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SEISMOTECTONICS AND MECHANISMS OF TSUNAMI GENERATION ALONG ACTIVE BOUNDARIES OF YOUNG, MARGINAL SEA BASINS AND SPREADING RIDGES OF THE SOLOMON ISLANDS REGION – Case Study: The Earthquake and Tsunami of 1 April 2007 in the Solomon Islands

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ABSTRACT

The Solomon Islands region is characterized by high seismic activity. During the last 100 years there have been numerous strong earthquakes with periodic variation of recurrence. Some of them on either side of the Solomon Island Volcanic Arc have generated destructive tsunamis not only in the Solomons but also in neighboring Papua New Guinea. Most of the larger magnitude earthquakes occur on the northeast side of the Solomon Island Arc and Trench along a 350 km segment, close to the Islands of Guadalcanal and San Christobal. On the northeast side of the Solomon Island Arc larger ruptures of adjacent slabs are possible which could involve the New Ireland segment or the North Solomon Trench. However, significant earthquake activity occurs also along the southeast side of the Solomon Island Arc, but not as frequently. A great magnitude 8.1 earthquake on 1 April 2007 in the southeast region generated a tsunami that was particularly destructive in the Islands of the New Georgia Group of the Northwest Solomon Islands. The present study examines the impact of this earthquake and of the tsunami it generated, and reviews the seismotectonic setting of the Solomon Islands region for the purpose of understanding the regional mechanisms of tsunami generation along the active boundaries of young, marginal sea basins and spreading ridges.

Keywords: *Solomon Island Volcanic Arc and Trench; San Cristobal Trench; Woodlark Basin; Seismotectonics; Marginal Sea Basins; Spreading Ridges.*

1. INTRODUCTION

A great magnitude 8.1 earthquake on April 1, 2007 struck the New Georgia Group of the Northwest Solomon Islands and generated a destructive tsunami (Fig. 1). There were numerous fatalities in the Solomons and in Southeast Papua New Guinea. A few minutes later a second earthquakeof 6.7 magnitude, occurred 75 miles west-southwest of Chirovanga, Choiseul, Solomon Islands, and 1,410 miles north of Brisbane, Australia.

