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**Earthquake Tectonics and Hazards on the Continents**

*17 - 28 June 2013*

# The Mechanics of Continental Deformation

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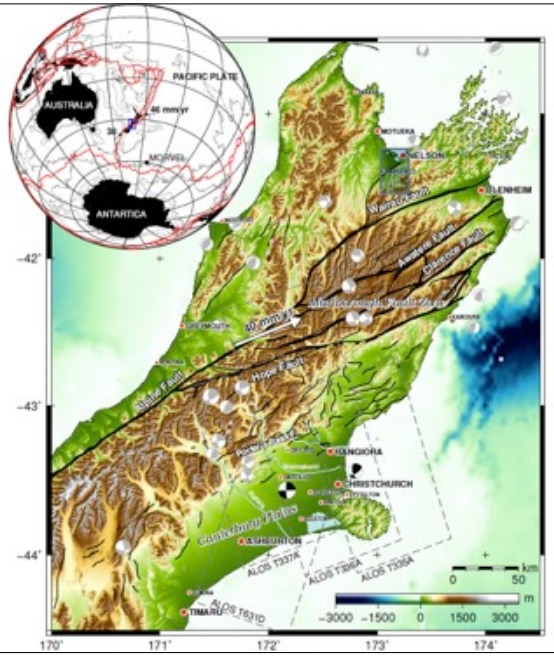
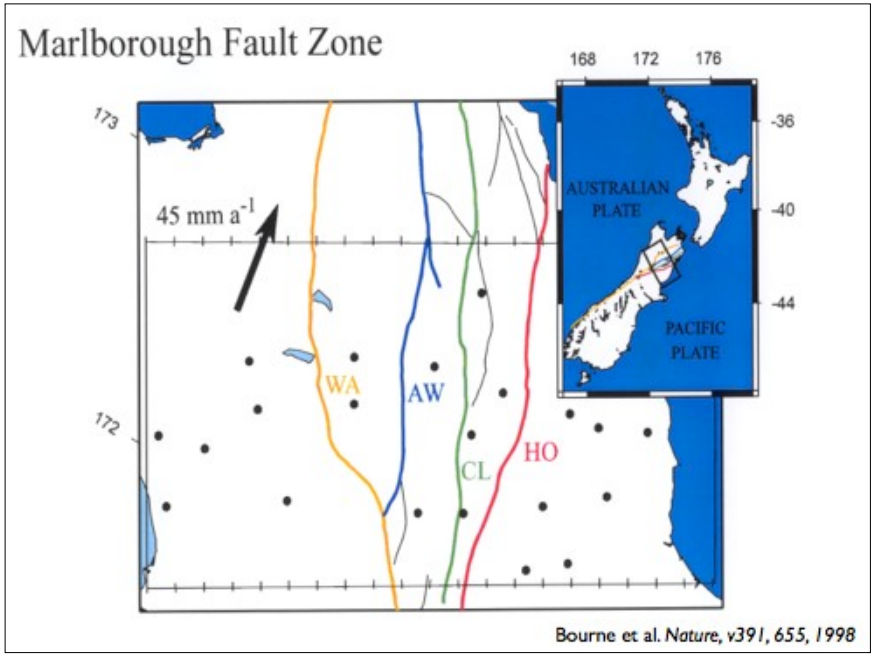
# Dynamics of Continental Deformation

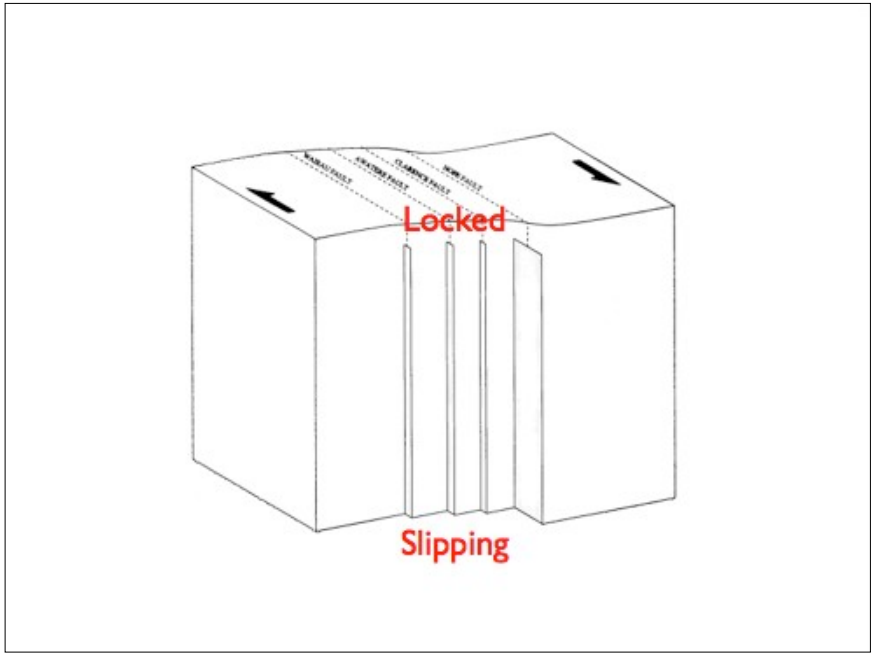
Philip England
ICTP Trieste, 25 June 2013

