[EA]Anomalous Uplift at Pitas Point and the 2019 Ventura River Earthquake Swarm: Whose fault is it Anyway?*

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Abstract

Based on four Recent ~8-m uplift events at Pitas Point (Figure 1) (Rockwell, 2011), many believe these represent earthquakes near M8 on the N-dipping Pitas Point-Ventura fault (Rockwell et al., 2014, 2016; Hubbard et al., 2014; McAuliffe et al., 2015; Ryan et al., 2015), part of the larger primarily offshore North Channel-Pitas Point-Red Mountain fault system (Kamerling et al., 2003). However, this model of multiple Holocene M8 events on the Pitas Point-Ventura fault has major problems, not the least of which are: failure of the 2D fold model used to properly infer subsurface 3D fault geometry, an implied Holocene slip rate for the blind Pitas Point-Ventura fault that is inconsistent with observations, and the marked lack of seafloor offset or widespread tsunami deposits expected from such shallow M8 events that would extend offshore (Sorlien and Kamerling, 2000; Johnson et al., 2013, 2017; Marshall et al., 2013; Sorlien and Nicholson, 2015; Nicholson et al., 2017). The reason for these discrepancies may be that uplift at Pitas Point is driven primarily by slip on the S-dipping, listric Padre Juan fault (Figure 2), not the Pitas Point-Ventura fault.

Fault and Fold Geometry

The Padre Juan fault juxtaposes the strongly N-verging San Miguelito anticline in its hanging wall above the more symmetric Ventura Avenue-Rincon anticline in its footwall (Figure 2) (Grigsby, 1988; Hopps et al., 1992; Nicholson et al., 2017). Fault and fold geometry are well determined by industry wells that produce from the distinctly different San Miguelito and Rincon oilfields, and by imaging offshore with seismic reflection data. The Padre Juan fault exhibits up to 2.6 km of dip separation, in contrast to ~200 m of inferred dip separation on the

Ventura fault at similar depths (Nicholson et al., 2017). The timing and slip involved for San Miguelito fold growth, and the specifics of 3D fault geometry require that much of this fault slip occurred while the Padre Juan fault acted independently and syntectonically with growth of the Rincon anticline, as Padre Juan fault splays both deform and are folded by this lower fold (Figure 2).

Recent Activity and Conclusions

Relocation of the 2019 Ventura River earthquake swarm indicates most events occurred on a NW-striking tear fault below the Pitas Point-Ventura fault, but at or above the Padre Juan fault (Figure 3 and Figure 4), while deep focal mechanisms also indicate sympathetic slip on a separate S-dipping nodal plane (Figure 4). This suggests that the Padre Juan fault is still Holocene active. The Padre Juan fault soles into the weak Rincon Shale at a depth of ~7 km and may thus represent a classic out-of-syncline thrust. Such faults are known to generate anomalously large slip for their size and may explain why the uplift at Pitas Point is so anomalous, localized, and not necessarily indicative of the average slip at depth during past large earthquakes (Nicholson et al., 2017). Rather, this uplift at Pitas Point is probably localized to where slip on the Padre Juan fault predominates, where the Padre Juan fault and Pitas Point-Ventura fault strongly interact, or where the tear fault concentrates strain, which limits the possible seismic and tsunami potential of the active fault(s) involved.