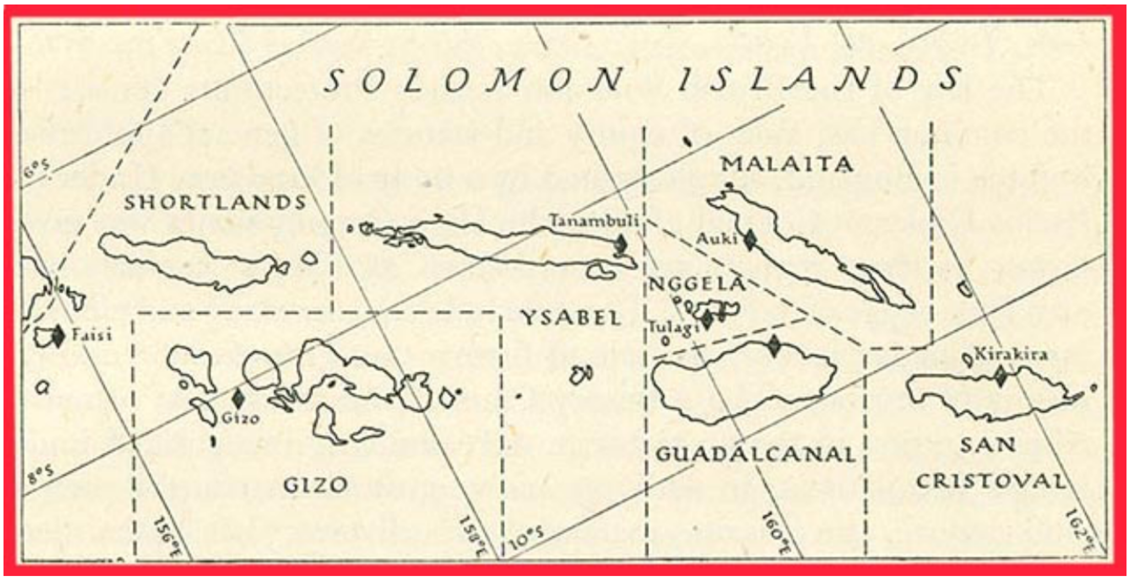

Fig. 1. The Solomon group of Islands

Tsunami waves of up to five meters in height struck mainly parts of the western province of the Solomon Islands. The waves were particularly destructive on Gizo, Noro and Taro Islands inundating as much as 50-70 meters (164-230 feet) inland. The waves were particularly destructive to buildings and homes. Large boats were washed ashore and communication links were wiped out. There was significant damage a Nusa Tupe island where the airport is located and the Provincial capital Gizo's main airport, hospital, and to coastal roads.

The Pacific Tsunami Warning Center (PTWC) in Honolulu issued a regional tsunami warning for the immediate area of the Solomon Islands, but because of the short time of the tsunami's travel time to the impacted areas, it did not help with timely evacuations. However a tsunami warning was expanded to include Papua New Guinea, Vanuatu, Nauru, New Caledonia, Northeastern Australia, Fiji, Chuuk, Pohnpei, Kosrae, Indonesia, Tuvalu, Kiribati, Kermadec Islands, Marshall Islands and New Zealand. An advisory was issued for Hawaii, but not a watch or warning. The warnings and advisory were cancelled nine hours later.

The following sections of this report examine the impact of this earthquake and of the tsunami, and a cursory review the seismotectonic setting of the Solomon Islands region for the purpose of understanding the regional mechanisms of tsunami generation along active boundaries of young, marginal sea basins and spreading ridges.

2. THE EARTHQUAKE OF 1 APRIL 2007 IN THE SOLOMON ISLANDS

On April 1, 2007, at 20:40 UTC, 7:40 a.m. local time (April 2, local date) a Richter magnitude 8.1, earthquake struck the New Georgia Group of the Northwest Solomon Islands and generated a destructive tsunami. Its epicenter was at 8.6° S., 157.2° E., or about 45km (25 miles) south-southeast of Gizo, a small fishing town on Gizo Island in the New Georgia Islands and 345km (215 miles) north-west of Honiara, (Fig. 2). Its focal depth was 10 km (6.1 miles). Based on the U.S.G.S. Centroid solution, the following values were estimated: Fault plane: strike=331 dip=38 slip=120; Fault plane: strike=115 dip=58 slip=69. A second quake of 6.7 magnitude a few minutes later, occurred 75 miles west-southwest of Chirovanga, Choiseul, Solomon Islands, and 1,410 miles north of Brisbane, Australia. According to residents at Gizo, the strong ground motions of the earthquake lasted for almost two minutes. The quake's motions were felt as far as Honiara, the capital of the Solomon Islands.

