# Develop Geological Model of Offshore Southern California (Borderland) for the Community Rheology Model

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## Introduction

The California Continental Borderland (offshore southern California) is an important part of the regional Pacific-North America transform plate boundary. The Geologic Framework (GF) maps the crustal blocks and major fault zone boundaries of these blocks (Fig. 1). For the initial model, the GF is based upon the tectonostratigraphic terranes (Howell & Vedder, 1981; Vedder, 1987) that describe the major crustal blocks (basement rocks) developed during the tectonic evolution of the Pacific-North America transform plate boundary. These blocks, including the Patton accretionary wedge, Nicolas forearc, Catalina subduction complex, and Pacific oceanic crust offshore southern California and northern Baja California. Crustal blocks are described by 1D crustal columns showing significant parameters, e.g., seismic velocity, density, thickness for the major layers of crustal basement and upper mantle structure. The crustal block columns are derived from published cross-sections of the region based on geophysical and geological investigations.

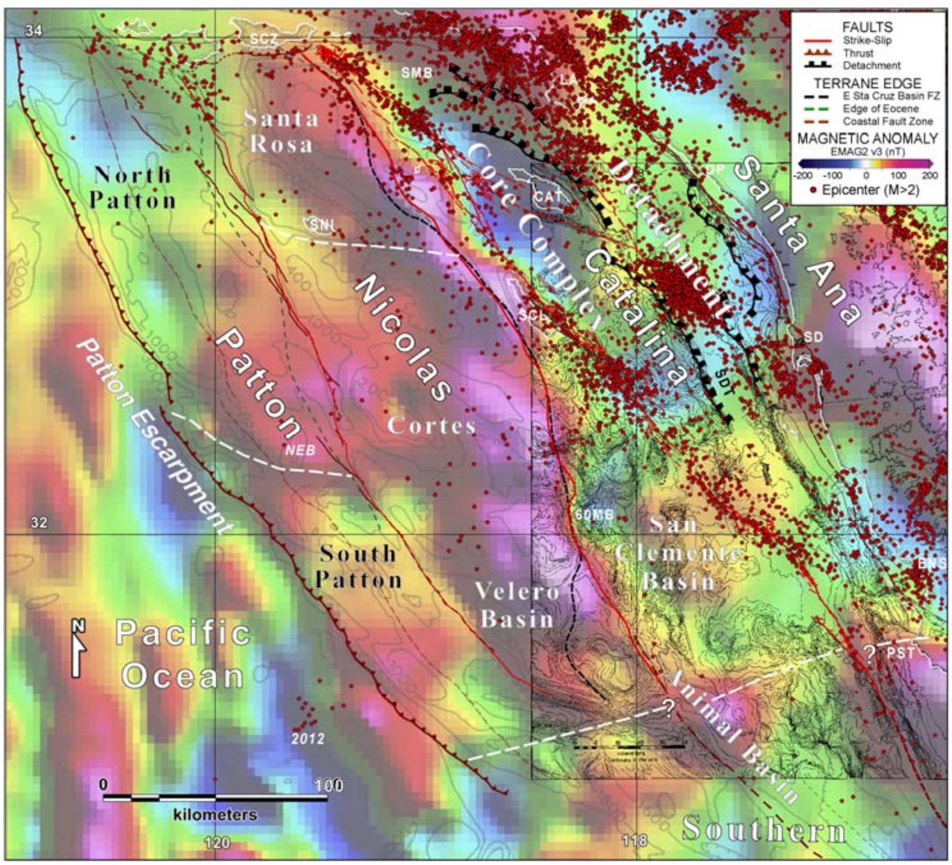


**Figure 1.** Map showing the major fault terrane boundaries (red lines) and original tectonotratigraphic terranes (after Howell & Vedder, 1981) with magnetic anomalies (EMAG2) and waveform-relocated seismicity (Hauksson et al. 2012, 2019 update). Dashed white lines show possible region boundaries. **PST** = Punta Santo Tomás, **SNI** = San Nicolas Island. **SDT** = San Diego Trough, **SMB** = Santa Monica Basin, **60MB** = Sixtymile Bank, **SD** = San Diego, **SCL** = San Clemente Island, **SCZ** = Santa Cruz Island, **DP** = Dana Point, **NEB** = Northeast Bank, **CAT** = Santa Catalina Island. Bathymetric contours on base map from Legg (1985).

## Geologic Framework Updates

Terrane boundaries tend to follow the edges of significant magnetic features including the high intensity ridge along the eastern edge of the Nicolas forearc terrane. Terrane subdivision into structural regions is suggested by the magnetic field patterns and seismicity. The Core Complex has low magnetic intensity whereas San Clemente Basin has relatively higher intensity. The Detachment region varies from high intensity near the Los Angeles Basin to low intensity offshore San Diego. Seismicity demonstrates the importance of the San Clemente fault zone to Borderland seismotectonics. The zone cuts diagonally across the Catalina terrane and shows significant clustering with some interesting northeast-oriented cross trends. A diffuse zone of epicenters crosses the Nicolas terrane along the San Nicolas Island escarpment.

