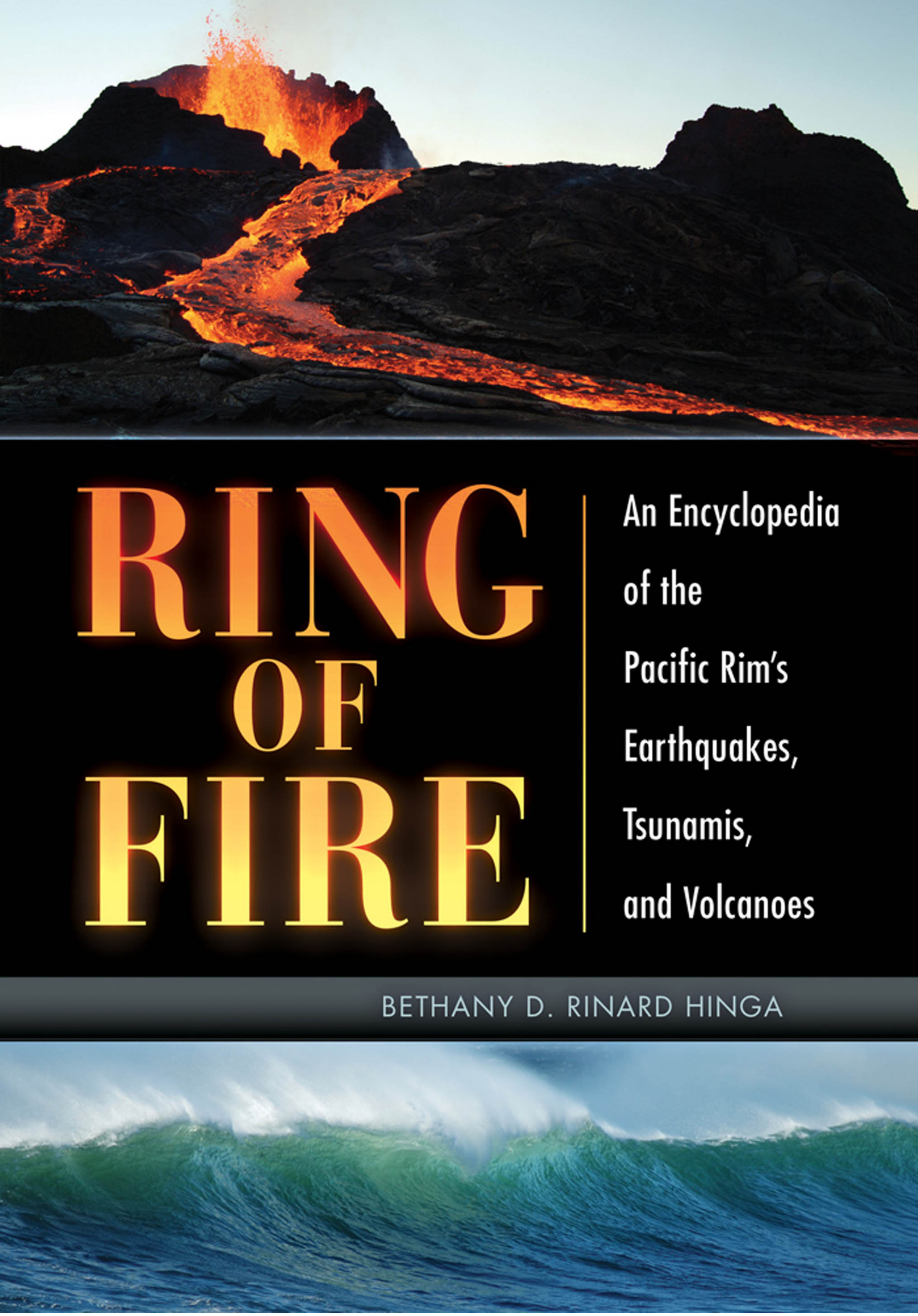
RING OF FIRE
An Encyclopedia of the Pacific Rim's Earthquakes, Tsunamis, and Volcanoes
BETHANY D. RINARD HINGA

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Preface

The Pacific Rim is one of the most geologically active regions of the planet. Here, it is possible to observe the raw power of planet Earth through unexpected and often violent events, such as volcanic eruptions, earthquakes, and tsunamis. This book examines the specific interactions of tectonic plates in and around the Pacific Ocean. The region of interest extends from the west coasts of North America and South America to the Aleutian Islands of Alaska. It extends from the Aleutian Islands southward through the Kamchatka Peninsula of Russia; through the Kuril Islands, Japan, and the Philippines; to Indonesia and southward to New Zealand. The Pacific Rim includes incredibly diverse geographic regions created by immense tectonic forces.

