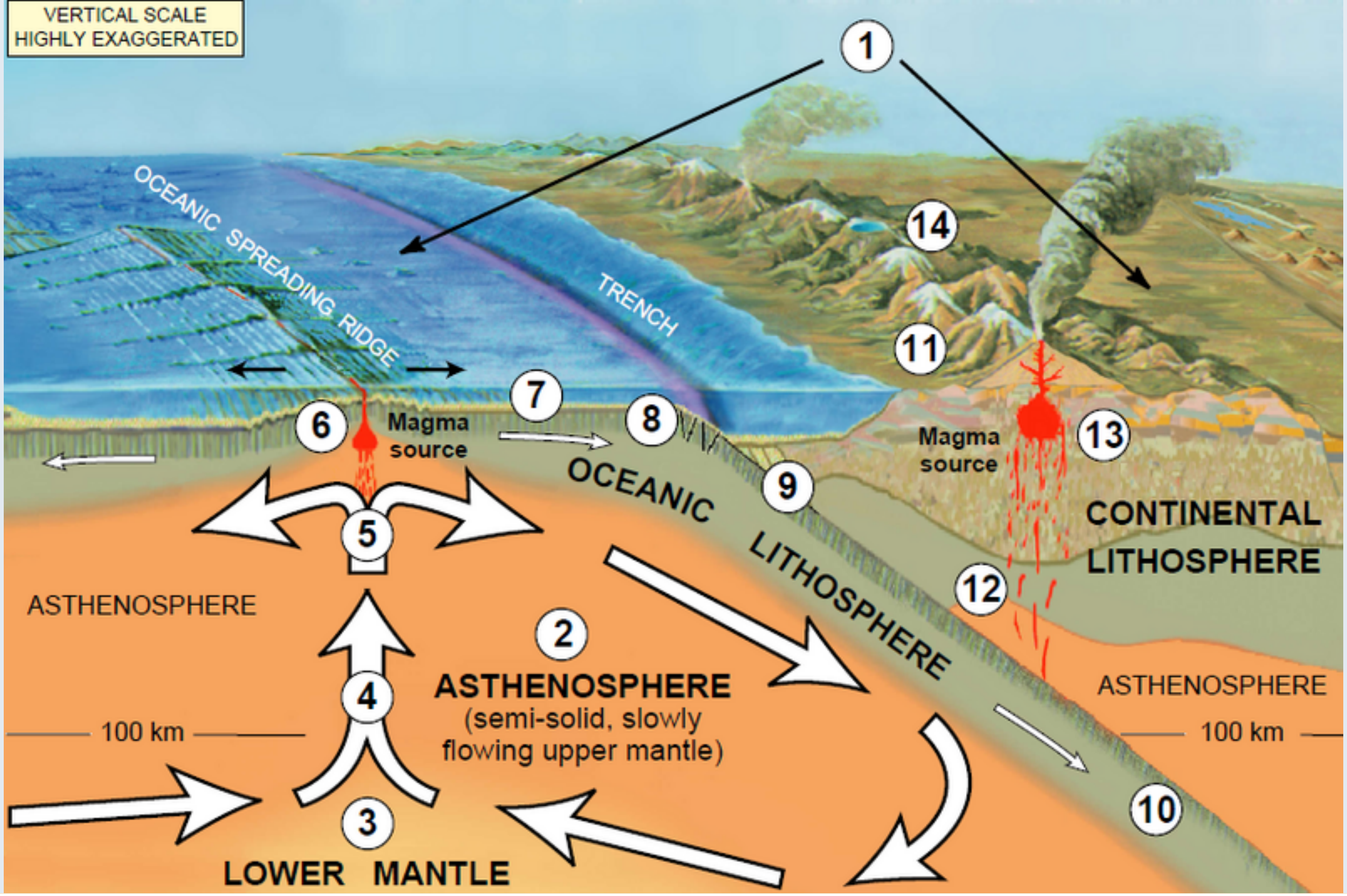
LAKE/OCEAN LOADING FLEXURE

Beineng ZHANG, SIO 234, NOV-23-2016



http://volcanoes.usgs.gov/about/edu/dynamicplanet/nutshell.php

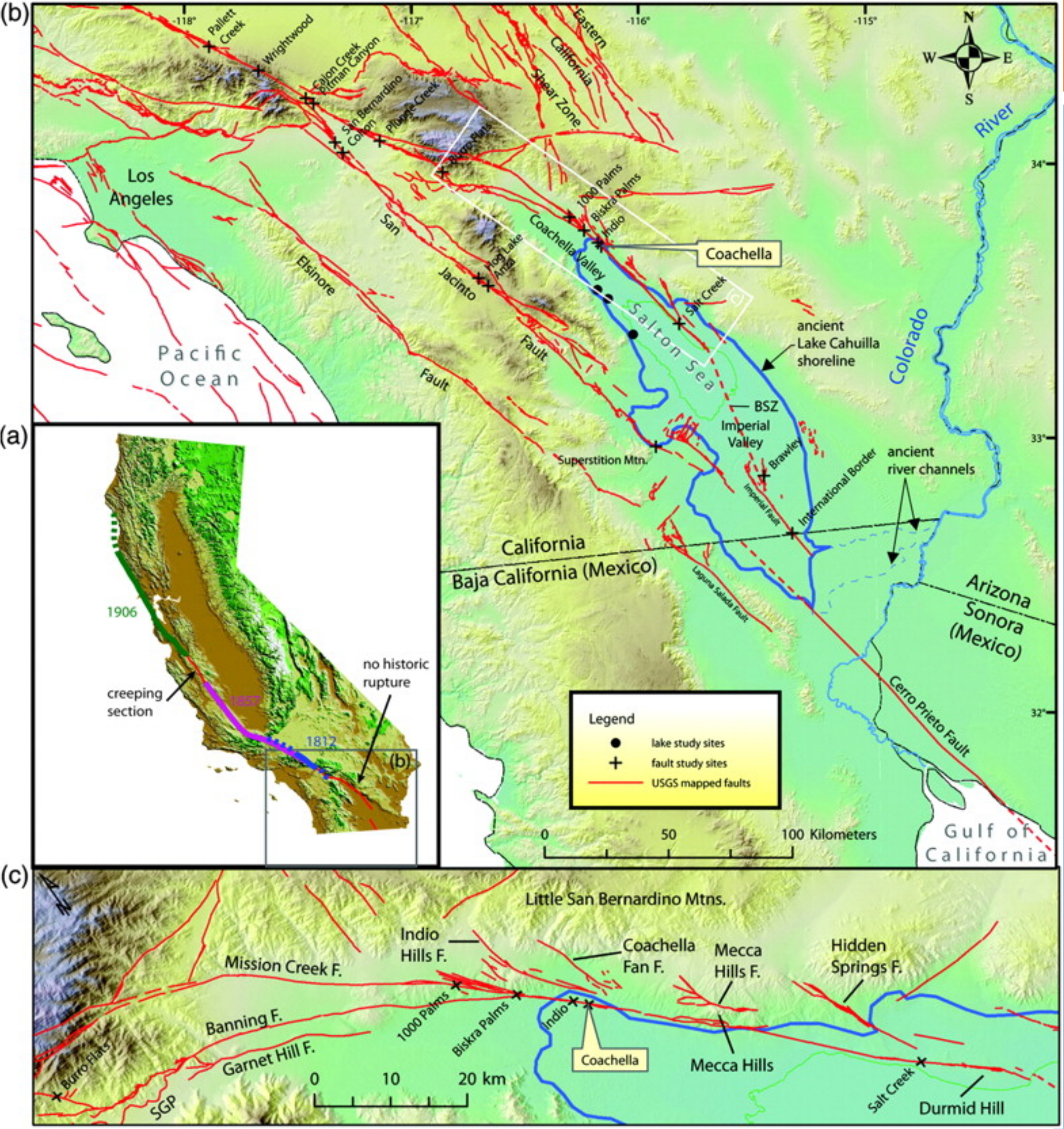
WHY INVESTIGATING LAKE/OCEAN LOADING

Apart from tectonic loading, other sources may also alter the state of stress of plates, thus contributing to the modulation of earthquake cycles.

