SCEC Report

The Mid-Channel thrust and its role in large, multi-segment earthquakes on the Ventura-Pitas Point fault system

SCEC Award 19105

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Motivation

The Ventura-Pitas Point fault system extends from the onshore Ventura Basin into the offshore Santa Barbara Channel and is considered to be the source of large, M>7.5 paleoearthquakes (Hubbard et al., 2014; Rockwell et al., 2016). However, it is observed that the slip and slip rate on the offshore Pitas Point fault is less than that of the Ventura fault (Perea et al., 2017; 2019).

We seek to determine if this discrepancy can be explained by the distribution of slip on other structures within the Channel. In particular, we focus on the Mid-Channel fault (Shaw & Suppe, 1994), which lies south of the offshore extension of the Ventura-Pitas Point fault system and underlies the Pitas Point and Mid-Channel anticlines (see locations, Figure 1).

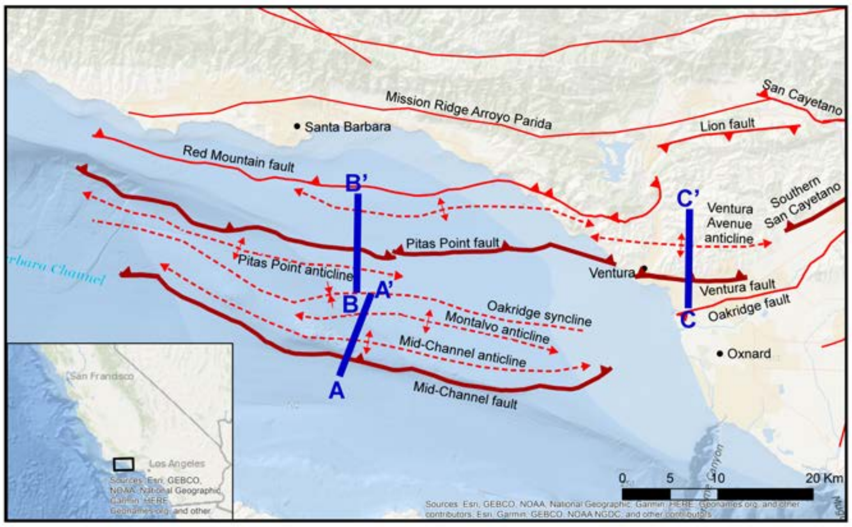

Figure 1: Map showing locations of major faults in the Ventura basin and Santa Barbara Channel, including the Ventura, Pitas Point, Southern San Cayetano, and Mid-Channel faults highlighted in dark red. Cross sections indicated by blue traces (Figures 2, 3). Surface traces from SCEC Community Fault Model 5 (Plesch et al., 2016).

Methods

We have focused on integrating all available geologic and geophysical data to fully constrain the activity and geometry of the Pitas Point and Mid-Channel fault systems through the development of balanced and retrodeformable geologic cross sections (see Figure 2 and Table 1 for data coverage and descriptions). The data includes 2 industry 3D seismic reflection surveys, ~675 industry 2D seismic reflection lines, and 65+ wells with horizon tops and dip markers (in our area of focus). We projected the wells with horizon tops and dip markers a short distance along strike onto the 2D seismic lines used to construct the cross sections.

We generated a series of cross sections using fault-bend-folding, fault-propagation-folding, and trishear methods (e.g., Suppe, 1983; Erslev, 1991; Shaw et al., 2005). Inverse and forward modelling was used to further constrain the geometry of complex structures. Shortening was calculated along the top of the Repetto horizon because it is present in relatively consistent thickness throughout the Ventura-Santa Barbara Channel region.

