Controversial Issues Related to Earthquake Hazards in the Santa Barbara-Ventura Area

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In all cases, the magnitudes of uplift events [observed at Pitas Point] are typically associated with large earthquakes in the M7.7–8 range, or larger – *Rockwell et al.,* 2016

This fault system could generate a large magnitude earthquake (>Mw 7.0) – *Perea et al.,* 2021

With Contributions From

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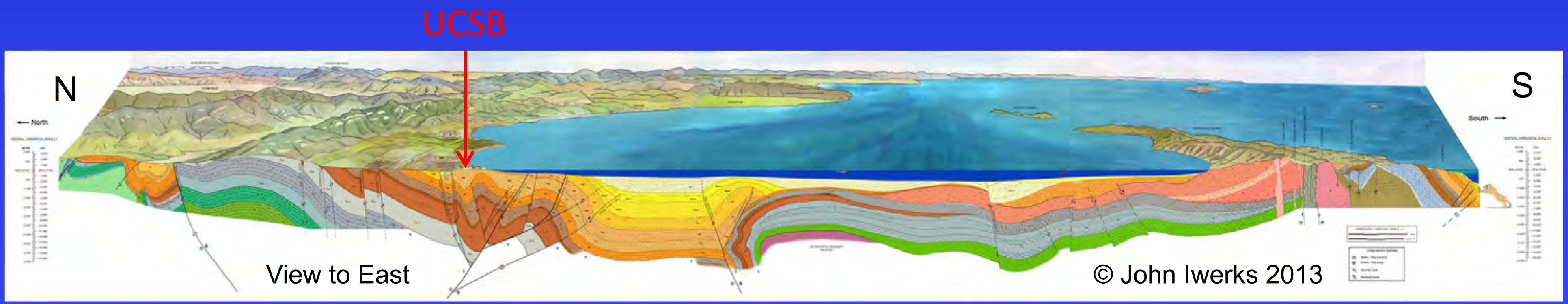


Perspective view looking east and geologic cross section across the Santa Barbara Channel - 23-ft wall mural at UCSB

Key Observations

Western Transverse Ranges block is tectonically rotated. It is therefore detached at base of crust; faults exhibit oblique slip and inherited moderate-to-steep-dip fault geometry.

Onshore Ventura and offshore Santa Barbara basins accommodate shortening by basin subsidence (2-3 mm/yr) and deformation is localized to the footwall of basin-bounding faults. Inelestic crustal processes like compaction, gravity sliding and aseismic folding can contribute to measured geodetic strains.

Based on extensive marine multi-channel seismic reflection data, the North Channel-Pitas Point-Red Mountain fault system extends from Ventura west to Pt. Conception, a distance of over 120 km.

Relocated hypocenters and other independent datasets indicate major faults (SYF, RMF, ORF, SCF) are through-going planar crustal faults with seismicity extending to 15-18 km depth and dips >50°.

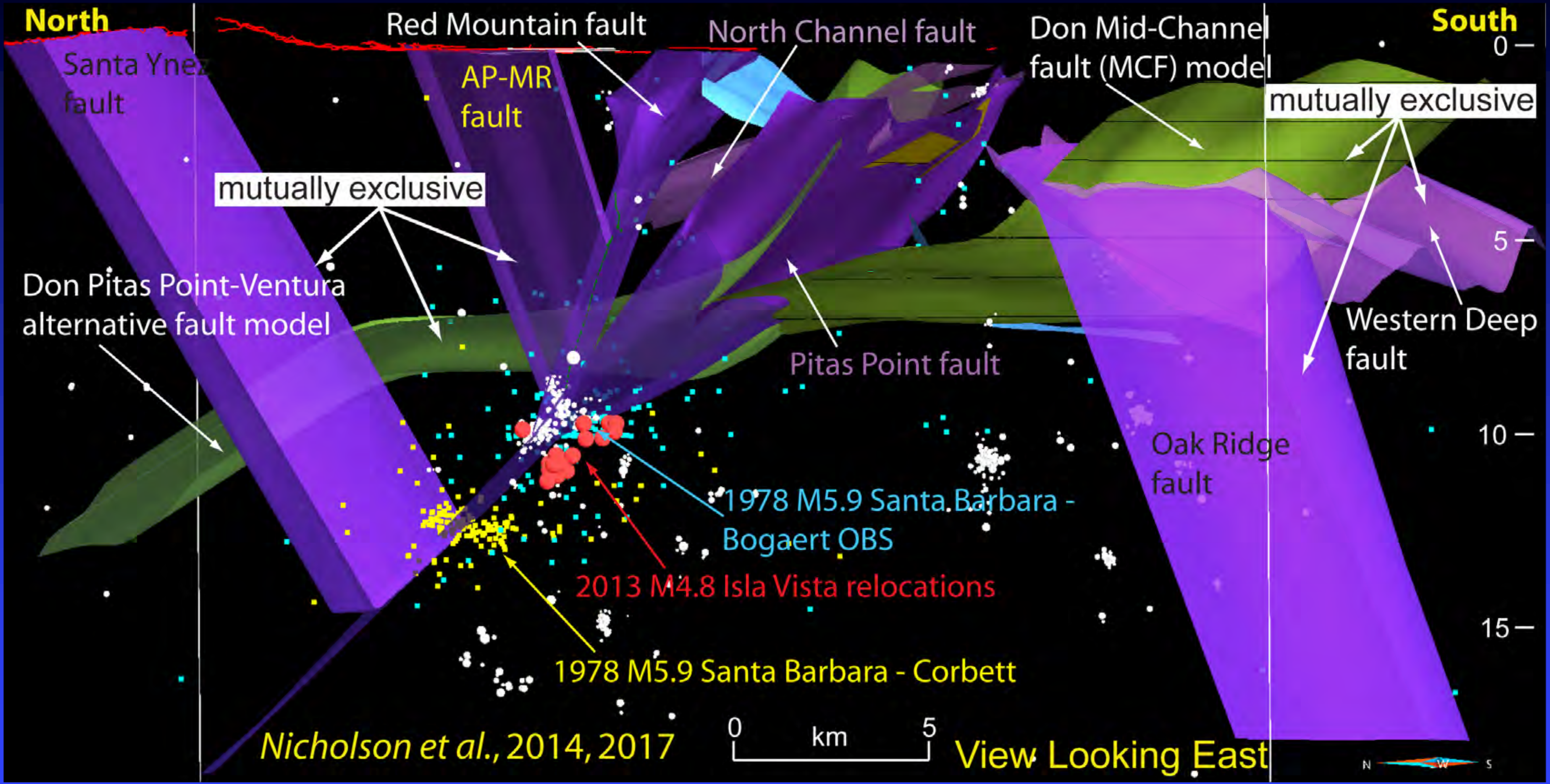
Major onshore faults (Mission Ridge, Mesa) exhibit oblique strike-slip and are steeply (>60°) S-dipping