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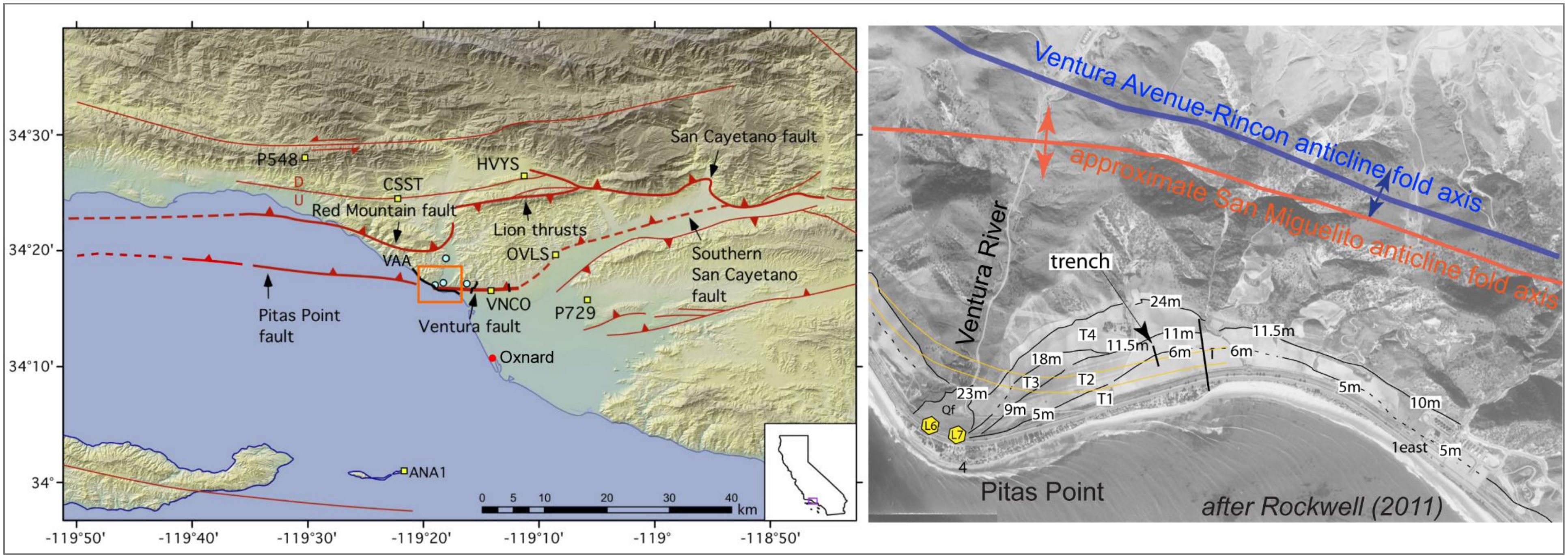

Figure 1. (left) Map of the eastern Santa Barbara Channel with the Pitas Point-Ventura fault (Rockwell et al., 2016). Orange box shows enlarged area at right. (right) Map of Holocene emergent terraces at Pitas Point indicating four 8-m to 11-m localized uplift events since 7 ka (after Rockwell, 2011; Rockwell et al., 2016).