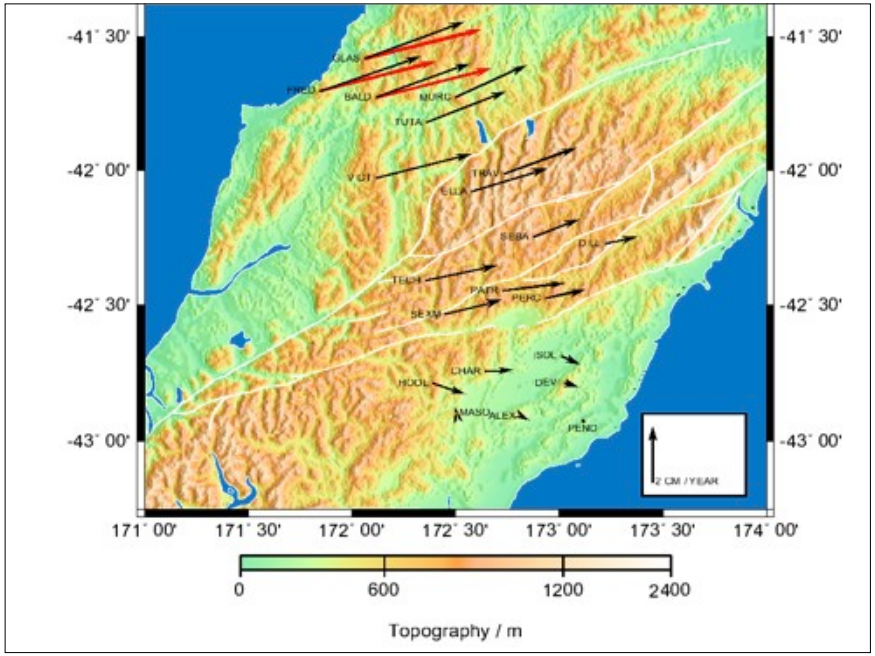
A portion of the Clarence fault, a strike-slip fault in the Marlborough region of the South Island of New Zealand.

