

ERTH 455 / GEOP 555

Geodetic Methods

– Lecture 23 (finish): Modeling - Plate Kinematics

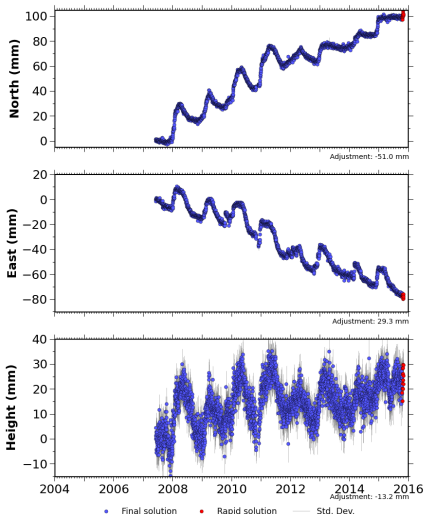
Ronni Grapenthin
rg@nmt.edu
MSEC 356
x5924

November 13, 2017

Guess The Process

P299 (Duckworth_CN2007) NAM08

Processed Daily Position Time Series

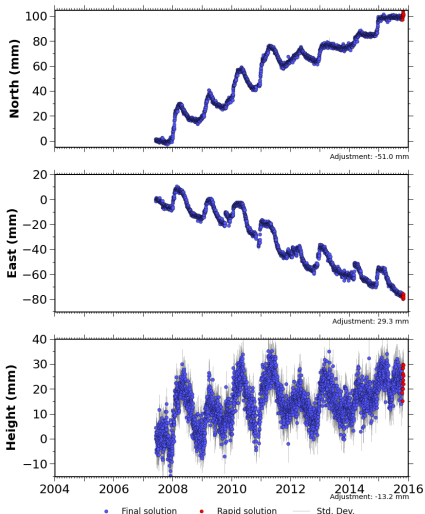


Source file: P299.gbo.nam08.pos Last epoch plotted: 2015-11-02 12:00:00

Guess The Process

P299 (Duckworth_CN2007) NAM08

Processed Daily Position Time Series



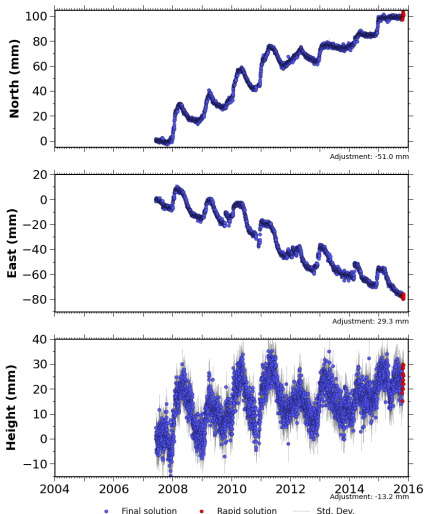
Source file: P299.gbo.nam08.pos Last epoch plotted: 2015-11-02 12:00:00



Guess The Process

P299 (Duckworth_CN2007) NAM08

Processed Daily Position Time Series



Source file: P299.gbo.nam08.pos Last epoch plotted: 2015-11-02 12:00:00



Guess The Process

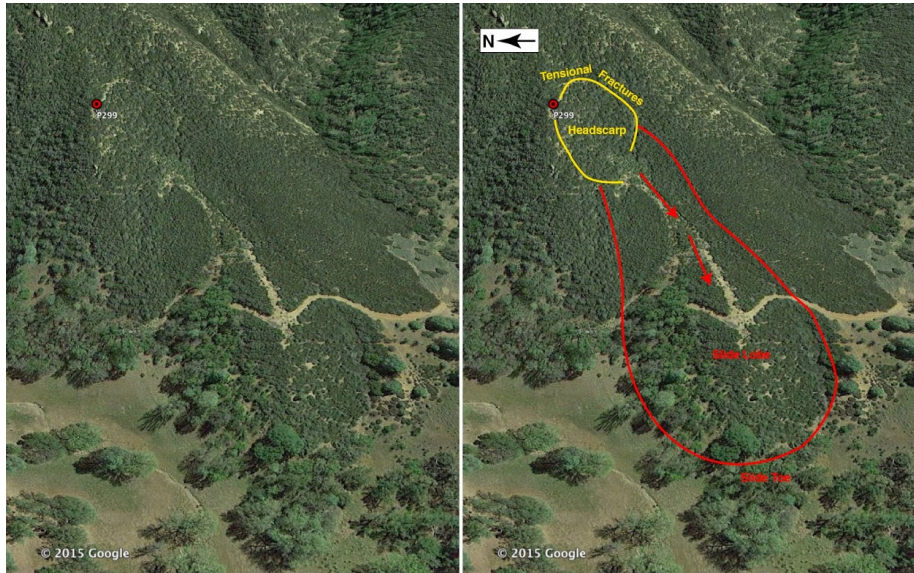


Figure 3. GoogleEarth view of P299 and landslide. The slide originates in the small bowl to the south of P299 and flow downhill into a lobe at the base. Original image (left) has been annotated to show extent of slide (right).

Plate Fixed Reference Frames

- Velocities with respect to "PLATE-NAME"
- very convenient for visualization purposes and modeling of tectonic deformation
- To convert into plate-fixed frame we need plate motion and velocities in the same geodetic frame (e.g., ITRF2008)
- Transformation:

Plate Fixed Reference Frames

- Velocities with respect to "PLATE-NAME"
- very convenient for visualization purposes and modeling of tectonic deformation
- To convert into plate-fixed frame we need plate motion and velocities in the same geodetic frame (e.g., ITRF2008)
- Transformation: subtract predicted motion based on plate angular velocity from observed velocity

Reference Frames – ITRF vs. fixed (stable North America)



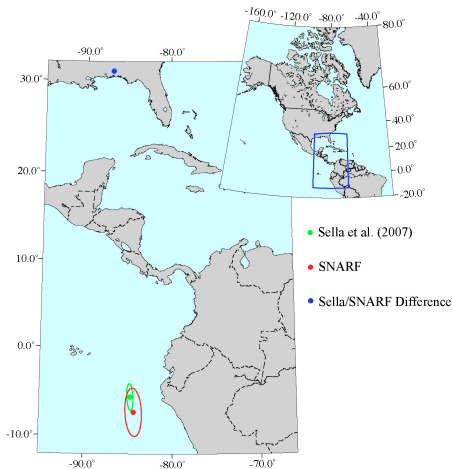
courtesy: Jeff Freymueller, UAF

Reference Frames – stable North America



- extension across Basin and Range
- Shear on San Andreas System
- Subduction strain in Cascadia, Alaska
- et al.

NOAM Poles

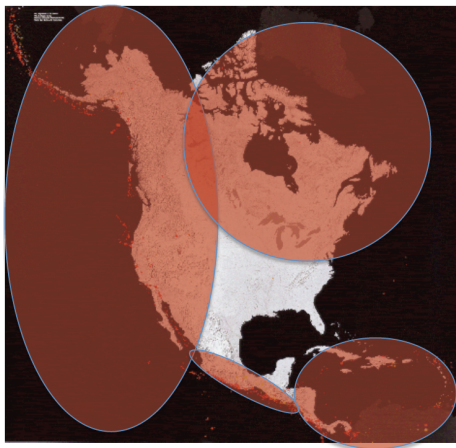


courtesy: Jeff Freymueller, UAF

- past studies: common that NOAM poles not within each others' confidence ellipses
- Difference between SNARF and Sella et al. (2007) is rotation about pole in SE US.

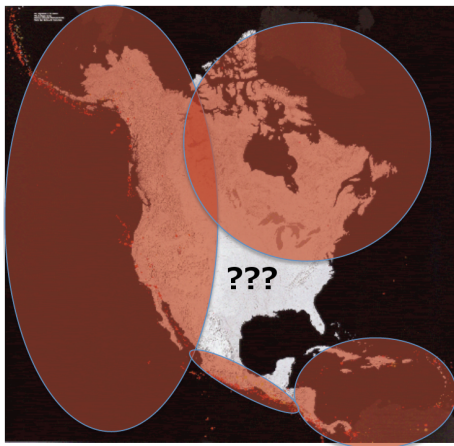
Why is NOAM Pole poorly determined?

