Geochemistry Geophysics Geosystems G3
AN ELECTRONIC JOURNAL OF THE EARTH SCIENCES
Published by AGU and the Geochemical Society

Article
Volume 10, Number 6
19 June 2009
Q06013, doi:10.1029/2009GC002430
ISSN: 1525-2027

Interactions between a transform fault and arc volcanism in the Bismarck Sea, Papua New Guinea

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[1] We present a new interpretation of the geological evolution of the western branch of the Bismarck Sea Seismic Lineation (BSSL) region, offshore the northwestern coast of Papua New Guinea, from mapping and interpretation of bathymetry and backscatter data acquired aboard R/V *Kilo Moana* in 2004. At present, the Schouten Islands parallel the Papua New Guinea coast, but this distribution results from the left-lateral displacement of some of these volcanic islands by the Bismarck Sea Seismic Lineation. The trend of the islands and seamounts was initially aligned N-S and then displaced by the BSSL. Wei Island lies on a large submarine edifice that may have formed as part of a leaky transform. Subsequent to forming, Wei Island was bisected, and its pieces were displaced 45 km. Using this distance together with the strike-slip rate for the Bismarck Sea Seismic Lineation (predicted from the North Bismarck Plate–South Bismarck Plate pole), the division occurred approximately 385,000 years ago.

Components: 7270 words, 10 figures.

Keywords: plate boundaries; strike-slip tectonics; volcanic islands; submarine canyon; Papua New Guinea.

Index Terms: 3039 Marine Geology and Geophysics: Oceanic transform and fracture zone processes; 3045 Marine Geology and Geophysics: Seafloor morphology, geology, and geophysics; 9355 Geographic Location: Pacific Ocean.

Received 12 February 2009; **Revised** 4 May 2009; **Accepted** 7 May 2009; **Published** 19 June 2009.

Llanes, P., E. Silver, S. Day, and G. Hoffman (2009), Interactions between a transform fault and arc volcanism in the Bismarck Sea, Papua New Guinea, *Geochem. Geophys. Geosyst.*, *10*, Q06013, doi:10.1029/2009GC002430.

1. Introduction

[2] Leaky transform faults, regions where a component of extension across the fault results in volcanic activity along it, are relatively common [*Kastens et al.*, 1979; *Taylor*, 1979; *Garfunkel et al.*, 1981; *Fisk et al.*, 1993]. Far less common are situations in which the fault plays a significant role in volcanism associated with a volcanic arc system. A notable example is Sumatra, where the Great Sumatra fault runs close to the locus of arc volcanism [*Sieh and Natawidjaja*, 2000]. The Bismarck Sea Seismic Lineation in Papua New Guinea cuts through volcanoes of the Schouten Islands (Figure 1). The volcanoes have chemical affinities to island arcs, but the tectonic setting of these volcanoes is enigmatic, in that no clear subducting slab exists either north or south of the chain, and their origin is debated [*Johnson et al.*, 1972; *Gill et al.*, 1993].

[3] The studies conducted by *Johnson et al.* [1972] and S. Day (field observations reported here) have shown that the western Schouten Islands are extinct volcanoes, while the eastern ones are morphologically young, and two have been active during the period of historic records [*Johnson et al.*, 1972]. The new bathymetric and backscatter data of the Schouten Basin presented here allow us to map the submarine parts of the islands and to differentiate volcanic cones and ridges, faults, lineations, and systems of submarine channels. The strike-slip characteristics of this plate boundary allow us to discuss the transition from strike slip to convergent tectonics and to use this information to help constrain the regional structures. We present a new reconstruction of the Schouten Islands as a result of these observations, and we speculate how the Schouten Islands may be subduction-related without showing visible surface signs of subduction or collision at present.

2. Tectonic Overview

[4] Papua New Guinea lies north of Australia in the Pacific Ocean, where the Australian and Pacific Plates converge obliquely, trapping several microplates in the collision. As a result the Indonesian and Papua New Guinea region are among the most tectonically complex and seismically active in the world. The dominant tectonic motion in the region is the west-southwest convergent motion of the Pacific Plate relative to the Australian Plate [*DeMets et al.*, 1994], although the existence of several rapidly rotating microplates has led to a wide variety of tectonic regimes throughout the region [*Wallace et al.*, 2004].

[5] The Schouten Islands lie approximately along the trend of the Bismarck volcanic Arc on the southern side of the Bismarck Sea (Figure 1). Most of the present-day volcanic activity in northwest Papua New Guinea, as well as in New Britain, occurs as a result of the north directed Solomon slab subduction along the New Britain Trench [*Woodhead and Johnson*, 1993], although the Solomon Sea plate is not visible on the surface west of the tip of the Huon Peninsula. Subduction is known to continue to the west, however, because of the location of the Wadati-Benioff zone [*Abers and Roecker*, 1991] and the presence of ^{10}Be in young lavas as far west as Karkar [*Gill et al.*, 1993], but not as far as the Schouten Islands (Figure 1).

[6] The Bismarck Sea lies between two trenches, the Manus Trench to the north and the New Britain Trench to the southeast (Figure 1). Convergence along the Manus Trench is presently very slow [*Tregoning*, 2002]. To the west, the New Guinea Trench is clearly defined in bathymetry and gravity anomaly data. It extends about 700 km along the northern coastline of New Guinea between approximately 134.5° [*Milsom et al.*, 1992] and 143.6° [*Hamilton*, 1979]. Several studies have suggested that convergence may occur at the New Guinea Trench [*Hamilton*, 1979; *Cooper and Taylor*, 1987; *Puntodewo et al.*, 1994; *Tregoning et al.*, 2000] and recent evidence for active subduction includes seismicity and seismic tomography imaging [*Tregoning and Gorbatov*, 2004].

[7] The South Bismarck Plate is trapped between the Australian and Pacific Plates and is rotating clockwise relative to Australia at a rate of 8°/Ma in response to this collision [*Tregoning et al.*, 1999]. The North Bismarck Plate is located between the South Bismarck and Pacific Plates, separated by an E-W belt of seismicity at 4°S and by a minor belt of seismic activity in the northern part of the Bismarck Sea [*Johnson and Molnar*, 1972]. Other authors have questioned the existence of a North Bismarck Plate [*Curtis*, 1973; *Krause*, 1973] but the plate kinematics derived from GPS site velocities support a North Bismarck Plate [*Tregoning*, 2002]. The boundary between the South and North Bismarck Sea Plates consists of a series of left-lateral transform faults and rifts that connect the transform segments [*Denham*, 1969; *Taylor*, 1979]. This boundary

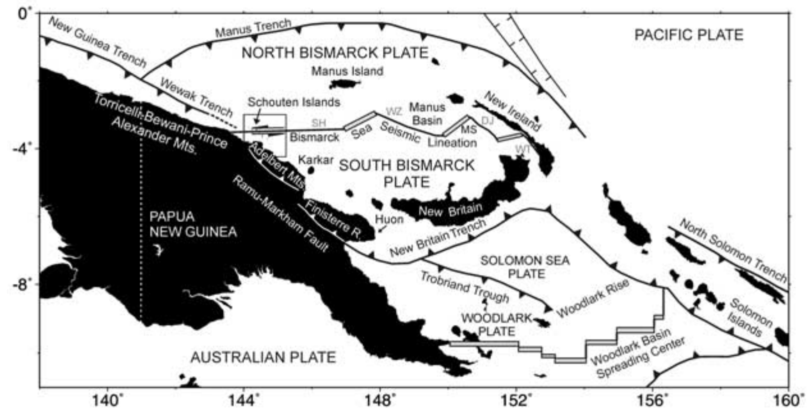

Figure 1. Regional tectonic setting of Papua New Guinea based on *Taylor et al.* [1994] and on *Tregoning et al.* [1998]. Rectangle shows study location. The transform faults segments of the Bismarck Sea Seismic Lineation Zone are abbreviated as follows: WT, Weitin; DJ, Djaul; WZ, Willaumez; SH, Schouten. MS, Manus Spreading Center.

was named the Bismarck Sea Seismic Lineation by *Denham* [1969]. It is well defined by the seafloor morphology and earthquake epicenter locations. The study presented here is located in the westernmost part of the boundary (Figure 1), where the fault planes are oriented E-W until it reaches land where the trend continues as a series of faults cutting westward through the Torricelli, Bewani, and Prince Alexander mountains [*Cooper and Taylor*, 1987].

[8] Nearly all of the Pacific-Australian convergence has been accommodated at the Bismarck Volcanic Arc system since about 10 Ma. The fore-arc terrain for this system is now exposed in the Adelbert and Finisterre Ranges and Huon Peninsula and the New Britain Island formed to the east [*Quarles van Ufford and Cloos*, 2005]. Within this context, the opening and evolution of the Bismarck Sea is a relatively recent geological event, that started when the back-arc area of the New Britain arc ruptured, forming the Bismarck microplate with strike-slip faulting and seafloor spreading along its northern boundary. The plate became a piece of lithosphere with distinct kinematics approximately 3.5 Ma [*Taylor*, 1979]. At this time, tectonic reorganization created the Manus Spreading center (MS, Figure 1) in the Bismarck Sea, which is among the fastest spreading centers in the world today, opening at 137 ± 5 mm/a, according to recent GPS studies [*Tregoning*, 2002].

[9] The Schouten Islands, therefore, lie at the convergence of at least two and likely three plate boundaries. Understanding the tectonic evolution of the islands and the adjacent sedimentary basins will therefore provide insights into the development of these plate boundaries.

3. Methods

[10] The data presented here were collected aboard the R/V *Kilo Moana* on cruise KM0419. The cruise occurred during November and December of 2004 and studied the Bismarck Volcanic Arc between longitudes 144° and 152°. The current study focuses on the Schouten Islands area, the westernmost part of the area covered by KM0419. Track lines for this area are displayed in Figure 2. Bathymetry was obtained with a Simrad EM120 multibeam echo sounder, operating at 12 kHz (±0.75 kHz) with 100% coverage of the seafloor.

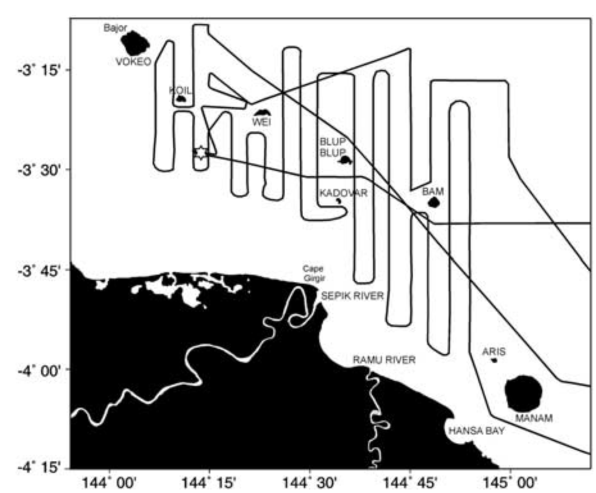

Figure 2. Location map of survey area showing bathymetry track lines collected during cruise KM0419. Star marks the location of a core site.