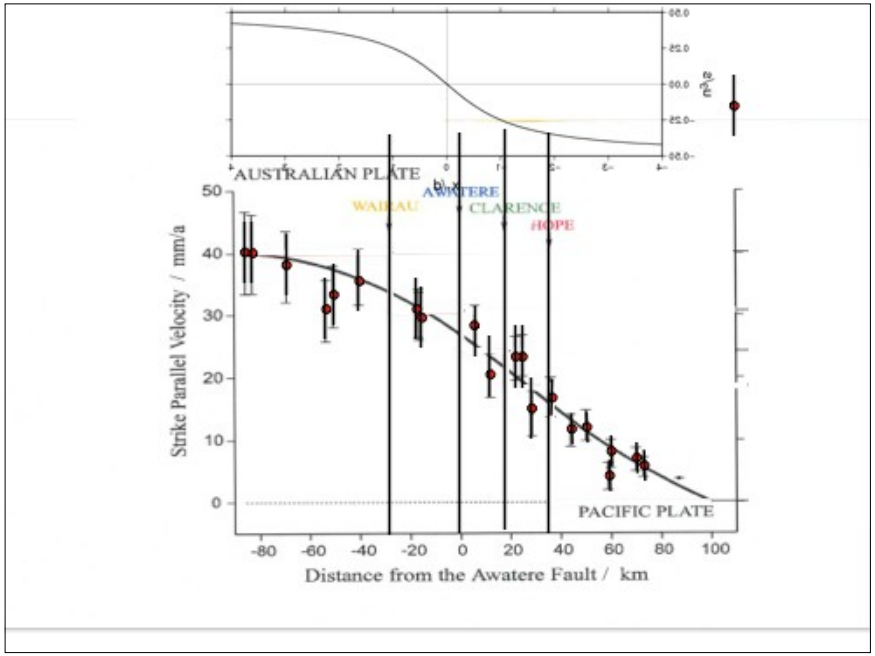


Triangulation 1982
GPS 1994



Thatcher 2009

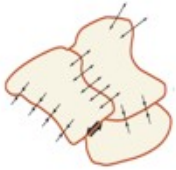


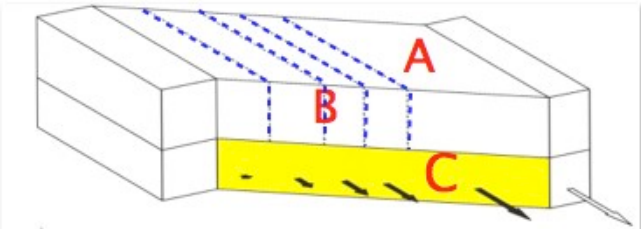
Plate tectonics

Continuum model

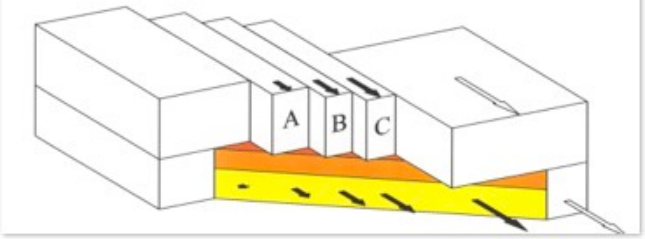
Figure 3

$$v = \omega \times r$$

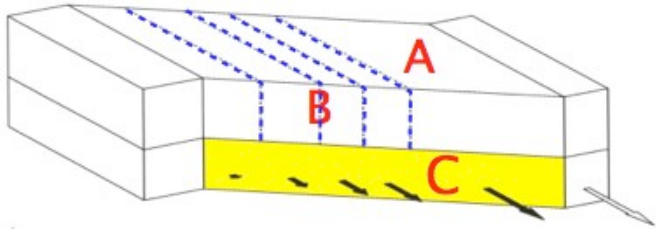
$$\frac{\partial \sigma_{ij}}{\partial x_j} = \rho g$$




A >>C ; B <<C : Blocks following fluid




Blocks or Continuum?

