Using local topography to constrain absolute stress
(with some additional thoughts on heterogeneity)

Karen Luttrell

Louisiana State University

Acknowledgements

- **Bridget Smith-Konter**, University of Hawaii
- **Jeanne Hardebeck**, US Geological Survey
- All Contributors to the SCEC Community Stress Model

LSU Students

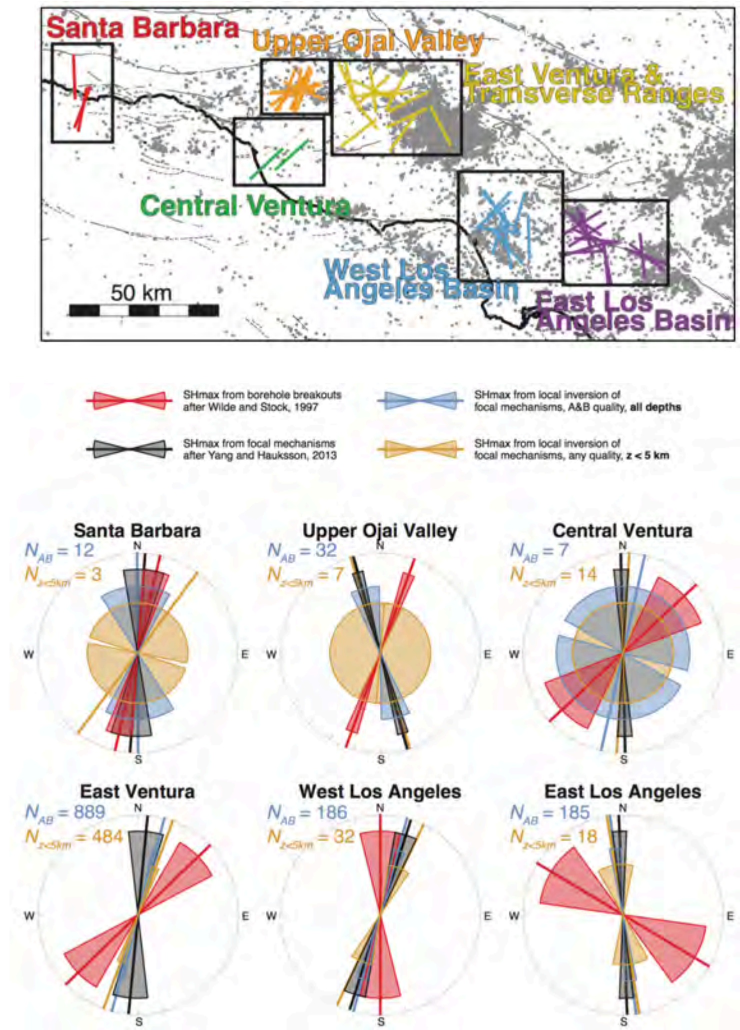
Joel Spansel (BS)
Erin Schwartz (BS)
Phoenix Harris (BS)
Elliott Helgans (MS)

What we're not going to talk about

- Do borehole breakout SHmax agree with focal mechanism inversion SHmax?
  - (not really)

- Why not?
  - Depth heterogeneity?
  - Lateral heterogeneity?
  - Temporal heterogeneity?

- We're testing "depth" and "lateral" by doing new FM inversions with only local Eqs
  - Fits better in some places/ circumstances…
  - But in others, differences can't be explained by differences in spatial sampling…



Luttrell and Hardebeck, ongoing

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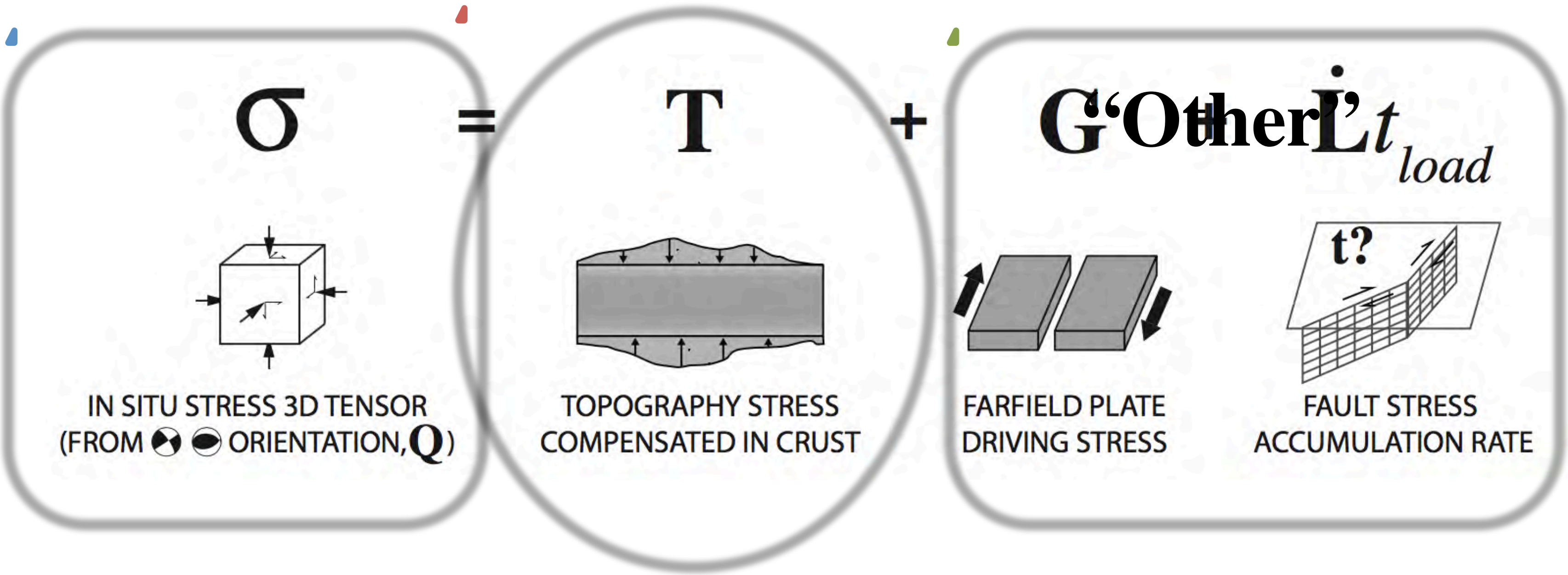
Simple forward model of stress field



