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THE TROBRIAND ISLANDS EARTHQUAKE AND TSUNAMI, 6 MARCH 1895

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ABSTRACT

An earthquake and tsunami struck the Trobriand Islands in March 1895 causing at least 30 deaths but until now the location and magnitude of the earthquake were quite uncertain. We have searched British and German colonial literature of the time to refine both parameters of Everingham's original estimates. Our magnitude of 7.3±0.3 and location at (8.4°S, 150.1°E) compare well with Everingham's magnitude 7-8 and (9°S, 151°E). Whilst the earthquake seems to be associated with the Trobriand Trench, very few others have occurred there since modern seismographs were deployed in the mid-1960s, certainly none of magnitude 7 or more, none with a thrust mechanism and none that have generated a destructive tsunami. We compare this earthquake and tsunami with the 1998 Sissano Lagoon earthquake, for which we have drawn an isoseismal map, and briefly discuss the implications for tectonic interpretation and hazard assessment.

INTRODUCTION

The island of New Guinea is at the corner of a collision zone between the Pacific and Indo-Australian Plates with several plate fragments or small plates wedged between them. Many researchers have studied or commented on the seismicity of this most interesting area including Richter (1954), Brooks (1965), Denham (1969, 1973, 1974), Everingham (1973, 1974, 1975, 1977), Ripper and Letz (1991, 1993), McCue (1984), Tregoning and others (1998) and most recently Anton (2009) but there is no consensus on a tectonic model.

It is always rewarding to investigate 'rogue' earthquakes that don't appear to fit the models and this was the impetus to investigate this large tsunamigenic earthquake in the Solomon Sea in 1895. At that time Germany controlled the northern half of eastern New Guinea, New Britain, New Ireland and Bougainville, while Great Britain claimed sovereignty over the southern half of eastern New Guinea (known today as the Independent State of Papua New Guinea), while the Dutch ruled over west New Guinea (now the Papua Province of Indonesia).

THE 1895 EARTHQUAKE

One of the first reports of the earthquake and possible aftershocks to reach the outside world was published in New Zealand in the *Grey River Argus*, Volume XXXVII, Issue 9093, 25 March 1895, Page 4, just two weeks after the earthquake. The shaking from not one but a series of earthquakes was felt in Port Moresby but clearly not on Thursday Island.

The following extract from *The Queenslander* of Saturday 25 May 1895, Page 1000 is typical of the descriptions in the contemporary Australian media and German reports.

> *The Acting Administrator of British New Guinea, in a despatch dated the 1st April, gives the following account of an earthquake and tidal wave experienced in the Possession on the 6th March last, obtained from an intelligent native of the island of Sim-Sim :— A little after sunset they experienced a shock, then followed a loud booming sound apparently not very far off, then another shock. After this there was a lull, and then they heard the noise of the advancing wave, which almost immediately afterwards swept over the flat. The waters knocked the frail native houses down and swept portions of them, together with household goods, into the sea. One child was drowned, and one man received severe abrasions of the skin. Those of the natives who did not manage to grasp the trunks of trees were washed into the sea. Our informant said that he caught hold of a cocoanut tree, and that the water reached to his armpits.*

Other reports indicate that the sea receded a considerable distance after the earthquake before crashing back onto the island. *The Queenslander* of 4 May 1895 reports:

> *It appears that on the night of the 6th March the islands received the full force of an earthquake, with a tidal wave, which swept everything before it. The natives are awfully frightened, and they informed us that the salt water left them at 6 p.m. on the 6th, and they could see the bottom of the sea quite dry for miles around them, when all of a sudden they*

could see a great cloud of water making towards them with an awful roar, which frightened them so that they all made for the cocoanut trees, where they remained until the great cloud of water passed over the islands.

In Nachrichten über Kaiser Wilhelms-Land und den Bismarck-Archipel, Ausgabe 1895, Page 52, missionary J. G. Pfalzer reports a very strong earthquake from his location in Simbang (near Finschhafen):

*On 6 March 1895, around 7 o'clock in the evening, a very strong earthquake was felt, not excessively violent or jerking pushes, but a strong, regular shaking like being in a strainer, that, perhaps, lasted for a few minutes. Immediately, I heard a strong quenching of the sea that quickly increased in intensity. I ran to the beach and the sea surface was strongly disturbed. It was an abnormal tidal wave that looked the same as on 13 March 1988 [*Authors: Tsunami associated with the Ritter Island eruption and collapse*]. Every 5 minutes a change from falling tide to rising tides, with the surge of 2 feet above the highest tide mark and the falling tide about 1 foot below the lowest mark of low tides. Although, the tide returned with great might, carrying-over and destroying everything that was within reach, boats, trees, etc.. This scenario lasted until 10 o'clock (in the evening), then the waves eased off and later on the moonlight gleamed on a glassy ocean surface.*

A location and magnitude of the earthquake were first tabulated by Everingham (1977) who estimated the magnitude as between 7 and 8 and the (uncertain) location at (9°S, 150°E). He reprinted reports and observations of the earthquake and tsunami, all sourced from the British administered Papua region. A search of the ISC database resulted in no events but NOAA reports the earthquake and tsunami as follows with a slightly different location, a magnitude of 7.5, a puzzling focal depth of 170km, and source unspecified:

Date	Time UTC	Mag	Location	Latitude	Longitude	Depth
18950306	08 35	7.5	W. Solomon Sea	-8.5	151.0	170

Other anecdotal accounts of the earthquake and tsunami were found in newspapers in the Australian National Library using their on-line search facility TROVE. It is interesting to note that the first reports of this earthquake received in Australia were from the crew of a German steamer *Isabel* that arrived in Sydney in mid-April 1895. It was also felt and later reported as a strong jolt by the crew of *Merrie England* anchored near the island of Jaga (Yaga) in the Trobriands.