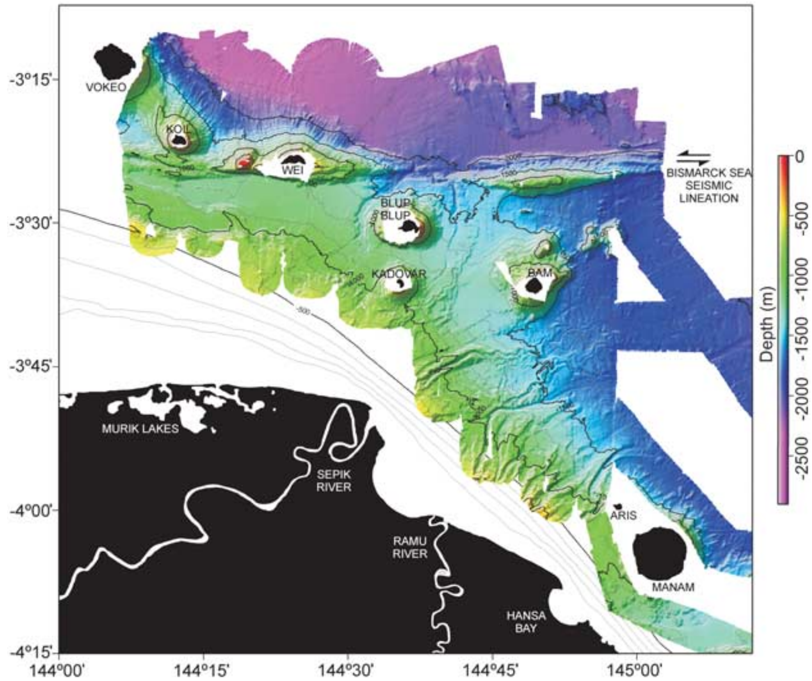

Figure 3. Bathymetric map of the Schouten Basin derived from 90-m gridded data and with a contour interval of 25 m. Contours from 0 to 500 m are each 100 m and come from satellite geodesy (D. T. Sandwell and W. H. F. Smith, Exploring the ocean basins with satellite altimeter data, 1997, available at http://www.ngdc.noaa.gov/mgg/bathymetry/predicted/explore.HTML).

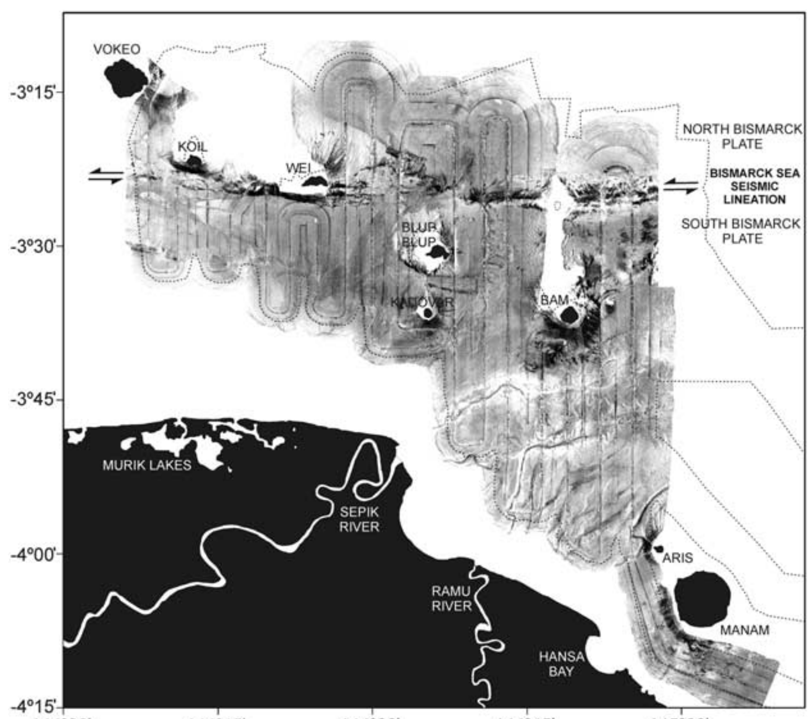

Figure 4. Side-scan image of the Schouten Basin with low backscatter light and high backscatter dark.

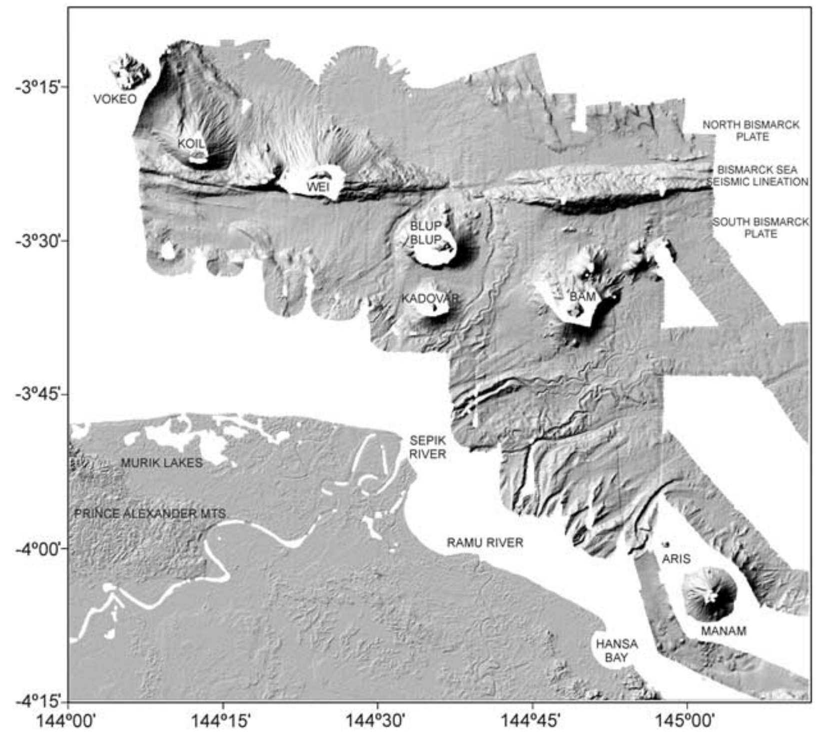

Figure 5. Shaded relief image of the bathymetry derived from 90-m gridded data. Apparent illumination is from the NW.

The sonar transducers are mounted in the port hull and the beams are transmitted across a total swath opening of up to 150°, depending on depth.

[11] Acoustic backscatter intensity images were obtained along most of the same track lines with the Hawaii MR1 Sonar, a portable shallow-towed system with swath width up to 7.5 times the water depth. The MR1 sonar transducers are housed in a 4.8 m long, 1600 kg vehicle that is towed beneath the surface mixed layer (80 to 120 m). Both bathymetry data and acoustic images were processed on board with Simrad's software by the Hawaiian Mapping Seafloor Group. After using a median filter we gridded the bathymetry and the acoustic data to 90 and 15 m, respectively, and created maps (Figures 3 and 4) and a shaded relief image (Figure 5) using GMT (Generic Mapping Tools [*Wessel and Smith*, 1995]).