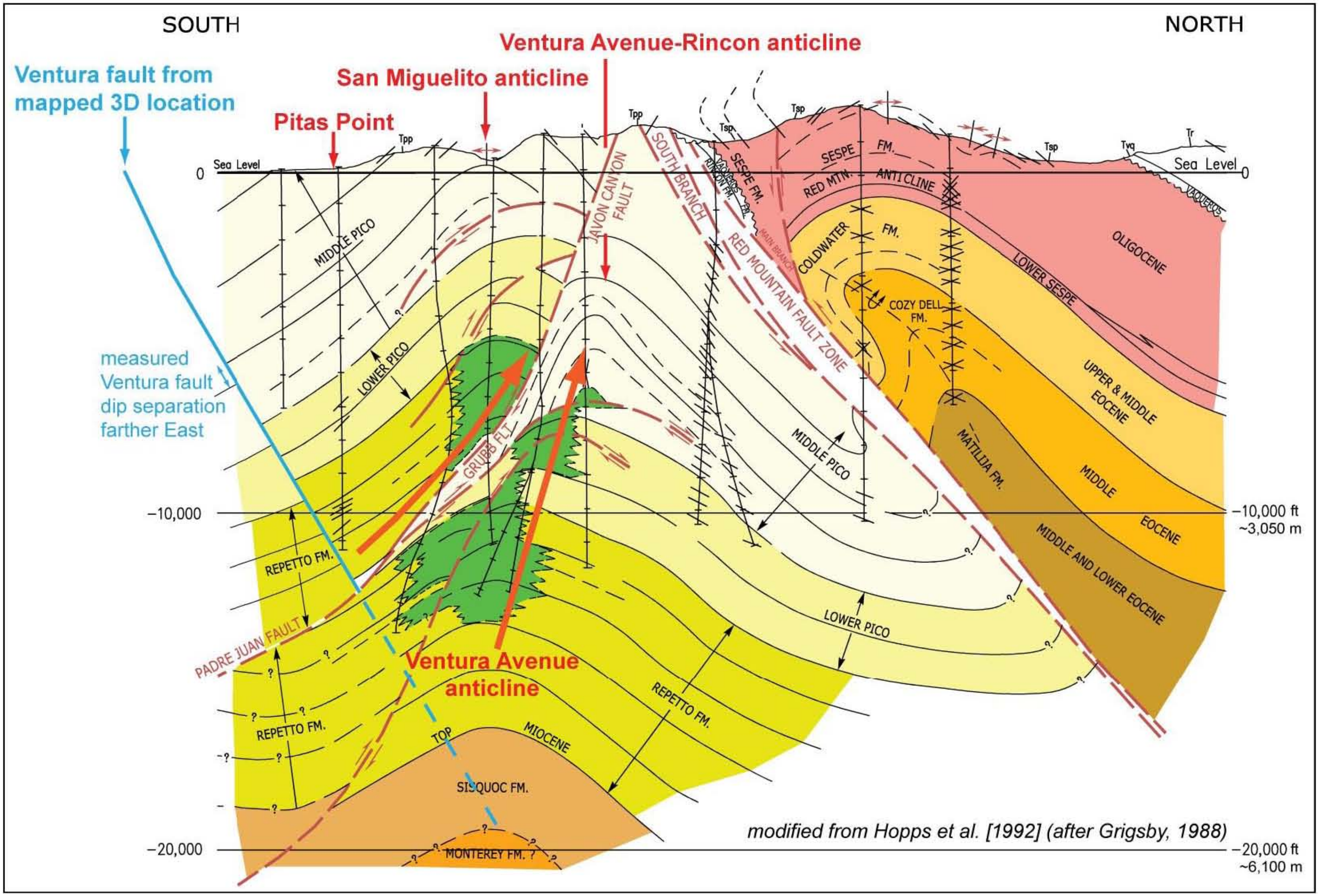

Figure 2. Revised cross section looking west located 3 km east of Pitas Point from industry well data (Nicholson et al., 2017). Padre Juan fault slip is syntectonic with growth of lower Rincon anticline as San Miguelito anticline emplacement both deforms and Padre Juan fault splays are folded by this lower fold. Padre Juan fault slip is independent of Ventura fault slip because upper fold emplacement requires moving material from the footwall to the hanging wall of the Ventura fault. Above 3 km, Ventura fault dip separation is ~200 m. Projecting actual 3D location of Ventura fault to depth indicates an offset at the Padre Juan fault, as otherwise the fault is inconsistent with deeper fold geometry and the axis of fold growth.

