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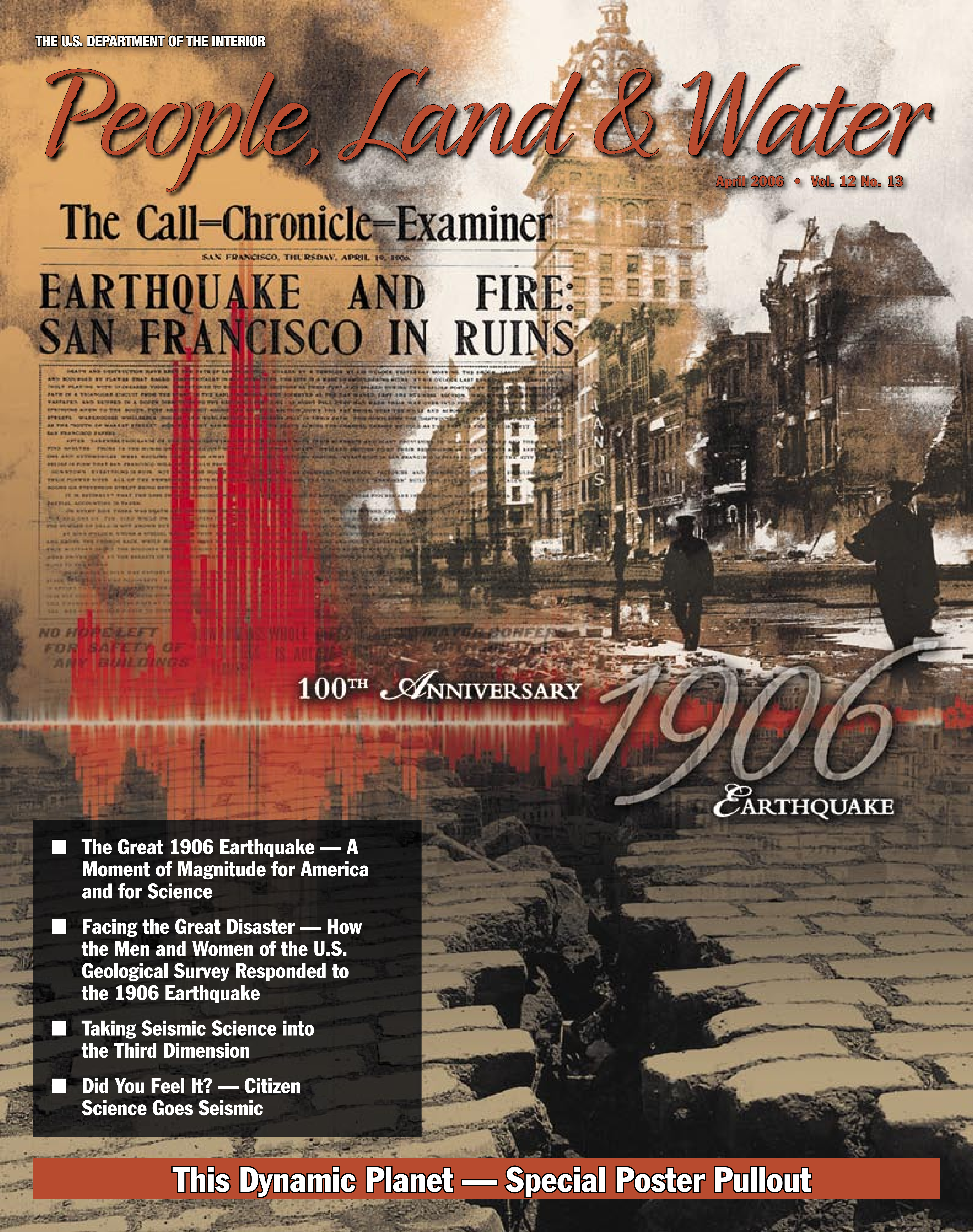

100TH ANNIVERSARY 1906 EARTHQUAKE

- The Great 1906 Earthquake — A Moment of Magnitude for America and for Science
- Facing the Great Disaster — How the Men and Women of the U.S. Geological Survey Responded to the 1906 Earthquake
- Taking Seismic Science into the Third Dimension
- Did You Feel It? — Citizen Science Goes Seismic

This Dynamic Planet — Special Poster Pullout

Letter from Lynn Scarlett

Message from Acting Secretary Lynn Scarlett

One hundred years ago, a devastating earthquake changed the way the San Francisco Bay Area, Calif., and the United States think about the power and unpredictability of the planet on which we live. Although much of what we now know about earthquakes was learned after April 18, 1906, the U.S. Geological Survey was pondering seismic issues for over 25 years before the great quake.

In fact, since its creation in 1879, the USGS has grown to become the nation's largest water, earth, biological science and civilian mapping agency. The USGS collects, monitors, analyzes and provides scientific understanding about natural resource conditions, issues and problems.

As part of these duties, the USGS plays a vital role in researching natural hazards and minimizing loss of life and property from the disasters they can lead to — from earthquakes to volcanic eruptions; from landslides and other forms of ground failure to geomagnetic storms; from floods, droughts, and coastal storms to wildfires; from fish and wildlife diseases to invasive species. USGS science assesses where natural hazards may occur and what the risks are to those who live near these hazards.

The USGS also works cooperatively with federal, state, tribal and local agencies to assist in emergency response efforts when catastrophes strike. USGS science provides information needed by the public to understand the hazards that may exist in their communities and to help mitigate losses and damages when they occur.

USGS is now a world leader in the natural sciences thanks to its scientific excellence and responsiveness to society's needs. Throughout this publication, you will see how one remarkable and terrible event in U.S. history did so much to bring the USGS to the forefront of earth science exploration and to bring natural hazard concerns to the forefront of the American consciousness.

Lynn Scarlett
Acting Secretary

Letter from P. Patrick Leahy

Message from P. Patrick Leahy

This special edition of *People, Land & Water* commemorates the 100th anniversary of the April 18, 1906, Great San Francisco Earthquake, which is deemed by many as the birth of earthquake science. Throughout the edition, you can enjoy stories about the history of seismology, survivor accounts, state-of-the-art developments in earthquake science, and profiles of USGS past and current premier earthquake scientists.

The 1906 earthquake and subsequent fire caused the loss of hundreds of lives, destroyed property and left approximately 225,000 people homeless.

From that moment, scientists and the public realized a compelling need to better understand the dynamic — and potentially hazardous — nature of Earth's seismic processes. Research began immediately, with scientists tackling what they saw before them — displacement of the ground along the San Andreas Fault.

From those seminal efforts, science has evolved from studying the effects of earthquakes to discovering the dynamics of plate tectonics, developing probabilistic earthquake hazard assessments, and installing sophisticated instrumentation deep into the San Andreas Fault itself. Earthquake monitoring has grown from days of analyzing reports of earthquake activity using calculations on globes with tape measures and compasses to a 24/7, global seismic network of seismographs, satellites and computers that capture and report earthquake events anywhere in the world almost instantaneously.

Scientific research, monitoring and assessment have provided the framework for improving building codes to construct earthquake-resilient buildings and infrastructure. ShakeMaps, which graphically show the differing degrees of shaking from an earthquake, can be available online within minutes for use by emergency-response teams in deploying resources to areas hardest hit.

We have built strong partnerships with government and non-government scientists, academia and other organizations throughout the world to delve deeper into the causes of earthquakes. The public, too, has contributed by answering the question posed on our Web site, www.usgs.gov, "Did You Feel It?" — a citizen-based approach to defining the magnitude of shaking in areas that lack dense instrumentation.

Now, 100 years after the 1906 Earthquake, science and technology mark a milepost on a journey that has brought us far and will take us still further. Seismology is an example of science in the public service, relevant and keyed to making our lives safer. We are proud to provide you with this publication that shows where we've been and where we hope to go. We hope you enjoy it.

P. Patrick Leahy
U.S. Geological Survey

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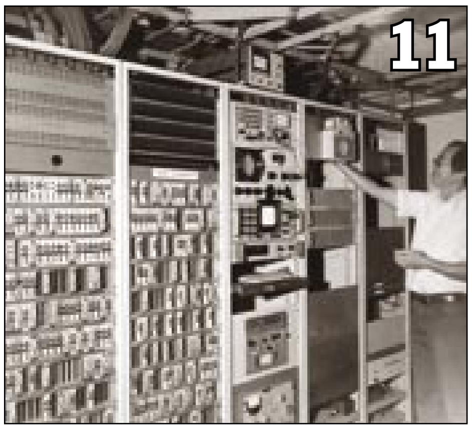

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USGS stenographer Adelena M. Fontaine. Photo: George R. Davis family.

People, Land, & Water Special Issue

The Interior Department manages 1 out of every 5 acres of land in the nation; provides resources for a third of U.S. domestic energy; works with 562 Indian tribes; provides water to 31 million residents through 824 dams and reservoirs; receives 450 million annual visits to 390 National Park System units, 544 wildlife refuges and vast areas of multiple use lands; provides opportunities for hunters and anglers; and works to improve habitat on public and private lands.

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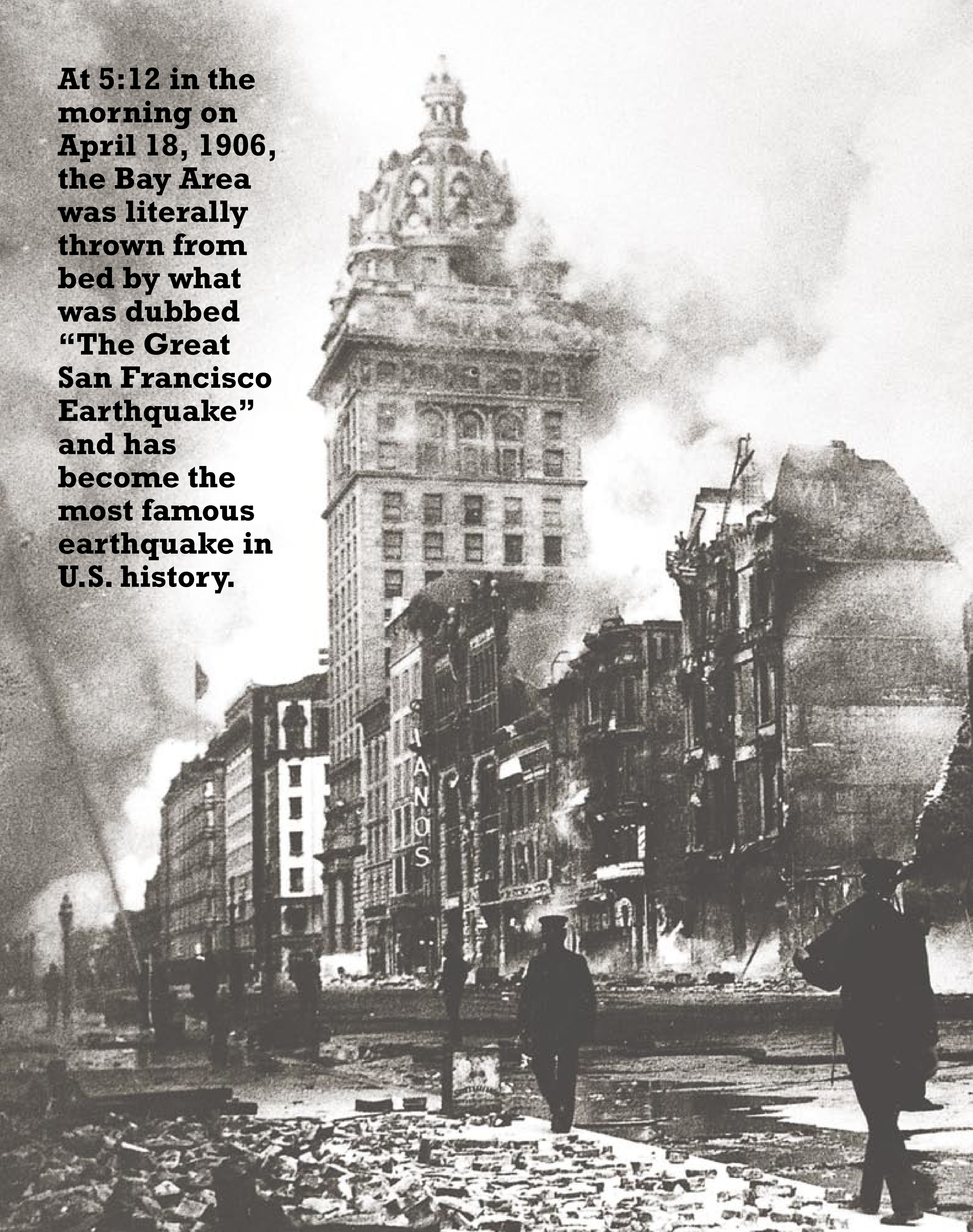
The historical photos on the cover of this special edition are courtesy of the California Historical Society. The newspaper photo is courtesy of the Library of Congress.

At 5:12 in the morning on April 18, 1906, the Bay Area was literally thrown from bed by what was dubbed "The Great San Francisco Earthquake" and has become the most famous earthquake in U.S. history.



A Moment of Magnitude for America and for Science

By David Hebert

In December 1904, a University of California at Berkeley geology professor named Andrew Lawson wrote the following in the university's newspaper: "History and records show that earthquakes in this locality have never been of a violent nature, as so far as I can judge from the nature of recent disturbances and from accounts of past occurrences there is not occasion for alarm at present."

Less than two years later, he might have considered a retraction.

At 5:12 in the morning on April 18, 1906, the Bay Area was literally thrown from bed by what was dubbed "The Great San Francisco Earthquake" and has become the most famous earthquake in U.S. history.

Starting under the Pacific, just off the coast of the San Francisco peninsula, the magnitude-7.9 temblor grew until it had caused shaking and damage along nearly 300 miles of the then-unknown San Andreas Fault in Northern California. Strong shaking lasted for nearly a minute, and in some places along the fault, the earth moved more than 25 feet.

For those who were there, it was surely a singular experience.

"My sensations … were of being on ship in a gale pounding against the rocks, being thrown this way and that, then up in the air, and dropped with a sickening thud that took away my breath," said Melissa Stewart McKee Carnahan in her 1908 book documenting her personal experiences of the earthquake. "It lasted twenty-eight seconds. Had it lasted ten seconds longer, I fear every building in San Francisco would have gone down."

As it was, 28,000 buildings were destroyed in San Francisco by both the earthquake and the subsequent fire, which blazed for three days — the shaking had damaged the city's water lines, rendering the fire department ineffective.

Throughout Northern California, at least 3,000 people were killed (most in San Francisco and many in the fire); and of San Francisco's some 400,000 residents, about 225,000 lost their homes. Damage losses have been estimated at more than $500 million (1906 dollars).

A repeat of this quake today would likely lead to thousands of deaths and possible economic losses in the hundreds of billions of dollars.

"This bombardment of nature caused greater destruction in the number of seconds it lasted than the most modern engines of war could accomplish in the same number of weeks," Carnahan said. "From whence did this tremendous force originate?"

For all the horror of this earthquake's destruction, it's this last question that might lend the disaster its lasting significance.

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Photo courtesy California Historical Society

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Before April 18, 1906, knowledge of earthquakes — how and where they occur and the hazards they pose — was relatively little. However, that was about to change.

"While the 1906 earthquake marked a seminal event in the history of California, it can also be remembered as the birth of modern earthquake science in the United States," said Mary Lou Zoback, a senior research geologist with the U.S. Geological Survey (USGS), in an April 2006 article for GSA *Today*. "It was the first time that an earthquake was recognized and documented as the result of a recurring tectonic process of strain accumulation and release."