Pitas Point exhibits four large (7-12 m) uplift events since 7 ka. This is the basis for inferring large M7.7+ earthquakes on the Pitas Point-Ventura fault, but could reflect local deformation processes instead.

Large Holocene uplift events at Pitas Point are anomalous and not seen elsewhere along the coast. Both Pitas Point and Ventura faults are blind and only exhibit minor folding near Pitas Point.

At Pitas Point, there are two active anticlinal folds, San Miguelito and Ventura Avenue-Rincon. Listric S-dipping Padre Juan fault is independently Holocene active in Ventura fault footwall and hanging wall.

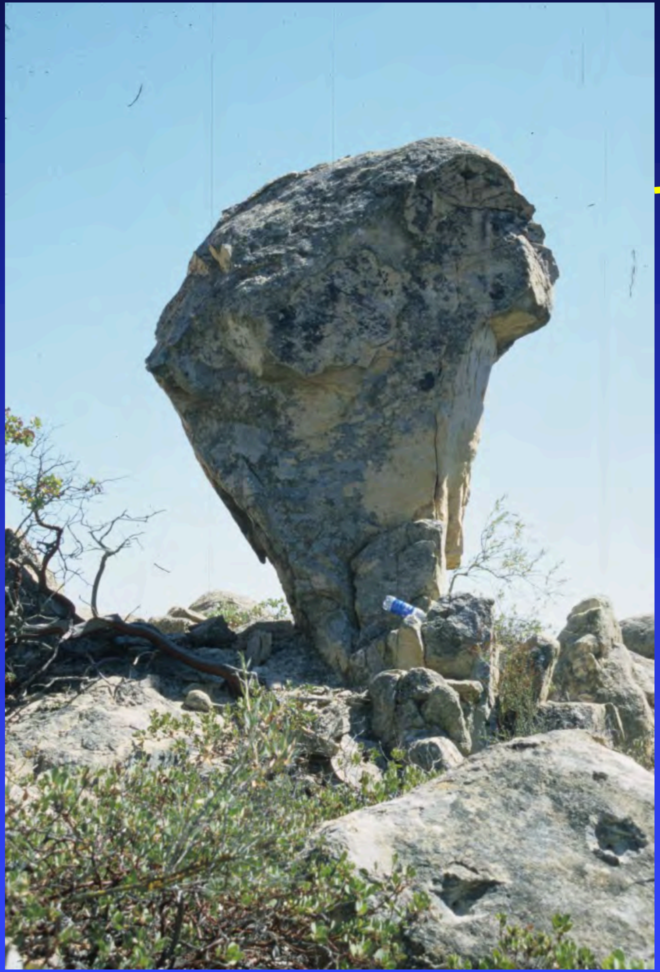
3D CFM Fault Models Compared with Independent Datasets



CFM5.3 preferred faults (purple) and alternative CFM7.0 ramp-flat Pitas Point-Ventura and Mid-Channel faults (green) from Don et al. (2021). Note correlation of steeply dipping CFM5.3 fault models with relocated seismicity, while Don models contradict and do not predict these events that primarily occur below the detachments in their assumed rigid, non-deforming footwall.