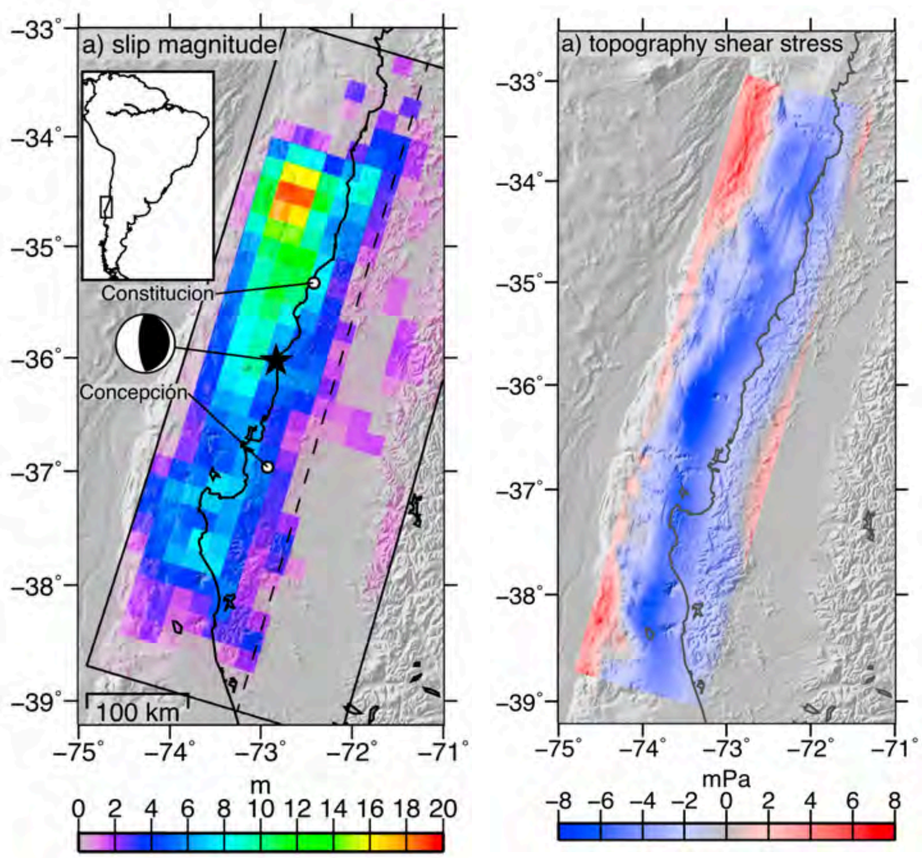
Find some indication of this

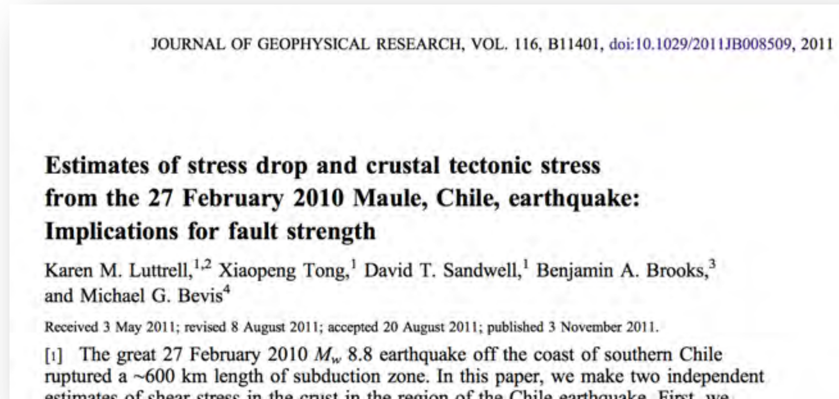
Calculate this

Figure out some bounding values for this

Previous Incarnations of Absolute Stress Constraint via Topography

megathrust earthquake




JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 116, B11401, doi:10.1029/2011JB008509, 2011

Estimates of stress drop and crustal tectonic stress from the 27 February 2010 Maule, Chile, earthquake: Implications for fault strength

Karen M. Luttrell,[1,2] Xiaopeng Tong,[1] David T. Sandwell,[1] Benjamin A. Brooks,[3] and Michael G. Bevis[4]

Received 3 May 2011; revised 8 August 2011; accepted 20 August 2011; published 3 November 2011.

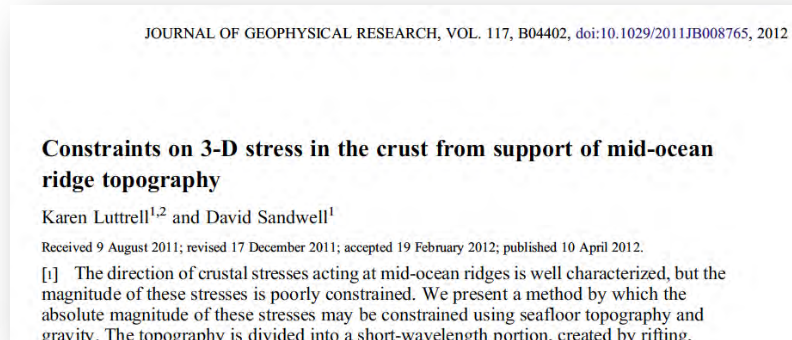
[1] The great 27 February 2010 M_w 8.8 earthquake off the coast of southern Chile ruptured a ~600 km length of subduction zone. In this paper, we make two independent

Compare forearc topography with slip direction to constrain driving stress and compare with stress drop

[*Luttrell et al.*, 2011]

Previous Incarnations of Absolute Stress Constraint via Topography

mid-ocean ridges



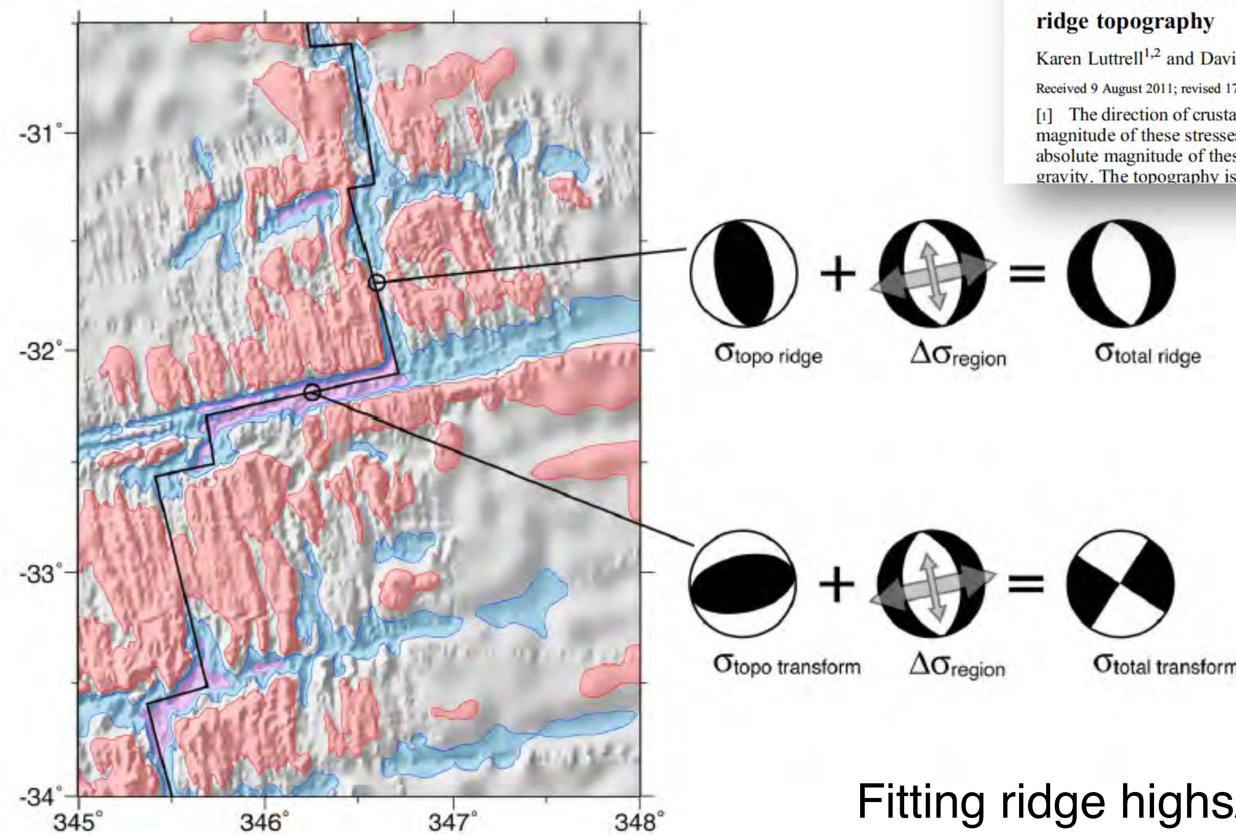
JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 117, B04402, doi:10.1029/2011JB008765, 2012

Constraints on 3-D stress in the crust from support of mid-ocean ridge topography

Karen Luttrell[1,2] and David Sandwell[1]

Received 9 August 2011; revised 17 December 2011; accepted 19 February 2012; published 10 April 2012.

