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Large Coastal Landslides and Tsunami Hazard in the Caribbean

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With nine volcanic peaks in a 750-square-kilometer area, Dominica, in the Lesser Antilles volcanic arc (Figure 1), has one of the highest concentrations of potentially active volcanoes in the world [*Lindsay et al.*, 2005]. Dominica is very hilly, and there have been numerous landslides, particularly on the island's wetter eastern and northern coasts.

Lindsay et al. [2005] consider the likelihood of gravitational collapses on the flanks of Dominica's volcanoes to be "low but not negligible." However, many factors make Dominica particularly prone to large landslides (>1 million tons): (1) extensive zones of weakened rock, due to hydrothermal alteration and/or intense tropical weathering; (2) oversteepened slopes associated with tectonic uplift and erosion of volcanic edifice foot slopes; (3) large amounts of rainfall on the volcanic uplands, especially during the hurricane season (June–October), with annual averages of up to approximately 6000 millimeters; and (4) occasional severe seismic activity, e.g., a magnitude 7.3 earthquake on 29 November 2007, with its epicenter between Dominica and Martinique, and another of magnitude 6.2 on 21 November 2004, with its epicenter between Dominica and Guadeloupe.

New Discoveries

This report highlights a landslide complex and associated tsunami hazard in northern Dominica, neither of which has been detected in previous studies, including in the assessment of tsunami risk in the Lesser Antilles carried out by *Boudon et al.* [2007]. Geomorphological, bathymetric, and seismic data suggest that Dominica's northern coast is bounded by an active fault structure, with the north flank of Morne aux Diables volcano displaying evidence of both shallow and deep-seated slope instability. A probable landslide block of approximately 1 million tons on the northern flank of the volcano has large tension cracks on its upslope margin and is strongly undercut by coastal erosion (Figure 1, block A). The most likely failure mechanism that could result in an additional landslide or in the fall of block A is a translational slide. Four similarly scaled shallow translational slides have left sparsely vegetated scars along this section of coastline.

Preliminary calculations indicate that if block A were to fall 50 meters, it would trigger tsunami waves with amplitudes of 2.8 meters. Our estimates are based on geomorphological surveys and the interpretation of 1:30,000 aerial photography, together with 1:25,000 topographic maps and three-dimensional visualizations provided by Google Earth™. It is possible that the removal of block A would destabilize adjacent upslope blocks and that the subsequent failure of those blocks—with blocks of 1–3 million tons falling 100–150 meters into the sea—would produce larger tsunami waves. Landslides of comparable size during the eruption of Italy's Stromboli volcano on 30 December 2002 generated tsunami waves that were locally 10 meters high [*Zaniboni and Tinti*, 2004]. Geomorphological mapping of northern Dominica also revealed remnants of large rotational landslides, which would have involved tens of millions of tons of rock, with basal slip surfaces below sea level. The northern flank of Morne aux Diables volcano is oversteepened and cut by east-west trending tension cracks, a situation that *McGuire* [1996, Figure 8b] attributes to the gradual collapse of a volcanic edifice subject to the gravitational stress field.

Zahibo and Pelinovsky [2001] reviewed records of tsunami activity around the nearby Guadeloupe archipelago for the past 400 years: Sixteen tsunami were of Caribbean seismic origin; five were of regional volcanic origin; three originated in activity that occurred beyond the Caribbean; and three were of unknown origin and may include tsunami triggered by large coastal landslides on nearby volcanic islands.

Guadeloupe's southern coast is just 40–60 kilometers north of Dominica, and it could be hit by the postulated tsunami within minutes. There is a significant tsunami hazard along Guadeloupe's south facing coastal zones, where many sections of coastline are not protected by coral reefs (which might absorb some of the tsunami wave energy) and have wide beaches with low-angle gradients (which leads to tsunami runup and increased tsunami wave heights). There is also significant tsunami vulnerability along the southern coast of Guadeloupe, where up