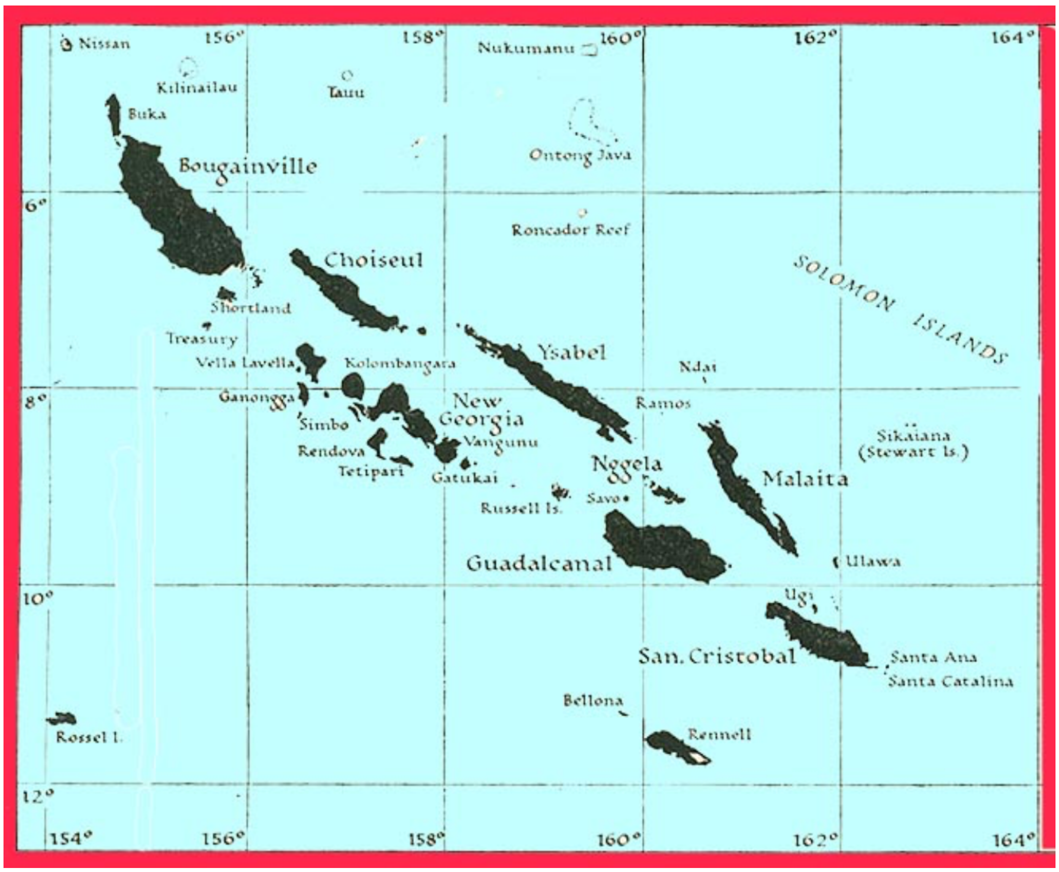

Fig. 2 Map of the New Georgia Group of the Northwest Solomon Islands.

There were several strong aftershocks following the main earthquake. The largest of these aftershocks, with a magnitude 6.4 struck at_11:45 hrs on _3 April 2007 near Gatokae and the surrounding areas of Marovo Lagoon in this Western province of the Solomon Islands.

3. THE TSUNAMI OF APRIL 2, 2007 IN THE SOLOMON ISLANDS

Destructive tsunami waves of up to five meters in height struck parts of Choiseul, Vella La Vella, Kolombangara, New Georgia, Gizo, Simbo and Ranoggah, in the western province of the Solomon Islands. The tsunami was particularly destructive at Gizo, Noro and Taro islands. The first tsunami wave reached the Gizo Township about five minutes after the earthquake. Fortunately the earthquake occurred during the day and most people seeing the sea receding moved to higher ground - thus many lives were saved. Ranunga Island was also struck by the tsunami.

There was substantial damage to the Western Provincial capital of Gizo and along the Entire Township and villages on the island. Gizo, the main town of about 1,000 people was hit by waves several meters high, destroying buildings, homes and washing people out to sea. Witnesses described the waves as inundating 50-70 meters (164-230 feet) inland. Communication links were wiped out. Large boats washed ashore and were deposited in the middle of the town. There was damage at Nusa Tupe Island, power failure and damage to telephone and extensive damage to Gizo's main airport and coastal roads. The Gizo hospital was inundated and was damaged extensively - making it inoperative.

On South Choiseul Island, waves of up to 10 meters in height swept through the village of Sasamunga. The waves penetrated up to 500 meters inland and destroyed at least 300 houses. Sasamunga lost its hospital and health centers. Also, the villages of Nukiki, Zepa and Luta sustained considerable damage. At Simbo Island the tsunami waves penetrated 200 meters inland. At Mono Island four people were reported missing.

In Southeast Papua New-Guinea, there were numerous fatalities. According to reports at least 50 people were killed (mainly by the tsunami) in the region. However, the death toll was probably greater since communications with remote islands were affected. According to the initial government damage assessment, about 916 houses were damaged or destroyed and about 50,000 people were affected.