This encyclopedia explores the vast Pacific region of the earth from historical, geographical, and geological perspectives. All entries pertain to some aspect of Pacific Rim volcanic, earthquake, or tsunami activity or the study of such events. It is thoroughly cross-referenced, which enables readers to further explore a topic simply by following suggestions about which other related entries might be of interest or provide further clarification on a subject.

The scope of this book is quite broad, ranging from the configuration of and interaction between the tectonic plates that comprise the Pacific region to descriptions of specific disastrous events—including features found on individual volcanoes. The book includes information about topics at both ends of this scale and from every point in between. I tried to tell important stories as was appropriate, rather than simply conveying facts. It has been my experience that often it is from the narrative that scholars learn most effectively.

I was approached in the spring of 2012 about writing this book. It has been an ever-present part of my life since that time—through two career changes, one cross-country move, and one new child. Through the experience of writing I have had a chance to relive some of my youth and many of my travels, as well as to learn more about distant lands I have yet to visit. I have been fascinated by the natural world, and specifically by volcanoes, since I was a child. When Mount St. Helens erupted in 1980, I was eight years old and living on a farm in central Iowa. I had family members who lived near Mount St. Helens. They sent me newspaper articles and photos, and brought me volcanic ash when they came to visit. From that time onward, I became obsessed by all things volcanic.

I entered college as the rare student—one who knew exactly what I wanted to do with my life . . . study volcanoes. I had some wonderful experiences as an undergraduate, when studying older volcanoes in Colorado and New Mexico. After graduation, I secured a coveted summer internship at the Hawaiian Volcano Observatory. Through the summer, I spent a great deal of time both in the laboratory and the field learning about Hawaiian volcanism by studying the ongoing eruption of the Kilauea volcano with my mentors, the first all-female Geology Group in the observatory's history. I was fortunate to reconnect with my friends at the Hawaiian Volcano Observatory when I began work on my dissertation a few years later. I worked with seismologist Dr. Paul Okubo, and used volcanic earthquakes within the western half of Kilauea to map its subsurface structure. To Dr. Okubo and the rest of the staff at the observatory who graciously assisted me in one major way or another as I learned the ins and outs of Hawaiian seismology and observatory databases, I will always be grateful.

I was fortunate to spend the first 17 years of my career in the classroom at Tarleton State University. I taught courses in geology—including natural disasters—to a generation of students. Most of this book, however, was written while I was employed at the University of Nebraska at Kearney. I wish to thank Dr. Kenya Taylor for her personal example, showing that it is possible—and, in fact, enjoyable—to engage in research even after leaving the classroom. Dr. Taylor encouraged me to keep my interests in geology alive as I moved from teaching in my academic field to an administrative role in higher education. This book serves as my bridge from one world to the other. I hope it serves as a bridge for you, as well, to an understanding of natural events that all too often turn into natural disasters.

Introduction

Geologists often speak of the earth as a dynamic planet—a world that constantly is in a state of dramatic change. Across much of the earth, however, it is difficult to see direct evidence of these rapid changes because most geologic processes are achingly slow. Even in the best of circumstances, it takes hundreds to thousands of years for sediment to be buried and turned into rock. Rocks are weathered into sand, but the weathering process can take thousands or even millions of years. Mountains can rise from the plains, but this often takes tens of millions of years. Why then is Earth considered such a dynamic planet? The answer lies in the relentless movement of the earth's tectonic plates.

The earth's plates are in constant motion because of the circulation of the upper mantle beneath them. At places where plates come into contact with each other, the earth changes rapidly and dramatically. It is at these places that earthquakes disrupt people's daily lives. It is at these places that volcanoes destroy landscapes, only to rebuild them in a new image. It is along shorelines with such plate contact that tsunamis can sweep in and carry away communities in a tragic few minutes. In very few places are these types of events seen more frequently than in the region called the "Ring of Fire."

The Ring of Fire is a name given most deservedly to the Pacific Rim. The Ring of Fire extends from New Zealand clockwise in an almost circular arc through the Tonga and Kermadec Arcs; then westward to Indonesia; northward through the Philippines, Japan, and the Kamchatka Peninsula of Russia; eastward through the Aleutian Islands; and then southward along the western coasts of North America and South America. The Ring of Fire also contains active regions within its interior, including the Galapagos Islands and Hawaiian Islands.