Contemporary German sources from the northern side of New Guinea and Neu-Pommern (today's New Britain), archived in Berlin, were investigated for this study. The felt reports from both sources are mapped and the approximate felt area drawn as shown in Figure 1 to constrain both the location (the approximate centre of the felt area) and magnitude (the size of the felt area by comparison with the felt area during later earthquakes with measured magnitudes in the region, mostly data from Port Moresby Geophysical Observatory reports).

There are few earthquakes located on the Trobriand Trench and this is the largest of them by far, and the only one known to have caused a destructive tsunami. Duda (1965) is alone in ascribing a location near the Trobriand Trough to a M 7.8 earthquake on 24 January 1902 at 23:27 UTC but this is not confirmed by other sources who attribute it to the plate boundary further north. The shaking in 1895 was not felt in Herbertshöhe (Kokopo near Rabaul) but was felt in Madang for example, and the tsunami was very localised, damaging just the Trobriand Islands and the east Papua Peninsula coast where three villages were destroyed, their occupants killed (annual report for British New Guinea tabled in the Australian Parliament). The very localized destruction was mirrored in the 1998 Sissano Lagoon earthquake and tsunami. Reports indicate the maximum run-up was about 6m. By analogy with the 1998 earthquake on the north coast, we infer that the source was a shallow, tsunamigenic earthquake and not just a simple shallow thrust. Neither a normal nor a strike-slip source would generate such a large, localised tsunami following an earthquake of this moderate magnitude.

The location must have been very local to the Trobriands as evidenced by the following observation at Sim-Sim (*The Queenslander* of 25 May 1895):

> *A little after sunset they experienced a shock, then followed a loud booming sound apparently not very far off, then another shock. After this there was a lull for a short time, and then they heard the noise of the advancing wave, which almost immediately afterwards swept over the flat*.

We surmise that this was the basis for Everingham's experienced assessment of the location. Another clue as to the location is that the wave struck the island of Sim-Sim on its western side so the focus was surely west of Sim-Sim, most probably within 50km of this location and perhaps less than 25km at (8.4°S, 150.1°E).

The listed place names and coordinates as shown in Figure 1 are in Table 1.

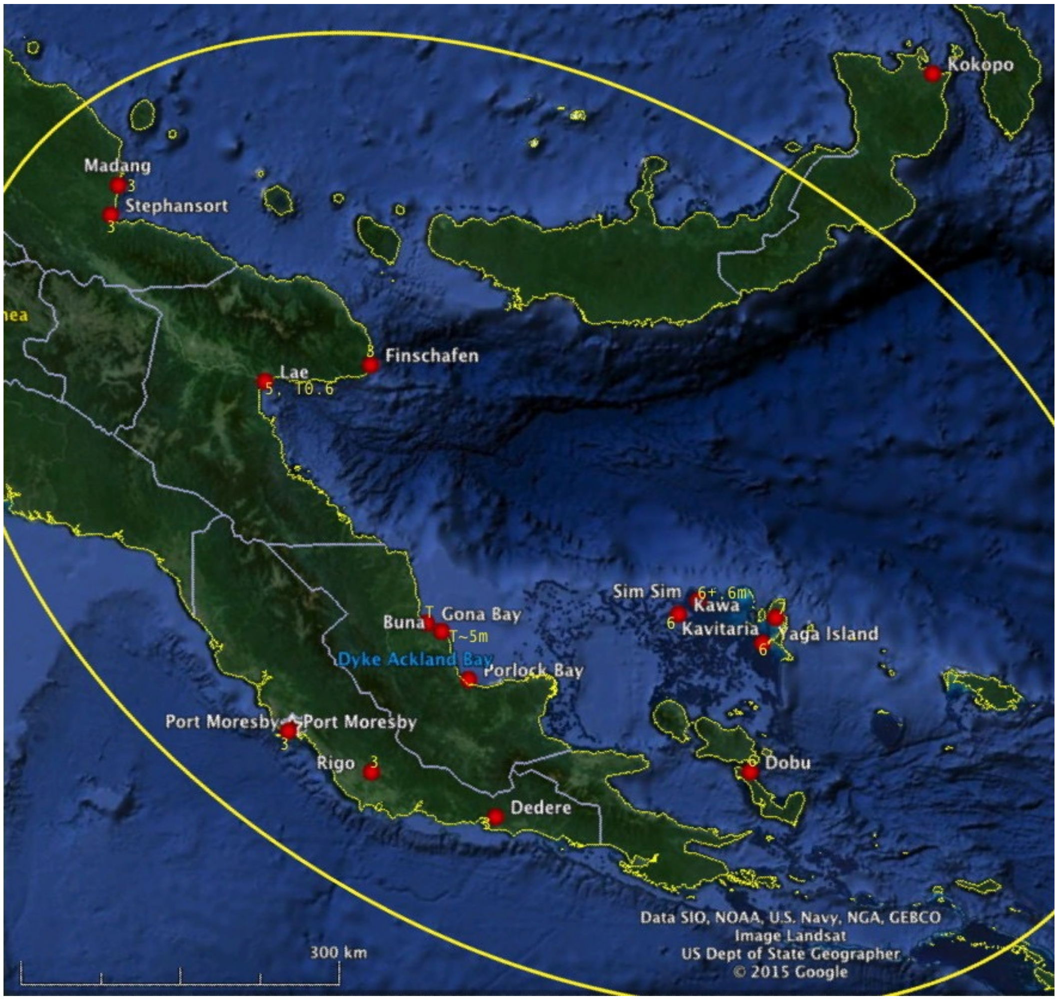

Figure 1. Felt area of the 6 March 1895 earthquake in the Trobriand Islands. The MM Intensity is given followed by the tsunami runup height (6, 6m) or just the tsunami height T~5m where reported or estimated.

