GEOPHYSICAL RESEARCH LETTERS, VOL. 30, NO. 16, 1872, doi:10.1029/2003GL017732, 2003

Guadalupe Island, Mexico as a new constraint for Pacific plate motion

J. J. Gonzalez-Garcia,[1] L. Prawirodirdjo,[2] Y. Bock,[2] and D. Agnew[2]

Received 13 May 2003; revised 9 July 2003; accepted 24 July 2003; published 30 August 2003.

[1] We use GPS data collected on Isla de Guadalupe and in northern Baja California, Mexico, to estimate site velocities relative to Pacific plate motion. The velocities of all three geodetic monuments on Guadalupe fit a rigid Pacific plate model with residuals of 1 mm/yr. Using the Guadalupe data and data from five IGS stations on the Pacific plate (CHAT, KOKB, KWJ1, MKEA, and THTI) we estimate an angular velocity for this plate that is consistent with other recently-published estimates. Our results indicate that Isla de Guadalupe lies on the Pacific plate, and that GPS data collection on the island usefully constrains Pacific plate motion and rigidity. *INDEX TERMS:* 1206 Geodesy and Gravity: Crustal movements—interplate (8155); 1243 Geodesy and Gravity: Space geodetic surveys; 8150 Tectonophysics: Plate boundary—general (3040); 8158 Tectonophysics: Plate motions—present and recent (3040). **Citation:** Gonzalez-Garcia, J. J., L. Prawirodirdjo, Y. Bock, and D. Agnew, Guadalupe Island, Mexico as a new constraint for Pacific plate motion, *Geophys. Res. Lett.*, *30*(16), 1872, doi:10.1029/2003GL017732, 2003.

1. Introduction

[2] Determining the motion and rigidity of the Pacific plate by geodetic means is difficult because most of the plate lies under water. The most recent study of Pacific plate motion [*Beavan et al.*, 2002] used data from 11 stations, most of them located in the central and western Pacific. Unfortunately, stations on the California coast and on the offshore islands are problematic because of possible tectonic activity in the continental crust. However, Isla de Guadalupe, being on oceanic crust, can potentially provide an important additional constraint on Pacific plate motion. As *Morgan* [1968] pointed out in the first paper on global plate motions: "If the distances between Guadalupe Island, Wake Island, and Tahiti, all within the Pacific block, were measured to the nearest centimeter and then measured again several years later, we suppose these distances would not change." With the Global Positioning System (GPS) we can now perform these measurements with even greater precision than in Morgan's thought experiment.

[3] This study uses GPS data collected from Isla de Guadalupe and northern Baja California, Mexico (Figure 1). Guadalupe lies about 300 km west of mainland Baja California and is formed by two partially overlapping Cenozoic shield volcanoes, dated to about 7 Ma [*Engel and Engel*, 1961]. While Guadalupe lies on oceanic crust, well offshore of the California Borderlands, it might not lie on the Pacific plate, since this region of the eastern Pacific is littered with fossil spreading centers and fracture zones [e.g., *Londsdale*, 1991], and may be part of a hotspot chain originating at the Fieberling guyot [*Batiza*, 1989]. The island itself forms the northern end of the Guadalupe Rift (Figure 1), a fossil spreading center that formed the boundary between the ancient Farallon plate and the Pacific plate. Just SW of Guadalupe is the Cedros Deep, a fossil trench reflecting the former California subduction zone and where the Farallon plate was being subducted until ~13 Ma [*Atwater*, 1970]. *Londsdale* [1991] suggests that tilting and minor deformation of even the youngest turbidite layers may indicate that slight tectonism still affects this fossil subduction zone.