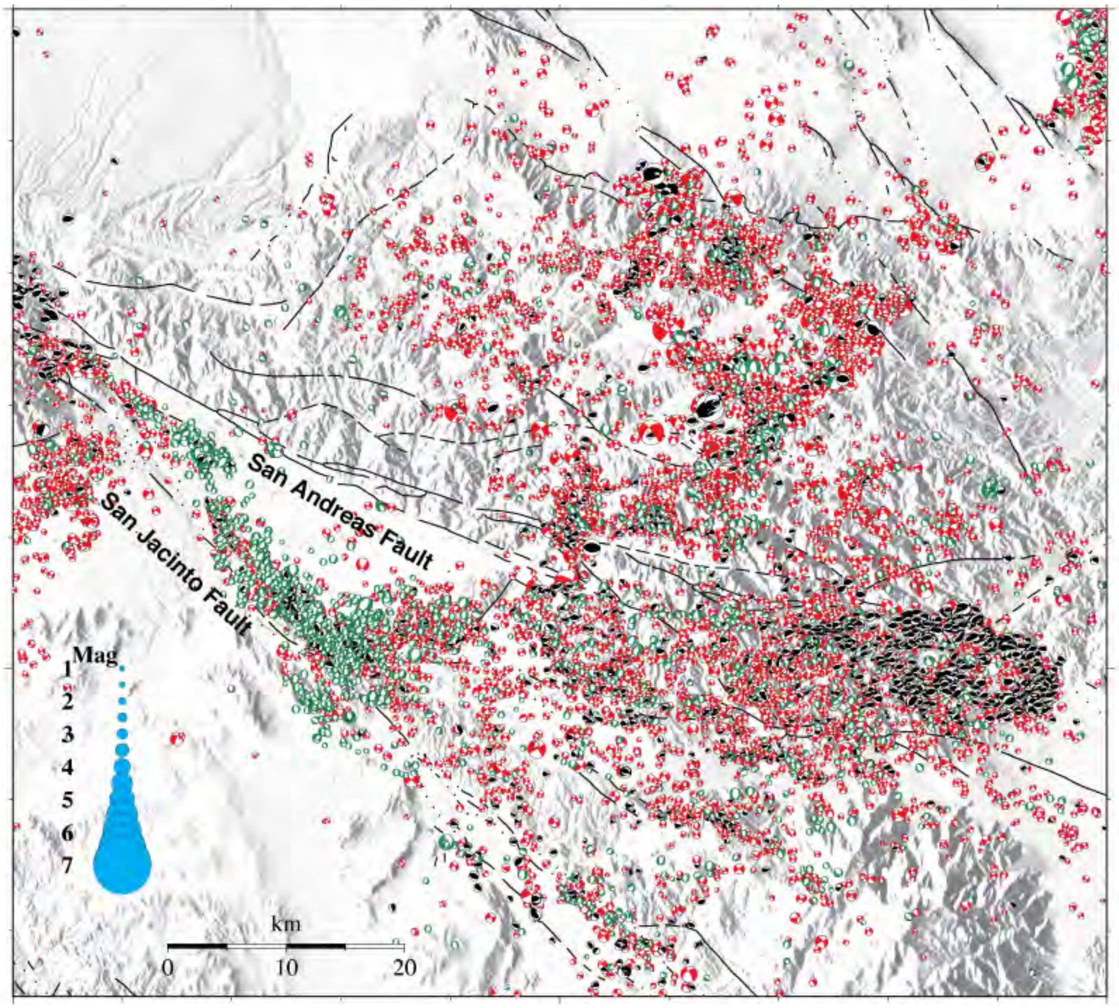
[1] The direction of crustal stresses acting at mid-ocean ridges is well characterized, but the magnitude of these stresses is poorly constrained. We present a method by which the absolute magnitude of these stresses may be constrained using seafloor topography and gravity. The topography is divided into a short-wavelength portion, created by rifting,



[*Luttrell and Sandwell*, 2012]

Fitting ridge highs/lows and transform lows/highs simultaneously with a single consistent 2-D stress field

Southern California is a lot more complicated: Varied faulting types



[*Yang et al*. 2012]

History of the CSM

Last year of SCEC 3

September 14, 2011:	Palm Springs	**Workshop on Strategies for Implementing a Community Stress Model**

SCEC 4: 2012-2016

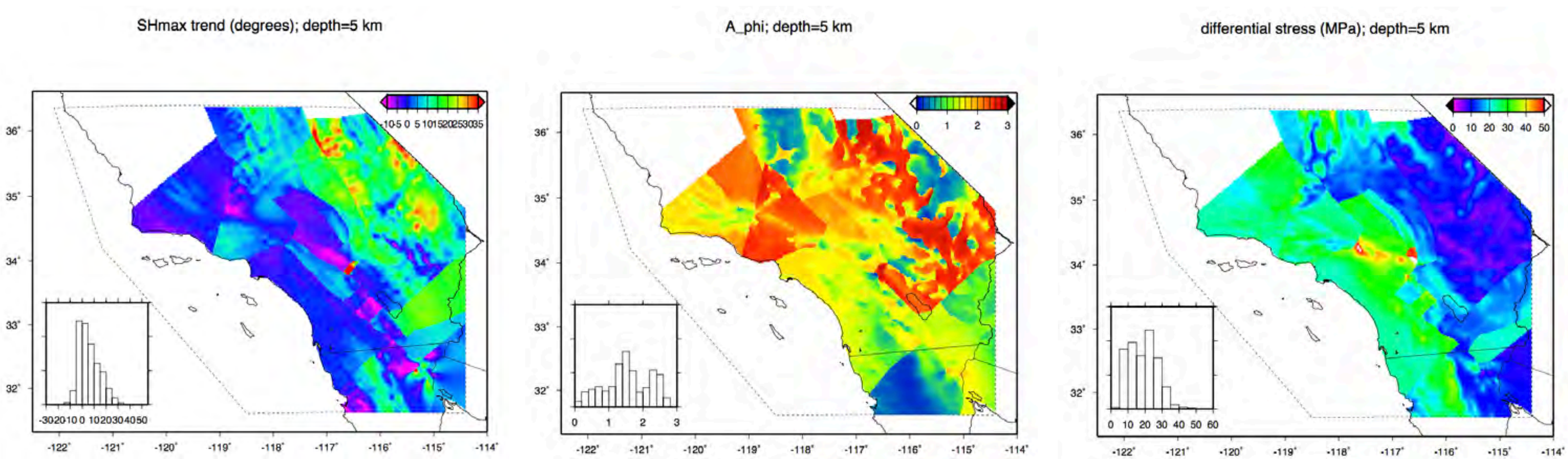
October 15-16, 2012:	USC	**SCEC Community Workshop: Community Stress Model**
May 29-30, 2013:	Menlo Park	**SCEC Community Workshop: Community Stress Model**
October 27, 2014:	Pomona	**SCEC Community Workshop: Community Stress Model**
September 13, 2015:	Palm Springs	**SCEC Community Stress Model (CSM) Workshop**

