MODELLING THE CENOZOIC UPLIFT OF THE SIERRA NEVADA

Laetitia Le Pourhiet Mike Gurnis Jason Saleeby

GEODYNAMIC CONTEXT :

At 28 Ma, the ridge separating the Faralon Plate from the pacific plate "collided" the North American plate South of the Sierra Nevada resulting in the end of the subduction regime and probably heating of the N. american lithosphere by the base.
In terms of plate tectonics s.s. (the shell kinematic model for earth), the Faralon plate disappears and is replaced by Juan de Fuca plate; meanwhile, a slab windows opens along the path of the northward migration of the Mendicino triple junction.

Kinematics the Pacific plate

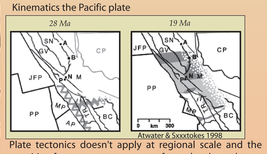
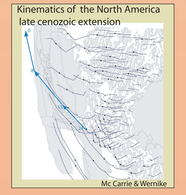


Plate tectonics doesn't apply at regional scale and the transition from convergent to transform plate boundary at the western end of the north american plate (CP here) is accompagned by large scale diffuse extension in the basin and range and more recently by the uplift of the Sierra Nevada.
From kineamtics reconstruction it is noticable that a major events take place in the Late Miocene time (12-6 Ma). This (ese) event(s) affect both the regional(continental) and the global (oceanic) kinematics and lead to the formation of the modern San Andreas Fault and predate the uplift of the Sierra

Kinematics of the North America late cenozoic extension

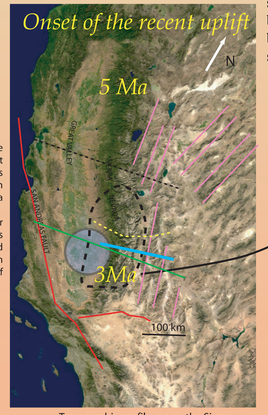


Kings river/Bishop discontinuity

Strike of Normal faults

location of the dense batholitic root

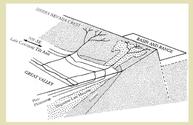
location of the fast sismic velocity anomaly



Topographic profile across the Sierra

Although it was formed 90 to 70 Ma ago, the Sierra Nevada is currently standing at very high elevation. Moreover, gravimetric and seismological data show that its relief is not suported by a crustal root.
Quantitative geomorphologic studies as well as sedimentological evidences indicates that the Sierra has been uplifted only recently (8-3 Ma depending on authors but they all agree on simultaneity of the uplift along the structure).

GEOMORPHOLOGY OF THE NORTHERN SIERRA

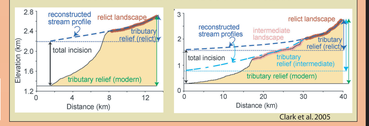


Unruh (1991)

STEEP FACE OF THE SIERRA NORMAL + STRIKE SLIP MOTION

High Heat Flow and Active Volcanism

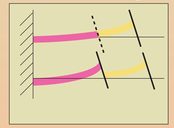
GEOMORPHOLOGY OF THE SOUTHERN SIERRA



Clark et al. 2005

FIRST QUESTION: HOW TO CREATE TOPOGRAPHY WITHOUT A ROOT

hypothesis 1:
The Sierra Nevada is a mega fold



hypothesis 2:
The Sierra Nevada is a tilted normal fault block.

hypothesis 3 : The "sudden" replacement of a cold lithosphere by a buyant asthenosphere beneath the Sierra has caused its uplift and is the force that support the present topography.

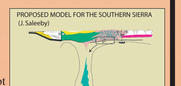
Hypothesis 1 and 2 requires elastic strength to maintain the topography, while hypothesis 3 relates to a change in mass distribution beneath the Sierra causing an isostatic (i.e. viscous) reajustement of the topography.