Table 1. Places where the 1895 earthquake shaking was reported felt

Place	Lat °S	Long °E	MMI	Comment
Port Moresby	9.4	147.2	3	Felt
Dedere (Abau)	10.2	148.7	3	Felt
Rigo	9.8	147.8	3	Felt
Kokopo	4.3	152.3	0	Not felt

Yaga Trobriand Is	8.74	150.96	6+	Felt onboard, ship heaved and trembled for a minute.
Kavatari	8.54	151.04	7	Trees swayed, liquefaction observed
Sim-Sim Island or Kumkwalego	8.42	150.45	6+	Strong shaking and 6m tsunami. One report mentions that the water receded first.
Dobu	9.75	150.87	6+	
Madang	5.2	145.8	3	
Finschhafen	6.6	147.8	3	
Stephansort	5.45	145.7	3	
Simbang near Finschafen	6.58	147.83	5	Strong but not jerky, small tsunami
Kawa	8.52	150.32	6	Shaking dislodged large coral overhangs but no tsunami

Various estimates of the earthquake source details are summarised in Table 2.

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Table 2. Parameters of the 1895 earthquake

Date	Time UTC	Lat °S	Long °E	Mag	Ref	Comments
1895 03 06	08:35	9	150	7-8	Everingham	
		8.5	151.0	Ms 7.5	NOAA	50-100 dead no reference.
		8.4	150.1	Ms 7.3	This report	More than 30 deaths

Whilst preparing this paper we looked at the felt reports for the 1998 Sissano Lagoon earthquake listed by Ripper and others (1999) to add to the intensity attenuation database. Some reports were recently found of the impact in Papua Province Indonesia (Joku, 1999) where it was felt as far as the capital Jayapura. From these reports we were able to draw an isoseismal map.The felt area is very similar to that of the magnitude 7 October 1968 Wewak earthquake (Denham, 1974). The offset of the high intensity shaking from the computed epicentre and area of maximum tsunami run-up is obvious in the inset Figure 2. The three epicentres are widely scattered indicative of the high uncertainty in the focal region, at least a source length apart, and this today let alone 100 years ago.

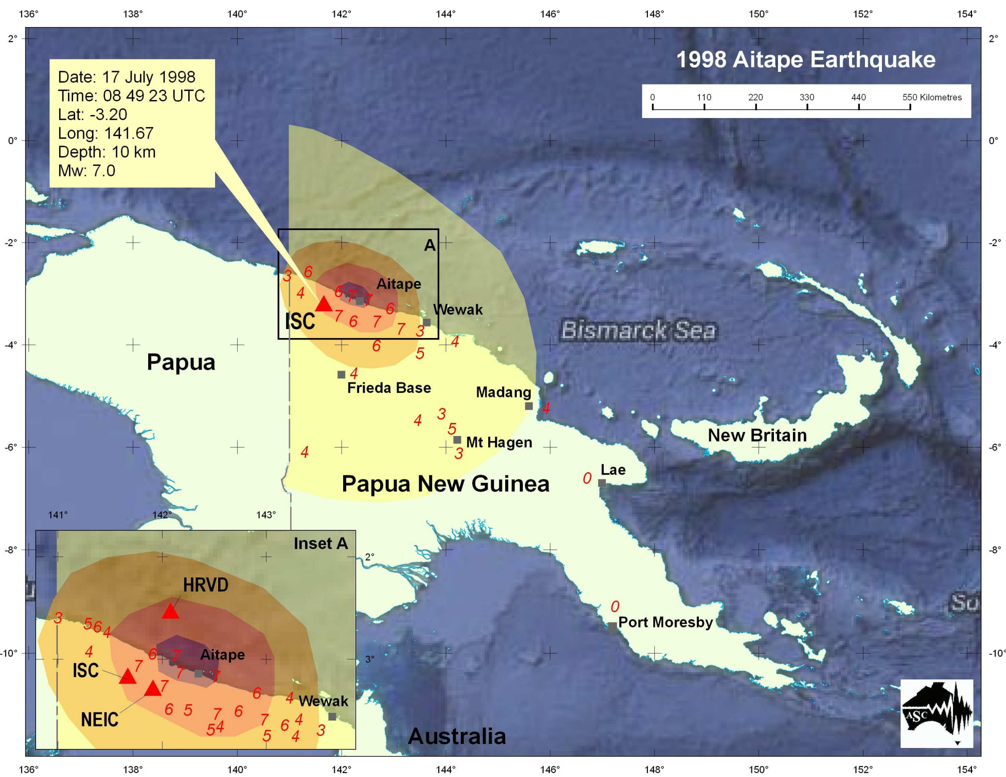

Figure 2. Isoseismal Map, MM intensity, of the destructive July 1998 Sissano Lagoon tsunamigenic earthquake.

THE MAGNITUDE ESTIMATE

The felt area is elongated along the axis of the Trobriand Trench as shown in Figure 2. The half-long axis or radius of perceptibility (Rp) along the major axis is about 575 km from the supposed epicentre NW of Sim-Sim Island to Madang. By comparison we have plotted the radius of perceptibility against magnitude (M) for other major earthquakes in Papua New Guinea, most of them around the Solomon Sea (Table 3, Figure 3), and obtain the following approximate equation:

$$M = 1.8 \ln Rp - 4.1$$

and from this we obtain a magnitude of 7.3. Perhaps the best comparison is with the October 1968 Wewak and 1970 Madang earthquakes, neither of which were felt as far as the Trobriand Islands. The ground shaking in the 1970 Madang earthquake was along the same path in reverse as the 1895 earthquake which would suggest a magnitude nearer 7 than 8. Our best estimate of magnitude is 7.3±0.3.

Table 3 Magnitude and radius of perceptibility from published isoseismal maps.