The three-dimensional geometry of the block boundaries includes the fault trace, dip and depth extent, and thickness of the principal displacement zone where relative movement is focused. Simple block boundaries consist of major faults included in the SCEC Community Fault Model (CFM) and new faults in the Outer Borderland to be added to the CFM. Initially, these boundaries consist of vertical strike-slip faults. Updated boundaries consider dipping faults including the former subduction megathrust along the Patton Escarpment and other low-angle detachments (or blind thrusts) that are important in many areas. Refined definitions of the complex block boundaries are recommended to describe the crustal character more accurately. In particular, major terrane boundary fault zones may be described as "fault wedges" formed by structural inversion of Miocene transtensional basins after oblique rifting was succeeded by transpression within the northern Borderland. These complex fault systems may produce large complex earthquakes involving multiple faults and fault segments that could be difficult to model with the simple preliminary fault model.

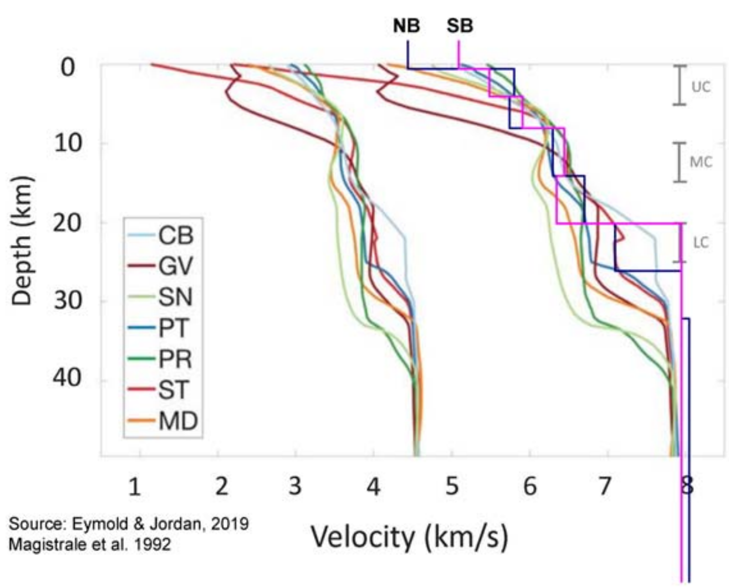


**Figure 2.** Seismic compressional velocity profiles for tectonic regions of southern California (Eymold and Jordan, 2019). The two layered versions are 1D profiles from Magistrale et al (1992) for the Northern Borderland (**NB**) and Southern Borderland (**SB**). The Northern Borderland profile is consistent with the Great Valley (**GV**) region, but shallower Moho (26 km). The Southern Borderland profile is consistent with the Continental Borderland (**CB**) region with the shallowest Moho (20 km) and higher velocity shallow crust. For the updated Borderland Geologic Framework, the NB profile is recommended for the Northern Nicolas terrane region (sub-terrane), whereas the SB profile is recommended for the Catalina Core Complex region of the Inner Borderland.

Recommended subdivision of the original four blocks to describe the offshore crustal character more accurately includes splitting the Inner Borderland Rift ***Catalina*** terrane into 1) western **Core Complex**, 2) eastern tilted crustal blocks with **Detachment Faults**, and 3) southern **San Clemente Basin** rhombochasm terranes (Figure 1). Additional subdivisions for Outer Borderland terranes may be useful, such as a northern, central and southern Nicolas terrane separated by the San Nicolas Island fault. Simple 1D velocity profiles (Figs. 2 & 3; Magistrale et al. 1992) for Northern and Southern Borderland regions appear reasonable to define the northern Nicolas forearc block and the southern Catalina Core Complex block of the Inner Borderland. The San Clemente Basin block is considered part of the Southern Borderland highly extended region.