4. Schouten Islands

[12] The Schouten Islands are six volcanic islands running parallel to the north of Papua New Guinea and forming the western end of the Bismarck Volcanic Arc: Vokeo, Koil, Wei, Kadovar, Blup Blup and Bam (Figure 2). Volcanism becomes younger eastward among these islands [*Johnson*, 1977]. The islands consist of andesite and low-silica dacite [*Johnson et al.*, 1972], having generally more clinopyroxene phenocrysts and lower total alkali contents than those with similar silica contents from other parts of the western Bismarck volcanic arc. One of the main petrological features of the Schouten Islands is the apparent absence of basalt from the whole group [*Johnson*, 1977]. They are named after Dutch explorer Willem Schouten, who observed an eruption during his passage through the area in 1616 that may have been from Bam Island.

4.1. Vokeo Island

[13] The westernmost of the Schouten Islands, Vokeo, is a volcanic island with an irregular but broadly equant shape and a maximum width of 8 km. It is a dissected remnant of an extinct volcano deeply eroded into a series of plateaus. Petrology analysis by *Johnson et al.* [1972] indicated andesite and low-silica dacite compositions. The island has fringing raised reefs within a few meters of sea level around most of the shoreline. We sampled the coral from the top of the platform formed by a raised reef at 2.1 m elevation above high tide at Baijor village, on the north side of the island (Figure 2). A C-14 date of 4950 ± 300 (2σ uncertainty range) calibrated years was obtained

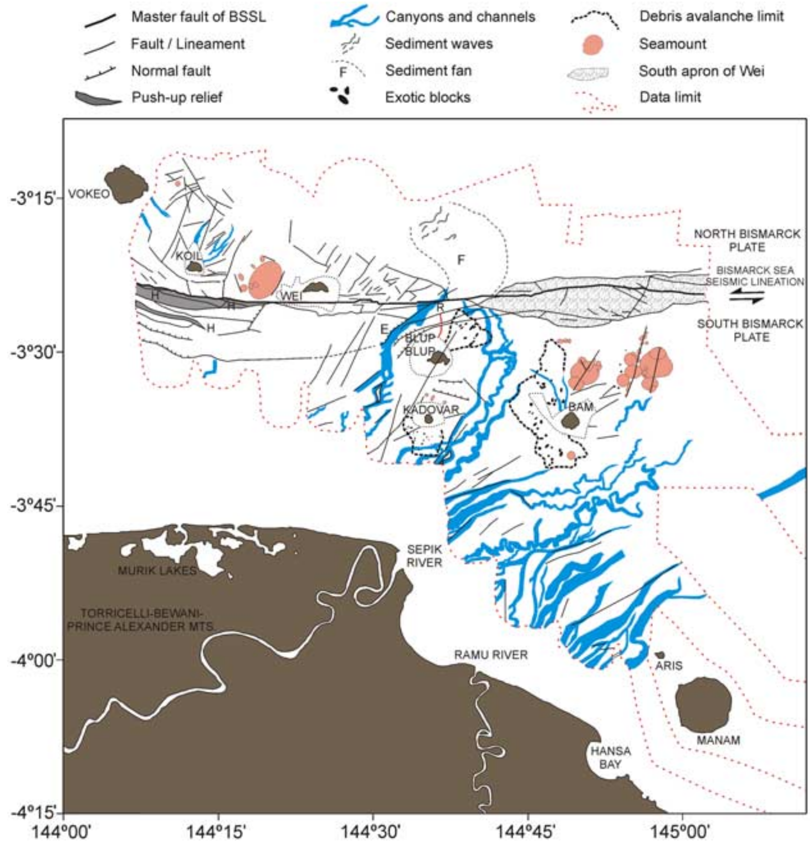

Figure 6. Morphological interpretation of the Schouten Islands based on bathymetric contour maps, backscatter maps, shaded relief images, and 3-D images of bathymetry. See legend.

for the coral. We did not find field evidence to discern whether the raised reefs are due to the high sea level stands in the middle to late Holocene [*Nunn*, 1995] or are a result of tectonic uplift. Warm and sulfurous springs occur on the north coast of the island, which could reflect residual magmatic gas discharges or basinal discharges along active faults adjacent to the island.

4.2. Koil Island

[14] Located between Vokeo and Wei, Koil is a low island composed of a series of raised coral reefs. The uppermost of these reefs form a flat-topped and steep-sided plateau between 30 m and 40 m above sea level, made of recrystallized corals with little fresh material. However, most of the island is formed by a platform of reef terraces only 2 m to 5 m above sea level composed of well preserved coral. Holocene sea level changes [*Nunn*, 1995] are not enough to explain the presence of corals reaching as much as 30 to 40 m above sea level. Thus we infer that at least part of the actual position of the corals is due to tectonic uplift.

[15] Koil's insular slope is very steep to the south and ends abruptly, tectonically controlled by one of the faults related to the Bismarck Sea Seismic Lineation (BSSL) (Figure 3). The BSSL changes orientation from E-W, south of Wei Island, to WNW south of Koil. It separates Koil's insular slope from a rough terrain to the south where other faults were found with the same orientations (Figures 5 and 6). By contrast, the insular slope NE and east of Koil is smooth (Figure 7). Several subma-

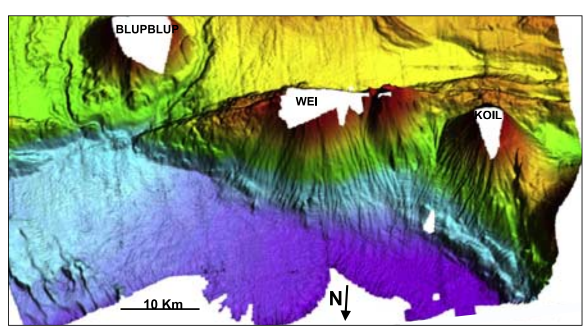

Figure 7. Three-dimensional image of the northern submarine flanks of Koil, Wei, and Blup Blup. View is from the north. Vertical exaggeration is × 2.5.