Why is NOAM Pole poorly determined?



courtesy: Jeff Freymueller, UAF

Why is NOAM Pole poorly determined?



courtesy: Jeff Freymueller, UAF

- tectonics in western North America
- glacial isostatic adjustment in northern North America
- SE is thought to be stable on geologic and geodetic time scales
- limited area to determine plate angular velocity, susceptible to bias



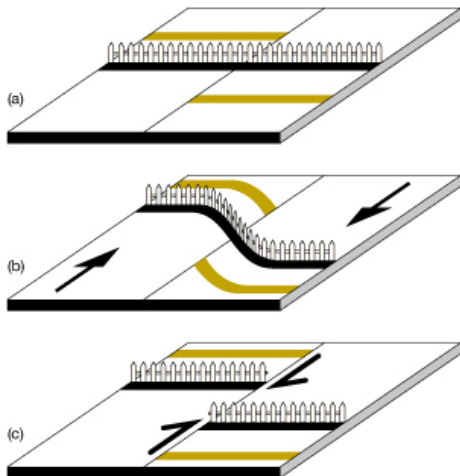
ERTH 491-01 / GEOP 572-02
Geodetic Methods

– Lecture 24: Modeling - Faults and Slip –

Ronni Grapenthin
rg@nmt.edu
MSEC 356
x5924

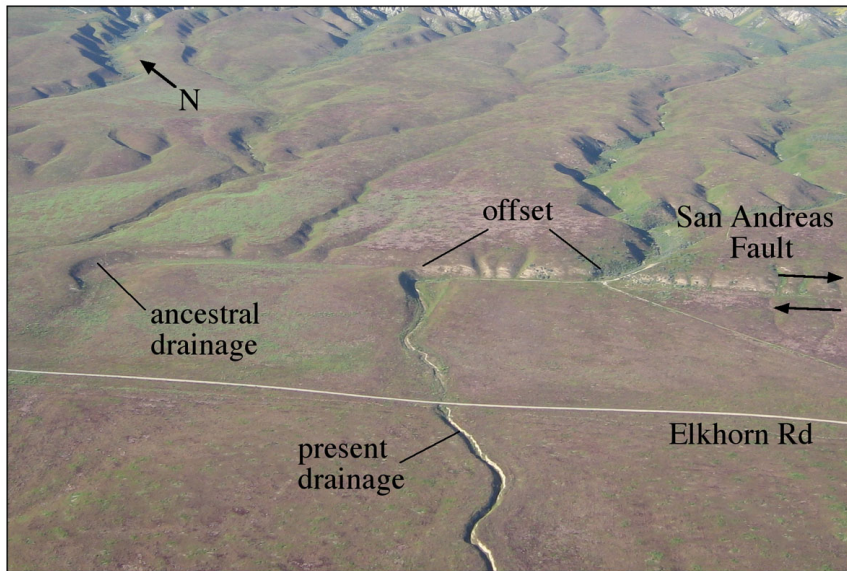
November 13, 2017

The Elastic Rebound Model



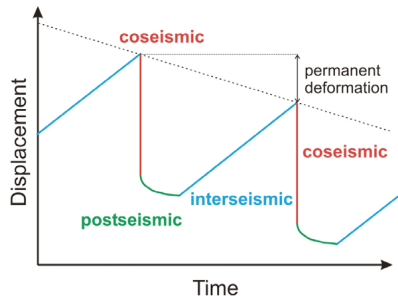
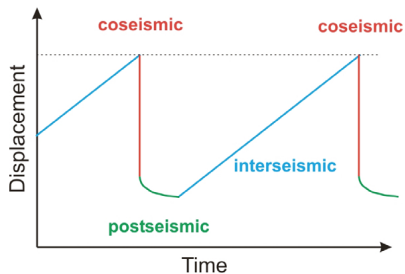
- Between earthquakes: steady motion on the fault
- Loads fault, strain accumulates in vicinity of fault
- During earthquakes: fault breaks, strain is released and fault vicinity catches up with far field motion
- Elastic system: interseismic strain accumulation is opposite of co-seismic strain release - no net straining.

