Seismic evidence for fragmentation of the Cocos slab in central Mexico

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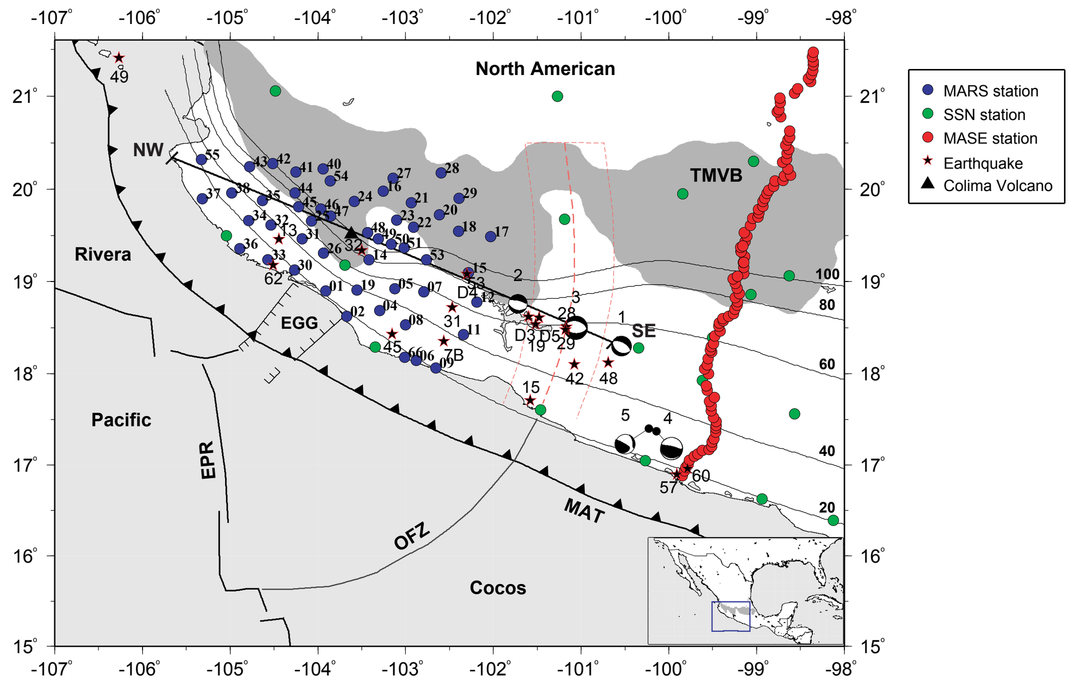
I. Abstract

