In the Aftermath of Haiti's Earthquake: A Discussion of Lessons Learned

PAGES 55–57

The 12 January 2010 earthquake in Haiti brought massive devastation to that country (see Figure 1). In this week's issue of *Eos,* three noted seismologists respond to questions from *Eos* senior writer Randy Showstack in a news roundtable format.

Paul Mann, senior research scientist with the Institute for Geophysics at the University of Texas at Austin, has just returned from Haiti, where he and a colleague worked on a fault rupture survey; they plan to conduct an offshore fault survey soon. Glen Mattioli, professor of geosciences at the University of Arkansas, Fayetteville, has been part of a team conducting a Global Positioning System (GPS) survey of Haiti to measure ground deformation following the earthquake and to install a number of continuous GPS sites to examine after slip, viscoelastic relaxation, and the time return to interseismic deformation (see Figure 2). Work by Mann, Mattioli, and their colleagues has been supported through a U.S. National Science Foundation Rapid Response Research (RAPID) proposal grant provided to Purdue University, with Eric Calais serving as principal investigator. Carol Prentice, a seismologist with the U.S. Geological Survey's Earthquake Hazards Team, has been conducting paleoseismic research on the active faults in the Caribbean region since 1991, including projects on Hispaniola, Puerto Rico, Trinidad, and Jamaica.

For more background information, see "Haiti earthquake underscores need for better use of seismic information" in *Eos* (*91*(4), 30–31, 26 January 2010). In addition, AGU has set up a blog to foster the discussion of science and policy issues surrounding the recent earthquake (http://www.agu.org/blog/Haiti/). Another blog, about some of the scientists' efforts in Haiti, is at http://haitigps.wordpress.com/.

NEWS ROUNDTABLE

What can science learn from the earthquake that shook Haiti on 12 January 2010? Following this earthquake, what concerns are there about the seismic potential and seismic hazards in Haiti, the Dominican Republic, and other potentially affected areas? Are there any specific geographic regions of concern you want to indicate?

Glen Mattioli: Given that the event on 12 January was on a fault that likely last ruptured in 1751, this earthquake provides an opportunity to understand quite a bit about this particular fault and strike-slip faults in the northeastern Caribbean in general. The initial geodetic measurements (postseismic) from the GPS and from interferometric synthetic aperture radar (InSAR) will be able to provide additional constraints on the rupture geometry and integrated slip of the M_w 7.0 event of 12 January. In addition, the geological observations will be used to determine whether the fault rupture propagated to the surface. Such information provides additional constraints on the geometry and slip of the event. Early reconnaissance and mapping by Roger Bilham (University of Colorado, Boulder) indicate that there is little evidence of surface rupture, although there are quite a bit of surface fracturing and some areas of significant uplift. Reconciling the geological and geomorphological observations with geodetic and seismic data will help us better understand why some shallow strike-slip events of approximately M_w 7 rupture to the free surface while others do not. It is not clear at this time why this is the case.

Installation of continuous GPS sites (both in the near and far field) will allow us to understand something about the length scale of deeper deformation and the rheological structure of the lower crust and upper mantle. Little is known about this particular region. So while the mechanism and magnitude of the event were not particularly unique, events like these are rare in the plate boundary zone of the North American and Caribbean plates. The continuous data will also help us determine when the portion of the fault that ruptured on 12 January "relocks" and starts the cycle of elastic strain accumulation anew.

Aftershocks and preliminary Coulomb stress transfer models suggest that increased stress may exist in the region to the west of the 12 January main shock. Given that the geometry of the fault and the finite slip are still not well constrained, these models remain somewhat uncertain. We hope that the measurements made by our postseismic response team will help in this critical area. Obviously, already weakened structures are highly vulnerable, but these issues are better left to the earthquake engineering community to evaluate.

Carol Prentice: Through detailed studies of the Haitian earthquake, including its aftershocks, its effect on positions of geodetic stations, tectonic surface deformation, and secondary effects such as landslides and liquefaction, we will learn a great deal about the Enriquillo–Plantain Garden fault (EPGF) and related seismogenic structures. These lessons will likely be applicable to similar plate-boundary strike-slip faults around the world. Additionally, we will learn about the soil conditions in Port-au-Prince that contributed to the terrible disaster. We will also have the opportunity to better understand and mitigate seismic risk not only in this location but also in other regions along the active Caribbean plate boundaries.