Throughout this book there are many recurring themes, including hazard (the likelihood that a natural event will occur) and risk (the ways that a population might be adversely affected by that event). The book includes references to the process of scientific discovery and (it is hoped) will provide an understanding of just how recently science became aware of the full range of possibilities within events such as volcanic eruptions. The strongest theme presented herein is plate tectonics. Without the tectonic setting found around the rim of the Pacific, there would be no Ring of Fire. Plate tectonics cause the dramatic events covered in this text . . . volcanoes, earthquakes, and tsunamis, and related events such as landslides and wildfires.

The specific tectonic setting that causes most events is called a subduction zone. A subduction zone is a type of plate boundary found where two plates meet and are moving toward each other. At these locations, one plate is forced downward and underneath another. Although it happens slowly—usually no faster than an inch or two per year—subduction is an extremely violent process. Beneath the solid tectonic plates found at the earth's surface is the upper mantle, which is another solid layer of the earth. One solid is being thrust downward into another solid material, resulting in a great deal of friction causing the plates to "stick" to each other. When strain builds to a critical level within the rocks at the plate boundary, the rocks break and slip, causing an earthquake.

The most violent earthquakes on the planet occur in subduction zones. In the history of recorded earthquakes, no greater earthquakes have occurred than those that happen within the Ring of Fire. The most significant earthquake ever recorded occurred just off the coast of Chile in 1960. It was a magnitude 9.5 earthquake that shook the earth for several minutes near the earthquake's epicenter, and caused the entire planet to vibrate for days afterward. The earthquake generated a tsunami that crossed the Pacific Ocean. It caused deaths in Hawaii and significant damage in Japan.

Another effect of subduction is the heating of the plate that has been thrust into the mantle. Although the upper mantle is not quite hot enough to melt the subducted plate at the types of pressures found at that depth in the earth, it certainly is hot enough to drive water from the subducted slab into the surrounding mantle. This process has an odd effect on the solid mantle above this plate: It lowers its melting temperature. The reduced melting temperature enables a small percentage of the mantle rock in that region to melt.

Molten rock is less dense than the surrounding solid rock, thus the molten rock rises. It can rise all the way to the surface where it feeds volcanic eruptions. Anywhere a subduction zone is found, there is a chain of volcanoes that marks the location in the mantle where melting is occurring. Entire island nations have been formed from hardened molten rock. One of the largest and most geographically diverse island nations on Earth is Indonesia. All of the islands within Indonesia were formed by a subduction zone. Whether the island was formed as a volcano rose from the sea or by immense forces pushing the sea floor up above sea level, tectonic forces birthed these islands. The same is true of Japan, the Philippines, and the Aleutian Islands.

Volcanoes formed at subduction zone sites are a type called a "composite volcano." This type of volcano often is tall and steep-sided, and produces great volumes of lava, volcanic ash, and other debris. The volcanic eruptions can be extremely violent, sending plumes of volcanic ash tens of thousands of feet in the air, turning daylight into instant darkness—sometimes for days at a time. Eruptions can issue forth pyroclastic flows—fast-moving torrents of hot ash and deadly gases—and send pieces of rock tumbling downhill at speeds approaching 100 miles per hour. Such an eruption incinerates, topples, or otherwise destroys everything in its path. If enough volcanic ash and microscopic droplets of sulfuric acid are sent high enough into the atmosphere, then a single eruption has the ability to cool the atmosphere and change weather patterns for more than a year.

The 1815 eruption of Tambora in Indonesia resulted in the year from 1815 to 1816 being dubbed “the year without a summer” in the northeastern United States and Europe. Because of the eruption, temperatures in those regions never reached typical summertime levels, and in some places snow fell in June. Crops failed. Skies glowed an eerie red. It even is suggested that the abysmal weather conditions inspired a young Mary Shelley—sequestered with friends in a castle that year—to write her masterpiece, *Frankenstein*. Although it is difficult to believe that a single eruption of a single volcano can have such far-reaching consequences, it is something that has happened time and again within the Ring of Fire.