SCEC 5: 2017-2021

January 15-16, 2019:	Pomona	**SCEC Community Stress Model (CSM) Workshop**

2012 Workshop: Initial Contributions

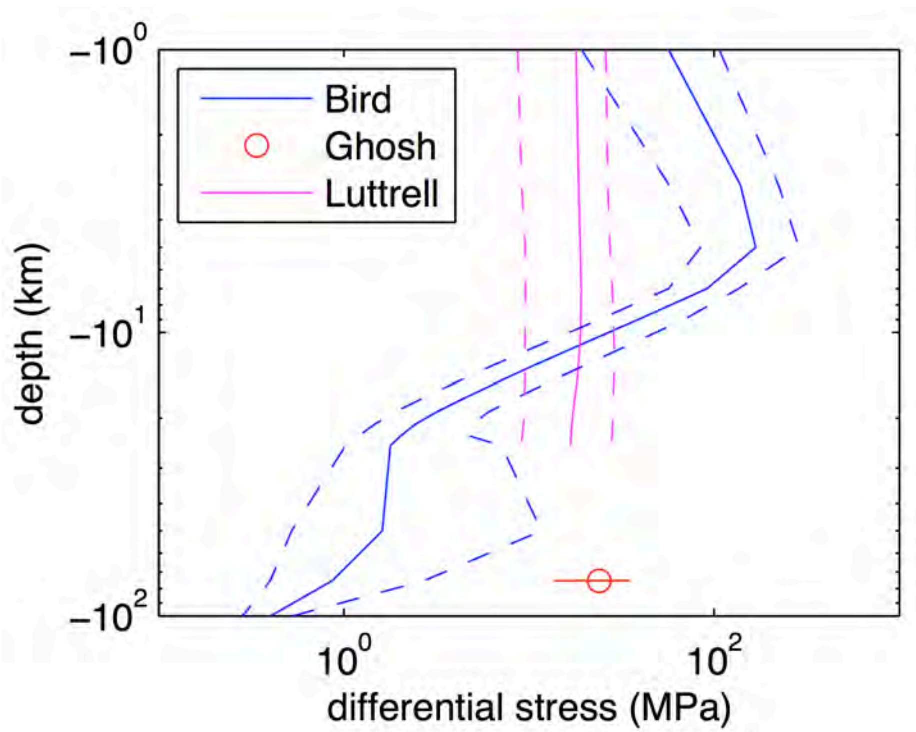
- **16 models submitted**
  - Stress magnitude (3 models)
    - Disagree on magnitude and magnitude of variation



Luttrell's contribution to CSM 2012: very very very very very preliminary

2012 Workshop: Initial Contributions

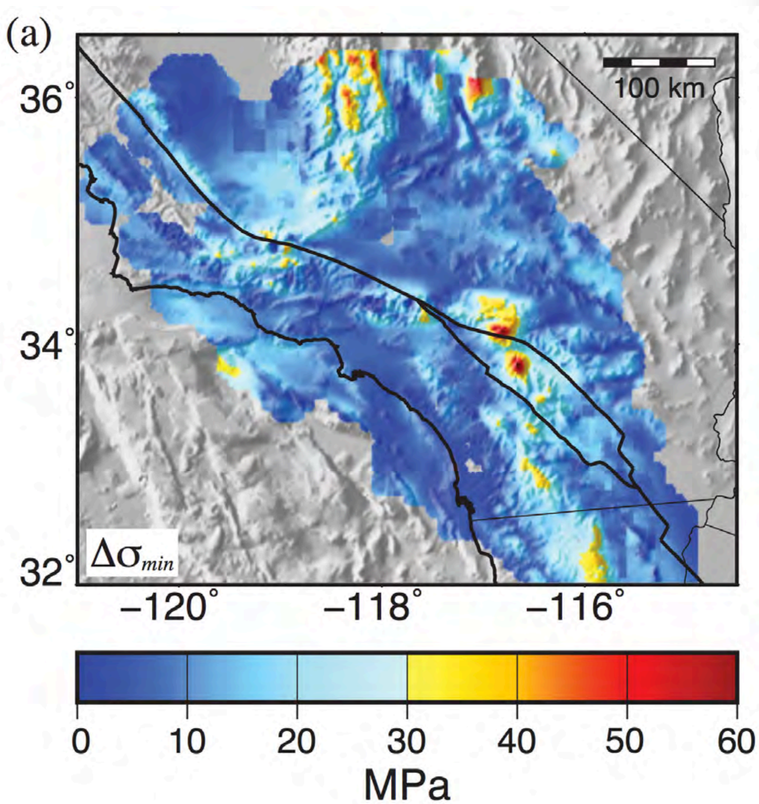
- **16 models submitted**
  - Stress magnitude (3 models)
    - Disagree on magnitude and magnitude of variation



"hmmmm, maybe it's worth trying to do this for real…"

- Karen's internal monologue, 2012

Eventually, after hitting lots of walls, a constraint on Absolute Stress via Topography



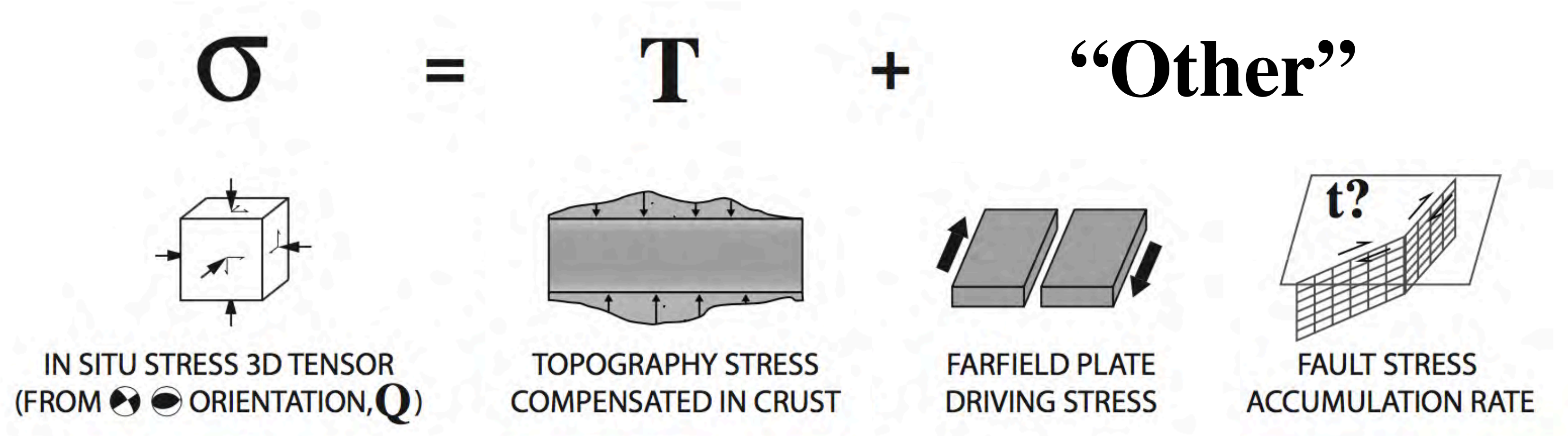
Geophys. J. Int. (2017) **211,** 472–482
doi: 10.1093/gji/ggx301
Advance Access publication 2017 July 22
GJI Geodynamics and tectonics

