Geomorphic evidence for recent deformation along the Southern San Cayetano fault

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Motivation

Problem:
Geologic rates on major faults are highly uncertain.

Needs:
- High resolution slip rates
- Location, geometry, and interactions of faults

Knowledge gap:
- Chronologic constraints on regional markers, e.g., ORF, VF

Western Transverse Ranges Faults and Plio-Pleistocene Saugus Formation
Without the Southern San Cayetano fault

- SCF slip rates decrease toward W (& expression)
- Possible slip rate deficit across central Ventura Basin (ages too uncertain to have confidence)

Red boxes = geologic slip rates (blue values = shortening equivalent)
Blue box = geodetic shortening rate with respect to Santa Monica Mountains (i.e., includes Simi Fault)

- Without the Southern San Cayetano fault, SCF slip rates decrease toward W (expression).
- A possible slip rate deficit across central Ventura Basin is noted, with ages too uncertain to have confidence.

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Rockwell (1988): WSCF 3.6 +/- 0.4 mm/yr
Hubbard et al. (2014): VF 4.4-6.9 mm/yr
Yeats (1988): ORF 1.7-12.5 mm/yr
Huftile & Yeats (1996): ESCF 7.4 +/- 3 mm/yr
Marshall et al. (2013): ~5.2, ~2.5

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- Rockwell (1988) provides a slip rate of 3.6 +/- 0.4 mm/yr for the WSCF.
- Hubbard et al. (2014) estimate a slip rate of 4.4-6.9 mm/yr for the VF.
- Yeats (1988) and Huftile & Yeats (1996) report slip rates of 1.7-12.5 mm/yr for the ORF and ESCF, respectively.

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Note: The diagram illustrates the slip rates and locations of various faults and sections, with red boxes indicating geologic slip rates and blue boxes showing geodetic shortening rates with respect to the Santa Monica Mountains (including the Simi Fault).
With the Southern San Cayetano fault (SSCF)

SSCF may be significant contribution to strain budget
Not included in hazard maps, but identified in industry well data (e.g., Pagenkopp fault)

Red boxes = geologic slip rates
Blue box = geodetic shortening rate with respect to Santa Monica Mountains (i.e., includes Simi Fault)
Hypotheses to be tested

• **H1:** An unmapped blind(?) or emergent(?) N-dipping reverse fault, the Southern San Cayetano Fault (SSCF), exists beneath the range front between Santa Paula and Fillmore.
  - **T1:** Conduct geomorphic mapping using lidar data to identify deformation.

• **H2:** Strain from the ESCF is being partitioned westward between the WSCF and the SSCF.
  - **T2:** Compare slip rate on ESCF to WSCF and SSCF using lidar offsets and cosmogenic isotope exposure ages.

• **H3:** The SSCF transfers strain from the ESCF westward across the Ventura Basin to the onshore Ventura fault (VF) and offshore Pitas Point fault system.
  - **T3:** Compare D-L plots and slip rates for ESCF, SSCF, and VF.

• **H4:** Strain is being transferred from the WSCF to the SSCF through time as deformation propagates southward into the basin.
  - **T4:** Assess whether slip rates on the SSCF increase through time, whereas slip rates for the WSCF decrease through time.
Evidence for active deformation in lidar data: SSCF
Orcutt Canyon: Geomorphology and cosmogenic isotope dating samples

Unpublished $^{14}$C age (Earth Consultants International, 2006)

16022-15860 cal BC (1σ)
Soil ages of terraces from Rockwell (1988)

<table>
<thead>
<tr>
<th>Terrace</th>
<th>Radiocarbon Age (years)</th>
<th>Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1</td>
<td>10-20</td>
<td>Soil Profile</td>
</tr>
<tr>
<td>Q2</td>
<td>&lt;250</td>
<td>Soil Profile</td>
</tr>
<tr>
<td>Q3</td>
<td>500-5,000</td>
<td>$^{14}$C dates, dendrochronology, soil profile</td>
</tr>
<tr>
<td>Q4</td>
<td>8,000-12,000</td>
<td>$^{14}$C dates, relative fault displacement</td>
</tr>
<tr>
<td>Q5</td>
<td>15,000-30,000</td>
<td>$^{14}$C dates, relative fault displacement</td>
</tr>
<tr>
<td>Q6</td>
<td>38,000-92,000</td>
<td>$^{14}$C dates, relative fault displacement</td>
</tr>
<tr>
<td>Q7</td>
<td>160,000-200,000</td>
<td>relative fault displacement</td>
</tr>
</tbody>
</table>

- Soil chronostratigraphy based on Ventura River terraces
- Cosmogenic isotope surface exposure dating will refine this chronology
Southern San Cayetano fault: Orcutt Canyon terraces

Ventura County 5m lidar data
Scarp in Q4 terrace at Orcutt Canyon
Evidence for active deformation in lidar data
SSCF: Fold near Fillmore

Depth profile on Q5 fan

Soil on Q5 fan
Cosmogenic isotope surface exposure dating samples

**WSCF: Bear Canyon Q4**

**SSCF: Orcutt Canyon Q5**

**WSCF: Orcutt Canyon Q4**

**SSCF: Timber Canyon Q7**

**WSCF: Bear Canyon Q6**

- **KR:** 8-12 ka
- **OCN:** 15-30 ka
- **TC:** 160-200 ka
- **Boulder Sample:** BCB15 80-100 +/- ka
- **OC4:** 8-12 ka
Proposed conceptual model including SSCF

