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New Insights into Geohazard Risks in Jamaica, Haiti, and The Dominican Republic: A Compendium of Recent Geoscientists *without* Borders Results.

Renee McDonald, University of Southampton and Southern Methodist University; Vanshan Wright, Matthew J. Hornbach, Gwen Carris, Connor Flynn, Zach Frone, Joey Fontana, Emma Giddens, Austen Klausen. Brett Mattingly, Cliff Mauroner, and Benjamin Phrampus, Southern Methodist University; Lyndon Brown, University of the West Indies at Mona; Paul Mann, The University of Houston, and Cecilia McHugh, Queens College, New York.*

Summary

The Greater Antilles islands of Jamaica and Hispanola experience infrequent but devastating earthquakes. Currently, it remains unclear (1) where active faults extend into western Jamaica and the western Dominican Republic, (2) what the probability of large (>Mw 7) earthquakes is in these island, and (3) what citizens can do to better prepare for such events. To begin addressing these questions, an interdisciplinary team of students and researcher, funded by SEG's Geoscientists *without* Borders, conducted a 10 day geophysical study in Jamaica and a 7 day geophysical study in Haiti and the Dominican Republic during the winter and spring of 2013. The Jamaica study included a detailed factor-of-safety analysis in Kingston Harbor, with particular emphasis on the Palisadoes sand spit and Port Royal that are home to the Norman Manley International Airport, and Jamaican Defense Force Coast Guard Headquarters, respectively. Our preliminary analysis indicates an Mw 5 earthquake at the western end of the Enriquillo-Plantain Garden fault could trigger slope failure in unconsolidated sediments near Port Royal, with a magnitude 7 event almost certainly capable of generating slope failures at this site. Ongoing analysis of sediment cores collected in Kingston Harbor provides insight into the timing and probability of slope failure. At the time of this submission, we are just preparing for our field campaign in Hispanola that analyzes the location and timing of earthquakes in central part of the island and possible hydrogeologic links to lake flooding in the region. We will provide preliminary result from our Hispanola study at the 2013 SEG annual meeting.

Introduction

Jamaica, Haiti, and the Western Dominican Republic historically experience infrequent, but destructive earthquakes along the Enriquillo-Plantain Garden Fault (EPGF)--the same fault system that activated in 2010, killing nearly a quarter-million Haitians and devastating the capital city of Port-au-Prince. This fault system extends within a few kilometers of Jamaica's capital city of Kingston, and was likely responsible for the 1692 and 1907 earthquakes in Jamaica that also destroyed much of the island (and like Haiti, resulted in complete destruction of Jamiaca's commercial capital in 1692). The EPGF fault appears to extend into the western Dominican Republic, beneath Lake Enriquillo, however, the exact location (and rupture frequency) of the fault system in this region is poorly constrained. As a result, it remains unclear (1) where active components of this fault system extend into western Jamaica and the western Dominican Republic, (2) what the probability is of large (>Mw 7) earthquakes along the fault system, and (3) what citizens can do to better prepare for these events. To begin addressing these questions, an interdisciplinary team of students and researcher, funded by SEG's Geoscientists *without* Borders conducted a 10 day geophysical study in Jamaica and a 7 day geophysical study in the Dominican Repubic/Haiti during the winter and spring of 2013. The study in Jamaica included 2D shallow water "chirp" seismic imaging, sediment coring, coastal slope surveying, and grain size analysis. We use these data to generate fault structure maps, and ultimately a detailed factor-of-safety analysis at key sites along the edge of Kingston Harbor.

At the time of this writing, we are currently in the midst of prepare a geophysical field study of central Hispanola for May 2013 that includes coring and chirp seismic imaging in Lake Enriquillo in the Dominican Republic and Lake Sumatre, in Haiti. A primary goal of this study is locating and constraining the timing of large earthquakes in this region. Additionally, we will conduct temperature and salinity measurements across the lakes to address possible causes and sources of anomalous lake flooding at these sites. We will present our initial findings at the 2013 SEG annual meeting.

PART I: Slope Failure Hazards in Kingston Harbour.