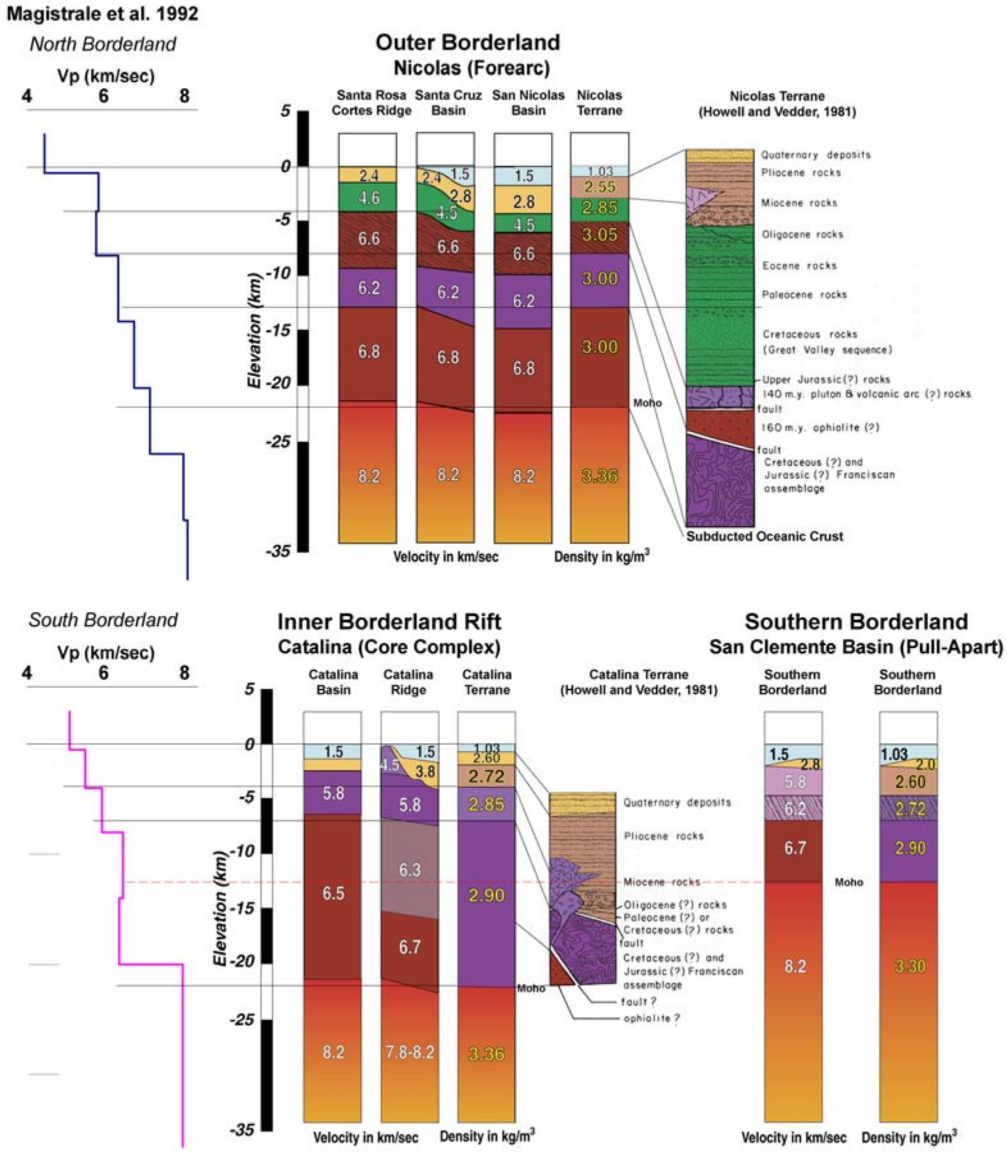


**Figure 3.** Proposed 1D compressional velocity profiles (Magistrale et al. 1992) for the northern Nicolas forearc and the Inner Borderland core complex terranes. The North Borderland profile puts the Moho deeper (26 km) which is consistent with the receiver function data from San Nicolas Island (Reeves et al. 2015). The South Borderland profile puts the Moho shallower (20 km) and has higher velocities in the shallow crust of the exhumed core complex terrane.

## Tectonic Regionalization

Tectonic regionalization of the southern California crust based on the 3D SCEC Community Velocity Model (Eymold and Jordan, 2017, 2019), shows anomalous features offshore where tomographic data resolution is good (Fig. 4). The south-southwest trending region of Mojave (orange) appears to follow the terminations of the major detachment faults in Santa Monica Basin, and is bent across the Santa Cruz-Catalina Ridge (San Clemente fault zone). The East Santa Cruz Basin fault zone boundary between Inner and Outer Borderland terranes appears to terminate the anomaly at the strong magnetic intensity feature near Osborn Bank. The Salton Trough (red) part of the anomaly may be related to volcanic intrusions near Santa Barbara Island, and the Great Valley (brown) anomaly matches the location of the thickest part of the post-Miocene sediments (blue contours, Vedder, 1987). The northern boundary follows the Anacapa-Dume fault zone. An aureole of Peninsular Ranges terrane dark blue) surrounds the anomaly at the southwestern and eastern edges, which may be a transition zone to the Continental Borderland region. The relationship between the north end of the major detachments and the terrane or tectonic region boundaries is uncertain and may be an important research topic for SCEC scientists.

