Earthquake Time Bombs

In a media interview in January 2010, scientist Robert Yeats sounded the alarm on Port-au-Prince, Haiti, as an "earthquake time-bomb," a region at critical risk of major seismic activity. One week later, an earthquake of catastrophic proportions struck the city, leaving over 100,000 dead and triggering a humanitarian crisis. No one could have predicted the exact timing of the Haiti earthquake, but by analyzing its proximity to an active fault and its earthquake history, Yeats was able to point out the severity of the threat to Port-au-Prince. He forewarned that Haiti, the poorest country in the Western Hemisphere, was woefully unprepared for such a major quake.

Now, in a shocking and timely study, Yeats sheds new light on other earthquake hot-spots around the world and the communities at risk, including Caracas, Kabul, Tehran, and Jerusalem. He examines these seismic threats in the context of recent cultural history, including economic development, national politics, and international conflicts, and draws comparisons between the capacity of first-world and developing-world countries to prepare for the inevitable. The killer combination of mass migration to megacities coupled with poor building standards is explored, while descriptions of emerging seismic resilience plans from some cities around the world provide a more hopeful picture.

Earthquake Time Bombs is essential reading for policy-makers, infrastructure and emergency planners, scientists, students, and anyone living in the shadow of an earthquake. This book raises the alarm so that we can protect our vulnerable cities . . . before it's too late.

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experience in earthquake geology worldwide, including acting as chair of an active fault working group of the International Lithosphere Program for several years and writing four previous books: *Geology of Earthquakes* (with Kerry Sieh and Clarence R. Allen), *Living with Earthquakes in California*, *Living with Earthquakes in the Pacific Northwest*, and *Active Faults of the World*.

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Acknowledgments

I decided to write *Earthquake Time Bombs* after completing a book called *Active Faults of the World* for professionals, also published by Cambridge University Press. Most earthquake professionals know where the time bombs are located, and I decided that I needed to help them make this information available to the general public we all serve. We can say *where*, even if we can't say *when*.

Over the last few decades of my career, I have been in a position to interact with my counterparts worldwide, where I learned that they, too, know where if not when. I visited many of the time bomb faults in the field, and I was able to talk to my colleagues working on these faults as well as private citizens who would be affected by the next damaging earthquake. They freely shared their information, and many of them are referenced below and in individual time bomb chapters. These people around the world have been my teachers, and many have become lifelong friends. My hope, shared by them, is that the information contained in the book will save lives. The book is dedicated to them.

Finally, I owe a great debt to my editors at Cambridge, starting with Susan Francis, whom I have met on several occasions as she shepherded me through *Active Faults of the World*, and Zoë Pruce, whom I have never met, but through our emails and her encouragement, I know her well enough to say thanks, not just for her editing skills but for her patience.

Why this book?

At the beginning of 2010, I was interviewed by *Scientific American* for a New Year's article on earthquakes. The interviewer, Katie Harmon, was well informed, and I enjoyed talking with her. I had just finished the Caribbean chapter of a book I had been writing for Cambridge University Press, *Active Faults of the World*, a chapter that had been fascinating to work on because Caribbean earthquake faults are so close to the United States, including my birthplace, Miami, Florida.

Somehow, the conversation turned to Port-au-Prince, the capital of Haiti, the poorest country in the Western Hemisphere. People have been moving to Port-au-Prince by the hundreds of thousands because that is where the jobs are, or appear to be. But the city lacks any social services, and there is no plan for where the new arrivals will live. So they are packed into the most abysmal slums, with shanties that are so fragile that it appeared a slight breeze would blow them down.

Port-au-Prince has a huge problem that is unrecognized by the government: It is adjacent to the Enriquillo plate-boundary earthquake fault, a structure that had not sustained a major earthquake near the city since the middle of the eighteenth century, prior to American (and Haitian) independence. I pointed out to Katie Harmon that Port-au-Prince is a time bomb. At the time of the previous earthquake, the city was a small town, but now it has a population in the millions, many living in dilapidated housing. If the Enriquillo fault ruptured, it would be a disaster of monumental proportions.

One week later, Port-au-Prince was destroyed by a large earthquake, killing more than 100,000 of its inhabitants.

Needless to say, Katie now had a major story, and she was on the phone immediately, asking breathlessly, "Did you predict the earthquake?"