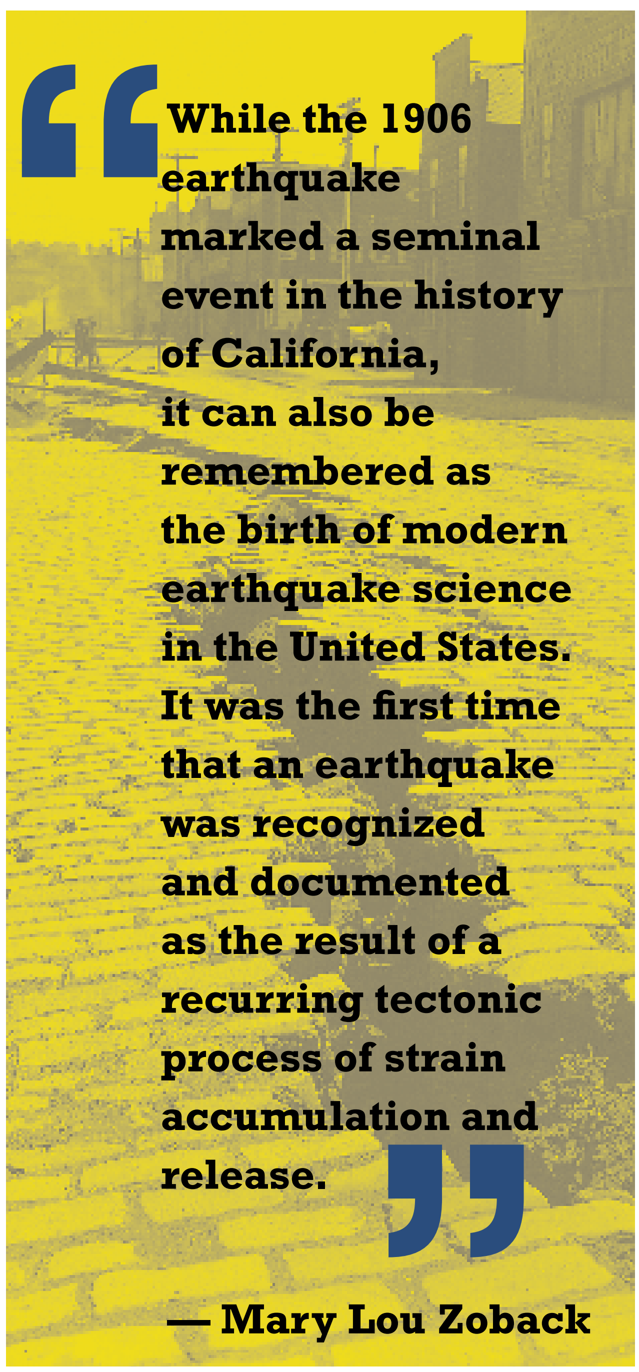
Much of that recognition and documentation was the work of Professor Lawson, whose ironic statement in 1904 about the relative lack of seismic hazards in the Bay Area underscored the need for scientific study and understanding.

With Lawson as its leader, a group of scientists and engineers documented the physical characteristics of the 1906 earthquake's faulting throughout California and published *The Report of the State Earthquake Investigation Committee, volume I*, in 1908. This report also included reports on shaking intensity and an atlas of 40 maps and folios.

A second volume of the report was published in 1910 under the editing of Harry Fielding Reid. This volume focused on the earthquake's seismological and mechanical traits, and it was from this research that Reid created the elastic-rebound theory of earthquake sources — the primary model of the earthquake cycle even today.

"H.F. Reid's work is one of the seminal studies of earthquake science in the 20th century," said Ross Stein, a USGS geophysicist.

"Their exhaustive data and thoughtful conclusions led to a number of new discoveries about the cause and effects of earthquakes," said Zoback of both volumes as well as a complementary report published by the USGS in 1907.



"While the 1906 earthquake marked a seminal event in the history of California, it can also be remembered as the birth of modern earthquake science in the United States. It was the first time that an earthquake was recognized and documented as the result of a recurring tectonic process of strain accumulation and release."

— Mary Lou Zoback

Photo courtesy California Historical Society

And these discoveries and observations still fuel seismic science nearly 100 years later.

"There is still much to be gained from study of the 1906 report, in spite of the fact that it is nearly a century old and in spite of the great increases in our understanding of the San Andreas Fault since the time of its publication," said USGS geologist Carol Prentice in a 1999 paper. "The 1906 report continues to supply information for modern studies in geology, geodesy and seismology."

The importance of continuing seismic research becomes apparent when one considers that a powerful earthquake is bound to happen again — a USGS-led study published in 2003 places a 62-percent probability on an earthquake of magnitude 6.7 or larger occurring in the Bay Area before 2032.

With that sort of likelihood looming, earthquake hazard science and mitigation by the USGS and its partners are vital to the safety and welfare of those living in the Bay Area as well as the United States' other seismically active places.

To ponder future possibilities, however, one should also peer into America's shaky past. In the relatively short time since its colonization and independence, the nation has seen many moments of major magnitude, including April 18, 1906.

Over the next several pages, you can find a narration of how USGS scientists in and near the Bay Area responded to the earthquake as well as firsthand accounts from others who were there.

A brief but significant seismic history of the United States can also be found along the bottom of the next several pages in the accounts of 18 such earthquake events, beginning in 1700.

For more information on the 1906 earthquake, visit http://quake.usgs.gov/info/1906/index.html.

Facing the Great Disaster: USGS Responds to the Earthquake

By Liz Colvard and James Rogers

Left to right: Robert B. Marshall (back to camera), A.I. Oliver, Albert H. Sylvester, Sidney N. Stoner, George R. Davis and A.B. Searle in the USGS Pacific Region Topographic Mapping office, circa 1904-1905. Marshall, Sylvester, Stoner, Davis, and Searle were all part of the USGS group that took the first boatload of relief supplies down the Sacramento River to San Francisco following the 1906 earthquake. Photo: George R. Davis family.

In 1906, the only permanent U.S. Geological Survey (USGS) office in California was the Pacific Region Topographic Mapping Office in Sacramento, some 70 miles up the Sacramento River from San Francisco Bay. The office had been established just three years earlier and was the only USGS office ever created for the sole function of topographic mapping. On April 18, 1906, many of the USGS topographers were in Sacramento preparing for summer fieldwork. It was that day that the great earthquake struck.

Although a small amount of shaking was felt in Sacramento, detailed information about the earthquake was slow to reach the residents there. Before the full extent of the damage was known, USGS topographic engineer George R. Davis, fearful that his 62-year-old father, Edward Davis, was caught up in the earthquake devastation, left Sacramento on the first train bound for San Francisco. “He was very worried. The phones were down and he wasn’t sure whether or not the hotel his father was living in was damaged,” says George Davis’ daughter Anna Davis Rogers, now 88 years old, recalling stories she heard of these events while growing up. “Fortunately [the hotel] hadn’t fallen down.”

Davis, a tall man with a quiet demeanor and a dry wit, was accompanied to San Francisco by fellow USGS topographer Clarence L. Nelson. Both were 29 years old and in excellent physical condition after a year spent mapping the Mt. Whitney quadrangle, which features some of the most rugged terrain in the conterminous United States.

Upon their arrival in San Francisco, the pair was fortunate to find the elder Davis unharmed at the hotel where he had been living. Nelson had brought his camera to get photographs while things were still “hot” and began taking what would become a memorable set of images. The three men wandered through San Francisco all night and the following morning, moving from one dramatic scene to the next. Nelson captured the horse-mounted dynamite squad, soldiers marching out from the Presidio and a rare scene of two horse-drawn fire engines with one engine drawing water from a cistern on Union Street. One ironic photograph shows refugees wending their way through rubble-filled streets in the direction of a wrecked City Hall. Flames of the burning district shone brightly against the darkness, and Nelson captured the surreal glow in several of his photographs, including one of Union Square with the Breuners building burning in the background.

USGS Topographers Swing into Action

Because of its proximity to the Bay Area, Sacramento — a growing capital city of 31,000 — figured prominently in early relief efforts. At a mass meeting on the Sacramento courthouse steps the morning of April 19, citizens cheered when Sacramento’s ad hoc General Relief Committee declared that they would not wait to be asked to help and that a riverboat had already been secured to transport supplies to San Francisco at the earliest opportunity.

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A Letter Home

Earthquake Survivor Percy J. Holmes Recalls the Historic Day’s Events

(This letter was published in a Connecticut newspaper, May 1906. Percy J. Holmes was the grandfather of the wife of John Filson, USGS emeritus.)

Merchant E. F. Hawley hands us the following letter from Percy J. Holmes, son of Joshua Holmes of Shelton: 2550 Pacific Avenue, San Francisco, Cal., April 26, 1906.

Dear Mother:

Your letter arrived this morning and I will answer it immediately. It is noon now and the first chance to have had to write to you since the earthquake. I tried everywhere in ’Frisco to send you a telegram, but could not get one off until Saturday, when Mrs. Magee went to Oakland. I gave her a telegram to send to you saying that Uncle William’s family and I were all well.

The quake was a great one. It happened at 5:13 a.m. and I was fast asleep, but was awakened by an awful roar and shaking. The whole house was shaking and I thought it was going to fall to pieces. I jumped out of bed and ran into the yard, but the bricks were falling so fast there that I “ducked” back into my room and slipped into my clothes. By that time the shake was over and I had to climb over about two feet of fallen bricks to gain the street.

The house next to ours was a brick one, in the course of construction. It was three stories, and the top story was shaken down, depositing about two tons of bricks into our driveway. All the streets were full of bricks, as the chimneys of the houses were all shaken down. About five minutes later we had another shock, not as heavy as the first and we have had slight shocks at long intervals, ever since. Yesterday we had another severe shock, and most everyone ran into the streets again, expecting a repetition of the first.

Magee’s house stood the shock finely, and with the exception of two of the chimneys, that were shaken down, it received very little damage.

The first shock was a “peach” all right. I was not badly frightened until after it was all over. The first thing I thought of was “I’m sorry for the people near Vesuvius,” but about five minutes after the shock I found myself trembling like a leaf, and felt as though I was freezing. You cannot imagine how terrible everything shook. I always thought that an earthquake was a rolling motion of the ground, but that one felt as though you rode a bicycle down a long flight of stairs. The sensation is terrible, a person feels so helpless; in fact you are nearly helpless, as the only thing you can do is to run to the nearest open place.

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America’s Shaky Past - The Top 18 Earthquake Events in the United States Since 1700

This Japanese map shows the Kuwagasaki Coast, an area affected by the tsunami in 1700.

Cascadia Subduction Zone (from British Columbia to Northern California)

Date: Jan. 26, 1700

Magnitude: 9.0

Damage: A resulting tsunami destroyed villages in the Pacific Northwest of the United States and damaged coastal areas in Japan, as geologic evidence corroborated by Native American oral traditions and Japanese written records indicate. The dollar amount of property losses is not known.

Number of deaths: unknown

Taken in 1935, this image shows the ruins of the first La Purísima Concepción Mission near Lompoc, Calif.

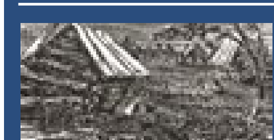
Wrightwood and Ventura, California

Dates: Dec. 8 and Dec. 21, 1812

Magnitude: ~7.5 and 7.1

Damage: These potentially related earthquakes damaged several missions, including the Mission San Juan Capistrano, where the church collapsed during mass. The Dec. 21 earthquake destroyed the Mission La Purisima Concepcion, near present-day Lompoc, Calif. The dollar amount of property losses is not known.

Number of deaths: 41 (40 in the San Juan Capistrano collapse)



This 19th-century illustration depicts the damage and chaos resulting from the 1811-1812 New Madrid earthquakes.

New Madrid, Mo.

Dates: Dec. 16, 1811; Jan. 23, 1812; Feb. 07, 1812

Magnitude: All estimated to be in an approximate range from 7.5 to 8.0

Damage: Structures collapsed or were damaged from Cincinnati to St. Louis; New Madrid was destroyed in the Feb. 7 earthquake. Areas in Arkansas, Illinois, Kentucky, Missouri and Tennessee experienced landslides, land uplifted and trees destroyed. At area rivers, banks collapsed, islands disappeared and waves overwhelmed or beached boats. The dollar amount of property losses is not known.

Number of deaths: unknown

Ka’u District, Hawaii

Date: April 2, 1868

Magnitude: 7.9

Damage: The earthquake and resulting tsunami and landslides destroyed homes, a large church and warehouses. The dollar amount of property losses is not known. More recently, the magnitude-7.2 Kalapana, Hawaii, earthquake in 1975 led to a local tsunami of more than 40 feet.

Number of deaths: 77 (tsunami, 46; landslide, 31)

A Look Back in Time

An Interview with a Survivor of the 1906 San Francisco Earthquake

(Excerpts reprinted from "Earthquake Information Bulletin" May-June 1977, Volume 9, Number 3)

By: Henry Spall

Bert L. Smith, Jr., was born in Eureka, Nev., and was in the Palace Hotel, San Francisco, at the time of the great earthquake of 1906. Now retired, he lives with his wife, Emily, in Santa Rosa, Calif., 45 mi north of San Francisco. From 1926 to his retirement in 1966, he had various assignments in the field of agriculture with such organizations as the U.S. Department of Agriculture and State and Federal farm and water agencies. For 18 yr he was involved with the Commonwealth Club of California and has been a Regent of the University of California.

H.S. What brought your family to San Francisco on April 18, 1906?

Smith. First let me back up a little. My mother's family founded Centennial, Wyo. My father's family was in the woolen business in Massachusetts. My father decided to come out West with his brother, and he landed in Wyoming long enough to work in the bank and marry my mother. After a short time in Mexico, my parents followed the mining boom into Nevada. You have to understand that in those days mining was either boom or bust.

H.S. Where were you living in 1906?

Smith. Eureka, Nev. My father was in banking and had various interests in the mining business. The year 1906 was a good one, and my father was enjoying a period of temporary affluence. So we decided to visit San Francisco for the shopping, but largely so my parents could go to the Opera and hear the great Italian tenor, Enrico Caruso.

H.S. And you stayed at the Palace Hotel?

Smith. Of course. That was what you did in those days if you were affluent. Caruso stayed there, too — although we didn't see him. We brought 1 or 2 trunks with us, rather more modest than the 200 trunks we were told that Caruso had brought with him.

H.S. What happened at 5:18 am the next morning?

Smith. Well, of course, it was dark at the time. I remember distinctly being awakened by the earthquake — and the shock, the terror of it all. And the efforts of my mother to calm us children as best she could. Then, we heard the panic from the room next door where our friends, the George Bartletts, were staying. They couldn't get to their children in an adjoining room because the earthquake had jammed the door shut.

H.S. What did your family do then?

Smith. Well, you must remember that I was a small child at the time, and at the age you don't recall all the minute details. But several distinct memories have stuck in my mind. I recall being dressed on the bottom steps of the magnificent stairway in the lobby of the hotel. There was fallen plaster from the ceiling all around us, and I couldn't help wondering if the chandeliers were going to fall, too.

One of my most vivid memories was of my mother with her hair uncombed and not braided around her head as she usually had it. That made a distinct impression on me.

I recall the discussions about if the Palace would burn and when it would burn. As you know, it survived the earthquake rather well, but it burned down later as the fire swept through the city. The answer from the hotel manager was that despite the very latest fire-prevention measures in the hotel, he thought it was probably going to burn. Perhaps because of this he gave us all our room keys as mementos.

H.S. What then?

Smith. We moved out of the hotel, and I recall our family riding on a wagon to Golden Gate Park. Here we lived for a few days in the tents that the Army had provided. We didn't have anything. All we had were the clothes we had walked out of the hotel with. At Golden Gate Park, I recall seeing the soldiers and the discussions about whether they were going to dynamite to try to check the fire.

Eventually the family was able to get on a train (at the station at Third and Townsend) to San Jose and then go up the east side of the Bay to Berkeley. Here we stayed with the Dewey Powell family for a few days until we were back on our feet and could return to Nevada.

In those days it used to be up over the hill on Southern Pacific, then

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As instructed in a telegram from USGS Director Charles D. Walcott, Robert B. Marshall, the geographer-in-charge of the USGS Topographic Mapping Office in Sacramento, announced to the Relief Committee that the USGS stood ready to send a complete outfit of camp property, horses, wagons and men sufficient to take care of 500 people and that he could be ready to leave that day. The offer was gratefully accepted, and Marshall was assigned to take charge of purchasing additional supplies, using the more than $50,000 in donations collected that day from the citizens of Sacramento.

"Men in the Sacramento office … hurried to the warehouses and packed blankets, tents, cooking stoves and utensils, folding tables, chairs, axes, picks, shovels and much other equipment. [They] loaded the big camp wagons, buckboards, and hitched teams to water tank wagons and brought them all to the wharf in Sacramento," wrote USGS stenographer Adelena Marie Fontaine.

In addition, Marshall bought large quantities of canned goods, milk, baby food, soup and other prepared food. At his request, a factory ran all night producing crackers and cookies. Marshall and the other USGS topographers soon had an old stern-wheeler, *San Joaquin*, "loaded to the waters edge with relief supplies."