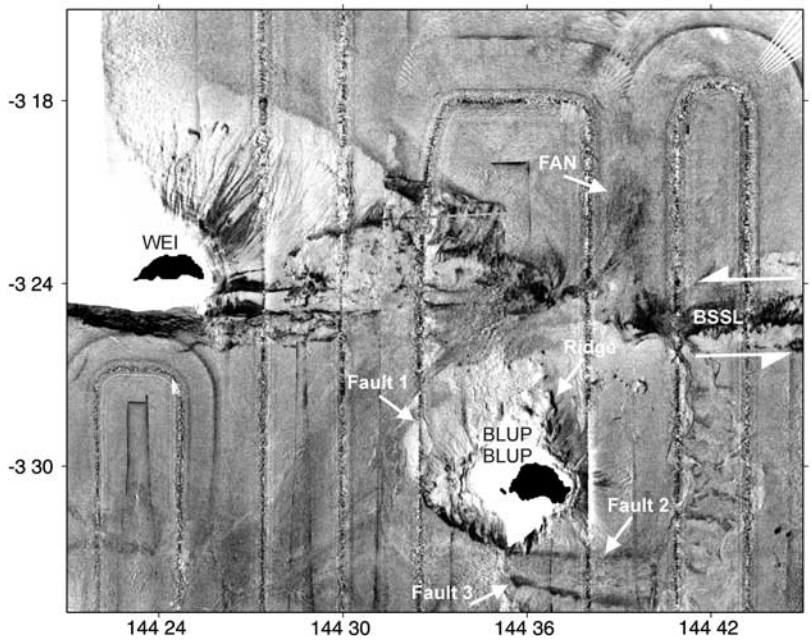

Figure 8. Side-scan image detail north of Blup Blup Island with low backscatter light and high backscatter dark, showing location of several faults around the island and a submarine fan north of the BSSL.

rine channels dissect this area, in general with a radial pattern. To the west a smooth saddle separates Koil from Vokeo island, and only minor channels are found in this area. Two faults oriented NE dissect the insular slope (Figure 6).

4.3. Wei Island

[16] Wei (or Viai) island has a crescent shape. It is 4.5 km long from east to west and less than 2 km wide, with a convex northern coast and a linear to embayed southern coast (Figure 3). The island has been deeply eroded and it is notably steep, especially on the south side. It is formed by a broadly north dipping, conformable sequence of thick, highly porphyritic andesite lavas. The exposed rocks are strongly weathered and a mature soil profile is developed on the island, which led *Johnson et al.* [1972] to consider Wei an inactive volcano. They also interpreted it as the remnant ridge of a larger volcano, most of which presumably, was removed by cauldron subsidence. Our data supports the interpretation that Wei is the remnant of a stratovolcano whose summit originally lay south of the midpoint of the present island, and it appears that part of the original volcanic island has been removed. The subaerial lavas dip directly into the sea on the north coast, without evidence of littoral or submarine volcanic rocks. Furthermore there are no uplifted reefs or terraces. A limited fringing reef is present off parts of the island, especially its eastern and western ends, but reef development at Wei is very limited compared to the adjacent islands of Koil and Blup Blup.

[17] Wei's submarine segment is elongated E-W (Figure 3) and its northern insular slope is broad and well developed (Figure 7). Several submarine channels cut the seafloor radial to the island. Some of them are controlled by NE trending faults (see interpreted faults in Figure 6), but the erosion seems to be of lesser importance than that of Koil's northern slope. Because the islands appear to young eastward [*Johnson*, 1977], Wei might have been exposed to erosion over a shorter time period than Koil, but major erosion on Koil could also be due to the fact that the latter is being uplifted.

4.4. Blup Blup Island

[18] Blup Blup is located approximately 30 km offshore from Cape Girgir (Figure 2) and it represents the emergent summit of a stratovolcano. It has an irregular shape, dimensions of 2 km by 3.5 km for the part above sea level and a summit elevation of 402 m. The island is deeply eroded and has a lagoon on the northwestern side and a circular drowned crater on the southwest side. These features, together with the presence of a well developed reef, especially on the western and northern coasts, suggest that the island has subsided since the end of its main growth period. No historic

eruptions are reported, but well preserved scoria cones, craters and hot springs of the northwest coast suggest limited young activity.

[19] Several faults related to the BSSL cross Blup Blup's northern insular slope. One of them cuts and displaces a segment of the island slope (Figure 6). The fault is recognized in the backscatter (fault 1 in Figure 8) from a sharp change in reflectivity, as well as other faults in the vicinities (faults 2 and 3 in Figure 8).

[20] Blup Blup's submarine flank has minor submarine channels carving the island's bulk, but in general it has not been deeply eroded (Figure 3). It is much less eroded than Wei and Koil, and this difference could be understood in terms of Blup Blup being a younger island with less time exposed to erosion. The most prominent feature in Blup Blup's insular slope is a volcanic ridge oriented N-S and located in the northeast submarine flank (Figure 8, R in Figure 6). The ridge is cut by two NE striking faults (Figure 6).

4.5. Kadovar Island

[21] Kadovar is located south of Blup Blup and 25 km north from the Sepik river mouth. The island is only 1.5 km long and wide, but has an elevation of 365 m. Kadovar consists of an older central volcano, and a summit crater within which a cumulodome has grown, flowing over the southern part of the crater [*Johnson et al.*, 1972; *Wallace et al.*, 1981]. Only the northern crater rim is preserved. Last historic activity may have been in 1700, as reported by William Dampier as he sailed by through the Schouten Islands. Fumarolic activity was reported in the early 1900s and recommenced in 1976, when all residents of the island were temporarily evacuated, although an eruption did not occur. Kadovar's submarine flanks are very little dissected by submarine canyons and only some minor channels and isolated seamounts disrupt the insular slope (Figures 5 and 6).

4.6. Bam Island

[22] Bam Island is the highest and southeasternmost of the Schouten Islands and lies 55 km NNE of the mouth of the Sepik River. The island is 685 m high, has an oval shape and dimensions of 2.4 by 1.6 km. It consists of the remnant of an older volcano to the NW and a younger volcano SW at whose summit is the active crater [*Cooke and Johnson*, 1981]. From field observations we suggest that the crater forms the center of a recent edifice that has filled in a lateral collapse scar. The northwest flank of the island is the oldest and most deeply eroded part of Bam. A single flank vent occurs near the northern tip of the island (see volcanic alignment in the north of Bam, Figures 5 and 6). The rest of the volcanic activity seems to have been centered on the summit. Thick sequences of fresh air fall lapilli and lapilli alluvium occur on the north coast, while the summit is formed by only partly vegetated welded spatter and clastogenic lavas.