Limits on crustal differential stress in southern California from topography and earthquake focal mechanisms

Karen Luttrell[1] and Bridget Smith-Konter[2]

[1]*Department of Geology and Geophysics, Louisiana State University,* E235 *Howe-Russell, Baton Rouge, LA* 70803*, USA. E-mail:* *kluttrell@lsu.edu*
[2]*Department of Geology and Geophysics, University of Hawaii,* 1680 *East-West Road, POST* 813*, Honolulu, HI* 96822*, USA*

Simple forward model of stress field



Need some additional information or assumptions

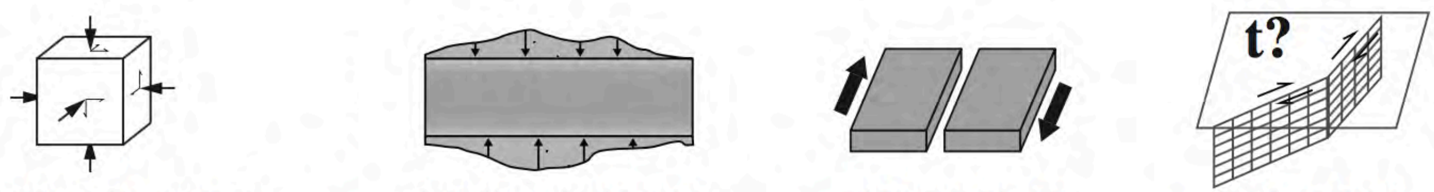
1. **Assume topography <u>is NOT</u> dominant in Southern California**

2. **Assume “other” <u>is</u> dominant in Southern California**

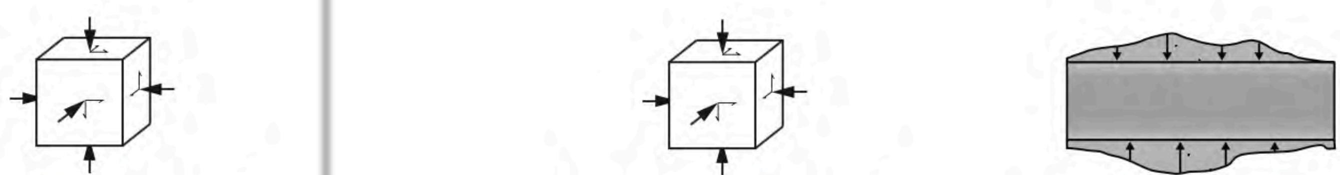
   i.e., topography is ~negligible

Simple forward model of stress field

$$\sigma \quad = \quad T \quad + \quad \text{“Other”}$$



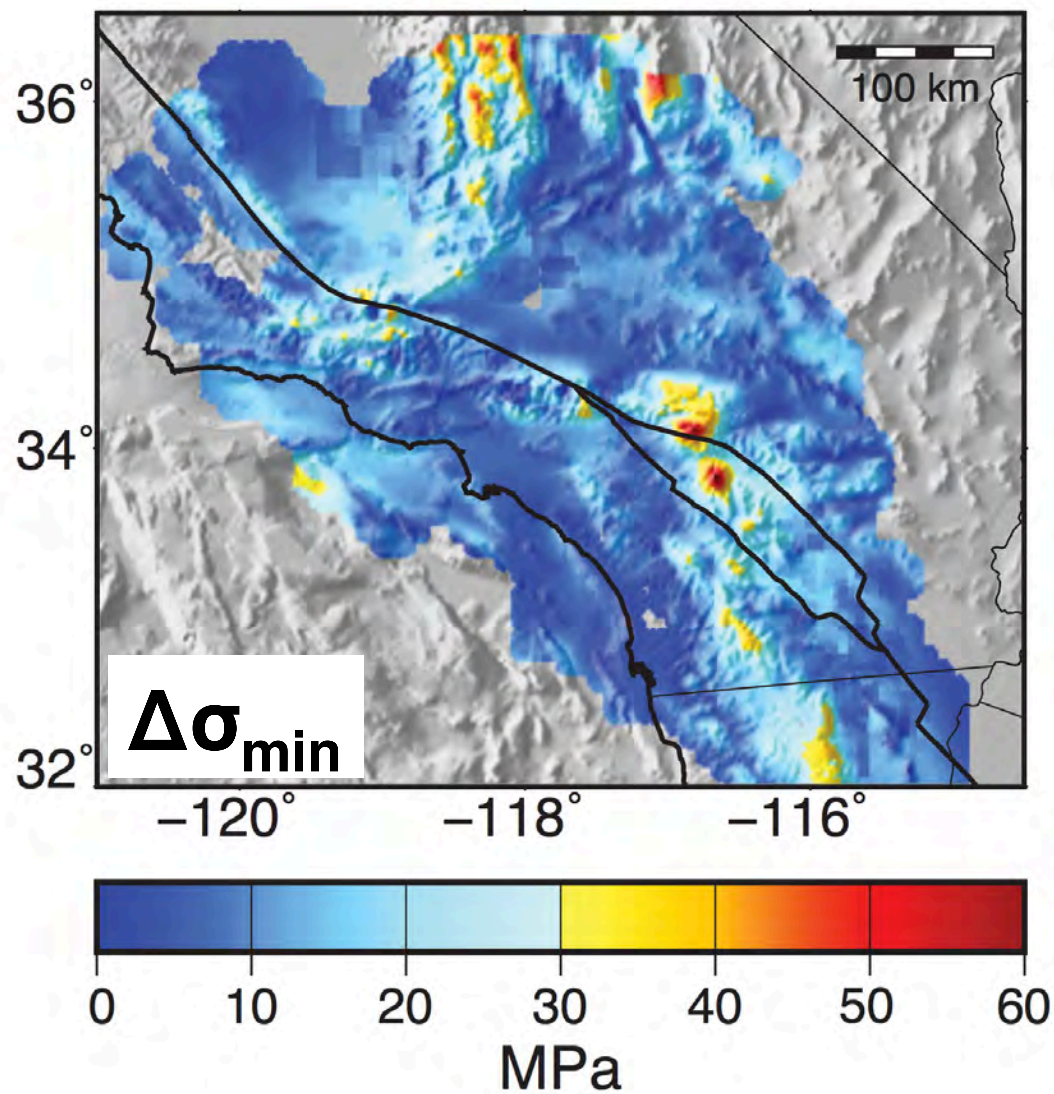
$$\sigma \quad \approx \quad \sigma * \Delta\sigma \; - \; T$$