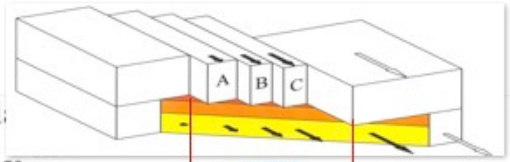


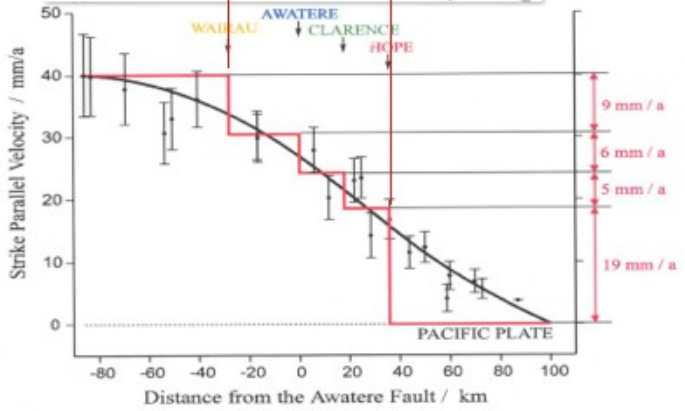

A >> B >> C : Plate tectonics

A >>C ; B <<C : Blocks following fluid

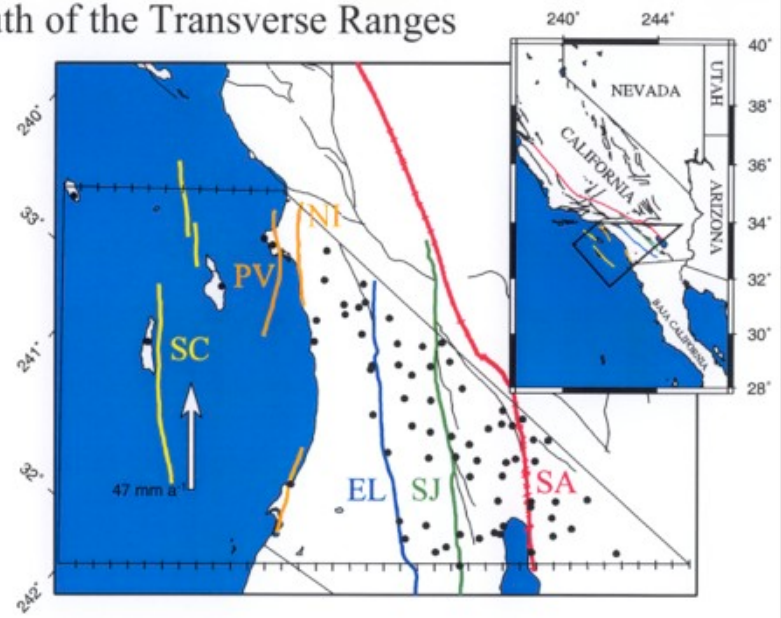
A & B < C : 'Blocks' deformed by fluid

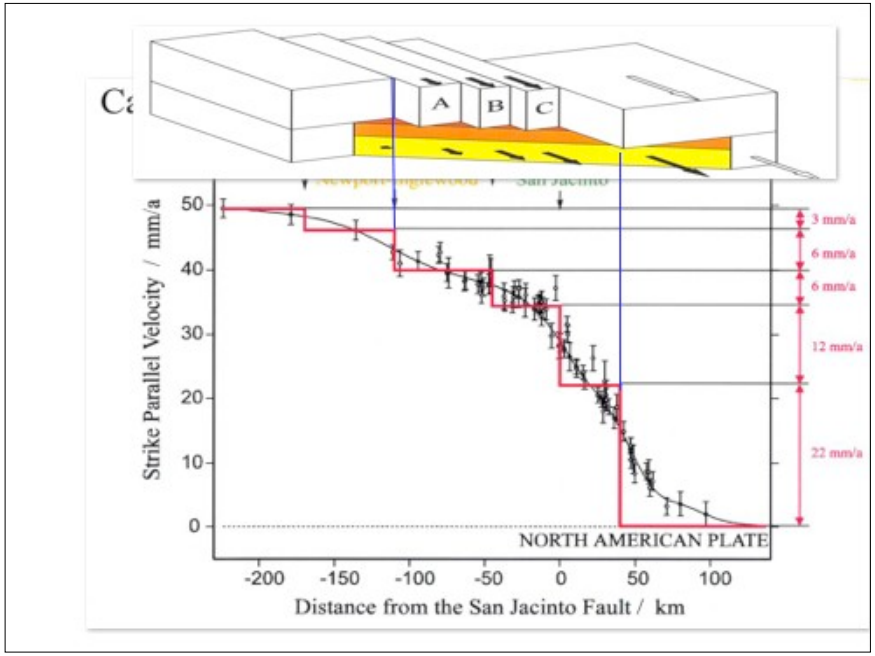
Calcul



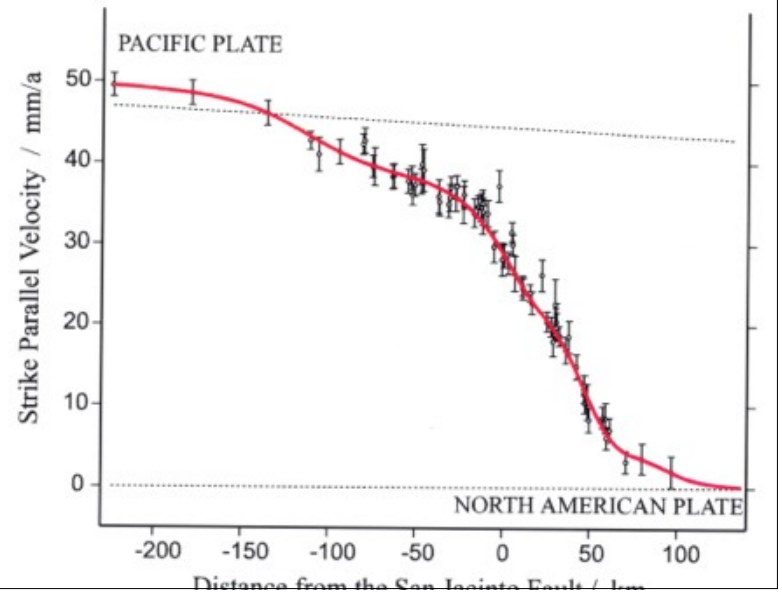



## South of the Transverse Ranges

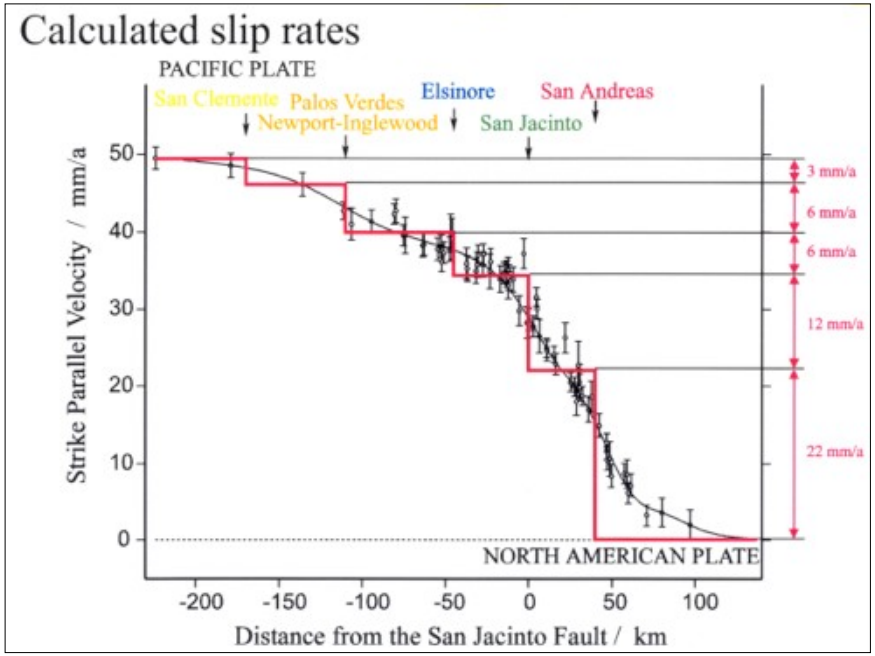



## Velocity profile 1970 - 1995




## Calculated slip rates



| South Island of New Zealand | | | Southern California | | |
|---|---|---|---|---|---|
| | Slip rates (mm/a) | | | Slip rates (mm/a) | |
| | Calculated | Measured | | Calculated | Measured |
| Hope | 19 | 20 – 25<br>11 – 17<br>19 ± 5 | San Andreas | 22 | 25 ± 5 |
| Clarence | 5 | 1 – 8<br>4 - 8 | San Jacinto | 12 | 12 +7-5 |
| Awatere | 6 | 5 – 7<br>5 – 10<br>6 – 7 | Elsinore | 6 | 5 ± 2 |
| Wairau | 9 | 4 ± 1<br>3.7 - 10.7 | Palos Verdes,<br>Newport – Inglewood | 6 | 5 - 6 |
| | | | San Clemente | 3 | 1 - 4 |

- So, it appears that the motion of blocks *might* be driven by a fluid medium (ductile lower crust) beneath them...
- What RULES would such a ductile medium obey?
- Newton's Second law of motion

$$\frac{\partial \sigma_{ij}}{\partial x_j} = \rho g$$

Gradients of stress are balanced by gravity.