"No, no, not at all," I replied. In my book, I could point out *where* the dangerous faults are, and even how active they are, but I could not say *when* the next big earthquake would strike – tomorrow or a hundred years from now.

In fact, some of my colleagues who were doing research in the region actually secured an audience with Haitian officials high in the government, about the earthquake danger prior to the earthquake. They described to the president's senior advisers an eighteenth-century earthquake of magnitude 7.5 on the Enriquillo fault and pointed out that a repeat of this earthquake today could cost hundreds of thousands of lives because of the great increase in population since the previous earthquake.

The government officials listened with concern, then asked the Big Question: "When will the next earthquake strike our city?" The response of their visiting seismic experts spoke to the uncertainty of earthquake science. We can point out the danger areas, but we can't predict when the next Big One will strike. It could strike tomorrow or a century from now.

So what did the Haitian government do?

Nothing.

Before condemning Haiti's short-sightedness, consider that Haiti, in addition to being the poorest country in the Western Hemisphere, has major problems that need to be addressed today: hurricanes, epidemics, the influx of thousands of unemployed Haitians to the capital city, a decrepit building stock, and virtually no social services. So can we blame the president if he puts on the back burner an earthquake that might not strike in a hundred years, long after he has left office?

The failure to predict earthquakes is our failure as scientists, despite the fact that major earthquake programs in Japan, China, and the United States were established with prediction as one of their

most important goals. It's the one big question society wants us to answer: "When's the next Big One?"

Some leading seismologists state that the structure of the Earth is too complicated, and we know too little about it to make earthquake prediction a practical near-term goal. So we focus on preparedness, asking people to prepare for a disaster that might not strike during their lifetimes.

However, we can say *where* even if we can't say *when*.

In addition, there are other earthquake time bombs, places where great numbers of people are moving to megacities, the greatest worldwide migration in human history. Many of these megacities are in poor countries lacking a social infrastructure, and several of these megacities are close to active faults. Some have experienced earthquakes in the past, but the cities were much smaller then than they are now, so earthquake losses were moderately low. Some of the time bombs are in the United States.

Once I realized this, I re-directed the focus *of Active Faults of the World*, the book I was writing, to call attention to these time bombs. For example, Kabul, Afghanistan, is a city that has been battered by decades of war. After the Soviets were expelled, millions of Afghan refugees returned to Kabul from camps in Pakistan and Iran and from the Afghan countryside. They had been terrorized by insurgent groups, most recently by the Taliban. When I was in Kabul in 2002, I found families living in the ruins of buildings scarred by war, buildings so fragile that it seemed that even a moderate earthquake would cause them to collapse. Attempts by my company and by the US Geological Survey (USGS) to address Kabul's earthquake hazard through USAID went nowhere, even after I pointed out that the nearby Chaman plate-boundary fault had generated an earthquake of magnitude 7.3 in 1505, and a repeat performance could kill more of Kabul's inhabitants than four decades of war.

Tehran is a desert city built at the southern edge of the snow-capped Alborz Mountains to take advantage of the streams coursing

down their southern slopes. This desert city is now the capital of a great nation undergoing drastic change after the Islamic revolution of 1979. The population has swelled to greater than ten million. The Alborz Mountains near Tehran have not experienced an earthquake since 1830, but these mountains have been convulsed by earthquakes of magnitude 7.3 or larger in the past 1500 years. Just north of the city, the North Tehran thrust is active, and faults have been found by Iranian geologists working with foreign experts even within the densely urbanized Tehran plain. The hazard from other faults within the city itself is unknown.

Many Iranian geologists, seismologists, and engineers have a clear-eyed view of the earthquake threat to the capital, but the construction industry and the city's building inspectors are notoriously corrupt, and the likelihood that new apartment buildings to accommodate the increasing population will be built to modern building codes is relatively low. The corruption problem was demonstrated in the easternmost suburbs of Istanbul, Turkey, in the Izmit earthquake of magnitude 7.4 in 1999 on the North Anatolian fault. Turkey has world-class seismologists, earthquake geologists, and engineers, but these experts were unable to prevent the construction of shoddy apartment buildings to accommodate newly arrived Turks from the countryside looking for work in Istanbul. Thousands died.