orientation *orientation*

Minimum in situ magnitude estimate: $\Delta\sigma_{min}$

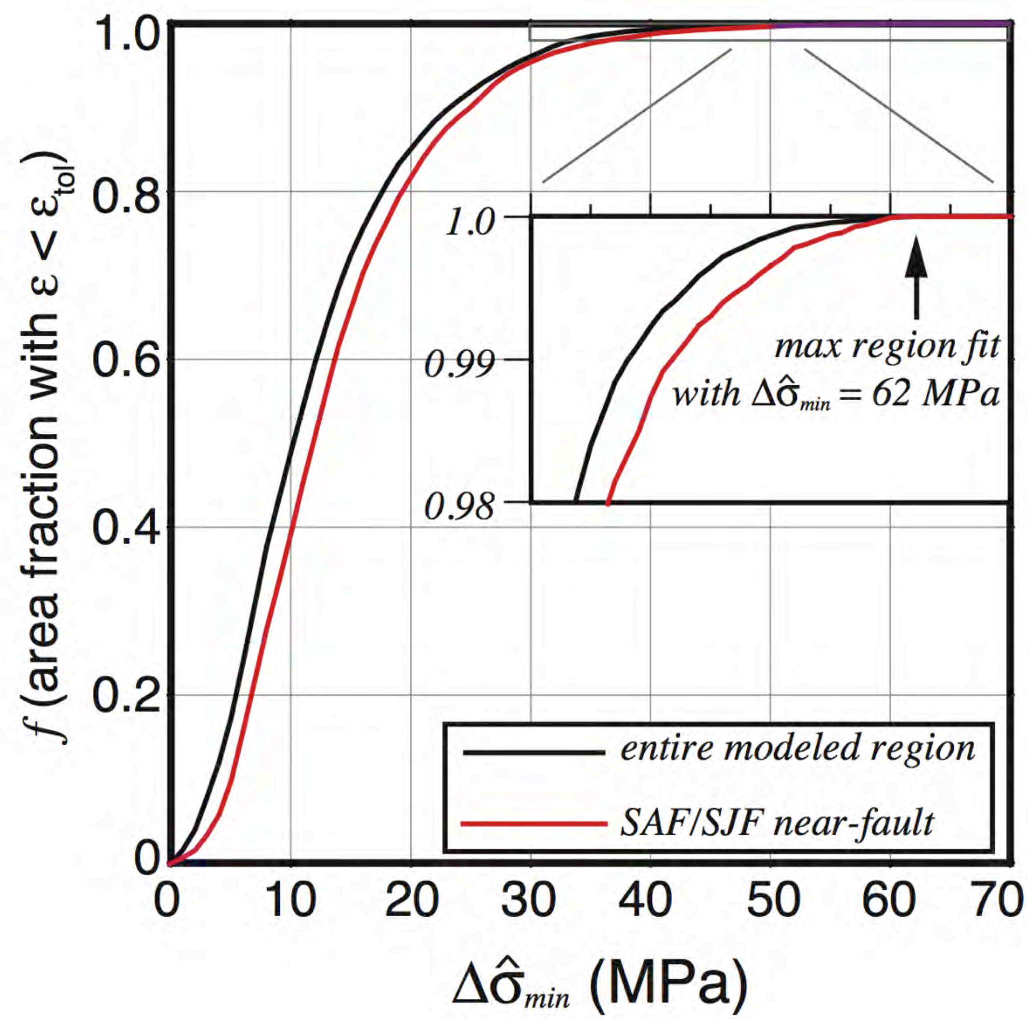
- $\Delta\sigma$ required to maintain *in situ* orientation to within ±15°, despite resistance from topography
- Across SoCal, ranges from ~10 – 60 MPa
- This is a lower bound: stress could be arbitrarily higher and fit just as well



[*Luttrell and Smith-Konter, 2017*]

Minimum in situ magnitude estimate: $\Delta\sigma_{min}$

- How does min $\Delta\sigma$ estimate vary across region?
- CDF of area able to support existing topography for *in situ* differential stress of a certain magnitude
- Similar result if near-fault areas considered seperately
- Most rugged topography requires $\Delta\sigma$ of 62 MPa



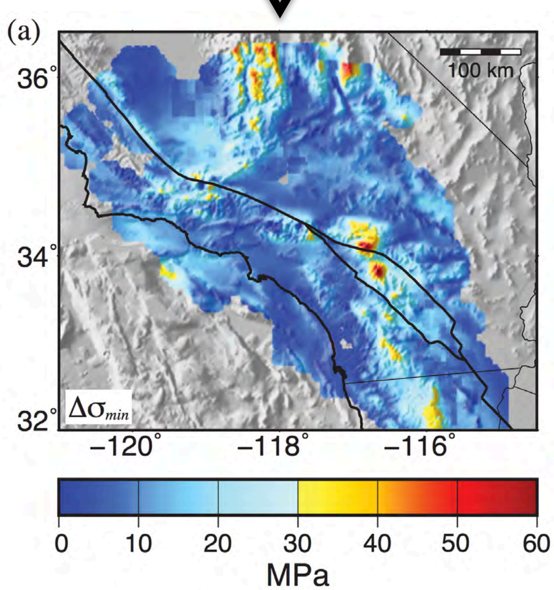
[*Luttrell and Smith-Konter, 2017*]

Which estimate should we use for $\Delta\sigma_{min}$?

Depends on how heterogeneous stress magnitude is…

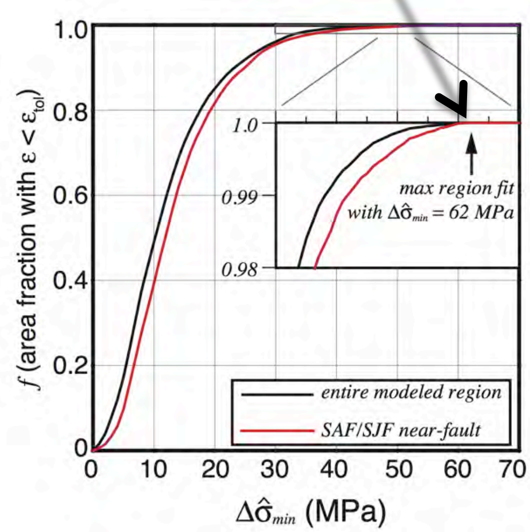
If variations are large relative to mean…

… this is the best estimate of $\Delta\sigma_{min}$ at each place



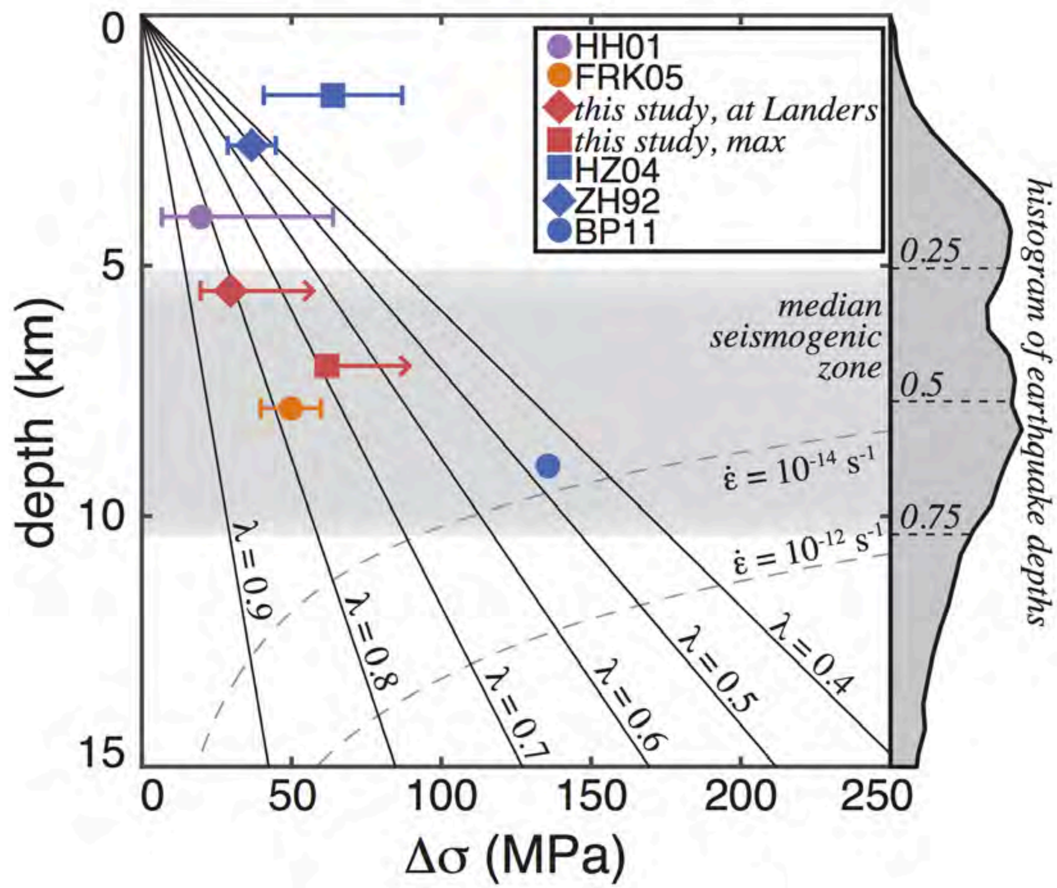
If variations are small relative to mean…

