Long Term Flexure of the Crust and Sismogenesis, Application to the San Andreas Fault (California)

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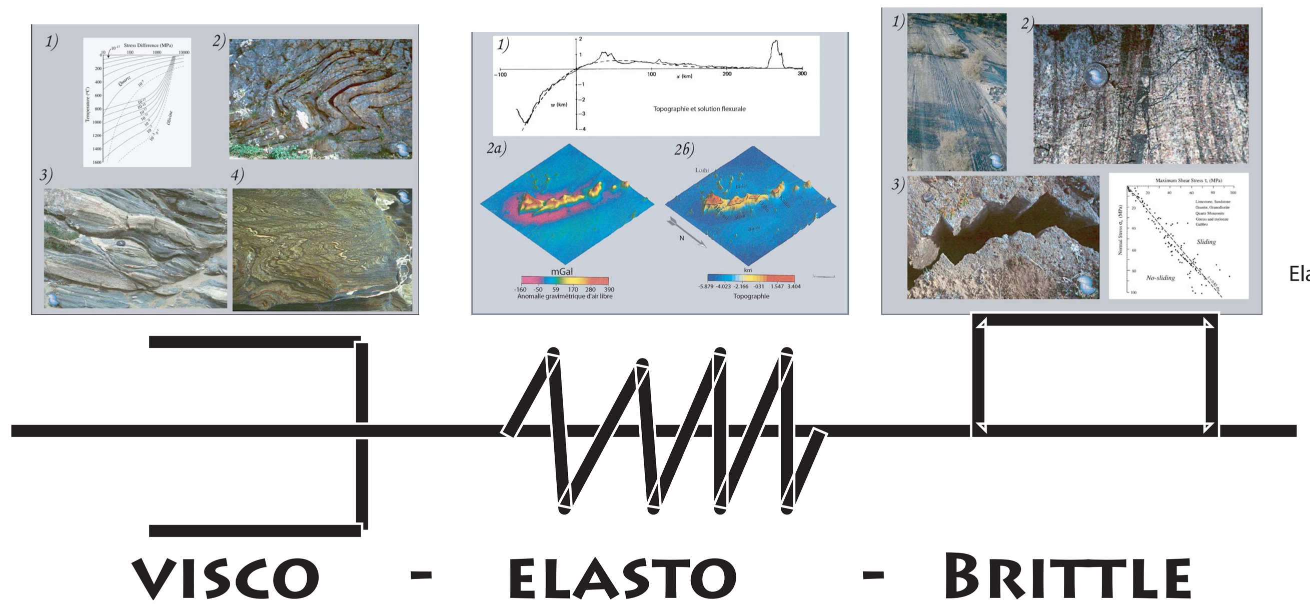
ABSTRACT: However, flexure affects the orientation and magnitude of principal stresses acting within the continental crust. We try to highlight some quantitative and putative links between flexure, the mechanical behavior of faults, their seismic activity at smaller time scale and to apply them to the well documented San Andreas Fault. First impact of flexure is that it allows building differential stresses both at the surface and at the base of an elastic plate without loading it in the center.

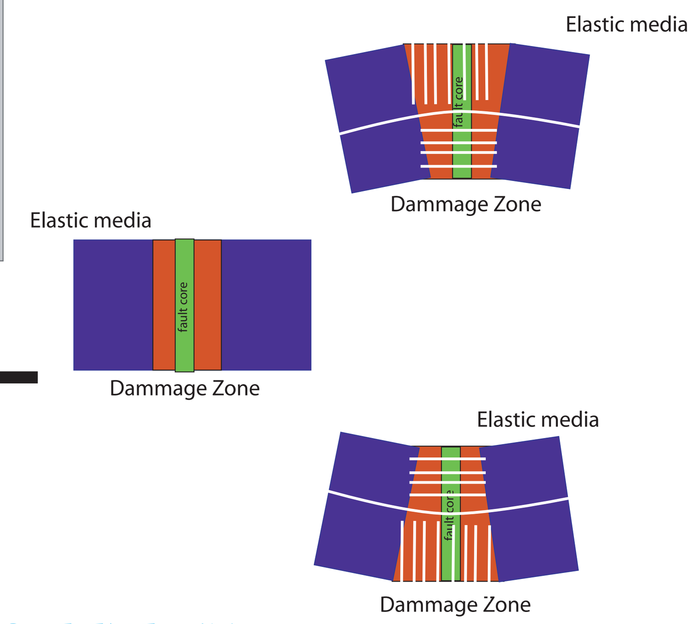
As the state of stress changes with depth favoring vertical joints in the extrado and horizontal joints in the intrado, the depth of formation of fluid barriers which help maintaining fluid over pressure up to lithostatic level, i.e. low effective strength, happens to be control by flexure. This model seems to apply at least for strike slip faults like the San Andreas fault.