Within the center of the Ring of Fire, in the vast blue waters of the Pacific, are two island chains that owe their existence to tectonic forces that have nothing to do with plate boundaries, but rather to a hot spot. A “hot spot” is an area of the mantle that, for reasons not yet fully understood by scientists, is unusually hot. Heat rises from as deep in the earth as (at least) the top of the lower mantle (and possibly deeper) to the upper mantle. The excess heat in the upper mantle causes melting to occur. Volcanoes form above the hot spot and then erupt frequently. Hot spots remain fixed in place, rooted to the location deep in the earth where they originate. Over time the plate above a hot spot moves. At the surface, a chain of volcanoes often is formed over a hot spot. This can be demonstrated with a simple thought experiment. Imagine a candle sitting stationary on a table. This represents a hot spot. If you take a piece of paper—representing a tectonic plate—and pass it slowly above the candle, you will find a scorched area in the paper that traces a line. That line represents a chain of volcanoes formed by the hot spot. The orientation of the line on the paper indicates the direction of movement of the paper as it was passed over the candle, and represents the direction of movement of the plate.

The Hawaiian Islands are an excellent example of a volcanic mountain chain created by a hot spot. The Hawaiian Islands have been intensely studied by geologists for more than 100 years. The volcanoes Kilauea and Mauna Loa make excellent natural laboratories for studying volcanism because they erupt frequently. These volcanoes also are much more approachable than those found at subduction zones, so it is relatively easy to design repeatable experiments to gather valuable longitudinal data sets. The Hawaiian hot spot has been active for at least 80 million years. This can be determined because it is possible to trace a single long chain of volcanoes from the current location of the hot spot—just off the southeast coast of the island of Hawaii—all the way north and west to the Aleutian Islands, where the northernmost underwater mountain in the chain (called a “seamount”) is poised to be subducted beneath the Aleutians. This mountain chain is known as the Hawaii-Emperor Seamount Chain, and is composed of thousands of volcanoes. In its geology, the chain holds a history of the movement of the Pacific Plate. Measuring a distance between two islands in the chain that are of known age enables researchers to determine how fast the Pacific Plate moved during the time interval measured. The seamount chain makes a sharp bend in the north-central Pacific, which can be unequivocally tied to a change in the direction of movement of the Pacific Plate. Without seamounts, a great deal of information about the Pacific Plate and its history would remain unknown.

The Pacific Rim is one of the earth's most geographically diverse and geologically dynamic areas. Throughout this book readers will discover many places that tell the fascinating story of the Ring of Fire. I hope you enjoy reading about these places and these events as much as I enjoyed writing about them.

Timeline of Disasters in the Pacific Rim Region in the Modern Era

1815:	Tambora Eruption, Indonesia	Largest eruption of Nineteenth Century. The climate cooled by more than a degree. Event caused “year without a summer” in Europe and northern North America.
1835:	Concepción Earthquake, Chile	Witnessed by Charles Darwin. Earthquake and resulting tsunami caused considerable damage in Concepción, Chile.
1868:	Arica Earthquake and Tsunami, Chile	Death toll of 25,000 due to earthquake and tsunami.
1883:	Krakatau Eruption (also known as “Krakatou” Eruption), Indonesia	Eruption produced ash clouds that darkened the skies for two days. Pyroclastic flows reached shorelines of Java and Sumatra. Caldera collapse generated a tsunami that was responsible for most of the 36,000 deaths associated with the eruption.
1896:	Sanriku Earthquake and Tsunami, Japan	More than 26,000 people died. The tsunami coincided with high tide; wave reached up to 125 feet (38 meters) high. The event occurred when a fishing fleet was at sea. The fishermen returned to discover their homes destroyed and their families gone.
1906:	San Francisco Earthquake, California, United States	Estimated to be a magnitude 8 earthquake and caused moderate damage. The resulting fire destroyed much of San Francisco. As many as 4,000 people were killed.
1912:	Katmai Eruption, Alaska, United States	This was the greatest eruption of the Twentieth Century, and occurred in a remote area of Alaska. Pyroclastic flows created the “Valley of Ten Thousand Smokes.”
1923:	Great Kanto Earthquake, Japan	This earthquake destroyed much of the Tokyo-Yokohama metropolitan area. Approximately 143,000 people were killed, and 71% of Tokyo residents and 85% of Yokohama residents lost their homes.