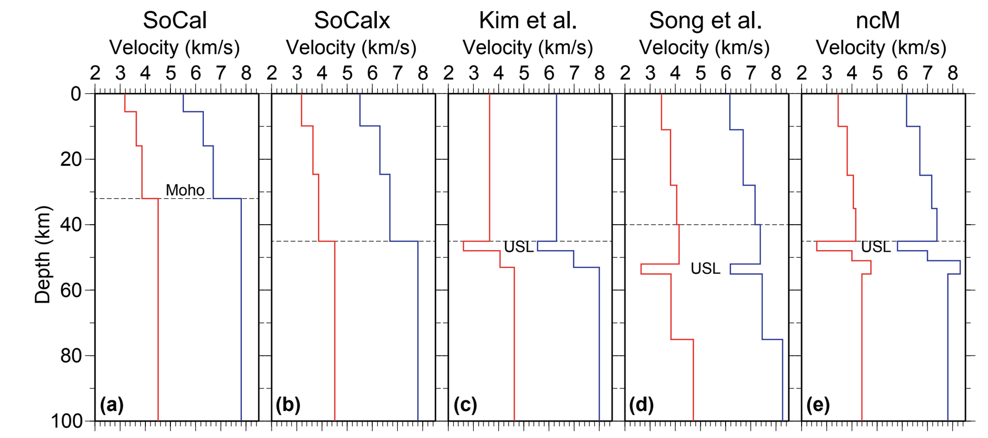
The fine-scale seismic structure of the central Mexico subduction zone, particularly the interface between the slab and overriding plate, is studied using shallow (~40-90 km) intraslab earthquakes of moderate magnitude (M4-6). Regional waveforms from the Mapping the Rivera Subduction Zone (MARS) seismic array are complicated and contain detailed information about the subduction zone structure. Identification of seismic phases, their arrival times, and any possible complexities in their waveshapes provide evidence of lateral variations in structure. The detailed waveform information obtained is used to model the structure of the subducted plates, particularly along the transition from flat to normal subduction, where recent studies have shown evidence for possible slab tearing along the eastern projection of the Orozco Fracture Zone (OFZ). The lateral extent of a thin low velocity layer imaged atop the subducted Cocos plate in recent studies along the Meso America Subduction Experiment (MASE) array is examined here using MARS waveforms. We find an edge to this low velocity layer which is coincident with the western boundary of the projected OFZ region. We use forward modeling of the 2D structure of the subducted Rivera and Cocos plates using a finite-difference algorithm in order to provide constraints on the thickness, velocity, and geometry of each slab's shallow seismic structure in this region. This modeling shows that the best approximation to the observed seismograms is obtained when there is an edge to the low velocity layer coincident with the western boundary of the projected OFZ region. Coupled with the results of recent plate motion studies which show that the Cocos plate north of the OFZ moves differently than that south of the OFZ, we propose that the Cocos slab is currently fragmenting into a North Cocos plate and a South Cocos plate along the eastern projection of the OFZ. This tearing event may be a young analogy to the mature Rivera-Cocos plate boundary.