Worse yet, the North Anatolian fault extends westward into the Sea of Marmara offshore from Istanbul, a city of 15 million. The city is under alert for an earthquake greater than magnitude 7 in a part of the fault lacking in earthquakes comparable to the gap filled by the last earthquake of magnitude 7.1 in 1766. The fault east and west of this part of the fault generated earthquakes earlier in the twentieth century, but this part has not. The city of Istanbul has finally awakened to the earthquake wake-up call from 1999, and the future for that city looks brighter because of the steps now being taken.

The list goes on: Caracas, Venezuela, close to a plate-boundary fault that extends along the north coast, probably generating an earthquake in 1812 that took the lives of 5–10% of the population of

Venezuela at that time; Guantánamo, Cuba, the large city and the US naval base and prison of the same name, close to the seismically active Oriente fault offshore to the south; Dhaka, Bangladesh, Chandigarh, India, and Islamabad-Rawalpindi, Pakistan, close to the seismically active Himalaya to the north; Nairobi, Kenya, close to the Laikipia Escarpment on the East African rift valley, generating the Subukia earthquake of magnitude 6.9 in 1928; and the cities of the central valley of Burma (Myanmar), including Yangon, Mandalay, and the new capital of Naypyidaw, all close to the plate-boundary Sagaing fault.

Not all the time bombs are in the developing world. The Los Angeles, California, metropolitan area has earthquake-protective laws in place, but engineers point out that a large number of nonductile concrete buildings are likely to fail the test of the next large earthquake. California's laws may be inadequate to protect its citizens from a large earthquake or to fend off developers who want to take the chance that they can build their project with a life of no more than 200 years and it won't be destroyed by an earthquake with a recurrence interval measured in thousands of years. The general public is aware that California is earthquake country, but not disturbed enough to strengthen buildings so that their inhabitants will survive the next inevitable earthquake. The Mayor of Los Angeles, assisted by the USGS, has taken on the challenge of making Los Angeles more resilient to a major earthquake on the southern San Andreas fault.

WILL THE NEXT GREAT URBAN EARTHQUAKE STRIKE ONE OF THESE CITIES?

Governments and societies tend to respond to a disaster only after it has happened, as illustrated by two hurricanes in the eastern United States, Katrina in 2005 and Sandy in 2012, and by the Kobe, Japan, earthquake of 1995. Society would also respond if scientists could predict the time, place, and magnitude of the next earthquake. Sadly,

we cannot. However, some cities are developing plans to ensure their resilience following a major earthquake, an idea that I hope is a good sign for the future.

The purpose of this book is to describe the threat faced by many cities throughout the world in hopes that their societies will respond to the danger before the earthquake, rather than picking up the pieces after the disaster has occurred and thousands of victims have been buried. I call these cities *earthquake time bombs*.

The Cascadia subduction zone, where I live, contains several large cities that I regard as time bombs. Groups of experts have prepared resilience surveys in the states of Washington and Oregon to determine the consequences of *not* getting ready for the earthquake disaster ahead of time. This can be rephrased as the cost of doing nothing. Although becoming earthquake-ready is expensive, in the billions of dollars, the cost of doing nothing is worse because it affects the entire society, including loss of jobs and tax revenues, as well as the shutdown of essential services and lifelines for months or years. This problem is dealt with in an international project called Global Earthquake Model (GEM).

This book is a wake-up call to our society and its leaders. The next great earthquake will be a disaster, but failing to prepare for it will lead to a catastrophe.

The book is written in two parts, plus a conclusion, and I have presented basic material in such a way that you don't have to start at the beginning. The first part provides a background in earthquakes and plate tectonics, including the concept of geologic time and an explanation of why we, as scientists, cannot tell you when the next huge earthquake will strike, or where. You can use this first part as a reference. The second part describes several earthquake time bombs around the world, most of which you have heard of for reasons other than earthquakes, such as Caracas, Tehran, Jerusalem, or Kabul. Some of these time bombs are in unexpected places: Seattle, Los Angeles, Tokyo. Each of the time bomb chapters may be read on their own without going back to the explanatory Part I, although you may want

to read the explanations as well as the descriptions of individual time bombs. I have provided references in case you want to learn more about a specific time bomb of particular concern to you.

Since three of the time bombs I describe are in the Pacific Northwest, I have a personal stake in this because I live here.