Elastic Strength of the crust as A link Between Quakes and Geodynamics?

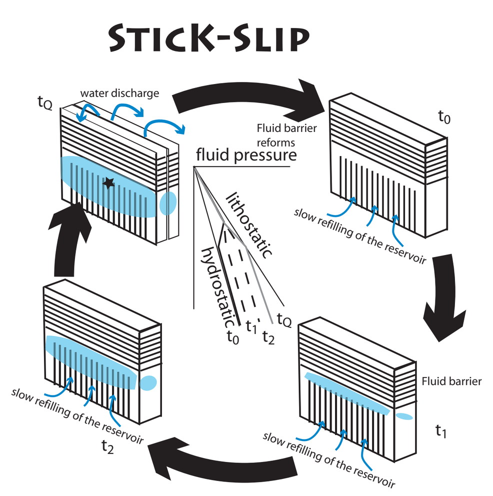
The simplest rheological model for the crust in shear is:



Elastic Flexure Controls the orientation of joints



And therefore ... . the fluid path ways



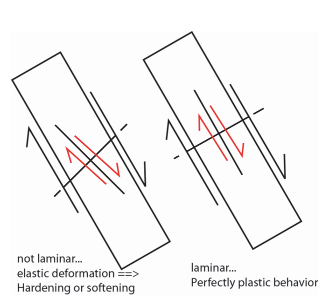
Elastic strain are small, however only elasticity may store energy over long time scale...

Do we observe that → somewhere ?

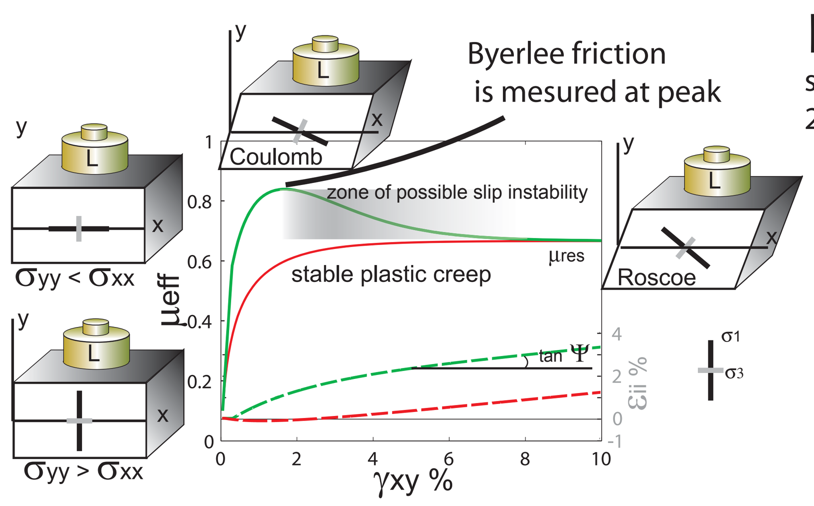
Faults and Quakes: A pseudo-static point of view

Mechanical Statements

I Continuum mechanics applies. Faults have a thickness in which Morh Coulomb elastic-plastic rheology applies and diplacement on the interfaces between the fault and surrounding media is compatible shear and normal component of the stress on the fault plane are continuous, only the fault parallel stress component can be dicontinuous.



