A geodetic study of the 22 January 2003 Tecomán, Colima, Mexico earthquake

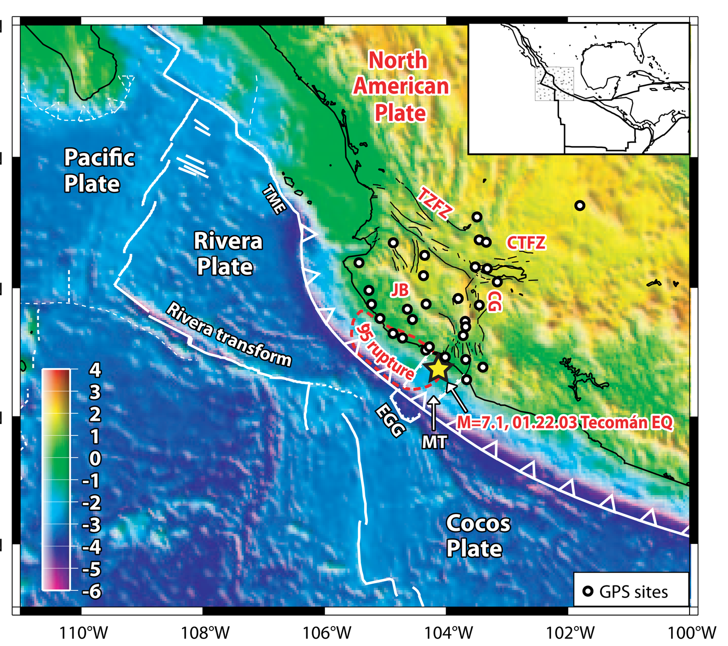
Stuart Schmitt — *Department of Geology and Geophysics, University of Wisconsin-Madison*, e-mail: stuart@geology.wisc.edu
Charles DeMets — *Department of Geology and Geophysics, University of Wisconsin-Madison*
Joann Stock — *Seismological Laboratory, California Institute of Technology*
Osvaldo Sánchez — *Instituto de Geofísica, Universidad Autonoma Nacional de México*
Bertha Márquez-Azúa — *Departamento de Geografía y Ordenación Territorial, Universidad de Guadalajara*

1. INTRODUCTION & TECTONIC SETTING

The 22 January 2003 Tecomán subduction earthquake ruptured the Middle America trench subduction interface near Tecomán, Colima, Mexico (Fig. 1). With an estimated magnitude between 7.1 and 7.6, the Tecomán earthquake caused the deaths or injuries of more than 1,000 people and damaged or destroyed more than 40,000 homes and businesses, mostly in and near the inland city of Colima. This area has a history of large earthquakes (1995, 1973, and two in 1932), and the 2003 event is the second to be observed geodetically. The latest GPS results give insight into the seismic behavior of this region.

Fig. 1. Tectonic setting of western Mexico.

JB: Jalisco Block;
CG: Colima Graben;
MT: Manzanillo Trough.



The seismotectonics of western Mexico are dominated by subduction of the Rivera and Cocos plates northeastward beneath the western edge of North America (Fig. 1). Subduction of the Rivera plate diminishes rapidly to the northwest along the Mexican coastline (Fig. 1), from a maximum rate of 38 ± 4 mm/yr at the Manzanillo Trough (*DeMets and Wilson*, 1997). Significantly faster subduction of the Cocos plate (52 ± 3 mm/yr) at the Manzanillo Trough implies differential Cocos-Rivera plate motion offshore. The transition between Rivera and Cocos plate lithosphere is poorly defined by kinematic and seafloor morphologic data and most likely consists of a broad zone of distributed earthquakes and deformation (*Bandy* et al., 1995) that intersect the trench near the Manzanillo Trough. The Manzanillo Trough and adjacent southern Colima graben are slow or inactive (*Serpa* et al., 1992) extensional features with deep sediment fill (*Bandy* et al., 1995).

