Solomon Island earthquake and tsunami damages reef, affects local economy

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Introduction

The 2007 Solomon Islands earthquake and tsunami (Fisher et al., 2007) will leave a significant imprint on both the geology and economy of the region. The earthquake sheared off and uplifted coral reef colonies, reactivated landslides, and rattled the nerves of the local population. The tsunami moved large volumes of sediment, some created by the earthquake, on to land and into deeper water. Piles of lagoonal coral species at the base of channels in the barrier reef, covered by finer grained lagoon and beach sediment have a higher chance of preservation as paleotsunami deposits than material deposited on land. Damage to the reef, however, will also have long-lasting implications of the local economy which relies heavily upon fisheries and dive tourism.

Our team of geologists, which included Solomon Islands governmental geologists, the regional geoscience commission (SOPAC), and local dive experts, visited the region one month after the event. A team of civil engineers arrived earlier to collect ephemeral data such as wave heights (Fritz and Kalligeris, *in press*), and communicated to us the best sites for sediment accumulation. We completed elevation and sediment sampling transects in the tsunami-affected on shore areas using standard methods (e.g. Moore et al., 2006). We documented the offshore effects using SCUBA diving, snorkeling, and an off-the-shelf sidescan sonar/bathymetry system (see Tronde-Inge et al., 2002 for description). A separate, but complimentary team documented the landslides using aerial surveys and field verification.

The Earthquake and Tsunami. On 2 April 2007 (7:39 AM local time) the subduction zone ruptured in an Mw=8.1 earthquake. The rupture zone extends for 100 km west of Gizo, the capital of the Western Province, stopping south of the Shortland Islands (Fisher et al., 2007; Figure 1). According to eyewitnesses, the lagoons emptied as soon as the

shaking stopped, and was quickly followed by the positive surge. The earthquake and tsunami combination was responsible for 52 deaths (Table 1).

Observations and Discussion. We visited severely damaged villages on the islands of Ghizo, Ranongga, Simbo as well as several small, uninhabited reef-islands around Ghizo (Njari, Makuti and Nusa Aghana). With the exception of Ranongga, each of these locations has a low-energy lagoon bordered by a barrier reef and a sandy beach. Each village is also located at a natural channel in the reef, which may have contributed to the damage.

The tsunami hit the villages we visited with similar magnitudes (Tapurai, 10 m; Pailongge, 6 m; Titiana, 6 m- Fritz and Kalligeris, *in press*). While each village exhibited substantial structural damage, the wave varied in its power. In Pailongge and Titiana, on Ghizo, homes made of thatched grasses and palm fronds were lifted off their foundations, floated some tens of meters inland, and deposited with surprisingly minimal structural damage (Figure 2a). Vehicles in these villages were not rolled, suggesting that the wave came in not as a turbulent bore, but rather as a rapidly-rising tide. It is possible that the steep morphology of the barrier reef reflected the majority of tsunami energy back out to sea to be dispersed, and the long wavelength provided a considerable amount of water to spill over into the lagoon and on to land. At Tapurai where the barrier reef-lagoon system is not as well developed, all structures in the tsunami affected area were destroyed, suggesting a wave with higher turbulence.

Mortality exhibited distinct variations between villages (Table 1). As mentioned above, the tsunami hit both Pailongge and Titiana with similar magnitudes, yet 13 people died in Titiana (6 of which were children under 8 years old), and none died in Pailongge. The people of Titiana are of Gilbertese (Polynesian) descent who migrated to the Solomons in the 1950s, and have no indigenous knowledge of tsunamigenic earthquakes. Many were exploring the lagoon as it emptied with the leading depression wave, and were overwhelmed by the subsequent peak. The Melanesian populace of Pailongge, however, gathered together the oldest and youngest members of the community and headed for higher ground after the shaking stopped, demonstrating an effective use of indigenous knowledge that saved their lives.

In the lagoons adjacent to these villages, the reef colonies also exhibited varying degrees of damage. Delicate colonies of *Acropora sp.* branching and table corals, along with *Porites sp.* coral heads which have evolved to thrive in low energy environments, were sheared off at their narrow bases, and came to rest near their original growth positions (Figure 2b). Had the tsunami been responsible for the damage, we would have expected to see more evidence of significant sediment transport, such as battering of table corals or transport away from their growth positions. We observed further evidence of strong shaking on the barrier reef at Nusa Aghana, where large boulders were broken off and deposited in deeper water underneath a fine layer of sediment.