Stress is allowed to rotate within the shear band, depending on the sense of rotation, the deviatoric stress in the surrounding elastic media will rise (hardening) or drop (softening)



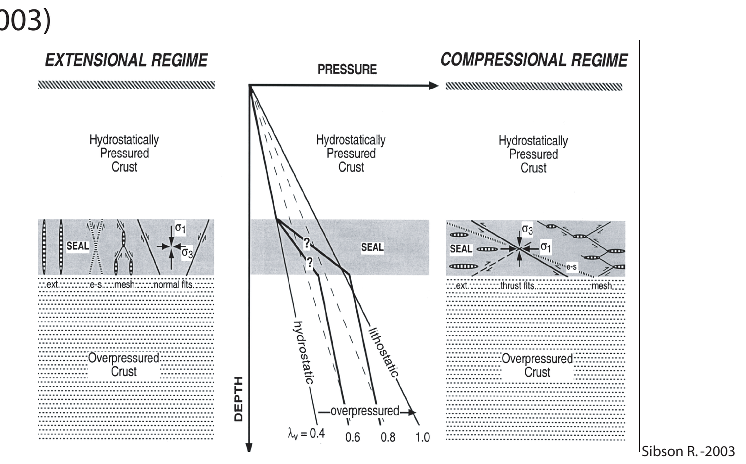
II Although it is possible to trigger a slip instability in a hardening material under dynamic loading (i.e. during an earth quake, see Leroy and Ortiz 1989). There should be an initial zone (patch) in which slip instability occurs in the static regime to initiate an earthquake.
Hence, the initiation of earthquake necessite some effective strain softening.

III This initial strain softening cannot be related to a modification of the nominal/ lab friction of the material because:

a) it is reproducible (happend at each rupture)
b) the amount of strain is small (otherwise there would be significant precursor to earthquakes)

Hence, I favour structural softening effects over wear.

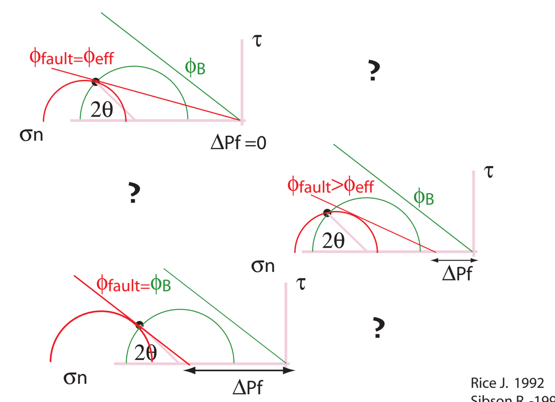
IV High fluid pressure, nearly lithostatic, may only be sustained if the sealing is in a compressive setting (Sibson 2003)



Effective Friction, stress inversions

Inverting strain mesurements issued from borehole breakouts, earthquake focal mechanism or microfracture one can get a the orientation of principal stress axis in the surrounding of faults.

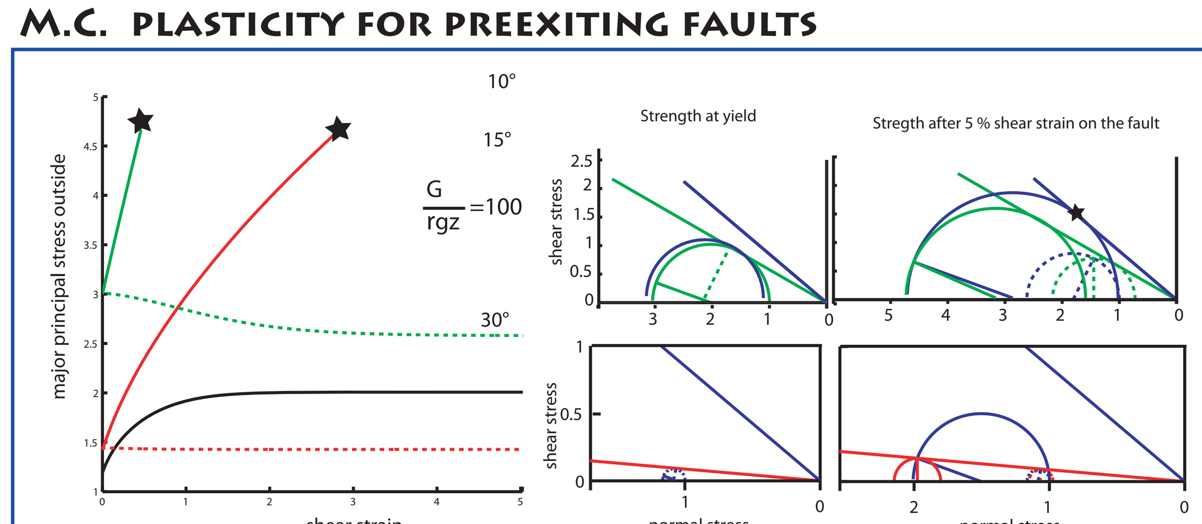
Comparing this orientation to the orientation of the fault one finds the effective friction of the fault.