2. DATA

Our GPS network consists of 31 geodetic markers that have been occupied annually since 1995. The Tecomán earthquake occurred one day after we initiated our 2003 occupation. Eight GPS receivers were operating during the earthquake, half at sites located relatively close to the rupture zone. We occupied an additional 19 sites within one week of the earthquake and one site five months after the earthquake. For sites operating during the earthquake, we determined coseismic offsets by differencing the locations from the day before the earthquake and the 22 h following the earthquake. For the other sites (hereafter called "quasi-coseismic"), we extrapolate the pre-earthquake location and difference it with the first post-earthquake position observed (Fig. 2).

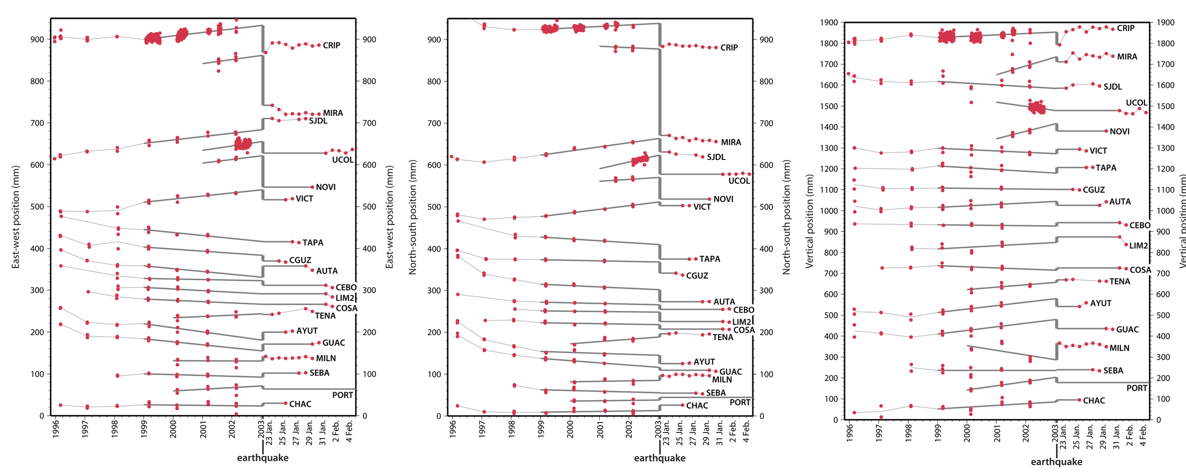


Fig. 2. GPS coordinate time series used to find the 19 quasi-coseismic offsets. The linear regression used to determine preearthquake site motion is shown by the medium-thickness lines. Thick vertical lines represent the quasi-coseismic offsets. Horizontal medium-thickness lines after the earthquake illustrate how post-earthquake site position is obtained from the first available GPS solution. Time scale differs before and after the earthquake.

3. METHODS

We use the commercially-available finite element package *ABAQUS* to model the region. Our 3D FEM mesh (Fig. 3) is designed to approximate the geometrical characteristics of the northern Middle America subduction zone. The model configuration and material properties share many similarities to those employed by *Masterlark* (2003).

To perform inversions with the FEM, we construct a linear system of the 3D surface deformations that result from slip on each pair of nodes (one oceanic and one continental) on the subduction interface. We allow for oblique slip, though all nodes must slip in the same direction. Finally, we impose a down-dip slip constraint.