This fine sediment layer was present at most locations. The earthquake and tsunami mobilized a great deal of sediment- in the lagoon, beach, and even on land. As the tsunami passed through the lagoon and over the beach, it picked up sediment which it subsequently deposited on land. At Tapurai, the deposit consisted of a mélange of lagoon and beach sediment combined with boulders from the hillside that backs the village. At Pailongge and Titiana, the sediment was mostly derived from the lagoon, and included

both fine grained coral and *Halimeda* fragments from the beach and lagoon, along with boulders from colonies killed by the event.

The volume of subaerial sediment deposits rarely accounts for the degree of sediment mobilized (Caminade et al., 2000; Moore et al., 2006), so a question remains as to the fate of this lost sediment. The redistribution of sediment disturbed the system's equilibrium, both on land and in the lagoon. Swift tidal currents in the lagoons reestablish the equilibrium by moving sediment choking their pre-event channels into deeper water via chutes and channels in the barrier reef. These same chutes and channels undoubtedly funneled some of the tsunami backwash out to sea, and subsequently removed some of the earthquake-generated sediment (i.e. broken coral colonies) into deeper water at the base of these channels (Figure 2c). During the weeks following the event, littoral processes continued to redistribute sediment, covering the tsunami-removed debris with a layer of finer grained material.

Coseismic land level changes caused further damage of the coastal ecosystems. On Ranongga, the 3 m+ uplift on the SE coast killed off vast stretches of coral, affecting ocean access (Figure 2d). At Kolokukunde, the estuary and associated mangrove swamp are now disconnected from the sea, which will affect the offshore fish nurseries (Figure 2e).

Numerous earthquake-induced landslides affected Ranongga, and to a lesser extent Vella Lavella where a landslide destroyed the health clinic at Leona village (Figure 2f). We found over ~~200~~ landslides on Ranongga alone. Two people were killed at Mondo village, which is located at the base of a reactivated landslide complex. Twelve other villages on Ranongga (1341 people) that are at risk of future landsliding. Debris choked streams on Ranongga, Vella Lavella, and Kolombangara present additional hazards as sediment may be mobilized following significant rainfall events. The Solomon Island government is considering relocating many of these villages.

Local Population's Recovery

The economic demographics and physical remoteness of the affected region left the population acutely exposed to this hazard. The earthquake destroyed buildings made from local resources, damaged the coral reef that sustains a large portion of the region's economy, and jeopardized water supplies and coastal access. While the earthquake/tsunami hazard has been reduced, reactivated landslides and debris-clogged streams are now increasingly hazardous to numerous villages.

Rapid economic recovery has the potential to mitigate the effects of the disaster, so it is critical that people resume their livelihoods as soon as possible following a disaster. Fishing and dive tourism account for a substantial proportion of the region's economy (~60% according to a local businessman and Member of Parliament), and each industry relies on the coral reef surrounding the islands. The earthquake damaged the delicate ecosystems that provide habitat for fish and scenery for divers, and it is still unclear how they will be affected. The World Wildlife Federation and World Fish Center in Gizo will continue monitoring fish stocks and coral reef recovery.

The most effective scientific educational and outreach efforts were made by officials from the Solomon Islands' government (NDMO, Department of Mines and Energy) working in concert with the regional geosciences authority (SOPAC) and non-

governmental organizations in the affected area. They speak the local *pijin* dialect, and recognize cultural subtleties that take varying degrees indigenous knowledge into consideration for future mitigation efforts (McAdoo et al., 2006). Local educational efforts such as these are especially critical in the near-field where buoy-based tsunami warning systems are of little benefit.

Conclusions. The coastal ecosystems (coral, fisheries, mangroves, and human) were most affected by the geologic changes associated with this earthquake and tsunami. The earthquake killed vast stretches of coral, both by strong shaking and coseismic uplift. Similarly, the uplift changed the hydrologic regime of estuaries and mangrove forests, causing widespread mortalities. The nursery services these ecosystems provide will likely affect fish stocks for years to come, and the situation must be closely monitored. Declining fish stocks not only affect the region's food security, but has broader economic implications associated with a potential decline in the dive tourism industry. Post-disaster recovery efforts must consider these implications to properly plan redevelopment options. Villages situated on reactivated landslides must have the highest priority for relocation as their risk is increased, whereas the tsunami affected villages should be rebuilt in the same locations with the tsunami recurrence interval in mind. As we do not know the long-term tsunami recurrence interval in this region, future studies need to know how paleotsunami deposits manifest themselves in this region, and then focus on the frequency and magnitude of past tsunamis.