However, asumimg continuity of stress there are many possible state possible inside the fault (red circle)
Therefore, this effective friction does not tell anything about the strength of the fault (the radius of the red circle).

Fortunately, using a full rheological computation instead of solely a rupture criteria it is possible to get more informations

M.C. plasticity for preexiting faults



Well oriented fault (plain lines) : friction angle compatible with lab experiments allows for larger stress drop and favor slip instability.

Very badly oriented fault (dashed lines) cause hardening and allow stable creep to occur only for effective friction approx. equal to the orientation vs. s1). For higher effective friction new fault form.

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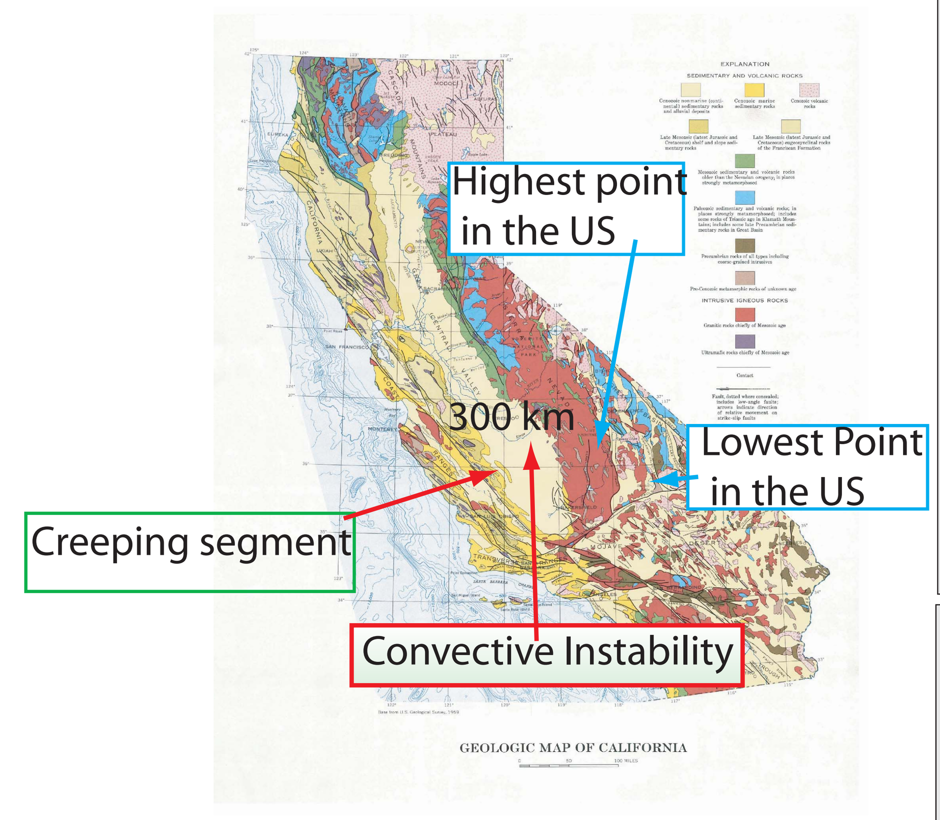
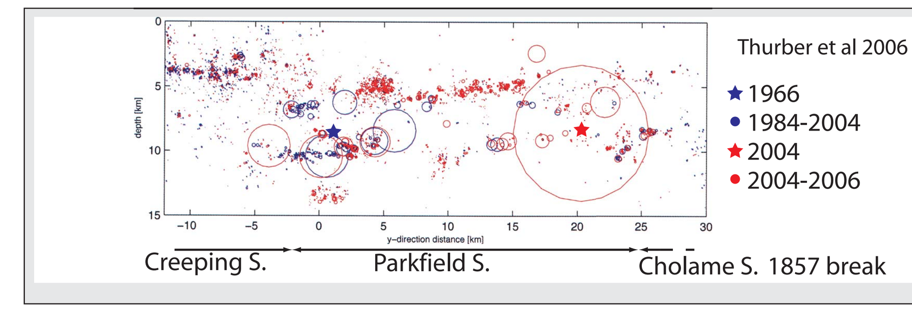
Application to the San Adreas Fault