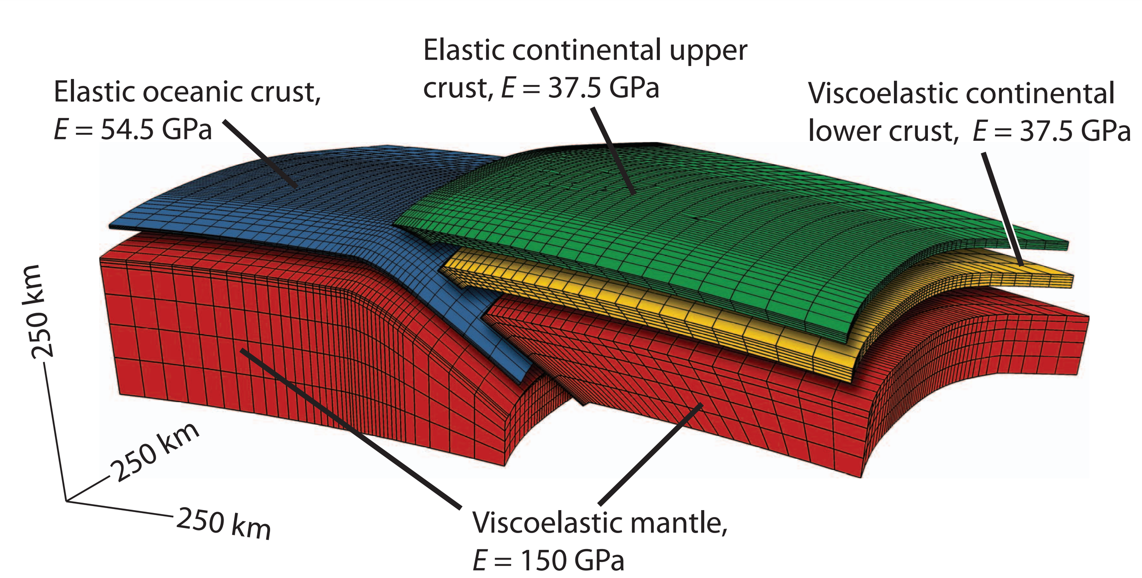


Fig. 3. Exploded view of finite element mesh employed for modeling. Values of Young's modulus E are shown. Coseismic deformation is modeled as a static step in the FEM, so the entire model behaves elastically.

4. RESULTS

The GPS-derived slip distribution is located offshore from the Colima Graben (Fig. 4). The rupture is focused on the earthquake epicenter found by the local seismic network (*Schmitt* et al.).

Moment release:	6.3×10^{19} N·m (M_w=7.1)
Slip direction:	N26°W (11° CCW of dip direction)
Depth range:	12 km – 40 km
Width of rupture:	80 km
Maximum slip:	3.85 m at 22 km depth