LAKE LOADING

Modulation of the earthquake cycle at the southern San Andreas fault by lake loading

(Luttrell et al. , 2007)



REGION OF INTEREST

SALTON TROUGH

Active Fault System:
San Andreas Fault
San Jacinto Fault,
Imperial Fault

Potential to produce large earthquakes, but no major ruptures on SAF and SJF for the past 300 year

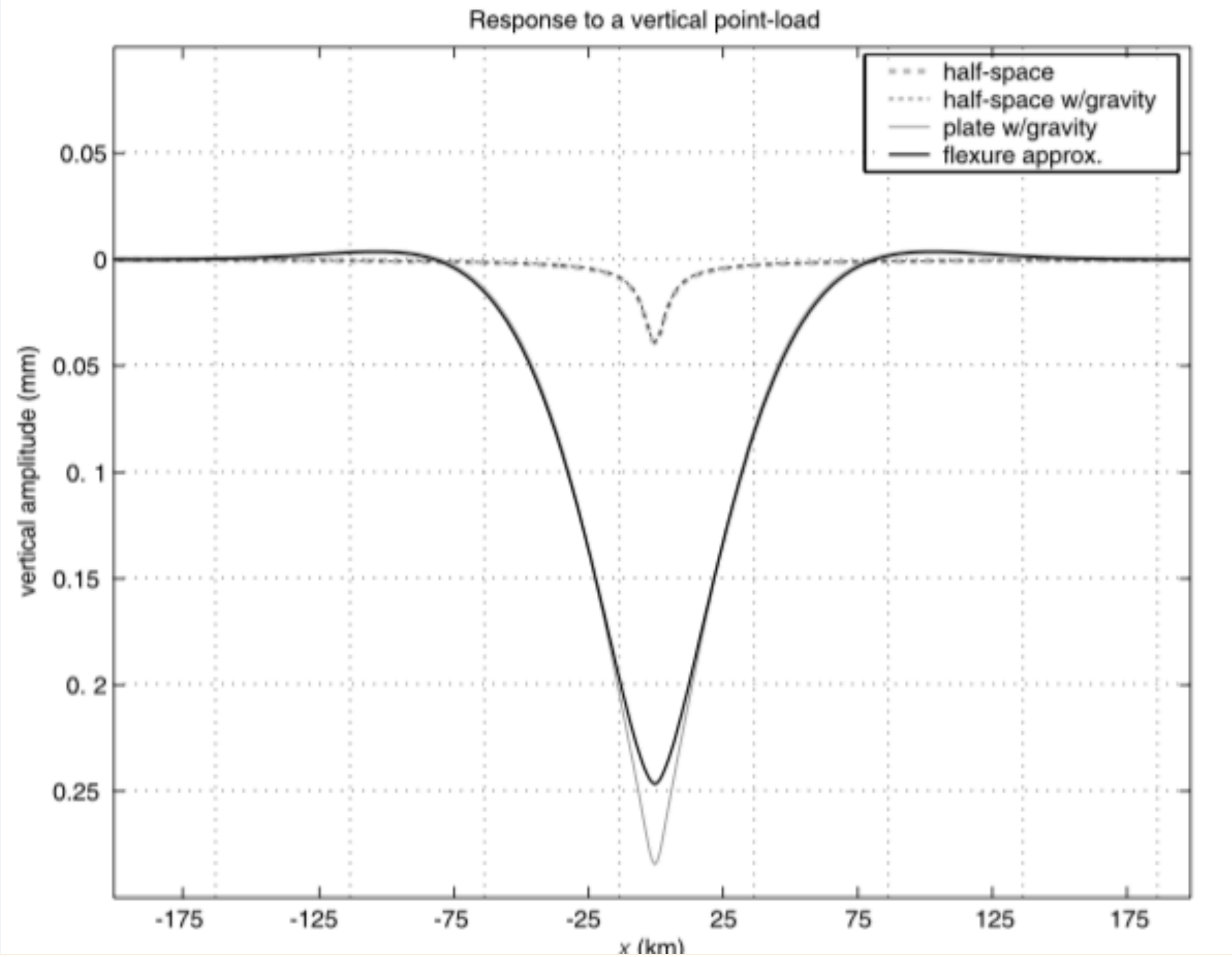
Philibisian et al. (2011)

