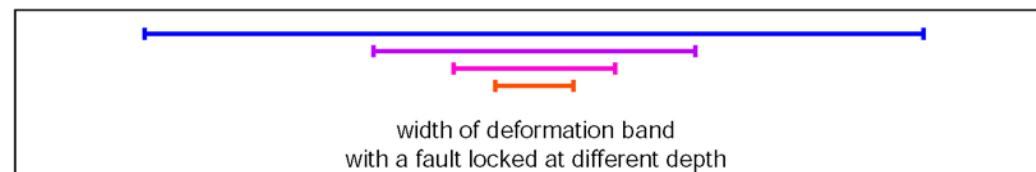
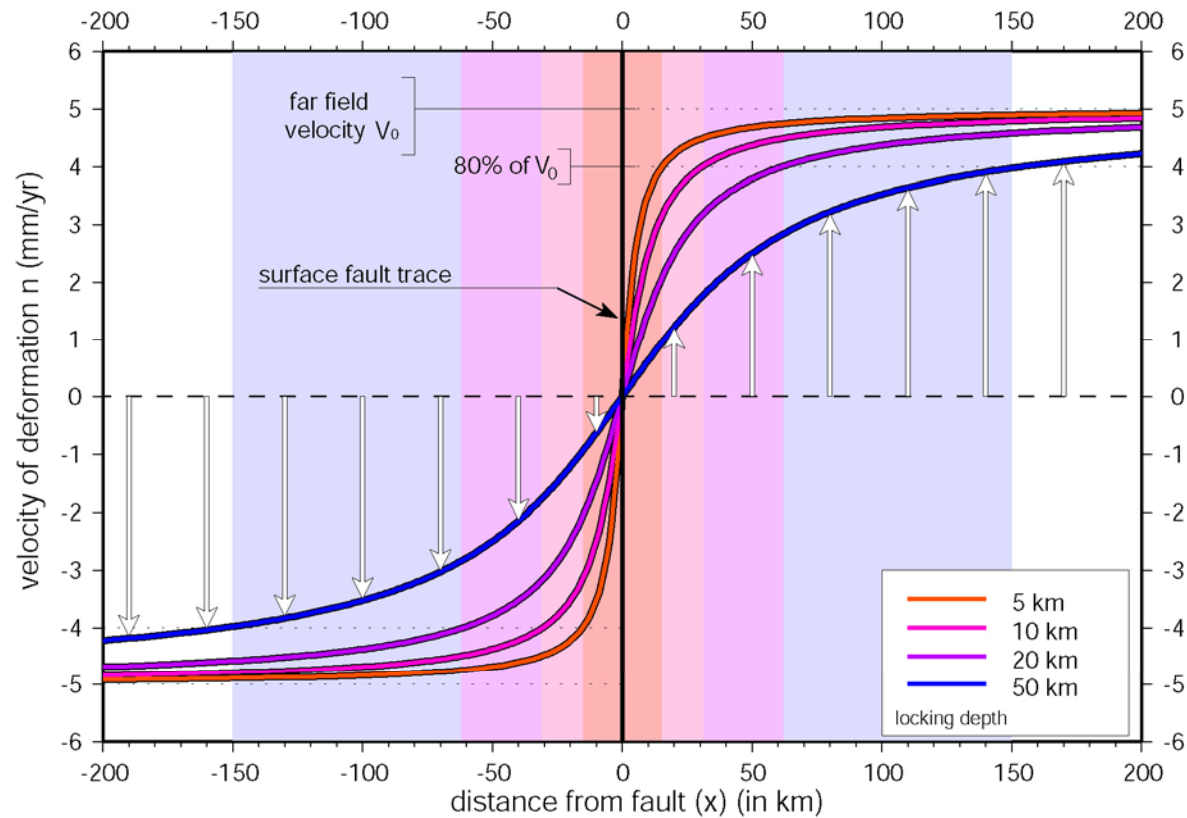


SEISMIC CYCLE

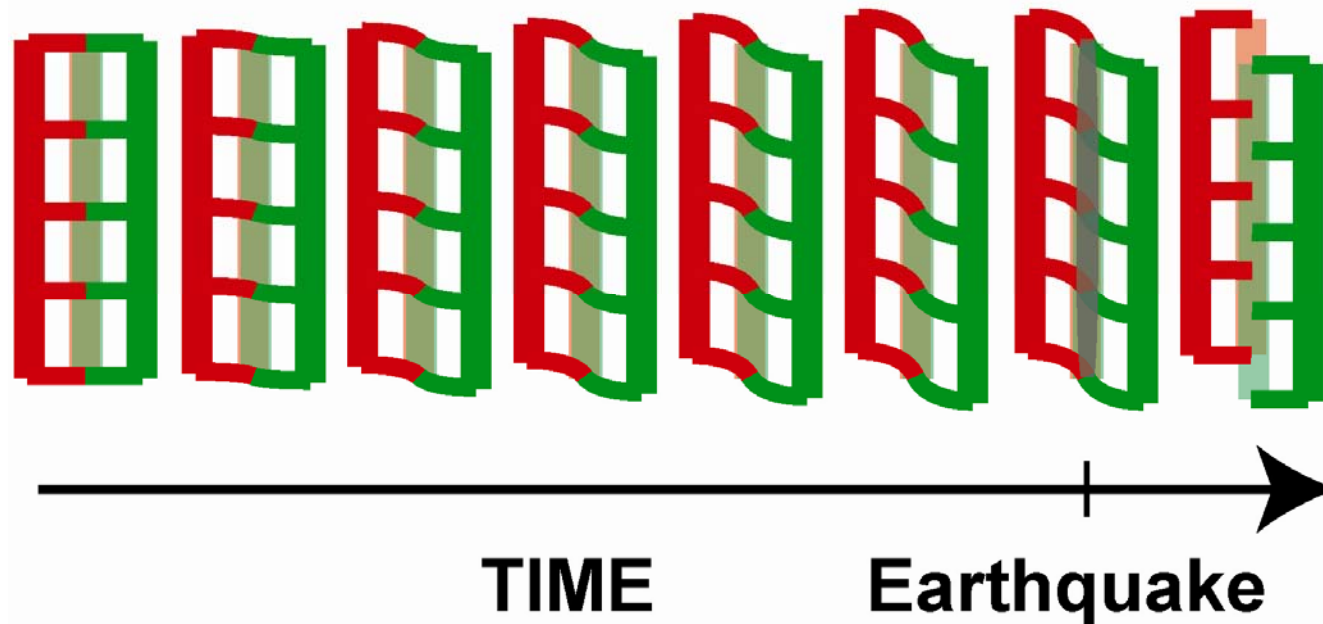
- Elastic accumulation and rupture on a fault. Example on a Strike-slip fault and a Subduction fault
- Size of an earthquake
- Time dependent station motion and earthquake cycle : READ and Wallace models
- Pre-seismic, co-seismic and post-seismic motions
- Triggering of earthquake
- Precursors ?

Arctang profiles

$$U_y = 2 \cdot V_0 / \Pi \arctang (x/h)$$

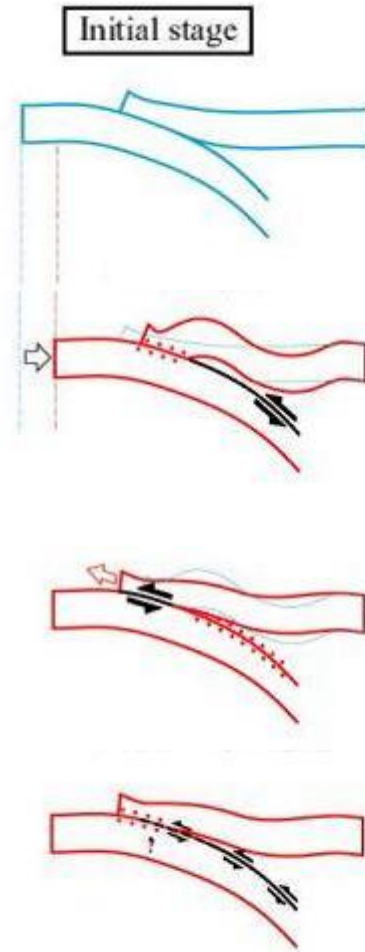
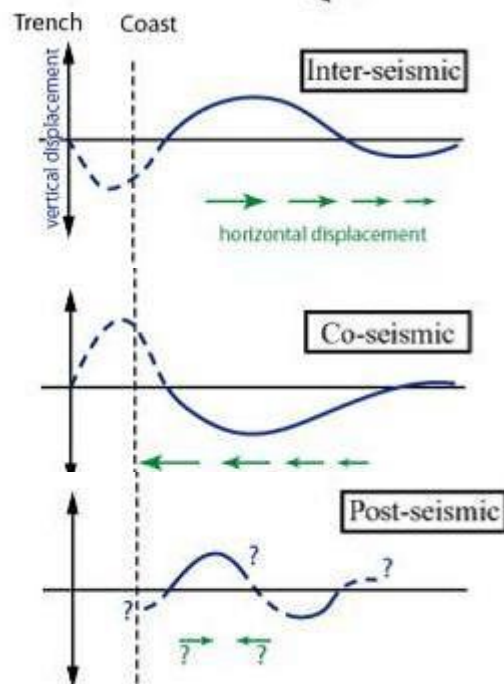
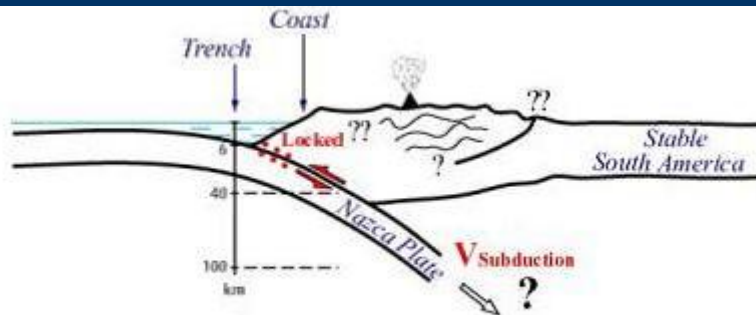


Elastic accumulation and rupture



Because the fault is locked, and the 2 plates want to move, they will deform. Deformation will accumulate (arctangent shape) until the accumulation is too much for the fault to resist. It then brakes : **it is an earthquake**

Seismic cycle in subduction context



100^s years

seconds -> minutes

months- -> years

Size of an Earthquake

Earthquake « size » or released Energy E , is proportional to :

- Quantity of slip (U)
 - fault velocity (V) \times time between earthquakes Δt
- Size of ruptured surface (S)
 - Length of rupture (L) \times Locking depth of fault (d)

