Evidence of a Collision between the Yucatan Block and Mexico in the Miocene

YoungHee Kim[1], Robert W. Clayton[1], and Fraser Keppie[2]

[1]Seismological Laboratory, California Institute of Technology, Pasadena, California 91125

[2]Department of Natural Resources, 1701 Hollis Street, Halifax, Nova Scotia, B3J2T9

Email: ykim@gps.caltech.edu

1 Abstract

We present the discovery of an anomalous south-dipping slab in southern Mexico. The main evidence comes from a clear receiver function (RF) image along a line across the Isthmus of Tehuantepec and is also supported by RFs from the sparse regional network in the area and from a previous global tomographic model. The slab dips at 35 degrees, is approximately 250 km in length, and appears to truncate the Cocos slab at approximately 100 km depth. We hypothesize that the Yucatan Block collided with Mexico at approximately 12 Ma. This scenario would explain the Chiapas Fold and Thrust Belt (CFTB) as the product of this collision and its age constrains the date of the event to be in the Miocene.

2 Data

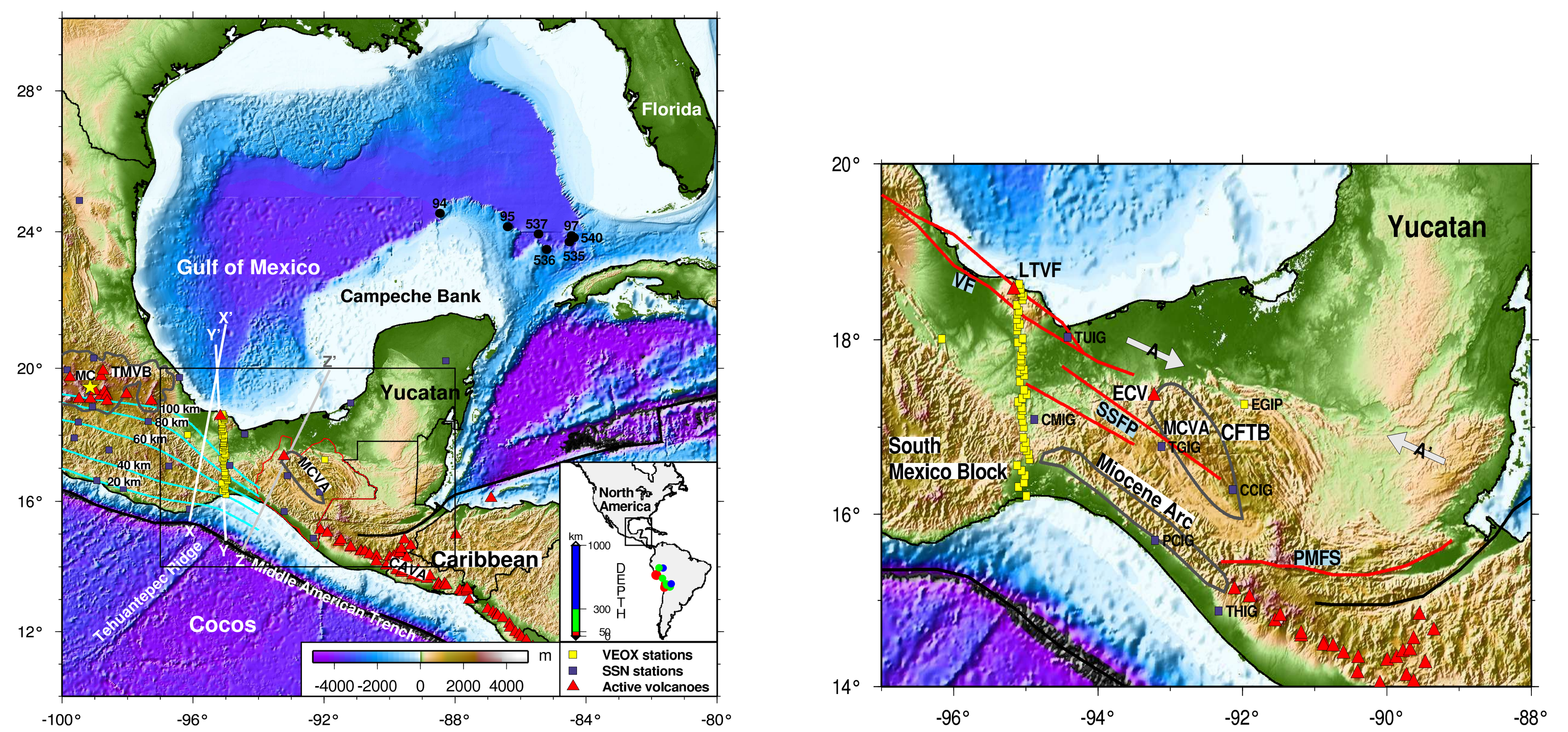

Figure 1: **Topographic-bathymetric map showing the region of the study and stations.** [left] Locations of tomographic profiles are indicated as lines X-X', Y-Y' (along the VEOX line), and Z-Z', and black dots with site numbers, just above the Campeche Bank, indicate DSDP drill holes. Isodepth contours of the Cocos Plate beneath the North American (NA) Plate (*Pardo and Suárez*, 1995) are shown as cyan lines in the map. Gray solid lines represent two volcanic belts: Trans Mexican Volcanic Belt, TMVB, in central Mexico, and Modern Chiapanecan Volcanic Arc, MCVA, in the Chiapas State (red solid line). Map of southeast (SE) events used in the analysis is in the inset. The events are recorded from the VEOX stations (yellow squares). [right] Regional map showing a lineament in the approximate location of the proposed Mexico-Yucatan suture zone, indicated by two gray arrows (A and A'). Red lines outline main fault systems in southern Mexico, and their locations were extracted from *Andreani et al.* (2008).