Date		Felt radius along long axis	Author	Location
20 Jul 1975	7.5	600	Everingham	Bougainville
9 Mar 1979	6.2	390	McCue	Papuan Peninsula
26 Jul 1971	8	720	Everingham	N Solomon Sea
14 Jul 1971	8	585	Everingham	N Solomon Sea
31 Oct 1970	7	625	Everingham	Madang
11 Apr 1978	5.7	175	McCue	Papuan Peninsula
23 Oct 1968	7	404	Denham	Wewak
5 Sep 1968	5.6	285	Denham	Southern Highlands
16 Sep 1976	5.9	370	McCue	Papuan Peninsula
17 Jul 1998	7.0	410	This paper	Sissano Lagoon

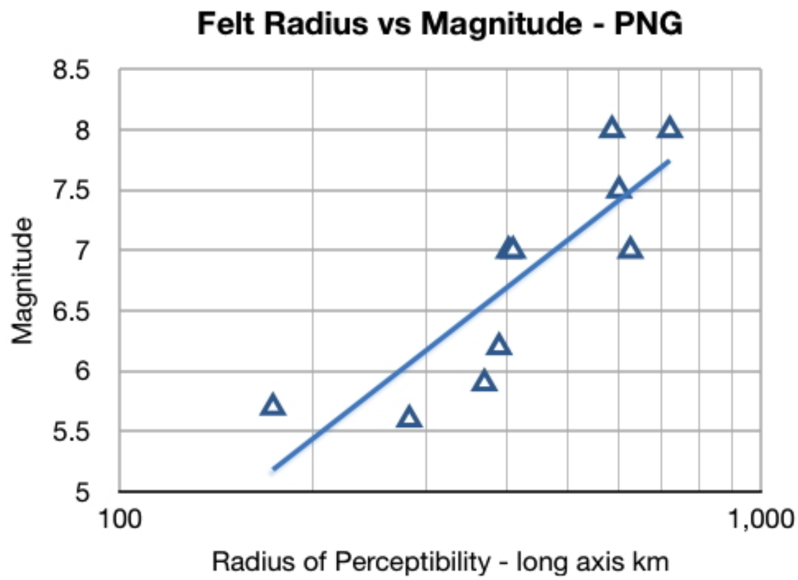

Figure 3. The felt radius, along the long or major axis of isoseismal maps of selected earthquakes in Papua New Guinea, versus magnitude. Events are listed in Table 1.

TSUNAMI

Reports indicate that the tsunami was very localised and/or directional, the water receded first then returned as a 6m high tsunami at Sim-Sim yet no impact was observed on Kawa only 20km away. A 'great wave' was reported in Porlock Bay on the Papuan Peninsula west of the Trobriand Islands where four villages were washed away, some of the villagers drowned. At Buna it is reported that 26 people drowned (Everingham, 1977). We have assumed the tsunami height there was 3 to 5m to cause the damage reported. At Simbang (near Finschhafen) the detailed sea-level observations made by missionary J. G. Pfalzer (Appendix 3) describe a typical tsunami with run-up of about 1m:

> *every 5 minutes a change from falling tide to rising tides, with the surge of 2 feet above the highest tide mark and the falling tide about 1 foot below the lowest mark of low tides. Although, the tide returned with great might, carrying-over and destroying everything that was within reach, boats, trees, etc. This scenario lasted until 10 o'clock (in the evening), then the waves eased off.*

Pfalzer measured both the period, 5 minutes is very short, and amplitude above and below the tidal limits. The maximum tidal range in the Huon Gulf at Lae is 1m so the actual tsunami run-up would have been about 1m at Simbang.

The tsunami is listed by the Russian Tsunami Laboratory Institute of Computational Mathematics and Mathematical Geophysics SB RAS Tsunami Laboratory, Novosibirsk, Russia in their Web Encyclopedia on Natural Hazards.

TECTONICS

There are as many models of the plate geometry in the Papua New Guinea region as there are publications on the subject as noted by Tregoning and others (1998), but they are not well constrained by the seismicity as shown in Figure 4. In particular the lack of seismicity along the Trobriand Trench is noticeable.