Because only a short section of the fault ruptured to produce the earthquake of 12 January, there remains a significant concern that large, near-future earthquakes might occur on the EPGF. The section of the fault closest to Port-au-Prince, between the 12 January epicenter and the end of the fault near Lake Enriquillo in the Dominican Republic, did not rupture in this event, and it has not ruptured since at least the eighteenth century. Historical earthquakes in 1770 and 1751 are likely candidates for the eastern EPGF, but no significant events have occurred since then. Detailed analysis of very high resolution imagery along the fault, combined with aerial reconnaissance by Roger Bilham, shows that there was no—or at most very little—surface rupture along the section of the fault closest to Port-au-Prince. In addition, most of the early aftershocks, which generally cluster in proximity to the main shock rupture segment, occurred west of the epicenter, suggesting no rupture east of the epicenter. This means that the section of the fault closest to Port-au-Prince remains "locked and loaded" and capable of a large earthquake at any time.

Unfortunately, we do not know enough about this fault to have a clear picture of whether it typically produces earthquakes on the time scale of several hundred years or whether it typically remains locked for longer time periods. The EPGF is very well expressed in the landscape along most of the Haitian peninsula, and it is apparent to earthquake geologists that past earthquakes have caused primary surface rupture on this fault, apparently unlike the *M* 7.0 of 12 January. This suggests that larger earthquakes have occurred on this fault and therefore will occur again. Paleoseismic studies are needed to help give a clearer picture of the behavior of the EPGF.

In addition, it is important to remember that the EPGF is only one of three major fault zones that directly affect the island of Hispaniola. A second strike-slip fault north of the EPGF, the Septentrional fault (SF), accommodates an even higher amount of the plate-boundary motion than the EPGF, according to geologic and geodetic data. Paleoseismic studies show that the most recent earthquake large enough to rupture to the surface along the SF east of the city of Santiago occurred more than 800 years ago. Combined with the current slip rate estimates, this implies that enough strain energy is currently stored along this fault to produce an even larger earthquake than the 12 January event. I am particularly concerned about Santiago, the second largest city in the Dominican Republic, with a population of nearly 2 million. Although models of stress change resulting from the Haiti earthquake show only a slight increase of stress on the SF, the data gathered so far indicate that this fault already posed a particularly significant seismic hazard for the northern Dominican Republic.

Paul Mann: There are about 18 *M* 7 events per year worldwide; most are in remote areas and are known only to the few local inhabitants and the seismologists who study them. Many strike-slip events of this type are remarkably similar in their characteristics, so it is unclear to me at this time if the follow-up research on the Haiti *M* 7 earthquake will lead to new scientific concepts or insights into the earthquake "process." But in the Caribbean, these larger events are so infrequent on faults like the EPGF, and this event may provide insights based on seismology, pre-event and post-event GPS data, intereferomtery, and modeling on what we might expect during future ruptures of other, perhaps adjacent, segments of the fault. For example, the Haiti event ruptured a long segment of a fault that continues for about 600 kilometers; if this rupture length is characteristic, then there are many more segments that could potentially rupture and produce similarly sized events.

In a larger view, the significance of this event is that it provides the science community with an important "learning moment." I would propose to AGU readership that scientists and science funders in the United States and in developed countries in Europe, Asia, and elsewhere need to become more proactive and systematic about focusing research efforts on faults capable of *M* 6–8 quakes, especially in densely populated areas with poor construction practices. Many of these densely populated areas are in developing countries that lack resources to train and employ geoscientists, especially those with the critical, specialized skills of seismology, geodesy, paleoseismology (i.e., fault-trenching methods), and earthquake outreach education. U.S scientists and those in other developed countries need to think collaboratively to develop funded programs that could reach out to facilitate more sustained and longer-term research and education in these types of countries. Building up this capability and the people to utilize it will take time and money. For instance, the Dominican Republic has seven seismographs and Haiti has none; neither country has an undergraduate degree program in geosciences.

For those of us working in these areas, this is truly "urban geology" that contrasts with the "natural geology" that originally attracted many of us to the geosciences. Our study areas include all of those areas most affected by human habitation in the broad belts of people that surround large cities in developing countries: rambling neighborhoods of temporary houses ranging from cinderblock to tents, community gardens, abandoned factories, large landfills, and harbors ringed by cement plants, dock facilities, utility plants, and filled with both modern freighters at anchor and rusty hulks protruding at the surface. As population grows on these small islands in the coming decades, the entire land area will become blanketed by this dense urban "footprint" of humankind. But the science payoff for "urban geology" is crucial because that knowledge base will help protect the lives of millions of people crammed into and around these large population centers.

Fig. 1. A collapsed school in Port-au-Prince, Haiti. Photographs were graciously provided by a team of scientists currently in Haiti. More photos and other information can be found at http://haitigps.wordpress.com/. Photo by Andy Freed.