Most of the damage occurred to the islands within the Woodlark Spreading Basin, where the tsunami energy was contained by the surrounding islands. However, a small tsunami was recorded by distant tide gauge stations. At Port Kembala (Australia) a 0.2 ft wave was registered with a 14 minute period. At Vanuatu, the recorded wave was 0.15 ft and the period ranged from 22 to 28 minutes. At Cape Ferguson (Australia) the tide gauge recorded 0.11 meter (0.4 ft) and a period of 12 minutes. At Manus (Papua-New Guinea) the tide gauge recorded 0.3ft maximum wave height and a period of 40 minutes. At Honiara (Solomons) the tide gauge recorded 0.6 ft and a period of 62 minutes.

4. PAST GREAT EARTHQUAKES AND TSUNAMIS IN THE SOLOMON ISLANDS REGION

Most of the earthquake activity on the northeast side of the Solomon Island Arc occurs along a 350 km segment of the North Solomon Trench close to Guadalcanal and San Christobal Islands. The region has produced about 10 major earthquakes in the last fifty years including the Ms 7.7 on June 15, 1966 and the Ms 7.7 on February 7, 1984 events (Richter magnitudes). The two great earthquakes of 14 and 26 July 1971 (about 12 days apart) had rather high moment magnitudes of Mw=9 and Mw=8.1. The earthquake of July

14, 1971 had its epicenter at 5.50 South 153.90 East in the New Ireland, Bismark Sea Region. The July 26, 1971 earthquake had its epicenter at 4.94 South, 153.17 East in the same region. Earthquakes in this region appear to occur as doublets, often within a few days of each other. Also, a great deal of strong earthquake activity occurs along the southeast side of the Solomon Island Arc.

As the April 2, 2007 event demonstrated, the region is capable of triggering great earthquakes and destructive tsunamis. On July 21, 1975, a magnitude 7.9 earthquake (epicenter at 6.60 South, 154.90 East), further north along the San Cristobal Trench, generated a large tsunami which hit Bougainville Island and killed an estimated 200 people. It is believed that the same tsunami was destructive also in the same western province of the Solomon Islands, but no details are available.

Major and great earthquakes can occur on either side of the Solomon Island Volcanic Arc. On the northeast side of the Solomon Island Arc larger rupture of adjacent slabs are possible which could involve the New Ireland segment or the North Solomon Trench. The most significant earthquake that would occur in the area that could approach an M9 magnitude earthquake would be expected near the Solomon Sea-Bismarck Sea triple junction, or one closer to the 1971 events. Any large earthquake in the region could generate a destructive local tsunami.

5. SEISMOTECTONIC SETTING OF THE SOLOMON ISLANDS REGION - UNDERSTANDING REGIONAL MECHANISMS OF TSUNAMI GENERATION ALONG ACTIVE BOUNDARIES OF YOUNG, MARGINAL SEA BASINS AND SPREADING RIDGES

In view of the high seismic activity of the Solomon Islands region, and in order to understand regional mechanisms of tsunami generation, the folowing is a cursory review of the prevailing tectonic interactions.

The Solomon Islands - an archipelago of 492 islands - is a volcanic arc along an extensive tectonic zone situated at an active margin boundary of two converging plates, where earthquakes occur frequently. The seismotectonic dynamics, geometry and direction of subduction in this volcanic arc region are complicated. Fig. 3 is a simplified diagram illustrating the type of oceanic/oceanic crust convergence occurring near the Solomon Islands Arc.

The spatial distribution of earthquakes on both sides of the Solomon Island Arc supports the existence of several subduction zones. Along the entire plate margin, there is not one simple plate boundary but a cluster of small plate boundaries which accommodate the mechanisms of the total interaction in the region (Brooks, 1965; Denham, 1969). The geometries of subduction differ for segments along the entire Papua-New Guinea and Solomon Islands region. One has to look at the geologic history of the entire Southwest Pacific to understand the complex evolutional dynamics that control present seismicity (and tsunami generation mechanisms) on both sides of the Solomon Island Arc.