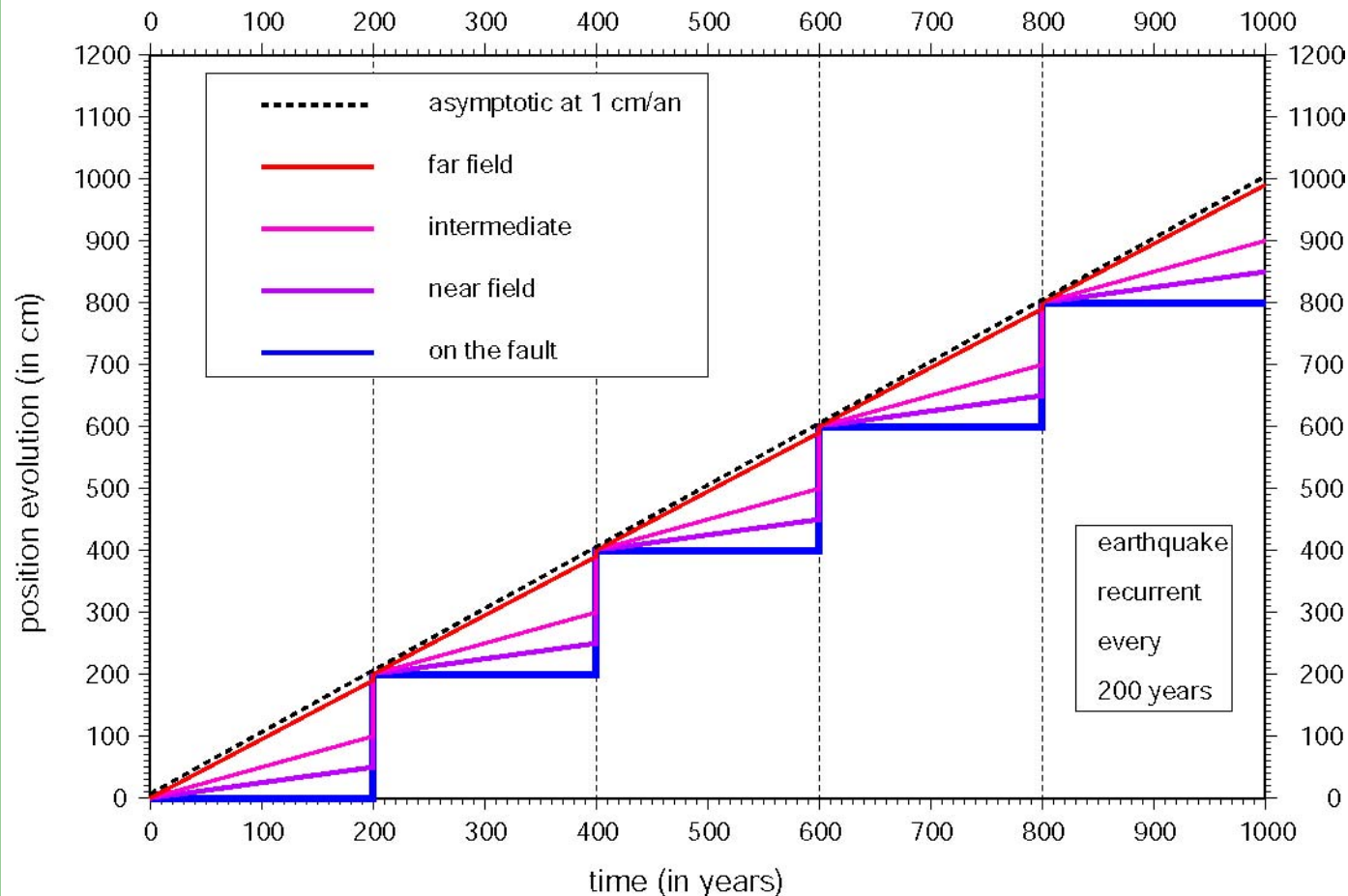
$$\Rightarrow E = \mu \times S \times U = \mu \times L \times d \times V \times \Delta t$$

Magnitude of an Earthquake :

$$M = \text{Log} (E)$$

Time & space dependant station motion

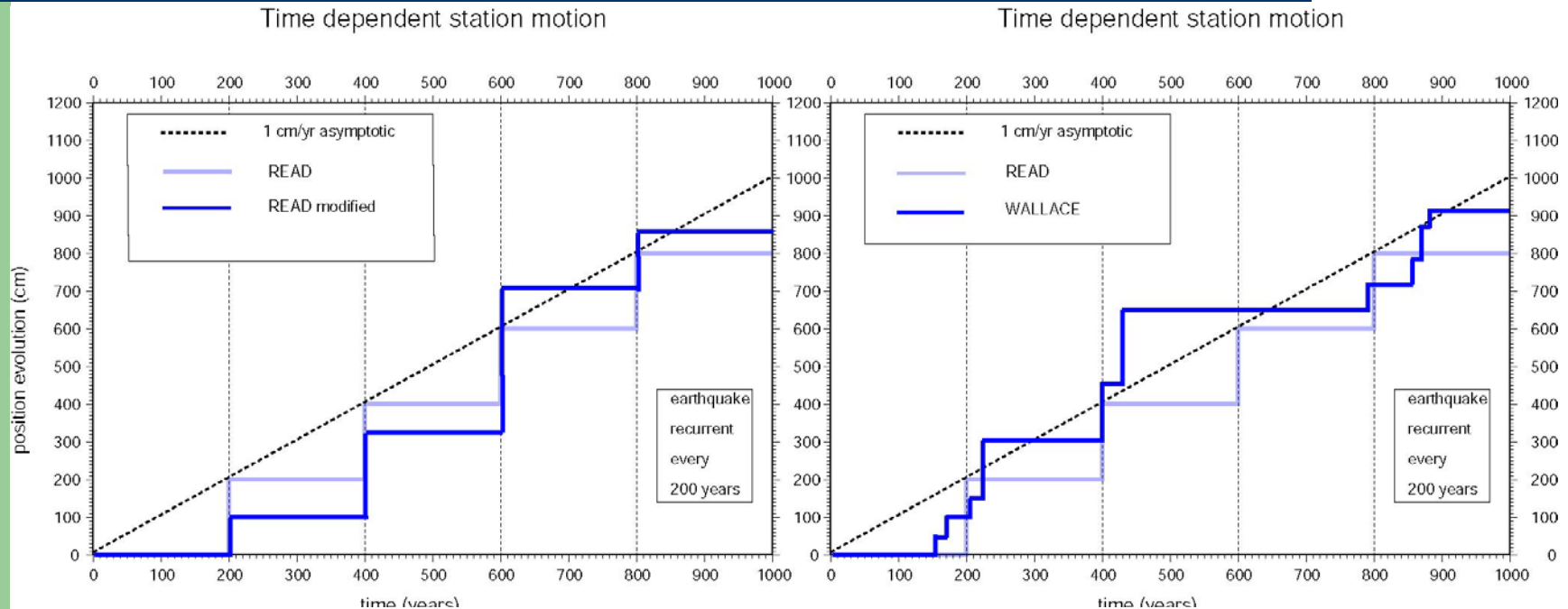
Time dependent station motion



Because the fault is locked, a station located close to the fault (blue line) is not moving for a long period of time (when deformation is accumulating). Then the station jumps suddenly, the exact distance that has been accumulated since many years.

On the opposite, a station far from the fault (red curve) will move steadily with plate tectonic velocity

Earthquake cycle : Read and Wallace models



The simplest model (**READ**) is : the same size earthquake (called **characteristic earthquake**) repeats regularly, every n hundred years (200 on the plot). This time interval is called **recurrence time interval**.

READ modified, suggests an earthquake may occur at **regular time** interval, but **different size** each time.

WALLACE model, suggests that **different size** earthquakes may occur in sequences (called **clusters**) and be separated by **different times** in a more chaotic way. It is only over a very long period of time and after many earthquakes that the average motion correspond to the plate tectonic velocity

Difficulty of earthquake prediction

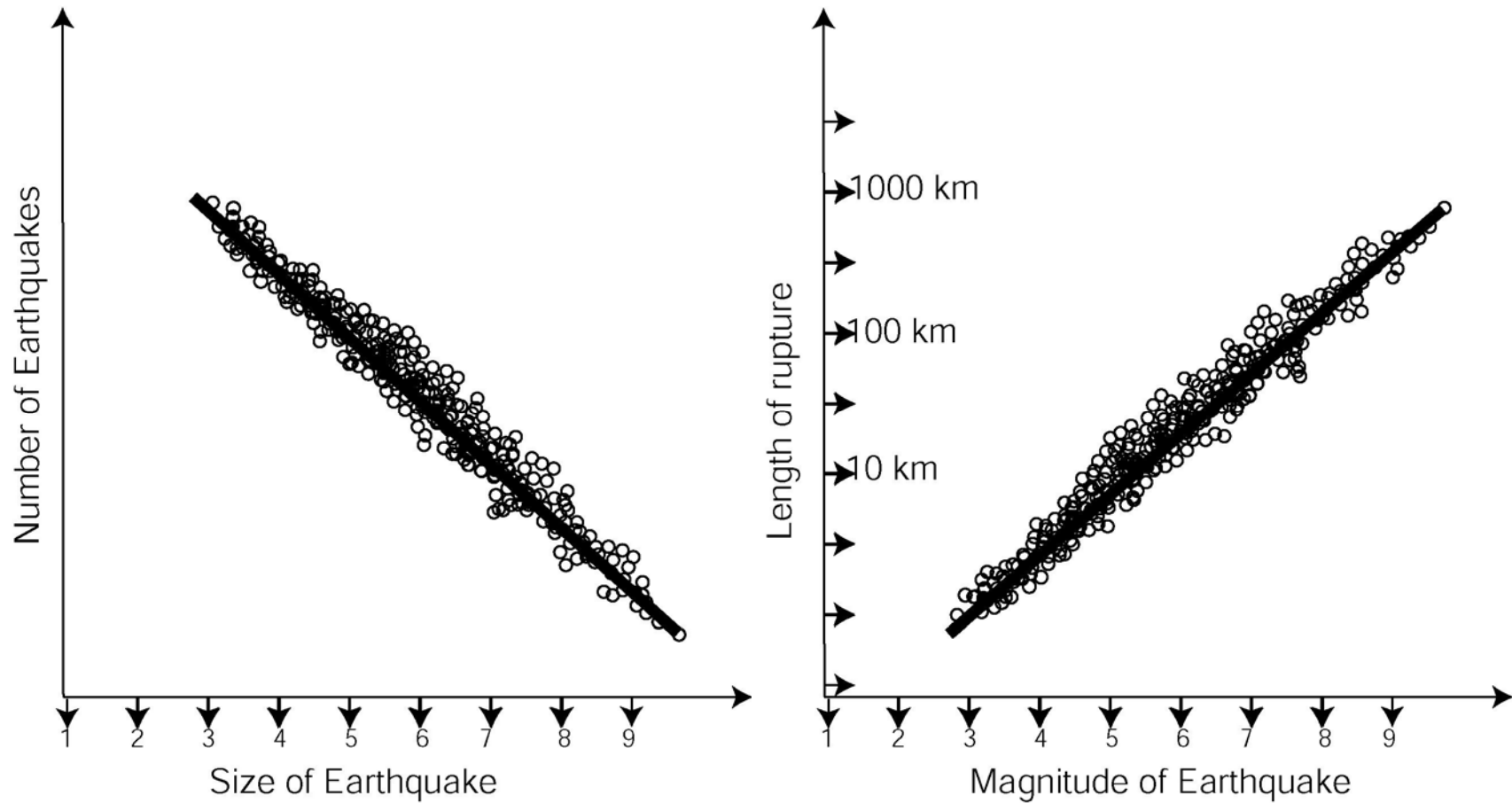
Even though a given fault can have a characteristic Earthquake repeating itself over a characteristic time, earthquake prediction is difficult because :

1. Those values can be **unknown**, especially if the characteristic time is very long
2. The earthquakes may occur at recurrence time interval, **plus or minus many decades (or centuries)**
3. Physical and/or rheological conditions may change with time and in particular **affected by earthquakes themselves**

Only lower bound of future Earthquake magnitude can be given, assuming :