1946:	Unimak Island Earthquake and Tsunami, Alaska, United States	The magnitude 8.1 earthquake generated a Pacific-wide tsunami. At Unimak Island, wave height was estimated to be more than 100 feet (30 meters). Scotch Cap Lighthouse on Unimak Island was destroyed and 159 deaths occurred in the Hawaiian Islands, where waves reached more than 30 feet (9 meters) in height. This disaster prompted formation of the Pacific Tsunami Warning System.
1951:	Lamington, Mount, Eruption, Papua New Guinea	Pyroclastic flows killed more than 3,000 people.
1960:	Chilean Earthquake and Tsunami	The greatest earthquake recorded to date, the magnitude 9.5 earthquake killed 5,000 people and generated a Pacific-wide tsunami. Waves were up to 75 feet (23 meters) high along the Chilean coast and 30 feet (9 meters) high in Hawaii. There were 61 tsunami deaths in Hilo, Hawaii, alone.
1964:	Anchorage Earthquake, Alaska	Second largest earthquake of the Twentieth Century (a magnitude 9.2), occurred in 1964 on Good Friday. The earthquake triggered landslides, including one that destroyed the Turnagain Heights neighborhood near Anchorage. A local tsunami was generated at Prince William Sound. Of 125 deaths attributed to the earthquake, 110 died as a result of the tsunami.
1970:	Chimbote Earthquake, Peru	Until the 2010 Haiti earthquake, the 1970 Chimbote earthquake was the deadliest disaster in the western hemisphere. In 2010, 76,000 people lost their lives in the magnitude 7.9 earthquake and the resulting landslides occurring near the base of the Andes.
1975:	Kalapana Earthquake, Hawaii, United States	The 1975 magnitude 7.2 earthquake damaged many buildings on the island of Hawaii. A local tsunami with wave heights up to 46.6 feet (14 meters) high caused two deaths and caused additional damage.
1976:	Guatemala Earthquake	The magnitude 7.5 earthquake occurred on the boundary between the Caribbean and the North American plates and caused 23,700 deaths.
1976:	Tangshan Earthquake, China	Deadliest earthquake of the Twentieth Century, it killed more than 200,000 people. Some estimates place death toll at more than 500,000. Most deaths were due to building collapses.
1980:	St. Helens, Mount, Eruption, Washington, United States	A catastrophic eruption triggered by a magnitude 5.0 earthquake and a massive landslide that decapitated the volcano. Fifty-seven people were killed. The volcano now has a 1.8-mile wide horseshoe-shaped crater. Later eruptions created a large lava dome in the crater.

1982:	El Chichón Volcano, Mexico	A large eruption that killed about 2,000 people and sent greater than expected amounts of sulfur dioxide aerosols into the atmosphere. The earth's atmosphere cooled by an average of 0.72° F (.04° C) for one year.
1985:	Mexico City Earthquake, Mexico	The epicenter of this earthquake was some distance from Mexico City, but silt and clay beneath the city amplified seismic waves and caused liquefaction. More than 400 buildings collapsed, including hospitals. The death toll was at least 9,500 people.
1985:	Nevado del Ruiz, Colombia	A relatively small eruption that generated a lahar which swept down the Lagunillas River and overtook the city of Armero. More than 22,000 people died.
1989:	Loma Prieta Earthquake, California, United States	Most of 63 deaths were caused by the collapse of elevated roadways, including the Cypress Freeway, Embarcadero, and Bay Bridge. This earthquake also is well-known because it interrupted the 1989 World Series.
1991:	Pinatubo, Mount, Eruption, Philippines	The second largest eruption of the Twentieth Century. The incident is considered to be a successful case of forecasting a volcanic eruption. Tens of thousands of people were evacuated from the immediate area before the volcano erupted, keeping the death toll down to about 300 people. Global temperatures dropped 0.72° F (.04° C) from sulfur dioxide aerosols injected into the atmosphere from this eruption.
1991–1995:	Unzen Eruption, Japan	The Mount Unzen Volcano is known for lava domes. A dome-building eruption in 1991 generated pyroclastic flows that killed volcanologists Katia and Maurice Krafft and Harry Glicken, as well as the 40 journalists accompanying them. The Kraffts and Glicken were filming pyroclastic flows for a film about volcanic hazards targeting public officials and those at risk from volcanic eruptions.
1993:	Galeras Volcano, Colombia	The small eruption of Galeras occurred while a group of volcanologists was inside the crater. Nine people died and many were severely injured.
1993:	Okushiri Island Earthquake and Tsunami, Japan	The magnitude 7.8 earthquake generated a local tsunami that killed 198 people. Japanese officials rebuilt the devastated areas and built a tsunami wall for protection.