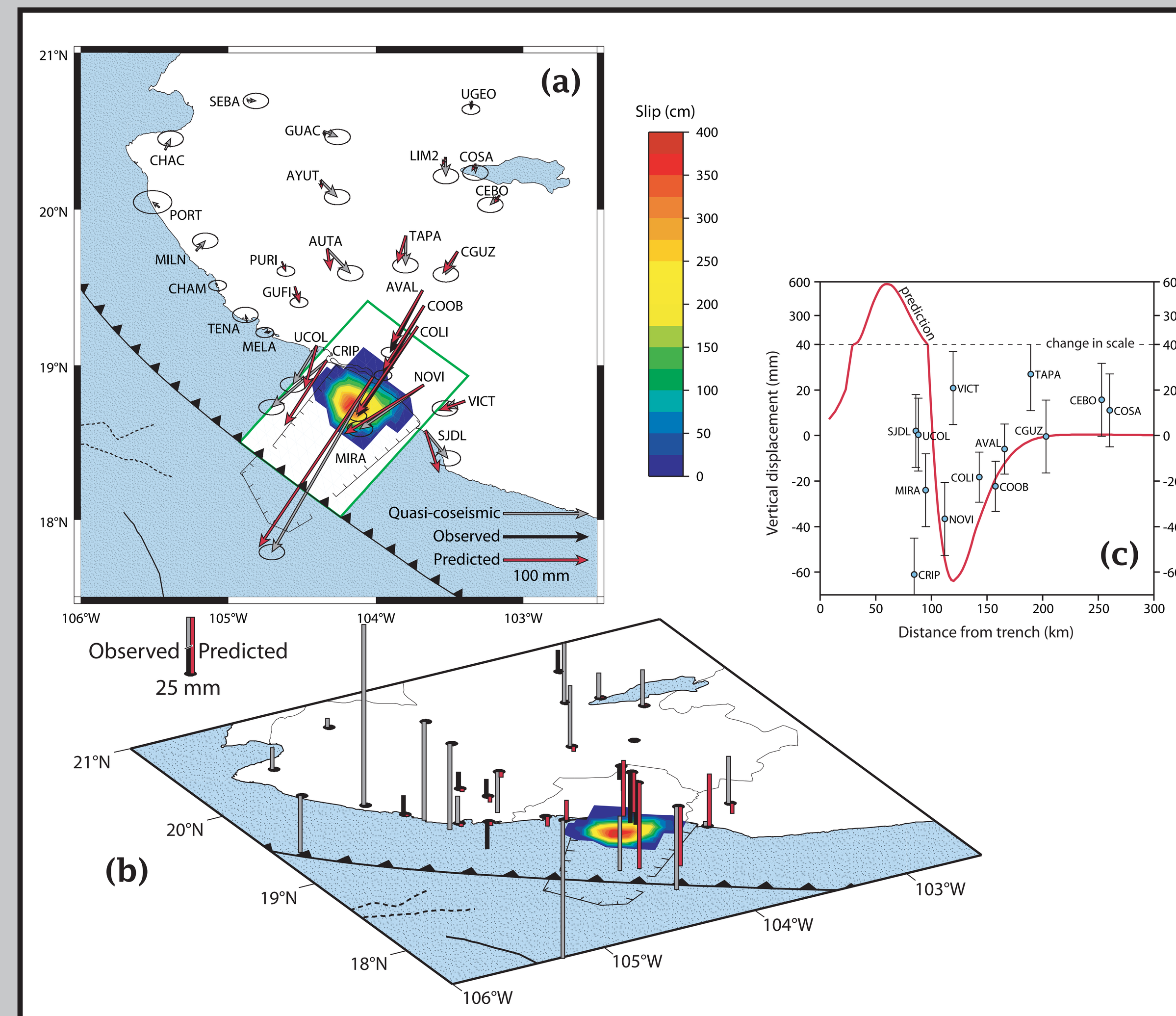


Fig. 4. **(a)** Best-fitting slip distribution; observed (gray and black arrows) and predicted (red arrows) horizontal displacements. **(b)** Vertical displacements; colors as in (a). **(c)** Predicted and observed vertical displacements for sites inland from rupture.

5. DISCUSSION

5.1 Comparison to seismological solution

Only one seismological slip distribution has been published (*Yagi* et al., 2004), based on a joint inversion of local and teleseismic data. The chief difference between the seismological and geodetic slip distributions is that the former extends to great depths. We tested the seismological slip distribution in our FEM (Fig. 5) and found that it produced large misfits of the vertical displacements, particularly at sites sensitive to deeper slip. Consequently, we contend that rupture did not extend as deeply as the seismological model suggests.