3 Image of Cocos Slab in Southern Mexico

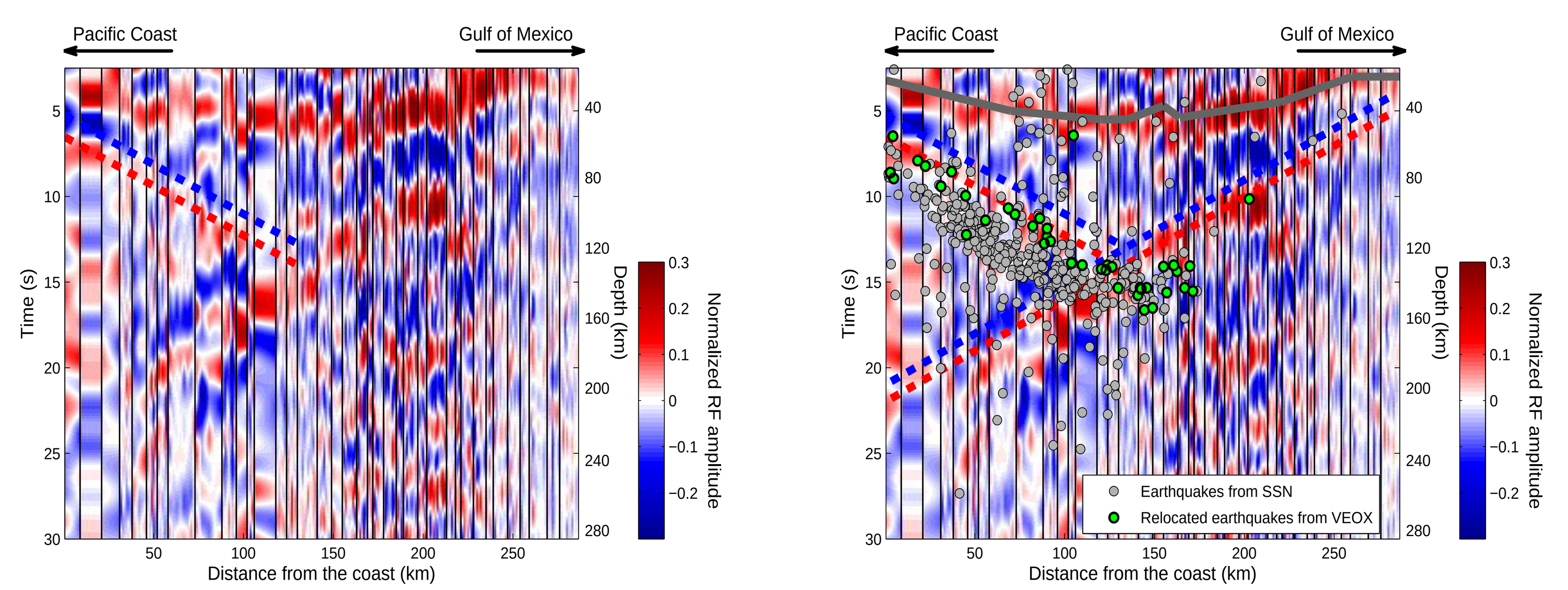

Figure 2: **Low-pass version of the RF image showing Cocos slab utilizing the data from all azimuths.** [left] RF image using seismograms from the 68 teleseismic earthquakes, filtered to 0.01-0.3 Hz. [right] The same RF image with the local seismicity. The RFs for each station are sorted by backazimuth of the incident wavefield. For each station, amplitudes of the RFs are transferred into a vertical column bin and linear interpolated within the column (separated by vertical lines). The top and bottom interfaces of the Cocos slab are indicated by dotted lines, and separated by 8-10 km thickness. Note that the P phase at zero second (the largest peak of the RF) is removed in the image to enhance the smaller signals after P. The time axis on the left hand side is directly transferred to the depth on the right hand side using IASP91 velocity model. The local earthquakes plotted are recorded from the SSN (gray circles) and the VEOX line (green circles). The 42 earthquakes from the VEOX line are recorded using the double-difference algorithm (*Castro Artola*, 2010).

4 Image of Yucatan Slab in Southern Mexico

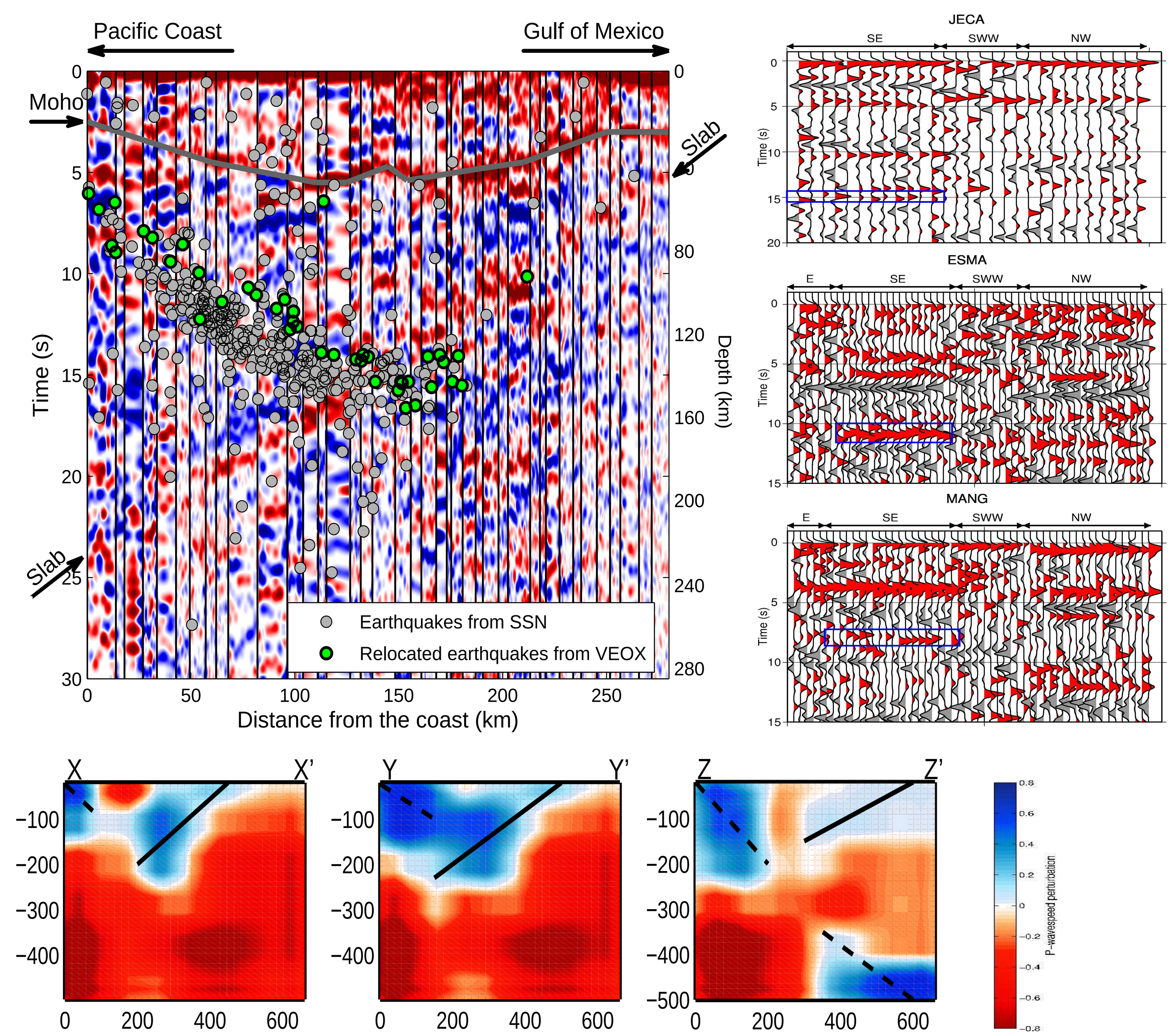

Figure 3: **1 s RF and global tomography results.** [top left] RF image showing the Moho and the Yucatan slab from the Gulf of Mexico. The locations of teleseismic earthquakes used to construct the RF image shown in Figure 1. [top right] RF gather from three stations along the VEOX line that shows the arrival (in a blue box) from the Yucatan slab only on the SE azimuths. [bottom] Cross sections of the profile X-X', Y-Y', and Z-Z' (Figure 1) through the global P-wave tomography model of *Li et al.* (2008), showing the image of the Yucatan slab (solid lines) and Cocos slab (dotted lines).

5 Unusual Tectonic and Volcanic Features

There are a number of anomalous tectonic features in southern Mexico that are assumed to be a result of subduction, but are not well explained by a simple Cocos Plate subduction model. Here we discuss some of these structures.

- **Tehuantepec Ridge (TR)**
  The TR is a quasi-linear feature on the Cocos Plate that is nearly tangent to the Clipperton Fracture Zone starting $\sim$600 km outboard of the MAT. It has been suggested to be caused by a 10° change in direction of the spreading ridge between 15 and 8 Ma (*Manea et al.*, 2005). The TR is proposed as the cause of a number of features in this region including the low topography across the Isthmus of Tehuantepec, the El Chichón, and the CFTB.
- **Polochic-Motegua Fault System (PMFS)**
  The PMFS is considered by most to be the boundary between the NA and Caribbean Plates, and its projection to the MAT is thought to be a triple junction between the NA, Cocos and Caribbean Plates (*Pindell and Dewey*, 1982). However, the PMFS is not actually observed to intersect the MAT (e.g., *Morgan et al.* (2008)). It has been proposed that the boundary actually turns north-west before the MAT and continues along the Chiapas Sinistral Fault System and then along the Veracruz Fault (*Andreani et al.*, 2008), thus making the projected point on the MAT only a false triple junction.
- **Unusual volcanic arc geometry in Mexico**
  The active arc is the place where the slab is at $\sim$100 km depth in central Mexico and the CAVA in the south. In between, the MCVA at a strike of $\sim$30° clockwise from the strike of the MAT lies $\sim$200 km above the Cocos slab (*Manea and Manea*, 2008). The Cocos slab, as delineated by seismicity (*Rebollar et al.*, 1999), ranges in dip from 50° to 54°, and hence cannot explain its oblique strike angle. In the northern part of the Tehuantepec Isthmus, the Cocos slab lies $\sim$250 km beneath the LTVF, or deeper if the slab truncation models are correct (*Rogers et al.*, 2002). Similarly, the slab beneath El Chichón is deeper than 200 km (*Rebollar et al.*, 1999).
- **Chiapas Fold and Thrust Belt (CFTB)**
  The CFTB, shown in Figure 2, is a compressive structure with $\sim$106 km of compression that occurred between $\sim$13 and $\sim$11 Ma (*Mandujano-Velazquez and Keppie*, 2009). The cause of this compression has been recently attributed to the interaction of the TR with the MAT (*Mandujano-Velazquez and Keppie*, 2009), but this does not explain why the forearc is not also compressed. The CFTB would be consistent with this being part of a collision zone between the Yucatan Block and Mexico. If so, this structure will provide an important constraint on the timing of the collision.

6 Tectonic Reconstruction Model for Southern Mexico

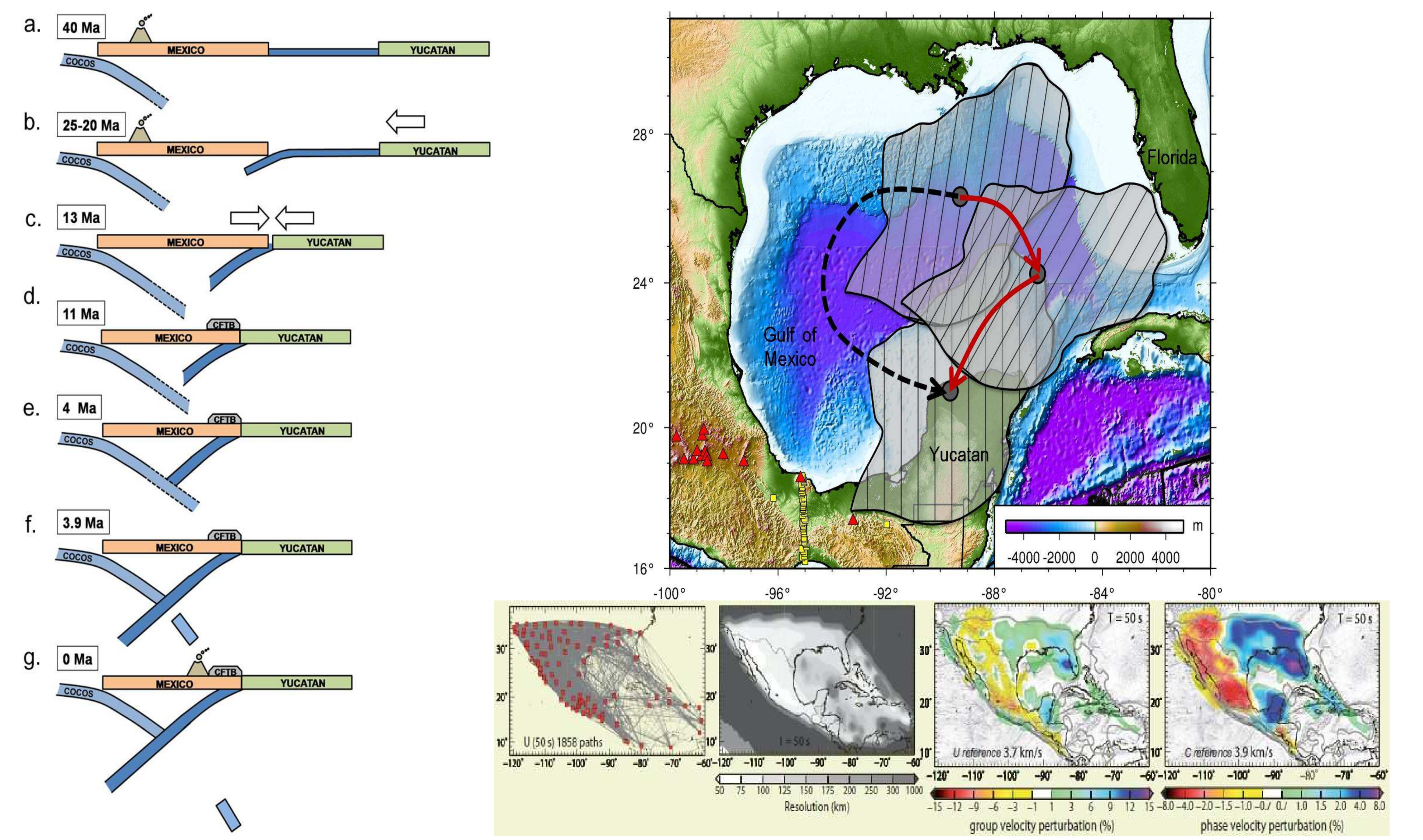

Figure 4: **Tectonic reconstruction diagram for southern Mexico.** [left] A schematic model shows the collision of the Yucatan in Mexico. The onset of subduction (25 - 20 Ma) is estimated assuming a subduction rate of 2$-$5 cm/yr and a slab length of 250 km. The date of truncation of the Cocos slab is taken from *Rogers et al.* (2002). The last stage (g) shows a present-day model for southern Mexico. [top left] Map view of the Yucatan Block rotations. The black dotted-line arrow represents the movement of the Yucatan Block based on the standard model by *Pindell and Dewey* (1982). The red solid-line arrow represents our proposed model. [bottom right] Path distribution, resolution, group velocity, and phase velocity maps by *Gaite et al.* (2010). At period from 40 to 50 s, the most striking feature is the low velocity anomalies at the Yucatan Block and Florida Peninsula.

7 Acknowledgments

This study was supported by the Gordon and Betty Moore Foundation through the Tectonics Observatory at California Institute of Technology.

References

Andreani, L., C. Rangin, J. Martinez-Reyes, C. Le Roy, M. Aranda-Garcia, and X. Le Pichon, R. Peterson-Rodriguez (2008), The Neogene Veracruz fault: evidences for left-lateral slip along the southern Mexico block, *Bull. Soc. Geol. France*, *179*, 195-208.

Castro Artola, O. A. (2010), Caracterizacion de la geometria de la zona benioff con una red densa de banda ancha en el istmo de tehuantepec, BA thesis, 44 pp., Universidad Nacional Autónoma de México, June.

Gaite, B., A. Villaseñor, M. Herraiz, A. Iglesias, and J.F. Pacheco (2010), Ambient noise surface wave tomography in Mexico, Gulf of Mexico and Central America, *Eos Trans. AGU, 91(26), Meet. Am. Suppl.*, Abstract S23B-06.

Li, C., R. D. van der Hilst, E. R. Engdahl, and S. Burdick (2008), A new global model for P wave speed variations in Earth's mantle, *Geochem. Geophys. Geosyst.*, *9*, doi:10.1029/2007GC001806.

Mandujano-Velazquez, J., and J. D. Keppie (2009), Middle Miocene Chiapas fold and thrust belt of Mexico: a result of the Tehuantepec Transform/Ridge with the Middle America Trench, *Geol. Soc. Lond. Spec. Publ.*, *327*, doi:10.1144/SP327.4.

Manea, M., V. Manea, L. Ferrari, V. Kostoglodov, and W. Bandy (2005), Structure and origin of the Tehuantepec Ridge, *Earth Planet. Sci. Lett.*, *238*, 64-77.

Manea, M., and V. Manea (2008), On the origin of the El Chichón volcano and the subduction of the Tehuantepec Ridge: A geodynamical perspective, *J. of Volcanol. Geotherm. Res.*, *175*, doi:10.1016/j.jvolgeores.2008.02.028.

Morgan, J. P., D. R. Ranero, and P. Vannucchi (2008), Intra-arc extension in Central America: Links between plate motions, tectonics, volcanism, and geochemistry, *Earth Planet. Sci. Lett.*, *272*, 365-371.

Pardo, M., and G. Suárez (1995), Shape of the subducted Rivera and Cocos plates in southern Mexico: Seismic and tectonic implications, *J. Geophys. Res.*, *100*(B7), 12357-12373.

Pindell, J., and J. F. Dewey (1982), Permo-Triassic Reconstruction of Western Pangea and the Evolution of the Gulf of Mexico/Caribbean Region, *Tectonics*, *1*, 179-211.

Rebollar, C., V. Espindola, A. Uribe, A. Mendoza, and A. Verti (1999), Distribution of stresses and geometry of the Wadati-Benioff zone under Chiapas, Mexico, *Geofis. Int.*, *38*, 95-106.

Rogers, R., H. Káson, and R. D. van der Hilst (2002), Epeirogenic uplift above a detached slab in northern Central America, *Geology*, *30*, 1031-1034.

Syracuse, E. M., and G. A. Abers (2006), Global compilation of variations in slab depth beneath arc volcanoes and implications, *Geochem. Geophys. Geosyst.*, *7*, doi:10.1029/2005GC001045.