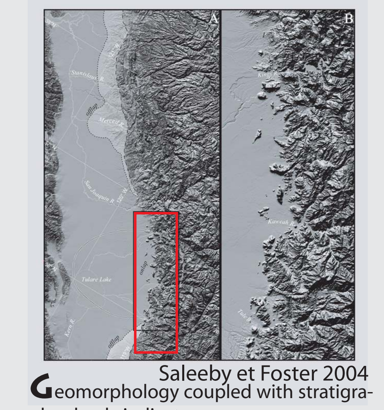
A coincidence or not ? The facts...

The San Andreas Fault is a system of dextral strike slip faults which runs from the Gulf of California (Mexico) to the Mendicino triple junction (Washington, USA). This plate boundary has been initiated 30 Myr ago as the ridge, which separated the Faralon plate from the Pacific plate, collided with the North American Plate (Atwater and Stokes 1998). The fault is segmented along strike and we are mainly interested with three segments which are located along the border of the Sierra Nevada micro-plate. In this area, the main fault is orthogonal to the regional maximum horizontal stress (Towend and Zoback 2001) and has therefore been recognized as a weak fault . However, the apparent frictional weakness of the fault does not prevent big earthquakes such as the one which destroy San Francisco in 1906 to occur In the middle of those two seismic segments, a 150 km long segment is creeping aseismically from Parkfield to San Juan Bautista. A question arises from those observations: what factor controls the apparent contrasting behavior of the fault along strike.





Flexure



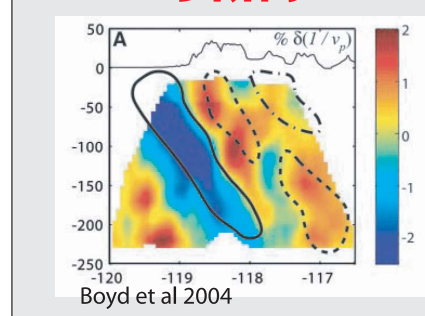
Saleeby et Foster 2004

Geomorphology coupled with stratigraphy clearly indicate:

1 : A long term (5-10 Myr) flexural tilt of the Sierra Nevada micro-plate all along its axis

2 : A recent increase of the downward tilt at the level outlined by the red rectangle

Drips



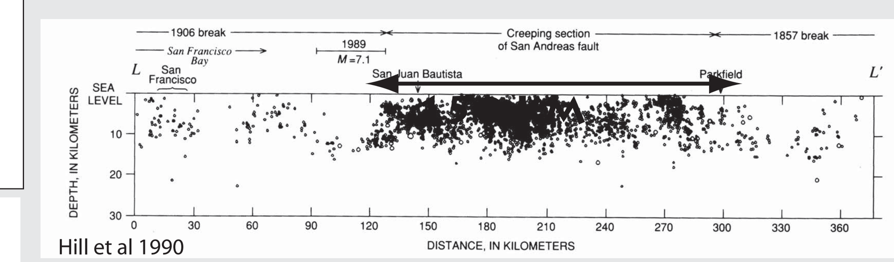
Boyd et al 2004

Seismic tomography outlines the presence of a fast body sinking toward the east beneath the Great Valley

while

Reciever functions show that East of this anomaly, the Moho has very weak signature.
Both are interpreted as the signature of the removal of the ultra-mafic root of the Sierra Nevada Batholith.