Hypothesis 2 would lead to the conclusion that the uplift of the Sierra occurs in response to the westward propagation of the extension in the Basins and Ranges province

Hypothesis 3 would state that the uplift of the sierra is due to :

- the opening of a "slab window" related to the migration of the mendicno triple junction
- the removal of a dense eclogitic root

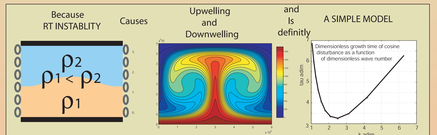
PROPOSED MODEL FOR THE SOUTHERN SIERRA (J. Saleeby)



The simultaneity of the uplift of the crest of the Sierra along the stucture seems to favour the removal hypothesis to the slab window one but there is no evidences for the existence of such a body north of the Fresno/Bishop line where the subidense an uplift pattern favour hypothesis 2.

RT INSTABILITIES IN THE LITHOSPHERE ?

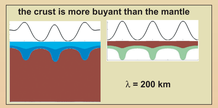
We first tested if the assumption of purely RT INSTABILITY (i.e. iso-viscous layer in an initially gravitationally unstable position, Growth rate is controled by the thickness of the layer and the viscosity of the "strongest layer"



(IF WE ASSUME THE LITHOSPHERE IS A VISCOUS BODY AT 3Ma TIMESCALE)

Lithospheric scale RT INSTABILITY has been proposed as a possible mechanism for the delamination of the Sierra Nevada Batholith.

BUT



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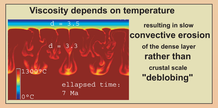
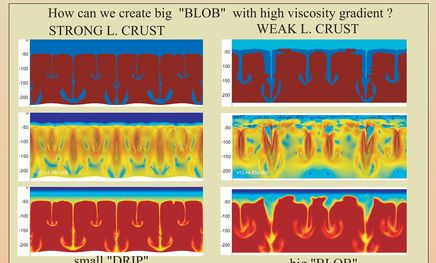


How can we create big "BLOB" with high viscosity gradient ?



delamination along shear zone rather than viscous RT instability

TOWARDS REALISTIC MODEL FOR THE SIERRA...

Physical model

Well established physics

complete equation of Newtown + thermal diffusion and advection

$$\rho g_i - \frac{\partial \sigma_{ij}}{\partial x_j} = \rho \frac{\partial V_i}{\partial t} \qquad \frac{DT}{Dt} = \frac{\partial}{\partial x_i}\left(k \frac{\partial T}{\partial x_i}\right) + \frac{H}{\rho C_p}$$

Complete range of rheologies (visco-elasto-plastic)

stress tensor can be shared in its isotropic and deviatoric part

$\sigma_{ij} = \sigma'_{ij} + \delta_{ij}\sigma$

$\dot{\varepsilon}_{ij} = \dot{\varepsilon}'_{ij} + \delta_{ij}\dot{\varepsilon}$

$\dot{\sigma}'^{visco}_{ij} = 2G\dot{\varepsilon}'^{visco}_{ij}$ $\quad \dot{\sigma}'^{el}_{ij} = 2\mu_{mod}\dot{\varepsilon}'^{el}_{ij}$

$\dot{\sigma}^{visco} = K\dot{\varepsilon} = -\dot{P}$ $\quad \dot{\sigma}^{el} = \mu_{mod}\dot{\varepsilon}^{el}$

rocks behaves as maxwell bodies in shear

$\dot{\varepsilon}'_{ij} = \dot{\varepsilon}'^{visco}_{ij} + \dot{\varepsilon}'^{el}_{ij}$

$\dot{\sigma}'_{ij} = 2G\left(\dot{\varepsilon}'_{ij} - \dot{\varepsilon}'^{visco}_{ij}\right)$

$\dot{\varepsilon}'^{visco}_{ij} = \frac{\sigma'_{ij}}{2\eta_{visco}}$

and as kelvin bodies in bulk

$\dot{\sigma} = \dot{\sigma}^{visco} + \dot{\sigma}^{el}$

$\dot{\sigma} = K\dot{\varepsilon} + \mu_{mod}\dot{\varepsilon}' = -\dot{P}^{el} + \mu_{mod}\dot{\varepsilon}'$