[4] On the other hand, a detailed bathymetric survey [*Krause*, 1961] revealed that the seafloor just east of Guadalupe consists chiefly of shallow, rolling seafloor covered by undisturbed sediment. Furthermore, while the continental crust of California Borderlands has significant seismicity [e.g., *Astiz and Shearer*, 2000], there are no earthquakes on or around Guadalupe (Figure 1). The trace of the San Benito fault lies about 150 km east of Guadalupe,

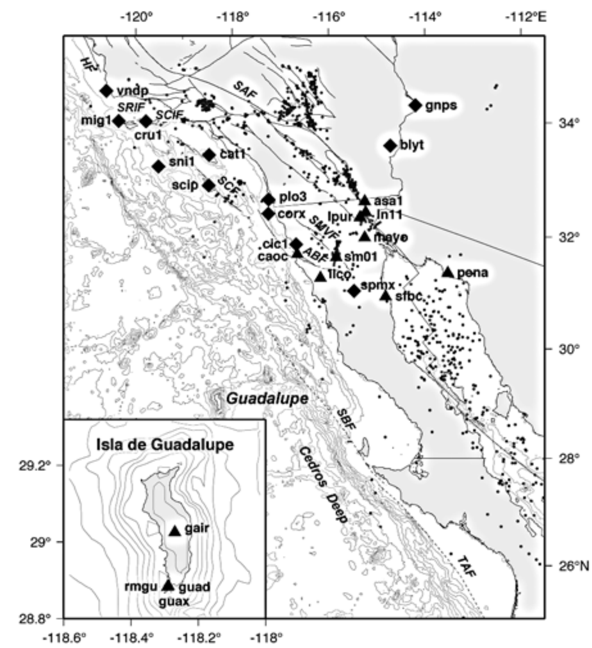

Figure 1. Tectonic background with bathymetry contoured at 500-m intervals, with inset showing a close up of Guadalupe. Triangles are GPS survey-mode stations; diamonds are continuous GPS stations. Black dots indicate $M > 4$ and depth <40 km earthquakes since 1973, from the NEIC catalog. ABF = Agua Blanca fault, HF = Hosgri fault, SAF = San Andreas fault, SMVF = San Miguel-Vallecitos fault, SCF = San Clemente fault, SciF = Santa Cruz Island fault, SriF = Santa Rosa Island fault.

[1]Centro de Investigación Clentífica y de Educación Superior de Ensenada, Baja California, Mexico.
[2]Cecil H. and Ida M. Institute of Geophysics and Planetary Physics, Scripps Institution of Oceanography, La Jolla, California, USA.

0094-8276/03/2003GL017732$05.00

Table 1. Days Per Year of Occupation for Regional Campaign Stations Used in this Analysis

Site	1991	1993	1995	1997	1999	2000	2001	2002	Span[a]
ASA1	–	3	3	2	1	–	1	4	9
CAOC	–	–	–	–	4	4	1	4	3
GAIR	8	–	–	–	–	–	2	7	11
GUAD	(3)[b]	–	–	–	5	–	11	8	11
LLCO	–	2	3	2	3	4	6	6	9
LN11	–	–	–	–	4	1	–	–	1
LPUR	–	6	5	3	8	2	2	3	9
MAYO	–	2	3	2	–	–	–	–	4
PENA	–	5	6	2	2	–	3	2	9
RMGU	–	–	–	–	2	–	1	6	3
SFBC	–	2	8	1	1	–	7	4	9
SM01	–	3	2	2	–	–	–	2	9

[a]Time span in years of each time series.
[b]The 1991 data from station GUAD were of poor quality and were not used in this study.

but we do not know whether it is currently active. The nearest known active faults are the Agua Blanca fault in northern Baja [*Dixon et al.*, 2000] and possibly the Tosco-Abreojos fault [*Spencer and Normark*, 1979], the southward continuation of the San Benito fault.

2. GPS Data and Analysis

[5] This study analyzes data from GPS surveys conducted from 1991 through 2002. The survey schedule is summarized in Table 1. The first GPS surveys on Isla de Guadalupe were conducted in 1989, but were not used because of the relatively high errors due to an incomplete satellite constellation and poor global tracking. The 1991 data were collected as part of a combined geodetic, geologic, and geophysical study [*Genrich*, 1992]. Between 1993 and 1997, three sets of measurements were taken in northern Baja California, in conjunction with experiments conducted by the Salton Trough Riverside County (STRC)

Table 2. Station Coordinates, Observed ITRF2000 Velocities, 1σ Uncertainties, and Residuals

				ITRF2000 velocity (mm/yr)				Residual[a]	
Site Code	Location	Lon. (E)	Lat. (N)	Ve	Vn	σVe	σVn	Ve	Vn
			Pacific Plate						
CHAT	Chatham, NZ	−176.5658	−43.9558	−41.3	31.8	0.6	0.5	0.7	0.2
KOKB	Kauai, HI	−159.6649	22.1263	−60.1	32.5	1.2	0.7	1.1	−0.2
KWJ1	Kwajalein	167.7302	8.7222	−71.0	27.3	1.0	0.5	−2.8	−0.8
MKEA	Mauna Kea, HI	−155.4563	19.8014	−61.7	32.7	0.9	0.5	−0.3	0.1
THTI	Papeete, Tahiti	−149.6094	−17.5765	−67.3	32.3	2.1	1.2	−1.9	0.3
GAIR[b]	Guadalupe Is.	−118.2696	29.0258	−46.8	23.5	0.3	0.2	0.4	−0.3
GUAD[b]	Guadalupe Is.	−118.2893	28.8851	−46.5	23.5	1.2	0.8	0.8	−0.2
RMGU[b]	Guadalupe Is.	−118.2923	28.8827	−46.0	24.3	1.3	0.9	1.3	0.5
CAOC[b]	BC, Mexico	−116.6412	31.8680	−37.8	20.3	2.6	1.8	6.4	−2.8
CAT1	Santa Catalina	−118.4830	33.4458	−40.4	18.8	0.8	0.6	2.7	−5.1
CIC1	Ensenada	−116.6674	31.8713	−38.6	18.9	1.2	0.9	5.6	−4.2
CORX	Coronados Is.	−117.2482	32.4154	−32.2	19.6	2.0	1.8	11.7	−3.8
CRU1	Santa Cruz Is.	−119.7848	34.0293	−41.5	21.5	1.5	1.1	1.4	−2.8
LLCO[b]	BC, Mexico	−116.1607	31.2566	−41.2	19.1	0.4	0.3	3.5	−3.8
LPUR[b]	BC, Mexico	−115.3429	32.3557	−32.4	15.2	0.4	0.3	11.0	−7.4
MAYO[b]	BC, Mexico	−115.2428	31.9884	−39.9	15.3	1.2	0.9	3.9	−7.3
SFBC[b]	BC, Mexico	−114.8071	30.9306	−40.6	16.5	0.4	0.3	4.1	−5.9
SM01[b]	BC, Mexico	−115.8348	31.6236	−41.5	18.7	0.6	0.4	2.8	−4.1
MIG1	San Miguel Is.	−120.3514	34.0383	−41.7	23.9	1.6	1.2	1.2	−0.7
PLO3	Point Loma, CA	−117.2430	32.6654	−37.4	19.8	1.5	0.9	6.2	−3.5
SCIP	San Clemente Is.	−118.4879	32.9144	−40.5	20.9	1.5	0.9	3.1	−3.0
SNI1	San Nicolas	−119.5244	33.2479	−41.7	20.4	0.7	0.5	1.8	−3.9
SPMX	San Pedro Martir	−115.4659	31.0450	−41.4	17.8	1.4	0.9	3.4	−4.9
VNDP	Vandenberg	−120.6164	34.5563	−41.2	20.5	0.6	0.8	1.4	−4.2
			North America Plate						
AMC2	Colorado Springs, CO	−104.5246	38.8031	−15.9	−8.1	0.7	0.5	−1.8	−0.7
AOML	Key Biscayne, FL	−80.1622	25.7347	−13.1	2.1	1.0	0.6	−2.2	0.3
BRMU	Bermuda	−64.6963	32.3704	−11.8	7.8	0.5	0.2	0.6	0.2
GODE	Greenbelt, MD	−76.8268	39.0217	−14.0	3.3	0.3	0.2	0.9	0.2
MDO1	Fort Davis, TX	−104.0150	30.6805	−12.2	−7.5	0.3	0.2	−0.3	−0.2
STJO	St. John's, Canada	−52.6777	47.5952	−15.3	11.3	0.6	0.4	−0.5	−0.6
USNO	Washington, D.C.	−77.0662	38.9190	−15.5	2.9	0.7	0.5	−0.6	−0.1
BLYT	Blythe, CA	−114.7148	33.6104	−14.3	−9.4	0.4	0.3	−2.5	1.7
GNPS	Parker, CA	−114.1894	34.3086	−9.7	−8.4	1.4	1.2	2.4	2.5
ASA1[b]	BC, Mexico	−115.2458	32.6292	−19.1	−2.9	0.6	0.4	−7.6	8.4
LN11[b]	BC, Mexico	−115.2238	32.4422	−14.6	−22.0	0.7	0.5	−3.1	−10.8
PENA[b]	Puerto Peñasco, Mexico	−113.5195	31.3538	−12.3	−9.9	0.6	0.4	−1.0	0.7
SFBC[b]	BC, Mexico	−114.8071	30.9306	−40.6	16.5	0.4	0.3	−29.5	27.6
GAIR	Guadalupe Is.	−118.2696	29.0258	−46.8	23.5	0.3	0.2	−36.6	35.7
GUAD	Guadalupe Is.	−118.2893	28.8851	−46.5	23.5	1.2	0.8	−36.3	35.8
RMGU	Guadalupe Is.	−118.2923	28.8827	−46.0	24.3	1.3	0.9	−35.8	36.5

Site codes written in boldface were used in Euler vector estimation for the respective plates.
[a]With respect to plate model.
[b]Survey-mode stations.

Table 3. Euler Vectors for Pacific and North American Plates

Euler Vector	Lat.	Lon.	Rate, °/Myr	Pole Error Ellipse			χ^2
				σ_{maj}	σ_{min}	Az.	
			Pacific Plate-ITRF				
Sella et al. [2002] (ITRF1997)	−64.21	112.74	0.655 ± 0.004	0.7	0.4	75	1.2
Beavan et al. [2002] (ITRF2000)	−63.75	110.86	0.677 ± 0.002	0.61	0.15	85	0.93
This paper, Core[a] (ITRF2000)	−63.79	110.46	0.672 ± 0.005	0.88	0.45	4	1.0
This paper, Core + Guadalupe[b]	−63.78	108.37	0.666 ± 0.004	0.51	0.26	161	1.0
Core + Guadalupe + MIG1	−63.78	108.33	0.666 ± 0.004	0.50	0.26	161	0.9
Core + Guadalupe + SNI1	−63.84	107.69	0.664 ± 0.004	0.49	0.25	160	2.4
Core + Guadalupe + VNDP	−63.96	107.74	0.665 ± 0.004	0.50	0.24	160	2.8
			North America-ITRF				
Sella et al. [2002] (ITRF1997)	−2.39	−79.08	0.199 ± 0.002	0.8	0.3	−6	1.05
Beavan et al. [2002] (ITRF2000)	−3.86	−83.96	0.199 ± 0.003	1.02	0.41	4	1.47
This paper (ITRF2000)	−3.60	−84.88	0.200 ± 0.005	1.7	0.7	91	1.7
			North America-Pacific				
Sella et al. [2002] (ITRF1997)	50.38	−72.11	0.755 ± 0.004	0.6	0.4	−79	
Beavan et al. [2002] (ITRF2000)	50.26	−75.04	0.773 ± 0.005	0.41	0.17	94	
This paper (ITRF2000)	49.89	−77.01	0.766 ± 0.007	0.24	0.17	70	

[a]The five "Core" Pacific plate stations are CHAT, KOKB, KWJ1, MKEA, and THTI.
[b]The Guadalupe stations are GAIR, GUAD, and RMGU.

Group [*Bennett et al.*, 1996]. Subsequently, surveys on Guadalupe and mainland northern Baja were performed in concert with the development of the Southern California Integrated GPS Network (SCIGN - http://www.scign.org), which included installation in 2001 of a permanent station GUAX on Isla de Guadalupe.

[6] We combine GPS data from the surveys in Mexico with data from continuous SCIGN stations in southern California and the Channel Islands. Altogether there are four geodetic monuments on Guadalupe: GAIR, GUAD, RMGU, and the continuous station GUAX (Figure 1 inset). Three monuments (GUAD, RMGU, and GUAX) are situated close together, within 500 m of one another, while GAIR is located 20 km to the north. Station GUAX has been providing data continuously since early 2002. The position timeseries for GUAX (http://sopac.ucsd.edu/cgi-bin/refinedTimeseriesListing.csgi.) is only one year long, and as such the estimated velocity is not yet reliable.

[7] We analyzed the GPS data in 24-hour segments using the GAMIT/GLOBK software suite as described in *Nikolaidis* [2002], resulting in daily station position estimates. We made use of a re-analysis of all global data in the Scripps Orbit and Permanent Array Center (SOPAC) GARNER archive (http://garner.ucsd.edu) since January 1991 in the ITRF2000 reference frame (http://sopac.ucsd.edu/cgi-bin/sector.cgi). The nominal reference frame used was the IGS realization of the ITRF2000 [*Altamimi et al.*, 2002]. For 1993–2002 data, the reference frame was established using the standard set of ITRF2000 reference stations. For 1991, the set of global stations was very sparse. The stations used to provide reference for the 1991 data were DRAO, HOB1, KOK0, TROM, TSU1, WSFM, WTM2, and YELL. Of these, only DRAO, TROM and YELL are part of the current core ITRF2000 network. Coordinates of the other 1991 reference stations were updated to align them with ITRF2000. Station velocities were estimated by performing a linear regression on the position timeseries. Realistic uncertainties for the velocity estimates were obtained by including full white noise + flicker noise covariances [*Nikolaidis*, 2002]. For continuous stations in North America and the Pacific, the noise amplitudes were based on analyses of the continuous timeseries of those stations [*Williams*, 2003]. For the survey stations in northern Baja and on Guadalupe, we assumed noise amplitudes equal to that of the continuous stations on the Channel Islands to get more realistic estimates of errors in site velocities.

3. Results and Discussion

[8] Table 2 gives velocities for all stations in ITRF2000. The estimated motions of the three Guadalupe sites (GAIR, GUAD, and RMGU) are consistent within 0.5 mm/yr for both the north and east components, with a mean of 23.8 mm/yr N and −46.4 mm/yr E.

[9] We estimated an Euler vector for the Pacific plate relative to ITRF2000 using our estimates of the velocities of the continuous stations CHAT, KOKB, KWJ1, MKEA, and THTI (Table 3). Our Euler vector is consistent with the Pacific plate vector obtained by *Beavan et al.* [2002] using velocities from 11 stations. We also computed an Euler vector for the Pacific plate relative to ITRF2000 using the same five continuous stations plus the three survey stations on Guadalupe (GAIR, GUAD, and RMGU). With the addition of the Guadalupe survey station velocities, neither the Pacific-ITRF2000 Euler vector nor the χ^2 changes significantly (Table 3). The normalized χ^2 for both cases is equal to unity, suggesting an excellent fit to a rigid Pacific plate model, and realistic velocity uncertainly estimates. After inclusion of the Guadalupe velocities the length of the vector is unchanged and its direction changes by less than one degree. Residual velocities relative to this newly estimated Pacific plate are given in Table 2 and are plotted in Figure 2. Residual velocities for the three Guadalupe survey stations are less than 1 mm/yr.

[10] We test whether the stations MIG1, SNI1, and VNDP, in the NW California Borderlands are part of the Pacific plate by adding them in turn to the Pacific plate pole estimation (Table 3). Station MIG1 (San Miguel) shows very little motion relative to the Pacific plate and fits the Pacific plate Euler pole very well (Table 2). However, MIG1 is located near the Santa Rosa and Santa Cruz island faults, both of which may have ruptured in the late Quater-

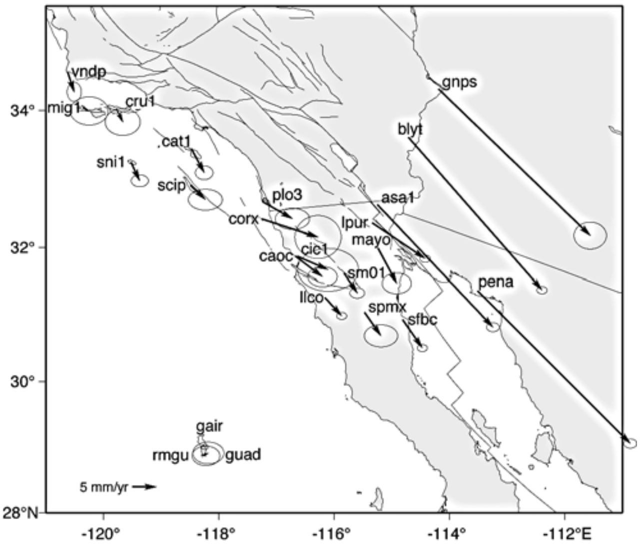

Figure 2. Plot of GPS velocity vectors relative to the Pacific plate as defined using "Core" + Guadalupe station velocities (see Table 3). Ellipses indicate 2-D 95% confidence limits based on the formal (white noise plus flicker noise) uncertainty estimates.

nary [*Jennings*, 1994], and as such MIG1 is not necessarily a reliable indicator of Pacific plate motion. Stations SNI1 (San Nicolas Island), VNDP (Vandenberg), and SCIP (San Clemente Island) have velocities larger than 3–5 mm/yr in the Pacific reference frame (Table 2) and are clearly not on the rigid part of the Pacific plate. *Dixon et al.* [2000] suggest that the motion at VNDP is affected by strain accumulation on both the San Andreas and the San Gregorio-Hosgri faults. Motion at station SNI1 may reflect strain accumulation at a nearby fault parallel to the dominant plate boundary strike, as suggested by *Beavan et al.* [2002]. The nearest known active fault is the San Clemente fault. SeaBeam surveys of the San Clemente fault zone by *Legg and Luyendyk* [1989] suggest evidence (offsets of late Quaternary sediment) of recent faulting, and relocation of the 1986 (M_L = 5.3) Oceanside earthquake sequence relates them to the San Clemente fault [*Astiz and Shearer*, 2000].

[11] We also estimate a pole of rotation for the North America plate relative to ITRF2000 using velocities at seven continuous GPS stations in North America. These seven stations fit the stable North America plate motion well (Tables 2 and 3). Station PENA (Puerto Peñasco, Sonora), on the NE coast of the Gulf of California, moves at the North American plate velocity. The full Pacific-North America plate motion thus appears to be present between PENA and Guadalupe, which lie on a line perpendicular to the plate margin. This is in marked contrast to further NW along the plate margin, where stations BLYT and GNPS show significant residual motion relative to North America (Table 2). The width of the deforming plate boundary zone appears to narrow significantly within a relatively short distance along the plate margin. Station SFBC, which lies on the straight line between PENA and Guadalupe moves at a fairly high velocity (7 mm/yr) relative to the Pacific plate, suggesting significant faulting west of that point.

[12] **Acknowledgments.** Supported by Consejo Nacional de Ciencia y Tecnologia (grant 28788-T), CICESE, and the Southern California Earthquake Center. SCEC is funded by NSF Cooperative Agreement EAR-0106924 and USGS Cooperative Agreement 02HQAG0008. The SCEC contribution number for this paper is 734. Data provided by SCIGN and its funders (W. M. Keck Foundation, NASA, NSF, USGS, and SCEC), and the International GPS Service (IGS). Logistical support to Guadalupe provided by Secretaria de Gobernacion and Secretaria de Marina-Armada de Mexico. Raul Ochoa, Alejandro Gonzalez, Adrian Gonzalez assisted with GPS surveys, Paul Jamason and Peng Fang provided continuous GPS solutions, Jeff Genrich provided the 1991 data and performed initial processing of the survey data. We thank John Beavan and Tim Dixon for their reviews.

References

Altamimi, Z., P. Sillard, and C. Boucher, ITRF2000: A new release of the International Terrestrial Reference Frame for earth science applications, *J. Geophys. Res.*, *107*(B10), 2214, doi:10.1029/2001JB000561, 2002.