II. Background

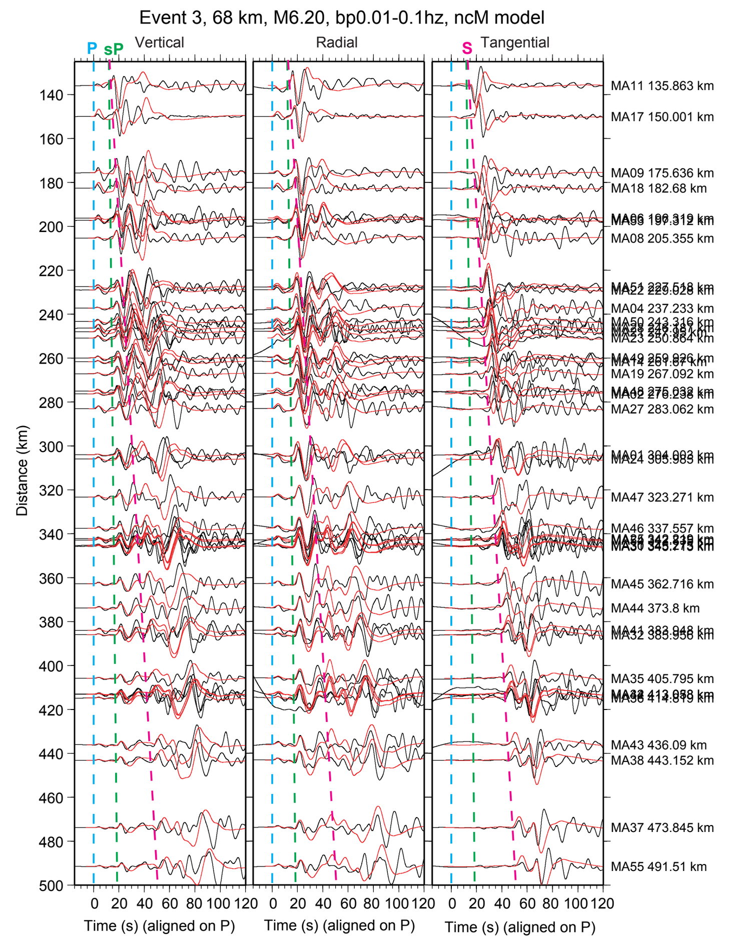


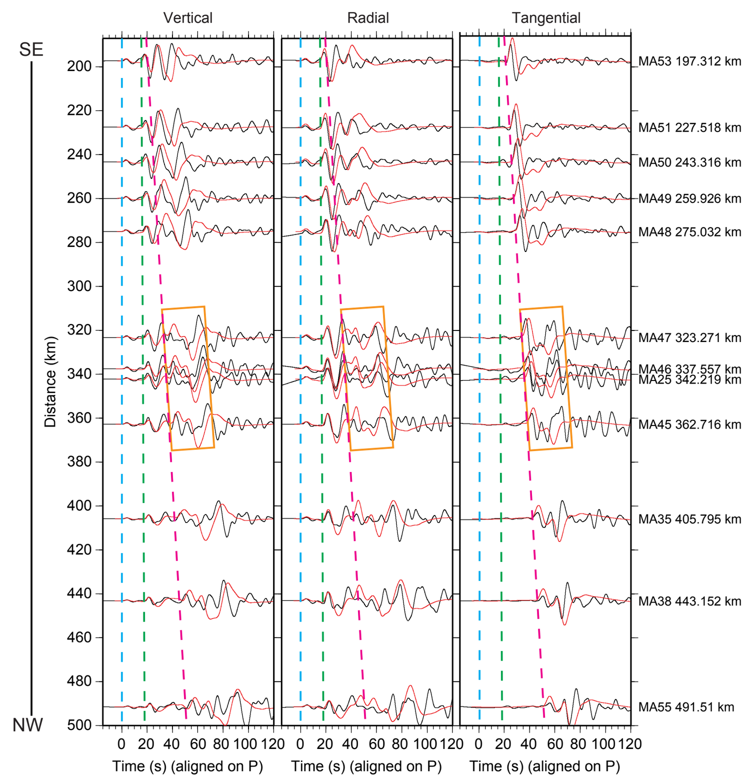
Regional tectonic map of the central Mexico subduction zone including locations of MARS, MASE, and Servicio Sismologico Nacional (SSN) seismic stations. The locations of the Orozco Fracture Zone (OFZ), Middle America Trench (MAT), East Pacific Rise (EPR), and Trans-Mexican Volcanic Belt (TMVB) are also indicated. Hachured lines indicate offshore El Gordo Graben (EGG) boundaries. Subducted slab isodepth contours from *Pardo and Suarez* (1995). The projected path of the OFZ beneath the North American plate is shown as a thick, red dashed line, with thinner, red dashed lines to either side delineating the estimated 100 km width of the fracture zone (*Blatter and Hammersley*, 2010). The thick northwest-southeast (NW-SE) trending line marks the location of the data profile and 2D velocity model cross-section.

III. 1D Velocity Modeling



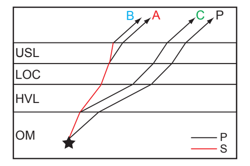
The sensitivity of observed waveforms to subduction zone structure is tested in 1D using five different models. Overall, the new central Mexico (ncM) model provides the most accurate prediction of the data, with the best fits to *P*, *sP*, and *SH* phases at all distances, along with an *S*-wave multiple at large distances. The SoCal model provides a comparable fit to these phases, but fails to predict some of the waveform complexities seen in both the data and the ncM model, such as the "shoulder" following *SV*. The uppermost slab structure in the ncM model, particularly the ultra-slow velocity layer, is likely responsible for reproducing the observed waveform complexities that the simpler SoCal model fails to predict.