Failure criteria

$F(\sigma) = \tau' - \sigma' \sin(\phi) - C\cos(\phi)$

Flow rule

$G(\sigma) = \tau' - \sigma' \sin(\psi)$

where

$\tau' = \sqrt{\left(\frac{\sigma_{xx} - \sigma_{yy}}{2}\right)^2 + \sigma_{xy}^2}$ $\quad \sigma' = -\frac{(\sigma_{xx} + \sigma_{yy})}{2}$

ϕ is friction angle, ψ is dilatation angle, C is cohesion

when yielding, consistancy can be write

$\dot{F}(\sigma, \lambda) = 0$

and constitutive relation become

$\dot{\sigma}_i = D_{ij}\dot{\varepsilon}_j - \frac{1}{d}\lambda D_{ij}\frac{\partial G}{\partial \sigma_j}$

where D is is elasticity, $\dot{\varepsilon}$ is strain rate, $\dot{\sigma}$ is rate of stress change and d a scalar

$d = \frac{\partial F}{\partial \sigma_i} D_{ij} \frac{\partial G}{\partial \sigma_j}$

No features of solutions prescribed a priori

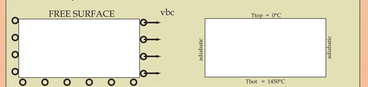
Numerical method

- Conservative finite difference (discrete model satisfies fundamental conservation laws)
- 2D thermo-mechanics
- Fully explicit
- faults are not predescribed lines they are „resolved"

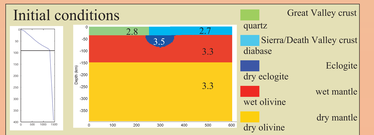
Varying parameters:

Rheology :
competence of the lower crust of the Sierra/Death valley
Boundary conditions :
vbc = 0 > purely dynamic
vbc = 5mm/yr > mixed dynamic/kinematic models
Initial conditions :
topography is compensated 'YES'
or not 'NO' at the begining of the experiment

Boundary conditions



Initial conditions

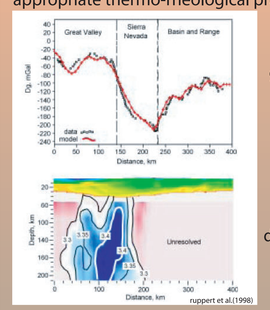


PRELIMINARY CONCLUSIONS OF 2D MODELING

Delamination is more likely to create 50-100km scale drips than viscous RT instability when proper (visco-elasto-plastic) rheology is taken into acount.

Delamination is also a possible explanation for the shift existing between the drip and the previous position of the dense eclogite body and the strong reflectivity of the Moho in the reciever functions.

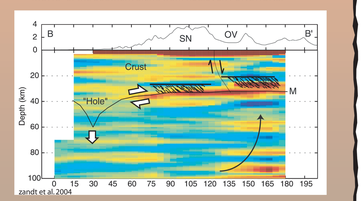
When initial topography is taken into account, only few model are able to delaminate in the timesclaed allowed by geological observation (max 30Ma between cessation of the subduction and the uplift of the sierra). It is then possible to better constrain the appropriate thermo-rheological profile of the crust



gravity

density

MOHO of the Southern Sierra from RECIEVER FUNCTIONS.



zandt et al. 2004

WHAT'S NEXT

With the parameters deduced from the 2D thermo-mecanical study it is now possible to use our 3D version of FLAC (SNAC) to make more realistic model of the uplift of the Sierra that will take into account the lateral disruption of the eclogite body as well as the strike slip component in the Walker lane belt.
The thermo-mechanical study also shows that bellow 70 km the model behaves as viscous. This will allow us to use more efficient numerical technic (e.g. eularian FEM like Citcom) in the mantle bellow that depth.