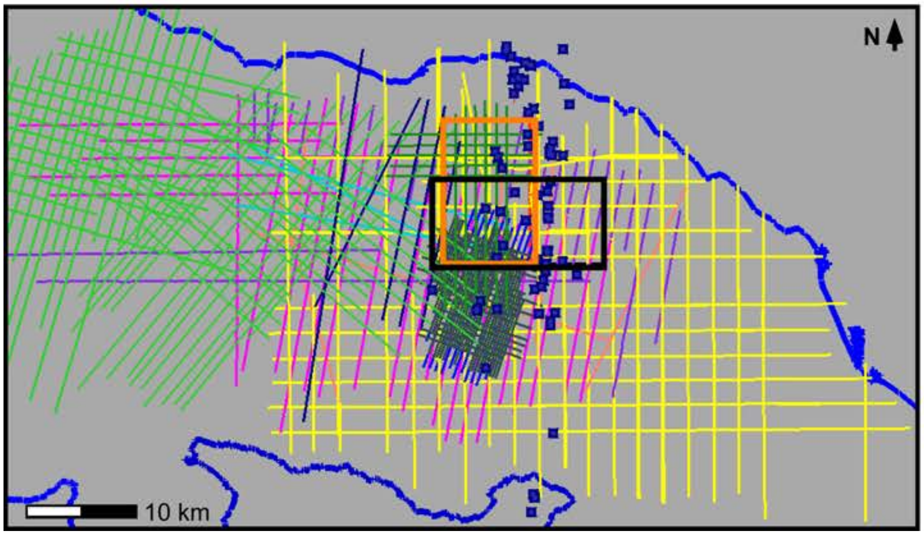

Figure 2: Data coverage in the Santa Barbara Channel. See Table 1 for description of data. California coast shown in blue. Wells shown as dark blue squares.

Table 1: Description of data coverage in the Santa Barbara Channel. See Figure 4 for locations

Map Symbol	Data Type	Name	Availability	Quantity	Year	Operator
(orange box)	3D seismic	Dos Cuadras	NAMSS	171 km^2	1982	BOEM
(black box)	3D seismic	Pitas Point	NAMSS	202 km^2	1982	BOEM
(blue line)	2D seismic	Blue Bottle		12 lines	1985	Grant Norpac
(purple line)	2D seismic	WC 84	NAMSS	221 lines	1985	WesternGeco
(magenta line)	2D seismic	WC 85	NAMSS	254 lines	1984	WesternGeco
(yellow line)	2D seismic	CSB		68 lines	1976	Delta Exploration
(green line)	2D seismic	ES		90 lines	1980	ESSO SEIS
(cyan line)	2D seismic	SBD		6 lines	1982	Digicon
(pink line)	2D seismic	SBW		12 lines	1980	Western Geophysical
(dark green line)	2D seismic	CDPS		12 lines	1983	Geophysical Service Inc.

Summary of Results

This past year's work focused on analysis of 2- and 3-D industry seismic reflection data and extensive well control, including dipmeter logs and horizon tops, to constrain the geometry and kinematics of the offshore Ventura - Pitas Point fault system (Redin et al., 1998; Don et al., 2019). Based on these data constraints, we generated a series of balanced cross sections using both inverse and forward modeling based on fault-related folding theories (Figure 3). These sections demonstrate that the offshore fold geometries are consistent with a ramp-flat-ramp geometry for the Pitas Point fault, with the mid-crustal flat located in the Miocene Monterey/Rincon shales. This geometry is nearly identical to that of the onshore Ventura fault (Hubbard et al., 2014), and thus supports the proposed linkage of the Ventura and Pitas Point faults (Sorlien and Nicholson, 2015; Levy et al, 2019).