In my experience, research on seismic hazards in developing countries is somewhat of a "stepchild" for U.S.-based funding agencies, because hazards research (especially fault trenching, high-resolution offshore fault imaging, and coring for age control) is "applied work" that may not yield new or exciting insights into "tectonic process" or fundamental ways about how the Earth works. Also, in my experience, there is the perception in the U.S. science community that applied hazards work in developing countries should be funded either by the local governments themselves or by commercial companies contracted by local governments, but in any case would fall outside the purview of U.S. organizations focused more on academic research. The U.S. Geological Survey (USGS) National Earthquake Hazards Reduction Program once funded our work in the early 1990s in the Dominican Republic (due to the proximity of these large faults to Puerto Rico) but has subsequently contracted to include work only in the United States.

So a key area for progress for funding agencies in the United States and other developed countries would be to recognize the profound societal impacts of earthquakes in developing countries such as Haiti and to expand funding efforts on the applied but important "earthquake triangle" of (1) geologic and geophysical fault research both on shore and offshore; (2) improvement in earthquake engineering, including retrofitting critical buildings and schools; and (3) earthquake education and outreach.

What areas might be the likely sites of near-future earthquakes in Hispaniola (Haiti and Dominican Republic)? In the short term, could this large Haiti event trigger an event on an adjacent segment of the EPGF zone, as observed along other strike-slip fault zones? Eric Calais (Purdue University, French National Center for Scientific

Research), Ross Stein (USGS), and others are working on stress models to investigate this along with collecting postquake GPS data to better constrain these models. Our trenching work that culminated in a *Journal of Geophysical Research* article (C. S. Prentice et al., *108*(B3), 2149, doi:10.1029/2001JB000442) forecasts that the SF zone in the densely populated Cibao Valley has not ruptured in 800 years and is therefore capable of generating a *M* 7.5 earthquake. Santiago, a city of about 2 million people, is centered within a wider fringe of small- to medium-sized towns and is less than 10 kilometers from the SF zone, with much of the city built on a poorly consolidated alluvial plain. The SF zone is exactly the same type of "time bomb" plate boundary strike-slip fault as the EPGF zone "time bomb" was to Port-au-Prince and its environs. Santiago and its surrounding towns in the Cibao Valley are therefore all high-priority areas to review construction practices and retrofit critical buildings, schools, homes, and so forth.

Another area of concern is Kingston, Jamaica, destroyed by earthquakes in 1692 and 1907 and now the main gateway and transportation hub of that country. Our current U.S. National Science Foundation program of integrated GPS and fault trenching on land and shallow seismic surveying over the submerged site of Port Royal in Kingston Harbour aims to understand whether the EPGF zone was the source of these destructive historical events or if there is instead an offshore fault that has not been recognized.

In summary, countries with faults threatening dense populations need to approach earthquake "defense" with the same energy, consistency, and level of scientific spending as devoted to their military defense. The *M* 7.0 Haiti event released about the same amount of energy as the largest thermonuclear bomb ever tested (32 megatons) and has been estimated to have affected 3 million inhabitants in Port-au-Prince and the surrounding area. Research spending should not be lopsided in any one area of the "earthquake triangle" and should move all three areas forward in tandem.

Fig. 2. Haitian and American science colleagues meet in Jimani, Dominican Republic, to plan a Global Positioning System (GPS) survey. (clockwise from left) Altidor Jean Robert (Haiti Bureau of Mines and Energy; BME), Roberte Bienaimé Monplaisir (BME), Estelle Chaussard (University of Miami), D. Sarah Stamps (Purdue University), Eric Calais (Purdue University), and Glen Mattioli (University of Arkansas). Chaussard, Stamps, Calais, Mattioli, and Andy Freed (Purdue University; not pictured) compose the GPS survey team. Photo by Andy Freed.

Are there other particular regions around the world that are also of high concern because of the possibility of a similar earthquake disaster?

Glen Mattioli: There are well over 40 million people who live in the plate boundary zone of the North American and Caribbean plates; while the hazard and risk are not uniform over the entire region, many are at risk in future large earthquakes. While the physical infrastructure in Haiti may have been well below average even for the Caribbean region, there are many structures within large population centers that may not fare well in another regional M_w 7 or larger event. The block model of D. M. Manaker et al. (*Geophys. J. Int.*, *174*(3), 889–903, 2008) suggested that the elastic strain accumulation along the other major through-going strike slip fault in Hispaniola, the SF, is approximately 25% larger than the EPGF. The city of Santiago, Dominican Republic, is close to this fault. Other faults offshore Puerto Rico and the Virgin Islands are less well constrained by geodetic observations because the subaerial exposures available to geodetic observations are farther from the mapped boundaries.