Wallace Creek



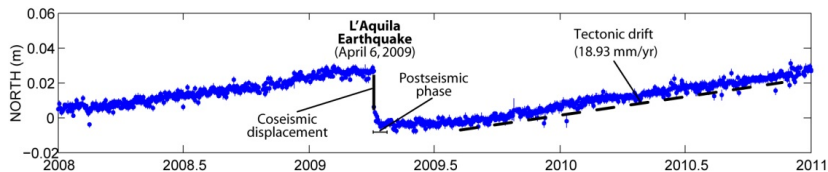
~ 100 yards

The deformation cycle



- **Interseismic:** constant velocity at given site - linear displacements
- **Co-seismic:** Step in timeseries controlled by magnitude, locking depth and distance of seismic rupture
- **Post-seismic:** afterslip, visco-elastic relaxation, poroelasticity; decay related to mechanism and lithospheric rheology

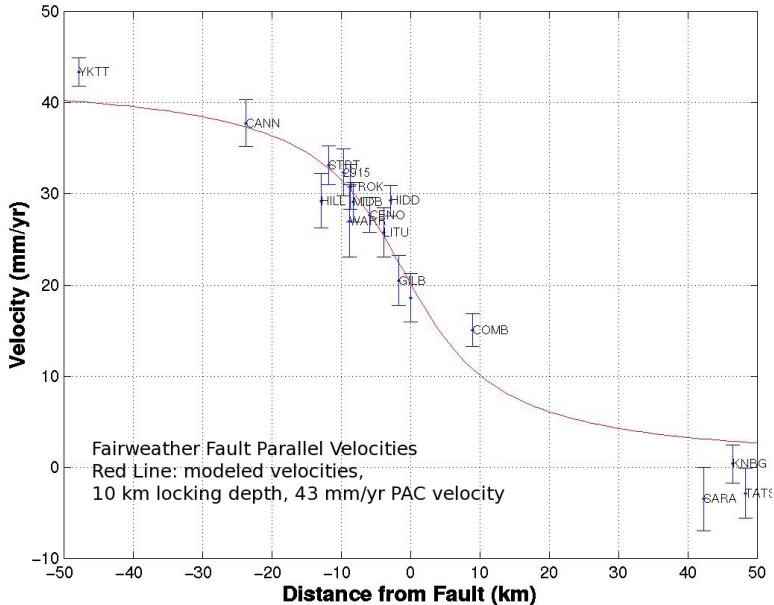
The deformation cycle



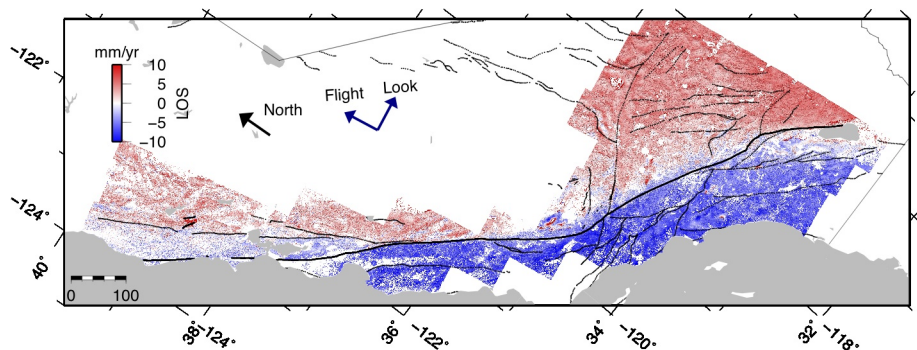
Roberto Devoti, INGV

- Earthquake: sudden slip on fault
- M_w 4-5: a few centimeters average slip on fault
- M_w 7: a few meters average slip on fault
- M_w 9: 10-20+ meters average slip on fault
- L'Aquila earthquake: M_w 5.9 - displacements depend on distance, magnitude, fault geometry

Deformation cycle: Interseismic (Fairweather Fault)