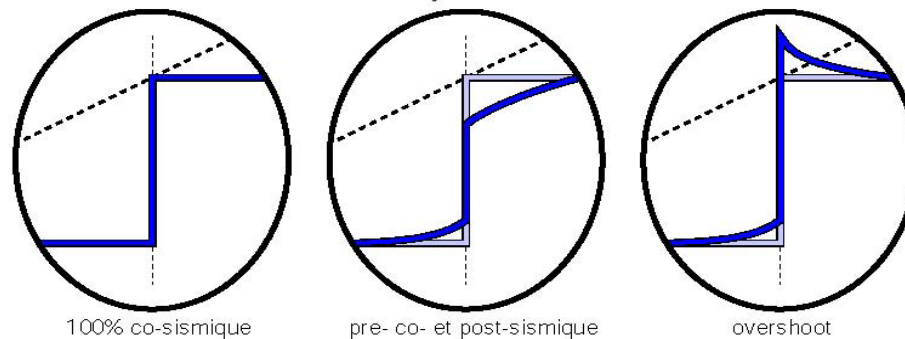
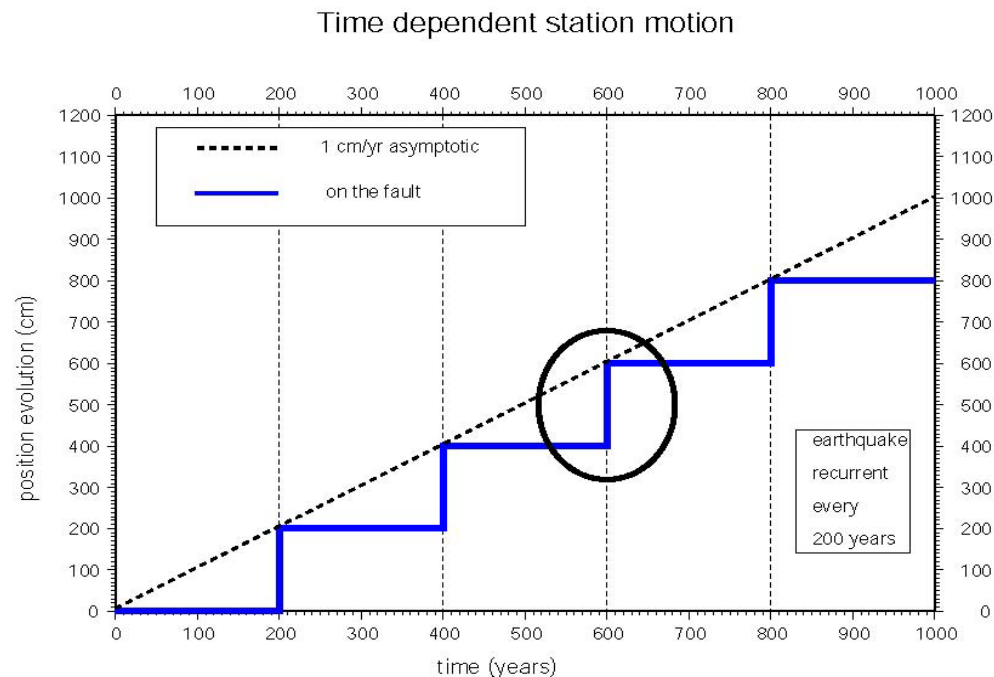
- a. time of latest event
- b. Current velocity on fault
- c. Locking depth of fault

Guttenberg-Richter Law



A fault of given length will give an earthquake of given magnitude

Zooming around earthquakes



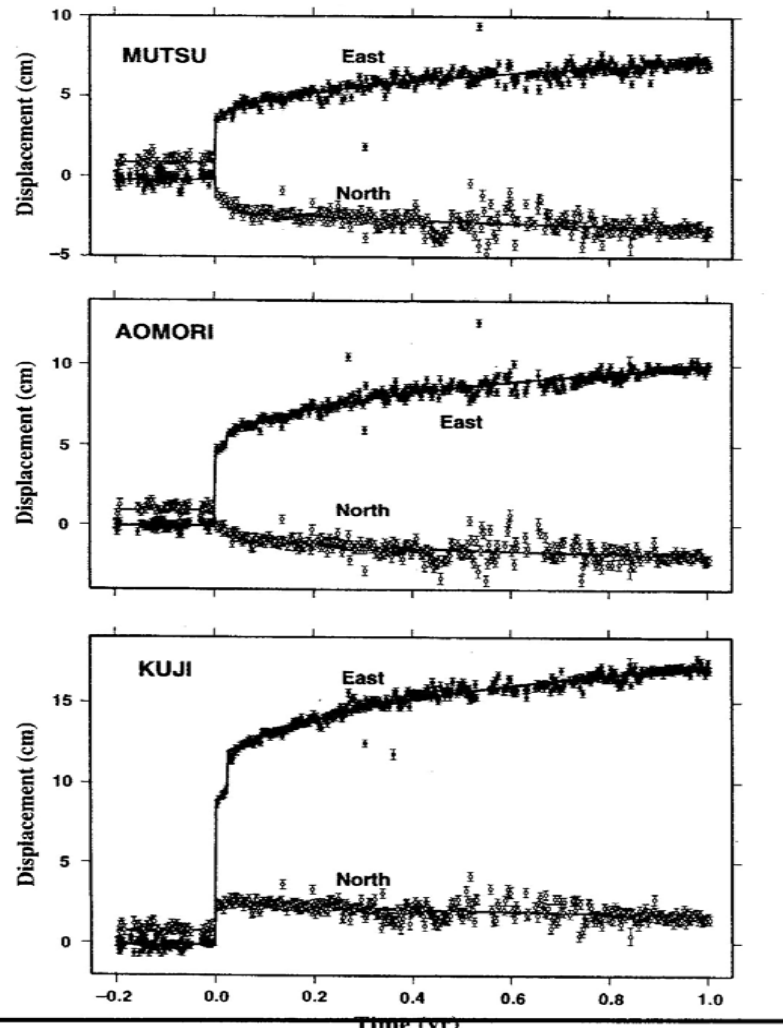
An earthquake may release in only a couple of seconds **100%** of the accumulated deformation.

But some slip may occur **before** and **after** the earthquake, the earthquake releasing **only part** of the accumulated deformation

Slip can then be :

- pre-seismic
- Co-seismic
- Post-seismic

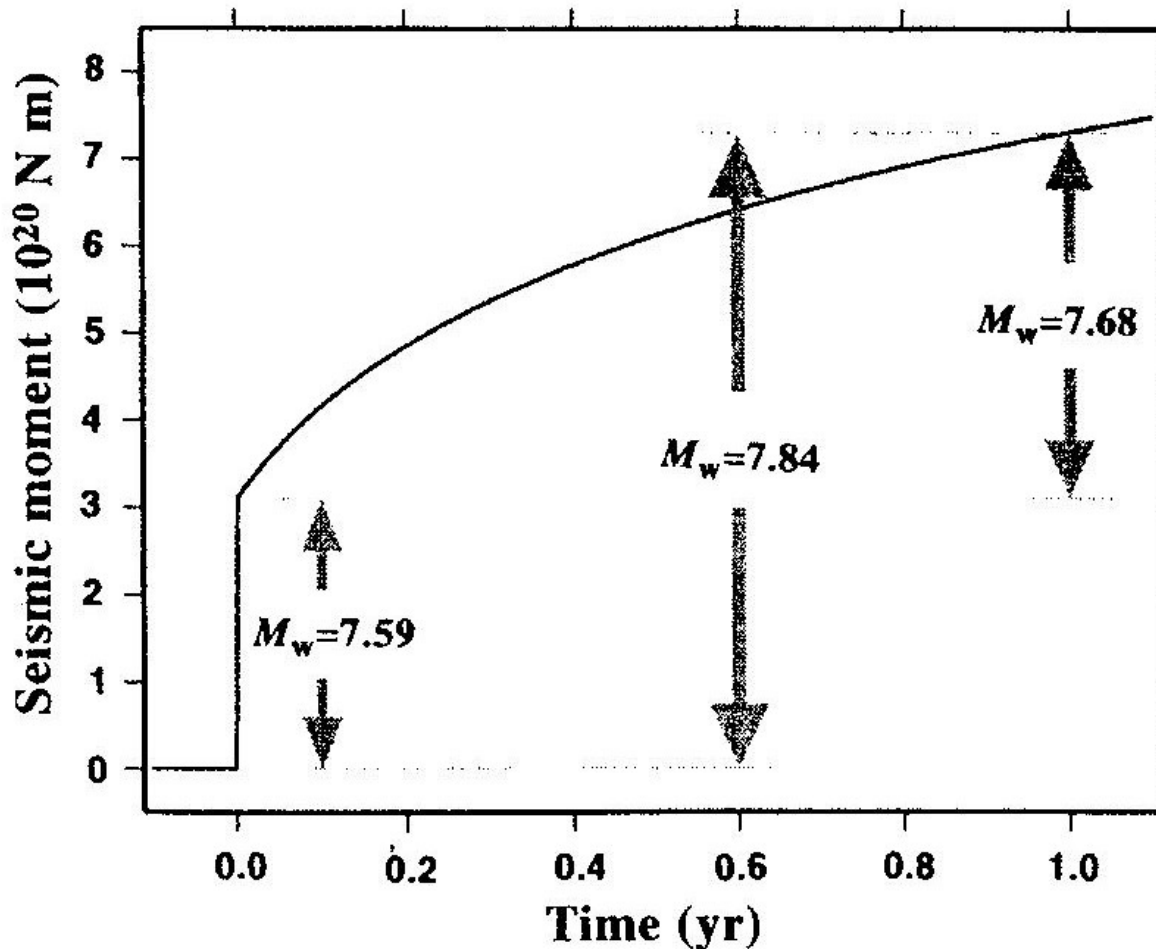
Post-seismic : K. HEKI, Nature 1997



Silent fault slip **following** an interplate thrust earthquake at the Japan trench

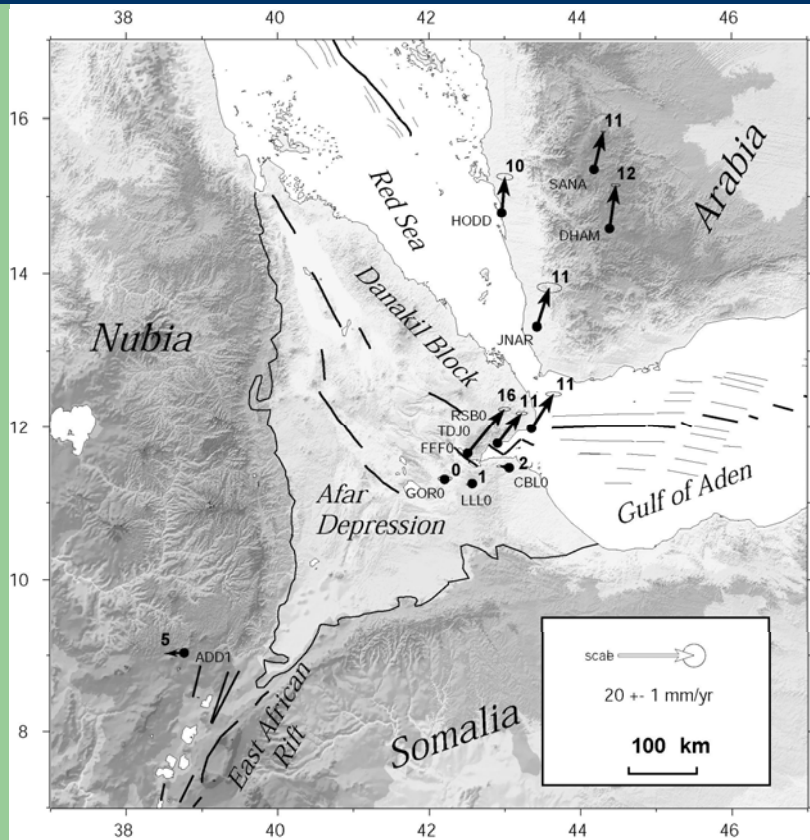
Horizontal coordinate time series before and after the **1994 Sanriku-haruka-Oki earthquake** observed at three GPS stations : Mutsu, Aomori and Kuji. Dots denote north and east components. Black lines are the model curves (stationary for $t < 0$, logarithmic decay for $t > 0$, discontinuity for $t = 0$).