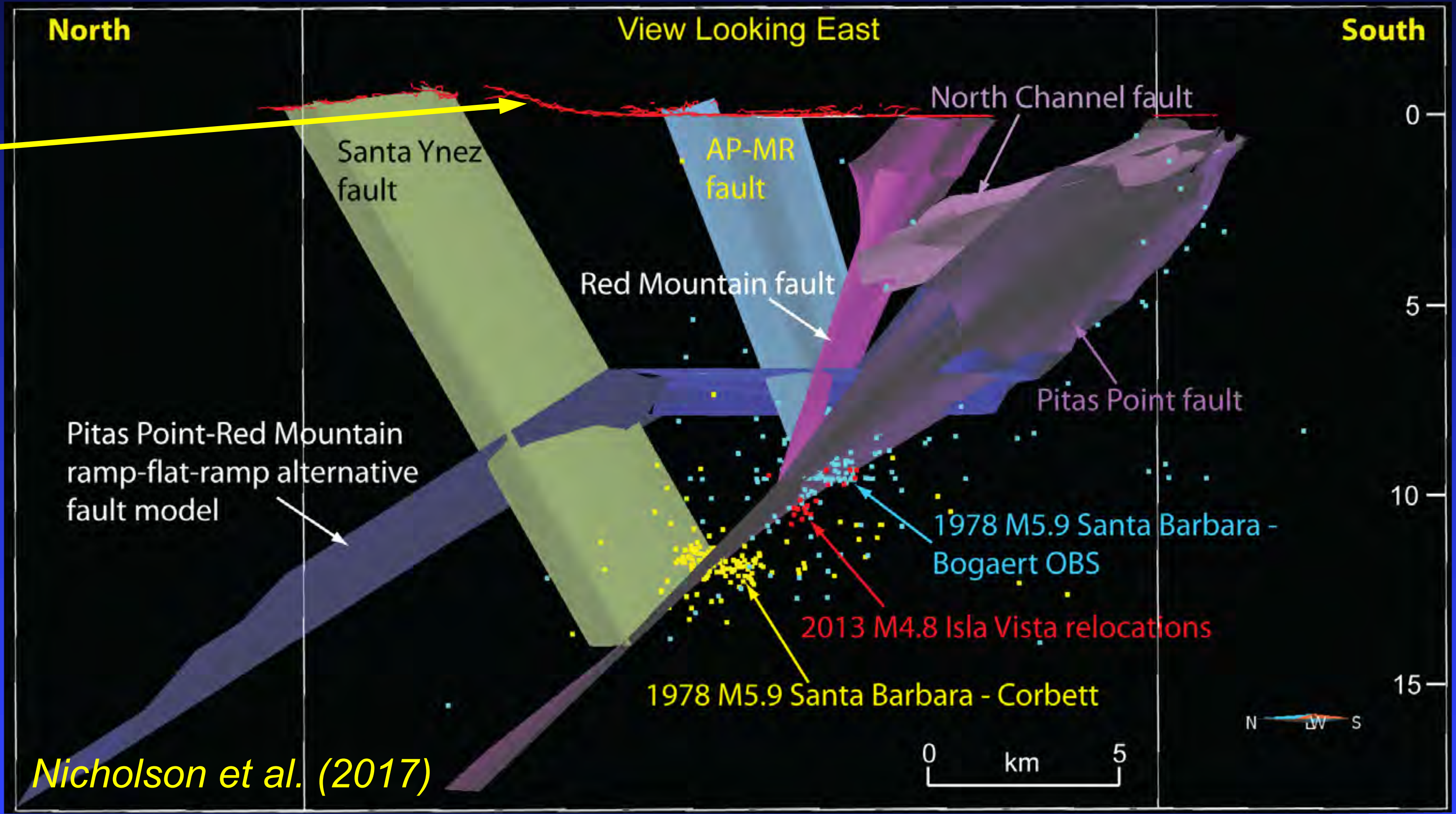
Ground Motion Hazards

Observations



Precariously Balanced Rocks exist directly above proposed N-dipping Pitas Point-Red Mountain ramp-flat fault model.

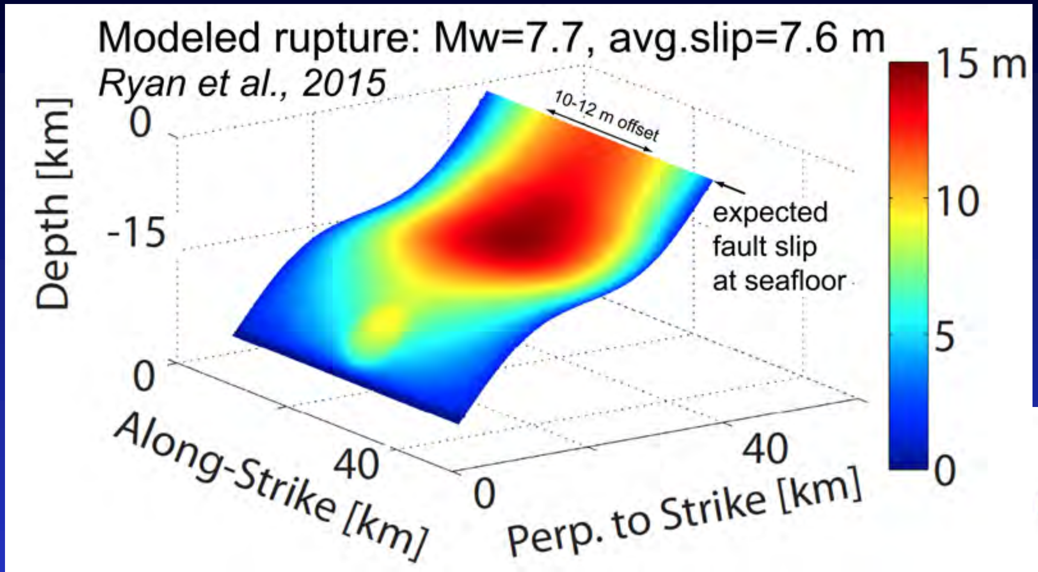
Models



Proposed ramp-flat Pitas Point-Red Mountain fault model is inconsistent with independent sets of relocated earthquakes associated with the 1978 M5.9 Santa Barbara and 2013 M4.8 Isla Vista events.