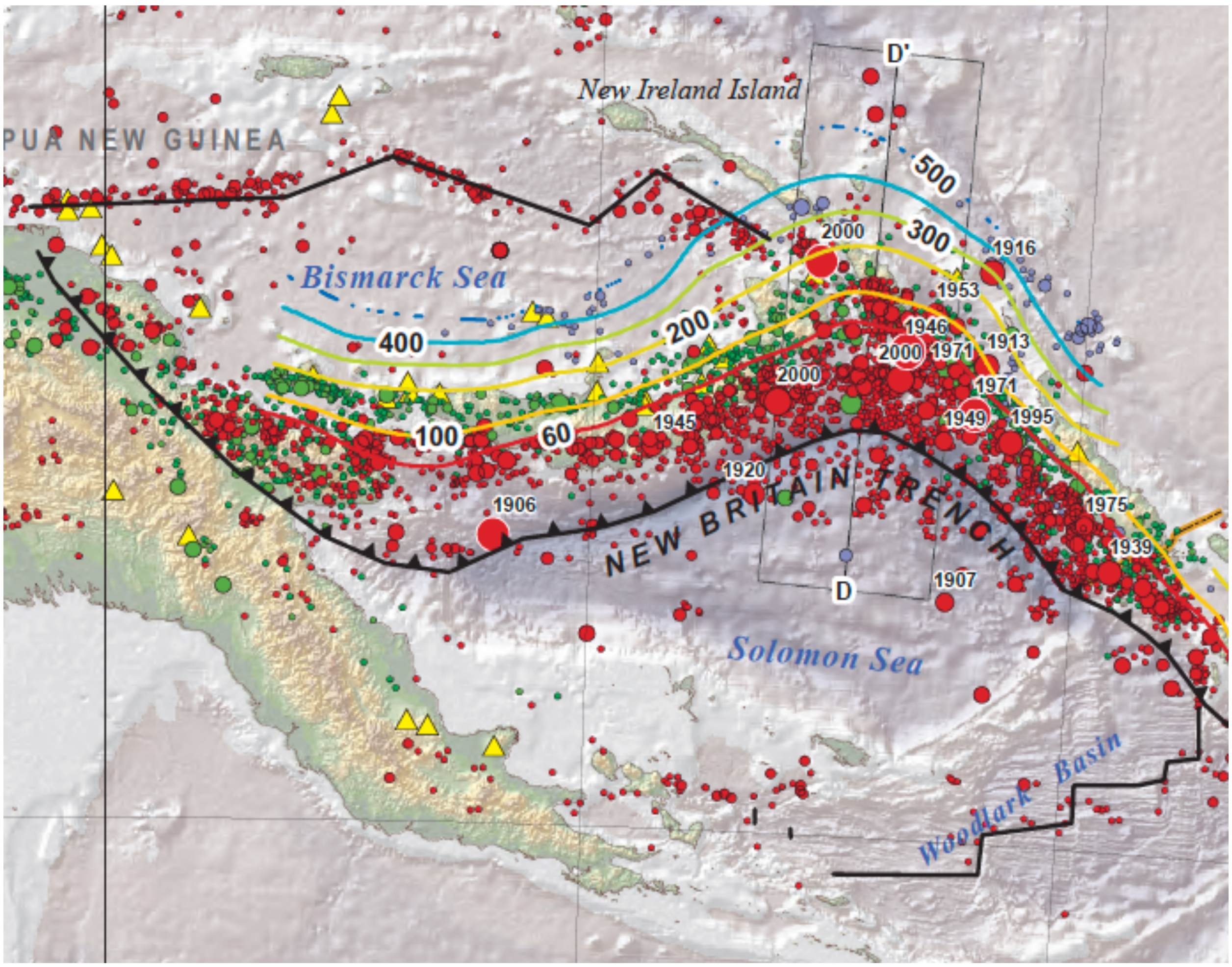

Figure 4. Seismicity of the Solomon Sea region (from Benz and others, 2011). The red dots are for earthquakes less than 70km deep, green dots for depth 70 – 299km and blue dots depth of 300km or more. The yellow triangles show some of the active volcanoes. There is remarkably little seismic activity to suggest that the Trobriand Trough is active. Researchers have based their models heavily on the topography or bathymetry rather than the seismicity.

A search of the ISC database from 1900 to 2012 centered at (8.5°S, 150°E) and radius of 1.5° yielded just 2 large (M > 5.9) earthquakes both of them between the New Britain Trench and the Trobriand Islands (Figure 5). Details of these two events are listed below.

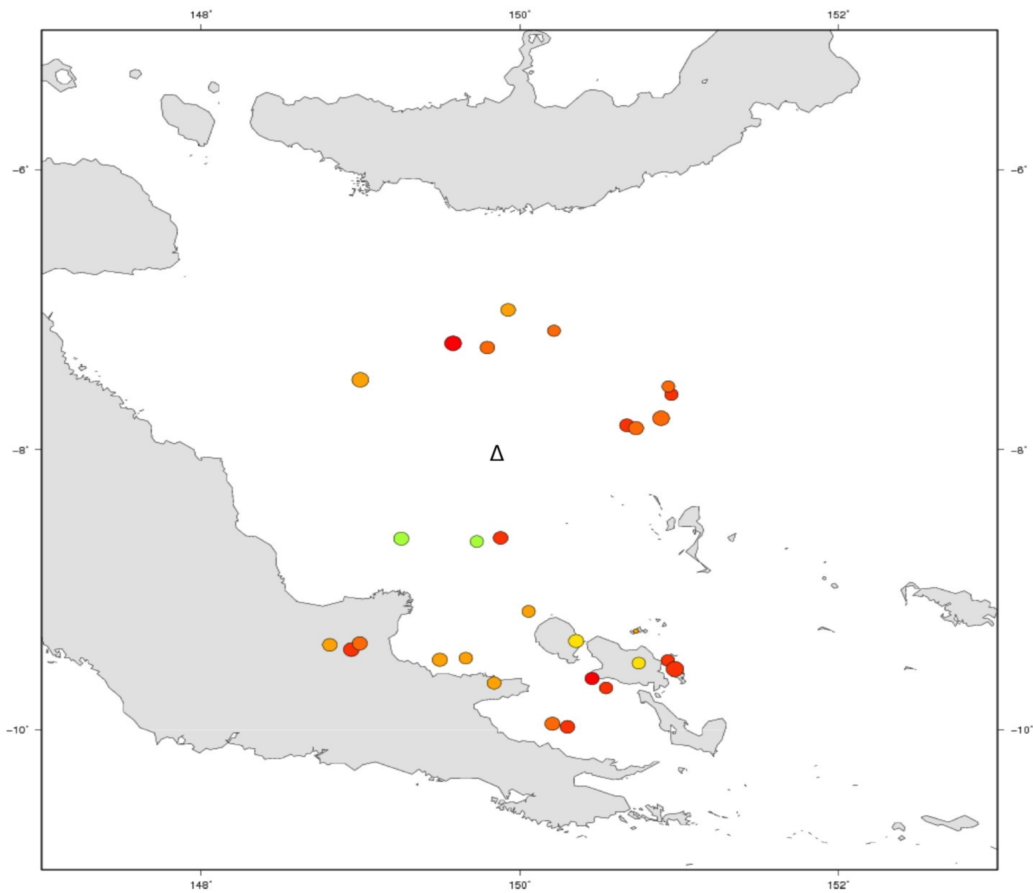

Figure 5. Seismicity from the ISC for the period 1900 – 2012, M≥5.5, centred on the triangle near (8°S, 150°E) and radius 1.5° (to mask the New Britain Trench seismicity). The Trobriand Trench is not defined by the seismicity, just a few scattered epicentres north and northwest of the Trobriand Island.