Sanriku-Haruka-Oki sequence

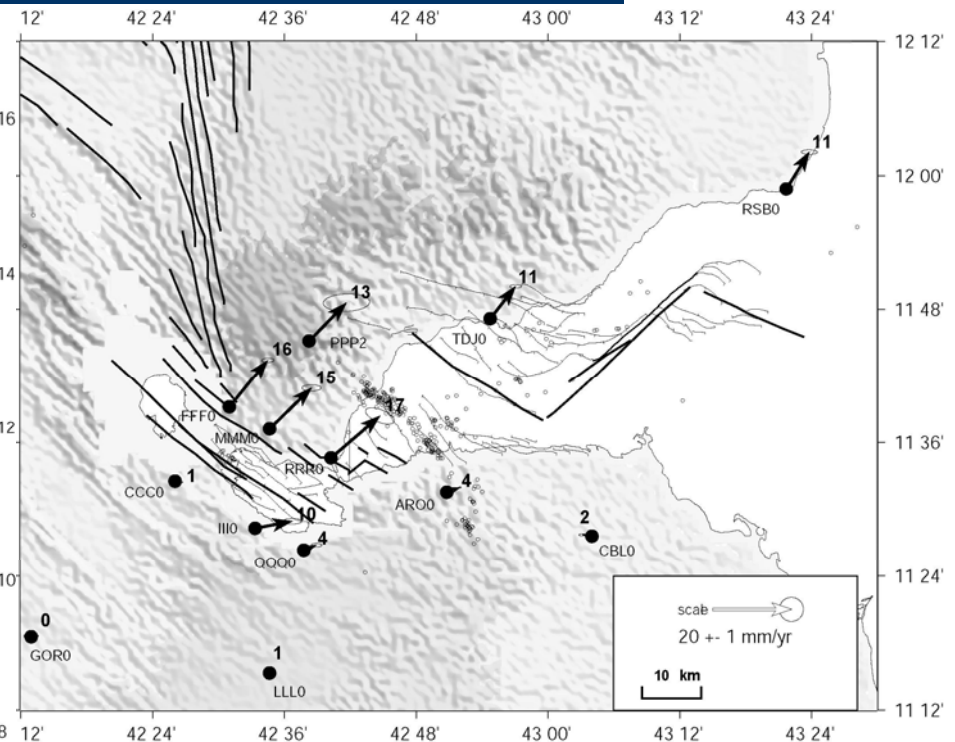


In that example, it is very clear that the **earthquake released only $\frac{1}{2}$** of the accumulated energy. The other $\frac{1}{2}$ was released later (over approximately a year) in a **silent and continuous** way

20+ years of Post seismic in Afar Rift

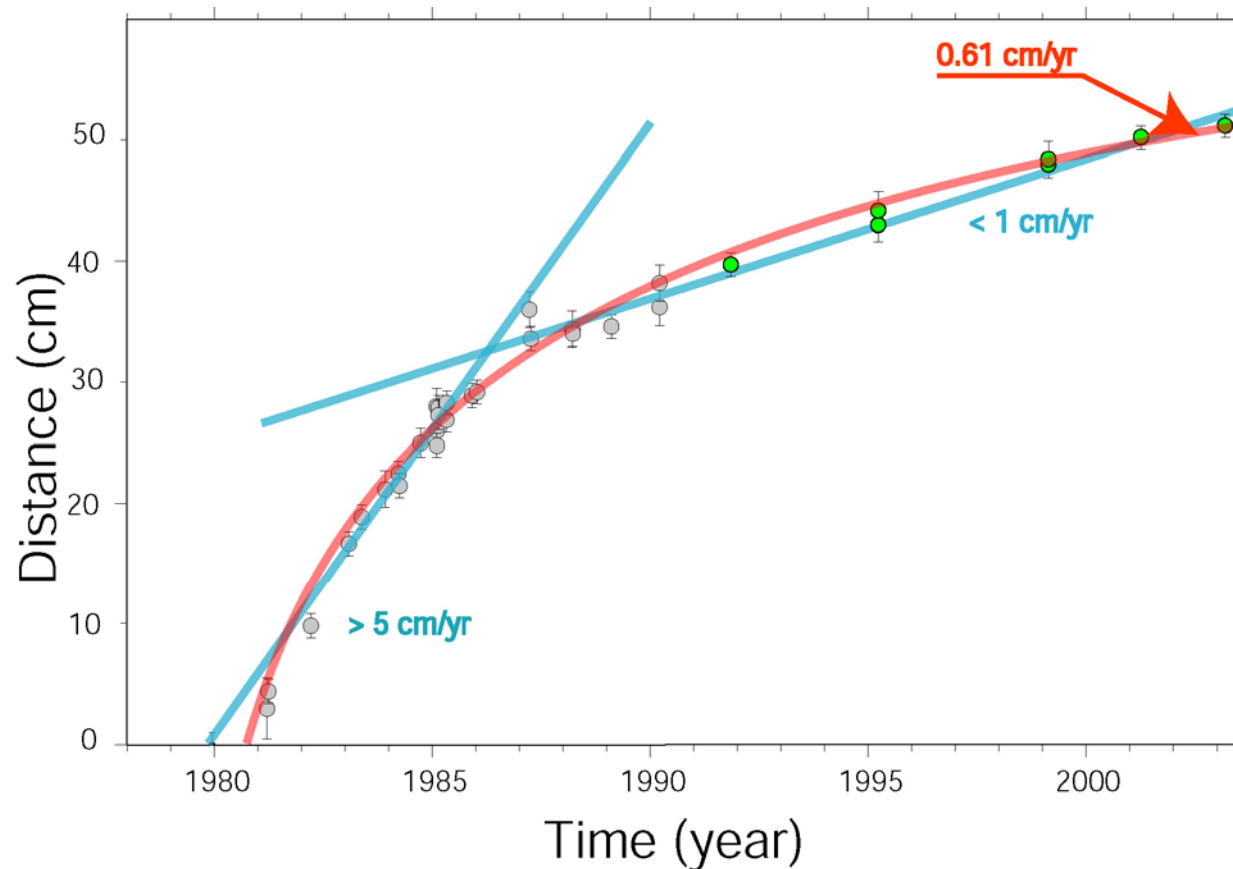


Far field velocities show plate tectonics long term rate of the red sea opening is 11 mm/yr



Local velocities in the rift show it is opening today at 16 mm/yr, and then the velocity is decreasing in space to 13 mm/yr, then the far field 11 mm/yr is reached 30 km further. It cannot be like that for ever, therefore the rift opening must slow down in the future.

20+ years of Post seismic in Afar Rift



Co-seismic (in 1979) = 1.5 m

Viscous relaxation = 50 cm

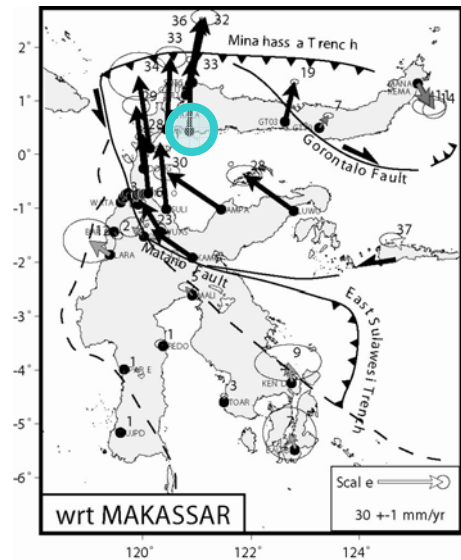
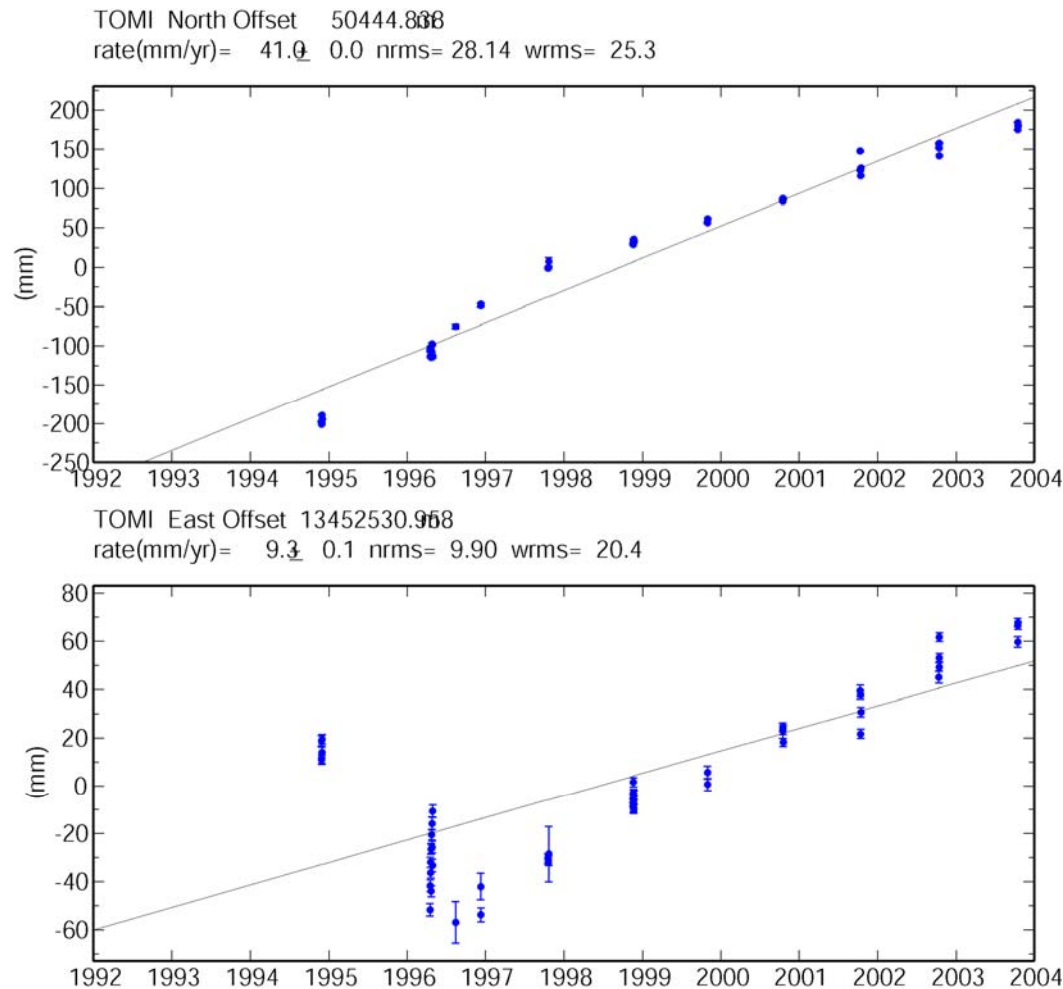
Present day velocity : +6.1 mm/yr