Tsunami Hazards

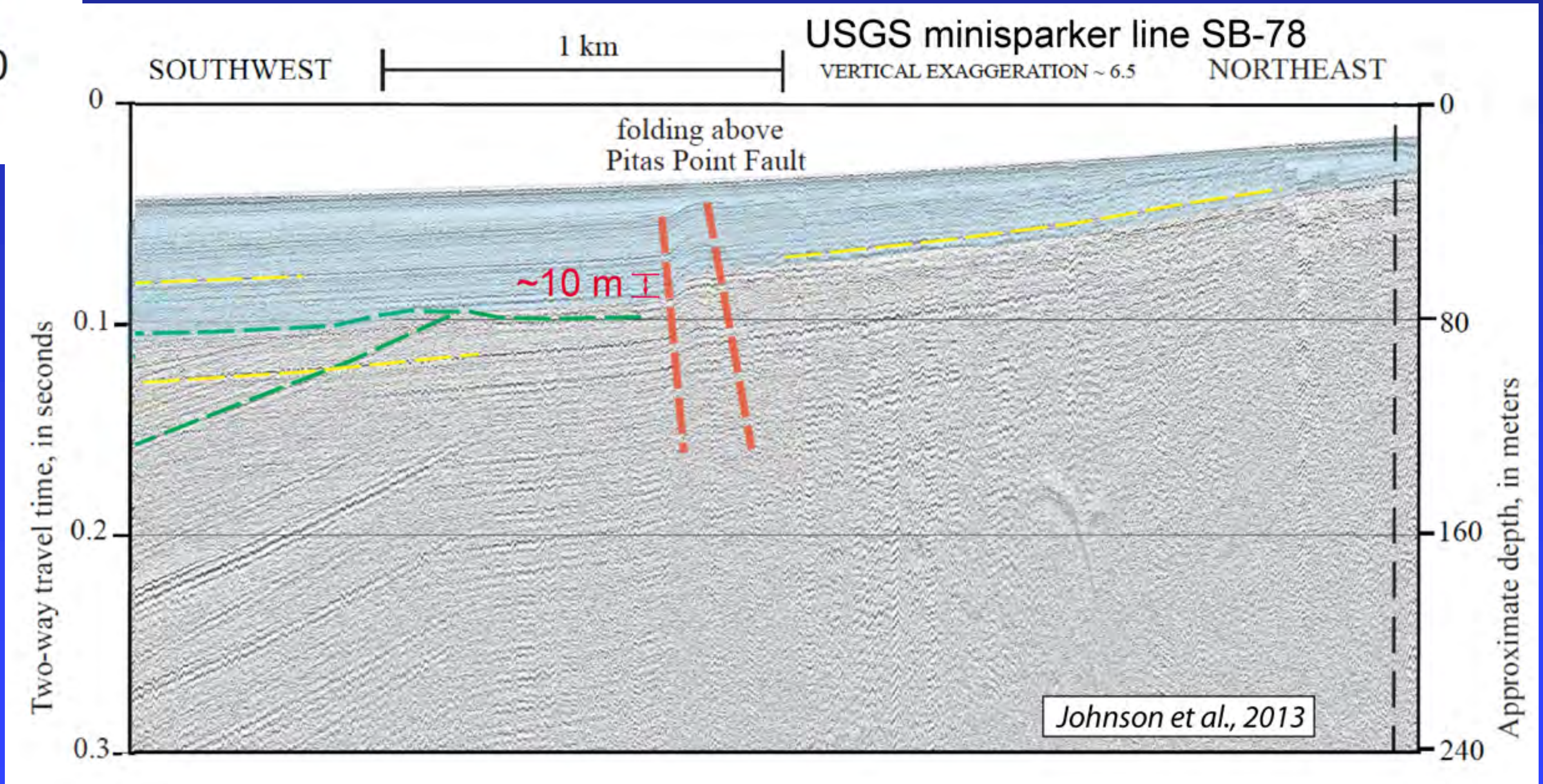
Model



Model prediction is 10-12 m of seafloor offset for each M7.7 rupture, or 40-50 m of seafloor offset for 4 events since 7 ka.