Quakes



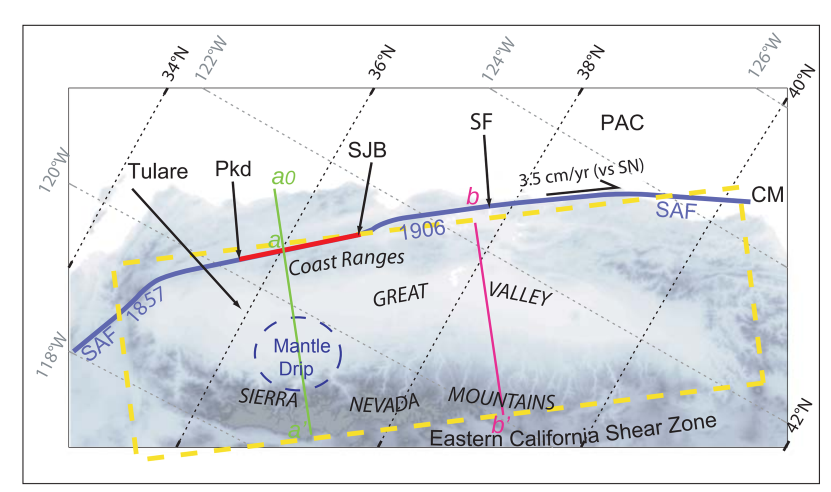
Hill et al 1990

The creeping segment is an 150km long band which concentrates a lot of seismicity at shallow (<12km) depths. It contrast with the size mean size of the body of ophilite in the Franciscan Complex. (see the ultra maphic body on the general map of california).

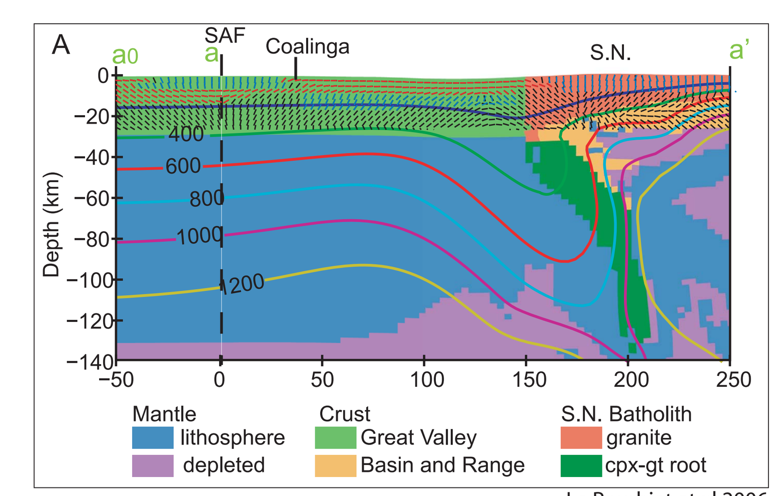
The seismic activity of this segment contrasts with its surrounding segments which ruptured with destructive earthquakes (Loma Prieta (1989), San Francisco (1906) and Carrizo Plain (1857)) .