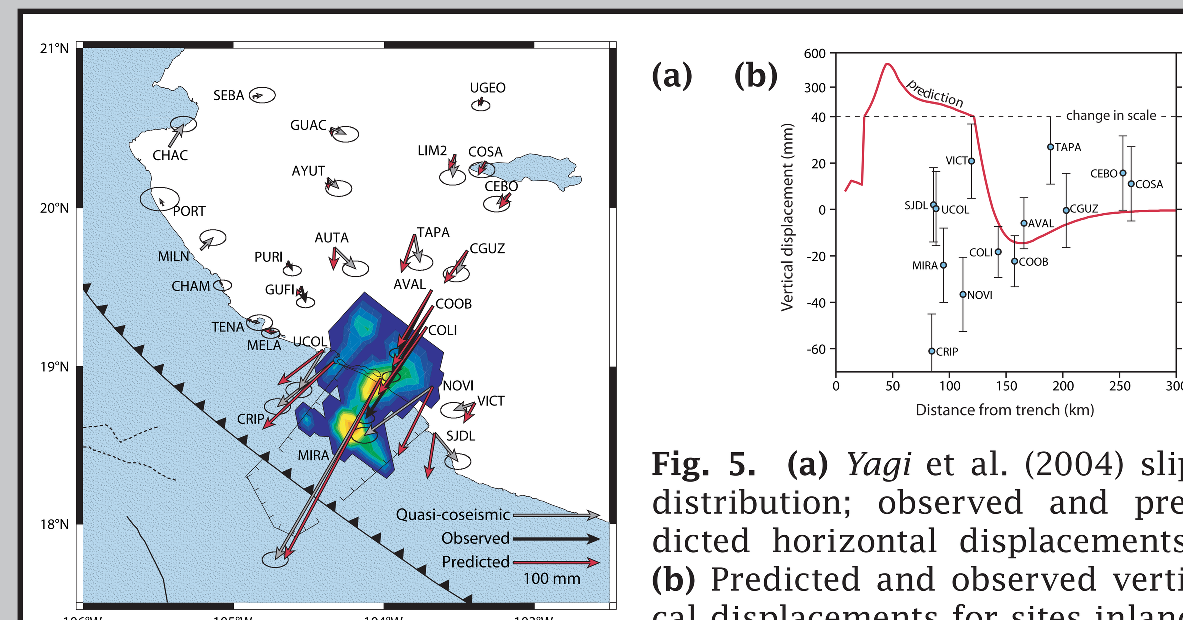


Fig. 5. **(a)** *Yagi* et al. (2004) slip distribution; observed and predicted horizontal displacements. **(b)** Predicted and observed vertical displacements for sites inland from the rupture.

5.2 Comparison to 1995 earthquake

The 1995 and 2003 earthquakes ruptured distinctly different parts of the subduction interface (Fig. 6) and only slightly overlap at the northwest edge of the Manzanillo Trough. Modeling of generic thrust faults indicates that the highest Coulomb stress changes occur along strike immediately at the edge of a rupture (*Lin and Stein*, 2004). This suggests that the 2003 Tecomán earthquake resulted from stress transfer from the adjacent 1995 event and its postseismic effects.

Both the up-dip and down-dip limits of the 2003 rupture are deeper than those of the 1995 earthquake. This may suggest:

(A) A fundamental change along the strike of the trench in the depth of seismogenesis, possibly caused by differences in the rates and angles of Rivera and Cocos plate subduction, or

(B) The presence of low-strength rock to greater depths, consistent with *Bandy* et al. (1995).

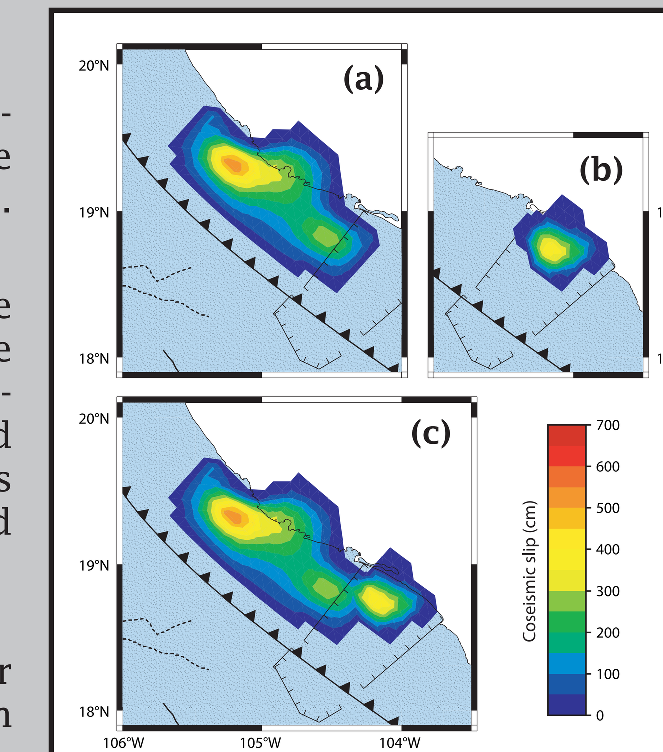


Fig. 6. **(a)** 1995 M_w = 8.0 earthquake slip distribution found with new FEM. **(b)** 2003 slip distribution. **(c)** Cumulative 1995 and 2003 slip.

