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Motion of the South Bismarck Plate, Papua New Guinea

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Abstract. The absolute motion of the South Bismarck Plate was first estimated by Tregoning et al. [1998] from three site velocities estimated from Global Positioning System (GPS) observations. We report an improved estimate of the Euler vector for this plate using site velocities derived from new GPS data which include the velocity of a site located ∼25 km from the pole of rotation. The GPS velocities of Madang, Witu, Jacquinot Bay and Finschafen can be modelled to within ∼3 mm/yr using a single pole of rotation located at 6.75°S, 147.98°E with a clockwise rotation rate of 8.11°/My. The known tectonic features and available geophysical data surrounding the South Bismarck Plate can also be explained by a rotation of the South Bismarck Plate about this pole.

1. Introduction

The South Bismarck Plate (SBP) is one of several microplates in Papua New Guinea (PNG) which are trapped in the collision of the Australian and Pacific Plates (Figure 1). The SBP is bounded on the southern side by the Solomon Sea Plate at the New Britain Trench, eastward and northward by the Pacific Plate at the Weitin Fault and the Bismarck Sea Seismic Lineation (BSSL) [Denham, 1969] and in the southwest by the Australian Plate at the Ramu-Markham Fault [Johnson, 1979]. Each of these boundaries represents a different form of interaction between the SBP and neighbouring plates; arc-continent collision with the Australian Plate, subduction of the Solomon Sea Plate and a combination of sinistral motion and extensional zones at the Pacific Plate boundary.

Tregoning et al. [1998] estimated an Euler vector which modelled the absolute motion of the SBP. This vector was derived from the GPS velocities of three sites, Madang, Witu Island and Jacquinot Bay (MAD1, WITU and JACQ - Figure 1) which were estimated as part of a large-scale GPS velocity field spanning most of PNG. The velocity of WITU was poorly determined owing to the sparse number of occupations of the site; hence, the estimation of the Euler vector was largely based on the velocities of JACQ and MAD1. We present new estimates of site velocities from recent GPS surveys and re-estimate the Euler vector of the SBP. Finally, we look at the predicted relative motions at the boundaries of the SBP and the Pacific Plate.

2. Geodetic Data

The geodetic data used in this analysis is a compilation of three datasets of GPS observations in PNG. We used data observed at MAD1, WITU and JACQ at various times between 1990 and 1996 [McClusky et al., 1994; Tregoning et al., 1998] and data collected in the Markham Valley region between 1996 and 1998 [Stevens et al., 1998] which includes observations at Finschafen (FINS - Figure 1), located ∼25 km from the pole of rotation of the SBP. Finally, we include observations made at FINS in April 1999 and WITU in September 1998.

The GPS data were analysed using the GAMIT/GLOBK software [King and Bock, 1997; Herring, 1997], following the procedures of, for example Feigl et al. [1993] to estimate satellite orbits, station coordinates, initial carrier phase ambiguities and tropospheric delay parameters at each site. Loosely constrained daily solutions were then used as quasi-observations in GLOBK to estimate station coordinates and velocities in a single free network. We then aligned this network with ITRF97 [Boucher et al., 1999] by computing 6 parameter Helmert transformations (3 rotations, 3 translations) of the coordinates and velocities of the 47 core International GPS Service (IGS) [Altamimi, 1998] sites in ITRF97. See, for example [Feigl et al., 1993; Tregoning et al., 1998] for comprehensive explanations of the analysis procedures.

The GPS daily solutions vary considerably in terms of the quality of the data and the number and location of the global tracking sites available. We used the same a priori uncertainties for all solutions which resulted in quasi-observations (ie station coordinates) used in the Kalman filter having different levels of accuracy, although similar a priori uncertainties. We accounted for this inconsistency by iterating the filter solution and scaling each quasi-observation by its estimated χ^2 per degree of freedom. This approach is reasonable for cases when the a priori modelling uncertainties are close to their true value [Dong et al., 1998] and produces a χ^2 per degree of freedom of ∼1 for each quasi-observation. See [Dong et al., 1998] for more information on the scaling procedure. The resulting uncertainties of the station velocities are ∼0.4 to 0.8 mm/yr for the north components and ∼0.8 to 2.3 mm/yr for the east components (Table 1) with the value depending on the number and time distribution of the observations at each site.

Using a white noise model in the analysis of the GPS data can lead to under-estimating the uncertainties of the GPS velocities by factors of 1.5-11 [Zhang et al., 1997; Mao et al., 1999]. We show below that, after multiplying our formal uncertainties by 1.5, we can model the motion of sites on the SBP with 95% certainty without invalidating the assumption that the SBP is moving as a rigid plate.