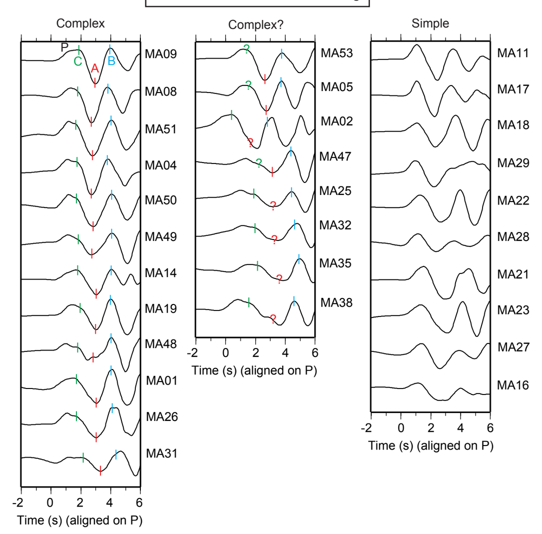


Profile across the MARS array along NW-SE line (see map in II) using the ncM model. Data are in black, synthetics are in red. For stations located within the TMVB, complex waveforms are observed after the arrival of the *S*-wave in the data (indicated by orange box) and are most prevalent on the transverse component. These complexities are not predicted by the model synthetics and may be indicative of a change in crustal structure within the TMVB region.