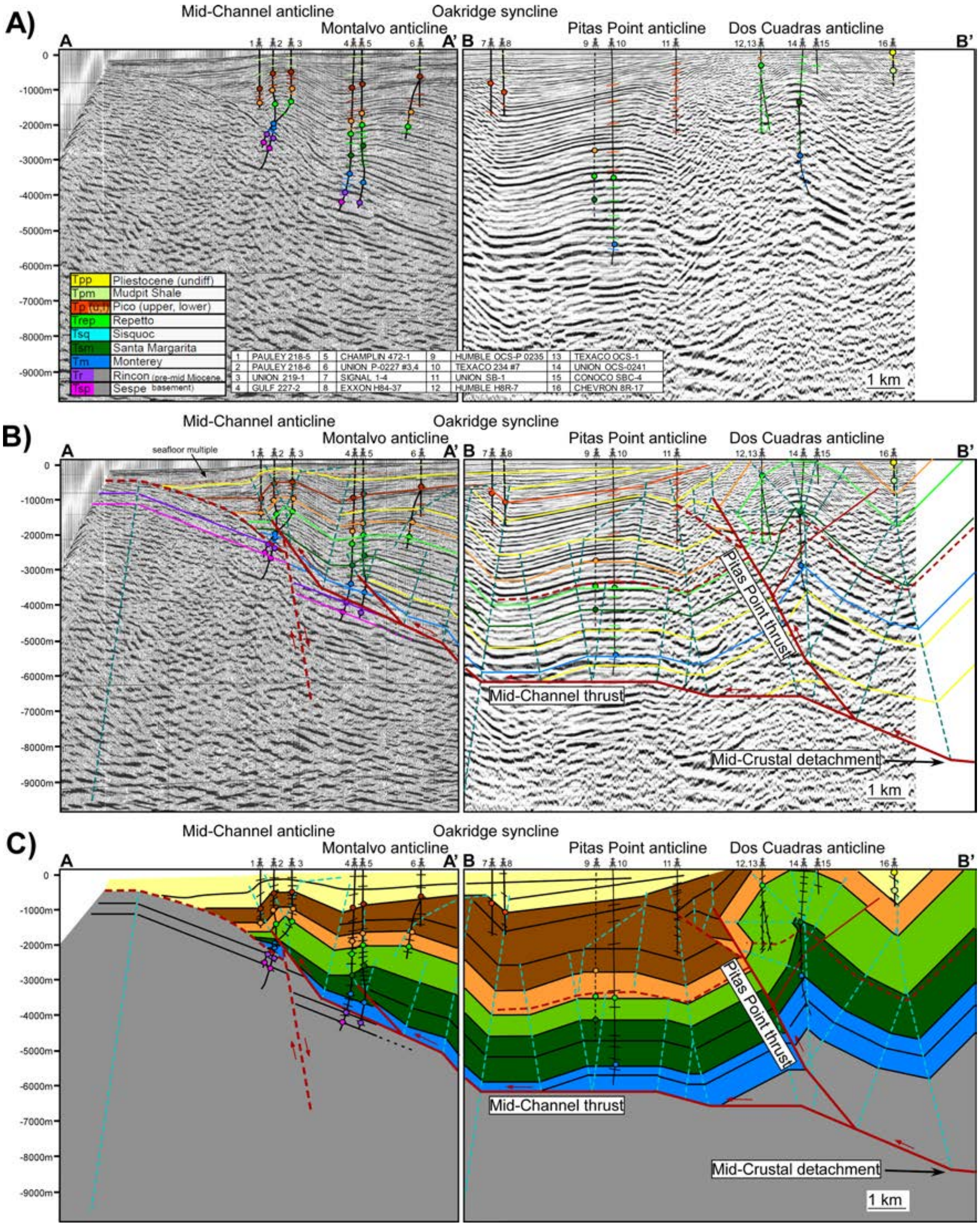

Figure 3: Cross sections showing offshore geometry of the Pitas Point fault system and its linkage with the Mid-Channel fault system (location Figure 1). A) Uninterpreted seismic reflection profile showing data projected from nearby wells. B) Interpreted seismic reflection profile showing linkage of Pitas Point and Mid-Channel fault systems. Dip changes, cutoffs, and discontinuous reflectors constrain the location of the Mid-Channel and Pitas Point thrusts. C) Geologic cross section of Dos Cuadras anticline / Pitas Point fault, Pitas Point anticline / Mid-Channel fault, and Mid- Channel anticline / Mid-Channel fault. Red lines are faults, with arrows indicating slip sense. Dark blue-green dashed lines are axial surfaces. Horizons colored based on stratigraphy, with internal stratigraphy shown in yellow. Dashed red lines are inactive faults or bedding parallel thrusts.

We note, however, that there is an important distinction between the onshore and offshore character of the fault systems. While all of the slip on the onshore fault system appears to extend upward along the Ventura fault ramp and is consumed by folding in the Ventura Avenue anticline, a significant amount of the slip on the offshore mid-crustal detachment extends south of the Ventura-Pitas Point fault. Specifically, the slip on this detachment forms the Pitas Point anticline (which lies in the footwall of the Ventura-Pitas Point fault) and extends toward the seafloor along the Mid-Channel thrust where it is consumed by a south-vergent, fault-propagation fold (Mid-Channel anticline) (Figure 4).