Far field velocity : +11 mm/yr

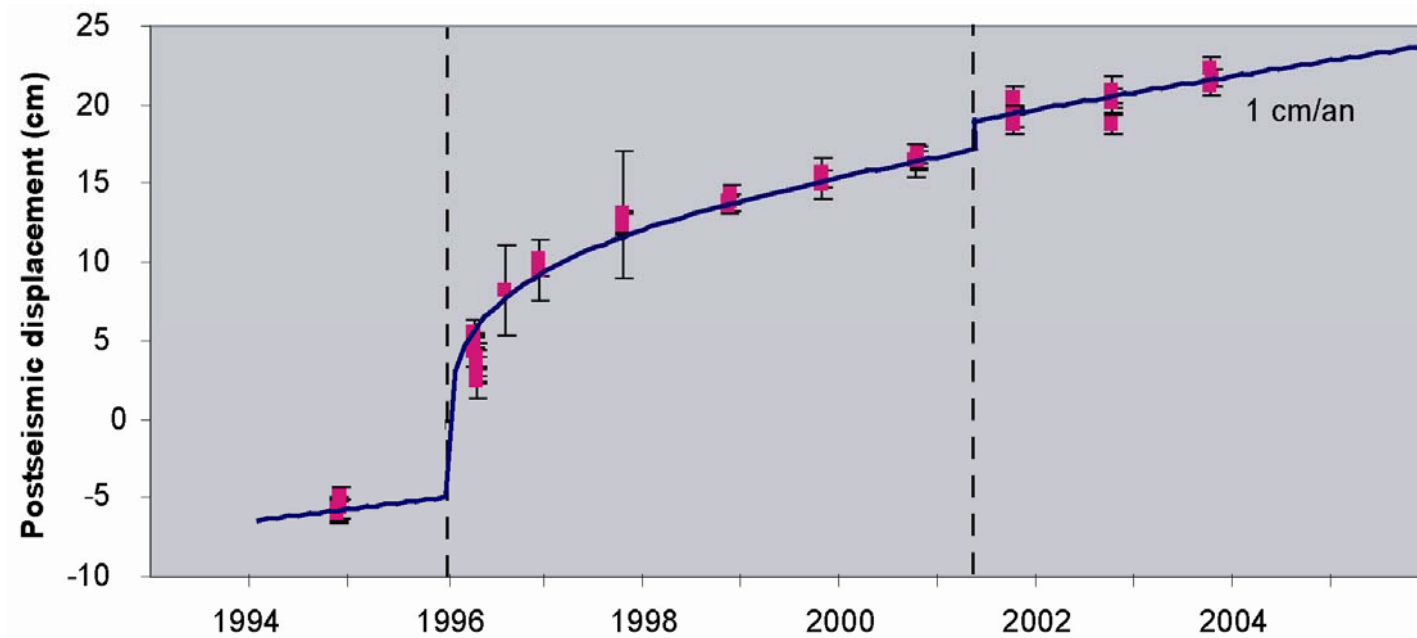
Accumulation : ~5 mm/yr

=> Next crisis in 200 years ?

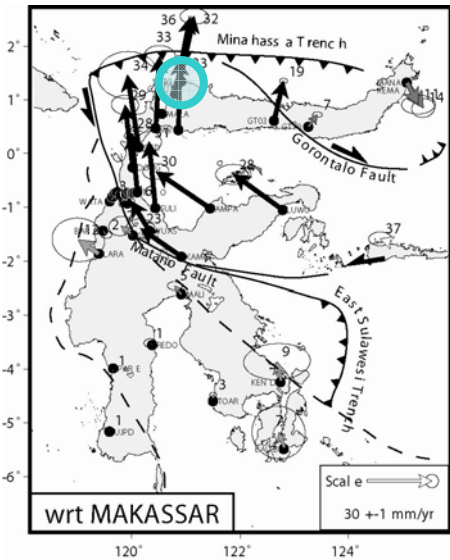
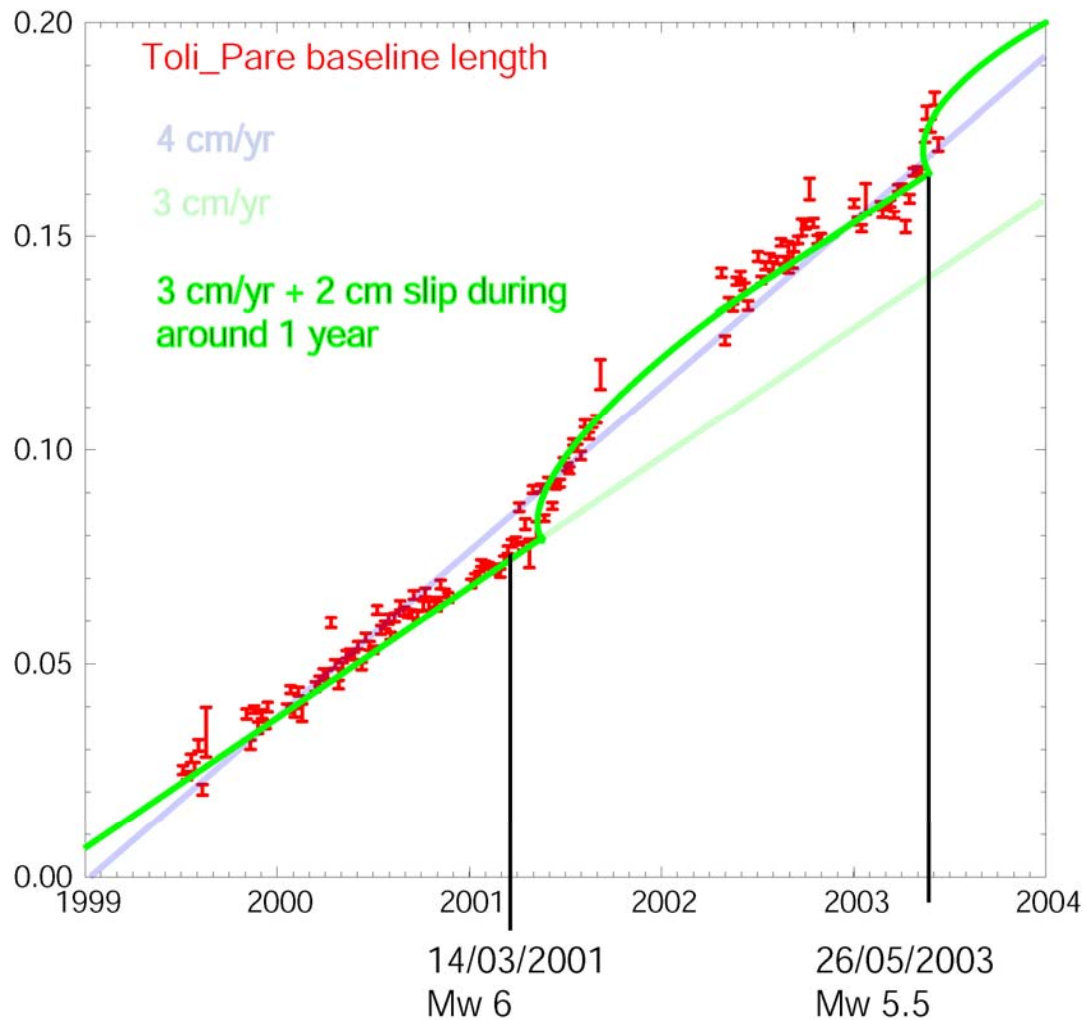
GPS time series in deforming area near a subduction



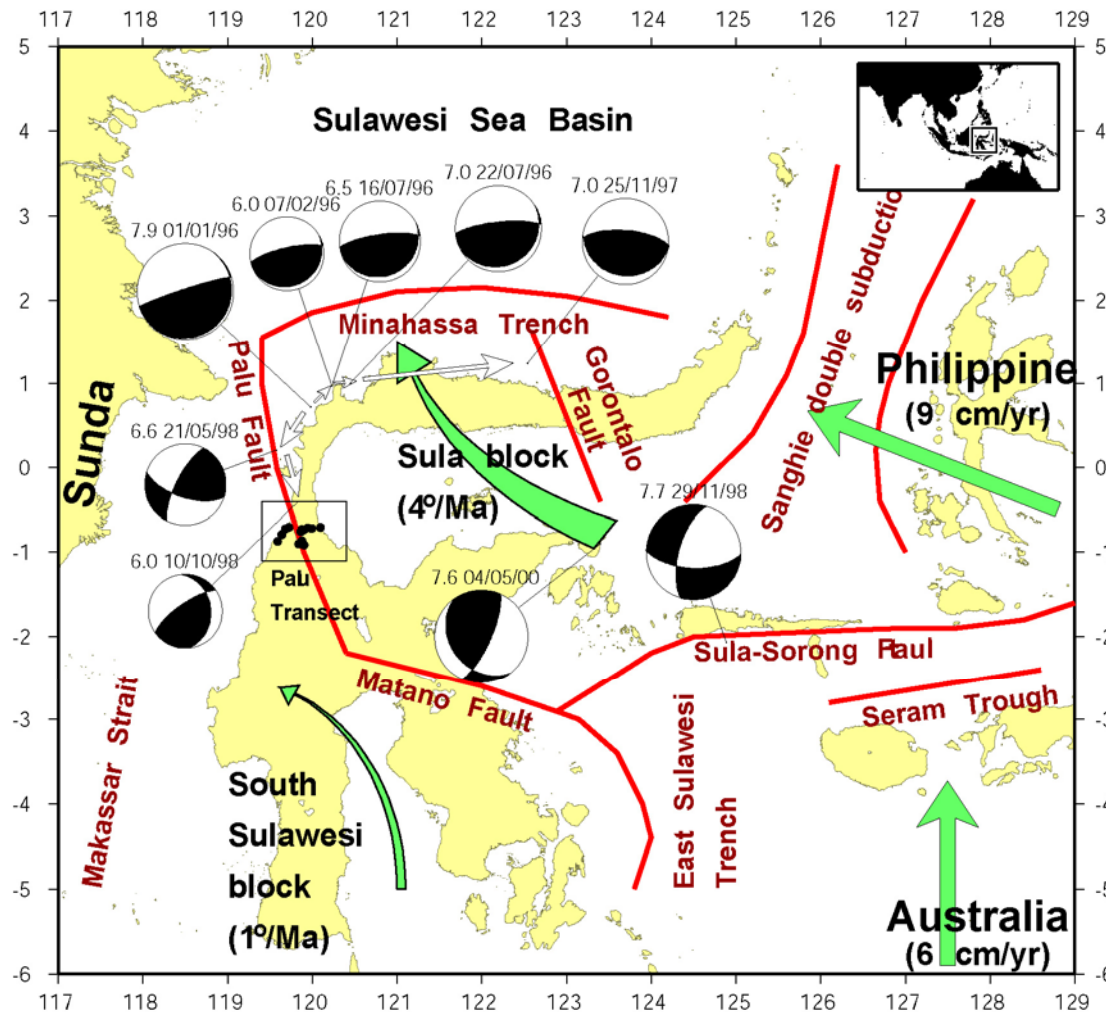
Post seismic relaxation model over 10 years



ToliToli Continuous station



Triggering of earthquakes : Vigny et al. JGR 2002



Start :

Mw 7.9 01/01/1996

1st phase :

eastward propagation (2 years) along Minahassa trench

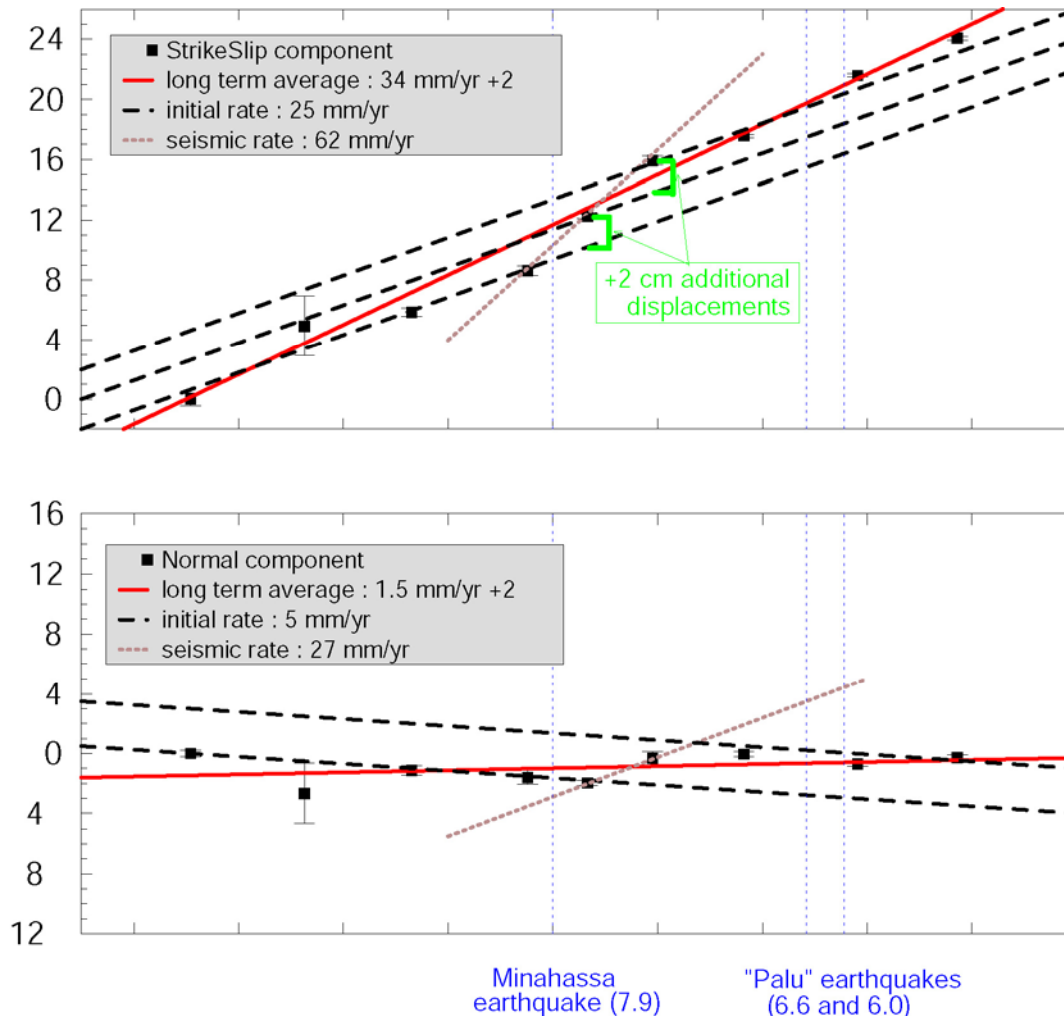
2nd phase :

Southward propagation on Palu fault

3rd phase :

Earthquakes around Sula and Luwuck

Surface deformation on Palu Transect



Along strike comp. has been anomalous twice:

- April 96 meas.
- December 96 meas.

The rate is stable since October 97

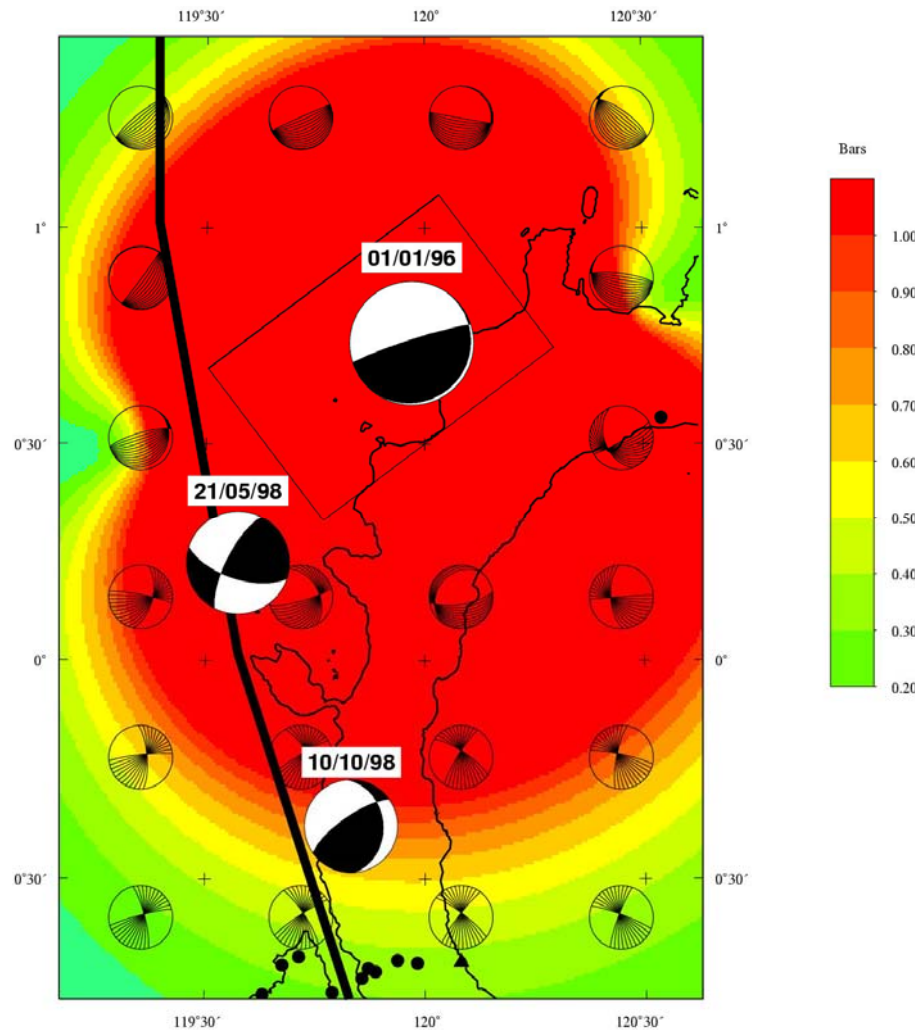
Normal component has been anomalous :

- December 96
- October 97

The rate is stable since october 98

The 2 earthquakes happened **after** the rates returned to normal

Coulomb stress increase



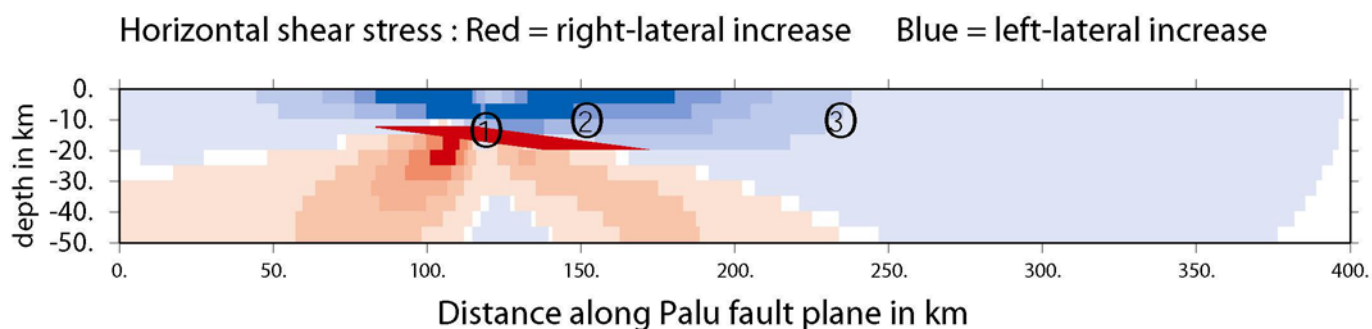
Coulomb Stress
generated in North
Sulawesi by the
01/01/96 earthquake

Stress is increased by
at least 1 bar (red area)
almost to Palu

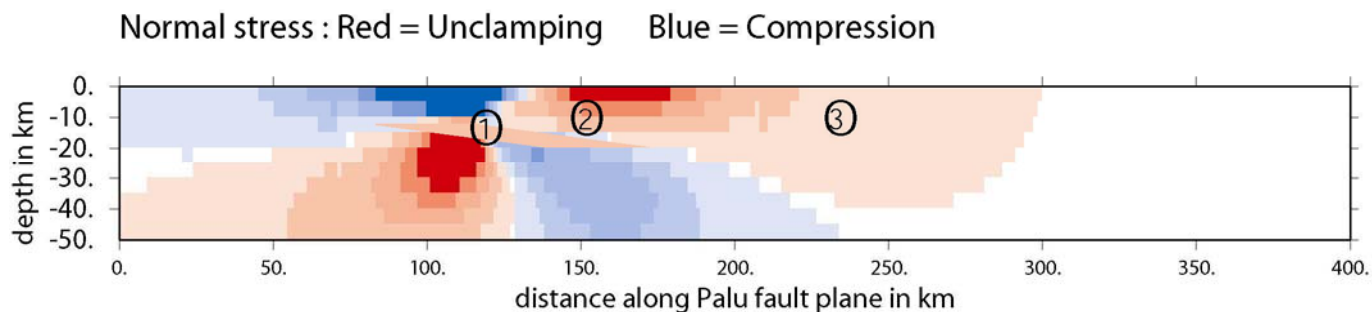
The 2 « Palu fault »
earthquakes occur in
the area of significant
stress increase

Coulomb Stress on Palu fault plane generated by 96 1st Eq

Shear stress on fault plane is increased => slip on fault



Normal stress on fault is decreased => unclamping of fault



Silent slip on Cascadian subduction zone

Dragert et al., Science, 292, May 2001

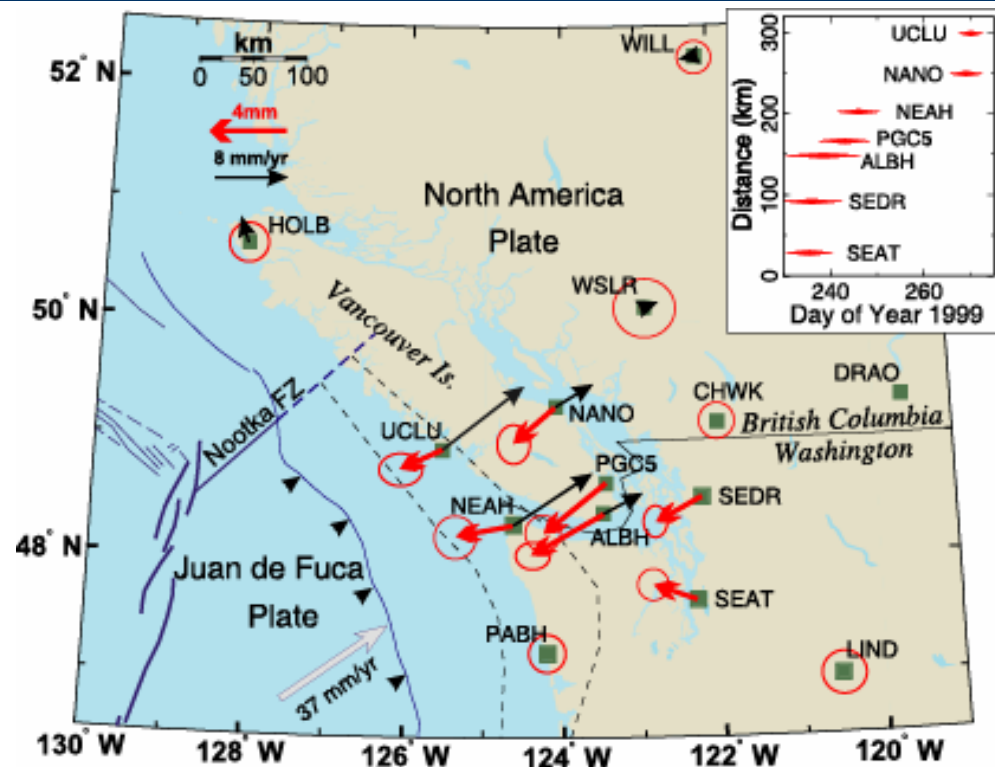


Fig. 1. Location of continuous GPS sites that are included in the routine analysis of GPS data carried out at the Geological Survey of Canada (GSC). Sites in Canada are operated and maintained by the GSC; U.S. sites, which form part of the PANGA (Pacific Northwest Geodetic Array) network, are operated by a consortium of university and government agencies. Bold (red) arrows show displacements (with respect to DRAO) due to the slip event. Error ellipses are double the 95% confidence limits derived from the formal regression errors of Table 1. Thin (black) arrows show 3- to 6-year average GPS motions with respect to DRAO (7). The two dashed lines show the nominal down-dip limits of the locked and transition zones from the model of Flück et al. (20). Inset shows the approximate time interval of the transient signal at each site along a northwest-striking line.

