Preliminary Report Regarding Coral Reef and GPS Measurements of Crustal Deformation Associated with the 2 April 2007 Gizo Great Earthquake

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Abstract

The 2 April 2007 earthquake, with an epicenter southeast of Gizo, ruptured several segments of the Solomon Islands arc convergent plate margin along the northern side of the San Cristobal-New Britain trench extending from near the southwest corner of Rendova Island until approximately the eastern end of Bougainville. A zone of uplift parallels the trench and approximately overlies the seismic rupture zone. Parallel to and along the northern side of the uplift zone is a wider zone of subsidence. Our observations of vertical movements from coral reefs and shorelines confirm a lack of uplift of southern Rendova and Tetepare. Instead, we found slight subsidence of southern Rendova and the eastern end of Tetepare. This indicates that the swath of uplift terminates somewhere west of Rendova. On this basis, we infer that rupture of the interplate thrust zone did not propagate from the epicenter eastward past Rendova and Tetepare Islands despite there being some aftershocks reported in this area. This observation leads us to seriously consider the possibility that the sooner or later the interplate thrust zone beneath Rendova and Tetepare and farther eastward could rupture and produce a large thrusting earthquake and tsunami. Furthermore it is also possible that failure of the interplate thrust zone on April 2 has increased stress on the fault farther east as may be indicated by slight subsidence of southern Rendova and western Tetepare. An alternative interpretation of reduced seismic hazard for Rendova and Tetepare Islands could emerge if our GPS measurements on Rendova Island indicate that significant aseismic slip has occurred beneath Rendova Island over recent years or following the April 2 earthquake. The possibility of a future Rendova-Tetepare earthquake is supported by the existence of fossil coral reefs on Rendova Island that document uplifts of 1-3 m during the past few

thousand years. The last such event is dated by ^{14}C at roughly 300 years ago. This provides clear evidence that episodic uplifts have occurred in the past at Rendova and Tetepare Islands and that it is likely that these uplifts were seismic and could have generated large tsunamis. Some large coral blocks on the shores of Tetepare could have been emplaced by such large tsunamis. However, we do not predict that a large Rendova-Tetepare earthquake is imminent. We can only say that such events have occurred and are certain to occur again sooner or later and that the 2 April event has the potential to accelerate the timetable for new events. Ranongga also had large uplifts in the past similar to that of 2 April 2007. However, because the interpolate thrust zone beneath Ranongga did rupture we believe that the potential for large thrusting earthquakes at Ranongga probably will be relatively low for the next few decades until more elastic energy accumulates in that area.

Introduction

On 2 April 2007 a "Great" earthquake occurred along the convergent plate boundary at the southern margin of the Solomon Islands arc with the epicenter located off the coasts of Gizo and Parara. Great earthquakes are designated based on a Richter scale magnitude of Ms $\geq$ 8.0 and occur on average only once every few years. The earthquake rupture propagated westward past Ranongga and the Shortlands and terminated near the eastern end of Bougainville. This rupture crossed Simbo Ridge, a transform fault system, separating the Australian and Solomon Sea Plates. Thus, the earthquake involved coseismic slip of both the Australian and Solomon Sea Plates, which have different convergence rates and directions relative to the Solomon islands. Convergence rates of the Australian plate at the New Georgia Group are ~ 100 mm/yr toward ~N75º W while the Solomon Sea Plate converges with the area farther west at a rate of ~130 mm/yr in a direction nearly perpendicular to the arc trend. These very rapid tectonic plate convergence rates have the potential to generate numerous shallow subduction zone earthquakes if interaction between the Solomon arc and the subducting plate involves a component of unstable slip that leads to cycles of elastic energy accumulation and release as earthquakes.