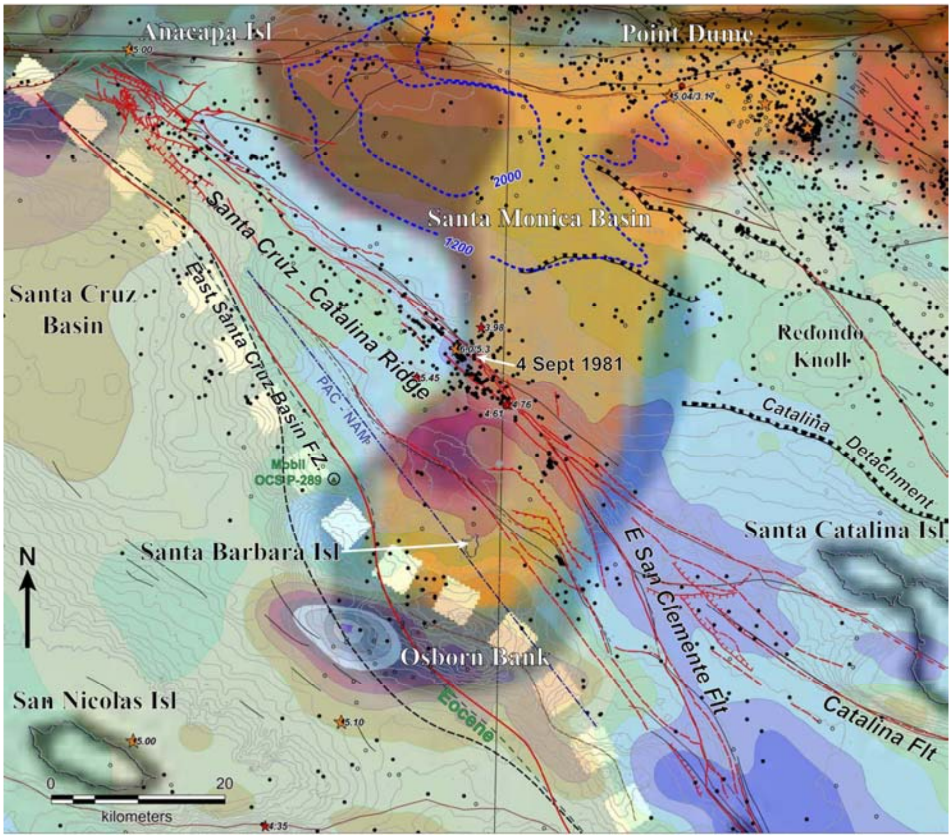


**Figure 4.** Map of anomalous tectonic regions (bright fuzzy colors) within the Continental Borderland based on tomographic correlations from the SCEC CVM S4.26 (Eymold and Jordan, 2017, 2019). These anomalies appear to correspond to significant geologic features evident in the crust related to the Miocene to Recent tectonic evolution of the PAC-NAM plate boundary along coastal southern California. Color-filled contour areas are aeromagnetic intensities (Langenheim et al. 1993). Gray contours are bathymetry at 100-m intervals (MMS). Wide dotted line is western edge of high-resolution tomographic coverage.

Seismicity in the Santa Barbara Island area is complex including the $M_w$6, September 4, 1981 earthquake sequence and several other moderate events (red stars in Fig. 4). The faulting is very complex with multiple fault intersections between the major terranes and tectonic regions. Receiver functions from an ocean-bottom seismometer array (Reeves et al. 2015) suggest a deeper Moho (about 30 km) at San Nicolas Island, compared Nicolas terrane in the depth (about 20 km) in the initial Geologic Framework. Although the fault along the San Nicolas Island escarpment is mapped as pre-Quaternary (CGS, 2010), the transverse character, seismicity, magnetic anomaly patterns suggest that a tectonic region boundary follows that feature. Earthquake focal mechanisms show thrust or oblique-reverse movement with a moderate north dip 40-50 degrees (Legg et al. 2015), which is consistent with multichannel seismic reflection profiles in the across the escarpment (DeHoogh et al. 2019). We will provide a digital fault trace to the Harvard group for incorporation into the SCEC CVM, and suggest a 45ºN dip.

## Conclusions

Further refinement of the Borderland Geologic Framework, based on comprehensive knowledge of offshore structure and tectonic evolution, is necessary to capture important mid-crustal and deeper features missing from the CVM where sparse seismograph coverage limits tomographic resolution. Increasing the crustal thickness in the Outer Borderland Nicolas terrane with an offset Moho may be necessary based on the receiver function data from San Nicolas Island. Updated crustal columns, seismic velocity profiles, crustal thickness estimates, and so forth may be added in future versions of the Borderland Geologic Framework for the Community Rheology model as new data are obtained. In particular, continuing refinements to the SCEC Community Velocity Model may provide better candidate velocity profiles from regions with similar geologic/tectonic character, although better seismograph coverage of the Outer Borderland would be most useful.

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