MODEL

- A Thick Elastic Plate Overlaying a Viscoelastic Half-Space
- Coulomb Stress (Readiness to Rupture)
  $$\sigma_C = \sigma_s - \mu_f \sigma_n$$
- Change in Normal Stress Due to Lake Level Changes

1. Lithosphere Bending
2. Pore Pressure (decrease normal stress)

Smith and Sandwell (2004)



A Thick Elastic Plate Overlaying a Viscoelastic Half-Space

Short-term: Viscoelastic half-space dominates.

Long-term: Elastic plate dominates.

SOLUTION of a Thin Elastic Plate

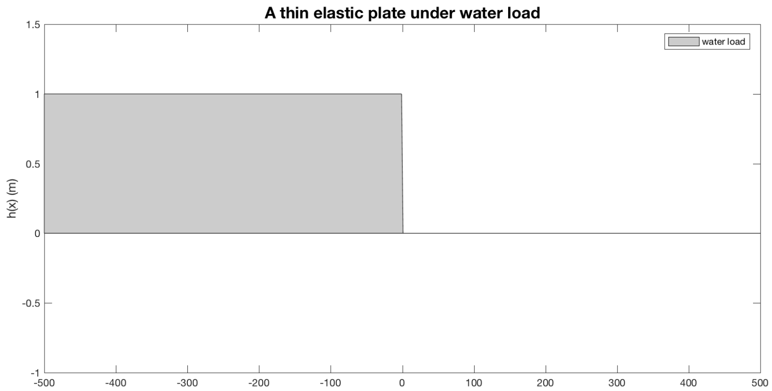
- Convolve the line-load solution with lake load expression

$$u(x) = \int_{-\infty}^{\infty} w(x^{'}) f(x - x^{'}) dx^{'}$$

Where

$$w(x) = \frac{V_o \alpha^3}{8D} e^{-\frac{x}{\alpha}} (cos\frac{x}{\alpha} + sin\frac{x}{\alpha})$$

(Turcott&Schubert 3.130)



Lake load

$$f(x) = 1 - H(x)$$

Flexural Parameter
$\alpha = \left[\frac{4D}{(\rho_m - \rho_w)g}\right]^{\frac{1}{4}}$
Flexural Rigidity
$D = \frac{Eh^3}{12(1-\nu^2)}$
Heaviside(Step) Function
$H(x) = 1 \ for \ x \geqslant 0$

DERIVATION(1)

$$u(x) = \int_{-\infty}^{\infty} w(x^{'}) f(x - x^{'}) dx^{'}$$

$$= \int_{-\infty}^{\infty} w(x^{'}) \left[1 - H(x - x^{'})\right] dx^{'}$$

Expect Odd Function. Consider Half-Space.

$$u(x) = \int_{0}^{\infty} w(x^{'}) \left[1 - H(x - x^{'})\right] dx^{'}$$

Where

$x < x^{'}$ $\quad 1 - H(x - x^{'}) = 1$

$x \geqslant x^{'}$ $\quad 1 - H(x - x^{'}) = 0$

DERIVATION(2)

$$u(x) = \int_0^x w(x^{'})dx^{'}$$
$$= \frac{V_o\alpha^3}{8D}\int_0^x e^{-\frac{x^{'}}{\alpha}}(cos\frac{x^{'}}{\alpha} + sin\frac{x^{'}}{\alpha})dx^{'}$$