Astiz, L., and P. Shearer, Earthquake locations in the inner continental borderland, offshore Southern California, *Bull. Seismol. Soc. Am.*, *90*, 425–449, 2000.

Atwater, T., Implications of plate tectonics for the Cenozoic tectonic evolution of western North America, *Geol. Soc. of Am. Bull.*, *81*, 3513–3536, 1970.

Batiza, R., Seamounts and seamount chains of the eastern Pacific, in *The eastern Pacific Ocean and Hawaii*, edited by E. L. Winterer, D. M. Hussong, and R. W. Decker, *Geol. Soc. of Am.*, Boulder, 289–306, 1989.

Bennett, R. A., W. Rodi, and R. E. Reilinger, Global Positioning System constraints on fault slip rates in southern California and northern Baja, Mexico, *J. Geophys. Res.*, *101*, 21,943–21,960, 1996.

Beavan, J., P. Tregoning, M. Bevis, T. Kato, and C. Meertens, Motion and rigidity of the Pacific Plate and implications for plate boundary deformation, *J. Geophys. Res.*, *107*(B10), 2261, doi:10.1029/2001JB000282, 2002.

Dixon, T., F. Farina, C. DeMets, F. Suarez-Vidal, J. Fletcher, B. Marquez-Azua, M. Miller, O. Sanchez, and P. Umhoefer, New Kinematics for Pacific-North America Motion from 3 Ma to Present, II: Evidence for a "Baja California shear zone", *Geophys. Res. Lett.*, *27*, 3961–3964, 2000.

Engel, C. E., and A. E. J. Engel, Composition of basalt cored in Mohole project (Guadalupe site), *Bull. Am. Assoc. Petrol. Geolog.*, *45*, 1799, 1961.

Genrich, J., Geophysical applications of GPS kinematic techniques, Ph.D. Thesis, Univ. of California, San Diego, 1992.

Jennings, C. W., Fault activity map of California and adjacent areas with location and ages of recent volcanic eruptions, California Geologic Data Map Series, Map No. 6. California Division of Mines and Geology, 1994.

Krause, D. C., Geology of the sea floor east of Guadalupe Island, *Deep Sea Res.*, *8*, 28–38, 1961.

Legg, M. R., and B. P. Luyendyk, Sea beam survey of an active strike-slip fault: The San Clemente fault in the California Continental Borderland, *J. Geophys. Res.*, *94*, 1727–1744, 1989.

Londsdale, P., Structural patterns of the Pacific floor offshore of Peninsular California, in *The gulf and peninsular province of the Californias*, edited by J. P. Dauphin and B. R. T. Simoneit, *American Assoc. of Petroleum Geologists Mem. 47*, 87–125, 1991.

Morgan, W. J., Rises, trenches, great faults, and crustal blocks, *J. Geophys. Res.*, *73*, 1959–1982, 1968.

Nikolaidis, R., Observation of geodetic and seismic deformation with the Global Positioning System, Ph.D. Thesis, Univ. of California, San Diego, 2002.

Sella, G. F., T. H. Dixon, and A. L. Mao, REVEL: A Model for Recent Plate Velocities from Space Geodesy, *J. Geophys. Res.*, *107*(B4), 2081, doi:10.1029/2000JB000033, 2002.

Spencer, J. E., and W. R. Normark, Tosco-Abreojos fault zone: A Neogene transform plate boundary within the Pacific margin of southern Baja California, Mexico, *Geology*, *7*, 554–557, 1979.

Williams, S. D. P., The effect of coloured noise on the uncertainties of rates estimated from geodetic time series, *J. Geod.*, *76*, 483–494, 2003.

J. J. Gonzalez-Garcia, Centro de Investigación Clentífica y de Educación Superior de Ensenada, Baja California, Mexico.

L. Prawirodirdjo, Y. Bock, and D. Agnew, Cecil H. and Ida M. Institute of Geophysics and Planetary Physics, Scripps Institution of Oceanography, La Jolla, California, USA. (ybock@ucsd.edu)