Background

This particular earthquake was unexpected in the sense that the Solomons arc from approximately Ranongga to the region of Nggatokae has no recorded history of large shallow subduction zone earthquakes such as occurred on 2 April. It has been suggested that the relative youth and high temperature of the Woodlark Basin crust would not allow brittle failure and seismic slip. On the other hand, the low rates of seismicity along the New Georgia arc sector could be taken as an ominous warning that plate convergence is being stored as elastic energy rather than being released continuously as numerous small earthquakes. It appears that the latter interpretation may be closer to the truth. In any case, the New Georgia Group is tectonically very active with Holocene uplift rates on Tetepare, Rendova, and Ranongga exceeding 6 mm/yr in some areas. The tectonic uplift is attributed to strong interaction of the Woodlark Basin seafloor with the base of the arc as it subducts because the Woodlark sea floor resists being pushed beneath the Solomons arc. The Woodlark lithosphere is actively forming at seafloor spreading centers offshore from New Georgia and is thus extremely young and buoyant so that it does not readily sink into the mantle at the subduction zone. In addition, the Woodlark Basin sea floor is very rugged and studded with topographically prominent structures such as the Simbo Ridge and Coleman Seamount, a volcanic edifice rising ~3000 m above the surrounding sea floor. The outer flanks of Coleman are presently thrusting beneath the arc just 20 km off the south coast of Rendova and may significantly resist subduction with consequent deformation of the outer arc revealed by extremely rapid uplift of southern Rendova and Tetepare Islands. Subduction of the Simbo Ridge is the likely cause of the particularly rapid uplift of Ranongga.

The extremely active tectonics of the New Georgia Group Islands led us to map Holocene uplift rates (Mann et al., 1998; Taylor et al., 2005) and to install a sparse network of seven GPS sites in the area in 1997 sites installed in Western Province with the assistance of the Department of Mines, Energy and Water Resources. We re-measured that network in 1998 and 2001 to obtain basic plate (Phillips, 2004). Thus, following the 2 April 2007 event, we possessed baseline studies that enable us to measure total movement on all seven GPS sites since 2001 that will include the coseismic displacements which are expected to include several meters of horizontal dislocation as well as the several meters of obvious uplift reported on Ranongga Island.

Preliminary work on Ranongga, Rendova, and Tetepare Islands indicates that uplift is accomplished in steps as great as several meters each. Corals that were uplifted and killed by some of these events have been identified and dated by radiocarbon, especially on Fearo Island and nearby on Rendova. For that area we identified at least four recent uplifts with the most recent one about 300 years ago. The past four large uplifts appear to have occurred within the past 2000 years or so. However, this is not a complete history. First, the dating should be done by a more accurate method using $^{230}Th/^{234}U$ because radiocarbon errors are too large. Second, the geographic extent of these uplifts is not known so Tetepare may have a distinct uplift history from Rendova. Third, there may be earthquakes and vertical movements of other types that do not create the larger 1-3 m steps that we have seen in the record of uplifted corals. However, the uplifted corals do document the fact that Tetepare, Rendova, and Ranongga have undergone repeated large uplifts that were most likely accompanied large earthquakes and that such events are certain to occur again in the future sooner or later.

Measurements of Deformation Associated with the 2 April 2007 Event

Within eight days of the earthquake we had secured a small amount of funding from the Jackson School of Geosciences of the University of Texas at Austin to conduct a quick response study of crustal deformation associated with the Gizo earthquake. Dr. Kerry Sieh of the California Institute of Technology sent Dr. Richard Briggs to assist with measurements of coral reefs from which we can determine vertical displacements. Dr. Michael Bevis of Ohio State University sent his student, Abel Brown, with seven GPS receivers to occupy our seven GPS. This includes one GPS receiver that will remain indefinitely at the World Fish Center at Nusatupe Island near Gizo to serve as a continuous GPS station that will, among other benefits, continue to measure ongoing crustal strain as the Earth adjusts to this large earthquake.

We began deploying the GPS receivers on 18 April and all were functioning by 23 April. The GPS sites are located on Simbo, the southern tip of Ranongga, at Saboro on southeastern Vella Lavella, Nusatupe Island next to Gizo, at Munda airport, at Husuzu on mid-eastern Rendova, and at Rava Point across the Balfour Channel from Tetepare. The GPS receivers (except Nusatupe) were removed on 8 and 10 May and will be returned to the United States.

In addition, we also made precise measurements of emerged coral colonies and other features that will provide a quantitative assessment of the vertical deformation, both uplift and subsidence. We made coral measurements GPS sites and circumnavigated Tetepare, Rendova, and Parara and examined much of the coasts of other islands including New Georgia, Kohinggo, Kolambangora, and Vella Lavella as well as many smaller islands. We were unable to get out to the Shortlands to evaluate vertical motions in that region.

The GPS data require processing before they can be interpreted and some adjustments based on tide models will be applied to the coral measurements. However, the coral data are sufficient to reveal some important aspects of the earthquake. The uplifted region is the most important for later use in modeling the earthquake parameters.