Ontong-Java Plateau begun to collide with the Solomon Islands section of the Outer Melanesian Arc, but several major events that followed resulted in the break-up and segmentation of the Arc. At the outset, the direction of subduction beneath the Solomon Islands and Vanuatu arcs was reversed. The subduction of the Pacific Plate stopped, and eastward subduction of the back-arc basins beneath the Solomon and Vanuatu Arc segments, begun.

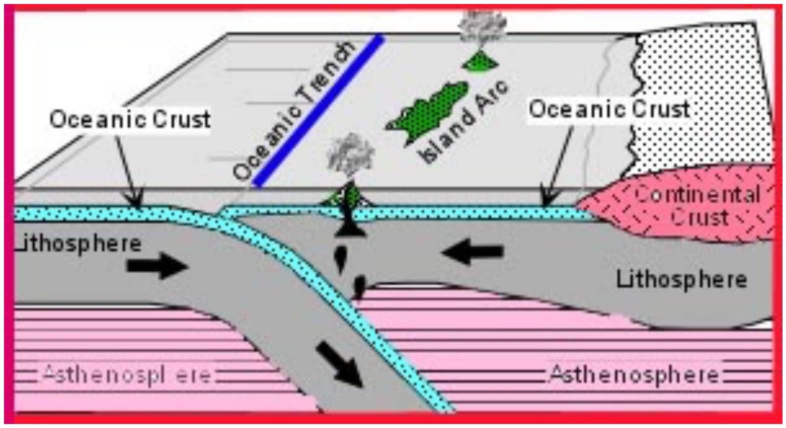

Fig. 3 Illustration of Oceanic/Oceanic Crust Convergence along certain regions of the Solomon Island Arc

In brief, the Solomon Island Arc is migratory arc system which developed from the early Eocene to Late Miocene as part of a continuous Outer Melanesian Arc (Rodd, 1993). The Arc extended from Papua New Guinea through the Solomon Islands, Vanuatu, Fiji and Tonga/Lau, to New Zealand. According to Rodd (1993), in the Late Miocene, the oceanic Ontong-Java Plateau collided with the Solomon Islands section of the Outer Melanesian Arc. Fig. 4 (modified after Goodliffe et al. 1999), shows the GrapBathymetry, Spreading Center, the Woodlark Ridge, and the Woodlark Spreading Basin in relation to the San Cristobal Trench in the vicinity of the New Georgia islands Group of the Solomon islands. The tsunami generating source area of the April 1, 2007 is pointed by the arrow and is near southwest subduction zone of the New Georgia Group of islands.

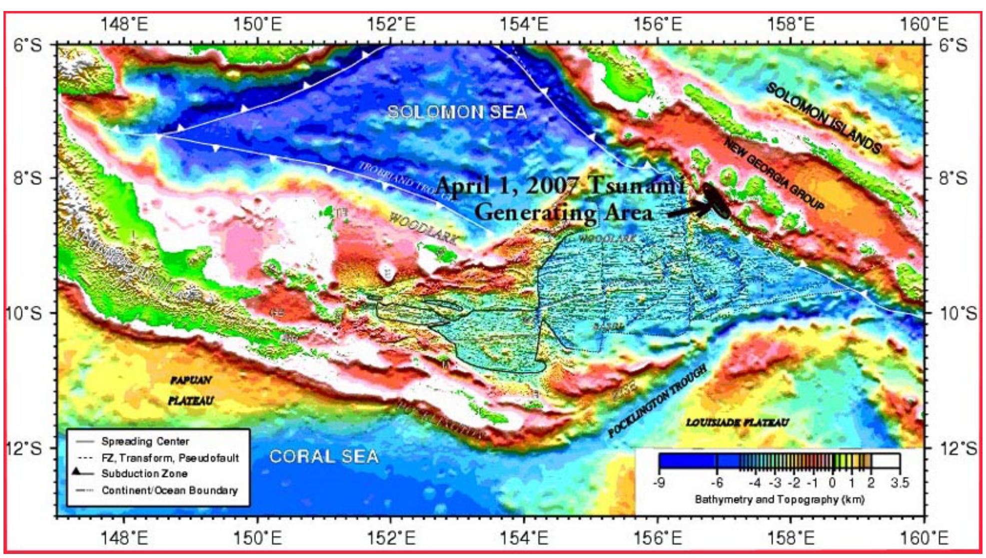

Fig. 4 Graphic showing Bathymetry, Spreading Center, the Woodlark Ridge, and the Woodlark Spreading Basin in relation to the San Cristobal Trench in the vicinity of the New Georgia islands Group of the Solomon islands. The tsunami source area is that pointed by the arrow. (Modified after Goodliffe et al. 1999)

