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

J. J. Gonzalez-Garcia, L. Prawirodirdjo, Y. Bock, and D. Agnew

Abstract

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).

1. Introduction

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.

This study uses GPS data collected from Isla de Guadalupe and northern Baja California (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.

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,
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

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>
<thead>
<tr>
<th>Site Code</th>
<th>Location</th>
<th>Lon. (E)</th>
<th>Lat. (N)</th>
<th>Ve</th>
<th>Vn</th>
<th>sVe</th>
<th>sVn</th>
<th>Residuals</th>
</tr>
</thead>
<tbody>
<tr>
<td>KNJ</td>
<td>Kwajalein</td>
<td>149.6094</td>
<td>19.8014</td>
<td>1.9</td>
<td>0.3</td>
<td>0.6</td>
<td>0.1</td>
<td>0.2</td>
</tr>
<tr>
<td>MDE</td>
<td>Fort Davis, TX</td>
<td>112.7430</td>
<td>23.9214</td>
<td>1.7</td>
<td>0.3</td>
<td>0.5</td>
<td>0.1</td>
<td>0.2</td>
</tr>
<tr>
<td>STJO</td>
<td>St. John’s, Canada</td>
<td>52.6777</td>
<td>47.5952</td>
<td>1.5</td>
<td>0.3</td>
<td>0.5</td>
<td>0.1</td>
<td>0.2</td>
</tr>
<tr>
<td>USNO</td>
<td>Washington, D.C.</td>
<td>70.6777</td>
<td>47.5952</td>
<td>1.5</td>
<td>0.3</td>
<td>0.5</td>
<td>0.1</td>
<td>0.2</td>
</tr>
</tbody>
</table>

Site codes written in boldface were used in Euler vector estimation for the respective plates.

aWith respect to plate model.

bSurvey-mode stations.
Table 3. Euler Vectors for Pacific and North American Plates

<table>
<thead>
<tr>
<th>Euler Vector</th>
<th>Lat.</th>
<th>Lon.</th>
<th>Rate, mm/yr</th>
<th>Pole Error Ellipse</th>
</tr>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(x^2)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Az.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(\sigma_{maj})</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(\sigma_{min})</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th>(\sigma_{maj})</th>
<th>(\sigma_{min})</th>
<th>Az.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pacific Plate-ITRF</td>
<td></td>
<td></td>
<td></td>
<td>(\chi^2)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sella et al. [2002]</td>
<td>-64.21</td>
<td>112.74</td>
<td>6.65 ± 0.004</td>
<td>0.7</td>
<td>0.4</td>
<td>75</td>
</tr>
<tr>
<td>Beavan et al. [2002]</td>
<td>-63.75</td>
<td>110.86</td>
<td>6.67 ± 0.002</td>
<td>0.61</td>
<td>0.15</td>
<td>85</td>
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<tr>
<td>This paper, Core [^a]</td>
<td>-63.79</td>
<td>110.46</td>
<td>6.67 ± 0.005</td>
<td>0.88</td>
<td>0.45</td>
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<td>This paper, Core + Guadalupe [^b]</td>
<td>-63.78</td>
<td>108.37</td>
<td>6.66 ± 0.004</td>
<td>0.51</td>
<td>0.26</td>
<td>161</td>
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<td>Core + Guadalupe + MIG1</td>
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<td>108.33</td>
<td>6.66 ± 0.004</td>
<td>0.50</td>
<td>0.26</td>
<td>161</td>
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<td>Core + Guadalupe + SN11</td>
<td>-63.84</td>
<td>107.69</td>
<td>6.64 ± 0.004</td>
<td>0.49</td>
<td>0.25</td>
<td>160</td>
</tr>
<tr>
<td>Core + Guadalupe + VNDP</td>
<td>-63.96</td>
<td>107.74</td>
<td>6.65 ± 0.004</td>
<td>0.50</td>
<td>0.24</td>
<td>160</td>
</tr>
</tbody>
</table>

| North America-ITRF    |       |       |             |\(\chi^2\)         |                   |      |
| Sella et al. [2002]   | -2.39 | -79.08| 0.199 ± 0.002| 0.8               | 0.3               | -6   | 1.05 |
| Beavan et al. [2002]  | -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| 1.17              | 0.7              | 91   | 1.7  |

| North America-Pacific |       |       |             |\(\chi^2\)         |                   |      |
| Sella et al. [2002]   | 50.38 | -72.11| 0.755 ± 0.004| 0.6               | 0.4               | -79  |      |
| Beavan et al. [2002]  | 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 GAIR is located 20 km to the north. Station GUAX has been providing data continuously since early 2002. The estimated motions of the three Guadalupe sites (GAIR, GUAD, and RMGU) are consistent within 0.5 mm/yr.

[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 \(\chi^2\) changes significantly (Table 3). The normalized \(\chi^2\) for both cases is equal to unity, suggesting an excellent fit to a rigid Pacific plate model, and realistic velocity uncertainty 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, SN11, 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-
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.

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References


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.