The Role of Mantle Tractions and the Crust

Lucy Flesch

Collaborators:

Attreyee Ghosh, William Holt, Scott King, Lianxing Wen, and John Haines

1Purdue University
2USC
3Stony Brook University
4Virginia Tech
5University of Cambridge
Sources of Lithospheric Stress

Lithospheric Stress Field boundary Condition
- plate motion
- Lithosphere
- Asthenosphere

Lithospheric Stress Associated with Basal Tractions
- Basal Tractions Associated with Large-Scale Mantle Convection
- density anomaly

Lithospheric Stress Associated with GPE
- plate motion
- surface
- density anomaly

CMB
Stresses associated with Gravitational Potential Energy (GPE) variations

Flesch et al., GJI, 2007
Determine 3 basis functions for each segment along the grid boundary
Kinematic Stress Indicators

Flesch et al., GJI, 2007

Strain Rates

Velocity
Stress field boundary conditions

Integrated effects of global tractions up to the boundary of the grid and GPE variations outside of the grid.

Flesch et al., GJI, 2007
Total Deviatoric Stress Field

Best fit to stress indicators inferred from the STYLE of the strain rates
- GPE variations
- plate interactions
- basal tractions?

Flesch et al., GJI, 2007
Basal Traction - Lid model

- Used method of Wen and Anderson (1997)

Flesch et al., GJI, 2007

5 MPa
Deviatoric Stresses Associated with Basal Traction Magnitudes?

Add stresses associated with GPE variations and scaled tractions, then solve for a new stress field boundary condition.
⇒ Trade off between scaled basal tractions and stress field boundary conditions

⇒ However, the sum of stress field boundary conditions + stresses associated with scaled tractions is a constant

⇒ GPE variations calibrate the magnitudes and style of stresses associated with basal tractions
Global Strain Rate Model

Kreemer et al. (2003)
Global Strain Rate Model
(Kreemer et al., 2003)

- Direction of principal axes
- Fault style

Correlation co-efficient:

\[ E = \sqrt{2\varepsilon_{\phi\phi}^2 + 2\varepsilon_{\theta\theta}^2 + 2\varepsilon_{\phi\theta}^2 + 2\varepsilon_{\phi\phi}\varepsilon_{\theta\theta}} \]

\[ T = \sqrt{2\tau_{\phi\phi}^2 + 2\tau_{\theta\theta}^2 + 2\tau_{\phi\theta}^2 + 2\tau_{\phi\phi}\tau_{\theta\theta}} \]

\[ e \cdot \tau = 2\varepsilon_{\phi\phi}\tau_{\phi\phi} + \varepsilon_{\phi\phi}\tau_{\theta\theta} + \varepsilon_{\theta\theta}\tau_{\phi\phi} + 2\varepsilon_{\theta\theta}\tau_{\theta\theta} + 2\varepsilon_{\phi\theta}\tau_{\phi\theta} \]

\[-1 \leq \frac{\sum_a \{e \cdot \tau\}}{\sum_a \{ET\}} \leq 1\]
Stress associated with GPE

Correlation = 0.54

Ghosh et al., GRL, (2008)
Successful models require a strong viscosity contrast between the lithosphere and the asthenosphere (100-10,000 times stronger than the lithosphere).

Ghosh et al., *GRL*, (2008)
Convection method of Wen and Anderson (1997)
Lid Model
Radial dependant viscosity
L: $1 \times 10^{23}$ Pa-s
A: $1 \times 10^{21}$ Pa-s

Ghosh et al., *GRL*, (2008)
Model does not produce deviatoric tensional stresses with observations in Basin and Range and Rio Grande Rift regions, tractions overwhelm the contribution from the GPE variations.

Correlation = 0.62

Ghosh et al., *GRL*, (2008)
Add Figure two

Ghosh et al., *GRL*, (2008)
Convection method of Wen and Anderson (1997)

Lid Model

Radial dependant viscosity

L: $5 \times 10^{22}$ Pa-s

A: $1 \times 10^{19}$ Pa-s

Ghosh et al., _GRL_, (2008)
Ghosh et al., *GRL*, (2008)

Correlation $= 0.64$

Total Deviatoric Stress Field

$\Rightarrow$ Deviatoric stresses now consistent with observations

$\Rightarrow$ Stresses associated with basal tractions very similar to stress field boundary conditions

Ghosh et al., *GRL*, (2008)
Ghosh et al., GRL, (2008)

Model 1
Correlation = 0.68
Asia = 0.42
Mediterranean = 0.54
W NA = 0.62

Model 8
Correlation = 0.69
Asia = 0.57
Mediterranean = 0.57
W NA = 0.64
East Asia migrating eastward independent of the India-Eurasia Collision

GPS data from Calais et al., *GRL*, (2007) (blue)

Model velocity (black)
Stresses associated with GPE variations calculated globally
Stress field
Boundary Conditions that represent the contribution from basal tractions
• Models run using CitcomS
• Rayleigh number of 4e7
• Buoyancy driven by S20RTS model (Ritsema et al., Science, 1999)
• Constant viscosity flow law
• Models run using citcomS
• Rayleigh number of 4e7
• Buoyancy driven by S20RTS model (Ritsema et al., Science, 1999)
• Variable viscosity flow law
• Models run using citcomS
• Rayleigh number of 4e7
• Buoyancy driven by S20RTS model (Ritsema et al., *Science*, 1999)
• Temperature-dependent rheology to the depth (pressure) dependent profile
What have we learned?

• Regional models alone cannot resolve levels of basal tractions but...

• GPE variations calibrate the magnitudes of stress associated with basal tractions

• Continental regions that have high GPE are important for isolating magnitudes of basal tractions/coupling

• Successful models involve stresses associated with GPE differences that are approximately equal in magnitude to the stresses associated with basal tractions