Results

In general, the area on the northern side of the convergent plate boundary, or trench, is expected to be uplifted by a thrust-type subduction zone earthquake. Indeed, we found that uplift occurred on much of Parara, the reefs extending from the end of Parara toward Gizo, the southern half of Gizo, all of Ranongga and areas extending into the southern part of Vella Lavella until approximately Liapari on the east are uplifted. The most spectacular uplift is on Ranongga, probably because it is the so close to the convergent plate boundary and because it is being underthrust by the prominent Simbo Ridge. Thus, the boundary between uplift and subsidence extends through the northern Vona Vona Lagoon, through the reefs between the end of Parara and Gizo, through Gizo and over through southern Vella Lavella and onward to the west parallel to the arc trend where it lies beneath sea level and can not be mapped.

We also detected what we expect to confirm as slight uplift of the southwestern corner of Rendova including the village of Hopongo. However, uplift clearly does not significantly affect either Rendova or Tetepare Islands. Instead, much of the south coast of Rendova appears to have subsided slightly as did the westernmost few km of Tetepare. The rest of Tetepare appears to be unaffected by vertical deformation. However, most of the west coast of Rendova has subsided even where it is on the same trend as the uplifted parts of Parara. We interpret this to indicate that the seismic rupture did not propagate eastward beneath Rendova and Tetepara. Subsidence of the northern and western parts of Rendova are expected because of their proximity to the uplifted sea floor offshore and onshore southern Parara even though most of southern Rendova did not uplift.

On the northern side of the uplifted zone is a broad area of subsidence that we have not mapped in great detail due to time constraints. Moreover, the geographic pattern of subsidence is less critical to understanding the event than is the uplift. However, it does appear that subsidence of more than 0.5 m has affected large areas. We will have better estimates of subsidence once our colleagues provide tidal adjustments for our measurements of depths of living corals below water level.

Summary

Critical early measurements of the crustal deformation in the New Georgia Group associated with the 2 April 2007 earthquake show that the rupture zone extends from near the southwest corner of Rendova through Gizo and Ranongga toward Bougainville. The area overlying the rupture zone underwent coseismic uplift on April 2. However, the rupture zone does not extend eastward beneath Rendova and Tetepare Islands. The southern coast of Rendova and the western end of Tetepare appear to have subsided. This could denote increased stress on this part of the convergent plate boundary which potentially increases the likelihood of a future earthquake on the interpolate thrust fault underlying Rendova and Tetepare. It also is possible that aseismic slip occurred beneath Rendova and Tetepare Islands and may have relieved stress and delayed the time of a future earthquake. Our GPS measurements on Rendova may reveal whether stress was relieved or if it increased following the 2 April 2007 event. We will report on this as soon as possible.

We know from previous work that Rendova and Tetepare have undergone episodic uplifts of 1 to 3 m each that may have been accompanied by tsunamis. We see this evidence in the form of emerged coral reefs and blocks of coral that appear to have been thrown on shore Tetepare by large waves. Such events are certain to happen in the future. However, the question is whether such future events are in the distant or the near future. At this point we simply do not know.

We also know from previous work that Ranongga had undergone large uplift events in the past and that its uplift rate is very rapid. The large amount of uplift of Ranongga on 2 April 2007 probably has consumed the stored elastic energy beneath the Gizo-Ranongga area and thus has reduced the potential for another large earthquake over the next few decades or longer.

The most important thing that we can now do to advance our understanding of future seismic risk in the Western Solomon Islands is to document the paleo-earthquake history of the New Georgia Group, and the Shortlands as well. This will allow us to understand the relationship between the present event and past events on Rendova, Tetepare, and Ranongga. For example, did the 2 April event cause uplift similar to that of previous uplifts of Ranongga? When in the past did Ranongga undergo uplift? Exactly when in the past have Tetepare and Rendova undergone? This would give us some idea of when a future earthquake and uplift might occur. We also need to determine the characteristic tectonic blocks that undergo rupture as units or groups of units in Western Province. For example, does Rendova Island have an uplift history distinct from Tetepare or do they uplift at the same time? Knowing this would help us to estimate the size of earthquakes and their potential hazard in the case of future events. Our goal is to organize a research project that would answer these questions while also contributing to our understanding of the relationships between subduction zone earthquakes, and the mechanisms that cause tectonic deformation of the Solomons arc and other arc systems.