INCLUDING THE SSCF:

Central Ventura Basin

SR-ORF cos(\theta) ORF
SR-WSCF cos(\theta) WSCF
SR-SSCF cos(\theta) SSCF

Fold Strain = 7-10 mm/yr (including Simi Fault)

D-L Plots

VF: L = ~40 km > Mw ~6.9
WSCF: L = ~20 km > Mw ~6.6
ESCF: L = ~20 km > Mw ~6.6
SSCF: L = ~25 km > Mw ~6.7

CUMULATIVE: L = ~85 km > Mw ~7.5
## Preliminary slip rate summary: SSCF vs. WSCF

<table>
<thead>
<tr>
<th>Terrace</th>
<th>Age (ka)</th>
<th>Offset (m)</th>
<th>Throw rate (mm yr(^{-1}))</th>
<th>Slip rate (mm yr(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Southern San Cayetano</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q4</td>
<td>8-12</td>
<td>11.7 (+0.7/-1.6)</td>
<td>1.46 (+0.09/-0.2)</td>
<td>2.07 (+0.12/-0.29)*</td>
</tr>
<tr>
<td>Q4</td>
<td>16.081</td>
<td>11.7 (+0.7/-1.6)</td>
<td>0.73 (+0.04/-0.1)</td>
<td>1.02 (+0.05/-0.13)**</td>
</tr>
<tr>
<td>Q5</td>
<td>15-30</td>
<td>23 (+1.02/-1.54)</td>
<td>1.53 (+0.07/-0.1)</td>
<td>2.17(+0.09/-0.15)</td>
</tr>
<tr>
<td>Q7</td>
<td>160-200</td>
<td>294 (+17/-5.4)</td>
<td>1.84 (+0.1/-0.04)</td>
<td>2.60 (+0.15/-0.05)*</td>
</tr>
<tr>
<td><strong>Western San Cayetano</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q4</td>
<td>8-12</td>
<td>8.13+/−1</td>
<td>1.02 (+/−0.12)</td>
<td>1.44 (+/−0.18)</td>
</tr>
<tr>
<td>Q6</td>
<td>92+/−13</td>
<td>156+/−7.9</td>
<td>1.95 (+/−0.1)</td>
<td>2.75 (+/−0.14)</td>
</tr>
</tbody>
</table>

**Note:** *Slip rates for the SSCF are based on a hypothetical 45° dip for the SSCF that is assumed the same dip as the WSCF.

**This is a C-14 age (sample C-14) from an unpublished geotechnical investigation (Earth Consultants International (2006)). The sample was taken at 2.7 m below the surface. This age is therefore, older than the true surface age and the corresponding uplift and slip rates are minimum rates.*
Preliminary Conclusions

- Geomorphological evidence suggests an unmapped blind(?) or emergent(?) N-dipping reverse fault, the SSCF, beneath the range front between Santa Paula and Fillmore (consistent with H1).

- Strain in the central Ventura Basin may be partitioned between the SSCF and the WSCF (possibly consistent with H2).

- The SSCF could link the ESCF to the VF (possibly consistent with H3) creating a ~85 km long rupture; such a multi-fault rupture could therefore produce a ~M\text{w} 7.5 (or greater) earthquake.

- Slip rates for the WSCF may have decreased by 50%, from 2.8 mm yr\(^{-1}\) since 80 ka to 1.4 mm yr\(^{-1}\) since 8 ka (possibly consistent with H4).

- Max. preliminary slip rates for the SSCF are 2.6 mm yr\(^{-1}\) since 160 ka, 4.2 mm yr\(^{-1}\) (using larger offset) since 15 ka, and 2.1 mm yr\(^{-1}\) since 8 ka (unclear relationship to H4 – future geochronology will refine slip rates).

- The SSCF is an active structure, which should be included in future seismic hazard maps, hazard assessments, and SCEC community fault model.

- However, more high-resolution chronologic data and trenching are necessary.
Extra slides
Evidence for active deformation in lidar data: WSCF
Western San Cayetano Fault (WSCF)

Possible scarps uplifted Q7 terraces

Scarp

EarthScope 0.5m lidar data
Western San Cayetano Fault (WSCF)

Soil on Q4 terrace

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<thead>
<tr>
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<th>Slip rate (mm yr(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q4</td>
<td>8-12</td>
<td>8.13 +/- 1</td>
<td>1.02 (+/-0.12)</td>
<td>1.44 (+/-0.18)</td>
</tr>
<tr>
<td>Q6</td>
<td>92 +/- 13</td>
<td>156 +/- 7.9</td>
<td>1.95 (+/-0.1)</td>
<td>2.75 (+/-0.14)</td>
</tr>
</tbody>
</table>
CGS Fault Activity Map of California
Industry well data: Pagenkopp fault
Western Transverse Ranges Faults and Plio-Pleistocene Saugus Formation
Base of Saugus Formation (Oak Ridge fault hangingwall)

$^{26}$Al-$^{10}$Be isochron burial dating results

SGC2: 1.08 $^{+0.04/-0.08}$ Ma (68% CI)
Top of Saugus Formation (Ventura fault hangingwall)

$^{26}$Al-$^{10}$Be isochron burial dating results

SVF:
365 $\pm$90/-114 ka
(68% CI)