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Developing a new benchmark to test coupled landslide-tsunami models at volcanic islands

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Volcanic islands are the source of some of the world's largest landslides and have the potential to generate large tsunamis. The magnitude of these tsunamis has been widely debated, but much uncertainty remains over both landslide dynamics and the capacity of the resultant tsunami to maintain damaging dimensions on ocean-basin scales. Recent tsunami models span an order of magnitude in their predictions of far-field wave heights for the La Palma collapse scenario. Resolving discrepancies in our understanding of landslide and tsunami processes requires a field dataset where both landslide and tsunami observations can be used to test current models. The event that best meets these criteria is the sector collapse of Ritter Island, Papua New Guinea, in 1888, which generated a tsunami that devastated shorelines to distances of up to 600 km (Day et al., 2015). Importantly, there are eyewitness observations of the tsunami height, arrival time and frequency at a range of locations around the Bismarck Sea (Day et al., 2015). The event can thus be used as a benchmark for testing models of landslide-generated tsunamis, if the volume, distribution and dynamics of the landslide mass can be reconstructed. A recent research expedition of the German RV SONNE collected new geophysical data over the Ritter Island landslide deposit. These data, alongside a range of direct observations and samples, will be used to generate a detailed interpretation of the Ritter Island landslide, and thus meet the aim of providing a field dataset for testing coupled landslide-tsunami models.

Geological setting

Ritter Island is located in the Bismarck Sea about 80 km north of New Guinea and some 20 km off the western end of New Britain. Situated between the islands of Umboi and Sakar (Figure 1), it forms part of the Bismarck Volcanic Arc, which results from the northward subduction of the Solomon Plate underneath the Bismarck Plate (Baldwin et al., 2012). Today

Ritter Island is a narrow crescent-shaped island, around 1.2 km long and 200 m wide, reaching an elevation of approximately 140 m above sea level. It is the remnant of a larger, steep-sided conical island that was around 750 m high before it collapsed in 1888 (Day et al., 2015). During the 19^{th} century, Ritter Island was known among navigators in the region as a highly active volcano, characterized by frequent Strombolian activity (Johnson, 2013). There is evidence for several submarine eruptions since 1888 that have constructed a cone with a current summit around 200 m beneath sea level. The subaerial remnant of the island is dominated by interbedded sequences of basaltic scoria and thin lava flows that is consistent with low-level Strombolian activity.

The 1888 collapse of Ritter Island, which had a primary volume around twice that of Mount St Helens landslide in 1980, is the largest historically recorded volcanic sector collapse. Contemporary observations of the tsunami triggered by this event suggest a single wave train that is consistent with one main phase of landslide movement and tsunami generation (Day et al., 2015). The landslide deposit is young enough to be preserved at the seafloor without significant overlying sedimentary cover, so that the primary morphology of the mass transport deposit can be examined today and used to understand the emplacement dynamics of a large volcanic-island landslide. Volcanic-island landslides with volumes of one to ten cubic kilometers, such as Ritter Island and the 1741 collapse of Oshima-Oshima, Japan, have a global recurrence interval of 100-200 years (Day et al., 2015). A similar event is likely to occur in the next 100 years, in contrast to the extremely large ocean island collapses (e.g. Canary Islands, Lesser Antilles) that have recurrence intervals of tens of thousands of years or more.

SO-252 oceanographic expedition

During a 6-week long expedition in November/December 2016, we mapped the Ritter Island collapse scar and deposit using hull-mounted multibeam systems, which gave high-resolution bathymetry (Figure 1) and acoustic backscatter data. A Parasound sub-bottom profiler with 10 cm resolution, as well as 2D multichannel seismic data and P-Cable 3D reflection seismic data, were collected to image the collapse deposit with 5 m vertical and horizontal resolution (Figure 1). Additional observations and samples collected across the deposit and island flanks, using towed video cameras and grabs, provide ground-truthing of the geophysical data and allow a detailed interpretation of landslide emplacement processes.

The acquired data show the three-dimensional structure of the Ritter Island landslide deposit, and enable reconstruction of the kinematics of the emplacement process. The new dataset will be used to: (i) quantify the overall volume of the material that has been mobilized; (ii) decipher the nature and extent of landslide disintegration; (iii) determine the location, distribution and size of transported blocks; (iv) identify the nature and origin of different regions of the landslide deposit; and (v) understand the relationship between landslides and the eruption history of Ritter Island and surrounding volcanoes. These are key parameters for determining the landslide failure and emplacement process and the dynamics of the 1888 tsunami. An initial assessment of the data indicates that the submarine flanks of Ritter Island expose similar clastic sequences to those in the subaerial scar, with an increase in more massive lava units in the lowermost part of the edifice. The landslide cuts deeply into the island structure, and the scar exposures suggest an edifice that is dominated by poorly indurated volcaniclastic sequences. The landslide mass bifurcated around a remnant block and dispersed within the channel between Umboi and Sakar (Figure 1), where it forms a deposit that is relatively flat at the margins and with irregular channelization in the central part. Parts of the landslide deposit travelled through a constriction between Umboi and Sakar and incorporated underlying seafloor sediment. Landslide dynamics appear to be strongly affected by minor changes in slope gradient. The deposition of the landslide entailed a progressive, multi-phase, brittle to plastic failure that mobilized material over a considerable distance, with incorporation of a major proportion of underlying seafloor sediment in the distal deposit. Seismic profiles through the distal deposit indicate that the 1888 landslide was only the latest of a series of large-volume volcanic landslides from the surrounding islands. Some blocks piercing the seafloor are in fact rooted within older and much larger landslide deposits. This information will provide the framework for coupled landslide-tsunami models which are required to assess the destructive potential of sector collapse-related tsunamis.

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