The deformation cycle: Interseismic



Tong et al, 2013, JGR

Co-Seismic: The 2002 $M_w=7.9$ Denali Earthquake



courtesy: USGS

Co-Seismic: The 2002 $M_w=7.9$ Denali Earthquake



courtesy: USGS

Co-Seismic: The 2002 $M_w=7.9$ Denali Earthquake



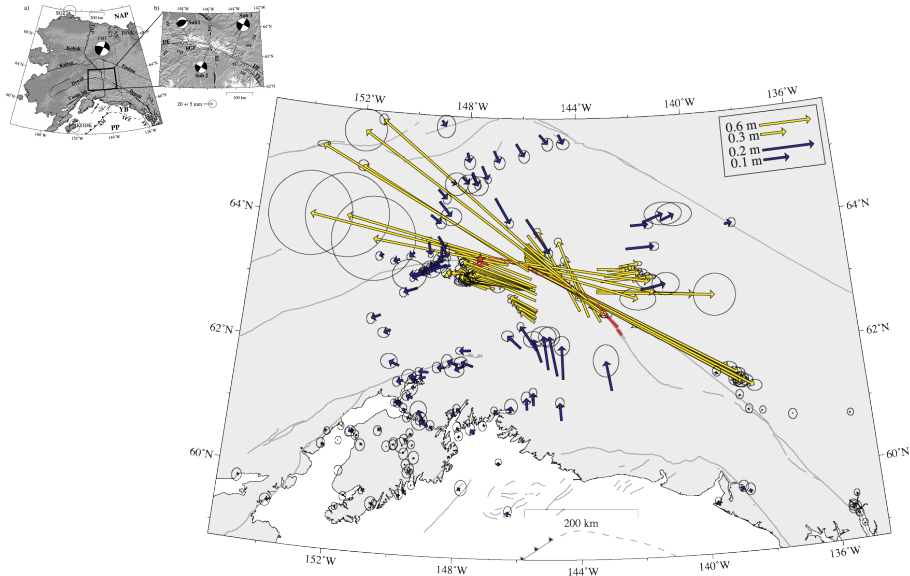
courtesy: USGS

Co-Seismic: The 2002 $M_w=7.9$ Denali Earthquake



courtesy: David Schwartz, USGS

Co-Seismic: The 2002 $M_w=7.9$ Denali Earthquake



Hreinsdóttir et al., JGR, 2006

Co-Seismic: The 2002 $M_w=7.9$ Denali Earthquake

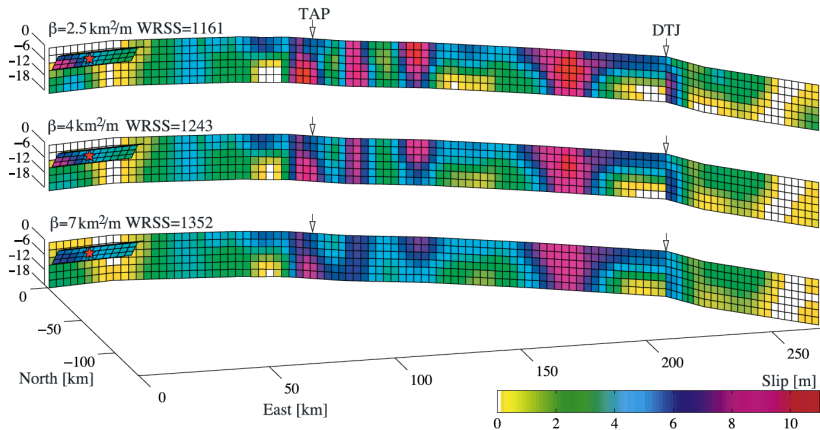
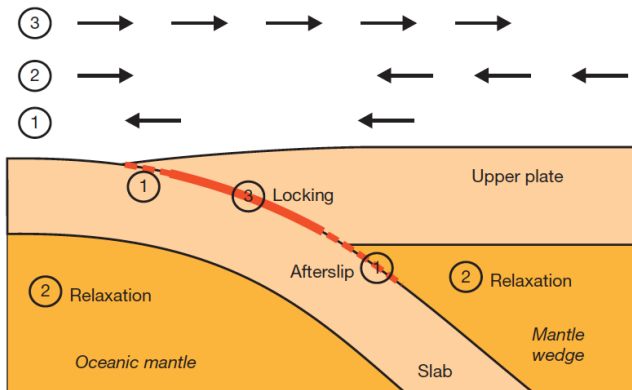


Figure 10. Range of reasonable coseismic slip models from the roughest ($\beta = 2.5 \text{ km}^2/\text{m}$) to the smoothest ($\beta = 7 \text{ km}^2/\text{m}$). The axes show easting, northing, and depth in km. TAP, Trans-Alaska pipeline; DTJ, Denali-Totschunda fault junction. Red star indicates the Denali Fault earthquake epicenter.

The deformation Cycle: Post-seismic



Earthquake cycle = rupture + ① + ② + ③

Figure 2 | Three primary processes after a subduction earthquake. (1) Aseismic afterslip occurs mostly around the rupture zone, (2) the coseismically stressed mantle undergoes viscoelastic relaxation, and (3) the fault is relocked. Arrows at the top show the sense of horizontal motion of Earth's surface, relative to distant parts of the upper plate, caused by each of these three processes.

The deformation Cycle: Post-seismic

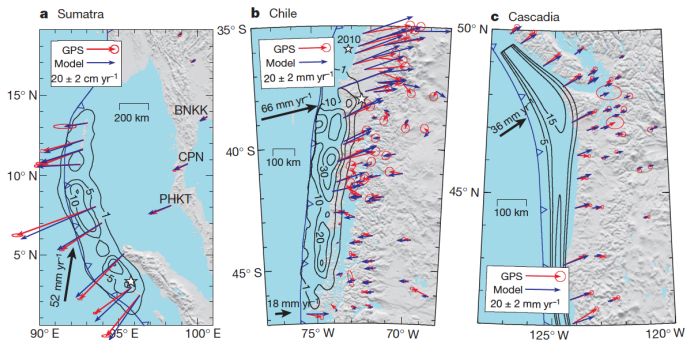
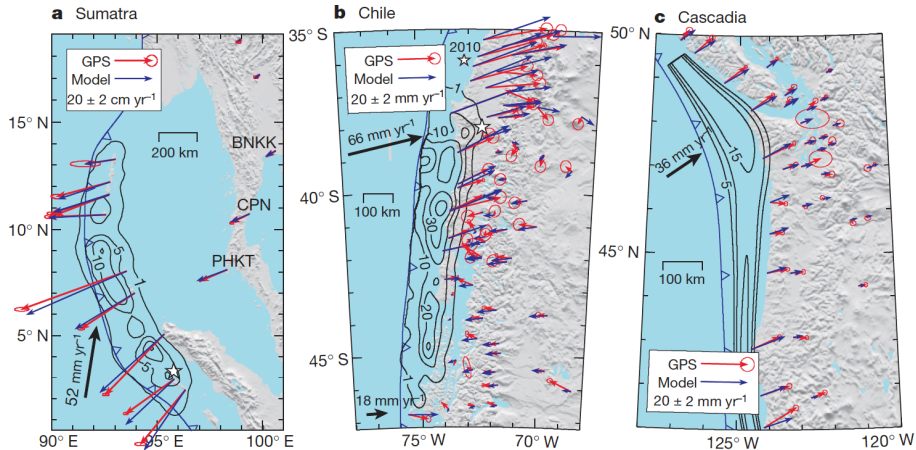


Figure 3 | GPS- (red) and model-predicted (blue) surface velocities for three subduction zones that are at different stages of the earthquake cycle. a. At Sumatra, one year after the $M_w = 9.2$ earthquake of 2004 (refs 20 and 21) (epicentre shown by star), all sites move seaward. Shown are ~ 1 -year average GPS velocities. More recent data show the same pattern²². Coseismic fault slip (contoured in metres) is based on ref. 56. Longer (~ 3 -years) time series from the three labelled far-field sites (BNKK, CPN, PHKT)³² helped constrain