At some point during the night of the 19th, the *San Joaquin* began its trip down the Sacramento River toward San Francisco. Aboard were Marshall; topographers A. Benson Searle, Sidney Stoner and Albert H. Sylvester; and field assistant Jake W. Muller. George Davis and Clarence Nelson were also on board. (After relocating the elder Davis in a hotel in Oakland and returning to Sacramento by train, the pair was informed that the *San Joaquin* was about to depart along with their USGS colleagues. The two decided to embark as well — their second trip to the beleaguered city in 48 hours.) The boat was accompanied by a barge under the direction of Almerin Sprague, the father of Sidney Stoner's fiancée, Marjorie Sprague. The barge carried wagons, horses and water barrels.

At 8 a.m. on the morning of April 20, the *San Joaquin*, with its load of relief supplies and USGS topographers, landed at the Presidio of San Francisco, where it was greeted with cheers. The military officer who met the boat immediately asked about baby food and milk and was overjoyed by Marshall's reply of "a carload." Volunteer stevedores, soldiers and citizens assisted the USGS men in unloading the shipment.

USGS topographer George R. Davis (standing) in the field, circa 1908. Davis rushed to San Francisco after the earthquake on April 18, 1906, to look for his father, who was living there in a hotel. Photo: George R. Davis family.

By this time, uncontrolled fires and continuous dynamiting had filled the air of San Francisco with heat, smoke and dust, making it unpleasant to breathe. Davis and Nelson attempted to renew their exploration of the ravaged city before the boat's return trip but were unable to bear the conditions for long. At one point, they quenched their thirst with cans of tomatoes found in an abandoned grocery store.

Staffers Work Overtime Aiding Refugees

Back in Sacramento, the women of the USGS family were hard at work. Stenographer Adelena Fontaine, Marjorie Sprague and the wives of Robert Marshall and Albert H. Sylvester volunteered to assist the Sacramento Women's Council as they processed thousands of refugees from San Francisco. "I worked on [the] general Relief Committee several nights, meeting trains crowded to the doors with refugees," wrote Fontaine. "We fed them, clothed them, took them to friends if they had any, and those who were destitute we assigned to the homes in the city whose doors had kindly been opened to welcome the unfortunates."

Fontaine recounted the story of one refugee, a young man of about 20, whose brother was mistaken for a looter and shot to death. "[He was] endeavoring to extricate his brother and their belongings from the hotel where they had lived, [and] saw his brother shot down before his eyes by a soldier. The soldier had made a mistake, and the boy was not stealing. This young refugee was a telegraph operator and volunteered his services [until] the building was abandoned; [he then] fled before the flames," wrote Fontaine. "He was in a dreadful state from exhaustion, hunger and exposure."

Mapping the Fault

The topographers in Sacramento were not the only USGS employees working in the vicinity of San Francisco. By great coincidence, eminent USGS geologist Grove Karl (G.K.) Gilbert had been in Berkeley (7 miles across the Bay from San Francisco) studying sedimentation and the effect of hydraulic gold-mining debris in the Sacramento River. A vigorous 63 years old in 1906, Gilbert was considered one of the top field and experimental geologists of his day. He was one

This home was damaged in the magnitude-6.9 earthquake on the Hayward Fault on Nov. 21, 1868.

Hayward, California

Date: Nov. 21, 1868

Magnitude: ~7.0

Damage: Communities along the Hayward Fault and in San Francisco and San Jose, Calif., suffered an estimated $300,000 (1868 dollars) in property damage. Before 1906, this was known as the "Great San Francisco Earthquake."

Number of deaths: 30

Parts of Charleston, S.C., lie in ruin after the earthquake on Aug. 31, 1886. (Photo J.K. Hillers)

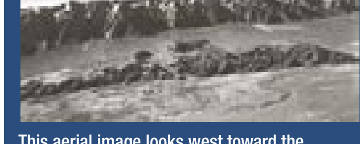
Charleston, South Carolina

Date: Aug. 31, 1886

Magnitude: 7.3

Damage: Many of the buildings in and around Charleston were damaged or destroyed, and railroad tracks around the city were twisted and shifted. Property damage was estimated at $5 to $6 million (1886 dollars).

Number of deaths: 60



This aerial image looks west toward the Sierra Nevada Mountains across Owens Valley, Calif., where an earthquake on March 26, 1872, caused heavy damage to the town of Lone Pine.

Owens Valley, California

Date: March 26, 1872

Magnitude: 7.4

Damage: This earthquake on the eastern side of the Sierra Nevada Mountains caused the destruction of more than 50 houses in nearby Lone Pine, Calif., and there were other reports of buildings collapsing, resulting in approximately $250,000 (1872 dollars) damage.

Number of deaths: 27

These are the remains of Jefferson Junior High in Long Beach, Calif., following the earthquake on March 10, 1933.

Long Beach, California

Date: March 10, 1933

Magnitude: 6.4

Damage: Property loss was estimated at $40 million (1933 dollars), as some sections of southern Los Angeles County and northern Orange County were almost totally destroyed.

Number of deaths: 115

of the first five principal geologists hired by the USGS when it was created in 1879 and served as its first “chief geologist.” His scientific reports are considered some of the best geologic papers ever written.

Gilbert wrote of his experiences on the morning of April 18: “It is the natural and legitimate ambition of a properly constituted geologist to see a glacier, witness an eruption and feel an earthquake. … When, therefore, I was awakened in Berkeley on the eighteenth of April last by a tumult of motions and noises, it was with unalloyed pleasure that I became aware that a vigorous earthquake was in progress. … In my immediate vicinity the destructive effects were trivial, and I did not learn until two hours later that a great disaster had been wrought on the opposite side of the bay and that San Francisco was in flames.”

As soon as regular ferry traffic to San Francisco was restored, Gilbert traveled across the Bay to observe the fires and the results of the earthquake firsthand. “The flames work with wonderful speed. While I lingered, whole squares were consumed. An hour is probably enough to raze a square of wooden houses.”

Gilbert’s assistant in Berkeley was 32-year-old François E. Matthes, a native of the Netherlands and a highly accomplished USGS topographer and geomorphologist. The USGS sent Matthes to California in 1905 for the express purpose of mapping Yosemite Valley. Matthes had garnered praise for his topographic map of the upper half of the Grand Canyon, which is one of the finest plane-table maps produced by the USGS. While Matthes was between field seasons in Yosemite, Gilbert hired him to research scientific articles that were written in Dutch and French.

Matthes, too, was jolted awake on April 18 by the earthquake: “Woke up 5 a.m. by violent earthquake, lasting 28 seconds. Found on getting up San Francisco enveloped in flames. Severe quake 8:15 while eat[ing] breakfast… Made tour of inspection of Berkeley; found brick chimneys demolished by the wholesale; many brick houses badly damaged. All day long dynamite blasts are heard from the city… Fire rages all night.”

There was no lack of scientific interest in the earthquake. Geologists and other scientists quickly flocked to the area. Local geologists gravitated around Andrew C. Lawson, chairman of the geology department at the University of California at Berkeley, and John C. Branner, professor of geology at Stanford University, both of whom worked part time for the USGS.

Three days after the earthquake, the governor of California appointed the California State Earthquake Investigation Commission, chaired by Lawson, to oversee and consolidate all of the scientific investigations. Gilbert was one of eight men assigned to the commission. Only Gilbert and one other had any experience with earthquake research. The commission ultimately brought together more than 21 scientists, architects and engineers to examine the earthquake. This included several members of Japan’s Imperial Earthquake Investigating Committee, considered at the time to be a leading authority on earthquake research. The commission primarily focused on studying surface changes caused by the earthquake, earthquake intensity, earthquake arrival times and the geophysics of the earthquake. Gilbert wrote several reports about the earthquake, and both he and Matthes took many post-earthquake photographs.

The Earthquake Commission quickly appropriated the services of François Matthes by sending him into the field to examine the effects of the earthquake north of San Francisco. He later mapped the trace of the San Andreas Fault through the northern part of the state. His maps were included in an atlas published by the commission, and his field observations were incorporated into the commission’s final report.

The USGS and the Army Corps of Engineers collaborated on a separate federal investigation of the earthquake’s effects on buildings and construction materials. Richard L. Humphrey from the structural materials division was the primary USGS representative on the team. He was dispatched to San Francisco one day after the earthquake. Gilbert contributed an overview of the earthquake to the team’s report.

It’s difficult to know what long-term impact the events of 1906 may have had on the USGS employees involved with it. They were all ordinary people who responded to a natural disaster in extraordinary ways.

A Look Back in Time

Continued from page 8

back to Eureka over a narrow gauge railroad from Palisade (near Elko), which was just a wide place in the track.

H.S. Did the earthquake have any long-lasting effects on your family?

Smith. I don’t think my mother ever recovered from the shock of going through something like that. From that day on she too — always wanted to have a light on at night or a candle with matches. She was never going to be caught in the dark again. She always had a money belt with money in it of course. When you think about it, these were very sensible precautions.

H.S. What about your father?

Smith. My father took it almost routinely. After the ups and downs of the mining business, he was used to commotions. We moved back to Eureka and then to Rhyolite. The next year, 1907, was very bad in mining, and our affluence was gone. We moved to Tonopah, then to Elko. My father just moved around according to the changing fortunes of the mining ventures in Nevada.

H.S. Have you been through many other earthquakes?

Smith. I would guess that my wife and I have been through 15 to 20 earthquakes since we were married. Curiously one of the first ones I experienced after the 1906 earthquake, occurred while my family was living in Oakland for a short while from 1910 to 1911. We had all gone to the Curran Theater in San Francisco. As we approached the balcony, we got a rather severe shake. There was an incipient panic. Don’t forget that this was only a few years after the 1906 earthquake, so you didn’t know what was going to happen. We got seated, and the manager told the audience not to be alarmed. Everything was in order. He said that we were safer in the theater than anywhere else. Just to relax and the show would go on. And we did! And it did! Things like that stick in your mind.

H.S. Any other memorable earthquakes?

Smith. Yes, quite a few. While we were fishing off the pier on holiday at Long Beach in 1918, we had a little earthquake which rattled the whole pier and rippled the water. My aunt lost her precious heirlooms in the 1933 earthquake at Long Beach when a corner china cabinet tipped over. Ever since then we’ve always buckled our cabinets to the wall.

I recall my wife’s first earthquake experience. We were living in Berkeley at the time. She was getting breakfast, and suddenly the silverware began dancing around on the table. “Something is happening,” she called out to me. “It’s just an earthquake,” I replied, “don’t worry.” So she went on frying the eggs.

Then there was 1958. My office was on the 9th floor of 821 Market Street in San Francisco. My partner in the olive business came into the office and propped his chair back up against the wall. Suddenly, he said “I’m having a heart attack.” And I said “No, you’re not. *We’re* having an earthquake.” The building just shook a little, and that was that.

H.S. Others?

Smith. Yes. The first time our three children experienced an earthquake was in Berkeley once in the middle of the night, and they all dived into bed with us. We were at Santa Barbara during the summer of 1952 relaxing in front of a motel when we felt a severe shake. I said to my wife that somewhere, someone was getting a devil of an earthquake. That was the Tehachapi (Kern County) earthquake. Later on that summer we had ranching friends who went through the Bakersfield earthquake. The only thing that happened to *them* was that their liquor came out of a closet, and the husband cut his foot on the broken glass as he was running out of the door.

H.S. Any earthquakes while you’ve lived in Santa Rosa?

Smith. Yes — the big earthquake in 1969. It was about 10 o’clock at night. We had no damage, but the chandelier rocked back and forth. We went out into the street and said hello to the neighbors. That’s what you do afterwards: Check on everyone else.

H.S. You were in the 1906 earthquake. Does it bother you that 70 years later you are now retired in the same general area?

Smith. Not at all. Earthquakes are a fact of life. It’s just something you have to live with. You remember what you’re supposed to do and what you’re not supposed to do. You can take some precautions, like buckling down the cabinets, having a stock of food for a week or two, putting some money away. We have a wrench handy to shut off the gas. We live in a wood frame house, bolted to the concrete foundation. You don’t need to increase the hazard if you can avoid it.

This political clubhouse in Hilo, Hawaii, was shattered by the earthquake-generated tsunami on April 1, 1946. (Photo: NOAA)

Aleutian Islands, Alaska

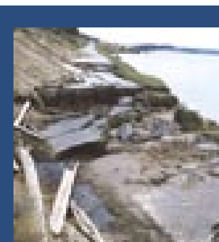
Date: April 1, 1946

Magnitude: 8.1

Damage: This earthquake generated a tsunami that struck Alaska, Hawaii and the west coasts of North and South America, causing more than $26 million (1946 dollars) in damage (mostly in Hawaii).

Number of deaths: 165 (all tsunami-related: 149 in Hawaii; 5 in Alaska; 1 in California)

This road was broken by a landslide caused by the earthquake at Hebgen Lake, Mont., on Aug. 17, 1959.



Hebgen Lake, Montana

Date: Aug. 17, 1959

Magnitude: 7.3

Damage: The most significant damage was caused by a large debris avalanche that dammed the Madison River, eventually creating a lake more than 150 feet deep. Damage to homes, highways, timber and other property was estimated at $11 million (1959 dollars).

Number of deaths: 28 (most caused by rockslides)

Residents of Tehachapi, Calif., fill the streets after the earthquake on July 25, 1952.

Kern County, California

Date: July 25, 1952

Magnitude: 7.3

Damage: The nearby towns of Arvin, Bakersfield and Tehachapi suffered extensive damage, and structures as far away as San Diego and Las Vegas (both more than 200 miles from the epicenter) were damaged. Property loss was estimated at $60 million (1952 dollars).

Number of deaths: 12 (on Aug. 28, 1952, an aftershock caused two more deaths)

Following the magnitude-9.2 earthquake on March 27, 1964, this section of a street in downtown Anchorage, Alaska, has subsided more than 10 feet.

Prince William Sound, Alaska

Date: March 27, 1964

Magnitude: 9.2

Damage: The earthquake (the largest ever recorded in the US) and ensuing landslides caused heavy damage to towns along Prince William Sound, especially Anchorage, where about 30 downtown blocks were damaged or destroyed. The earthquake also generated a tsunami that struck Alaska, the U.S. West Coast and Hawaii. Property loss was about $311 million (1964 dollars).

Number of deaths: 125 (15 earthquake-related, all in Alaska; 110 tsunami related: 98 in Alaska; 11 in Calif.; 1 in Oregon)

A Letter Home

Continued from page 7

At one place it moved the streets from 10 to 15 feet to one side. Three blocks below us it moved the whole street and left cracks three or four feet wide. At Van Ness avenue, about seven blocks from here, it bulged the macadam into ridges two feet high. On Valencia street, for a block, where the ground was "made," it dropped about seven feet, and a hotel in that block sunk two stories out of sight, and as the large water mains broke there, it flooded into the hotel and about 50 people were killed.

As soon as I could dress I started down town to see what damage was done. Some buildings were shaken down and all were damaged to a greater or less extent. The dome of the city hall was nearly shaken down, but a number of the large buildings were not damaged at all by the 'quake,' but the fire burned them all. The most modern structures are still standing, although they are burned inside.

For three days everyone was packing, where they had time before the fire caught them, and most everyone was hauling all they could pull out to the parks and sands. Everything that had wheels was used to carry away the most valuable belongings. Some had two bicycles with a wooden frame between them carrying bedsteads, Morris chairs, baby carriages, trunks, etc. There were people with sheets containing their belongings. It was a sad sight.

I was driving the auto all day and most of the night, carrying Red Cross nurses, army officers, fire hose, water in boilers and about everything.

The night that the fire came to Van Ness avenue we worked all night, carrying dynamite and nitro-glycerine to the dynamiters. Van Ness avenue is 125 feet wide, and they blew up a whole block wide, the length of the street, and thus saved the residential part of the city. Van Ness was the best of the residential streets in the city and it looked awful to see those palaces blown up.

I carried the dynamite into the most beautiful house on the street. We put it in two cases. Most everyone was hurrying out of town, but Mr. Magee had all three of his machines working. One of them was running on a rim without any tire, but he did not care. I do not care to boast, but with those three machines and a small squad (about eight) of soldiers, we saved this end of the town. When we saw that the flames would not cross the avenue we went home at 5 a.m. At one place it crossed and it took some fast dynamiting to stop it. You see, the main trouble was no water, as the earthquake had broken the mains. While the fire was burning so fiercely, the city was light night and day. The smoke hung over the city in one vast cloud and the reflection of the fire on this smoke made a most terrible night.