… $\Delta\sigma_{min}$ everywhere must be large enough to support max



Do these results make sense?

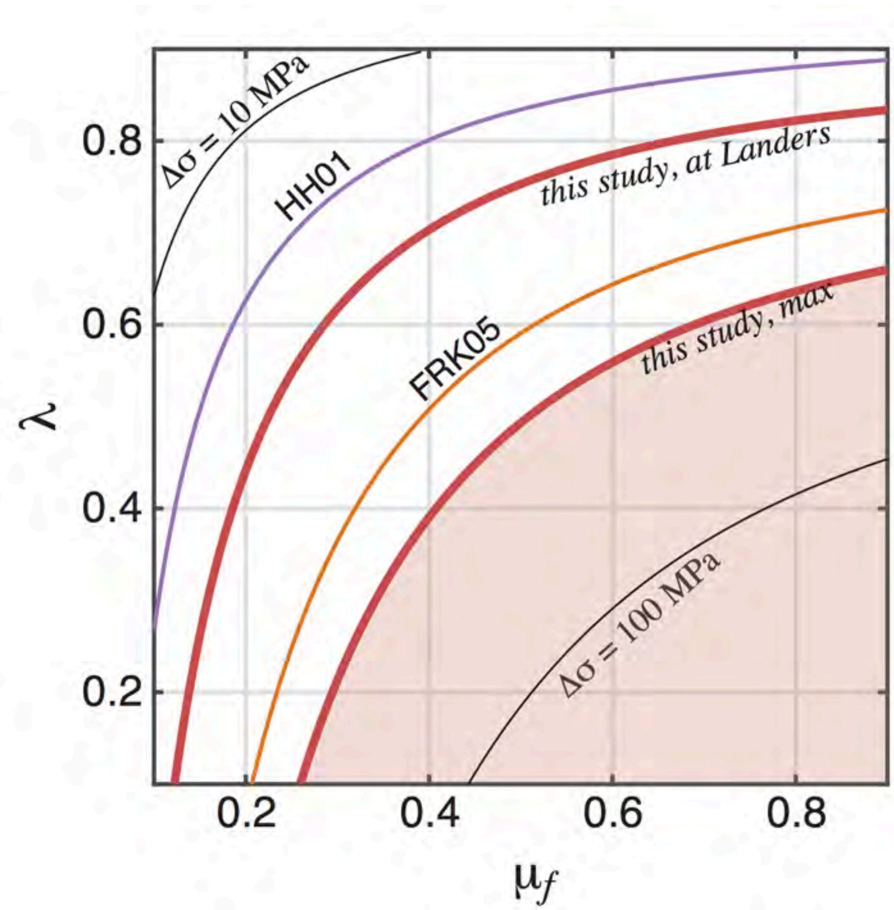
- Compare with estimates from
  - Shallower drilling
  - Deeper exhumed crustal rocks
  - Landers aftershock rotation
- Max required stress is concordant with shallower and deeper estimates
- Landers region is high, but within error bars
- YSE places a lower limit on fault friction and an upper limit on pore pressure



[*Luttrell and Smith-Konter, 2017*]

Do these results make sense?

- YSE places a lower limit on fault friction and an upper limit on pore pressure
- At max required stress,
  - Fault friction can't be very low ($\mu_f > 0.3$)
  - Pore pressure can't be very high ($\lambda < 0.7$)
- Heterogeneous stress field more permissive



[*Luttrell and Smith-Konter, 2017*]

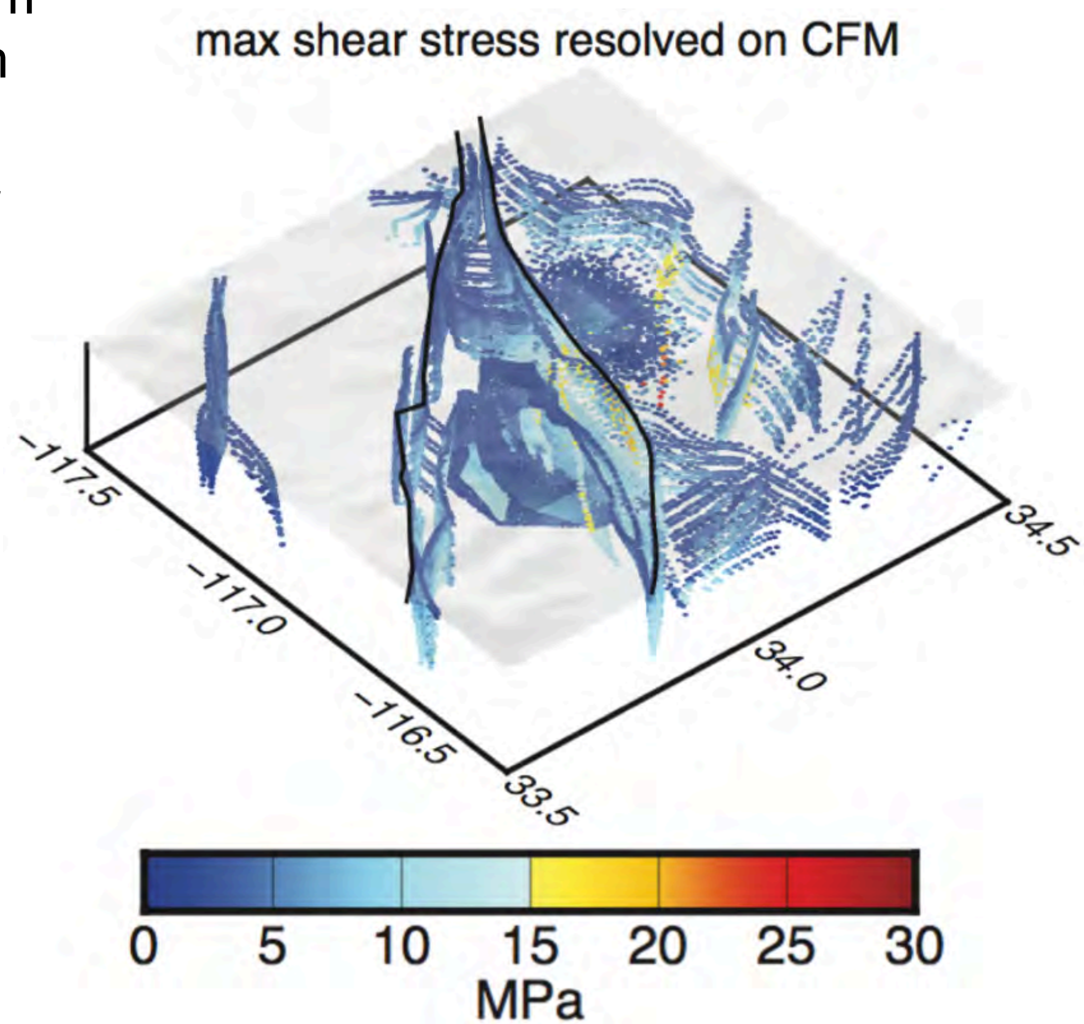
How much shear stress on the faults?