Integration by Parts

$$\int e^{-\frac{x}{\alpha}} sin\frac{x}{\alpha}dx$$

$$j = e^{-\frac{x}{\alpha}} \qquad dk = sin\frac{x}{\alpha}dx$$

$$dj = -\frac{1}{\alpha}e^{-\frac{x}{\alpha}}dx \qquad k = -\alpha cos\frac{x}{\alpha}$$

$$\int e^{-\frac{x}{\alpha}} sin\frac{x}{\alpha}dx = -\alpha e^{-\frac{x}{\alpha}} cos\frac{x}{\alpha} - \int e^{-\frac{x}{\alpha}} cos\frac{x}{\alpha}dx$$

FINAL EXPRESSION

The result yields

$$u(x) = \frac{V_o \alpha^3}{8D} \left[-\alpha e^{-\frac{x'}{\alpha}} cos \frac{x'}{\alpha} \right] \Bigg|_0^x$$

$$u(x) = \frac{V_o \alpha^4}{8D} \left(1 - e^{-\frac{x}{\alpha}} cos \frac{x}{\alpha} \right)$$

Solution of Lithosphere Bending Under Lake Load

$$u(x) = \frac{V_o \alpha^4}{8D} \left(1 - e^{-\frac{|x|}{\alpha}} cos \frac{|x|}{\alpha} \right) sign(x)$$

NORMAL STRESS

$$\epsilon_{xx} = -z_o \frac{d^2u}{dx^2}$$

$$\sigma_{xx} = \frac{E}{1-\nu^2}\epsilon_{xx}$$

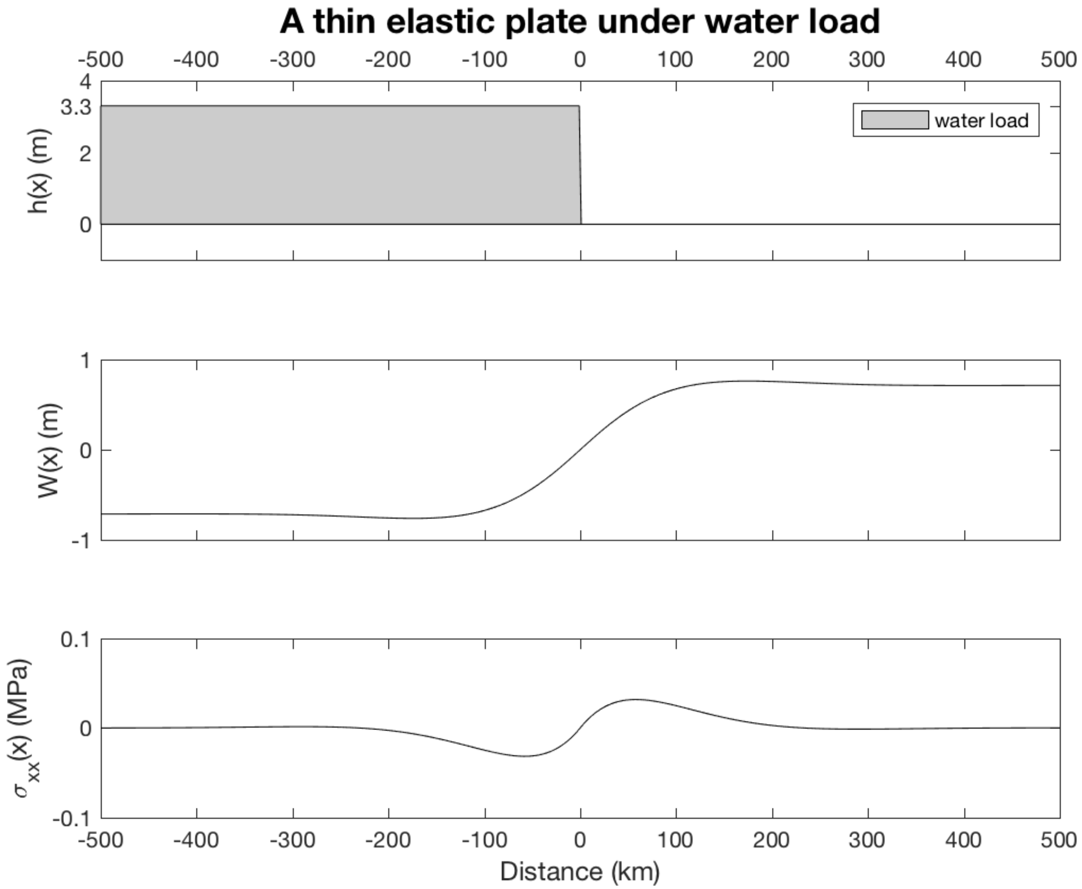
$$\sigma_{xx} = \frac{3V_o\alpha^2}{H^2}(\frac{z_o}{H})e^{-\frac{|x|}{\alpha}} sin\frac{|x|}{\alpha} sign(x)$$