5.3 Comparison to 1932 earthquakes

The 1932 earthquakes share attributes with the 1995 and 2003 earthquakes that suggest possible triggering relationship for earthquakes along this part of the trench. *Singh* et al. (1985) approximate the rupture areas of the 3 June (M_w ≈ 7.9) and 18 June 1932 (M_w ≈ 7.8) earthquakes from isoseismal lines defined from damage reported by regional newspapers (Fig. 7). However, not all large earthquakes in the region trigger large adjacent ruptures—the 30 January 1973 M_w = 7.5 Colima earthquake did not trigger a subsequent rupture in the Manzanillo Trough.

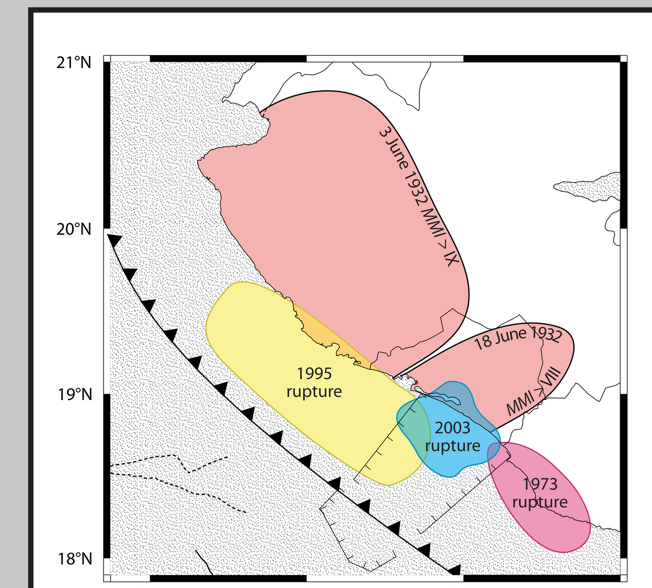


Fig. 7. Historical seismicity.

REFERENCES

Bandy, W., C. Mortera-Gutierrez, J. Urrutia-Fucugauchi, and T. W. C. Hilde (1995), The subducted Rivera-Cocos plate boundary: Where is it, what is it, and what is its relationship to the Colima rift?, *Geophys. Res. Lett., 22*(22), 3075-3078.

DeMets, C., and D. S. Wilson (1997), Relative motions of the Pacific, Rivera, North American, and Cocos Plates since 0.78 Ma, *J. Geophys. Res., 102*(B2), 2789-2806.

Lin, J. and R. S. Stein (2004), Stress triggering in thrust and subduction earthquakes and stress interaction between the southern San Andreas and nearby thrust and strike-slip faults, *J. Geophys. Res., 109*, B02303.

Masterlark, T. (2003), Finite element model predictions of static deformation from dislocation sources in a a subduction zone: Sensitivities to homogeneous, isotropic, Poisson-solid, and half-space assumptions, *J. Geophys. Res., 108*(B11), 2540.

Schmitt, S. V., C. DeMets, J. Stock, O. Sánchez, B. Márquez-Azúa, and G. Reyes (2005), A geodetic study of the 22 January 2003 Tecomán, Colima, Mexico earthquake, in preparation for submission to *Geophys J. Int.*

Serpa, L., S. Smith, C. Katz, C. Skidmore, R. Sloan, and T. Pavlis (1992), A geophysical investigation of the southern Jalisco Block in the State of Colima, Mexico, *Geofís. Int., 31*(4), 475-492.

Singh, S. K., L. Ponce, and S. P. Nishenko (1985) The great Jalisco, Mexico, earthquakes of 1932: Subduction of the Rivera Plate, *Bull. Seism. Soc. Am., 75*(5), 1301-1313.

Yagi, Y., T. Mikumo, J. Pacheco, and G. Reyes (2005), Source rupture process of the Tecomán, Colima, Mexico earthquake of January 22, 2003, determined by joint inversion of teleseismic body wave and near-source data, *Bull. Seism. Soc. Am., 94*, 1795-1807 (2004)