They are now blowing down the dangerous walls that were left standing. A peculiar incident happened to me. A fellow came and got me to fix his carburetor for him, as he could not make it work. It was a Locomobile. After I had fixed it, I looked over the levers to see how it worked and took it out to see if I could run it. I had only gone a few steps when three soldiers stopped me and told me to take the machine to headquarters, which was only a block away, to drive a captain to the Presidio. They were ordered to seize the first auto and I happened to be the first. I told the captain I had never run a Locomobile before and that he was risking his life. He thought I was lying, and so he pulled his "six shooter" on me, and told me to run the car and to run it easy, too. I knew he meant it, so I thought I had better do the best I could. He said he would shoot me if I did not go easy. I drove him for four hours. Mr Magee was mad and he got me a pass signed by the governor of the state, the mayor of the city and the commander of this division of the army. It says: "Do not detain bearer for any cause whatever." These are the highest passes issued and only about a half dozen were given out.

I heard Mr Magee tell a man that he had lost about every source of income. Do not worry about me, as the fire is out and I will keep out of all danger.

Write soon.
Love to All from
Percy J. Holmes

When the Dust Settled – What Became of the USGS Employees Who Responded to the Great Earthquake?

By Liz Colvard and James Rogers

After 1906, what became of the USGS employees who responded to the great earthquake?

Chief Geographer Robert Marshall moved up to the position of chief geographer for the entire USGS in 1908. Although he did not go overseas, he served as a topographer with the U.S. Army during World War I and achieved the rank of colonel. Marshall was a close friend of John Muir and a charter member of the Sierra Club. In 1916, he was loaned out to serve as superintendent of all the national parks immediately prior to the creation of the National Park Service. Marshall left the USGS in 1919 and returned to California, where he became known as the "Father of the Central Valley Project" when he obtained $200,000 from the California legislature to study his plan for a series of dams, canals and aqueducts to bring water to California's fertile Central Valley.

Photo courtesy California Historical Society

Ten years after the earthquake, stenographer Adelena Fontaine married topographer George Davis. She remained with USGS until the birth of their only child, Anna Davis Rogers, who provided much of the information and some of the photographs for these articles. Their grandson, James Rogers, is also one of the authors of this article.

Topographer George Davis continued to map the High Sierra. He was the first person to take pack stock over Muir Pass and made the first ascents of Black Mountain, Milestone Mountain and Mount Baxter. In 1917, one year after he married stenographer Adelena Fontaine, Davis took over Robert Marshall's old position as chief geographer for the USGS Pacific Region.

Topographer Clarence Nelson stayed with the USGS for his entire career. He left California in 1907 and moved on to mapping projects in Puerto Rico, Argentina, Alaska and other parts of the United States. He went overseas with the Army during World War I, eventually reaching the rank of colonel with the Army Reserve. From 1922 to 1923, he was loaned out to the National Park Service to serve as acting superintendent of Mount Rainier National Park.

Topographer Hal Sylvester transferred to the U.S. Forest Service in 1907. In 1908, he became the superintendent of Wenatchee National Forest in the Cascade Mountains of Washington, where he remained until his retirement in 1931. He is credited with naming more than 1,000 geographic features in Washington. Historian Harry Majors calls him "one of the supreme figures in the history of the Cascade Mountains."

Topographer Sidney Stoner and Marjorie Sprague were married soon after the earthquake. Stoner did not remain employed with the USGS.

Geologist G.K. Gilbert published the results of his research on hydraulic gold-mining debris in 1914 and 1917. At the same time, he continued his interest in earthquake research by serving as a member of the Scientific Committee of the Seismological Society of America, which was formed in the fall of 1906. Although he and the unconventional San Francisco botanist Alice Eastwood (whom he met through the Sierra Club) were intimate friends for many years, they did not get engaged until 1918, when Gilbert was 75 and Eastwood was 59. Gilbert died before the marriage took place.

Topographer François Matthes' topographic map of Yosemite Valley was published in 1907. It is considered by some to be one of the most beautiful topographic maps ever created. Between 1910 and 1911, he was in charge of mapping Mount Rainier National Park and twice hauled his heavy survey equipment to the summit of Mount Rainier. He spent the remainder of his career as a leader in USGS topographic mapping and in the study of the geology and geomorphology of Yosemite National Park.

San Fernando, California

This freeway interchange in San Fernando, Calif., lies broken following the earthquake on Feb. 9, 1971. (Photo: R. Kachadoorian)

Date: Feb. 9, 1971

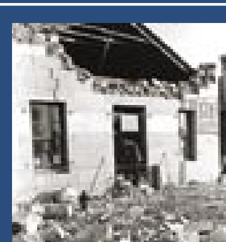
Magnitude: 6.6

Damage: Losses were estimated at $505 million (1971 dollars), as two hospitals and two dams were severely damaged, and several freeway overpasses collapsed.

Landslides also damaged highways, railroads and pipelines. More than 2,000 people were injured.

Number of deaths: 65 (49 in collapses at the San Fernando Veteran's Administration hospital).

Borah Peak, Idaho



This wall's collapse killed two children in Challis, Idaho, during the earthquake on Oct. 28, 1983. (Photo: Sue Villard, Challis Messenger)

Date: Oct. 28, 1983

Magnitude: 7.0

Damage: This was the largest quake ever recorded in Idaho. It caused $12.5 million (1983 dollars) in damage to the Idaho towns of Challis and Mackay. In addition to structure damage, the temblor resulted in several rock falls and landslides, a temporary lake and tremendous surface faulting.

Number of deaths: 2

Seismic Technology Evolves into the 21st Century

By Heidi Koontz

USGS scientist emeritus Waverly Person remembers the days when a rotary phone, a pen, a globe and a keen sense of geography were the required ingredients for locating earthquakes around the world.

Things have changed dramatically since he was a newly minted seismologist.

"We really had to scramble," he says, referring to earthquake response in the '50s and '60s, when he and his fellow scientists did calculations on globes with tape measures and compasses. "It might take a day or a day-and-a-half to get information from remote locations."

That struggle makes Waverly all the more appreciative of the real-time data and global-monitoring systems available now. "It's great to be a part of the change and to have had a hand in getting there," said Person, who recently retired after a 51-year career as a premier earthquake scientist. [See page 13.]

Today, the USGS has the most extensive seismic monitoring and response system in the nation and works with numerous universities to advance understanding of the cause and effects of earthquakes and with emergency response agencies in the interest of public safety and hazards mitigation.

Throughout history, a variety of instruments has been developed to measure movement of the earth.

By definition, seismographs, seismometers and seismoscopes are instruments used to detect and measure the intensity, direction and duration of movements of the ground (as caused by an earthquake).

The earliest account of such technology is a seismoscope invented by the Chinese philosopher Chang Heng in A.D. 132. The instrument consisted of eight dragonheads, facing the eight principal directions of the compass. Below each of the dragonheads was a toad with its mouth opened toward the dragon. The mouth of each dragon held a ball, and when an earthquake occurred, one of the dragon mouths would release a ball into the open mouth of the toad situated below. The direction of the shaking determined which of the dragons released its ball.

The ancestry of today's USGS seismic instrumentation can be traced back to the late 1800s. And while the dragonheads had been replaced by more advanced creations, the equipment of that era was still a long way from the sophistication of today's machinery.

"At the time of the 1906 earthquake there were less than 100 seismographs operating around the world. Today there are thousands," said USGS scientist Gray Jensen, who has been tracking earthquakes for the USGS for more than 30 years.

John Milne, an English seismologist and geologist, invented the first modern seismograph and promoted the building of seismological stations. In 1880, Sir James Alfred Ewing, Thomas Gray and Milne, all British scientists working in Japan, began to study earthquakes. They founded the Seismological Society of Japan, and the society funded the invention of seismographs to detect and measure earthquakes. Milne invented the horizontal pendulum seismograph in 1880.

The horizontal pendulum seismograph was improved after World War II with the Press-Ewing seismograph, developed in the United States for recording long-period waves. With the advent of modern electronics, conventional magnet-and-coil seismometers and geophones became the typical sensors. Electronic amplifiers were then used to produce highly sensitive seismographs. Electronic feedback was added to these devices to create sensors with the maximum in dynamic range, frequency range and sensitivity. Ultimately, arrays of these sensors were connected to computers to produce today's fully automated seismic networks.

Although USGS scientists are currently unable to predict earthquakes, the advances in technology since 1906 allow them to provide much needed information for saving lives and pinpointing risk.

Compiled with assistance from Gray Jensen, Steve Walter, Jack Van Schaack and David Hebert.

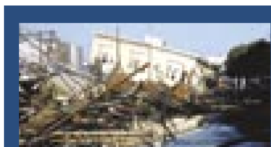
> **"At the time of the 1906 earthquake there were less than 100 seismographs operating around the world. Today there are thousands."**
>
> **— Gray Jensen**

This seismoscope, invented in A.D. 132, represents the earliest account of technology used to record information about earthquake shaking. During an earthquake, the direction of the shaking determines which dragon releases its ball.

Geotech Helicorder model drum recorder used widely since the mid 1900s to record and display seismic records. Now used mainly for visitor and press displays. Whole-day records like this can be produced on computer but requests still come in for the drums.

A room full of Develocorders. These were devices with a roll of 16mm photographic film in them. They also had 16 galvanometers with very tiny lights attached. The row of lights was focused on the film as it was drawn past. This caused a line to be drawn on the film for each light. The galvanometers would cause the light to move from side-to-side in response to the seismic signal which was then recorded on the film. The film was then developed internally over the next ten minutes. Finally the developed portion of the film was projected on a glass screen for viewing. The film was changed each day and the removed film could then be viewed on a larger projector for analysis of the records.

Loma Prieta, California



This section of San Francisco's Marina District is destroyed following the earthquake on Oct. 17, 1989. (Photo: C.E. Meyer)

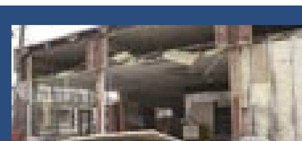
Date: Oct. 17, 1989

Magnitude: 6.9

Damage: The most severe damage occurred in Oakland and San Francisco, where many buildings and elevated-freeway and bridge spans collapsed. Pipelines, port facilities, airport runways and levees were also damaged, and more than 1,000 landslides occurred near the epicenter in the Santa Cruz Mountains. Damage was estimated at $6 billion (1989 dollars), and more than 3,500 people were injured.

Number of deaths: 63

Nisqually, Washington



This business in Seattle has sustained heavy damage following the Nisqually, Wash., earthquake on Feb. 28, 2001. (Photo: Kevin Galvin, FEMA)

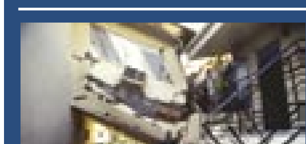
Date: Feb. 28, 2001

Magnitude: 6.8

Damage: This earthquake, including its resulting landslides, caused $4 billion in damages to buildings, highways and other structures in the cities of Olympia, Seattle and Tacoma. Approximately 400 people were injured.

Number of deaths: 1

Northridge, California



This section of a Los Angeles-area apartment complex is broken in half following the Northridge, Calif., earthquake on Jan. 17, 1994. (Photo: FEMA)

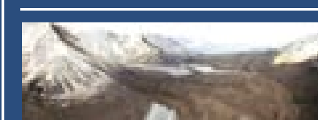
Date: Jan. 17, 1994

Magnitude: 6.7

Damage: In the Los Angeles area, an estimated $20 billion in losses were sustained through damage to more than 40,000 buildings, collapses of freeway overpasses and subsequent fires. More than 5,000 people were injured, and more than 20,000 lost their homes.

Number of deaths: 33

Denali, Alaska



The Trans Alaska Pipeline System near the Denali Fault has shifted but remains intact following the earthquake on Nov. 3, 2002, thanks to its slider bar supports. (Photo: Rod Combellick, Alaska Division of Geological and Geophysical Surveys)

Date: Nov. 3, 2002

Magnitude: 7.9

Damage: Despite being the largest onshore earthquake in nearly a century, the Denali quake was significant for what it did not do: rupture the Trans Alaska Pipeline System. In anticipation of just such an event, the pipeline was engineered to shift on Teflon-coated slider bars where it crossed the fault. Despite nearly 20 feet of displacement, the pipeline did not spill a drop and was quickly back in service.

Number of deaths: 0

History of the USGS Earthquake Hazards Program

By Susan C. Wells

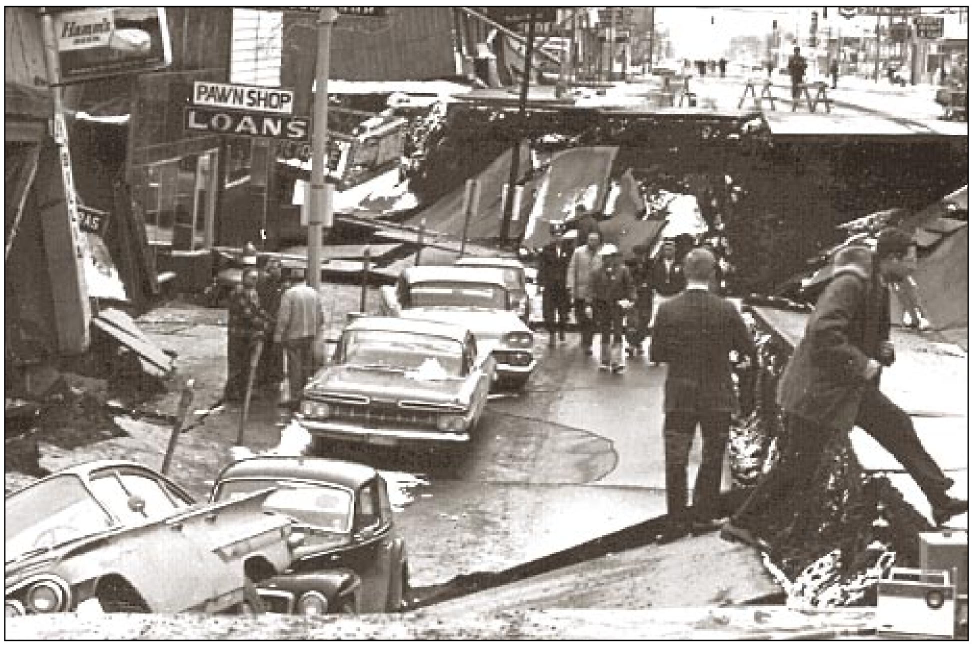
Scientific study of earthquakes in the United States arose from three seismic events that occurred in the eastern, central, and western parts of the country beginning in the early 1800s. In the winter of 1811–1812, three magnitude-8.0 earthquakes shocked New Madrid, Mo.; a magnitude-7.3 earthquake devastated Charleston, SC, in 1886; and in 1906, the magnitude-7.9 earthquake struck San Francisco. Although Charleston's event was thought to be an anomaly because no surface evidence showed that faults had triggered the earthquake, scientists had begun to recognize a direct link between faults — or seeming breaks in the earth's surface — and earthquakes. In 1895, geologist A.C. Lawson at the University of California at Berkeley studied a fault south of San Francisco and named it the San Andreas Fault. At the time he didn't realize the small fault was part of a vast system of faults along the western edge of California. After the great San Francisco earthquake, scientific research revealed its true extent and scientists began speculating that energy building up along these fissures eventually released and shook the earth.

In the 1950s, a permanent USGS site in seismically-active California was established in Menlo Park, 30 miles south of San Francisco. Its focus was primarily geologic and topographic mapping; but seismology was beginning to take root with little fanfare and little funding. Two events soon propelled seismology into the national spotlight, one was due to the nature of human relations and the other to the dynamic nature of the Earth.

The Nuclear Connection

Scientist emeritus John Filson, a former chief of the Earthquake Hazards Program, recalls that early advancements in the field of seismology were closely tied to nuclear energy, both in monitoring nuclear arms testing and in developing seismic safety standards for nuclear reactors. To avoid global catastrophe from radioactive contamination, a treaty prohibiting nuclear testing in the atmosphere, in outer space and underwater, was signed in 1963. However, it did not prohibit underground testing.