Table 2 shows the rate of change of baseline lengths (with 95% confidence interval uncertainties) between the sites listed in Table 1. To within the uncertainties of our estimates,

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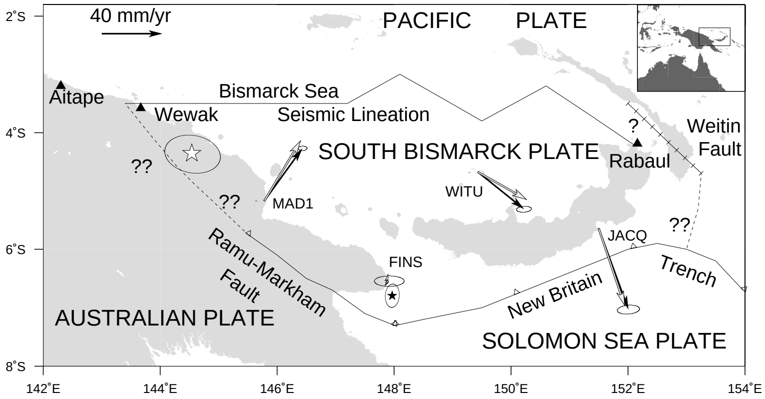

Figure 1. Map of the South Bismarck Plate and surrounding features. GPS ITRF97 site velocities and associated 95% confidence error ellipses are plotted (solid arrows), along with predicted motions using the earlier model of Tregoning et al. [1998] (white arrows). The absolute pole of the South Bismarck Plate (solid star) and the relative pole of the Australian and South Bismarck Plates (open star) are plotted with 95% error ellipses.

none of the rates of change of baseline length is significantly different from zero; hence, we conclude that these sites appear to be moving as part of a single, rigid plate.

3. Euler Vector Estimation

We inverted the 4 GPS site velocities to estimate an absolute Euler vector which represents the motion of the SBP in the ITRF97 reference frame (Table 3). Table 1 shows the relative motion of the sites with respect to our new estimated pole and to the pole of Tregoning et al. [1998]. The new pole clearly fits the observed velocities more closely (Table 1 and Figure 2). The pole position and the 95% error ellipse of the new pole are shown in Figure 1.

Knowledge of the rigid motion of the SBP forms the basis for the analysis of deformation which is occurring at the boundaries of the South Bismarck/Pacific Plates in New Ireland and the South Bismarck/Australian Plates at the Ramu-Markham Fault. These regions are the subject of ongoing investigations into present-day tectonic motion. Since the pole of the SBP is located close to the plate itself, a small change in pole position can result in significant changes in the predicted site velocities. The new pole estimate falls within the error ellipses of the pole estimated by Tregoning et al. [1998]; however, their pole lies outside the 95% error ellipse of our estimate. The estimated rates of rotation of each pole are not significantly different at the 68% confidence level. The difference in the two Euler vector estimates results from both additional GPS observations at the sites since 1996 and a more accurate definition of the terrestrial reference frame (ITRF97 rather than ITRF94). The difference in the predicted motion is ~4 mm/yr in southern New Ireland, ~5 mm/yr near Wewak and ~3 mm/yr in the Huon Peninsula.

We have computed new relative poles for the Australian-South Bismarck and Pacific-South Bismarck Plates in ITRF-97 (Table 3). These relative poles will be used below to predict the motion at the boundaries of the SBP.

4. Discussion

Tectonic motion in Papua New Guinea can have major ramifications on the lives of the local people. Events such as the Sandaun tsunami in July 1998 [Letz et al., 1998] which devastated the northern coastline near Sissano, and the volcanic eruptions at Rabaul in 1994 [McKee et al., 1995], which destroyed the township of Rabaul, have occurred close to the boundaries of the SBP. In addition, in April/May 1999 a sequence of earthquakes with $M_w > 6$ occurred along the southern boundary of the SBP from New Ireland to the Ramu-Markham Fault. Hence, defining the boundaries and understanding the motion of this microplate brings into sharper focus areas of PNG that face significant risk from tectonic events. Recent paleomagnetic studies in the Finis-

Table 1. Site Codes, Observed Absolute Site Velocities and Associated (one sigma) Uncertainties, and Velocities Relative South Bismarck Plate using the Plate Models of *Tregoning et al.* [1998] and this study.

Site	Latitude	Longitude	Absolute Velocity ITRF97				Velocity Relative to *Tregoning et al.* [1998]		Velocity Relative t This Study	
			V_n	V_e	σ_{V_n}	σ_{V_e}	V_n	V_e	V_n	V_e
FINS	S6°36.9′	E147°51.3′	2.6	2.4	1.3	4.0	-4.3	0.8	0.6	-0.
JACQ	S5°38.7′	E151°30.3′	-53.2	19.5	1.2	3.0	-2.7	2.5	1.9	1.
MAD1	S6°12.7′	E145°46.9′	34.7	25.1	0.6	1.2	-4.8	1.3	0.4	0.
WITU	S4°41.3′	E149°26.1′	-24.4	30.4	0.8	2.0	-6.4	-1.5	-1.6	-2.