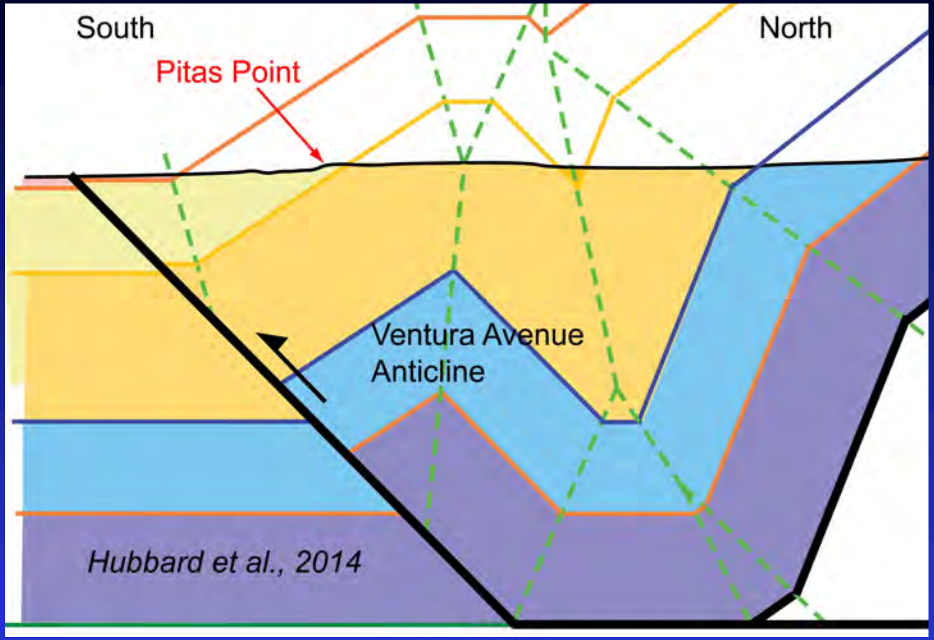
Observations

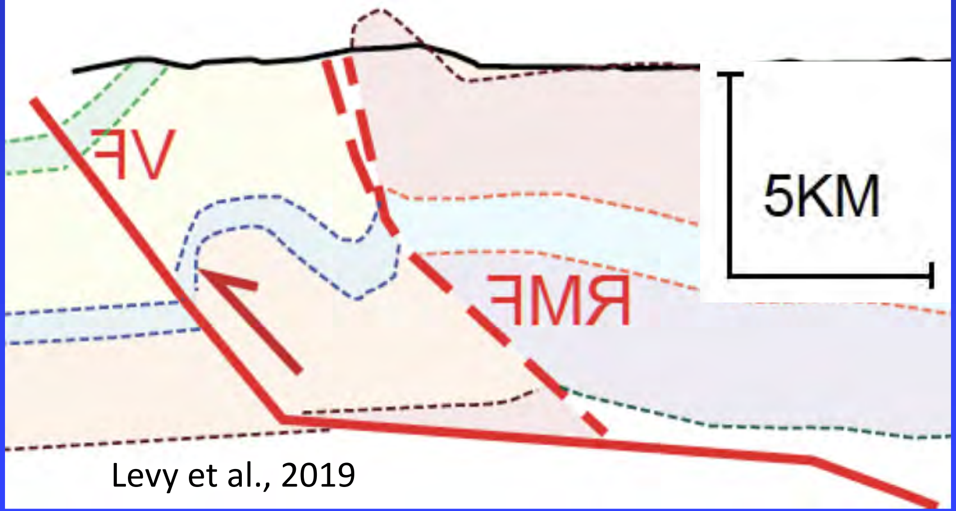
At the Pitas Point fault, the LGM transgression unconformity dated at about 10-12 ka exhibits only minor (~10 m) folding and no offset . Farther west, this unconformity is not deformed.