As a result, the Department of Defense began to support a broad-based program in basic and applied seismic research. This program included the development of the Worldwide Standardized Seismograph Network. During the 1960s, data from this network was used to establish the theory of plate tectonics, an essential element of modern understanding of earthquake causes and occurrences. The drive toward seismic safety standards for nuclear reactors helped improve seismic hazard analyses, particularly in the eastern part of the United States.



The 1964 Alaska earthquake released perhaps twice as much energy as the 1906 San Francisco Earthquake, was felt over an area of almost 500,000 square miles and triggered a tsunami that traveled along the coast from Alaska to California. The next year, the USGS Center for Earthquake Research was established.

The Great Alaska Earthquake

The biggest boost in earthquake awareness in the United States occurred in the aftermath of the great Alaskan earthquake of 1964. This magnitude-9.2 earthquake killed 15 people in Alaska and spawned a tsunami that took more than 100 lives along the Pacific Coast from Alaska to California.

By placing instrumentation far beneath the Earth's surface, the San Andreas Fault Observatory at Depth marks a major advance in the pursuit of understanding earthquakes.

The next year, the USGS Center for Earthquake Research was established in Menlo Park, hailed as one of the largest centers for study of the earth sciences in the world. Scientists became crusaders with a quest: earthquake prediction. Jim Devine, USGS Senior Advisor for Science Applications, recalls how everyone felt that muscle and brains could make it happen, but even now, 40 years later, earthquake prediction remains the "Holy Grail" of seismology.

Consolidation of Earthquake Studies

The U.S. Coastal and Geodetic Survey, part of the National Oceanic and Atmospheric Administration (NOAA), had been involved since 1900 in earthquake monitoring and research. By 1972, a network of nearly 600 strong-motion seismographs was installed throughout the United States and Central and South America. In 1973, the U.S. Coastal and Geodetic Survey was merged with USGS seismological studies. The U.S. Coastal and Geodetic Survey's National Earthquake Information Center, in Golden, Colo., was transferred to the USGS. [See page 14.]

National Earthquake Hazards Reduction Program

The Disaster Relief Act of 1974, referred to as the Stafford Act, gave the USGS authority to issue geologic-related hazard warnings — including earthquakes — with the caveat that "predictions of the precise location, time and magnitude of specific earthquakes cannot generally be made now." It did allow that broad-scale estimates of earthquake susceptibility were available for various regions of the United States, principally California.

As a result of this legislation, the USGS National Seismic Hazards Mapping Project sprang to life, providing connections between earthquake research and hazards mitigation. Hazard maps have become the basis for the seismic sections of model building codes such as the Uniform Building Code. [See "Building Safer" page 26.]

In 1976, the National Science Foundation and the USGS developed a report titled *Earthquake Prediction and Hazard Mitigation: Options for USGS and NSF Programs*, referred to as the "Newmark-Stever Report," that combined needs assessments, state of knowledge reviews, and recommended provided programs and budgets on which to base a national earthquake hazards reduction program.

In 1977, Congress enacted the Earthquake Hazards Reduction Act, recognizing the important role of scientific research in the mitigation process, and establishing the National Earthquake Hazards Reduction Program (NEHRP), a multi-agency effort that includes the USGS earthquake monitoring and research programs.

A year later, the USGS Earthquake Hazards Program was established to carry out the mandates of NEHRP. The USGS, with the most extensive seismic monitoring and response system in the nation, joined forces with other agencies and universities to advance understanding of the causes and effects of earthquakes. Work also began in conjunction with emergency-response agencies to address public safety and hazards mitigation.

The Loma Prieta Earthquake

In 1989, the magnitude-6.9 Loma Prieta earthquake caused significant damage in an extended area around San Francisco.

"I remember answering more than 2,000 phone calls in the week after the Loma Prieta earthquake of 1989," says Earthquake Hazards Program assistant Joyce Costello, who has been with the USGS earthquake program for 33 years. "Callers wanted to know if this was 'the big one' — an earthquake equal to or greater than the 1906 San Francisco earthquake. It wasn't."

A curious bit of wisdom from Loma Prieta was the increased awareness that emergency responders can also be immobilized in an earthquake. In some cases, firehouses had been shaken off kilter with their doors jammed shut and trucks trapped inside. Hazards emphasis shifted from predicting the occurrence of earthquakes to predicting and mitigating their effects.

Advanced National Seismic System

In 1997, Congress reauthorized NEHRP with a specific request for development of a "real-time seismic hazard warning system." This paved the way for development of the Advanced National Seismic System. [See page 22.] Begun in 2000, the system has helped integrate, modernize, and expand earthquake monitoring and notification nationwide.

Parkfield Prediction

Between 1857 and 1966, six magnitude-6.0 earthquakes occurred at intervals of approximately 22 years along the San Andreas Fault near Parkfield, Calif. In 1985, USGS scientists took advantage of the seeming regularity of these earthquakes and set up extensive research instrumentation in the area. They boldly predicted the next sizable earthquake would occur in 1988, 22 years after the last one. Instead, it arrived in September 2004, after providing a wealth of valuable research data.

In 2004, the USGS and the National Science Foundation, as part of the EarthScope science initiative, went even further and began drilling a deep hole to install instruments directly within the San Andreas Fault near the point of the previous magnitude-6.0 earthquakes, forming the San Andreas Fault Observatory at Depth (SAFOD).

USGS Senior Advisor for Science Applications Jim Devine recalls that improvements in earthquake monitoring and advances in seismology and geomagnetism made the 1950s and 1960s a very exciting time for scientists. "Nothing has matched it since," he says.

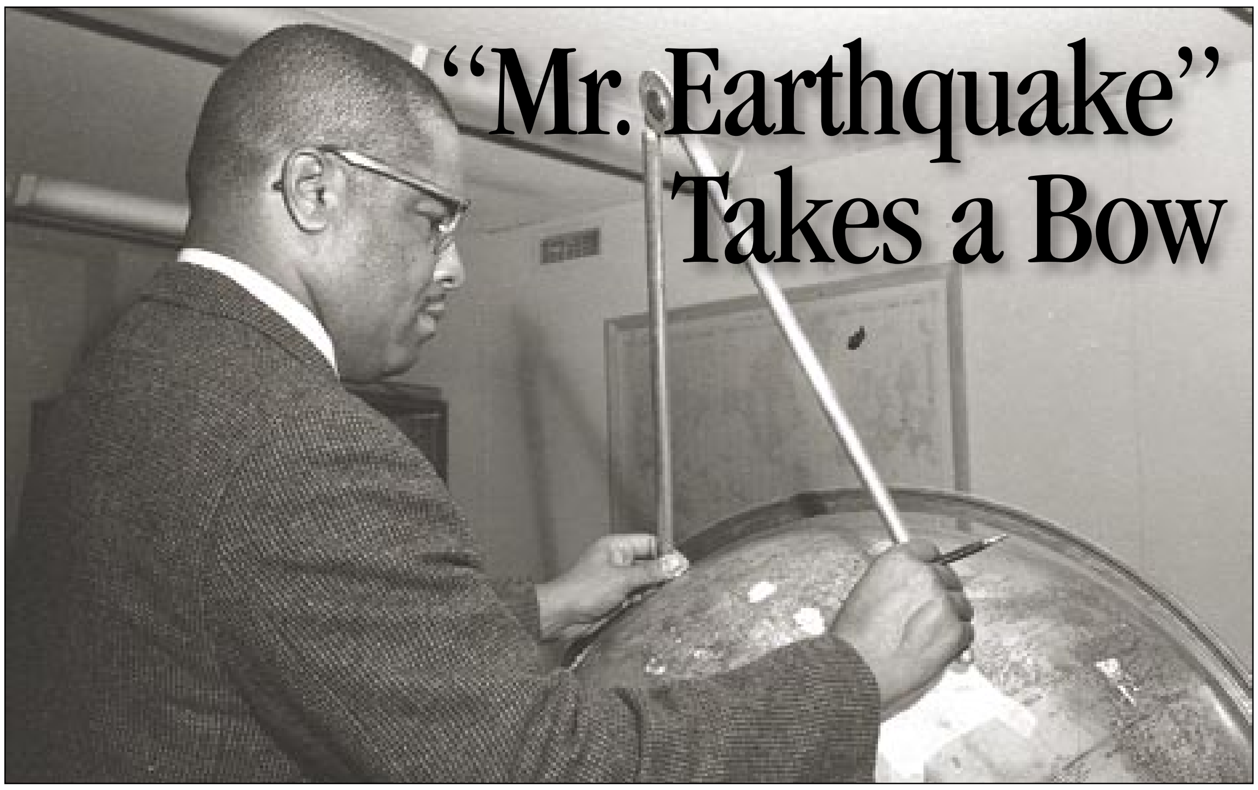
SAFOD is providing direct information on the composition and mechanical properties of rocks in the fault zone, the nature of stresses responsible for earthquakes, the role of fluids in controlling faulting and earthquake recurrence, and the physics of earthquake initiation and rupture. By observing earthquakes "up close," SAFOD marks a major advance in the pursuit of a rigorous scientific basis for assessing earthquake hazards and predicting earthquakes. This work ties in with the National Earthquake Hazard Reduction Program's efforts to protect lives and property from earthquake hazards.

The Future

"Short-term prediction is still in the future," says Senior Science Advisor for Earthquake and Geologic Hazards David Applegate, "but we are making great strides at minimizing loss of life and property right now by providing assessments of hazard zones and delivering rapid post-event information for first responders and emergency managers."

The USGS continues to improve existing earthquake monitoring, assessment and research activities with the ultimate goal of providing the nation with a new generation of earthquake products to improve earthquake mitigation and response. On the horizon is an extensive, coordinated seismic-monitoring network that will instantly register ground motion and signal an alarm if an earthquake occurs near a populated area — automatically opening the firehouse doors seconds or minutes before the tremblors arrive.

"Mr. Earthquake" Takes a Bow



Waverly Person uses the technology of the day to locate earthquakes.

By David Hebert and Heidi Koontz

After 51 years of educating audiences around the globe about earthquakes, USGS scientist Waverly Person called it quits on Feb. 3, 2006. Person is well known among media circles as *the* person to call when an earthquake happens anywhere in the world. Known by many as "Mr. Earthquake," he is a fixture both in classrooms and on television sets.

Before becoming a government scientist, he served in both World War II and the Korean War with the U.S. Army. He then took his bachelor's in mathematics to a position as a science technician with the Department of Commerce, which oversaw federal seismic monitoring in the 1950s.

Person was literally thrown in front of the media spotlight in 1964 following the magnitude-9.2 earthquake that hit Anchorage, Alaska.

In the lobby of the Commerce Building in Washington, D.C., was a seismograph; and the ink used to create seismograms was spilled everywhere because of the machine's drastic response to the huge quake. The lobby was full of curious people, some with microphones and cameras, asking questions about the situation. Person saw what was happening and told his supervisor, "Somebody needs to talk to those people."

"Well, there's nobody else here," the supervisor responded. "You've got to talk to them."

And that's exactly what he did. Media, citizens, students — anyone who asked a question about earthquakes, he answered. Some notable names of inquirers over the years include Tom Brokaw, Dan Rather and Matt Lauer.

Of course, Person is a natural when it comes to talking to people.

"It's one of the things I enjoy most of all," he says. "I've always tried to put news to the general public in a way they can understand it — to get the message to the vast majority. When there's an earthquake, people are frightened. If you relate the information to them so that they understand, they calm down."

Behind the public view, Person has some historical feats to boast. He marched alongside Dr. Martin Luther King, Jr., and has been coined the nation's first black earthquake seismologist.

"I've learned a lot along the way," said Person. "And the path hasn't always been kind."

He feels lucky to be a noticeable face to younger generations and to have the opportunity to persuade minority students to pursue science. Thus, Person will continue educating this demographic about seismology through speaking at inner-city classrooms.

Last year, U.S. Rep. Bob Beauprez (Colo.) recognized Person's 50 years of government service at a ceremony honoring his career.

"You want economic advice, you go to Alan Greenspan. You want to know anything about seismic activity, you see if you can get Waverly Person on the line," said Rep. Beauprez in a *Denver Post* article commemorating Person's 50th anniversary.

So who will fill Person's shoes?

"Waverly is a hard act to follow — not only because of his calm under fire, but also his incredible encyclopedic mind for earthquake history," said Jill McCarthy, director of the USGS Geologic Hazards Team in Golden, Colo. "For the past few years, we've been training other scientists to deal with media inquiries, and we've been developing earthquake databases and computer programs that attempt to replicate what Waverly knows intuitively from decades of hands-on experience. Even still, we realize that things just won't be the same without Waverly."

And they haven't been.

"People still call and ask to talk with Waverly about rumblings they've felt," said John Bellini, a geophysicist who was hired by Person 7 years ago. "We tell them he's retired, and a bit of shock ensues."

Person, a long-time Boulder, Colo., resident, and his wife, Sarah, plan to enjoy each other's company and travel around the country to visit family. And since he is now a scientist emeritus, you might just see him in the background the next time a "big one" hits.

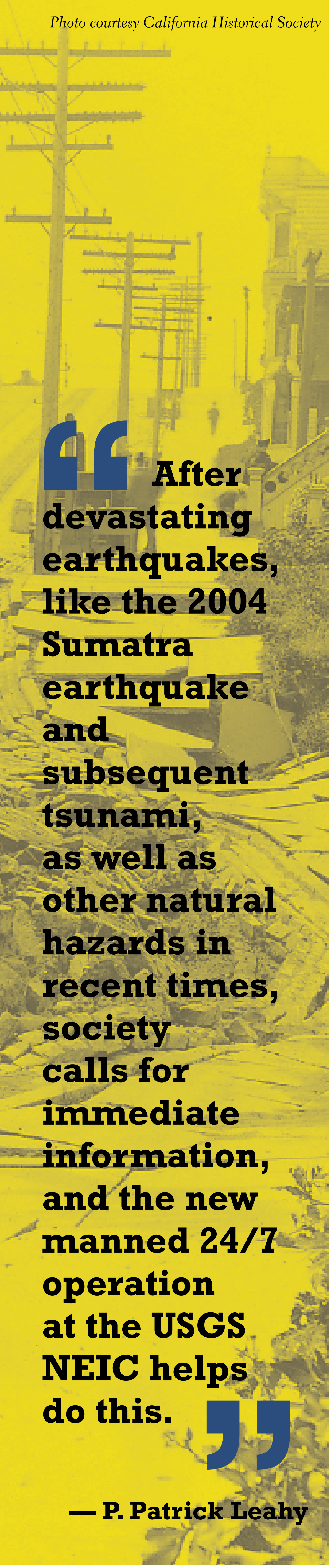


Photo courtesy California Historical Society

"After devastating earthquakes, like the 2004 Sumatra earthquake and subsequent tsunami, as well as other natural hazards in recent times, society calls for immediate information, and the new manned 24/7 operation at the USGS NEIC helps do this."

— P. Patrick Leahy

The World's Source for Earthquake Information

The USGS National Earthquake Information Center

By George Choy and Heather Friesen

The USGS National Earthquake Information Center (NEIC) is responsible for the comprehensive monitoring and reporting of earthquake activity for our nation and the world. Nearly 30,000 worldwide earthquakes are located each year by NEIC. Rapid reports are issued for those earthquakes that register at least a magnitude 4.5 in the United States, a magnitude 6.5 anywhere else in the world or any magnitude if the earthquake is known to have caused damage.

This information is communicated to federal and state government agencies that are responsible for emergency response, to government public information channels, to national and international news media, to scientific groups and to private citizens who request information. When a damaging earthquake occurs in a foreign country, the earthquake information is passed to the staffs of the American embassies and consulates in the affected countries and to the United Nations Department of Humanitarian Affairs.

NEIC has come a long way since its beginnings in 1966 in Rockville, Md., as part of the National Ocean Survey of the Department of Commerce. Before 1966, the U.S. Coast and Geodetic Survey, a forerunner of the National Ocean Survey, had coordinated the collection of seismological data in the United States. In 1972, the NEIC was transferred to Boulder, Colo., and in the following year, it was made part of the USGS. NEIC was moved again in 1974 to its present location in Golden, Colo.

In the 1960s, NEIC received most of its data from analog stations via telegraph or telephone circuits. It could take several days for the location and magnitude of an earthquake to be finalized. Today, NEIC receives more than 1,000 channels of digital waveform data in real time from approximately 475 digital seismic stations worldwide using dedicated satellite circuits and Internet links. For the largest events, locations and magnitudes are determined in minutes. While NEIC once provided only the basic information on the location and size of the earthquake, it now provides information on the extent of the affected area, on the location and degree of damage potential and on the tectonic and historical context.