In recent years, several research investigations have been undertaken in the region to help understand present processes of subduction, accretion and fragmentation of oceanic plateaus at subduction zones and their deformational effects on the overriding Solomon island arc (Mann, 1997; Mann et al. 1997, 2004; Mann & Taira, 2004; Goodliffe et al. 1997, 1999; Phinney et al. 1999, 2004; Martinez et al. 1999; Miura et al. 2005; Taira et al. 2004; Taylor et al. 1995, 1999, 2005; Cowely et al. 2004).

The researchers are looking at different models of tectonic interactions. For example, one of the models postulates wedging of the Solomon Island Arc beneath the Ontong Java plateau - the largest oceanic plateau in the world - Northeast of the Solomon Islands. The other model postulates an oceanic accretionary wedge geometry with northeastward component towards the Ontong Java plateau (Fig. 5).

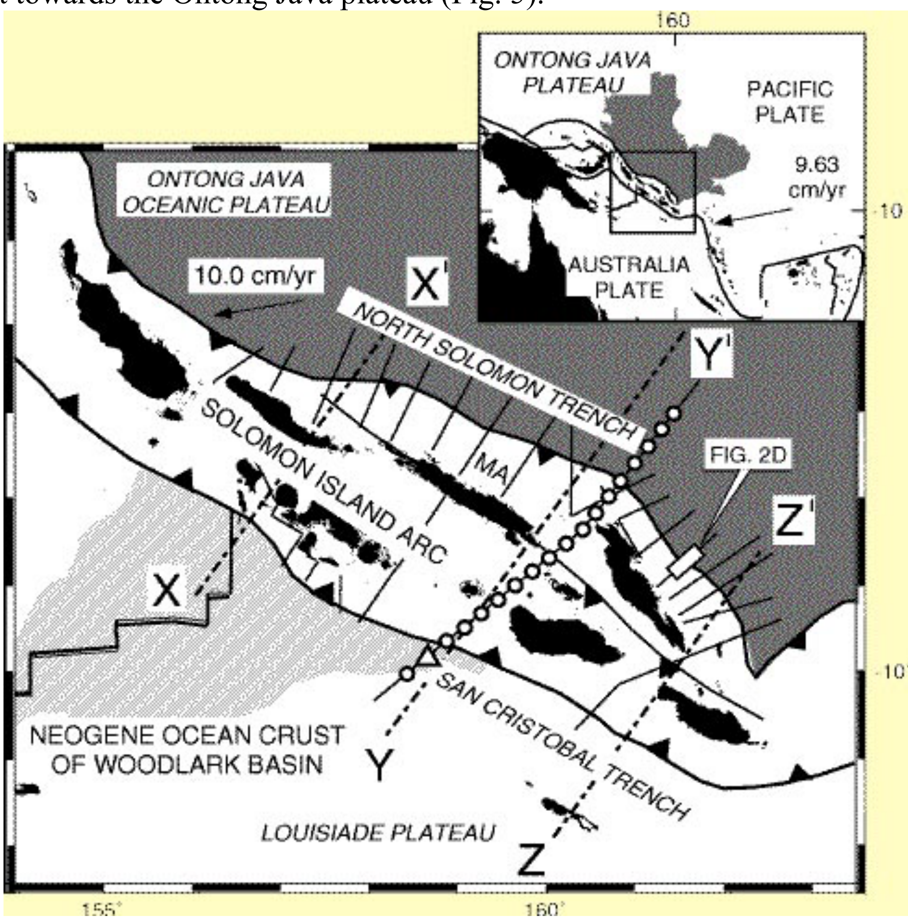

Fig. 5. Map of the University of Texas (Institute of Geophysics from studies conducted in the Solomons) showing the Ontong Java Institute of Geophysics Oceanic Plateau, and the North Solomon Trench on the Northeast of the Solomon Island Arc and the San Cristobal Trench in relation to the Woodlark Ridge and Spreading Woodlark Basin on the Southwest.