Methods

The seismic survey consisted of collecting 4.0kHz center-frequency chirp data on 16 NW-SE trending cross lines in Kingston Harbor, Jamaica. These data, combined with previous chirp data collected across the harbor in 2009 provide insight into the geologic structure beneath the harbor as well as the slope angle of unconsolidated sediment. We use these data in concert with sediment analysis to predict the earthquake magnitude necessary for slope failure and possible tsunami generation at the site. We sampled and analyzed beach sediments to obtain grain

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size, grain roughness, level of sorting, as well the angle of repose for typical sand grains found along the coast. The aim of this analysis is to gain an understanding of the physical nature of the beach, the variation in the measured parameters, and ultimately, to determine the ground shaking necessary to trigger slope failure. The slope stability and sediment analysis surveys focused along 3.5 km of the Palisadoes shoreline in the vicinity of Port Royal and along the east and west ends of the Harbor (figure 1).

For this analysis we calculated the angle of repose using the premise that for a sand pile to fail, the tangential stress across the pile (τ) must be greater than the forces holding the pile together, which are the normal compressive stress due to gravity (σ) and the internal friction coefficient between sand grains (κ). This concept is expressed by the relationship necessary for failure: $\tau > \kappa\sigma$. To find the point at which the sand pile would fail, it was necessary to determine the τ that would overcome the calculated κ and σ. Additionally, we calculated κ from direct measurements where $\kappa = \tan\theta_c$ and θ_c is the critical angle of wet sand that we measured directly using the methods of Mason et al., 1998 and Halsey et al. 1999. Several cores were also collected in the harbor and we are using these cores to conduct similar slope stability analysis in other areas of Kingston Harbor. Seismic data shows evidence for at least one active fault in this region running parallel to Long Mountain. We collected sediment cores near this fault in order to determine sedimentation rate, and from this, constrain the rate of sediment deformation associated with fault movement. The work on these cores is on-going and will include Pb_{210} dating as well grain size analysis.

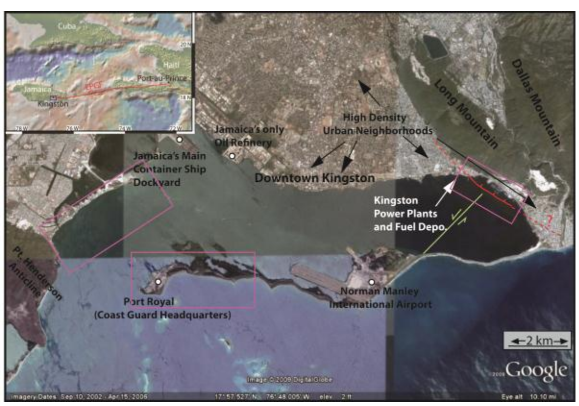

Figure 1: Mapview of Kingston Jamaica. Inset shows the location of the EPGF (red) with respect to Jamaica and Hispanola. The main figure shows a satellite photograph of Kingston Harbor obtained from Google Earth. The red line shows the location of a young active normal fault; the green shows the location of a relic strike slip fault. Pink boxes show locations where we acquired either multiple sediment cores or conducted detailed shore line sediment analysis.

Results

Using the angle of repose determined by the sediment analysis for dry sand of 32.7°, we calculated a κ, the coefficient of static friction, of 0.642, consistent with other studies for sands. Other studies suggest κ values can range between 0.61 for sand-rich sediments and 0.2 for mud-rich sediment (Kopf and Brown, 2003).. Sediments at Port Royal extend to a depth of approximately 18 m below sea level before they reach basement limestone. Using mohr circle analysis where we assume sigma 1 is vertical, no elevated fluid pressures such that poroelastic effects on sigma 3 are minimal (Engelder and Fischer, 1994), and an average poisson's ratio of 0.4, we calculate a shear stress of 0.04 MPa necessary to cause failure. We calculate the acceleration required for failure using:

$$F = Ma = \tau A$$

Where M is the mass of the sediment column that is 1 m x 1 m x 18 m volume, τ, 0.04 MPa, is the shear stress necessary for failure, a is the acceleration, and A is the unit area (equal to 1 m^2) . Solving for a, we find the acceleration necessary for failure is 1.26 N, or 0.128 g (where g is the acceleration due to gravity). Note that this is a minimum estimate, since it assumes strong grain contacts with high sliding coefficient values and no elevated fluid pressure.

We use the graph below (figure 2) to correlate ground acceleration and distance from the historically most active region of the EPGF (~30 km from Kingston) to earthquake magnitude. From this, we determine that an earthquake with Mw 5 to 6.8 (depending on sediment strength) could generate enough force for slope failure near Port Royal and in Kingston Harbor. These values are generally consistent with historical observations of slope failure during past earthquake events in Jamaica. Preliminary statistical analysis of earthquake data suggests a high probability of such an event within the next 100 years.

