Observations Relating to 3D Fault Geometry and Seismic Hazard in the Santa Barbara-Ventura Area: Findings from the SCEC Commemorative 1925 Santa Barbara Earthquake Workshop

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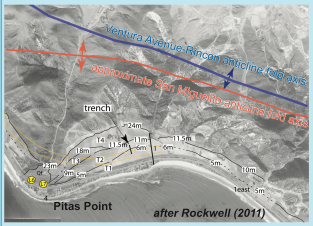
SCEC CEM Poster #331

This is NOT the Ventura Avenue Anticline!

It is the distinctly separate San Miguelito Anticline!

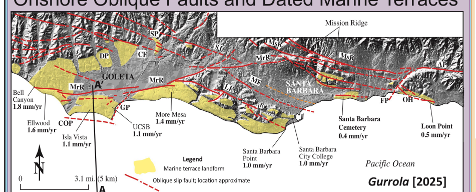
N-verging San Miguelito anticline is being driven by the S-dipping, listric Padre Juan fault, which also drives the uplift at Pitas Point. Photo credit Art Sylvester.

Map of Holocene Emergent Terraces at Pitas Point

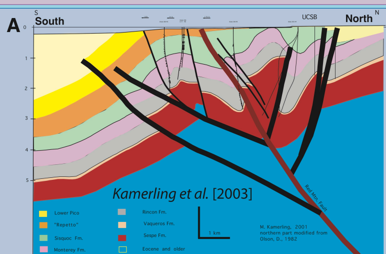


Uplifted marine terraces at Pitas Point reflect four 8-11 m uplift events since 7 ka, and a local uplift rate of 6-7 mm/yr [*Rockwell et al.*, 2016]. This uplift rate is significantly higher than observed elsewhere along the coast [*Gurrola*, 2025] and is driven primarily by slip on the Padre Juan fault [*Nicholson et al.*, 2017; *Hsieh and Suppe*, 2020].

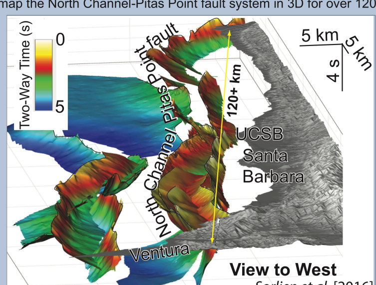
Onshore Oblique Faults and Dated Marine Terraces



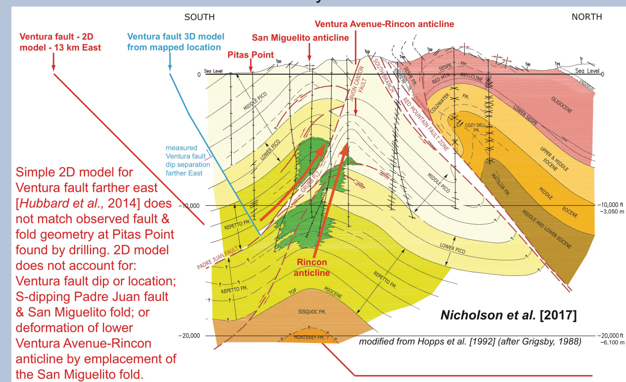
Mapped onshore faults (red lines, Mission Ridge, More Ranch, Mesa, etc.) are oblique-strike-slip and steeply S-dipping (>60°). Slip rates are ~1–2 mm/yr. Dated marine terraces indicate uplift rates that decrease from west (1.8 mm/yr) to east (0.5 mm/yr)[*Gurrola*, 2025], significantly less than at Pitas Point.



(**above**) Subsurface fault & fold geometry defined by industry MCS & well data. Onshore S-dipping faults merge with offshore N-dipping oblique faults to define a single master oblique fault at depth. (**below**) Marine seismic reflection data can map the North Channel-Pitas Point fault system in 3D for over 120 km.

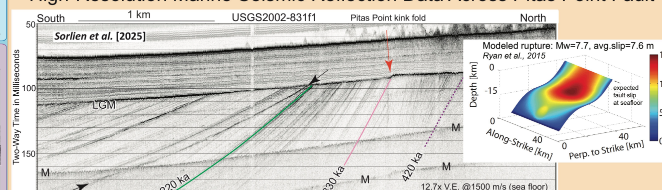


Structure Cross Section from Industry Well Data 3 km East of Pitas Point



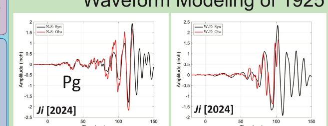
This cross section near Pitas Point demonstrates that: 1) there are two independent active anticlinal folds present (San Miguelito and Ventura Avenue); 2) S-dipping, listric Padre Juan fault exhibits ~2.6 km of offset since 250 ka and is Holocene active; 3) timing of upper San Miguelito fold uplift along Padre Juan fault was contemporaneous with growth of lower Rincon anticline, as emplacement deforms the lower fold and Padre Juan splays are also folded; and 4) Padre Juan fault slip needed to emplace San Miguelito fold is unrelated to the Ventura fault because this involves moving material from the footwall to the hanging-wall of and across the Ventura fault itself.