On the Southwest side of the Solomon Island Arc near the New Georgia Islands where the April 1, 2007 earthquake occurred, the tectonics are also very complicated - as also illustrated by Figure 6 (Yu-Ting Kuo, et al, 2017), and additionally supported by GPS observations.

The April 1, 2007 earthquake occurred near the suduction zone in close proximity to the San Cristobal Trench, on the east end of the Woodlark Basin and very near the triple junction formed by the subduction of the Woodlark Spreading Ridge.

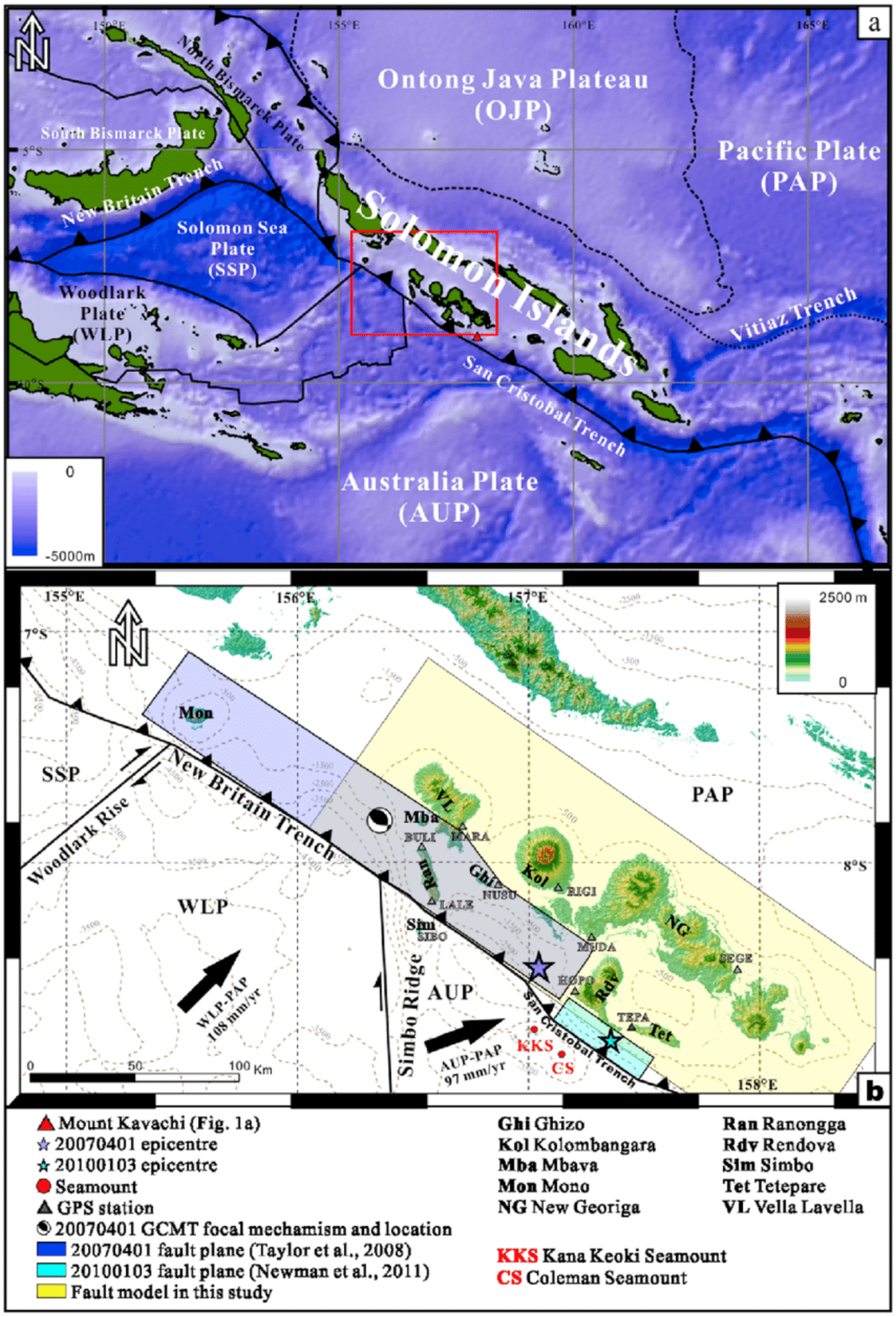

Fig. 6. Bathymetry and plate tectonic features around the Solomon Islands (red box represents region shown in Figure 1b). (b) Plate tectonic setting for the Western Solomon Islands and the inferred rupture zones of the 2007 and 2010 earthquakes (After Kuo et al, 2017)

The April 1, 2007 earthquake's estimated rupture, with an orientation of about 331 degrees, parallels the orientation of the direction of the axis of the San Cristobal trench Fig. 6). As stated, the Woodlark Basin is a young marginal basin which is both propagating westward (from a spreading center) into the Papuan Peninsula while - at the same time - spreading and being subducted eastward beneath the Solomon Islands (Taylor et al. 1995, 1999, quoting Weissel et al., 1982) - in this case beneath the New Georgia Island Group.

It is difficult to comment further on the dynamics of the region and its potential for future tsunami generation as there is no known historical tsunami data. As pointed out (Shinohara et al. 2003), without detailed and accurate seismicity studies, it is difficult to accurately describe the plate subduction processes of this complex zone. The region does not represent a typical subduction zone as other tsunamigenic areas of the world - since there is spatial progression from continental rifting to seafloor spreading and to shallow subduction at the eastern margin of the Woodlark Basin. Such mechanism of shallow subduction beneath a volcanic island arc can account for large earthquakes and destructive tsunami generation. However - and although earthquakes in this region that can occur may be large in magnitude - the rupture lengths may be limited, the tsunami generating areas may be relatively small, and the tsunami impact may be confined by the physical barriers and the local bathymetry of the Woodlark basin and of surrounding island groups trapping tsunami energy. Thus, no tsunami with far reaching impact can be expected from this region.