[23] Bam is one of the most active volcanoes in Papua New Guinea, with a long record of historical eruptions recorded since 1872 [*Taylor*, 1955; *Johnson et al.*, 1972; *Cooke and Johnson*, 1978]. Most reports have been restricted to small to moderate explosive activity from the summit crater, but the inhabitants have an oral tradition of a major eruption leading to many deaths and the temporary evacuation of the island seven generations before 2005, possibly in the mid-1800s. Minor eruptive activity in the late 1950s led to another temporary evacuation. Since then, steam plumes and fumarolic activity have occurred along fracture systems both within the summit crater and around its rim. Most recently, beginning in 2004, a new set of arcuate, en echelon fractures has opened between the summit crater and the western sidewall of the northeast facing collapse scar. Fumarolic activity along these fractures was reported in 2004 and was continuing during field work on the island in August 2005.

5. Tectonics of the Bismarck Seismic Lineation Zone

[24] We have used the KM0419 bathymetry and side-scan backscatter intensity data to map the geomorphology of a section of the Bismarck Sea Seismic Lineation (BSSL). This sinistral strike-slip fault was recognized by *Denham* [1969] as a band of shallow seismicity extending across the Bismarck Sea. *Taylor* [1979] described the focal mechanisms occurring in three main groupings, each associated with a separate transform segment. The fault planes on the westernmost section are oriented E-W and may continue onshore in a series of anastomosing faults along the northern coastal ranges of New Guinea [*Cooper and Taylor*, 1987]. The BSSL has four distinct segments, named from east to west the Weitin, Djaul and Willaumez faults [*Martínez and Taylor*, 1996], and a westernmost one, named here the Schouten fault (WT, DJ, WZ and SH in Figure 1).

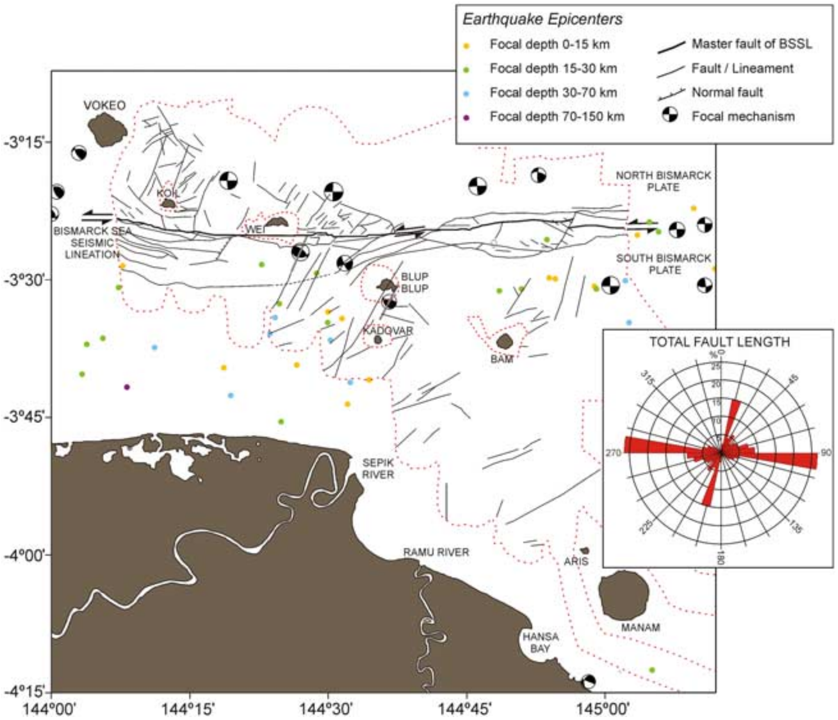

Figure 9. Seismicity of the Schouten region. Epicenters of relocated earthquakes events from the *Engdhal et al.* [1998] database represented by depth and updated to 2004. Focal mechanisms are from CMT Harvard Catalog [*Dziewonski et al.*, 1981]. Rose diagram for all faults and lineaments calculated by length.

[25] The western section of the BSSL intersects the Wewak trench (Figure 1). The master sinistral strike-slip fault trace of the BSSL is oriented 088° to the east of Wei Island (144°21.5) and 100° to the west of the island. However, a number of structures parallel to the BSSL have been recognized and mapped (Figures 3–6). This structural geometry could be a result of strain partitioning to accommodate oblique shortening, suggesting convergence across this part of the BSSL.

[26] To the west of Blup Blup Island a series of secondary structures link to the main fault trace and form an angle of about 45° to the master strike-slip fault (E in Figure 6). These structures have been identified as normal faults in the bathymetry and backscatter images (Figures 3 and 4), and we interpret them as a deformation pattern typical of intraplate strike-slip termination zones. Following *Storti et al.* [2003], such normal faults may indicate confined intraplate strike-slip faulting, occurring when the displacement decreases and is fully accommodated by strain within the plate interior. In the eastern sector we have not mapped secondary structures typical of termination zones, but faults parallel to the BSSL are also present.

[27] We interpret some bathymetric highs related to the BSSL as regions of uplift (Figure 3 and H in Figure 6). Some of these highs might be the result of localized transpressional deformation related to bends occurring in the fault system (push-ups [after *Woodcock and Schubert*, 1994]). The master fault of the BSSL has local restraining and releasing bends.