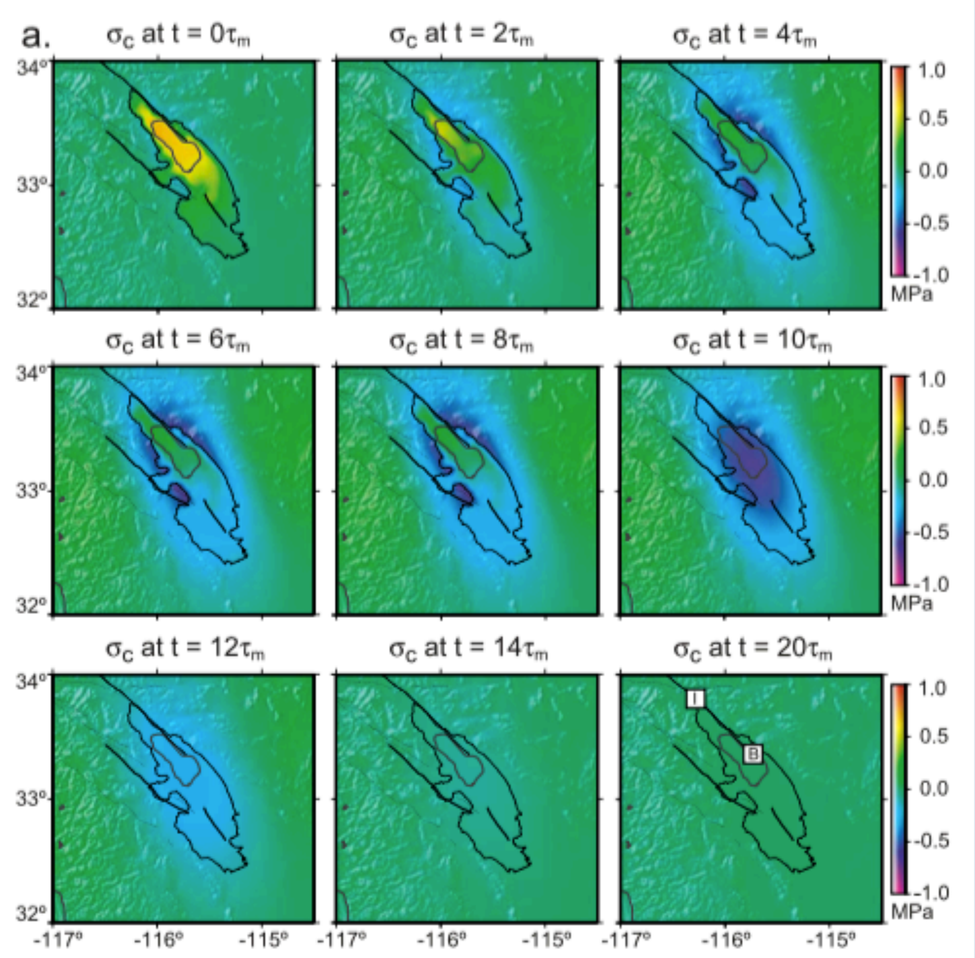
Values Chosen
Young's Modulus
$E = 70\ GPa$
Poisson's Ratio
$\nu = 0.25$
Plate Thickness
$H = 30\ km$
Seismogenic Depth
$z_o = 5\ km$
Line Load
$V_o = \rho_w gh$

A Thin Plate at Water Depth = 3.3km

Without effect from pore pressure,

the plate experiences compressional deformation in the lake and tensile deformation outside.