Acknowledgements

Without the help of the Government of the Solomon Islands and the National Disaster Management Office we would not have been able to complete our research. B. Manele and J. Thomas at World Wildlife Fund Gizo, Save the Children, World Vision, and UNICEF also provided assistance, as did L. Kong at UNESCO. D. and K. Kennedy and G. Griffiths in Gizo coordinated the logistics. This work was funded by the United States National Science Foundation Small Grants for Exploratory Research program (EAR-0734982) in concert with a NSF Partnership in International Research and Education Grant (OISE-0530151), and the sonar equipment was provided by Weston Geophysical.

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	Population (% of affected pop.)	Number of Dead (% of village pop.)	Children (under 10) dead (% of dead)
Ghizo			
Gizo	3302 (77.6%)	2 (0.1%)	0
New Manra	*206 (4.8%)*	*8 (3.9%)*	*5 (62.5%)*
Titiana	*366 (8.6%)*	*13 (3.6%)*	*8 (61.5%)*
Pailongge	76 (1.8%)	0	0
Kolombangara	89 (2.1%)	0	0
Nusa Mbaruku	*216 (5.1%)*	*10 (4.6%)*	*8 (80.0%)*
TOTAL	**4255**	**33**	**21**
Simbo			
Tapurai	234 (85.4%)	7 (3.0%)	1 (14.3%)
Riguru	40 (14.6%)	2 (5.0%)	0
TOTAL	**274**	**9**	**1**
Ranongga			
Mondo	341 (100%)	2 (0.6%)	0
TOTAL	**341**	**2**	**0**
Vella Lavella			
Sambora	319 (76.7%)		0
Lambulambu	97 (23.3%)	2 (2.1%)	2 (100%)
TOTAL	**416**	**2**	**2**
Choisuel			
Luti	101 (24.6%)	1 (1.0%)	0
Lologae	9 (2.2%)	1 (11.1%)	0
Sagiae	21 (5.1%)	1 (4.8%)	0
Sepa	165 (40.2%)	1 (0.6%)	0
Sasamunga	114 (27.8%)	2 (1.7%)	0
TOTAL	**410**	**6**	**0**
GRAND TOTAL	**5696**	**52 (0.9%)**	**24 (46.2%)**
Gilbertese	***788 (13.8%)***	***31 (59.6%)***	***21 (87.5%)***

Table 1. Mortality statistics. Island name in bold, followed by community name. The immigrant Gilbertese population (in italics) suffered higher per capital mortality rates than the indigenous Melanesian populations. Children also made up for a high percentage of deaths. Data from the National Disaster Management Office, Gizo.

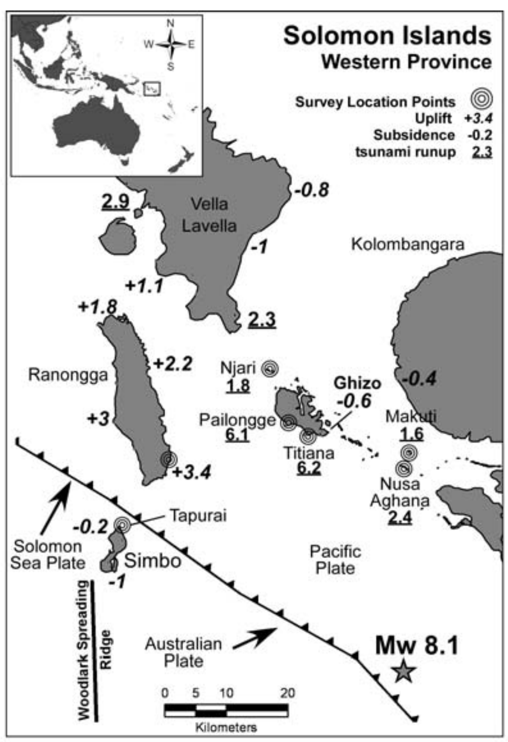

Figure 1. Index map of the Solomon Islands' Western Province. Concentric circles represent sites visited on this survey. Values in italics correspond to uplift (+) and subsidence (-), and underscored numbers are tsunami runup. Data points outside of our survey come from Fritz et al. (in press), and Nishimura et al. (personal communication). Arrows represent plate convergence directions (Mann et al., 1998)