High-Resolution Marine Seismic Reflection Data Across Pitas Point Fault



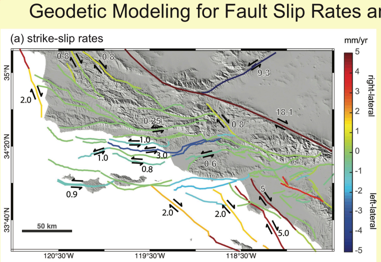
USGS chirp line 831 located ~10 km west of Pitas Point. Last Glacial Maximum (LGM) unconformity dated at ~12 ka is only deformed ~2 m by kink folding above the blind Pitas Point fault (red arrow). Paired black arrows show angular unconformity whose dip and age indicate progressive tilting above and continued slip on the S-dipping Padre Juan fault. Expected 10-12-m seafloor offsets at the Pitas Point fault [*inset*] predicted by rupture models for each of the four M7.7+ earthquakes used to explain the uplift events at Pitas Point since 7 ka are not observed.

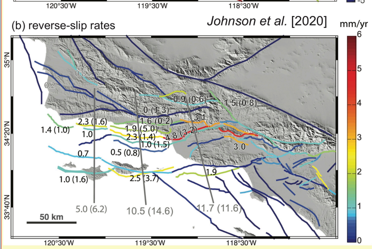
Waveform Modeling of 1925 M6.5 Santa Barbara Earthquake



Comparison of UC Berkeley Bosch-Omori (red) and synthetic (black) records for the 1925 Santa Barbara event. Forward modeling supports M6.5, and a focal depth (10 km) and oblique focal mechanism (high-angle S-dipping or low-angle N-dipping) for this event similar to the 2013 M4.8 Isla Vista earthquake used as an empirical Green's function. This geometry would be consistent with slip on either the Mesa or Pitas Point fault, but below the inferred modeled detachment.

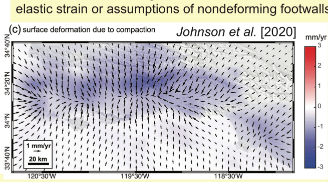
Geodetic Modeling for Fault Slip Rates and Basin Compaction Effects



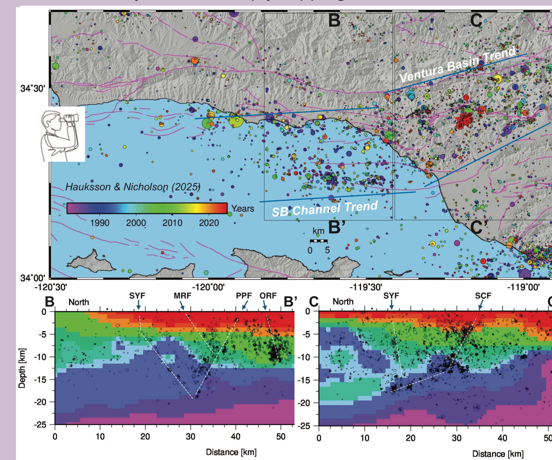


Inversion of geodetic data using 3D fault models in a visco-elastic half-space provide estimates of strike-slip (**a**) and reverse-slip (**b**) fault slip rates [*Johnson et al.*, 2020]. A major point, often overlooked, is that there is about **5 mm/yr of left-slip across 3 major faults in the SB Channel** (RMF, PPF, ORF), as compared with about **6-8 mm/yr of reverse-slip** across the same 3 faults. Onshore, SYF and MRF are also oblique-slip faults. This implies the fault systems are fundamentally oblique, and as such, they are not and can not be modeled as thrust faults, or presume to exhibit inferred low-angle (<45° dip) thrust fault geometry.

In addition, modeling surface deformation due to 3D basin sediment compaction (**c**) [*Johnson et al.*, 2020] predicts **surface subsidence rates of 2–3 mm/yr** and **horizontal contraction rates of up to 2 mm/yr** in the Santa Barbara and Ventura basins. This inelastic, non-recoverable component of geodetic strain needs to be considered in evaluating inferred accumulation rates of elastic strain or assumptions of nondeforming footwalls.

