Stress Patterns in the San Jacinto Fault Zone and South Central Transverse Ranges

Niloufar Abolfathian
Patricia Martínez-Garzón, Yehuda Ben-Zion
SCEC CSM Workshop, Pomona, January 2019

1University of Southern California, Los Angeles, USA
2GFZ German Research Centre for Geosciences, Potsdam, Germany
Introduction:
• Refining the methodology (Martínez-Garzón et al., 2016)
• Inverting focal mechanisms for the principal stress orientations and the stress ratio

Objectives:
• Obtaining a reliable, high-resolution information about stress parameters in Southern California near San Jacinto Fault Zone (SJFZ) and South Central Transverse Ranges (SCTR)
• Coming up with ingredients affecting the stress in the crust
Methods:

• MSATSI software (Martínez-Garzón et al., 2014), an updated version from SATSI (Hardebeck and Michael, 2006; Michael, 1984).
• A linear damped stress inversion on the earthquake focal mechanisms.
• Determines the orientation of the principal stresses and the stress ratio:

\[ R = \frac{\sigma_1 - \sigma_2}{\sigma_1 - \sigma_3} \]

Refinement (Martínez-Garzón et al., 2016):

○ Using declustered seismicity.
○ Selecting the fault plane with the largest fault instability (Vavrycuk, 2014)
○ Discretizing the focal mechanisms using an updated *k-means* technique.
San Jacinto Region: (CH, HS, TR)
Years: 2000 to 2009

10,829 focal mechanisms declustered catalog

South Central Transverse Ranges: (CP, SGP)
Years: 1981 to 2017

~3,200 focal mechanisms declustered catalog

CH: Crafton Hills
HS: Hot Springs
TR: Trifurcation area
CP: Cajon Pass
SGP: San Gorgonio Pass

Data:
- Seismicity catalog by Hauksson et al., (2012)
- Earthquake focal mechanisms catalog by Yang et al., (2012).
- Declustered following Zaliapin and Ben-Zion, (2013).
Key point:
Transpressional stress regime adjacent to the highest topography.

In Strike-slip regime: \[ R = \frac{\sigma_1 - \sigma_2}{\sigma_1 - \sigma_3} \]

- \( R \) increases (\( R \to 1 \)), stress regime towards transpressional.
- \( R \) decreases (\( R \to 0 \)), stress regime towards transtensional.

Abolfathian et al, in prep
Key point:

Transpressional stress regime adjacent to the highest topography.

In Strike-slip regime:

$R$ increases ($R \to 1$), stress regime towards transpressional.

$R$ decreases ($R \to 0$), stress regime towards transtensional.

Fialko et al., 2004

Abolfathian et al., in prep
Maximal Horizontal Compressional Stress ($S_{H_{\text{max}}}$) in SCTR

Key point:
No significant rotation in the $S_{H_{\text{max}}}$ direction.

$S_{H_{\text{max}}}$ is estimated following Lund and Townend (2007)
-Faulting types following Zoback (1992).
Crafton Hills (CH):

Key point:
**Extensional region** adjacent to intersection of San Andreas and San Jacinto faults

Significant rotation of maximum horizontal compressional stress (SHmax) with depth

-S\textsubscript{Hmax} is estimated following Lund and Townend,(2007)

In Strike-slip regime:
R increases (R \rightarrow 1), stress regime towards transpressional.
R decreases (R \rightarrow 0), stress regime towards transtensional.
Crafton Hills (CH):

Key point:

In Strike-slip regime:
R increases ($R \to 1$), stress regime towards transpressional.
R decreases ($R \to 0$), stress regime towards transtensional.
Hot Springs area (HS):

**Key point:**
**Strike-slip at shallow depth, larger focal mechanism variety with depth.**
**Increased stress ratio in deeper area**

In **Strike-slip regime:**
R increases \((R \rightarrow 1)\), stress regime towards transpressional.
R decreases \((R \rightarrow 0)\), stress regime towards transtensional.
Hot Springs area (HS):

Key point:

In Strike-slip regime:
- $R$ increases ($R \to 1$), stress regime towards transpressional.
- $R$ decreases ($R \to 0$), stress regime towards transtensional.

Increased stress ratio in deeper area towards transpressional.
Trifurcation area (TR):

Key point:
- Strike-slip stress regime
- Rotation of the principal stress axes and \( S_{H\text{max}} \)

In Strike-slip regime:
R increases (\( R \to 1 \)), stress regime towards transpressional.
R decreases (\( R \to 0 \)), stress regime towards transtensional.
Trifurcation area (TR):

- **Strike-slip stress regime**
  - $R$ increases ($R \rightarrow 1$), stress regime towards transpressional.
  - $R$ decreases ($R \rightarrow 0$), stress regime towards transtensional.

**Key points:**
- Strike-slip stress regime
- Rotation of the principal stress axes and $S_{Hmax}$
Summary:

• Significant variations of stress parameters with depth:
  o Transpressional stress components in regions with high topography, similar observed in CP, SGP and HS.
  o Transtensional components near Crafton Hills (CH)
  o Rotation of maximum horizontal compressional stress ($S_{Hmax}$) in CH
  o Rotation of the principal stress plunges is observed deeper than ~9 km at CH, HS and TR areas

• Abrupt variation in stress ratio near Cajon Pass!
Stress Distribution in SCTR:
Data separated in three different regions: between the SJF and SAF strands, western and eastern sections
**Stress Distribution in SCTR:**

Data separated in three different regions: between the SJF and SAF strands, western and eastern sections.
**Stress ratio distribution in the SCTR:**
Variations in the trend of stress patterns between the two main fault strands (SJFZ and SAF)

R increases ($R \to 1$), stress regime towards transpressional.
R decreases ($R \to 0$), stress regime towards transtensional.
Temporal changes of the stress before and after El Mayor event:

**Trifurcation area (Depth 6-9 km):**

<table>
<thead>
<tr>
<th>Year</th>
<th>Number of focal mechanisms</th>
</tr>
</thead>
<tbody>
<tr>
<td>2008-2009</td>
<td>2901</td>
</tr>
<tr>
<td>Oct2010-2012</td>
<td>2429</td>
</tr>
</tbody>
</table>

- Consistency in $S_{H_{max}}$
- Increase in stress ratios in Trifurcation area at 6-9 km
  (R-value: 0.52 → 0.79)
Summary:

• Significant variations of stress parameters with depth:
  o Transpressional stress components in regions with high topography, similar observed in CP, SGP and HS.
  o Transtensional components near Crafton Hills (CH)
  o Rotation of maximum horizontal compressional stress ($S_{Hmax}$) in CH
  o Rotation of the principal stress plunges is observed deeper than ~9 km at CH, HS and TR areas

• Abrupt variation in stress ratio near Cajon Pass!

• Variation in stress ratios trend between main two fault strands of San Jacinto and San Andreas where hypocentral depth of seismicity also gets deeper
Ingredients affecting the spatial distribution of the stress in the crust:

**Structure:**
- Number and geometry (dip, junctions, etc) of the major faults
- Rheology (Moho depth/ brittle-ductile transition zone, topography)

**Loading:**
- Tectonic Loading (Partitioning of plate motion among main faults)
- Gravity (Depth dependent; effects of topography)

**Focus on temporal changes of stress parameters!**

Selected References: