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Motion partitioning between the Pacific plate, Baja California and the North America plate: The Tosco-Abreojos fault revisited

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[1] During the FAMEX cruise of the R/V L'Atalante (April 2002), swath bathymetry and seismic profiles were recorded along the Baja California margin from 23° to 27°N. The upper-slope of the margin exhibits active faulting of recent sediments along the Tosco-Abreojos fault system (TAFS). Flower structures evidence strike-slip motion along the TAFS. Right lateral strike slip faulting, associated in places with small extensional features, are consistent with present-day slip and extension rates predicted along the TAFS. The TAFS thus belongs to the western active boundary of a Baja California Block yet not totally transferred to the Pacific plate.

INDEX TERMS: 1645 Global Change: Solid Earth; 1744 History of Geophysics: Tectonophysics; 3025 Marine Geology and Geophysics: Marine seismics (0935); 3040 Marine Geology and Geophysics: Plate tectonics (8150, 8155, 8157, 8158); 3045 Marine Geology and Geophysics: Seafloor morphology and bottom photography.

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1. Introduction

[2] Subduction along western Baja California is widely accepted to have stopped 12 Myr ago when transform motion between the Pacific (PA) and North America (NA) plates started [Stock and Hodges, 1989]. From 12 to 5 Ma right lateral transform motion occurred along the Tosco-Abreojos fault system (TAFS) supposed to be the plate boundary between 23° and 28°N (Figure 1a). Transform motion lasted until the opening of the Gulf of California at 5–3.6 Ma [Spencer and Normark, 1979; Lonsdale, 1991]. Consequently, the PA-NA plate boundary is assumed to be located in the Gulf of California since 5–3.6 Ma, with Baja California being part of the PA plate since then.

[3] Although the PA-NA plate motion is considered to be steady since 3.16 Ma, seafloor spreading in the Gulf of California has accelerated since 3.5 Ma [DeMets, 1995], which implies that Baja California has moved

relative to the PA plate [DeMets and Dixon, 1999] (i.e., Baja California has not been rigidly coupled to the PA plate since 3.5 Ma).

[4] Faults along the western margin of Baja California presumably accommodated some or all of this questionable motion between a Baja California block and the PA plate [Fletcher and Munguia, 2000]. Offshore Baja California, the TAFS is a candidate to accommodate such motion (Figure 1b). However, this fault system is presented as an inactive tectonic feature since 5 Ma [Spencer and Normark, 1989]. Nevertheless, sparse bathymetric and single-channel seismic profiles show that the TAFS controls bathymetric scarps and, in places, crosscuts younger seafloor strata [Spencer and Normark, 1979; Normark et al., 1987; Ness and Lyle, 1991]. Moreover, seismic activity on the continental borderland [Fletcher and Munguia, 2000] indicates active tectonism.

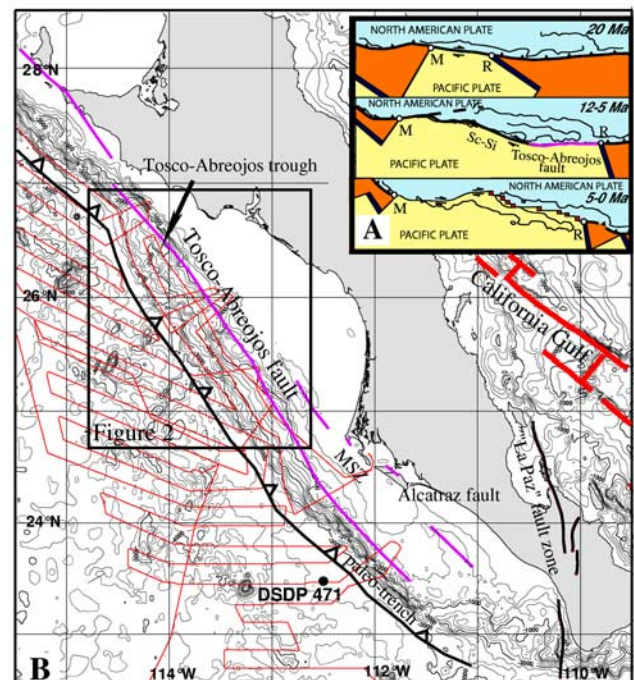


Figure 1. A) Evolution of the Pacific-North America plate margin during the last 20 Ma [after Dickinson and Snyder, 1979] R: Rivera triple junction; M: Mendocino triple junction; SC-SI: San Clemente-San Isidro fault. B) Bathymetric map of the Baja California margin [from Smith and Sandwell, 1997]. MSZ: Magdalena seismic zone; Soft red lines: FAMEX cruise. TAFS from Spencer and Normark [1989]; “La Paz fault” from Fletcher and Munguia [2000].

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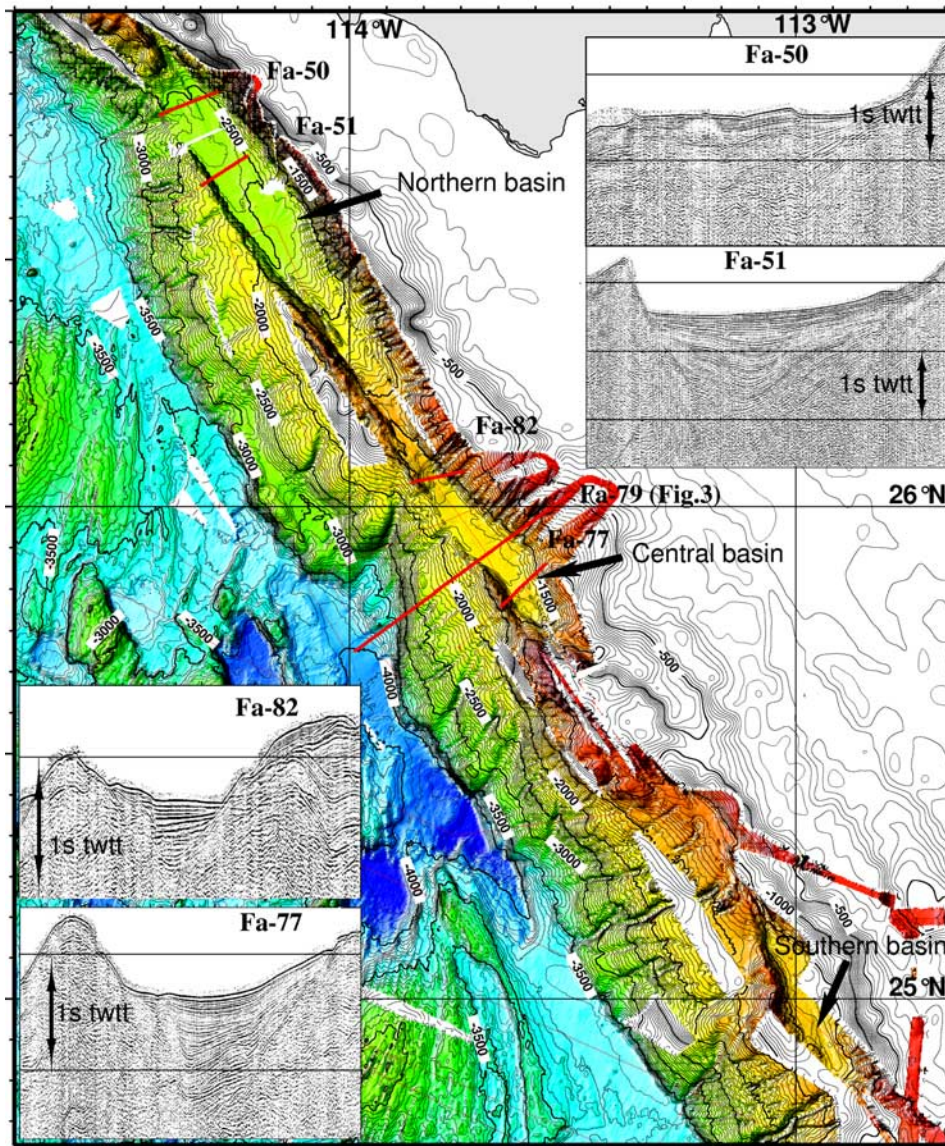


Figure 2. Swath bathymetry of the Tosco Abreojos trough. Red lines: soft = Famex profiles; thick = displayed seismic lines.

[5] During the FAMEX cruise swath bathymetry and seismic profiles (300 inch³ GI guns tuned in harmonic mode; six 50m-long channels streamer; 10s pop-rate at a 10 knots speed, 3-fold coverage; 4s record-length) were collected along the TAFS (Figure 1b). These new data evidence that modern PA-NA plate motion is partitioned between the Gulf of California and the TAFS along the Pacific margin of Baja California.

2. Structural Features

[6] Swath bathymetric data between 27° and 24.5°N (Figure 2) show three 35–40°W trending elongated *en échelon* basins in the middle slope that define the Tosco-Abreojos trough [Spencer and Normark, 1979].

[7] The northern basin (15 km wide, 70 km long) reaches a maximum depth of 2600 m. It exhibits a morphological asymmetry with a linear 750m-high steep scarp to the west and a less steep 1500m-high scarp to the east being concave

seaward. Seismic data (Figure 2) evidence that these scarps are morphological expression of two major fault systems. The western fault system dips 40° toward the continent, whereas the eastern fault system dips 35–30° seaward, suggesting that the two faults intersect at depth. Indeed bathymetric data show that the two fault systems bounding the northern basin connect to one another to the north and to the south. Therefore, these fault systems define a flower structure that controlled the basin location and dynamics. In some places, the two fault systems are associated with small linear 50m-high ridges with gutters displacing the flat floor of the basin (line Fa-50, Figure 2). Such morphological features trending 25° relative to the main fault direction evidence active right lateral transtensional motion along the flower structures.

[8] The main structure of the central and southern basins (10 km wide, 45 km long) is similar to that of the northern basin (Figure 2). The fault systems bounding these basins define flower structures in the prolongation of the northern

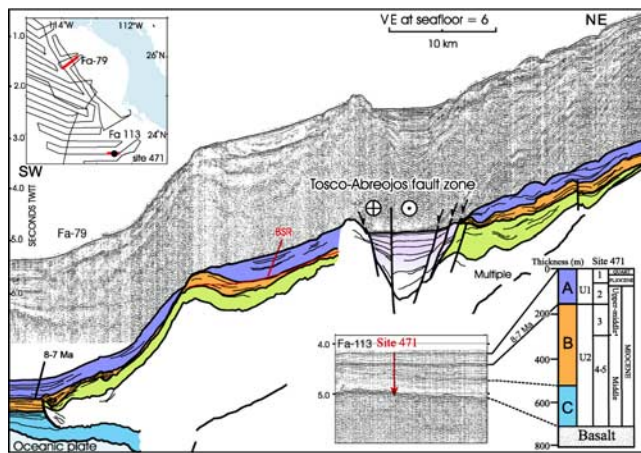


Figure 3. Seismic line Fa-79 (location on Figure 2) (A, B and C are seismic units label). Ages are from the correlation with the DSDP site 471 crossing by the seismic line Fa-113. DSDP site 473 stratigraphic column (1-5 = lithologic units; U1-U2 = seismic units) is from *Yeats and Haq* [1981]. The base of the U1 unit is 8–7 Ma in age. We correlate the unit A with the unit U1.

basin system. Seismic profiles show that the central basin's main scarps correspond to 30° seaward dipping fault tracks that bound the sediment deposits within the basin (Fa-82 and Fa-77, Figure 2; Fa-79, Figure 3). A normal component along the faults is evidenced on the seismic lines (Figures 2 and 3).

[9] The new seismic lines extend into the area of DSDP Site 471 (Figure 3), and allow us to project the DSDP results [*Yeats and Haq*, 1981] into the area of the TAFS. Seismic profile Fa-79 exhibits several acoustic units (labeled A, B, C from top to bottom, Figure 3). Unit A extends from the oceanic plate to the lower slope of the continental margin. According to the microfossil assemblage at Site 471, the base of the unit A is assumed to be 8–7 Ma in age. It unconformably overlies the subduction front and the seaward prolongation of the trench fill sediment (i.e., units B and C). Moreover, unit A extends landward covering older slope sediment along the middle and upper slopes, including the Tosco-Abreojos trough (i.e., the central basin) filled with 1.5 stwt of sediments. However, the ages of most of the sediments in the central basin remain unknown.

[10] The data collected during the FAMEX cruise show that (1) the TAFS is an active tectonic zone characterized by flower structures, (2) the TAFS is a right lateral transtensional strike slip fault zone, and (3) although the age when the TAFS initiated is poorly constrained, there is no clear evidence for tectonic activity older than 8–7 Ma.

3. Discussion

[11] Landforms related to strike-slip faults tend to be much less conspicuous, commonly discontinuous and usually shorter lived than those forming along convergent or divergent plate boundaries and associated features are hard to recognize in the field [*Sylvester*, 1988]. *Spencer and Normark* [1979, 1989] interpreted the Tosco Abreojos trough as a relict feature related to 12–5 Ma strike-slip faulting. Our data indicate no continuous valley but several

“*en échelon*” basins separated by linear scarps. Also, these basins are recent and active, and result from right lateral strike slip faulting associated with flower structures along the TAFS. Our data do not provide any information about when the TAFS started. We note that very similar features in shape and size are observed on other active transcurrent fault systems. For example along the active Marmara strike-slip fault, the Sea of Marmara exhibits several *en échelon* basins with 1000–1500 m thick sediment infill [*Le Pichon et al.*, 2001], comparable to those observed along the TAFS. We thus suggest that the Tosco Abreojos trough is not a relict feature, but is related to continuous strike-slip fault activity since at least 5 Ma.

[12] Partitioning of the PA-NA relative motion across Baja California has been inferred from plate kinematic observation and models [*DeMets*, 1995; *Dixon et al.*, 2000]. This conclusion stemmed from the apparent discrepancy between PA-NA velocities measured in the Gulf of California with velocities derived from the global Nuvel-1A model [*DeMets*, 1995]. Furthermore, GPS site velocities relative to North America in coastal Alta and Baja California appear significantly slower than the Pacific plate rate [*Dixon et al.*, 2000]. These authors concluded that the San Clemente-San Isodoro (SC-SI) fault continued offshore Baja California to connect with the Magdalena seismic zone that include known faults such as the Alcatraz and other unnamed Quaternary faults (Figure 1).