Jump in time series

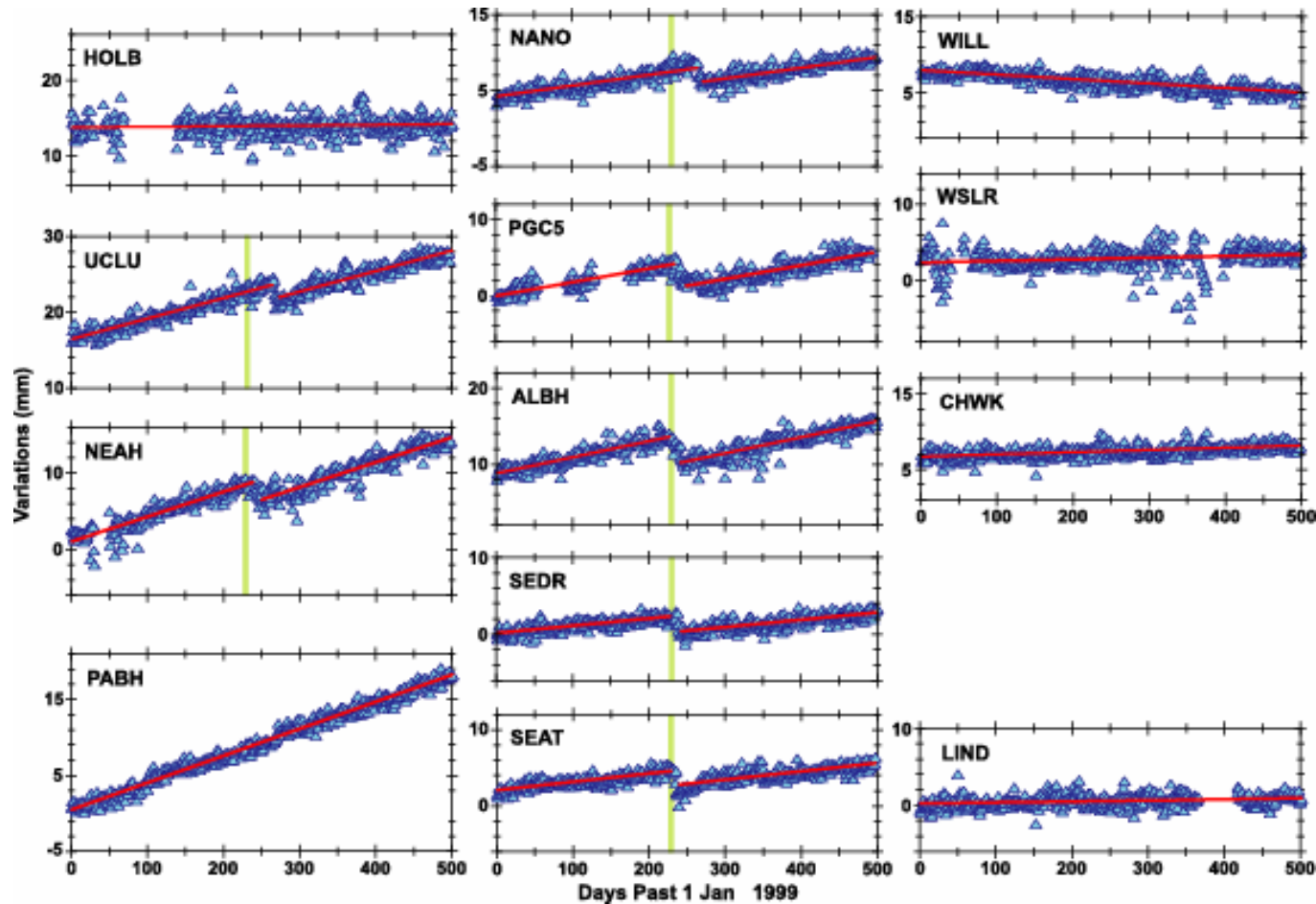


Fig. 3. Filtered series of daily variations in relative tide with respect DRAO. Annual have also been moved. Red lines the best-fitting trends, which summed constant fore and after transient. The green bars indicate the earliest date detection (day the transient).

Silent slip on subduction interface

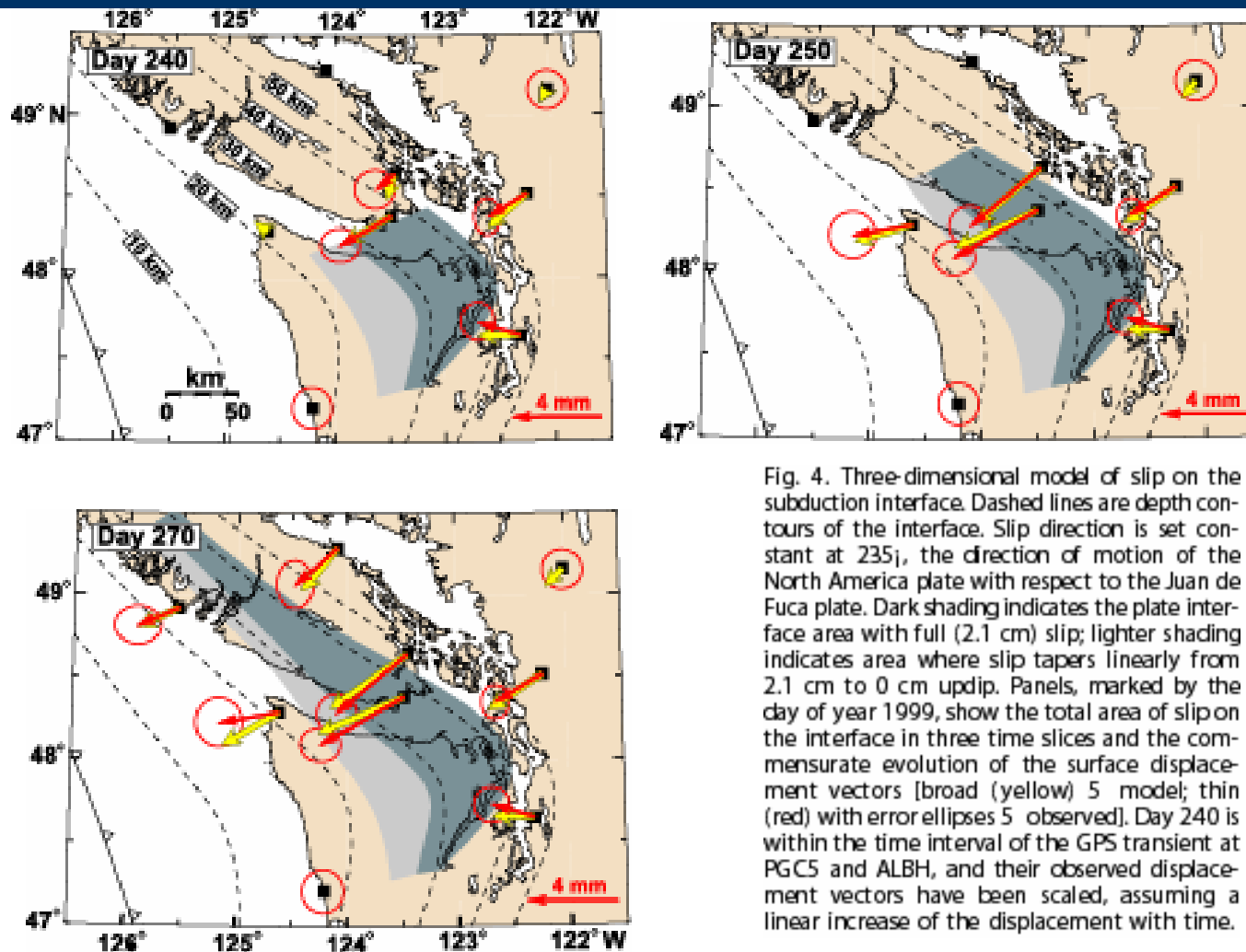
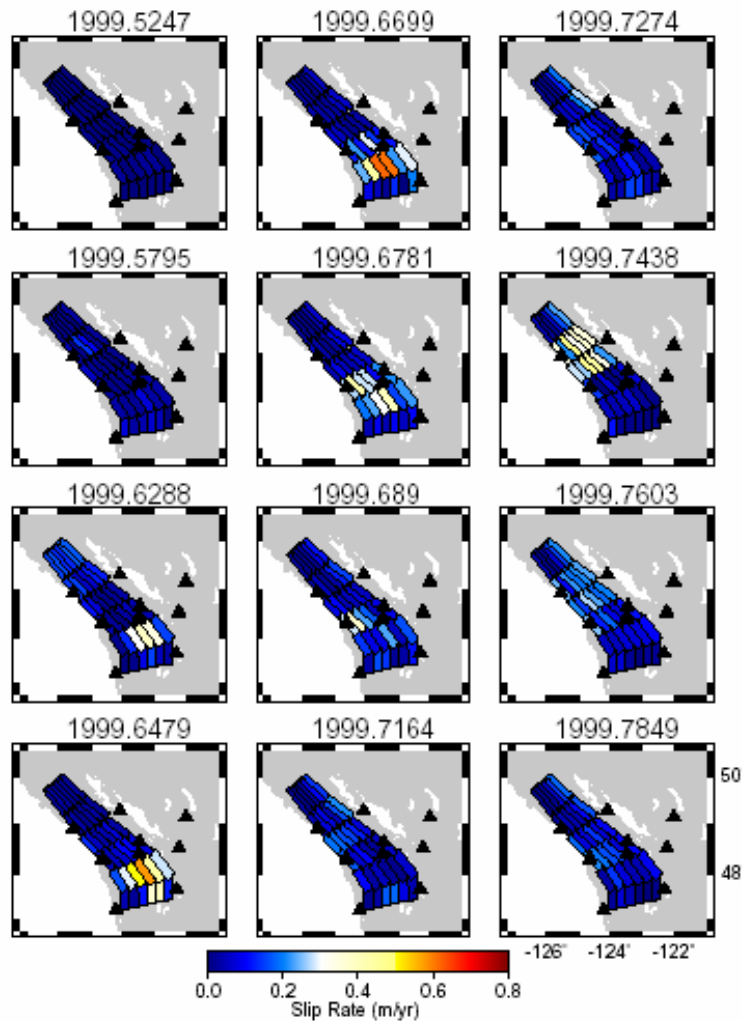