1. 1975/02/07 04:51:40   7.24°S 149.58°E   9 Ms 6.4 (NEIS) ISC

This large Ms 6.4 shallow earthquake to the northwest of the Trobriand Islands was below the Trobriand Trench, felt widely notably at Rabaul (note that the 1895 event was reported not felt at nearby Kokopo). No mechanism was computed.
(Felt I=IV MM Kandrian, Gloucester, III Popondetta, Salamoa, Rabaul, II-III Esa'ala, Bolubolu, I-II Tufi, Sanaroa. Also Felt at Losua.)

This is a well-constrained location, surrounded by seismographs of the then extensive PNG network, the gap only 22°. The depth too is well controlled, 9 ± 7km, supported by depth phases such as PcP.

2. 2000/07/16 03:57:48 7.78°S 150.89°E 12 Mw 6.6 (HRVD) ISC
This large shallow (12km deep) earthquake north of the Trobriand Islands below the Trobriand Trench is from the ISC.

None of the nodal planes parallels the strike of the Trobriand Trough. They are more likely fractures in the outer rise of the Solomon Sea plate subducting under New Britain.

Three computed focal mechanisms for this earthquake are shown in Figure 6. They can't all be right, maybe none are right, but none of them are shallow thrusts as would be expected if the Trobriand Trough subduction zone was the source.

Figure 6. Focal mechanisms published by the ISC for the 16 July 2000 earthquake in the west Solomon Sea. Note that the HRVD mechanism (3rd image) and one of the two NEIS mechanisms (2nd image) are 'normal', the other a strike-slip mechanism, not thrusts as supposed by models of a subducting slab at the Trobriand Trench.

http://volcano.oregonstate.edu/vwdocs/volc_images/southeast_asia/papua_new_guinea/tectonics.htm (accessed on 30 May 2015).

Bird (2003) shows a more extensive Woodlark Plate (Figure 7.1) than other authors such as Hamilton, 1979 in Figure 7.2. The proposed tectonic configuration by Taylor and others (1991) and Tregoning and others, 1998 are shown for comparison with our postulated model influenced strongly by the seismicity.

http://swpacificplates.weebly.com/caroline-north-bismarck-south-bismarck-manus.html (accessed on 30 May 2015).

http://volcano.oregonstate.edu/vwdocs/volc_images/southeast_asia/papua_new_guinea/tectonics.htm (accessed on 30 May 2015).

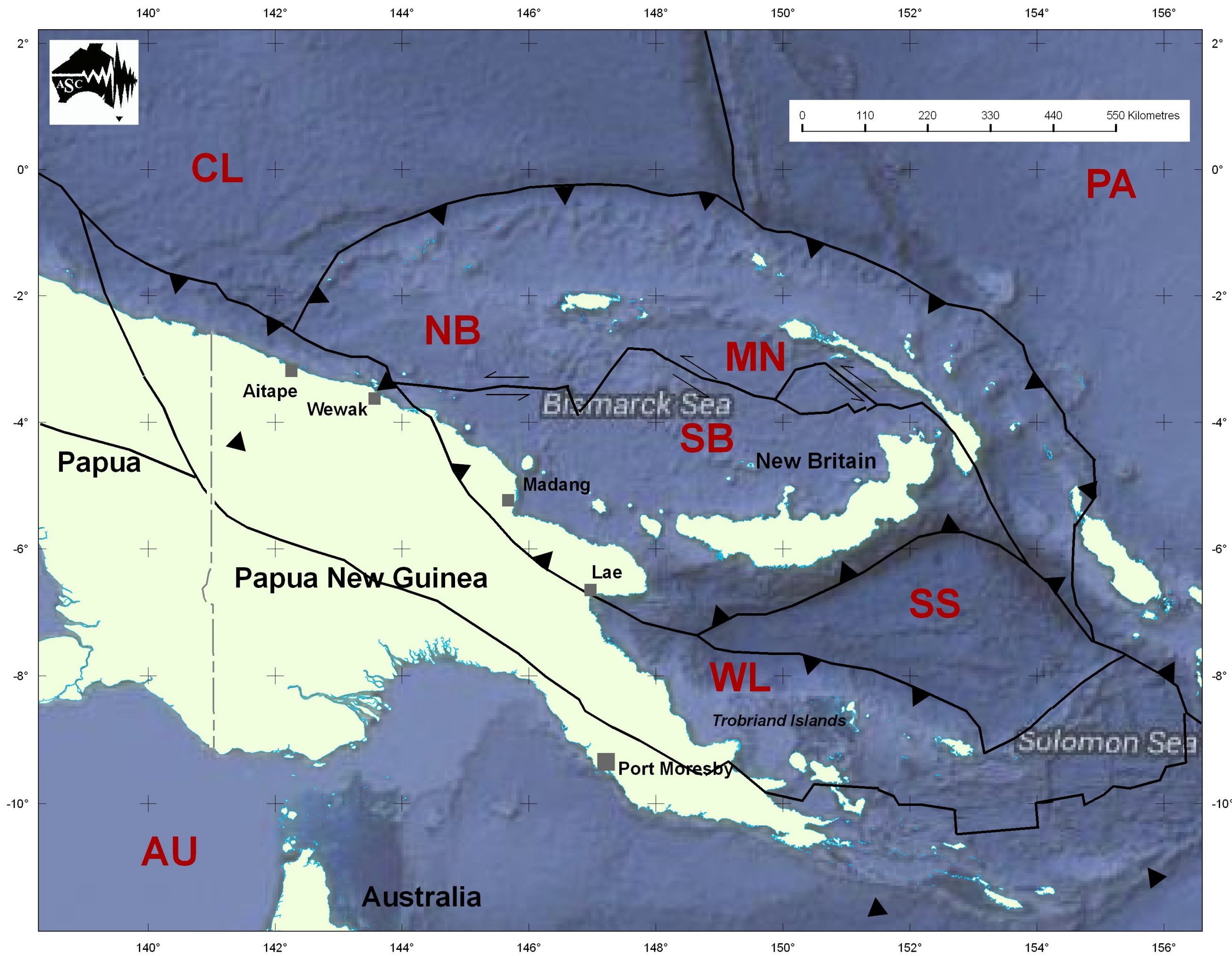

Figure 7.1 Plate configuration by Bird (2003) and Kelsey Lamothe. AU, CL, MN, PA, NB, SB, SS, WL are their postulated Australian, Caroline, Manus, Pacific, North Bismarck, South Bismarck, Solomon Sea and Woodlark Plates. Their Woodlark Plate extends from the Solomon Trench through the New Guinea Highlands to the Caroline Plate.