Accelerations are zero.


- So, it appears that the motion of blocks *might* be driven by a fluid medium (ductile lower crust) beneath them...
- What RULES would such a ductile medium obey?
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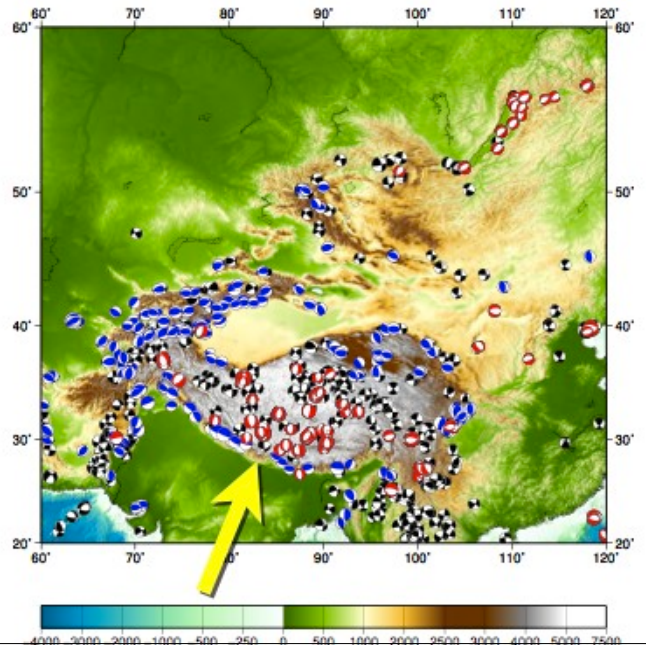
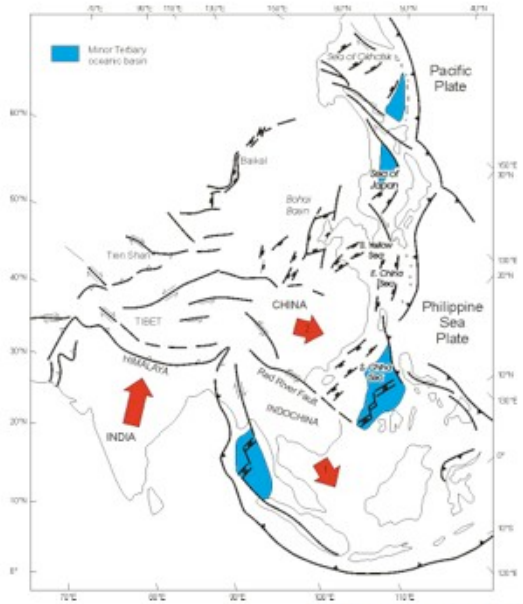
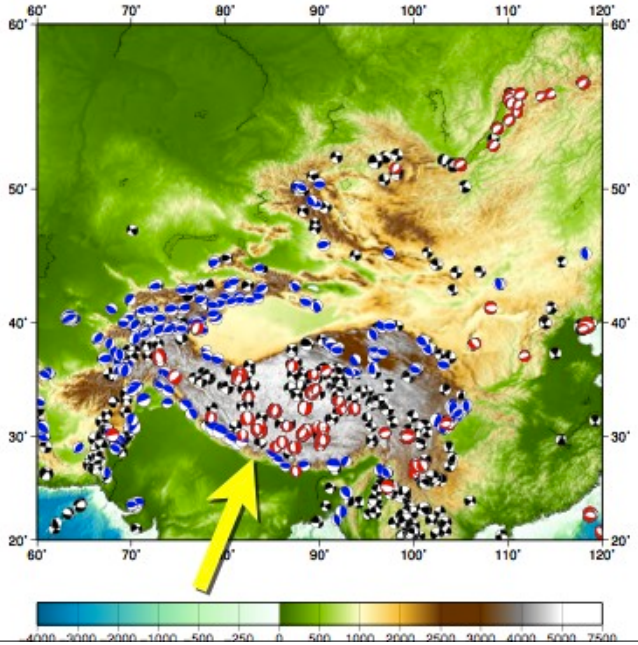