The urgency for assessing the extent of natural disasters as quickly as possible was painfully evident in the aftermath of the Sumatra-Andaman earthquake in late December 2004. In order to determine the location and magnitude of significant earthquakes as rapidly and accurately as possible, NEIC implemented round-the-clock-on-site staffing in January 2006. This was complemented with a state-of-the-art processing system that became fully operational in March 2006. This new seismic-event processing system identifies, locates and measures the size of earthquakes with unprecedented speed and accuracy.

"After devastating earthquakes, like the 2004 Sumatra earthquake and subsequent tsunami, as well as other natural hazards in recent times, society calls for immediate information, and the new manned 24/7 operation at the USGS NEIC helps do this," said P. Patrick Leahy, USGS.

It took an hour to process the information about the December 2004 Sumatra earthquake. With the new system, it will take 12 to 13 minutes to process the same information. The immediate transmission of this information to cooperative agencies such as tsunami warning centers is critical. Previously, there were 25,000 contacts to notify; now the list is up to 54,000, and the demand for rapid notification keeps growing.

"We are improving all the time," said Harley Benz, director of the NEIC. "The new systems are more robust, accurate and contain new information critical for emergency-response applications. We're essentially replacing 20-year-old technology."

Location and magnitude, the staples of earthquake reporting, are now being supplemented by information equally important to describing and understanding the impact of an earthquake.

The Community Internet Intensity Map (or "Did You Feel It?") project collects information about ground shaking following significant earthquakes. Persons who experience an earthquake can go online to share information about its effects. A Community Internet Intensity Map is then generated and automatically updated with real-time data from these first-hand accounts. [See page 33].

Left to right: U.S. Congressman Bob Beauprez listens to NEIC director Harley Benz describe new earthquake technology. Joan Fitzpatrick, Linda Pratt and Jill McCarthy observe.

A new system, the Prompt Assessment of Global Earthquakes for Response (PAGER), is being designed to estimate damage from major earthquakes worldwide based on estimates of people and property exposed to potentially damaging levels of ground motion. The system promises to be a significant tool for emergency relief organizations such as the U.S. Agency for International Development. PAGER information will also be available to scientists and the public.

A new earthquake notification service sends out earthquake alerts to subscribers via e-mail. With the new service, users can customize the contents of the alerts they receive. For instance, they may define regions of interest, set magnitude thresholds, specify time periods such as day and night, opt for "Aftershock Exclusion," and enter various notification addresses. Anyone can subscribe to the notification service.

"The USGS Earthquake Hazards Program Web site allows Internet users to find the information they need," said Lisa Wald, USGS geophysicist and Webmaster at the NEIC.

The Web site receives more than one million hits per day. All products of the NEIC are available to the public via the USGS Earthquake Hazards Program Web site, http://earthquake.usgs.gov.

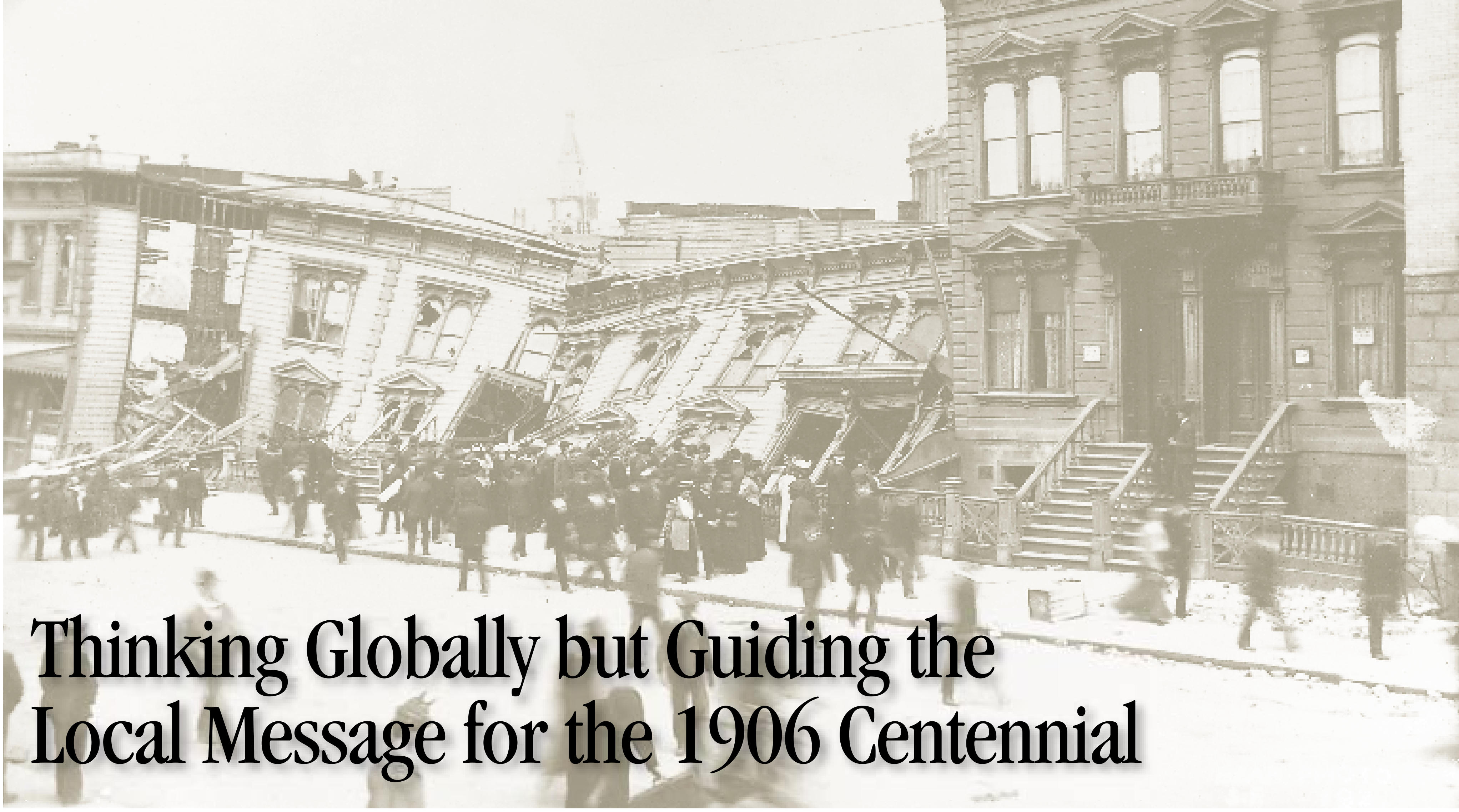


Photo courtesy California Historical Society

Thinking Globally but Guiding the Local Message for the 1906 Centennial

By Stephanie Hanna

As the pace of events builds toward a crescendo on April 18, 2006, for the Centennial of the Great San Francisco Earthquake, Mary Lou Zoback's work week extends into the weekend and often well into the evening. She is currently regional coordinator for the USGS Earthquake Hazards Program in Northern California and chairs the steering committee of federal, state, local and private partners making up the 1906 Centennial Alliance. In this role, Zoback routinely fields calls and conducts interviews with the news media, speaks at up to four public events per week, attends multiple meetings and recruits new partners to assist in the funding and distribution of new and important products for first responders, decision makers and an interested public.

"It's important to view the 1906 Centennial as an incredible, teachable moment," Zoback explained. "Living in California, we see huge vulnerabilities from earthquakes, both to individuals and to society. The high probability of large, devastating urban earthquakes exposes society to enormous vulnerabilities. So the 1906 Centennial becomes an invaluable opportunity to remind people, 'It will happen here,' and to encourage citizens to push their communities and governments to help them prepare. The Hurricane Katrina disaster, unfortunately, emphasizes that we have to be proactive."

Zoback is a senior research scientist with the USGS Western Earthquake Hazards Team in Menlo Park, Calif. Her primary research interest is the relationship between earthquakes and stress in the Earth's crust. Areas of recent study include the San Andreas Fault system, the Basin and Range area of the western United States and intraplate regions such as the central and eastern United States.

"It's important to view the 1906 Centennial as an incredible, teachable moment," says USGS senior research scientist Mary Lou Zoback.

After the Centennial commemoration in April, Zoback plans to return full time to her research. Her current research interest is in understanding the deformation caused by active fault systems such as that associated with the epicenter of the 1906 earthquake. The geologic evidence and persistent small earthquakes indicate that in this region, the Earth's crust is pulling apart. She would like to determine the likelihood that the next big Bay Area earthquake will occur in this region and what additional risk and damage might occur from a similar magnitude earthquake that begins either south or north of this area and "steps over" to devastate areas further along the San Andreas Fault.

Early in her career with USGS, Zoback headed the International Lithosphere Program's World Stress Map Project. A team of 40 scientists from 30 countries focused on compiling, standardizing data collection and interpreting geologic and geophysical data on the modern-day stress field. Working by telex and fax between 1986 and 1992, before the advent of the Internet, the team made important discoveries about stresses acting in the interior of the Earth's tectonic plates and producing earthquakes. In recognition of the significance of this and other work, Zoback was elected to the National Academy of Sciences in 1995. She is currently the only USGS member of the NAS and also serves as a member of the NAS Council.

Zoback joined USGS in 1978 after receiving her Ph.D. in geophysics from Stanford University. From 1999 to 2002, she was chief scientist of the Northern California Earthquake Hazards Program. Zoback has served on numerous national committees and panels on topics ranging from continental dynamics and storage of high-level radioactive waste to science education. She is active in several professional societies and served as the president of the Geological Society of America from 2000 to 2001. In 1987, she received the American Geophysical Union's Macelwane Award for significant contributions to the geophysical sciences by a young scientist of outstanding ability.

When asked what draws her from research to her dedication to public outreach on earthquake hazards and preparedness, Zoback said, "I think it's my personality. When I see problems, I want them to be fixed. The study of geology and geophysics shows us that earthquakes are not random events and that they will happen again where they have happened before, so we must help society be prepared."

Zoback was instrumental in the redesign and recent publication of "Putting Down Roots in Earthquake Country — Your Handbook for the San Francisco Bay Region," an earthquake preparedness guide. This publication by USGS and 11 other partners was published in September 2005 and has already reached nearly a million people and is expected to be translated into Spanish, Vietnamese, Cambodian and Chinese during 2006. [See page 34.]

Zoback is married to a fellow geophysicist, Mark Zoback, a professor at Stanford University and principal investigator on the National Science Foundation San Andreas Fault Observatory at Depth (SAFOD) project. The Zobacks have a grown son and daughter and are residents of Stanford. Combining their love of adventure and common interest in geology, they recently climbed Mount Kilimanjaro in Africa, went trekking in Bhutan and are planning to climb to Macchu Pichu in Peru after the 1906 Centennial activities subside.

Chain Reaction: Earthquakes that Trigger Other Natural Hazards

Compiled by Diane Noserale and Tania Larson

A fire destroys much of a major city. The side of a mountain collapses and then explodes. A train of waves sweeps away coastal villages over thousands of miles. All of these events are disasters that have started with or been triggered by an earthquake. Some of the triggers were among the largest earthquakes ever recorded. But the disasters that followed were often so large that the earthquakes were overshadowed, and so, we hear about the eruption of Mount St. Helens; devastating landslides in Washington and Pakistan; and tsunamis in Chile, Japan and the Indian Ocean. To understand these events, we need to remember the earthquakes.

Tsunamis

On Dec. 26, 2004, an earthquake ruptured an 800-mile length of the sea floor from northern Sumatra to the Andaman Islands. A monstrous series of waves rolled across the Indian Ocean. Together, the earthquake and tsunami took more than 200,000 lives in 11 countries.

In 1960, the largest earthquake ever recorded, a magnitude-9.5, hit Chile. Many survived the earthquake, only to perish in the tsunami that followed. The leading wave hit Hawaii in 15 hours. It struck Japan nearly 24 hours after the earthquake. More than 2,000 people were killed in Chile, 61 in Hawaii and 138 in Japan. Hawaii reported $75 million in damage (1960 dollars), Japan $50 million. In the Philippines, 32 people were killed or missing, and the United States suffered $500,000 in damage.

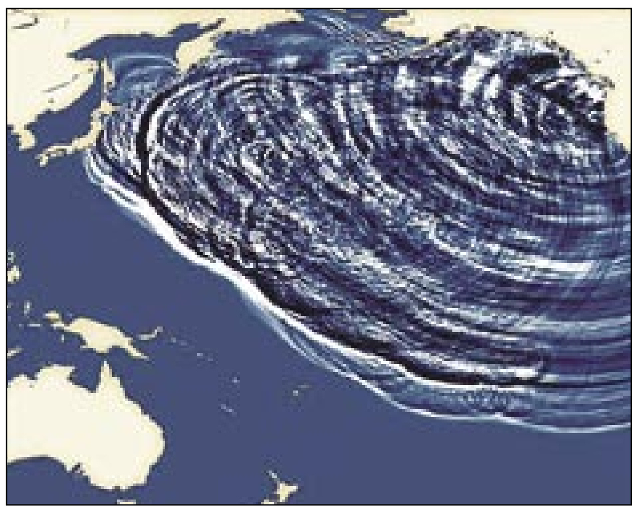
Hundreds of years earlier, on January 26, 1700, America's Pacific Northwest was unknown to most of the world — a blank spot on maps of that time. Beneath the shallow waters offshore, an enormous earthquake unleashed, sending a series of waves that would engulf the Pacific Ocean. About 10 hours after the earthquake, the tsunami's leading wave reached Japan. The waters swept away houses, flooded fields and inundated crops, frightening villagers with a disaster that seemed to have come from nowhere. That this tsunami had been triggered by an earthquake off the West Coast of North America would remain unknown until the 1990s, when the link was established through a combination of North American geology and Japanese historical research.

Volcanoes

Volcanoes produce a variety of hazards — hot-ash and mudflows, landslides, tsunamis, lava flows and volcanic gases. And quite often, small-to-moderate earthquakes serve as a warning of an impending eruption. Volcanoes erupt when hot, liquid rock, called "magma," moves upward through cracks in the Earth's surface. This motion, and the building up of pressure, generates volcanic earthquakes. Monitoring volcanoes for these tremors has proven a powerful tool in the prediction of volcanic eruptions.

Scientists have known that movement of magma often triggers earthquakes, but they are discovering that this relationship may also work in reverse. Scientists are looking at earthquakes that meet very specific criteria: a magnitude of 6 or higher; a location on major fault zones near a volcano; and a later eruption of a nearby volcano. They are finding evidence that these earthquakes might have triggered the eruptions.

In the early morning of Nov. 29, 1975, a magnitude-7.2 earthquake struck the Big Island of Hawaii. Less than 45 minutes later, Kilauea Volcano starting erupting. That eruption ended after about 17 hours. The small volume of magma and brief duration suggest that the eruption was triggered by the earthquake.



In January 1700, a mysterious tsunami hit Japan without the warning that a nearby earthquake usually provides. Nearly three centuries later, discoveries in North America revealed its source. The evidence tells of a catastrophe that helps guide preparations for future earthquakes and tsunamis in the United States and Canada. Read the scientific detective story in "The Orphan Tsunami of 1700."

This was not the first eruption on Hawaii that appears to have been triggered by an earthquake. Other scientists have linked Hawaii's largest historic earthquake, estimated to have a magnitude of at least 7.5, in 1868 to a small eruption from Kilauea.

On June 15, 1991, Mount Pinatubo in the northern Philippines exploded, sending a column of ash into the atmosphere. About 11 months earlier, a magnitude-7.8 earthquake had struck about 60 miles from the volcano. Scientists from the USGS and the Philippine Institute of Volcanology and Seismology have found that these two events were related. According to the study, compression from the earthquake might have squeezed a small volume of magma into the volcano's reservoir. Strong ground shaking might have also compressed the reservoir or triggered movement along previously stressed faults that allowed magma to ascend into the volcano.

Following a massive eruption, a volcano can collapse, as the empty magma chamber cannot support the weight of the material above. The result is a large, concave structure called a "caldera." These structures are found around the world. Yellowstone and Crater Lake are two examples in the United States. Research shows that activity at calderas often occurred within months or even hours of large regional earthquakes, sometimes as a precursor to the earthquakes and sometimes as a result of them.

Landslides

Heavy rain, wildfires, volcanic eruptions and human activity often work together to cause landslides. In hilly terrain, earthquakes can easily cause landslides, and these landslides are often more destructive than the triggering event.