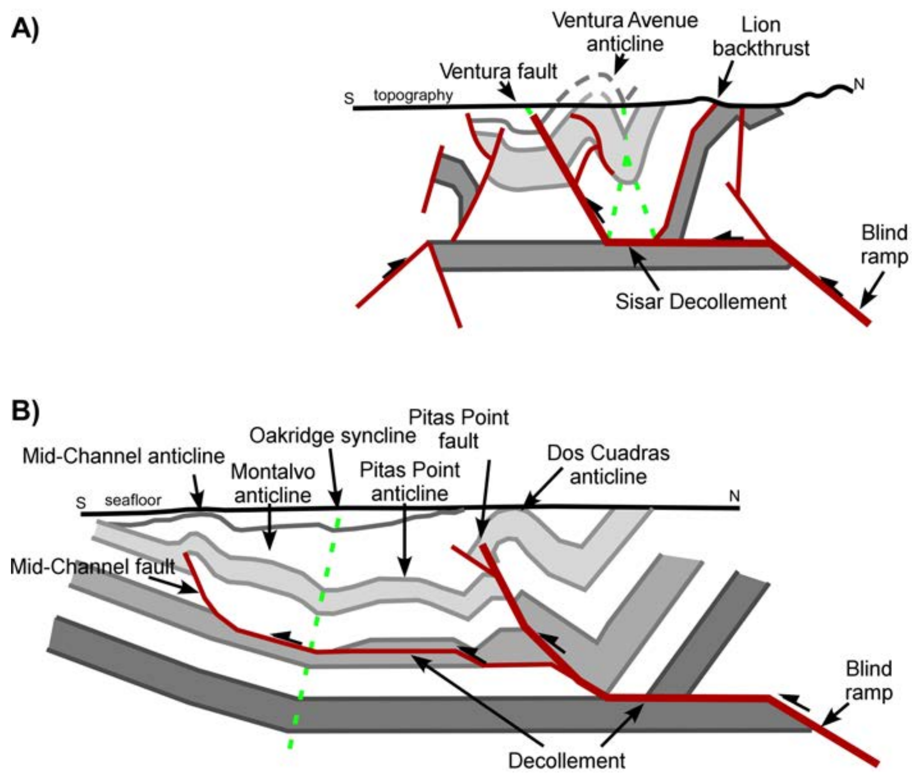

Figure 4: Schematic cross sections comparing geometry of the Ventura-Pitas Point fault system onshore (A) and offshore (B). Model A illustrates that onshore, displacement is concentrated on the Ventura fault within the Ventura Avenue anticline while offshore the displacement in Model B is partitioned between the Pitas Point (Dos Cuadras anticline) and Mid-Channel (Pitas Point and Mid-Channel anticlines) thrusts. Location of (A) indicated by C-C' in Figure 1; location of (B) indicated by A-A', B-B' in Figure 1. (A) modified from Hubbard et al., 2014.

To understand the behavior of this system, we calculated the total shortening along the onshore and offshore segments of the fault system (Don et al., 2019). Based on the cross section presented in Hubbard et al. (2014), this analysis indicates that there has been 20% shortening (or 2.5 km) across the onshore Ventura fault system. The offshore sections presented in Figure 2 indicate that there has been 19% shortening (or 3.7 km) across the Pitas Point and Mid-Channel faults. The similarity in total shortening percentages further supports the proposed linkage of the onshore and offshore fault systems and the prospect for large, multi-segment ruptures and their associated tsunami and ground shaking hazards. Moreover, the analysis highlights that while all of the shortening onshore is accommodated by the Ventura fault, the offshore deformation is partitioned between the Pitas Point and Mid-Channel faults.

Conclusions

Cross section analysis suggests that the Mid-Channel anticline is formed by a thrust fault that deepens to the north and links with the Pitas Point Fault and extending north along the mid-crustal detachment. Shortening analysis indicates that the onshore and offshore fault systems accommodate a similar amount of shortening. However, offshore the shortening is accommodated in the linked Pitas Point Mid-Channel fault system while onshore shortening is fully consumed within the Ventura fault system. We suggest that this reconciles the discrepancy in slip and slip rate inferred for the offshore portion of the fault system by Perea et al., (2017) with that of onshore fault system by Hubbard et al., (2014). These results suggest that future offshore earthquakes could rupture the Pitas Point thrust, the Mid- Channel thrust, or both, having important implications for due to the sea floor uplift and impact on tsunami genesis.

SCEC Publications

Don, J., Plesch, A., Newman, M. M., & Shaw, J.H., (2019, 08). Linkage of the Ventura-Pitas Point and Mid-Channel faults and its implications for large, multi-segment earthquakes. Poster Presentation at 2019 SCEC Annual Meeting. SCEC Contribution 9479.

We are currently prepared an article for submission to BSSA with other SCEC collaborators.

References

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Hubbard, J., Shaw, J.H., Dolan, J., Pratt, T.L., McAuliffe, L. and Rockwell, T.K., 2014. Structure and seismic hazard of the Ventura Avenue anticline and Ventura fault, California: Prospect for large, multisegment ruptures in the western Transverse Ranges. Bulletin of the Seismological Society of America, 104(3), pp.1070-1087.

Levy, Y., T.K. Rockwell, J.H. Shaw, A. Plesch, N.W. Driscoll, H. Perea, 2019, Structural modeling of the Western Transverse Ranges: An imbricated thrust ramp architecture. *Lithosphere* doi: https://doi.org/10.1130/L1124.1

Perea, H., Ucarkus, G., Driscoll, N. W., Kent, G. M., Levy, Y., & Rockwell, T. K. (2017). New high-resolution seismic data reveals the Holocene active structures and deformation events in offshore Ventura basin, CA. Poster Presentation at 2017 SCEC Annual Meeting.

Perea, H., Ucarkus, G., Driscoll, N. W., Kent, G. M., Levy, Y., & Rockwell, T. K. (2019; in press). Faulting and Folding of the Transgressive Surface Offshore Ventura Records Multiple Earthquake Events in the Holocene. Geosphere.

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Suppe, J. (1983). Geometry and kinematics of fault□bend folding. American Journal of science, (283), 684-721.