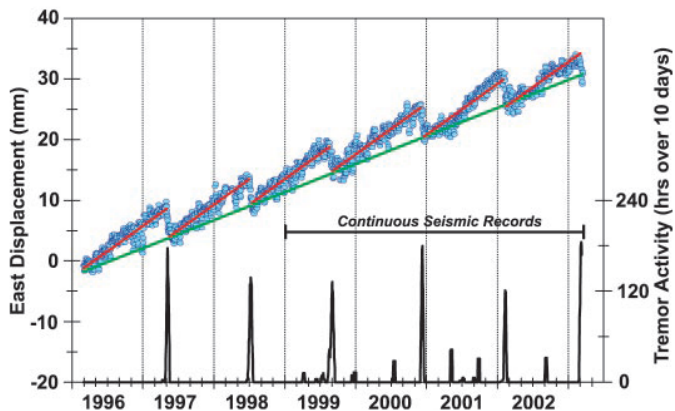
afterslip and transient rheology (ref. 48). **b.** At Chile, four decades after the $M_w = 9.5$ earthquake of 1960, coastal and inland sites show opposing motion. Coseismic slip is from ref. 14. For sources of GPS data, see ref. 17. The northernmost areas show wholesale landward motion before the 2010 $M_w = 8.8$ Maule earthquake. **c.** At Cascadia, three centuries after the $M_w \approx 9$ earthquake of 1700, all sites move landward. The model is an updated version of ref. 8. A more comprehensive GPS compilation shows a similar deformation pattern¹⁶.

The deformation Cycle: Post-seismic



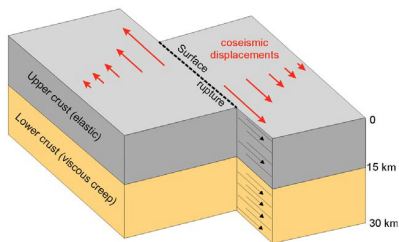
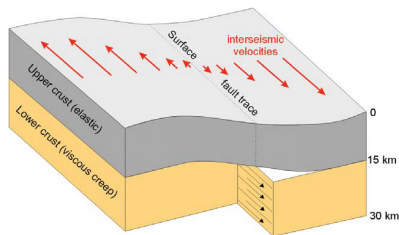
Wang et al., 2012, Nature

The deformation Cycle – Slow Slip



Rogers & Dragert 2003, Science

Physics of Faults



- stick-slip sliding (seismic)
 - 2 sides of interface stuck together: friction
 - slip occurs when friction is overcome
 - slip controlled by dynamic friction, healing
- stable sliding (aseismic):
 - 2 sides slide continuously past each other
 - slip occurs all the time
 - slip controlled by plastic, ductile or viscous yielding
- transient slip also occurs (slow slip events)

Geodetic data → Slip on a Fault

How to get this?

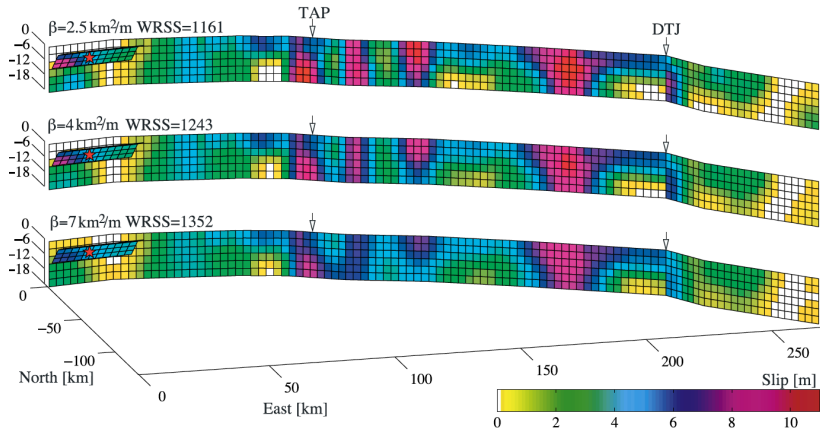


Figure 10. Range of reasonable coseismic slip models from the roughest ($\beta = 2.5 \text{ km}^2/\text{m}$) to the smoothest ($\beta = 7 \text{ km}^2/\text{m}$). The axes show easting, northing, and depth in km. TAP, Trans-Alaska pipeline; DTJ, Denali-Totschunda fault junction. Red star indicates the Denali Fault earthquake epicenter.

Geodetic data → Slip on a Fault

Green's function = displacement due to unit slip on fault patch