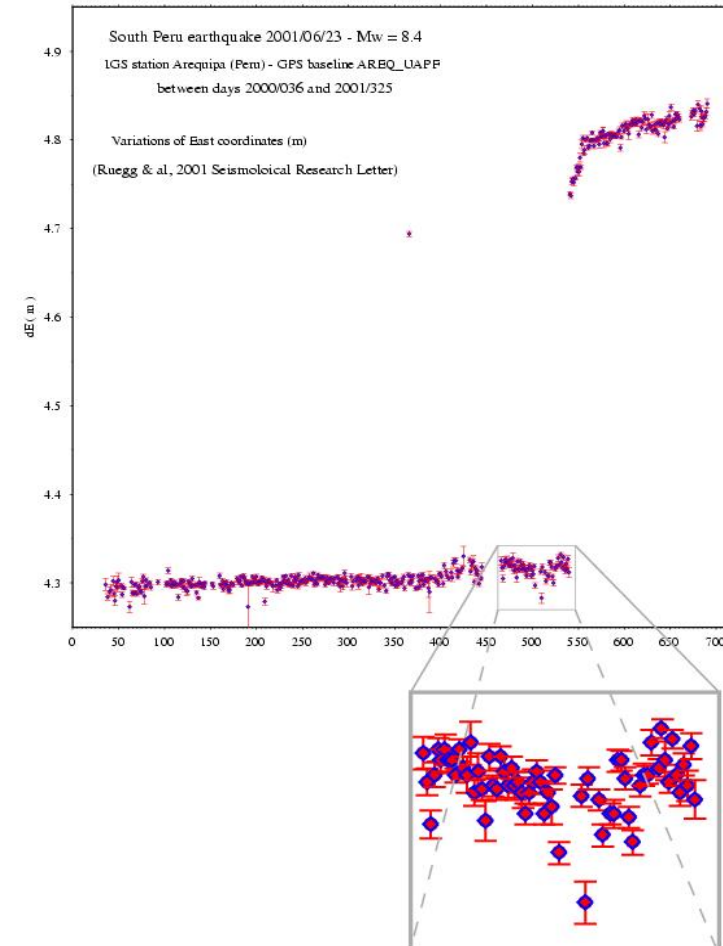
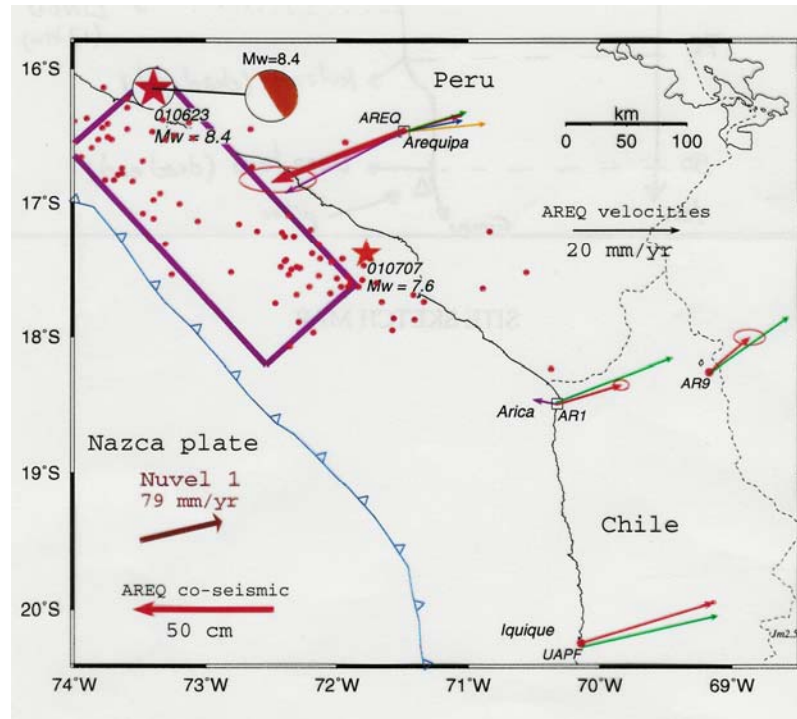
Fig. 4. Three-dimensional model of slip on the subduction interface. Dashed lines are depth contours of the interface. Slip direction is set constant at 235° , the direction of motion of the North America plate with respect to the Juan de Fuca plate. Dark shading indicates the plate interface area with full (2.1 cm) slip; lighter shading indicates area where slip tapers linearly from 2.1 cm to 0 cm updip. Panels, marked by the day of year 1999, show the total area of slip on the interface in three time slices and the commensurate evolution of the surface displacement vectors [broad (yellow) 5 model; thin (red) with error ellipses 5 observed]. Day 240 is within the time interval of the GPS transient at PGCS and ALBH, and their observed displacement vectors have been scaled, assuming a linear increase of the displacement with time.

McGuire and Segall, *G.J.Int.*, 2003.



Maps of the estimated slip-rate as a function of time and station distribution (black triangles).

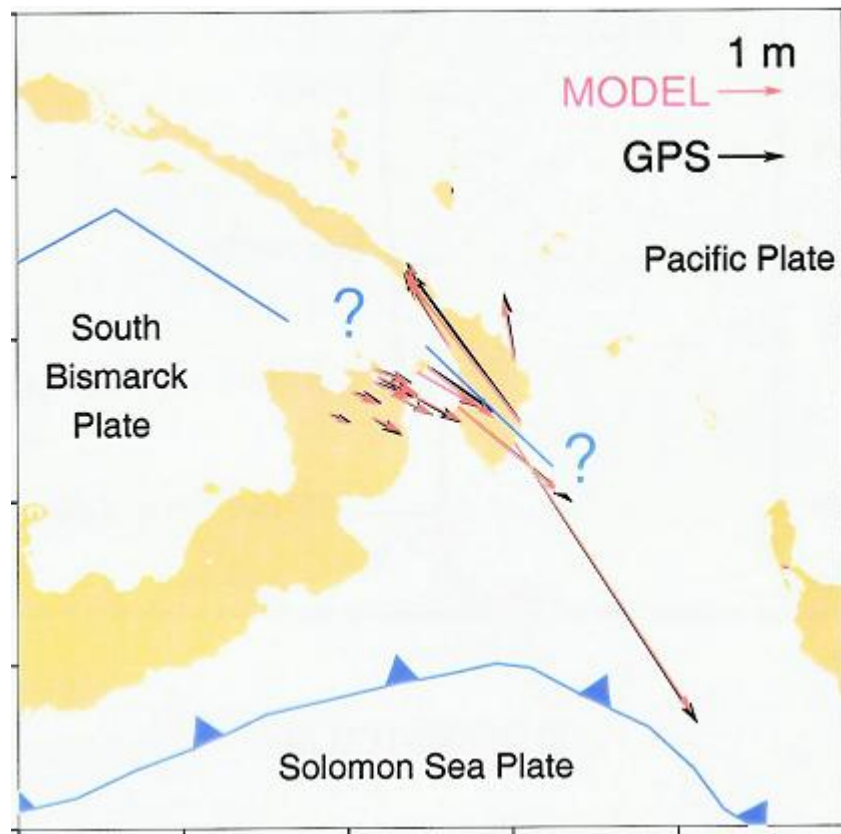
Ruegg et al., 2001, *seismological research letters*



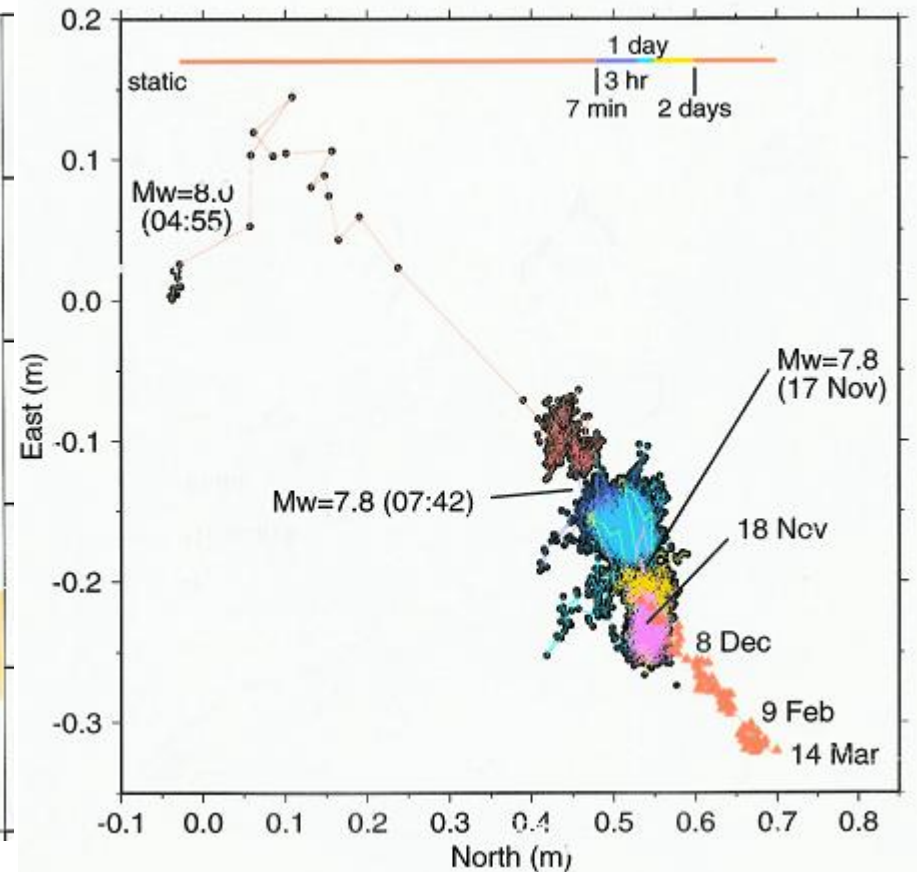
Towards detection of
preseismic motion

Co- and post-seismic in Papua – New Guinea

Tregoning, 2002, unpublished

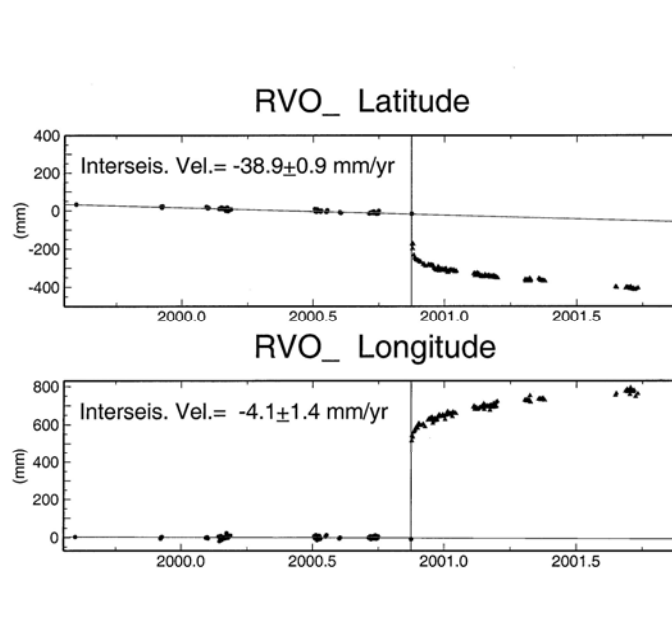


PNG Co-seismic displacements



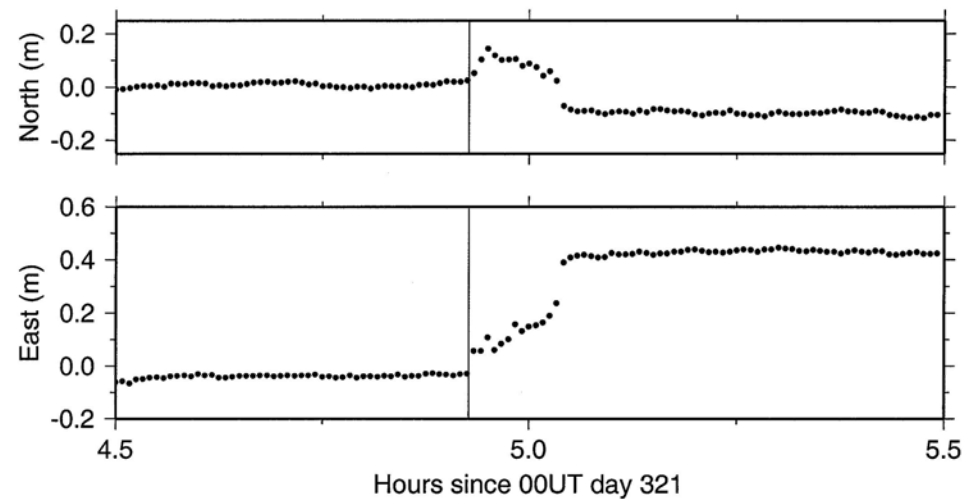
Co- and post-seismic motion of Rabaul

Kinematic positioning during the earthquake



From coseismic jump ...

Kinematic Position of RVO_ during Quake 1



...to kinematic measurement of position **during** the earthquake

Assessing Fault plane slip

Z. Cakir PhD thesis, IPGP, Paris, France, 2003