[28] The most prominent of those bathymetric highs is located north of Bam island and northeast of Blup Blup Island. It has a length of 40 km within the mapped area and a lenticular shape with a variable width reaching a maximum of 9 km in the central area. The crest of this high is at 820 m, rising from depths of 2100 m to the north and 1680 m to the south (Figure 3).This prominent topographic high is much larger than the other highs and does not seem to be a transpressional structure as there is no correspondingly large bend in the fault system. We propose instead that this high was the southern apron of Wei Island (south apron of Wei, Figure 6). The island has been displaced left-laterally by the BSSL a distance of 45 km to the west. The master fault of the BSSL is located within 2 km of Wei's south coast. With this interpretation, Wei appears to be the remnant of a stratovolcano whose summit originally may have lain south of the present island. It appears that at least half of the original volcanic island has been

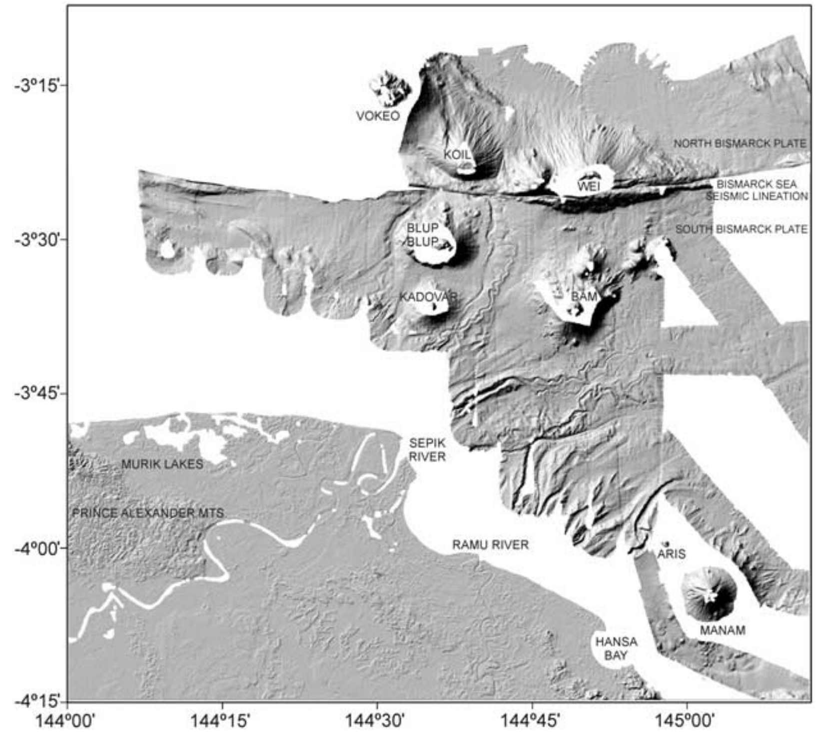

Figure 10. Reconstruction of the bathymetry before the Bismarck Seismic Sea Lineation displaced the island of Wei left-laterally to the NE. Note that Wei's position follows a N-S lineation of seamounts including Bam island and that Koil is also aligned N-S with Blup Blup and Kadovar. Shaded relief image derived from 90-m gridded data. Apparent illumination is from the NW.

removed. Our data reveals a large contrast offshore north and south of Wei, with a well developed insular slope and apron on the north side, eroded by a radial system of submarine canyons (Figure 7), and an exceptionally steep and planar insular slope on the south side, that also lacks the presence of an insular apron (Figures 3–5).

[29] Koil Island seems to be uplifting and Vokeo could be as well, on the basis of the presence of emerged reefs, due to the tectonics of the BSSL. Both islands are located NW of the main bend in the BSSL, where its direction is WNW instead of ENE, and they are likely the older islands of the Schouten, where uplift due to magmatic processes is not expected. In Wei, the closest island to the BSSL, neither uplift nor subsidence has been noticed, but its location does not correspond with the bend of the BSSL. The remaining islands, Blup Blup, Bam and Kadovar, which are farther from the BSSL, are either stable or subsiding.

[30] Besides the main BSSL fault system, numerous other faults have been recognized and mapped in the Schouten area. Some of them were distinguished because they cut previous structures, like seamounts, volcanic lineations, channels and canyons. Others are inferred because they produce sharp inflections in the bathymetric maps or create abrupt changes in the backscatter character. In the shaded relief images some faults were seen by changes in shadow as we altered the illumination direction and altitude. A rose diagram for all the faults and lineaments calculated by length (Figure 9) allows us to differentiate the main structural directions. The primary direction is approximately E-W and is a result of the several faults associated with the BSSL. In addition to the primary direction, the other predominant direction is NE-SW and is the result of several faults of such orientation. These faults may also control local volcanism through the alignment of seamounts in the submarine flanks of Bam Island.

6. Discussion

[31] We find that the Bismarck Sea Seismic Lineation cuts and displaces Wei Island left-laterally. In an attempt to reconstruct the past geometry for Wei Island we digitally displaced the separate parts of the Wei platform along the BSSL using a Digital Elevation Model of the Schouten (Figure 10). This reconstruction indicates that Koil Island could have been positioned north of Blup Blup, forming a N-S

lineation with Blup Blup and Kadovar islands. Wei Island was located north of Bam, forming a N-S lineation with Bam and several other seamounts.

[32] The wide area occupied by the aprons of Wei, Koil and a shallow seamount in between may have acted as a barrier to the sediments of the North Sepik sedimentary system. Between Koil's apron and the seamount located east of it (Figure 9), there is a passage with a linear structure that cuts the apron and has been interpreted as a fault in Figure 6.

[33] The open passage between both sides of Wei's apron has now a total length of 7.5 km and the total distance that both sides of Wei have been left-laterally displaced is 45 km. GPS-derived velocities predict 117.2 mm/a strike-slip motion and 23 mm/a of convergence on the Bismarck Sea Seismic Lineation near Wei Island [*Tregoning et al.*, 1999; *Tregoning*, 2002]. More recent GPS-derived estimations based on a larger database and including earthquake slip vectors predict 116.9 mm/a of motion parallel to the BSSL and 13.5 mm/a convergence near Wei Island [*Wallace et al.*, 2004]. Extrapolating the 116.9 mm/a movement calculated by *Wallace et al.* [2004] for the distances of 7.5 km and 45 km, the opening of the passage started 60–65,000 years ago and that the separation of Wei Island started up around 385,000 years ago.

[34] The Wei Island edifice must be at least 385,000 years, since at that time it was being displaced by the BSSL. *Taylor* [1979] suggested that a small component of extension could exist together with the predominant strike-slip motion along this segment of the BSSL, and periods of transform "leakage" may have been episodic. If the Wei platform is older than 385,000 years, then the BSSL could have been active south of the platform first, jumping to its to its present position 385,000 years ago when displacement began. Several jumps on the transform segments of Manus Basin have been mapped by *Martínez and Taylor* [1996]. Transform faults, like the BSSL, cut the oceanic lithosphere and are preferential places for ascent of magmas, so that a very small component of extension is needed to have volcanism, easily explained by bends on the trace.