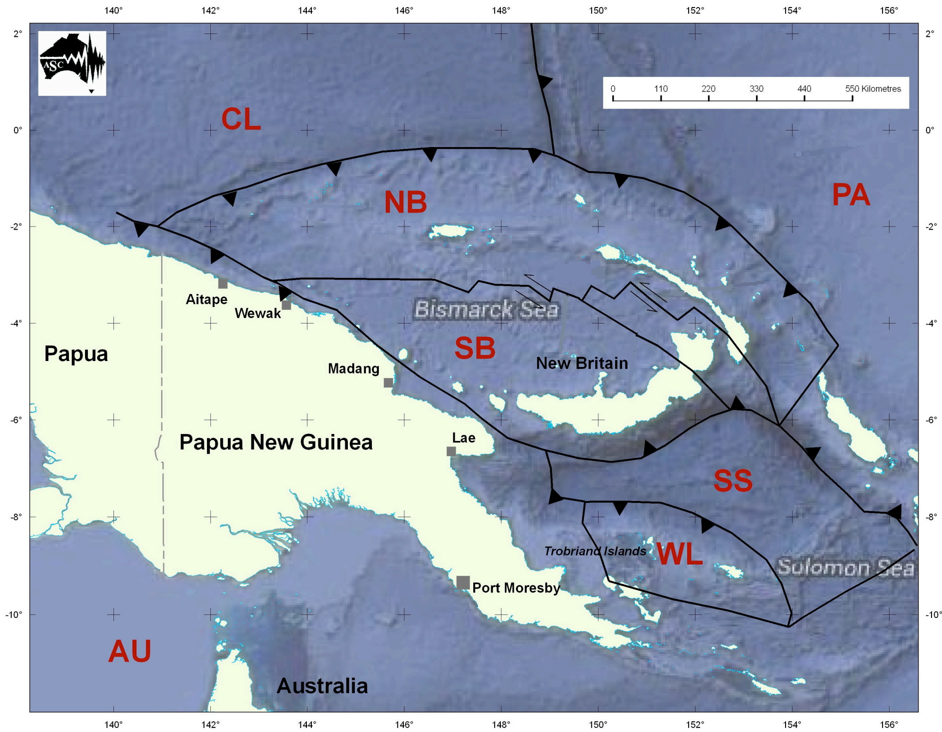

Figure 7.2 Plate configuration by Oregon State University (simplified from Hamilton 1979). They show an active Trobriand Trench where a Solomon Sea Plate (SS dips under a Woodlark Plate (WL).

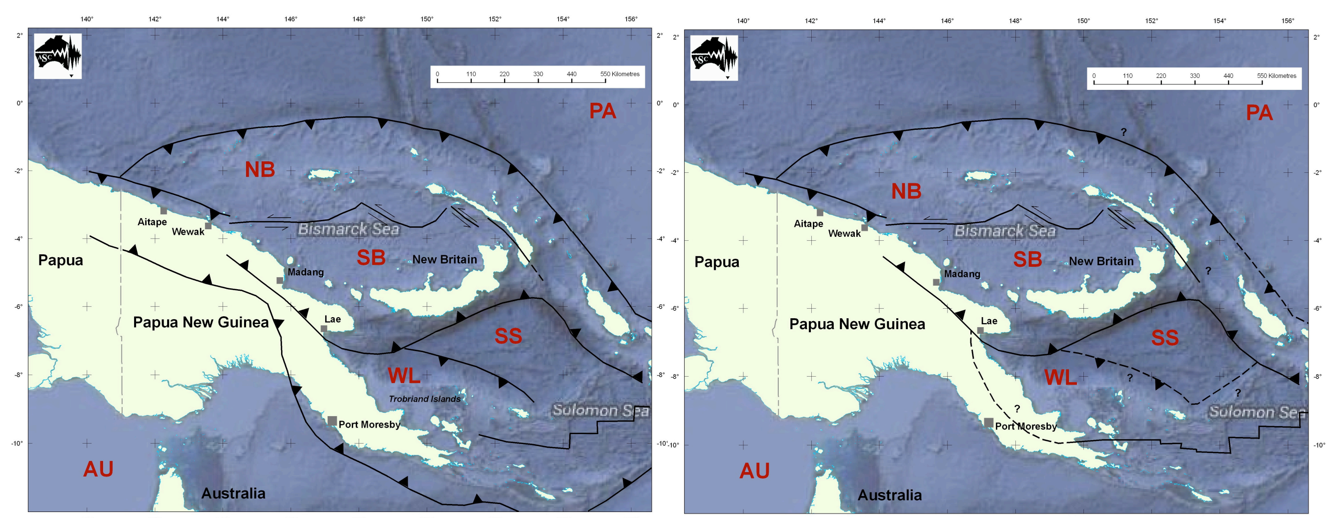

Figure 7.3 Two other postulated geometries (left) by Taylor and others (1991), and Tregoning and others (1998), the latter apparently querying the currency of the Trobriand Trough.