In 1964, the magnitude-9.2 earthquake that violently shook southern Alaska also induced huge landslides throughout Anchorage, including the downtown business district. The 1994 Northridge earthquake triggered more than 10,000 landslides in the hills around Los Angeles.

On May 18, 1980, a magnitude-5.1 earthquake triggered the collapse of the north flank of Mount St. Helens, resulting in the largest landslide ever recorded. Debris raced down the mountain at speeds in excess of 180 miles per hour. Within about 10 minutes, enough debris to fill 250 million dump trucks traveled up to 14 miles down the valley, destroying buildings, bridges and many miles of highway. The debris dammed the North Fork Toutle River and its tributaries and posed hazards to downstream communities because of the possible failure of the dams and catastrophic flooding. With an earthquake, a massive landslide, a volcanic blast and flooding — Mount St. Helens was truly a multi-hazard disaster.

The Clear Case for Multi-Hazard Science

From the 1700 orphan tsunami to the 1991 Mount Pinatubo eruption, these examples show that, to be truly understood, hazards cannot be studied in isolation. By developing a better understanding of how one hazard event has triggered others in the past, we are working to identify potential hazards before they become multi-hazard disasters.

The USGS, along with numerous partners, carries out research and monitoring designed to reduce losses from future hazards. From improving building codes to identifying hazard zones and evacuation routes, integrated science can provide emergency managers with the information they need to continue to make America safer from natural hazards. After the tragic events of 2004 and 2005, scientists have redoubled their efforts to help the public learn how to recognize the danger and survive natural hazard events. These hazards will always be with us, but by examining both individual hazards and how they relate to one another, scientists are building a bigger picture and a better understanding that is helping to save lives and property.

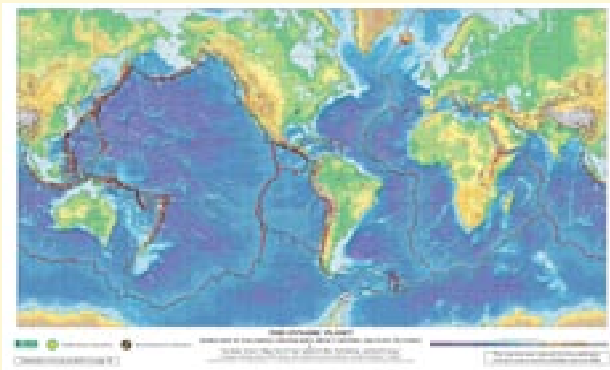
This Dynamic Planet

The following pages are a special poster pullout featuring the front of the USGS map, "This Dynamic Planet."

About "This Dynamic Planet"

This map shows many of the features that have shaped — and continue to change — our dynamic planet. Most new crust forms at ocean ridge crests, is carried slowly away by plate movement, and is ultimately recycled deep into the earth — causing earthquakes and volcanism along the boundaries between moving tectonic plates. Oceans are continually opening (for example, Red Sea, Atlantic) or closing (for example, Mediterranean). Because continental crust is thicker and less dense than thinner younger oceanic crust, most does not sink deep enough to be recycled and remains largely preserved on land. Consequently, most continental bedrock is far older than the oldest oceanic bedrock.

The earthquakes and volcanoes that mark plate boundaries are clearly shown on this map, as are craters made by impacts of extraterrestrial objects that punctuate Earth's history, causing some catastrophic ecological change. Over geologic time, continuing plate movements, together with relentless erosion and redeposition of material, mask or obliterate traces of earlier plate-tectonic or impact processes, making the older chapters of Earth's 4,500-million-year history increasingly difficult to read. The recent activity shown on this map provides only a present-day snapshot of Earth's long history, helping to illustrate how its present surface came to be.



The map is designed to show the most prominent features when viewed from a distance, and more detailed features upon closer inspection. The back of the actual "This Dynamic Planet" map zooms in further, highlighting examples of fundamental features, while providing text, timelines, references and other resources to enhance understanding of this dynamic planet. Both the front and back of the map illustrate the enormous recent growth in our knowledge of planet Earth. Yet, much remains unknown, particularly about he processes operating below the ever-shifting plates and the detailed geological history during all but the most recent stage of Earth's development.

The complete and full-sized version of "This Dynamic Planet" will be available from the USGS in the summer of 2006.

Legend

Volcanoes — Data from Global Volcanism Program, Smithsonian Institution, Washington, D.C.; accessed at http://www.volcano.si.edu/world/summary.cfm, March 16, 2005

- Erupted A.D. 1900 through 2003
- Erupted A.D. 1 through 1899
- Erupted in Holocene time (Paste 10,000 years), but no known eruptions since A.D. 1
- Uncertain Holocene activity and fumarolic activity

Impact Craters — Data from University of New Brunswick, Planetary and Space Science Centre, Earth Impact Database; accessed at http://www.unb.ca/passc/ImpactDatabase/. October 23, 2003 (also see Grieve, 1998). Geologic age span: 50 years to 2,400 million years. Crater diameter indicated below

- <10km
- 10 to 70 km
- >70 km (shown at actual map scale)

Notable Events — Numbers next to a few symbols — of many thousands shown — denote especially noteworthy events, keyed to correspondingly numbered entries in tables found on the back of the map. These numbered events have produced devastating natural disasters, advanced scientific understanding or piqued popular interest. They remind us that the map's small symbols may represent large and geologically significant events.

- 5 Volcanoes
- 9 Earthquakes
- 25 Impact craters

Plate Tectonics

Divergent (sea-floor spreading) and transform fault boundaries — Red lines mark spreading centers where most of the world's volcanism takes place; thickness of lines indicates divergence create, in four velocity ranges. White number is speed in millimeters per year (mm/yr) from DeMets and others (1994). The four spreading-rate ranges are <30 mm/yr; 30-59 mm/yr; 60-90 mm/yr; and >90 mm/yr. Thin black line marks the plate boundary, whether sea-floor spreading center or transform fault. On land, divergent boundaries are commonly diffuse zones; therefore, most are not shown. The only transform faults shown on land are those separating named plates.

Plate motion — Data from Rice University Global Tectonics Group. Length of arrows is proportional to plate velocity, in millimeters per year. These approximate rates and directions are calculated from angular velocities with respect to hotspots, assumed to be relatively fixed in the mantle (see plate motion calculator at http://tectonics.rice.edu/hs3.html).

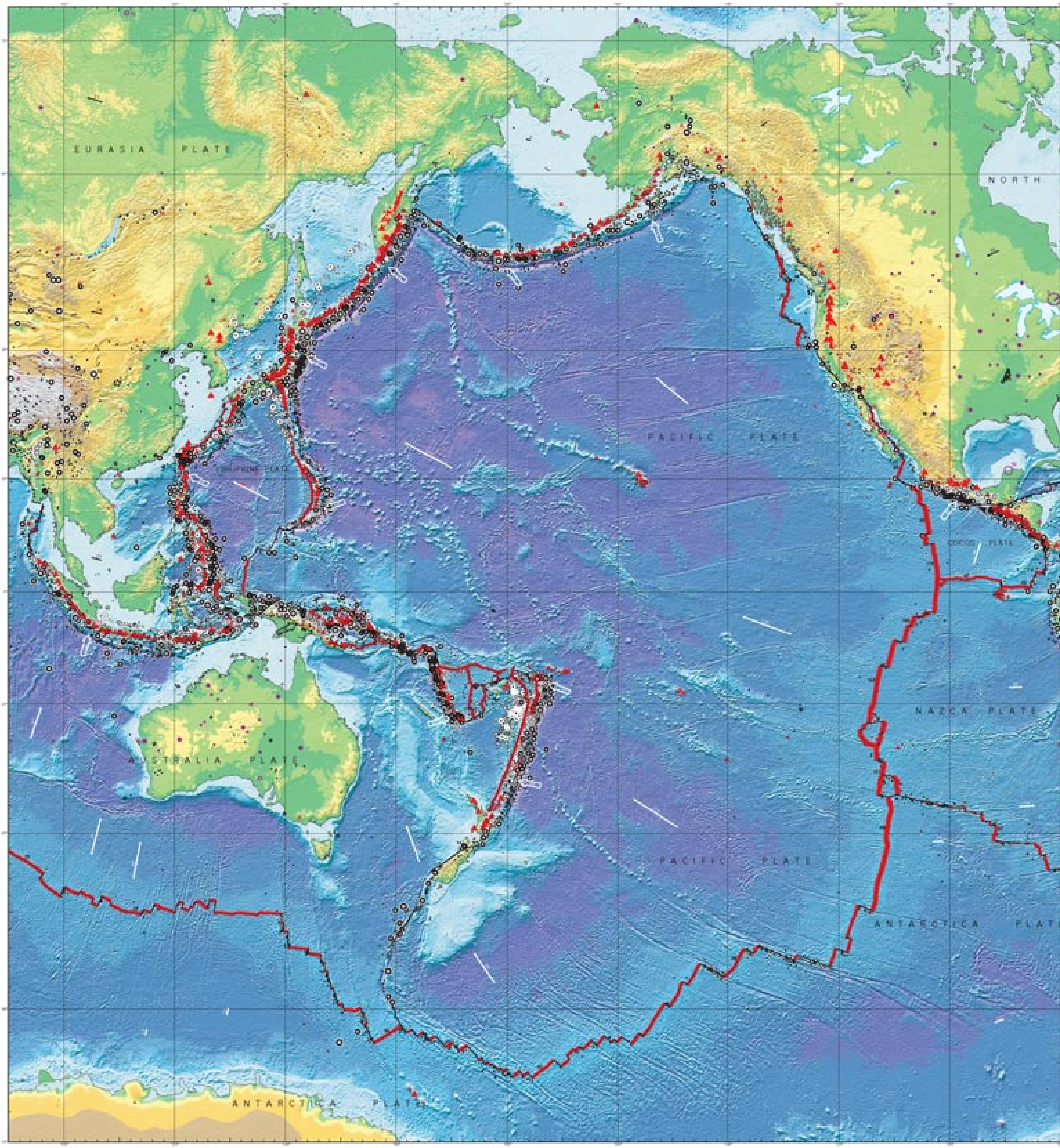
Plate convergence — More accurately known than "absolute" plate motion, convergence data are shown by arrows of uniform length showing direction and speed, in millimeters per year relative to the plate across the boundary. Data from Charles DeMets (University of Wisconsin at Madison, written commun., 2003) and Bird 2003)

Earthquakes — Data from Engdahl and Villaseñor (2002). From 1900 through 1963, the data are complete for all earthquakes >6.5 magnitude; from 1964 through 1999, the data are complete for all earthquakes >5.0 magnitude. Most location uncertainties <35 km. Eleven more recent major or great earthquakes (magnitude >7.7) have been added for completeness through 2004; data from USGS National Earthquake Information Center at http://neic.usgs.gov/, accessed January 4, 2005. An epicenter is the surface location of the first rupture on an earthquake fault. Symbols shown represent epicenters. For earthquakes larger than about magnitude 7.0, the size of the rupture zone, which can extend hundreds of kilometers from the epicenter, is larger than the symbols used on this map

Depth to earthquake, in km	Magnitude of earthquake			
	5.0–5.9	6.0–6.9	7.0–7.9	≥8.0
<60	•	•	○	○
60–300	•	•	○	○
>300	○	○	○	○
Global average occurrence[1]	1319/yr	134/yr	17/yr	1/yr

[1]Earthquakes of magnitude <5 (not shown on map) are much more frequent, with ~13,000/yr in the 4.0–4.9 range alone. Data from USGS National Earthquake Information Center.

- Earthquakes that occurred from 1750 to 1963 within stable plate interiors on continents — Data from A.C. Johnston (Center for Earthquake Research and Information, University of Memphis, written, commun., 2002). Even though these epicenters do not meet the precise location criteria of Engdahl and Villaseñor (2002), they are plotted here to remind readers of the potentially hazardous earthquakes that are distant from known plate boundaries. Size of symbol proportional to earthquake magnitude
- Notable pre-1900 earthquakes — Nos. 1,2,3,6 and 7



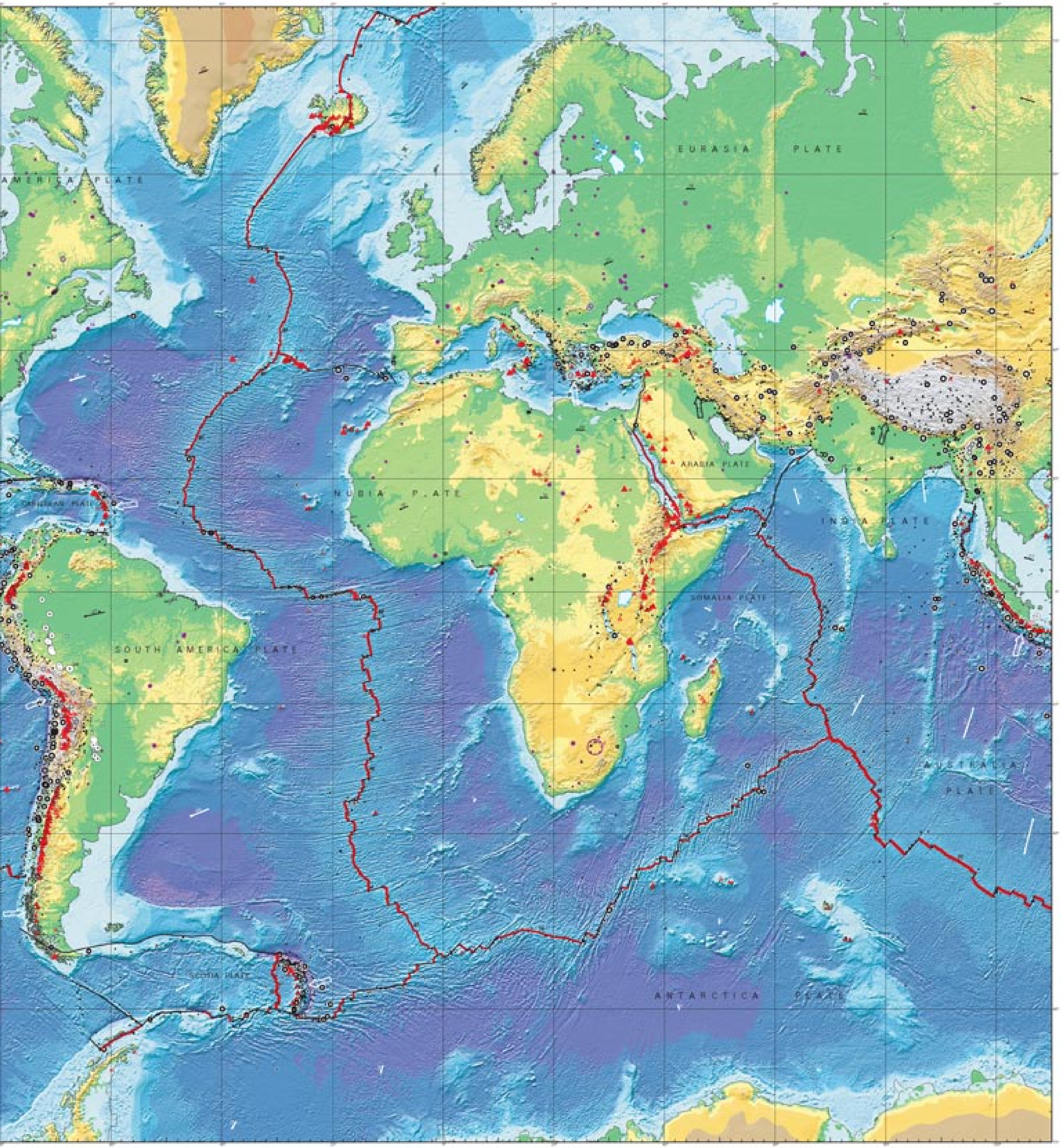
THIS DYNAM

WORLD MAP OF VOLCANOES, EARTHQUAKES

By
Tom Simkin,[1] Robert I. Tilling,[2] Peter R. Vogt,[3] Steph
Cartography and graphic design by Will R. Stettner,[2] with contribut
[1]Smithsonian Institution, [2]U.S. Geological Survey, [3]U.S. Naval Research Laborator

USGS science for a changing world Smithsonian Institution Naval Research Laboratory

Explanation of map symbols on page 17.