6. CONCLUSIONS

The great magnitude 8.1 earthquake of 1 April 2007 that struck the New Georgia Group of the Northwest Solomon Islands, generated a tsunami particularly destructive on Gizo, Noro and Taro islands. The rupture length of this earthquake was limited, the tsunami generating areas was relatively small and the tsunami impact was confined by the physical barriers and the local bathymetry of the Woodlark basin and by the surrounding island groups, which trapped and contained most of the tsunami's energy. No significant waves were recorded by distant tide stations. This indicates that no tsunami with far reaching Pacific Ocean impact can be expected from the Woodlark basin region.

In general the present study confirmed and concluded that the seismotectonic dynamics of the Solomon Islands region and the mechanisms of tsunami generation along active boundaries of young, marginal sea basins and spreading ridges are complex. Destructive local tsunamis can be generated on either side of the North Solomon Islands trench and volcanic Island arc - which are bounded by zones of opposing subduction where strong earthquakes occur frequently.

It is difficult to accurately describe the plate subduction processes of this complex zone. The region does not represent a typical subduction zone as other tsunamigenic areas of the world. In this region there is spatial progression from continental rifting to seafloor spreading and to shallow subduction at the eastern margin of the Woodlark Basin.

Several research investigations of the region have been taken to help understand present processes of subduction, accretion and fragmentation of oceanic plateaus at subduction zones and their deformational effects on the overriding Solomon island arc. Such mechanisms of shallow subduction beneath a volcanic island arc can account for large earthquakes and destructive tsunami generation. However, in spite of the fact that earthquakes in this region may be large in magnitude - the generated tsunamis are locally destructive but historically do not have far reaching Pacific-wide destructive impact.

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