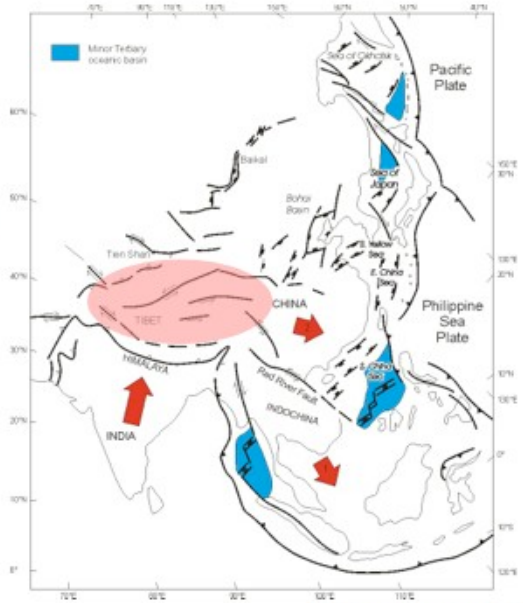



Tapponnier et al, 1986




## Predictions:

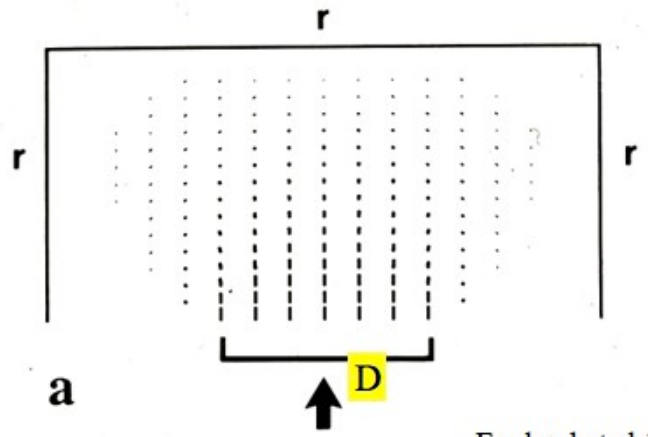
Deformation field dominated by a small number of major (strike-slip) faults, slipping at 15-30mm/yr