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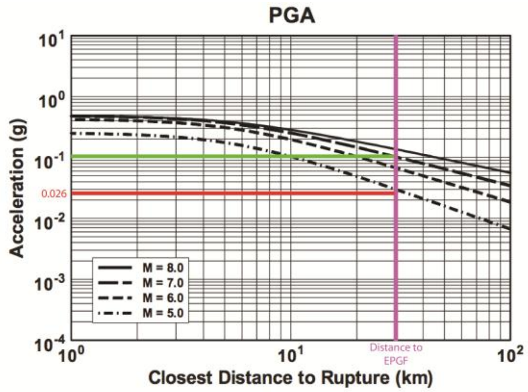

Figure 2: peak ground acceleration versus distance for different shallow earthquake events along strike slip faults (adapted from Campbell and Bozorgnia, 2008). Red line indicates the minimum ground accelerations likely necessary to trigger failure for sediments at Port Royal; the green line indicate the maximum estimate of the ground accelerations needed to trigger failure in sediment grains at Port Royal. The purple line shows the distance from Port Royal to western end of the EPGF. Note that a Mw 5 to 7 event produces enough acceleration to promote failure. The mathematical and experimental results are consistent with historical observations for this region.

Part II. Limnological Geohazards in Hispaniola

Lake Enriquillo and Saumatre present significant hazards to both Haiti and Dominican Republic. Lake Enriquillo, already the largest lake in the Caribbean, has more than doubled its size within the last eight years [from approximately 165 km^2 in 2004 to 349 km^2 in 2012 (Fieser, 2012).] Simultaneously, water levels in Lake Saumatre are also steadily rising (Daniel and Lopez, 2012). Lake Enriquillo’s hypersaline waters (at times 2-3 times that of the Caribbean Ocean) is reported to have displaced sixteen communities in two provinces (10 000 families plus livestock), flooded 1 000 properties, destroyed 46 500 acres of agriculture and amassed at least US 2.5 million dollars in costs (Daniel and Lopez, 2012; Fieser, 2012; Luna and Poteau, 2011). Five kilometers to the west, Lake Saumatre is reported to have covered the Dominican Republic customs buildings in its brackish waters. At times, the water from one or both lakes has blocked the highway that connects both countries leading to a disruption in communication and trade.

The exact cause of the anomalous increase of water in both lakes is unclear. Several researchers have suggested that increases in the lake water levels may be correlated to increases in precipitation rates. Others have suggested that deforestation may have disrupted infiltration rates in the hydrological cycle leading to increased run off or percolation of water into the lakes. It is our understanding, however, that few if any study has approached the problem from a geological perspective (ie. how does the regional geology define ground water flow and do the floods result in-part from neo-tectonism on the Enriquillo-Plantain Garden fault that cuts through these lakes?). This study will employ coring and chirp seismic imaging methods to understand the structural characteristics of the Lake that may give evidence to recent neo-tectonic changes within the region. The study will also conduct temperature and salinity measurements across the lakes to address possible causes or sources of anomalous lake flooding at these sites.

Regardless of the cause of the increase in water levels in Lake Enriquillo and Saumatre, we can all agree with Daniel and Lopez (2012) that the increased water levels can be “a slow-motion disaster and potentially catastrophic for two countries already burdened by major environmental challenges.”

Conclusion

New geophysical data collected in Kingston Jamaica during the winter of 2013 provide new insight into geohazard risk. Seismic images show evidence for active faulting in the eastern half of the harbor, as well as a relic but possibly intermittently active left lateral strike slip fault extending just east of Norman Manley International Airport. Detailed analysis of marine and shoreline sediments combined with angle of repose and slope failure analysis suggests only a relatively moderate (>Mw 5) earthquake along the Enriquillo Plantain Garden Fault is necessary to cause slope failures in Kingston Harbor. Our earthquake probability study utilizing ~30 years of earthquake data collected by the University of the West Indies at Mona indicates a high likelihood of such a failure occurring within the next century in Jamaica. Ongoing analysis of other sediments around the harbor will shed further light on slope failure probabilities in the harbor and whether these events are capable of generating significant tsunamis. Upcoming work (May 2013) in central Hispanola will provide further insight into the geological conditions near the eastern end of the Enriquillo Plantain Garden Fault, and if they play a role in widespread lake flooding at the Haiti/Dominican Republic Border. We look forward to presenting these preliminary results at the SEG 2013 annual fall meeting.

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