Our own preference is shown in Figure 8, based almost exclusively on the epicentres of the most recent shallow earthquakes, allowing for the large uncertainties in the locations. This is only possible in very active regions. The obvious boundaries of the Australian and Pacific Plates are constructed first, these then help define the smaller plate fragments in the collision zone between them, akin to the fault gouge in the shear zone of a low strain brittle collision. The type of boundary is defined by the earthquake focal mechanisms which also yield the apparent slip directions.

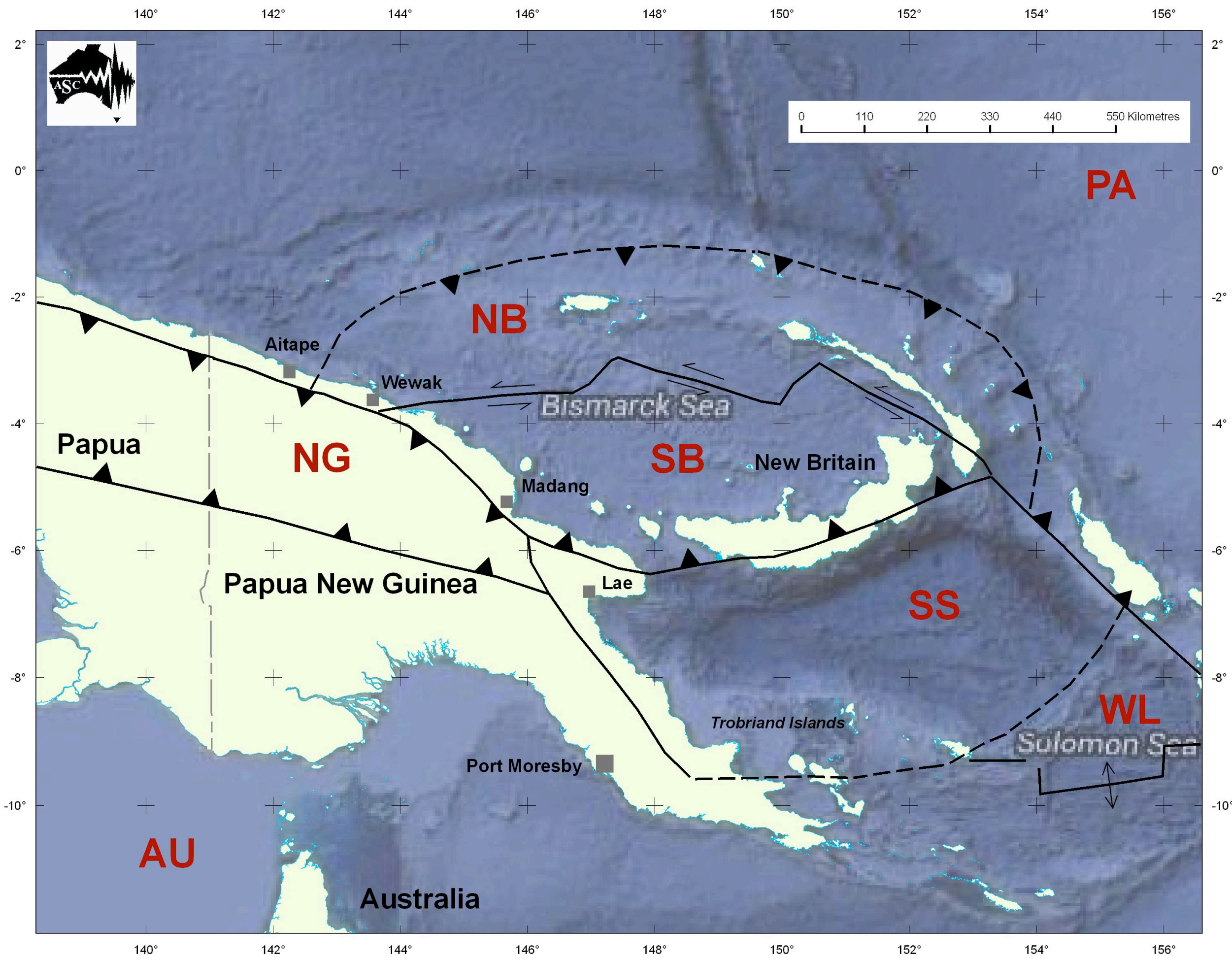

Figure 8. Plate geometry superimposed on the shallow seismicity as proposed in this paper, the Trobriand Trough not active. The Southern Highlands Seismic Zone on the southern boundary of the New Guinea block (NG) links to the Papuan Peninsula and Woodlark Spreading Ridge, the three comprising the north-eastern edge of the Australian Plate.

The 1895 earthquake, it's location and magnitude, the fact that it generated a significant local tsunami implying a shallow rupture and typical tsunamigenic mechanism should then fit into the tectonic model but it doesn't.

DISCUSSION

This study of the 1895 earthquake in the Solomon Sea has reduced the uncertainties in its location and magnitude to a more acceptable level using intensities, with data compiled from German and British colonial reports of the time. This led us to question the activity of the Trobriand Trench and thence the existence of a Woodlark Plate not only on the basis of the lack of more recent seismicity but also on the earthquake mechanism of one of the two large recent earthquake nearby. By our reckoning, the Solomon Plate would extend from the Woodlark spreading ridge in the south right through to the New Britain Trench in the north, and from the Bougainville Trench in the east to the Papuan Peninsula in the west.

The seismological data favour an undivided Solomon Sea Plate. On this interpretation the Trobriand Trough is inactive and the 1895 earthquake would then have been an intraplate earthquake with, consequently, a longer return period than if it had been an interplate event. Earthquake hazard assessments for the Trobriand Islands and region are quite dependent on the model adopted (see Ripper and Letz, 1993) and whether the Trobriand Trough is an active plate boundary or not is critical to the modelled outcome.

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