Paul Mann: There are many places in the world discussed in review papers and textbooks by Roger Bilham, Robert Yeats (professor emeritus, Oregon State University), and others that describe in detail large seismogenic, thrust, strike-slip, and normal faults forming parts of interplate boundaries or seismically active intraplate areas that are very close to (or beneath) areas of dense populations who are living in poorly constructed buildings and have low levels of earthquake education.

Areas of high concern would include all of these areas that are at various stages of their cycle of large rupture followed by gradual strain accumulation over hundreds to thousands of years. Have all the seismogenic faults been identified? Can trenching faults show where they are in their earthquake cycle? What are the building practices, given the potential size of the events? These are big tasks, especially in areas that have a small geoscience infrastructure, but this challenge could be addressd by an integrated effort on the part of the U.S. and world science community.

Carol Prentice: Yes, there are many such places, and several are in the Caribbean and Central America. The Greater Antilles, Jamaica, Puerto Rico, Hispaniola, and Cuba all lie along the plate boundary between the North American and Caribbean plates, and they are therefore subject to large and potentially damaging earthquakes. The South American–Caribbean plate boundary is another significant concern, especially for Trinidad and northern Venezuela. Caracas, Venezuela, is particularly vulnerable. One of the greatest concerns worldwide is in India, along the area of the Himalayan front, where strain rates are high, the growth of cities has been rapid, and little thought has been paid to earthquake hazard. This region may well give us the largest earthquake disaster yet. Iran, with its distributed zone of active faults, is another concern.

What are the responsibilities of scientists in regard to these kinds of hazards?

Paul Mann: To move quickly, especially in this environment where the first rain will eradicate many of the earthquake-related features that are important for characterizing the event. To provide the population and first responders with a fact-based assessment of future quakes. Driving around, we would hear Eric Calais reassuring people on Haitian radio programs. To provide scientific information crucial for the rebuilding process and the question of whether to relocate the city. We need to know the possible size of potential future events to engineer safer buildings. Volunteer structural engineering groups are assessing the safety of damaged buildings, but this is a large city with many damaged structures and a large displaced population anxious to move out of tent cities.

Where to rebuild requires understanding the geology and local site responses under the city, including amplifications at hilltops, built over fluvial channels, and buried sand layers that can liquefy. As reconstruction starts, it is critical to educate builders, because poor construction has greatly magnified the death and destruction from this event. For example, smooth bar is widely used as reinforcement, but its smoother surface does not bind as tightly to concrete. Unwashed river sand is also common and leads to a weak, crumbly concrete. Failed soft-story constructions are everywhere, from humble single-story houses to the presidential palace. There are many areas where the rapid response of scientists is important. We need to educate military and government groups about why it is important to facilitate this type of rapid response scientific work. We improvised and relied on the "kindness of strangers" to complete our work but at a cost of speed and efficiency.

Glen Mattioli: This is an excellent question. While it is important to communicate effectively that there is substantial hazard and risk related to earthquakes as well as other natural phenomena in the region, the general public and civilian authorities are not well equipped in many cases to understand the limits of our understanding and models. To quote a recent news article I wrote for the group of scientists active in this seismic hazard research in the region, "What is clear from the Haiti earthquake and its aftermath…is that good science and engineering must be complemented by adequate preparation, appropriate policy regarding earthquake hazards, and meaningful regulations regarding the design and construction of civil infrastructure." One thing is clear: New construction and critical infrastructure must be properly designed and sited to mitigate the inevitable future seismic events.

Carol Prentice: Scientists have a responsibility to tell it like it is: to give the best picture of the situation that scientific information can provide. With seismic hazard, the job is particularly difficult; this is a young and interdisciplinary science, with many unknowns and uncertainties, and we may sound to the public like we are waffling when we speak in terms of probabilities rather than certainties or when we qualify our statements with the real unknowns with which we inevitably grapple. In addition, it can be difficult to convince people of the need to incur the expense of preparing for an earthquake that may or may not occur during one's lifetime or even during one's children's and grandchildren's lifetimes.

Nevertheless, there are a few scientific certainties that we can and must convey as best we can: Large earthquakes will occur on plate-boundary faults, even in places where they have not occurred for hundreds of years; population density along those plate boundaries has increased significantly in the past century; and the devastating effects of inevitable, if still unpredictable, large earthquakes can be significantly decreased with the application of appropriate building codes and engineering.

I believe this is a matter of fundamental human rights: The information that scientific and engineering knowledge offers belongs to all of humanity, not just to those of us fortunate enough to live in the nations of the developed world where an earthquake of *M* 7 will not wreak anywhere close to the disaster resulting from the earthquake in Haiti. That so many suffered from the occurrence of a *M* 7 earthquake is reprehensible given our scientific knowledge and engineering expertise, and it should serve as a wakeup call for the Earth science and engineering communities.