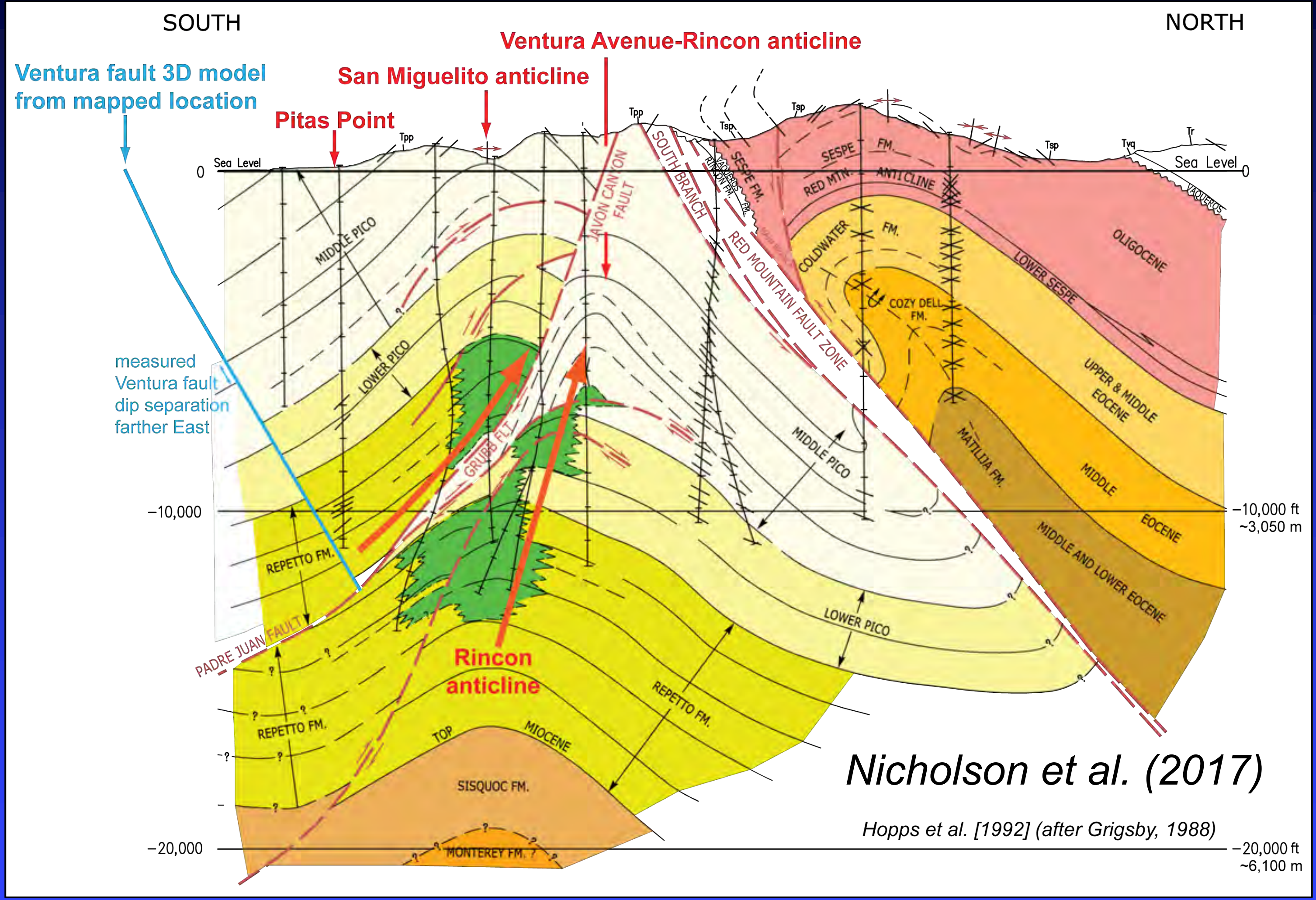
Subsurface Geology from Industry Data

Models





Observations

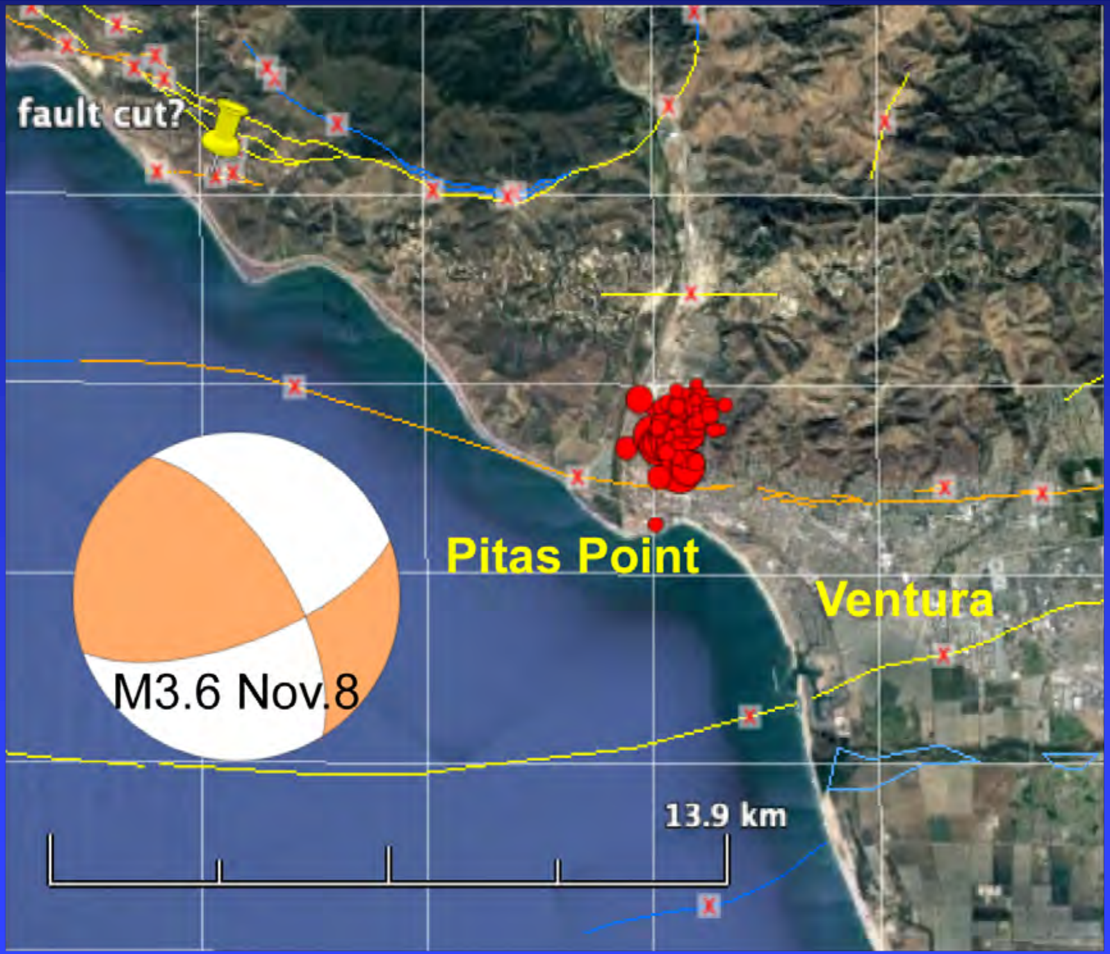


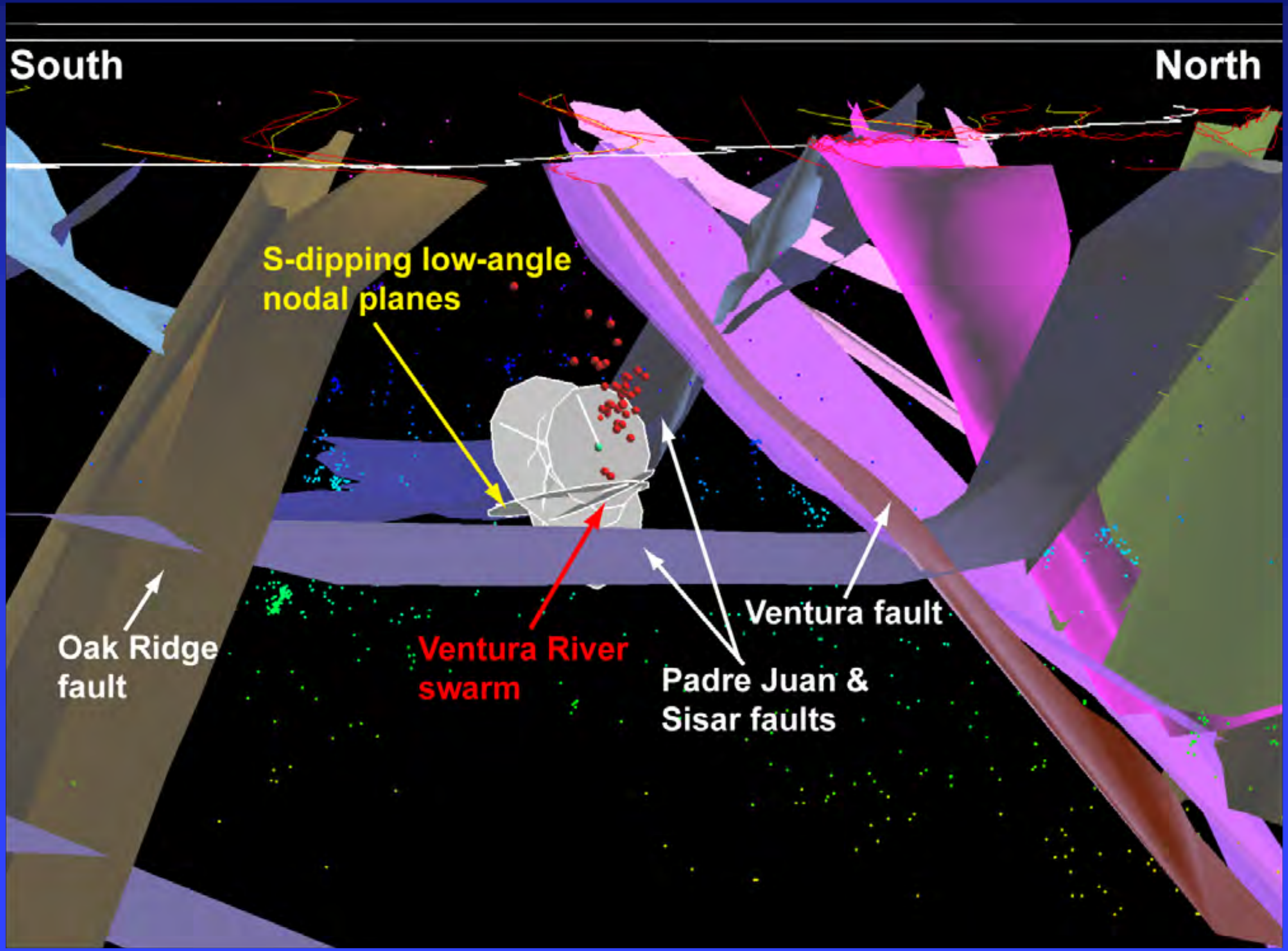
Subsurface Fault & Fold Structure from Industry Wells 3-km East of Pitas Point

S-dipping, listric Padre Juan Fault is Holocene Active

2019 Ventura River swarm occurred in the footwall of the Ventura fault. Focal mechanism of largest event indicated NW-striking oblique slip.

2019 Ventura River swarm exhibited oblique slip on a NW-striking cross fault and reverse slip on low-angle nodal planes consistent with slip on the S-dipping, listric Padre Juan fault





Fundamental Conundrum

Hypothesis #1

Large (7-12 m) uplift events at Pitas Point reflect repeated large magnitude M7.7+ earthquakes on the Pitas Point-Ventura fault. The Pitas Point-Ventura fault is blind.

Ergo

Multiple M7.7+ Holocene earthquakes can occur on active faults at depths of 3-10 km without producing noticeable surface rupture or seafloor offset.

Problem

Such large shallow M7.7+ earthquakes without corresponding surface rupture on moderately dipping faults (RM-PPF, SCF) have not been seen before.

Hypothesis #2

Large (7-12 m) uplift events at Pitas Point are anomalous and reflect local crustal processes or an unusual structural complexity.

Ergo

Unusually large, multiple uplift events can be driven by local processes or structural complexity within a small area and relatively short period of time (7 ka) without very large M7.7+ earthquakes involved.