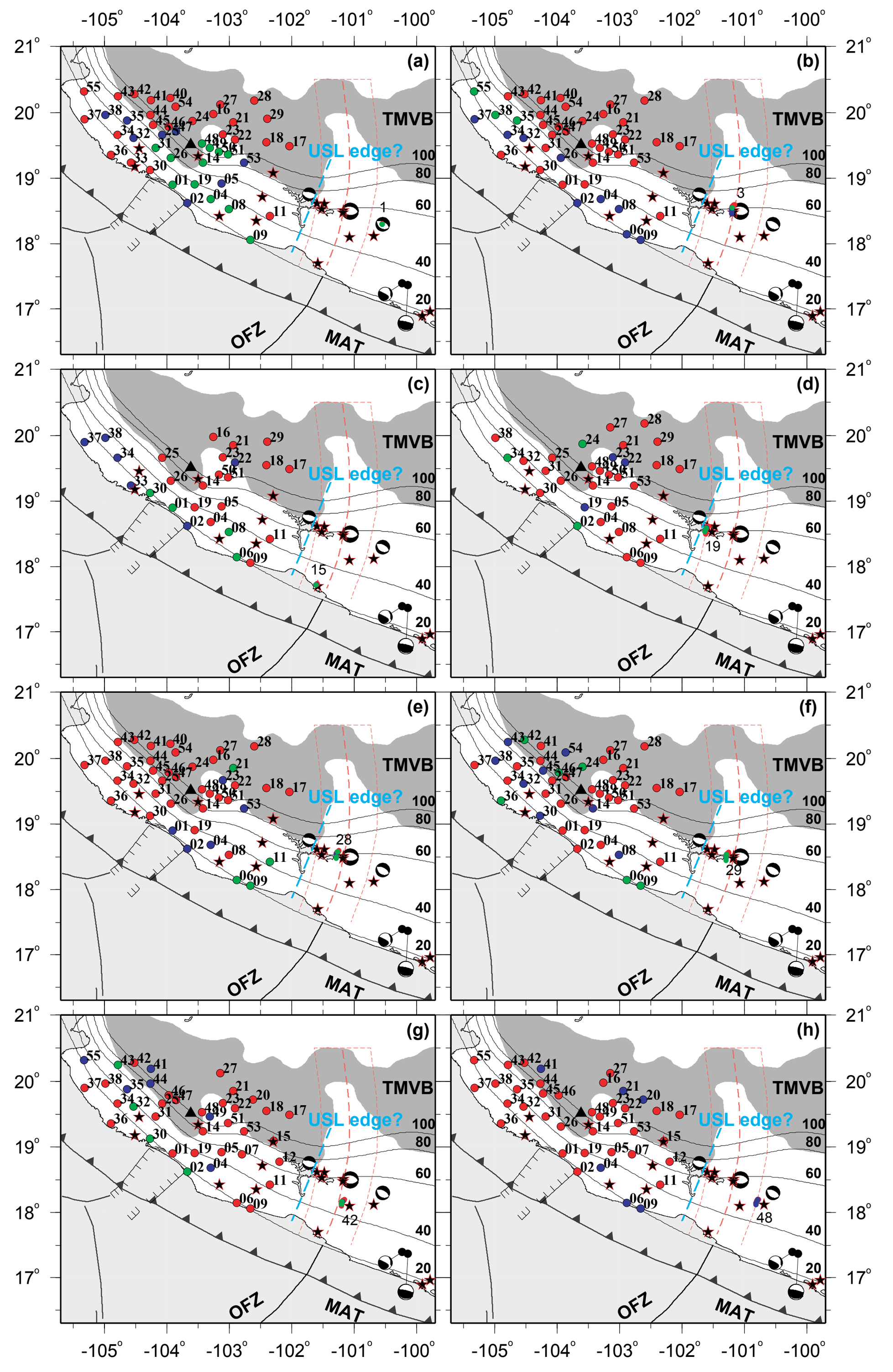
IV. Ultra-slow Velocity Layer



Schematic illustrating the ray paths of the P-wave and the three S-to-P phases (A, B, C) that comprise the complex P waveform.

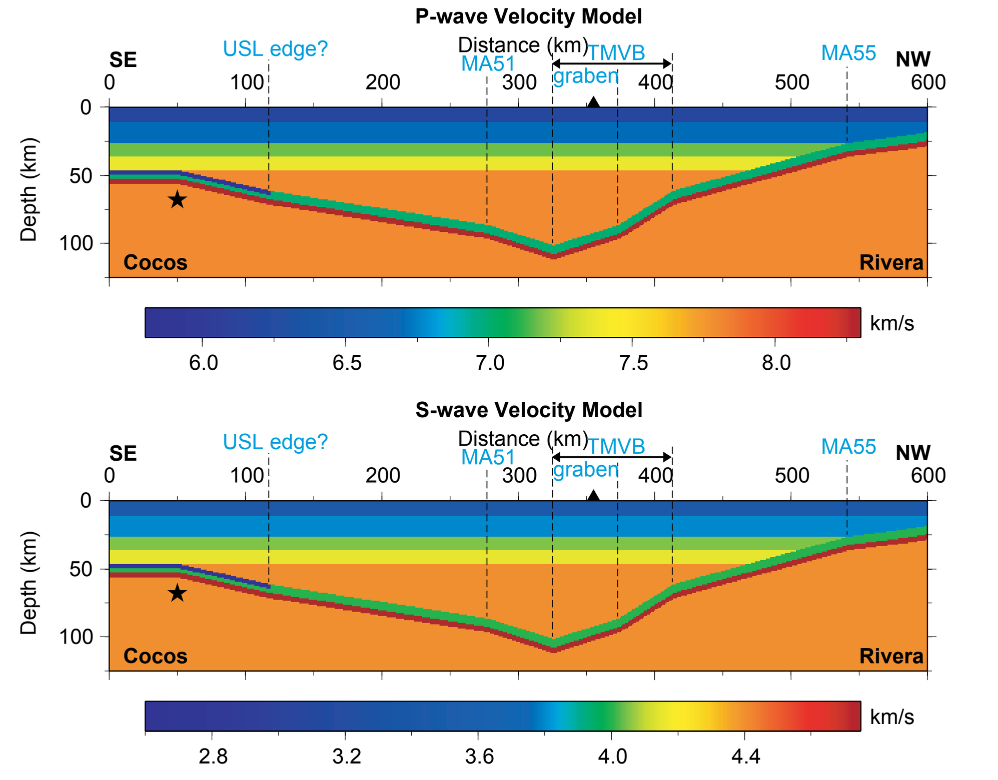


Examples of complex (left), possibly complex (middle), and simple (right) P waveforms from event 1. S-to-P phases A, B, and C are indicated by red, blue, and green tick marks, respectively. All three of these phases are visible in the complex waveforms within 4 sec of the P-wave. Questions marks on the possibly complex waveforms indicate a phase that is not easily identified. Simple waveforms lack the shoulder in the direct P pulse indicative of the C phase and also have uncharacteristic A and B phases, indicating there is no USL present.