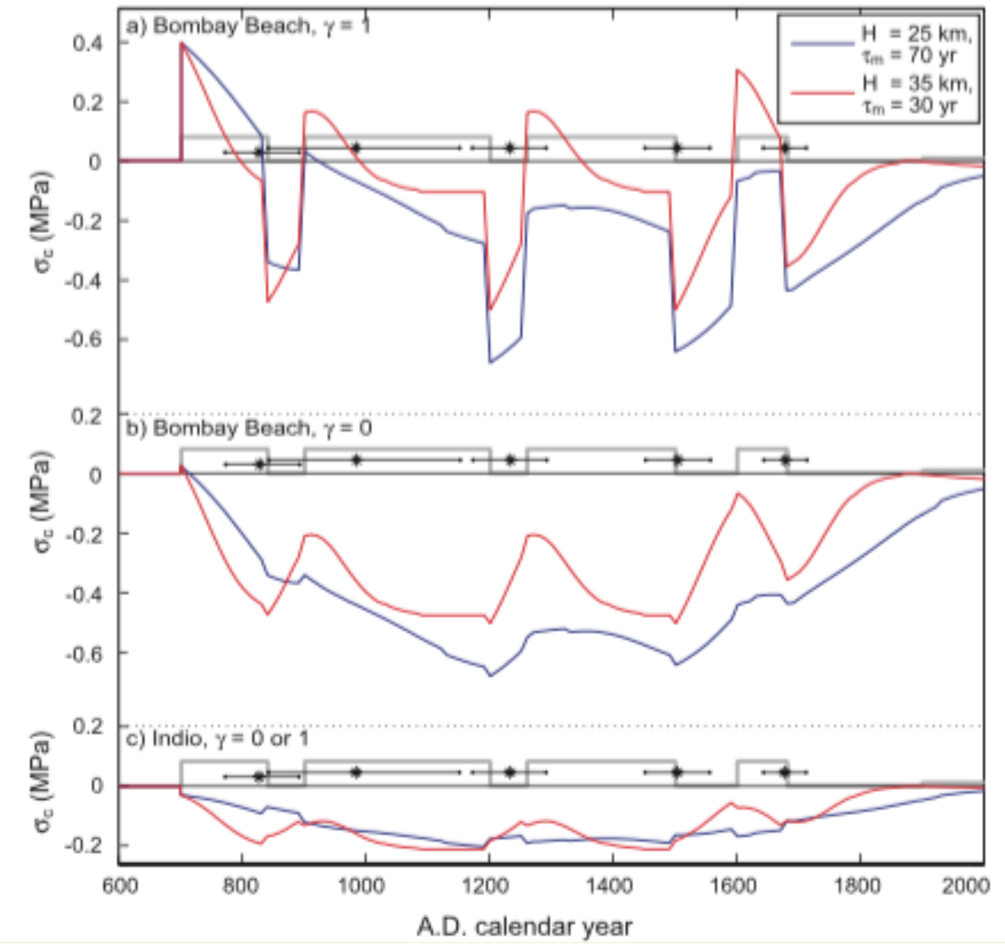




Luttrell et al. (2007)

Stress Field Over Time

Coulomb stress perturbations due to a single cycle of lake formation and desiccation. The lake fills at 0tm, remains full, and falls at 10tm. Negative Coulomb stress decreases the likeliness of rupture.