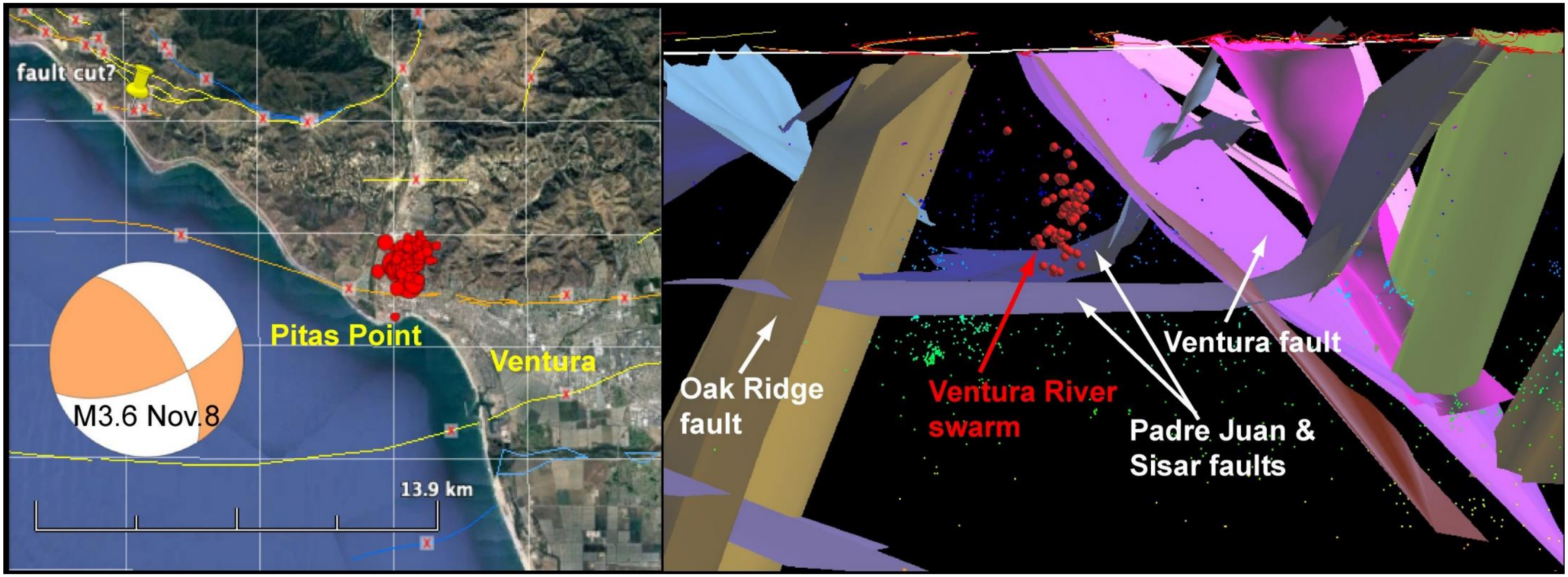

Figure 3. Relocated double-difference hypocenters (red spheres) of 2019 Ventura River earthquake swarm shown in map (left) and cross section (right). Locations from E. Hauksson; 3D fault surfaces from CFM-v5.3 (Nicholson et al., 2019). Map inset shows focal mechanism of largest swarm event and reflects right-slip on a NW-striking nodal plane consistent with the right-step between the onshore Ventura fault and offshore Pitas Point fault. Note swarm sequence is below the Ventura fault, but at or above Padre Juan fault, indicating on-going Ventura fault footwall deformation and possible continued Holocene displacement on the Padre Juan fault.

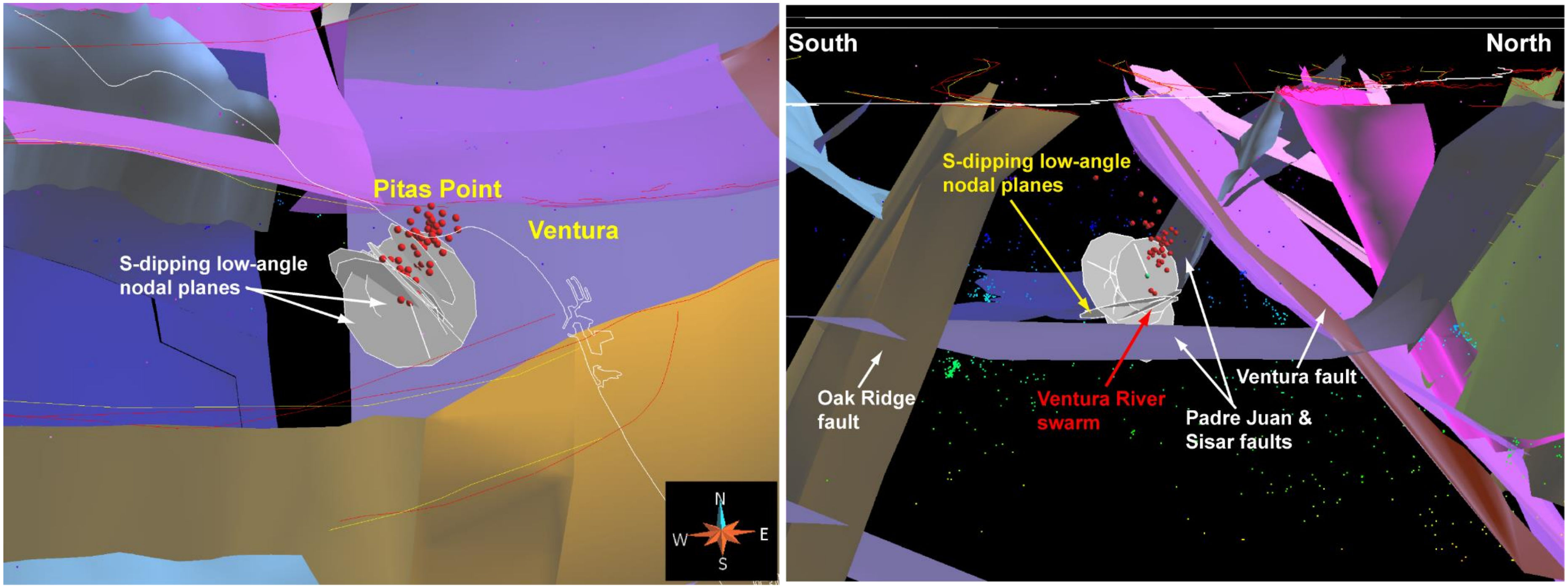

Figure 4. Map (left) and cross section view looking West (right) of relocated 2019 swarm hypocenters (red spheres) and preferred focal mechanism nodal planes (gray disks) of seven largest swarm events that suggest a steeply dipping, NW-striking right-slip tear fault and seismic slip on a S-dipping Padre Juan fault.