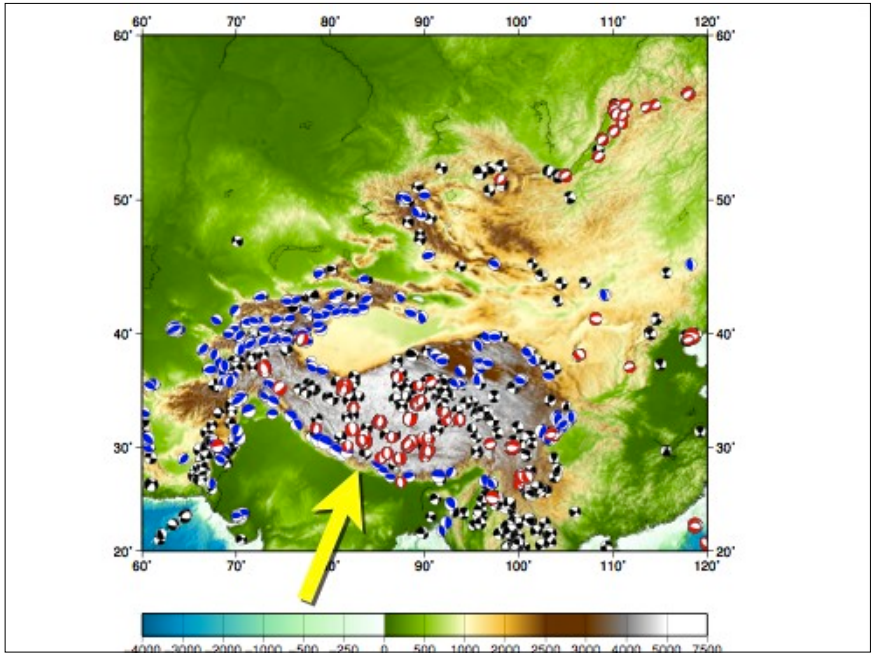

Tapponnier et al, 1986

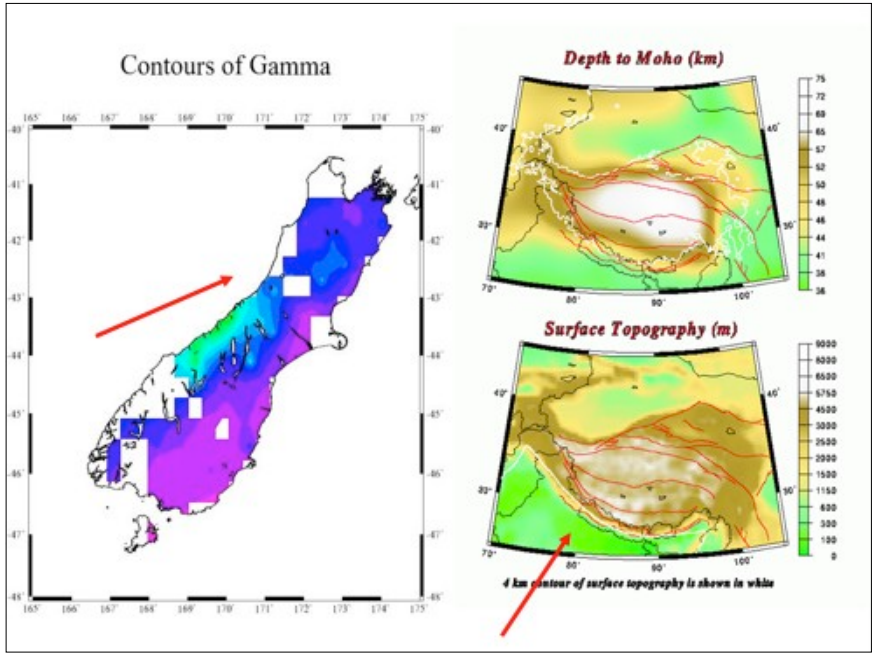
## Convergent or Divergent Boundary

$$V(y) \approx V_0 \exp(-\pi \sqrt{n}\, y / 2D)$$



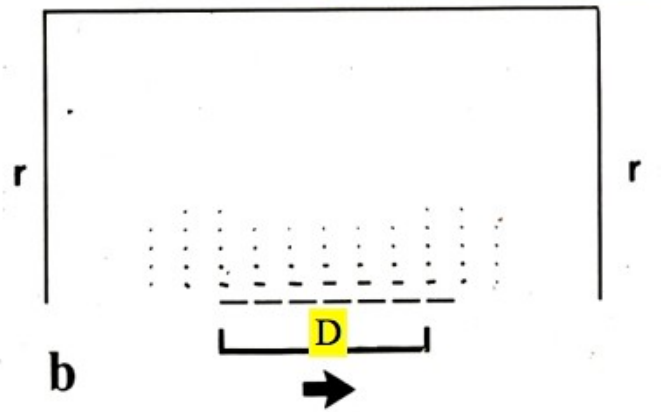

England et al 1985



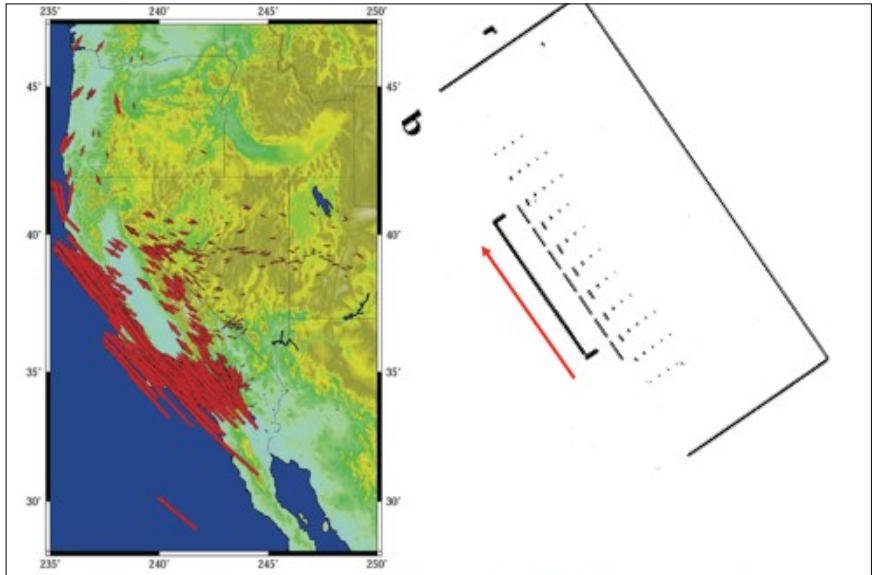




## Strike-Slip Boundary

$$U(y) \approx U_0 \exp(-2\pi \sqrt{n}\, y / D)$$