Luttrell et al. (2007)

Coulomb Stress vs. Earthquake Cycle

2 Best Fitting Models (H=25km, Tau=70yr) and (H=35km, Tau=30yr)

Perturbation 0.2–0.6 MPa within the lake and 0.1–0.2 MPa outside the lake

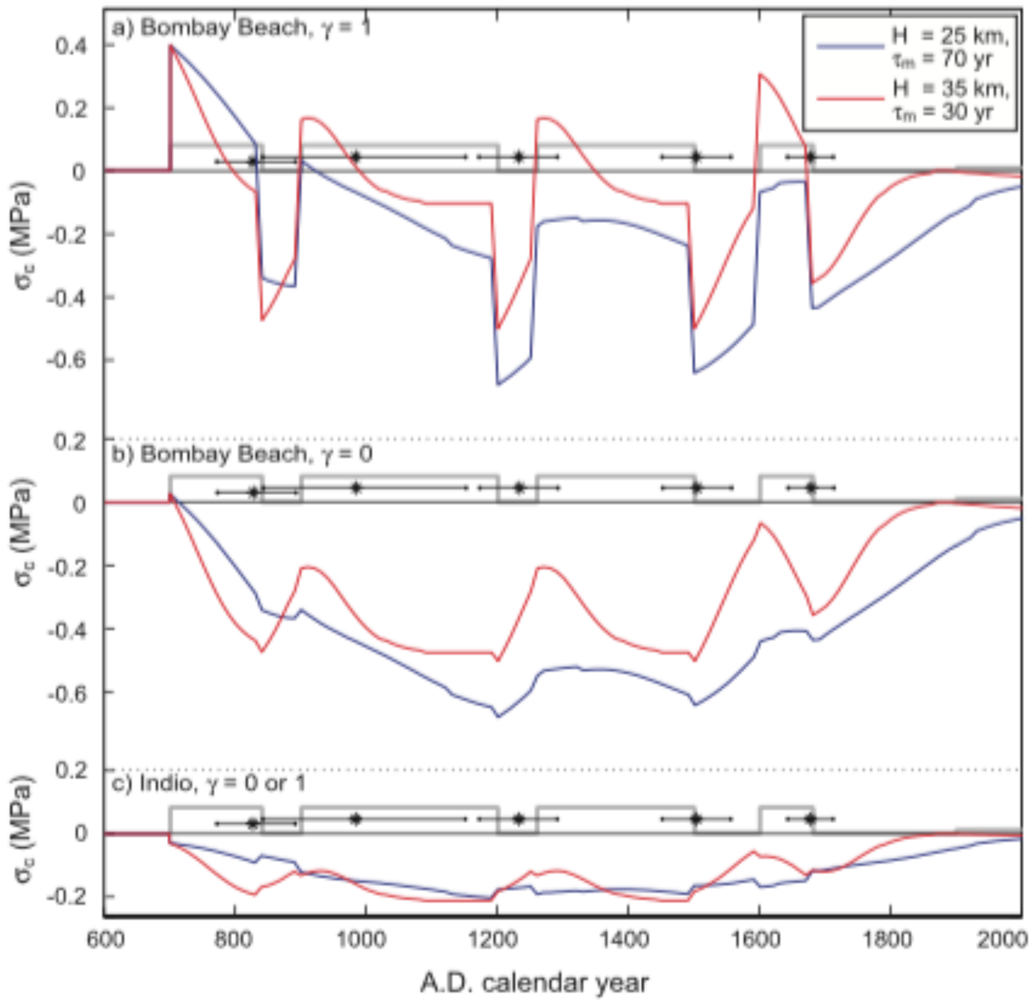
An order of magnitude smaller than Coulomb stress associated with tectonic loading. (Therefore lake perturbations are likely to modulate the earthquake cycle only when faults are near critically stressed.)

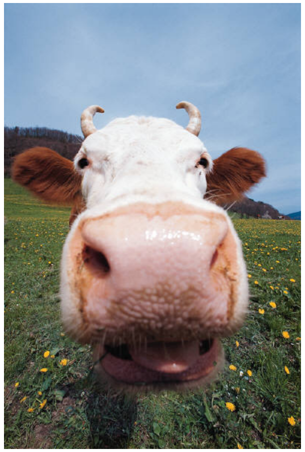
OCEAN LOADING

Ocean loading effects on stress at near shore plate boundary fault systems

Luttrel and Sandwell (2010)

THANK YOU





Luttrell et al. (2007)