- Maximum shear stress from depth dependent minimum stress field estimate
  - Based on *Luttrell and Smith-Konter*, [2017]

- Resolve on CFM planes
  - [*Plesch et al.*, 2007; *Nicholson et al.*, 2013]

- Gives the right rake (not surprising, orientation is mostly from focal mechanisms)

- Shear stress generally ~5-20 MPa, varies with depth and fault orientation

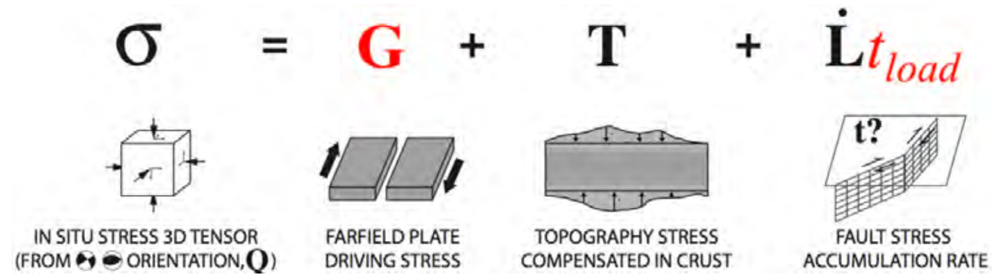


What’s new and current?

- Can we explicitly make sense of the near fault areas using the stressing rate models?

- Cajon Pass is a good place to start

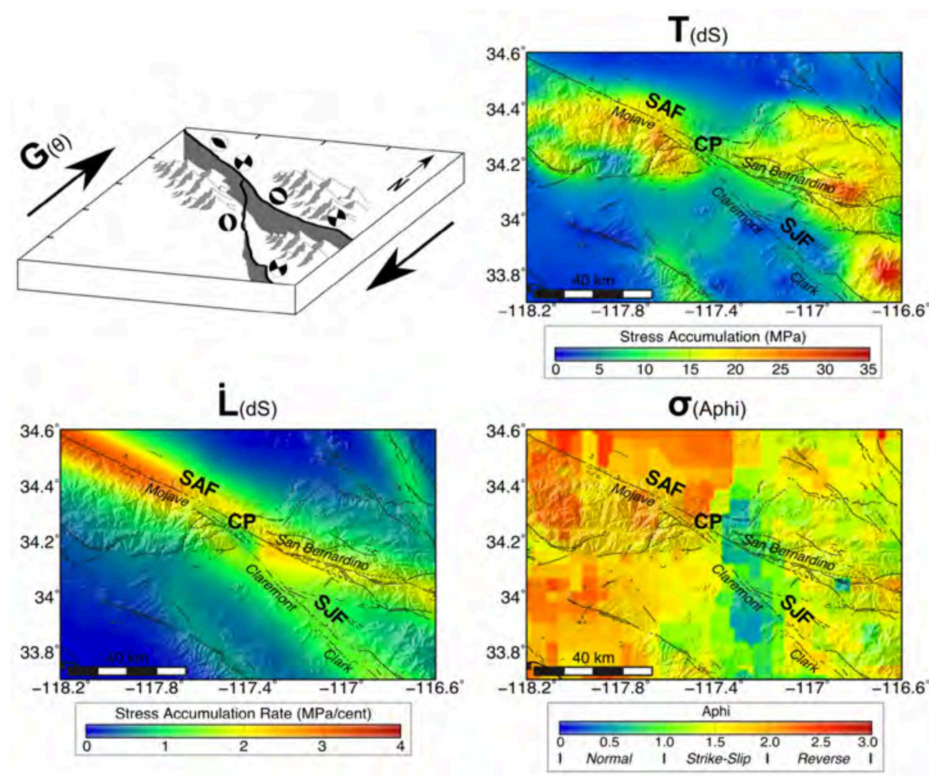
- Two types of free parameters



[Yang & Hauksson, 2013]

[Luttrell & Smith-Konter, 2017]

[Smith-Konter & Sandwell, 2009]

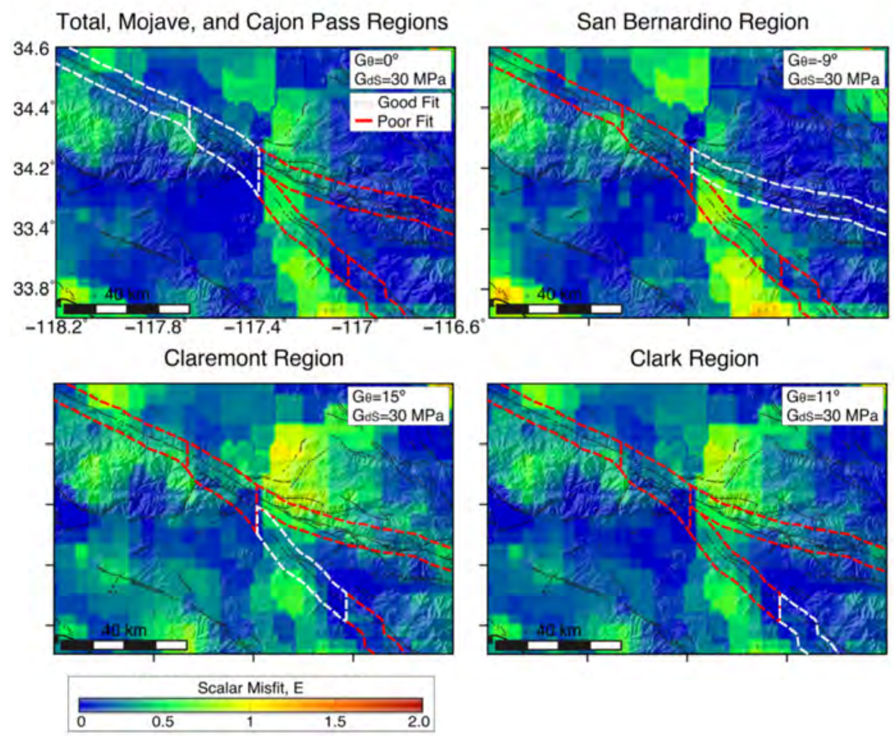


Elliott Helgans, LSU MS student

What's new and current?

- Can we explicitly make sense of the near fault areas using the stressing rate models?
- Cajon Pass is a good place to start
- Two types of free parameters
- **Bottom line: can make it fit ok if…**
  - Fault loading times are very long (1000s of year)
  - **OR**
  - **G** orientation varies within even this small region
  - …

Model misfits along different fault segments



Helgans et al [AGU, 2018]


Thanks! Questions?