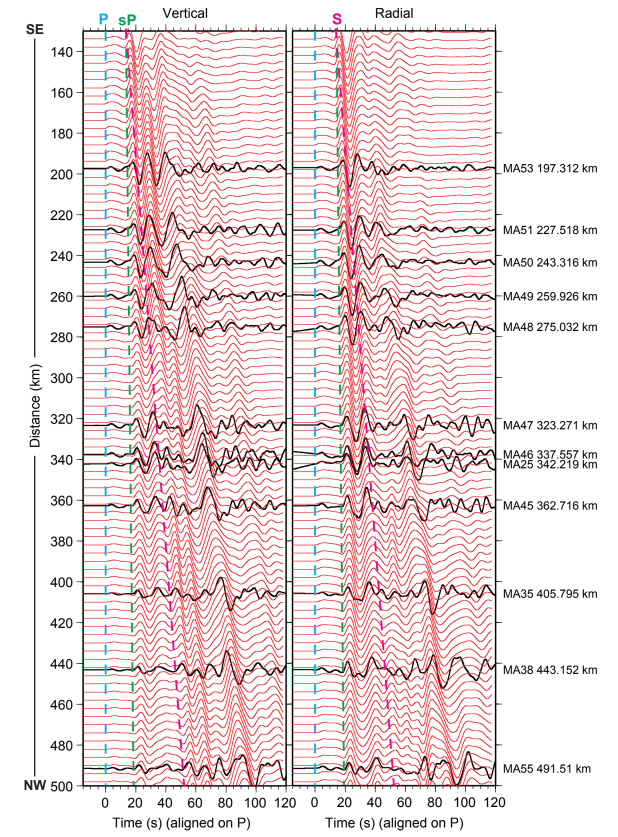


Local S-to-P conversion points from the top of the Cocos slab (small circles) for MARS stations which recorded complex (large green circles), possibly complex (large blue circles), or simple (large red circles) P waveforms for the eight events which exhibited complexity (conversion points are colored corresponding to station). An approximate location for the western edge of the USL atop the slab is proposed (blue dashed line) based on the locations of these conversion points.

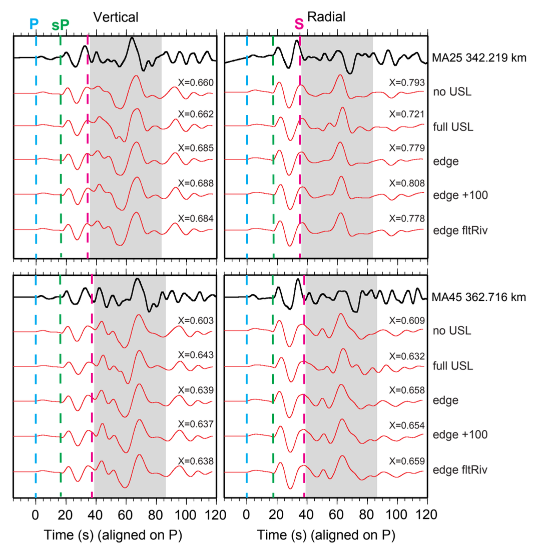
V. 2D Velocity Modeling



2D velocity model of the upper 125 km subduction zone structure across the MARS array along the NW-SE line (see map in II). *P*- and *S*-wave velocities are from the ncM model. Subducted slab shape is estimated from isodepth contours. Locations of the approximate USL edge, stations MA51 and MA55, Colima graben, TMVB, and Colima volcano (black triangle) are indicated for reference. The location of event 3 used in the modeling is shown by the black star.