Units in mm/yr

Table 2. Rates of Change of Baseline Lengths and Associated 95% Confidence Intervals.

	FINS	JACQ	MAD1	WITU
FINS	-			
JACQ	2.0±7.6	-		
MAD1	-0.7±5.6	0.9±5.2	-	
WITU	-3.1±5.0	2.0±5.4	-3.1±3.4	-

Units in mm/yr

terre Range have shown evidence for a continuous clockwise rotation of the Finisterre Arc terrane since 5 Ma [Weiler and Coe, 1998]. The coherence of the declination anomalies suggests that the rotation results from a rigid plate rotation of 40°at a rate of 8°/Myr. Such motion is consistent with our estimated motion of the SBP about an Euler pole in the Huon Gulf and provides independent support for our estimated motion of the SBP. There is very close agreement between rates of rotation estimated over a 5 year period from GPS and over a 5 My period from palaeomagnetic data.

The location of the western extremity of the SBP is not certain. The South Bismarck Plate may terminate where the BSSL meets the New Guinea continent near Wewak, whilst the Ramu-Markham Fault terminates near the western end of the Finisterre Range. Geodetic and seismic studies across the Ramu-Markham Fault have revealed that the fault is a north-dipping, low-angle mid-crustal detachment fault that connects to a steep ramp below the Markham Valley [Stevens et al., 1998]. Monitoring of this fault is currently underway as part of another project.

The relative pole of the Australian and South Bismarck Plates is located close to the boundary between these two plates (Table 2 and Figure 1). The SBP and Australian Plate predicted motions are the same at this location. Hence, this boundary zone is probably a region of low strain accumulation in the lithosphere and there may not be a well defined boundary between the plates; rather, a gentle transition from one plate to the other.

The type of relative motion between the South Bismarck and Pacific Plates changes several times along their common boundary. In the west (145°E), the predicted motion is 120 mm/yr in a 76°direction along a section of the BSSL which trends E-W [Taylor, 1979]. Our model implies that there is ~116 mm/yr strike-slip motion and ~30 mm/yr of convergence occurring, consistent with the the conclusions of Taylor [1979] who suggested that this section of the transform fault may act as a "leaky" transform rather than a pure strike-slip fault. The predicted spreading on the actively spreading NE-SW segment of the BSSL (near 150°E) is 130 mm/yr in a 115°direction, consistent with the estimate of 132 mm/yr from sea-floor magnetic anomalies [Taylor, 1979].

Taylor [1979] showed the eastern transform fault of the BSSL continuing southeast through the eastern tip of New Britain. Whilst there is some bathymetric evidence of this fault off the coast near Rabaul, there is no obvious continuation of it to the east of the Gazelle Peninsula (R. Binns, pers. comm.). It is more likely that the majority of the strike-slip motion occurs further east on the Weitin Fault which cuts through the southern part of New Ireland (Figure 1) or that the relative motion is distributed over a number of faults throughout the region [Mori, 1989].

If we adopt the Taylor model, the predicted relative motion on this postulated fault through New Britain is 134 mm/yr with an azimuth of 309°. If the boundary lies along the Weitin Fault, the predicted relative motion is 139 mm/yr with an azimuth of 313°. In both cases, the motion is approximately parallel to the transform faults which bear ~320°[Mori, 1989]. The convergent component of the relative motion normal to the Weitin Fault would be ~17 mm/yr; however, this value is sensitive to the assumed strike of the Weitin Fault. A GPS network which spans the eastern margin of the SBP was established in September 1998. Future observations of this network will reveal the current tectonics of the region and will help to identify the likely regions of rapid relative motion.

Table 3. Absolute and Relative Euler Vectors for the South Bismarck Plate, the South Bismarck/Australian (SBP-Aus) and the Pacific/South Bismarck Plates (Pac-SBP).

Euler Vector	Latitude	Longitude	rate[a] (°/My)	Pole Error Ellipse σ_{maj}	σ_{min}	Azimuth
SBP: This Study	6.75°S	147.98°E	8.11±0.16	0.10	0.06	4
SBP: [Tregoning et al., 1998]	6.7°S	148.3°E	8.15±0.30	0.22	0.15	358
SBP-Aus: This Study	4.36°S	144.54°E	7.91±0.33	0.24	0.16	281
SBP-Aus: [Tregoning et al., 1998]	4.5°S	144.6°E	7.98±0.02[b]	0.49	0.48	5
Pac-SBP: This Study	10.61°S	147.01°E	8.44±0.33	0.36	0.15	8
Pac-SBP: [Tregoning et al., 1998]	10.2°S	146.9°E	8.46±0.02[b]	2.38	2.28	84

[a] Rotation is in a clockwise direction about the pole. The error ellipses of the poles are described by the 1σ semi-major and semi-minor axes of each error ellipse and the clockwise angle from True North of the semi-major axis.