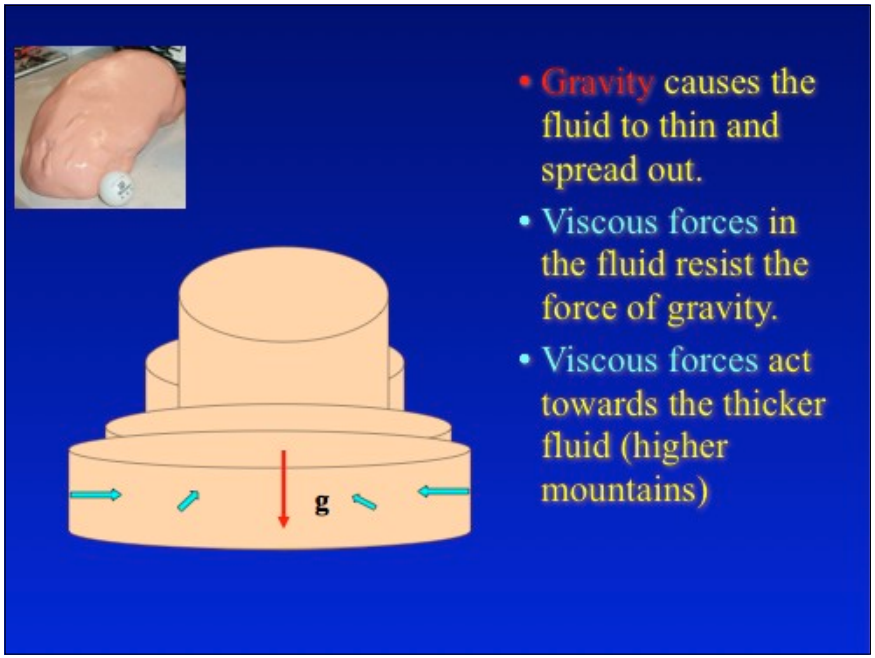


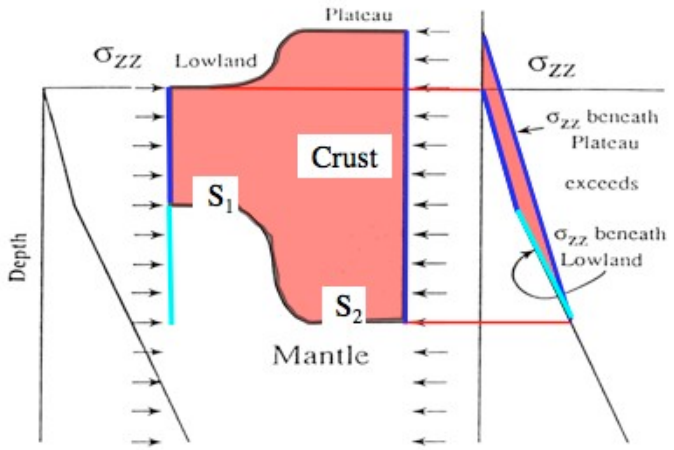

England et al 1985

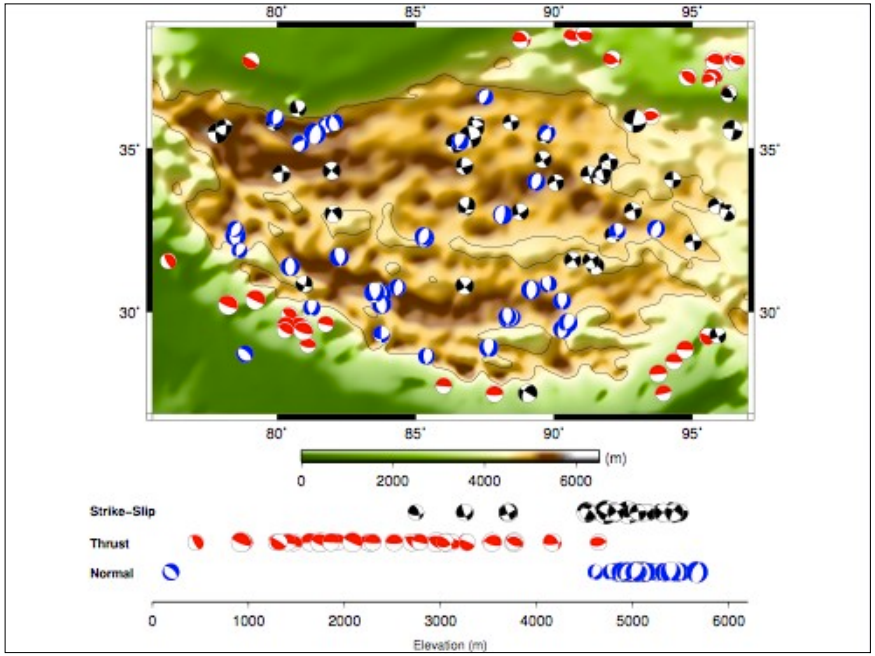


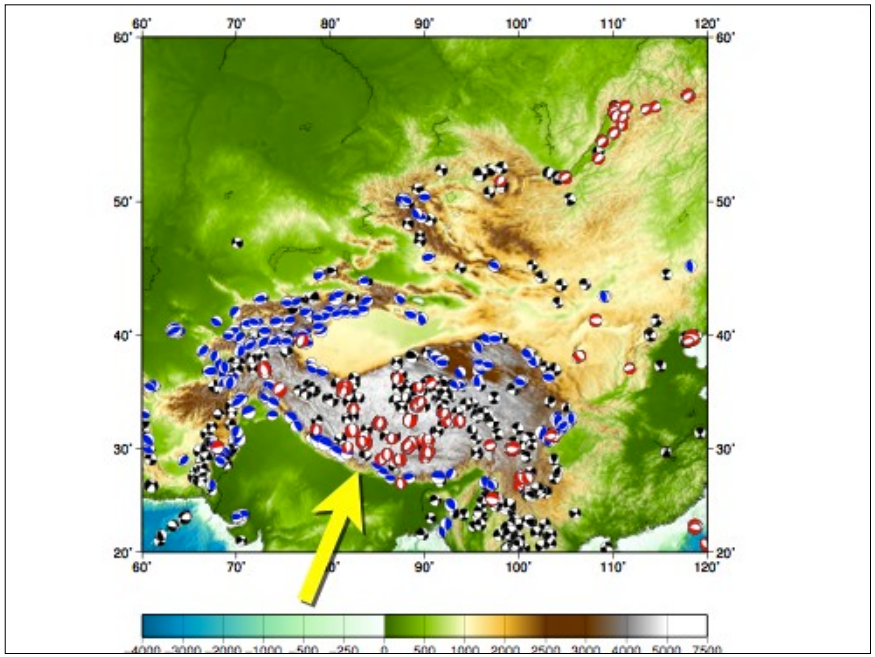

Similar decay of velocity with distance from the boundary, but picture is complicated by the

## Buoyancy Forces






## Central Apennines, D'Agostino et al, 2011, Geology