[13] Our evidence for recent faulting along the TAFS suggests that the TAFS, despite its oblique trend relative to the PA-NA direction of motion, may be the missing link

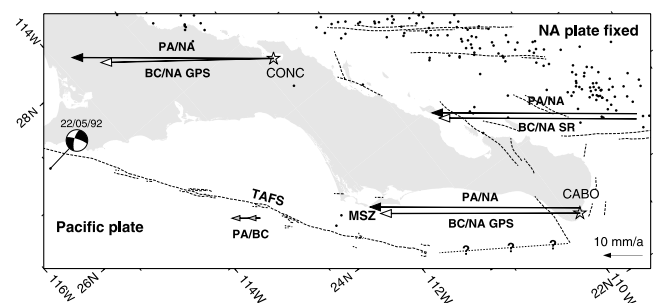


Figure 4. Kinematic predictions and observation in the southern Baja California relative to the North America plate (NA) reference frame. Geodetic motion (full arrows) of the Pacific Plate (PA) is from *Argus and Gordon* [2001]. Observed motion (open arrows) of Baja California (BC) is based on GPS measurements (CONC and CABO sites [*Dixon et al.*, 2000]) and on the central seafloor spreading magnetic anomalies at the Gulf Rise (0.78 Ma [*DeMets*, 1995]). The minimum and maximum Pacific/Baja California velocities (grayed arrows, 3 to 7 mm yr⁻¹) derived by subtracting the BC/NA from PA/NA motion vectors at CONC site (see text) are compatible with the right-lateral strike-slip motion with an extensional component observed along the TAFS and with focal mechanisms from the Harvard catalog. Earthquake epicenters (black dots) are from the NEIC catalog (mb > 4.5). Faults (dashed lines) are after *Spencer and Normark* [1989], except for the TAFS trace derived from this study. MSZ = Magdalena Seismic Zone. Mercator oblique projection relative to the PA/NA rotation pole.

that accommodates slip motion between the Pacific plate and a Baja California block, from the SC-SI to the Magdalena fault systems. Slip rates along this fault can be inferred by comparing the GPS velocity of the CONC site reported by *Dixon et al.* [2000], located due north of our survey area of the fault (Figure 4), with a geodetic estimate for the Pacific plate velocity [*Argus and Gordon*, 2001]. Relative to the North American plate, the CONC site moves at a $43.6 \pm 2.2 \text{ mm yr}^{-1}$ rate whereas the Pacific plate moves with a velocity of 50.9 mm yr^{-1} . Correction for elastic strain accumulation reduces the resulting difference of 7 mm yr^{-1} to $\sim 3 \text{ mm yr}^{-1}$. Using these bounds and assuming that there are no active faults between the CONC site and the TAFS, and taking into account the 15 degree departure of the TAFS orientation relative to the CONC motion vector, the present-day slip rate along the TAFS trend would range from 3 to 7 mm yr^{-1} with a small extensional component ranging from 1 to 2 mm yr^{-1} . The orientation and order of magnitude of these predicted rates are consistent with our evidence for recent right-lateral transtensional motion along the TAFS.

[14] To the north, the TAFS connects with the San Andreas fault system through offshore faults [*Ness and Lyle*, 1991]. Southward continuation of the TAFS is more problematic. Based on our data set, the southernmost rectilinear scarps can be followed to $23^{\circ}15'N$ where it splays into several faults, including landward faults [*Yeats and Haq*, 1981]. *Fletcher and Munguia* [2000] proposed that the TAFS probably connects with active normal faults ("La Paz" fault zone, Figure 1) across the Baja California tip.

4. Conclusion

[15] The major tectonic features along the TAFS and associated basins (i.e., the Tosco Abreojos trough) are clearly indicative of active tectonics. The TAFS is not a relict feature, but exhibits evidence for continuous strike-slip faulting activity since at least 5 Ma. The right lateral displacement recorded along this fault system results from transtensional stresses consistent with kinematic predictions. Present-day kinematic models suggest a partitioning of PAC-NA relative motion [*DeMets*, 1995; *DeMets and Dixon*, 1999; *Fletcher and Munguia*, 2000]. We confirm that the TAFS presently accommodates motion between the Baja California Peninsula and the Pacific plate. The TAFS may thus represent the boundary between the Pacific plate and a Baja California Block, bounded to the east by the Gulf of California spreading system. The distribution of movement between the Pacific and North American plates for the last 5 Myr must be reconsidered in the light of this observation.

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