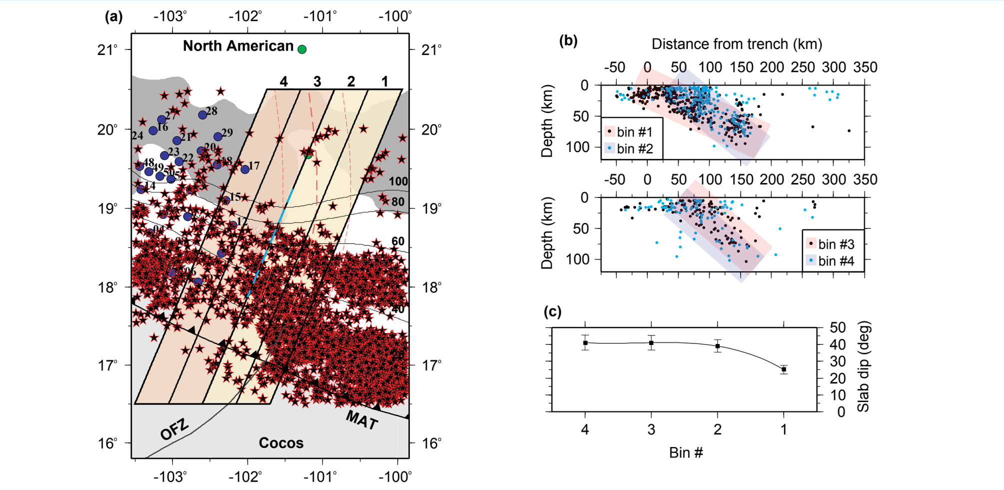


2D modeling results of event 3 along the NW-SE profile. The arrivals of the major phases in the data are indicated. The model predicts the *P* and *sP* phases reasonably well at all distances and the *S*-wave at most distances. A later unidentified large amplitude phase is predicted reasonably well by the model at distances greater than ~320 km.



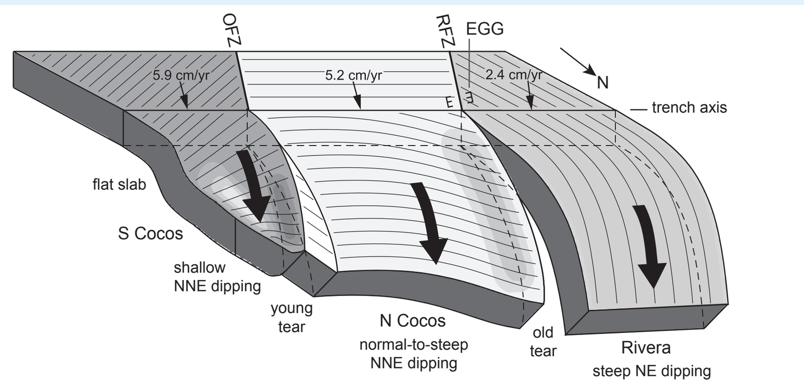
Comparison of 2D modeling results for five different models. The primary variance among the models was the USL. Segment of waveform illustrating greatest variance among the models is shaded grey. Cross-correlation coefficients (X) are shown.

VI. Slab Dip



Seismicity and slab dip across the USL edge. (a) Map of epicenters (stars) from 2001-2011 SSN event catalog. Data in four 50 km wide bins parallel to the USL edge (blue dashed line) are analyzed for changes in slab dip across this region. (b) Cross-sections of seismicity in the S Cocos slab (top) and N Cocos slab (bottom). (c) Plot of slab dip across the data bins. Error bars are weighted by the number of events in each bin.

VII. Slab Tear Model



3D schematic of the two-tear model illustrating the geometry of the S Cocos, N Cocos, and Rivera plates, along with the Orozco (OFZ; young tear) and Rivera (RFZ; old tear) fracture zones. Plate convergence rates and directions (small arrows) are shown at the trench.

VIII. Conclusions

-Our results show there is a western boundary to the ultra-slow velocity layer atop the Cocos slab. This boundary is approximately coincident with the western margin of the projected Orozco Fracture Zone region.

-The best fitting 2D model uses ncM velocities and has an edge to the USL in our proposed location.

-Based on the USL edge location, 2D modeling results, and results of recent plate motion studies, we propose that the Cocos slab is currently fragmenting into North and South Cocos plates along the projection of the OFZ. This tearing event may be a young analogy to the mature tear along the Rivera-Cocos plate boundary.

References

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Acknowledgements

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