[35] There is a marked contrast in between the E-W elongated morphology of Wei's platform and the other islands. The islands of Blup Blup, Kadovar and Bam, have platforms with a roughly circular morphology, while Koil is slightly elongated in a N-S direction, further evidence of the preferential N-S direction of volcanic alignments here. However, Wei has a platform more than 2 times longer in an E-W direction than in its shorter N-S axis. If we include as part of Wei the seamount located just next to it in its western side, then the platform is 3 times longer E-W than it is N-S. Wei's volcanism could have been produced during one or more extensional periods alternating with the dominant strike-slip activity along the BSSL. The elongate morphology of Wei could be interpreted as indicating island construction that was contemporaneous with strike-slip activity, supporting an approximate 385 ka age for this edifice, instead of a much older one. This interpretation can be tested by dating the rocks of the Wei platform.

[36] In the Schouten segment of the BSSL we found evidence of the convergent component predicted by *Tregoning et al.* [1999], *Tregoning* [2002], and *Wallace et al.* [2004, 2005] such as the existence of push-up structures, the azimuth of the pure strike slip segment at 144°40′E and the compressive focal mechanisms near Blup Blup, Wei and Vokeo islands (Figure 9).

[37] A fundamental unanswered question that remains is what is the origin of the Schouten Islands? We have presented evidence that Wei Island is likely the surface manifestation of a large volcanic edifice formed along the "leaky" BSSL transform. The islands of Kadovar, Bam, Blup Blup, and Koil, when reconstructed for displacement of the Wei edifice, lie along two N-S to NNE-SSW lines, in striking contrast to the WNW trend of the western Bismarck volcanic arc. This orientation is consistent with extension directions along the left-lateral fault system (Figure 9). In such strain regime, volcanism aligned in a NNE direction might be expected. While this orientation might be consistent with shear along the BSSL, the composition of the volcanoes would be expected to be basaltic. In fact, these volcanoes lack basalts and are the most silica-rich of any along the Bismarck arc [*Johnson*, 1977]. Thus, they are compositionally most consistent with arc volcanism.

[38] In this case, could the Schouten volcanoes indeed be arc-related? Looking along the Bismarck arc, the volcanoes north of New Britain are related to the subducting Solomon Sea plate, and an excellent case has been made that the volcanoes to the west of New Britain as far as Manam are also arc-related, but the surface effects of subduction have been greatly modified by rapid rates of collision [*Lock et al.*, 1987; *Silver et al.*, 1991; *Gill et al.*, 1993; *Abbott et al.*, 1994; *Wallace et al.*,

2004]. The uplifted colliding elements are still visible to the east in the Finisterre and Adelbert Ranges, but not even a trace of a colliding element is seen south of the Schouten Islands. One possibility is that earlier strike-slip faulting, seen at present onshore west of Wewak, may have displaced such terranes westward, opening a gap in the colliding blocks through which the Sepik and Ramu rivers have flowed and built their deltas. This process would have to have occurred in a short enough time interval to allow the subducting slab to generate the volcanic products we observe on the islands. An aggressive geochronologic study of both the islands and the fault systems onshore to the west of Wewak would be required to either allow or reject this idea.

7. Conclusions

[39] 1. The Bismarck Sea Seismic Lineation bends in its western termination, changing from a 088° orientation east of Wei to a 100° orientation west of it. Several faults parallel to the BSSL have been mapped and interpreted as resulting from strain partitioning to accommodate oblique shortening. This obliquity suggests convergence across this part of the BSSL.

[40] 2. Koil Island has been uplifted, as noted by the presence of emerged reefs 30 to 40 m above sea level. We relate this uplift to the tectonics of the BSSL, since this island is located very close to its western termination coinciding with a bend of the major fault where other push-up structures have been mapped. Emerged reefs were found also in Vokeo island, but only a few meters above sea level. Their age of about 5000 years leave open its interpretation, since they could reflect either tectonic uplift or Holocene sea level changes.

[41] 3. The bathymetric high located north of Bam Island is likely the south apron of Wei Island. The Bismarck Sea Seismic Lineation has displaced both parts of the island a distance of 45 km left-laterally. This separation began approximately 385,000 years ago. Wei Island could have been built just prior to its initial displacement, indicating that a small component of extension could exist together with the predominant strike-slip motion. On the other hand, if Wei Island were older than this segment of the BSSL, activity on the fault may have occurred south of the island and later jumped to its present position and began to displace Wei.

[42] 4. The growth of the islands and seamounts in the Schouten region may have been controlled by roughly north to NE oriented lineations. Later displacements by the BSSL resulted in the distribution of island parallel to the coast.

[43] 5. The origin of the Schouten Islands is still uncertain. Volcanic activity associated with wrench faulting along the BSSL provides an explanation consistent with their preslip orientation, but their composition is not that expected of such an origin. Formation by subduction is most consistent with the composition of the rocks, but there is no sign of subduction either north or south of the Schouten Islands. We speculate that lateral faulting onshore may have provided the structural gap for the Sepik-Ramu river systems, and these changes have disguised the earlier collisional structure that is presently observed to the SW. This idea remains to be tested.

Acknowledgments

[44] This work was supported by National Science Foundation grant OCE-0327004 to Eli Silver and Steve Ward. A predoctoral grant to Pilar Llanes Estrada from Universidad Complutense de Madrid and University of California (IES Program) and postdoctoral grants "Profesores de la UCM en el extranjero 2007" and "Becas del Amo 2008" from Universidad Complutense de Madrid made her participation in this investigation possible. The project MICINN CTM 2006-13666 (Caribe Norte Project) helped to fund this research. We are indebted to the officers, crew, and scientific party of the R/V *Kilo Moana* for their cooperation at sea. Discussions with Brian Taylor (SOEST), G. De Vicente (UCM), and A. Olaiz (UCM) were helpful in developing this manuscript. We are very grateful to Hugh Davies and Jim Robins for their continued support of our studies in PNG and to Wally Johnson and Doug Masson for their review and comments on this paper.

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