremor Reversals

Houston, Delbridge, et al., in review
Array of Arrays UW EarthScope Project

- 8 arrays
  - 10+ 3-comp SPs
  - 10 SP verticals
- Summer 2009
  - (missed it)
- Summer 2010
  - (got it)
- maybe more.
Array of Arrays UW EarthScope Project

Olympic National Park

- Arrays
- FBO Boreholes
- Existing stations

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Tremor and locked zone
Characteristic migrations

Obara, JGR, 2010
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
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
Along Strike Migration and Segmentation

- Steady movement, halting, jumping

- 2008 event occurred over nearly the entire margin

Kao et al., 2007

Brudzinski, pers. comm.

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Parkfield precursors?

Shelly, GRL, 2009
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?

Abers et al., Geology, 2009
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?

Nov. 17, 2009 in Seattle Times

Abers et al., Geology, 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.