Modeling it

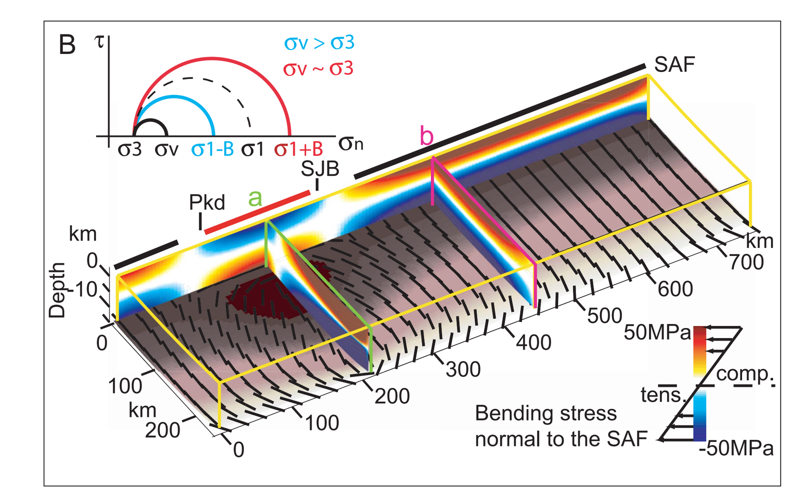
Localisation of the different models and observations



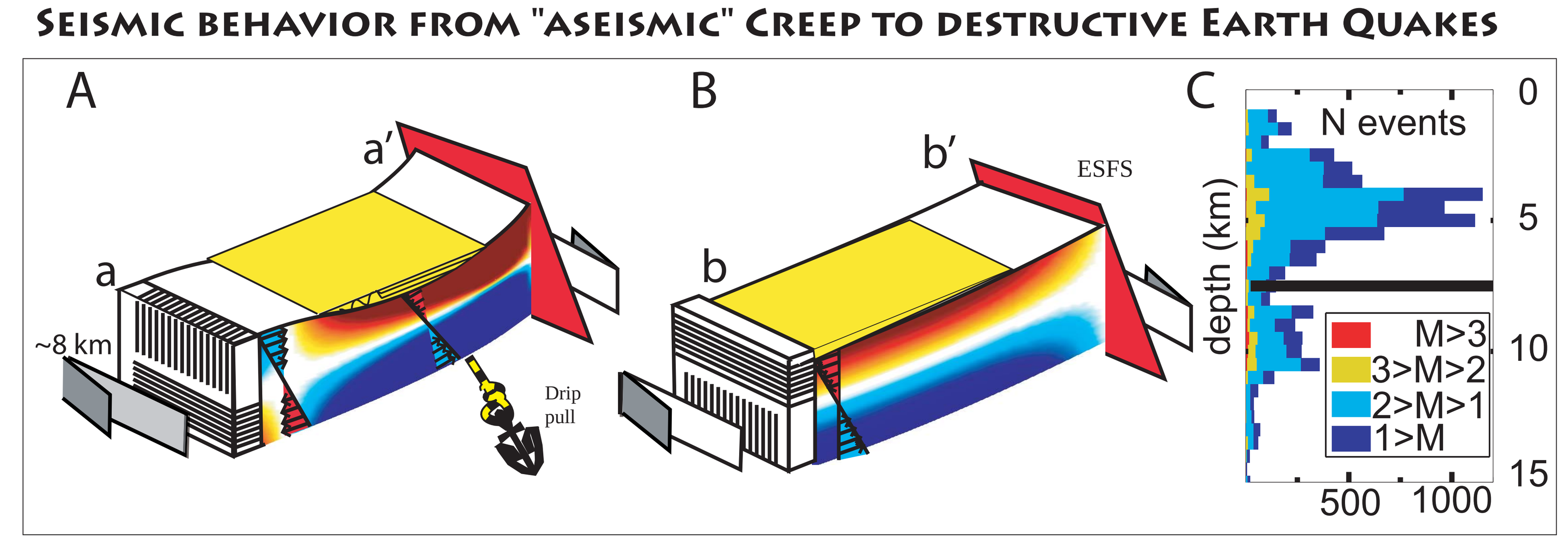
Results of the 2D plane strain thermo-mechanical model



Results of 2D plane stress model determining flexural bending due to convective instability



Variation of jointing along the strike of the SAF causes the contrasting seismic behavior from "aseismic" creep to destructive earth quakes



Parametric study of the effect of coupling and plate thickness

Presented model