[b] The rotation rate uncertainties of *Tregoning et al.* [1998] were unrealistically small because of an error in the program used to calculate their relative Euler vectors.

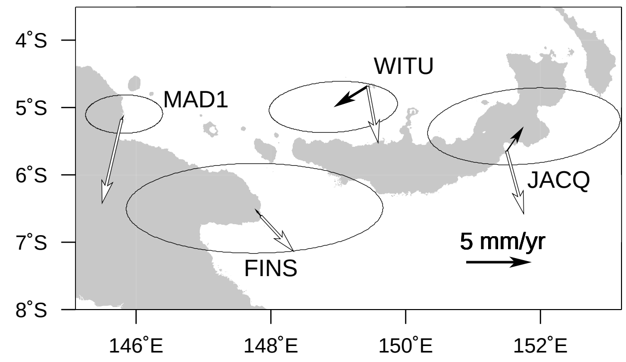

Figure 2. GPS velocities relative to the predicted motion of the South Bismarck Plate from this study (solid arrows with 95% confidence error ellipses) and Tregoning et al. [1998] (white arrows). The residual velocities of the GPS vectors with respect to the new model (solid arrows) are so small that they are barely visible at MAD1 and FINS.

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References

Altamimi, Z., 1998 IGS reference station classification based on ITRF96 residual analysis, IGS Workshop, Darmstadt, Germany, 9-11 February, 1998.

Boucher, C. Z. Altamimi and P. Sillard, The ITRF97 International Terrestrial Reference Frame (ITRF97). IERS Technical Note 27, Observatoire de Paris, Paris, 1999.

Denham, D., Distribution of earthquakes in the New Guinea-Solomon Islands region, J. Geophys. Res., 74, 4290-4299, 1969.

Dong, D., T.A. Herring, and R.W. King, Estimating regional deformation from a combination of space and terrestrial geodetic data, J. Geodesy, 72, 200-214, 1998.

Feigl. K., et al., Space geodetic measurements of crustal deformation in central and southern California, 1984-1992, J. Geophys. Res, 98, 21,677-21,712, 1993.

Herring, T.A., GLOBK global Kalman filter VLBI and GPS analysis program, Version 4.1, Mass. Instit. Tech., Cambridge, 1997.

Johnson, R.W., Geotectonics and volcanism in Papua New Guinea: a review of the late Cainozoic, BMR J, Aust. Geol. Geophys., 4, 181-207, 1979.

King, R.W., and Y. Bock, Documentation for the GAMIT GPS anaylsis software, release 9.6, Mass. Instit. Tech., Cambridge, 1997.

Letz, H., K.McCue, I.D. Ripper, and M. Somerville, The 1998 Aitape earthquake: Aftershock distribution, historical earthquakes and tsumanis of the region, EOS Trans., 79(45),F564, 1998.

Mao, A., C.G.A. Harrison, and T.H. Dixon, Noise in GPS coordinate time series, J. Geophys. Res., 104, 2797-2816, 1999.

McClusky, S., K. Mobbs, A. Stolz, D. Barsby, W. Loratung, K. Lambeck, and P. Morgan, The Papua New Guinea satellite crustal motion surveys, Aust. Surv., 39, 194-214, 1994.

McKee, C., et al., The 1994 eruption at Rabaul volcano, Papua New Guinea, paper presented at the General Assembly, Int. Union of Geod. and Geophys., Boulder, CO, 1995.

Mori, J., The New Ireland earthquake of July 3, 1985, and associated seismicity near the Pacific-Solomon Sea-Bismarck Sea triple junction, Phys. Earth. Planet. Int., 55, 144-153, 1989.

Stevens, C., R. McCaffrey, E.A. Silver, Z. Sombo, P. English, and J. van der Keive, Mid-crustal detachment and ramp faulting in the Markham Valley, Papua New Guinea, Geology, 26, 847-850, 1998.

Taylor, B., Bismarck Sea: Evolution of a back-arc basin, Geology, 7, 171-174, 1979.

Tregoning P., et al., Estimation of current plate motions in Papua New Guinea from Global Positioning System observations, J. Geophys. Res., 103, 12,181-12,203, 1998.

Weiler, P.D., and R.S. Coe, Study of the actively colliding Finisterre Arc Terrane, northeastern Papua New Guinea, EOS abstract, 79, 221, 1998.

Zhang, J., Bock, Y., Johnson, H., Fang, P., Williams, S., Genrich, J., Wdowinski, S, and J. Behr, Southern California permanent GPS geodetic array: error analysis of daily position estimates and site velocities, J. Geophys. Res., 102, 18,035-18,055, 1997.

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