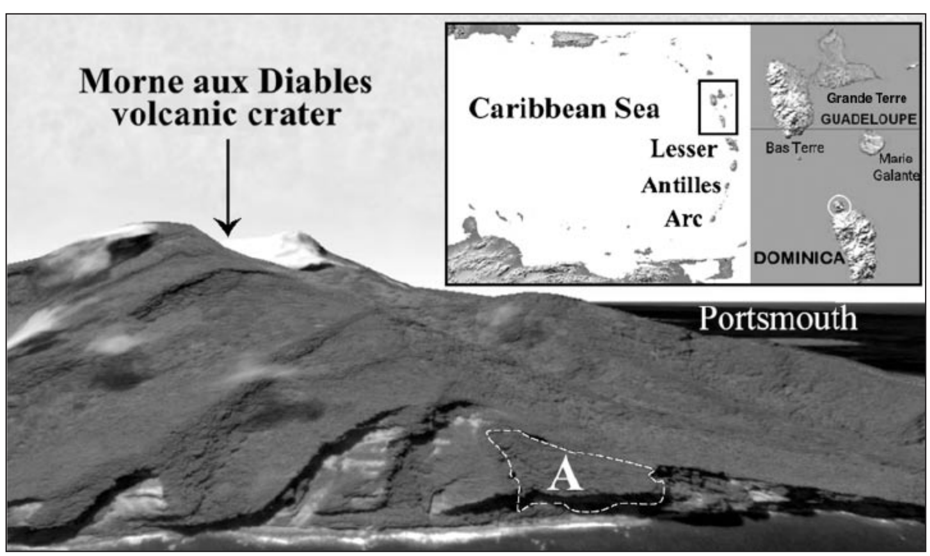

Fig. 1. Oblique view, looking south, of the north flank of Morne aux Diables volcano, Dominica. Area A is a probable landslide block of approximately 1 million tons (source: Google Earth™). Insets show (left) regional setting and (right) the Guadeloupe archipelago and Dominica, with Morne aux Diables circled in white (source: NASA).

to 30,000 people could be affected on the densely populated island with popular tourist beaches.

Global Significance

Globally, many other forested volcanic islands have oversteepened and highly eroded edifices, where large landslides could cause significant harm to local communities and trigger tsunami. These sites are inherently difficult—and often dangerous—to survey via fieldwork. Google Earth™ provides a freely available and easy-to-use means of examining volcanic islands. Areas targeted as potentially hazardous can then be examined in more detail using archive aerial photographs and/or high-resolution optical satellite images (15–90 meter pixels). Satellite radar, which can operate through clouds or ash plumes, is particularly useful, and the RadarSat and TerraSAR-X satellites provide imagery with 1–3 meter pixels.

However, very high resolution satellite imagery (i.e., pixels less than 3 meters) remains expensive, typically in the US$1,000–10,000 range, which is problematic for low-income nations. The United Nations Charter on Space and Major Disasters has improved the situation, with free and rapid supply of satellite imagery to disaster-affected countries; however, it is a reactive system, limited to crisis response. The data cost problem still remains for low-income countries that are proactive and wish to produce disaster preparedness maps.

Another problem with mapping slope instability features on forested volcanic islands is that most types of remote sensing only show the top of vegetation cover. Fortunately, laser altimetry (or light direction and ranging (lidar)) can penetrate forest cover, revealing ground morphology. Airborne lidar has been used to map jungle-covered volcanic slopes on Lihir Island, Papua New Guinea [*Haneberg et al.*, 2005]. The Lihir lidar survey had an average laser strike spacing of 0.4 meter, which resulted in a 2-meter gridded elevation model, enabling the mapping of slope instability features. The cost of an airborne lidar survey over a remote island is high (at least $2000 per square kilometer) and beyond the budgets of most small island nations. However, where a major landslide hazard has been identified on a forest-covered volcanic island, the most effective hazard assessment strategy is an airborne lidar survey, supported by ground-based geomorphological mapping and geotechnical sampling.

This new study of landslide and tsunami hazards facing Dominica and Guadeloupe could stimulate some disaster risk reduction measures. For instance, an airborne lidar survey, supported by ground surveys of geomorphology and geotechnical conditions, would determine the severity of the north Dominica landslide hazard and enable improved estimates of the tsunami hazard. Given that a lidar survey of northern Dominica would be very expensive, an initial low-cost risk reduction strategy would be to reduce tsunami vulnerability on the southern coasts of Guadeloupe. Inhabitants and tourists in communities likely to be affected by tsunami should be alerted about how to recognize tsunami waves and be aware of local refuge sites, such as multistory reinforced-concrete buildings. Publicity about the potential tsunami hazard should help to raise the awareness of emergency planners, disaster managers, and the population of Guadeloupe.

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