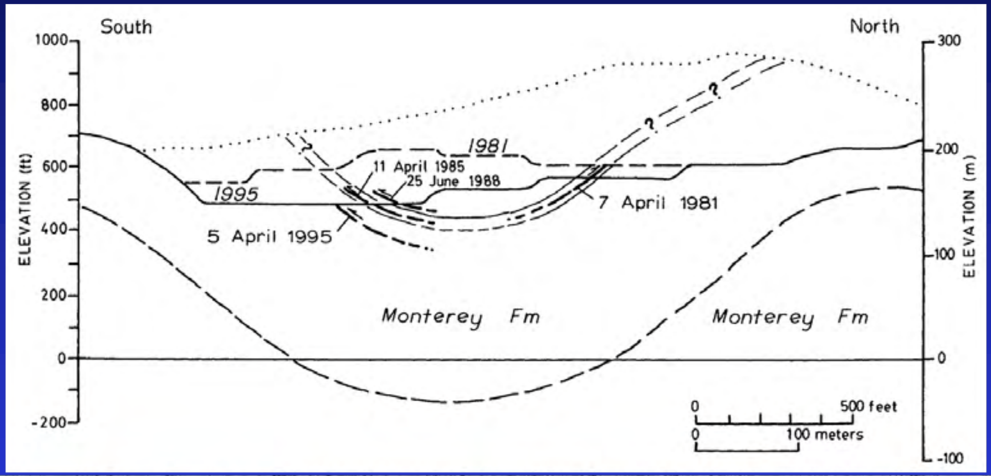
Problem

Such large (8-10 m) multiple uplift events without large M7.7+ (but maybe smaller M7.0+) earthquakes have not been seen before and never before were imagined.

Out-of-Syncline thrust faults can generate unusually large displacements for their size

Due to a weak sedimentary layer, shallow M2.3 earthquake near Lompoc triggered ~0.25 m of surface rupture. Such surface displacements are normally associated with a M6.0 earthquake.

Anomalous Surface Displacement from M2.3 Out-of-Syncline Thrust Earthquake



Important Controversial Issues to Resolve

- Is the unusual uplift at Pitas Point representative of multiple large M7.7+ earthquakes on the blind Pitas Point-Ventura fault (with comparable displacements over tens of kilometers), or is it anomalous and related to local processes and structural complexity (and not indicative of the slip at depth farther along strike)?
- Is this uplift driven primarily by slip on the S-dipping listric Padre Juan fault, N-dipping Ventura fault, or some combination? Are other factors like a cross fault and Pitas Point-Ventura fault restraining bend also involved?
- What is the first-order fault architecture driving Western Transverse Ranges deformation?
- Are the principal faults (Pitas Point, Red Mountain, Mission Ridge, etc.) detached at some shallow crustal level (7-8 km) or are they steeply dipping to depths of 15-18 km?
- If detached, what is the geologic and geophysical evidence for the depth and dip of this detachment, or is this geometry simply model driven? If not detached, how is the fault geometry more accurately modeled in 3D?
- What is the regional pattern of surface and seafloor uplift and fault displacement? And again, is this pattern driven primarily by N-dipping or S-dipping faults or some combination?
- What can dynamic rupture models tell us about the ground motions, surface and seafloor displacements expected from a repeat of 1925 or a much larger 7.4+ regional earthquake?
- Does the presence of a line of Precariously Balanced Rocks behind Santa Barbara and Montecito limit the maximum magnitudes and ground motions the active faults can or have produce?
- To what extent are measured geodetic strains elastic (and thus related to the seismic hazard), or do they also reflect inelastic processes related to basin subsidence, compaction, gravity-sliding and other processes?

Pitas Point Unique Characteristics

- Pitas Point has two active anticlinal folds: San Miguelito and Ventura Avenue.
- N-verging San Miguelito fold is being driven by the S-dipping, listric Padre Juan fault (PJF).
- PJF exhibits 2.6 km of throw since 250 ka and is independently Holocene active.
- In contrast, Ventura fault (VF) exhibits only ~300 m of throw at similar depths.
- PJF deforms and is deformed by the Ventura Avenue anticline in its footwall.
- PJF soles out into the very weak Rincon shale at a depth of ~7 km.
- As an out-of-syncline thrust, PJF can generate unusually large displacements for its size.
- In addition to PJF slip and anticlinal folding, the onshore VF steps 2.6 km right onto the offshore Pitas Point fault.
- This right-step in the left-oblique-reverse slip Pitas Point-Ventura fault creates a restraining bend that can help accentuate local uplift.
- 2019 Ventura River swarm confirmed the S-dipping PJF is Holocene active in the VF footwall and revealed a NW-striking cross fault at Pitas Point.
- Combination of PJF, VF, cross fault, anticlinal folding and PP-VF restraining bend can all be contributing to uplift at Pitas Point without requiring M7.7+ earthquake slip.

Workshop Objectives

- What are the primary, first-order data and observations that any model for the unusual patterns of uplift and differential subsidence, and the 3D subsurface fault geometry and strain must satisfy?

What are the proper criteria to evaluate, validate and discriminate between competing fault models and model assumptions used to assess the inferred hazard potential in this area?

What are the likely source faults for the 1925 and 1978 Santa earthquakes, and how do these faults relate to the fault architecture driving Western Transverse Ranges deformation?

What can dynamic rupture models tell us about the ground motions, and surface and seafloor displacements expected for a repeat of 1925 or a much larger M7.4+ regional earthquake?

What is the pattern of Holocene surface and seafloor uplift and fault displacement, and is this pattern driven primarily by N-dipping or S-dipping faults, or some complex combination?

- Is the unusual uplift at Pitas Point representative of slip farther along strike (and thus large magnitude M7.7+ earthquakes), or is it anomalous and reflects some other local process?

- Are the major active fault systems fundamentally detached and if so, what is the depth and dip of this detachment? If not, how is fault geometry more accurately modeled in 3D?