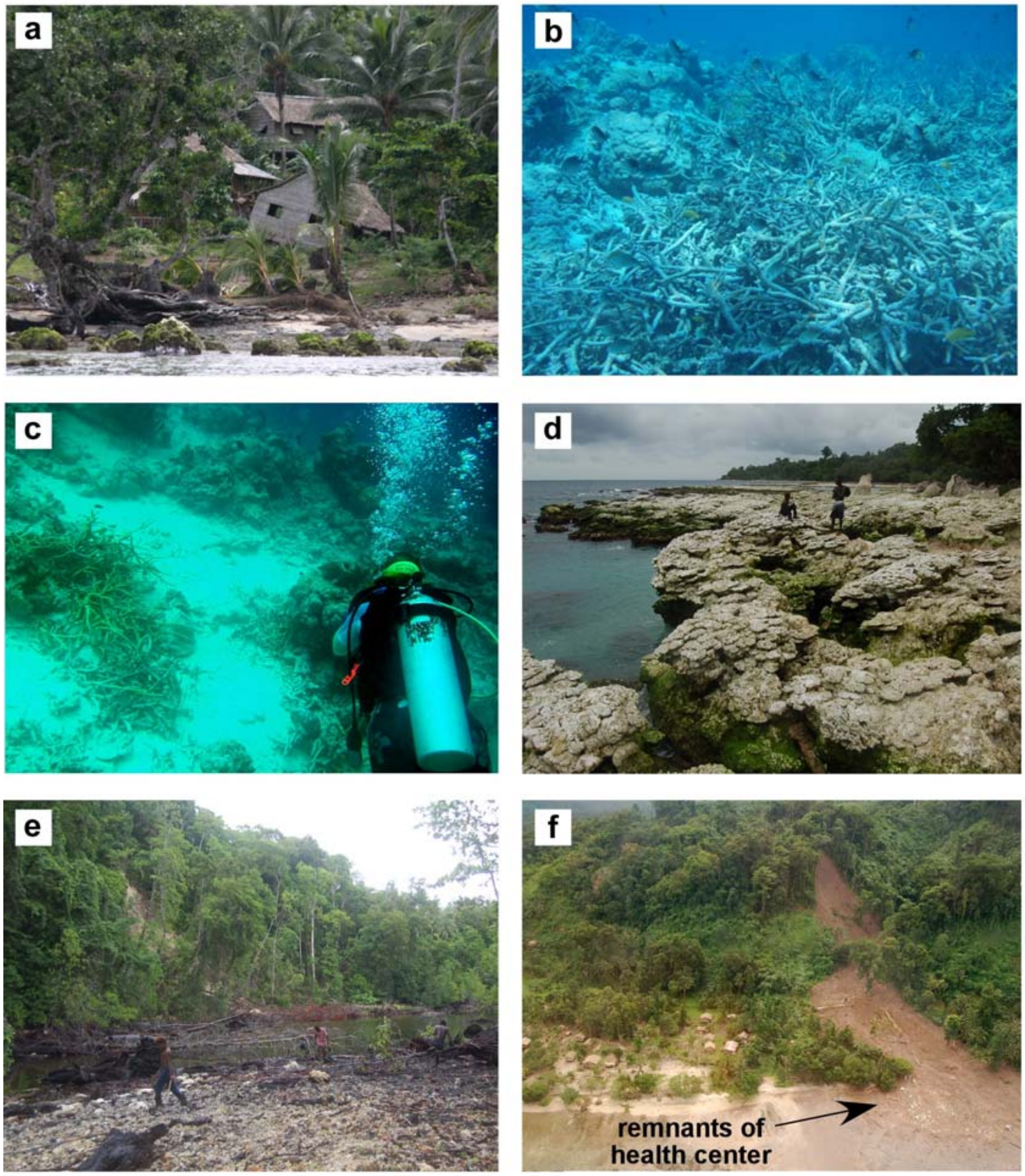

Figure 2. Examples of tsunami damage. a) At Pailongge, large coral boulders were deposited at the head of a channel in the barrier reef. Despite the strength of the wave here, houses (background) were floated off their foundations and pushed several meters back. b) Branching *Acropora sp.* coral colony at Njari after the earthquake. The sheared off colonies came to rest near their original growth positions, indicating that damage was done by the earthquake, not the tsunami. c) *Acropora sp.* colonies along with finer-grained lagoon sediment delivered from the Njari lagoon into deeper water via a series of chutes on the barrier reef. d) Uplifted reef on the SE coast of Ranongga. e) The Kolokukunde estuary, SE Ranongga, was turned into a river following the earthquake and uplift, which could affect fish nurseries. f) A landslide at Leona village on Vella Lavella, destroyed the local health center. The risk for communities affected by landslides is perhaps higher due to landslide dams blocking streams that could burst.