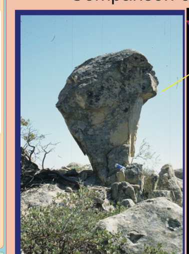


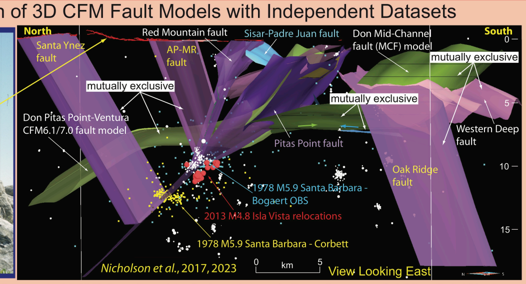
Relocated Seismicity Define Steeply Dipping Planar Faults to >10 km Depth



Relocated seismicity [*Hauksson & Nicholson*, 2025] define steeply dipping (>50°) planar surfaces for the Santa Ynez (SYF), Mission Ridge (MRF), Pitas Point (PPF), Oak Rdge (ORF) & San Cayetano (SCF) faults, a possible low-angle detachment (in C-C') and two regional trends (SB Channel, Ventura Basin) that represent extensive footwall deformation.

Comparison of 3D CFM Fault Models with Independent Datasets





(***right***) Oblique 3D view looking east of CFM5.3 preferred faults (purple), and alternative ramp-flat Pitas Point-Ventura (PP-VF) and Mid-Channel faults adopted by CFM7.0. Note correlation of steeply dipping CFM5.3 PP-VF, Red Mtn & Oak Ridge faults with independent relocated 1978 M5.9 Santa Barbara (blue, yellow), 2013 M4.8 Isla Vista (red) and 2008-2017 (white) seismicity [*Nicholson*, 2023, 2024; *Ross et al.*, 2019]. Alternative ramp-flat models contradict and do not predict these events that all occur below the modeled detachments in their assumed rigid, non-deforming footwalls. (***left***) One of several Precariously Balanced Rocks located behind Santa Barbara and Montecito [*Brune*, 2009]. Such features can provide independent constraints on the size and maximum strong ground motion the inferred earthquakes associated with the Pitas Point uplift and the active faults in the Santa Barbara-Ventura area can and have produced.

Critical Observations Related to 3D Fault Geometry & Seismic Hazard

- ***Active fault systems are oblique and steeply dipping.*** Major onshore faults (Mission Ridge, Mesa, etc.) are steeply (>60°) S-dipping and oblique-strike-slip; these merge with N-dipping, offshore oblique-reverse faults (Red Mtn, Pitas Point) to form a master N-dipping oblique fault at depth. Based on mapping, imaging, drilling, geodetic data, and seismicity, major faults (Red Mtn, San Cayetano, Santa Ynez, Oak Ridge) are planar, oblique and steeply dipping (>50°) to 15-18 km depth.
- ***In 3D, the oblique North Channel-Pitas Point fault system is complex.*** Extensive grids of 2D and 3D seismic reflection data allow mapping of the offshore complex and segmented, oblique North Channel-Pitas Point-Red Mtn fault system in 3D for over 120 km, with components of strike-slip increasing to the west [*Sorlien et al.*, 2016, 2025; *Kluesner et al.*, 2020].
- ***Large uplift events & uplift rate at Pitas Point are anomalous.*** Four major uplift events and high uplift rate at Pitas Point are not found elsewhere along the coast [*Gurrola*, 2025], or farther along strike of the Pitas Point-Ventura fault. What correlations do exist typically reflect smaller and fewer uplift or tilt events since 7 ka [*Perea et al.*, 2021; *Anthonissen*, 2025].
- ***At Pitas Point, there is not one but two active anticlinal folds –*** the upper N-verging, asymmetric San Miguelito anticline in the hanging wall of the S-dipping, listric Padre Juan fault, and the distinctly separate lower Ventura Avenue-Rincon anticline in the Padre Juan's footwall [*Grigsby*, 1988; *Hopps et al.*, 2012; *Nicholson et al.*, 2017; *Hsieh & Suppe*, 2020].
- ***S-dipping, listric Padre Juan fault is independently Holocene active.*** The fault exhibits ~2.6 km of dip separation since 250 ka. Because emplacement of the San Miguelito fold involved moving material from the footwall to the hanging-wall of the Ventura fault, this fault slip occurred while the Padre Juan fault (PJF) was acting independently. High-resolution MCS reflection data indicate continued progressive limb rotation and tilting in the footwall of the Pitas Point fault above the lower PJF, which indicates, together with seismicity, that the S-dipping listric PJF is Quaternary and Holocene active.
- ***Both the offshore Pitas Point fault and onshore Ventura fault are blind.*** Pitas Point fault has not exhibited near-seafloor fault rupture in most places since 500 ka [*Sorlien et al.*, 2016], and only minor kink folding of the LGM unconformity close to Pitas Point [*Johnson et al.*, 2017; *Perea et al.*, 2021]. The marked lack of surface or seafloor rupture and lack of uplift event correlation along strike both onshore [*Anthonissen*, 2025] and offshore [*Perea et al.*, 2021] for all 4 Pitas Point uplift events suggests the earthquakes associated with the uplift events are more like M7.0+, and not M7.7+ as previously inferred.

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