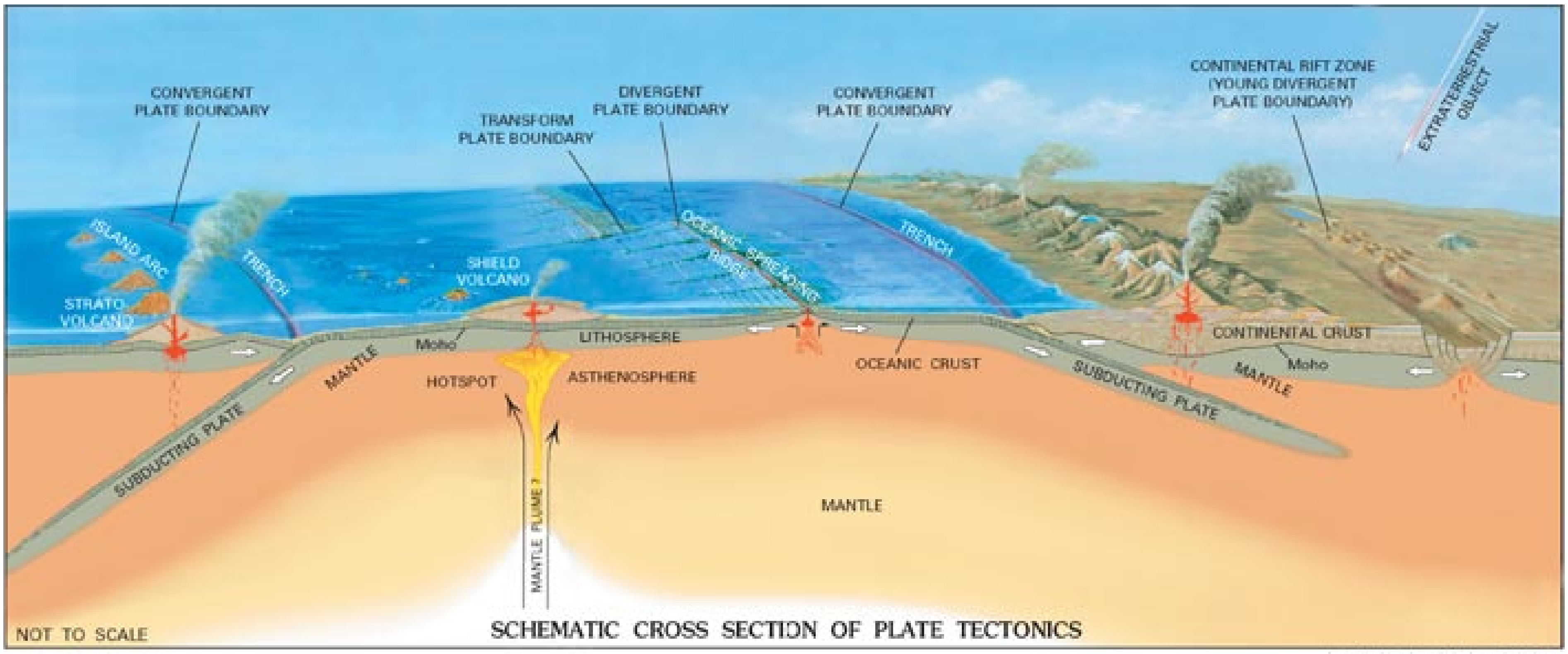


MIC PLANET

S, IMPACT CRATERS, AND PLATE TECTONICS

en H. Kirby,[2] Paul Kimberly,[1] and David B. Stewart[2]
ions by Antonio Villasenor,[4] and edited by Katharine S. Schindler[2]
y, [4]Institute of Earth Sciences Jaume Almera, Spanish National Research Council

This map has been reduced for this publication.
Full size version will be available summer 2006.



José F. Vigil and Robert I. Tilling

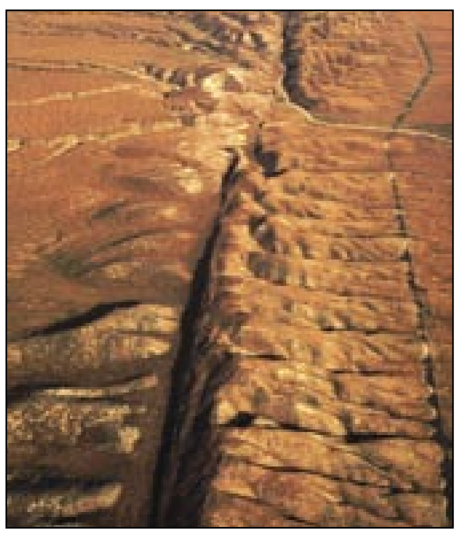
Earthquake Basics

The Fundamentals and Terminology of Earthquake Science

An **earthquake** is a sudden movement of the Earth's crust caused by the abrupt release of pressure that has accumulated over a long time. The energy it releases can be generated by a sudden dislocation of segments of the crust; by a volcanic eruption; or by human activities, such as mining, oil extraction and filling reservoirs. Most destructive earthquakes are caused by dislocations of the crust. The crust may first bend, and then, when the stress exceeds the strength of the rocks, break and "snap" to a new position.

The Earth is formed of several distinct layers that have very different physical and chemical properties. The outer layer, which averages about 22 miles in thickness, consists of about a dozen large, irregularly shaped, brittle **plates** on top of a pliable inner layer. These plates are constantly moving, their edges sliding over, under, away from or past each other. Most earthquakes occur at the boundaries where the plates meet.

All earthquakes occur along faults, which reflect zones of weakness in the Earth's crust. A **fault** is a fracture in the Earth's crust where two blocks of the crust have slipped with respect to each other. Even if a fault zone has recently experienced an earthquake, there is no guarantee that all the pressure has been relieved. Another earthquake could still occur within a short period of time. Many of the most active faults are deep within the crust and are not visible at the surface, especially where the plates are colliding with each other.



Aerial view of the San Andreas Fault slicing through the Carrizo Plain in the Temblor Range east of the city of San Luis Obispo, Calif. Photo: Robert E. Wallace.

The **hypocenter** of an earthquake is the location beneath the surface where the rupture of the fault begins. The **epicenter** of an earthquake is the location directly above the hypocenter on the surface of the Earth. The **focal depth** of an earthquake is the depth from the Earth's surface to the hypocenter. The location of an earthquake is commonly described by the geographic position of its epicenter and by its focal depth.

Measuring Earthquakes

When an earthquake occurs, vibrations called **seismic waves** are generated. These waves travel outward from the source of the earthquake along the surface and through the Earth at varying speeds depending on the material through which they move. The vibrations produced by earthquakes are detected, recorded and measured by instruments called **seismographs**. By responding to the motion of the ground surface beneath it, a seismograph creates a zigzag line called a **seismogram** that reflects the changing intensity of the vibrations. From the data expressed in seismograms, scientists can estimate how much energy was released and determine the time, the hypocenter and the type of faulting of an earthquake.

Magnitude verses Intensity

The severity of an earthquake can be expressed in several ways. The **magnitude** of an earthquake describes its size. Most magnitude computation procedures (sometimes referred to as the **Richter scale**) measure the amplitude of various seismic waves. The **moment magnitude** is a measure of the physical dimensions of the zone that ruptured in the earthquake (i.e., the area of the fault that ruptured) times the amount of offset, and that too can be estimated from data processed by modern seismographs. [See "Measuring Magnitude" page 25.]

In general, each earthquake has one preferred magnitude, but each person who feels or observes a quake can describe its intensity at their location. The **intensity** is an observation of how strongly a shock was felt at a particular location.

To quantify the effect or intensity of an earthquake, scientists use the **Modified Mercalli Intensity Scale**. While magnitudes are expressed as Arabic numbers and in theory have no upper or lower limits, intensity is expressed in Roman numerals I-XII. Evaluation of earthquake intensity can be made only after eyewitness reports and results of field investigations are studied and interpreted. (Was it barely felt, did it knock dishes off shelves, destroy poorly constructed buildings or destroy almost all buildings?)

Although magnitude is an important factor in the effect of an earthquake, earthquakes of large magnitude do not necessarily cause the most intense surface effects. An earthquake's destructiveness depends on many factors: magnitude, focal depth and local geologic conditions, as well as the distance from the epicenter, the population density, and the design and construction types of buildings and other structures. The combination of these factors is often what determines the difference between slight damage and catastrophe.

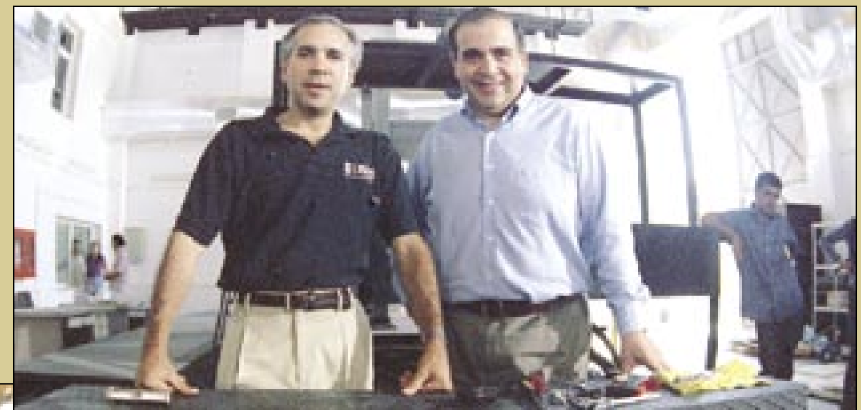
Compiled by Steve Vandas with assistance from Diane Noserale. Much of the information was obtained from the USGS publication "Earthquakes" by Kaye M. Shedlock and Louis C. Pakiser.

What it's Like to be an Earthquake Scientist

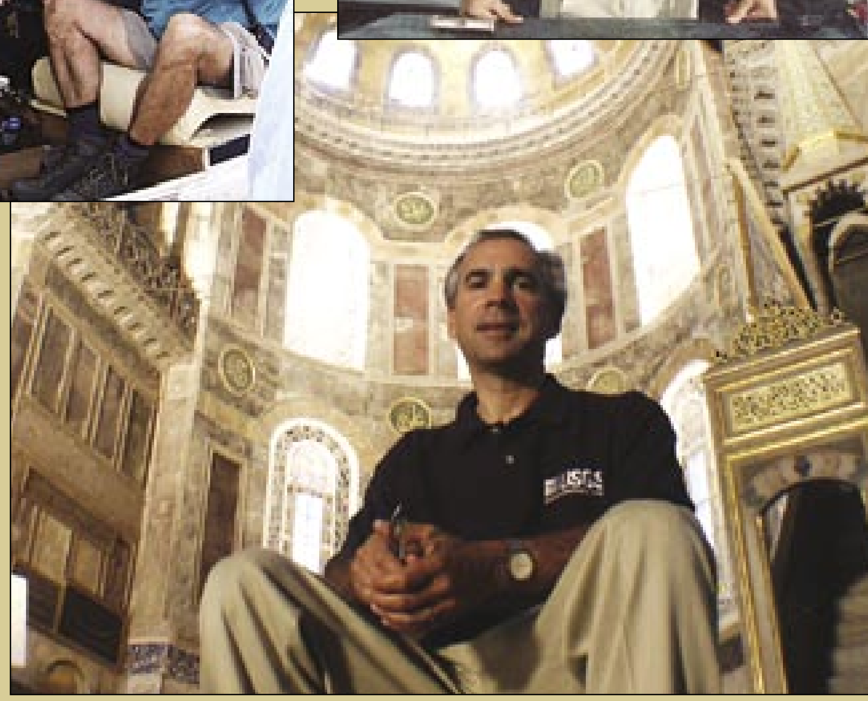
Talking with USGS Geophysicist Ross Stein

By Tania Larson

Above, Ross Stein prepares for a flight to film the fault and the city of Istanbul for the IMAX/National Geographic film "Forces of Nature." Stein wears a climbing harness underneath his jacket so he can lean out of the helicopter, and the chopper's doors are removed in order to fit the IMAX camera inside.



Above, Ross Stein with Professor Mustafa Erdik at the Bosphorous University earthquake engineering shake table.



At left, Ross Stein sits in Istanbul's Aya Sofya, which was the largest domed structure in the world for 600 years. It has sustained 12 large earthquakes in 15 centuries, serving as an ancient seismometer for earthquake scientists. Built as a Christian cathedral by Justinian in A.D. 537, becoming an Islamic mosque in 1453 and a secular museum in 1938, it is one of the world's great religious, architectural and scientific marvels.

In a field where the work is critical to saving lives, earthquake scientists often operate at a dizzying pace, collaborating with partners around the world as they try to solve the many mysteries of the Earth's processes. And just when they least expect it, they are thrown into the public spotlight, expected to respond to the fear and confusion that inevitably follow natural disasters with answers they may or may not have. It is tough, challenging work; but for most, the rewards of scientific discovery and knowing that they are giving something back to society make it all worthwhile.

USGS geophysicist Ross Stein sums up his average day with two words: "collaborative chaos." Ostensibly, Stein says, his job is to examine how one earthquake sets up the next, how one earthquake can promote or inhibit another. In reality, he does much more.

"In some ways," he says, "I'm an entrepreneur. I have to raise funds, account for them and make sure they are being used responsibly. In some ways, I'm a teacher, working with high school, college and post-doctoral students, making sure they learn the trade and take wing. And in some ways, I'm a student, learning from my colleagues and trying to do a better job of understanding earthquakes."

Stein is currently working on roughly half a dozen projects, and his office is virtually a revolving door as colleagues, post-docs and student interns come and go with questions, problems and ideas.

One of the joys of the job, Stein says, is simply being a research scientist, following his ideas to wherever they lead. "I have the opportunity to follow my own hunches, to raise the funds, do the research and make it happen — and that's my shot," he says.

One of the challenges, Stein says, is trying to figure out the strengths and weaknesses of your ideas, finding competing ideas and testing them against your own. Stein makes no bones about the fact that science research is competitive. Considering the innate bias of wanting to prove your own theories right, he feels the competition is healthy.

"There is a competition of ideas," he says. "You need to be constantly surveying alternatives, examining them for strengths and fine tuning your theories. It's a process that is very competitive and very open."

Earthquakes are complicated events, and discovering how the pieces fit together takes not only collaboration and ingenuity, but also a balance of knowing when to look for a new piece of the puzzle and when to stick with the piece you are already working with.

As Stein points out, however, earthquake science is peculiar in that it is largely an experimental science, yet earthquake scientists cannot set up their experiments. Because they do not know when and where earthquakes will occur, they do not have the preparation and careful planning afforded to other experimental sciences. It is difficult to have the right equipment set up in the right spot at the right time.

In earthquake science, opportunities come unexpectedly. "Usually," Stein says, "when you are working frantically to finish up something else." This creates a dilemma. "When they hit," says Stein, "you have to make a decision about whether to drop what you're doing to chase something new, something that could turn out to be a phantom, or stick to what you're doing and possibly miss the bus for something that could be a new breakthrough."

Stein believes that in order to be successful, earthquake scientists need to find a balance. He says, "You can't always chase something new or you'll never finish. And you can't always finish what you're working on or you'll never discover anything new."

"It's a painful choice," he admits. "But if you can't handle that choice, this isn't the field for you."

Although some scientists are happiest working close to home, Stein seems to jump at opportunities to cross an ocean. This is because he believes international efforts are imperative to advancing the science. He says, "We're never going to fully understand earthquakes in the United States unless we go to places where the earthquakes are big, frequent and well-recorded."

He is currently working on projects connected to Japan, Algeria and Turkey. "Japan," Stein says, "is lush in the quality of records." Algeria and Turkey, on the other hand, are more vulnerable. He says, "They have numerous earthquakes, but their records are not as good. So, international work is some giving and some taking. We're learning in some places and offering something back in others."

Communicating to the public is another way earthquake scientists give back. It is also a big responsibility. "There is a strong connection with the public," Stein says. "They are interested in what we do, and we have a responsibility to speak honestly. We have a twin responsibility: to tell what we know and what we don't know."

In times of disaster, there can be a lot of pressure for information. "When you are least prepared is when you will have to talk to the public," Stein says. "Fifteen minutes after an earthquake, there will be 30 cameras on you. And that's when you know the least. You have to be honest, clear and straight with people."

"We have to play it straight," Stein emphasizes, "not pretend what we don't know and not hold back what we do know. That's our contract with the public. That's an important element of being a government scientist and one I enjoy and value."

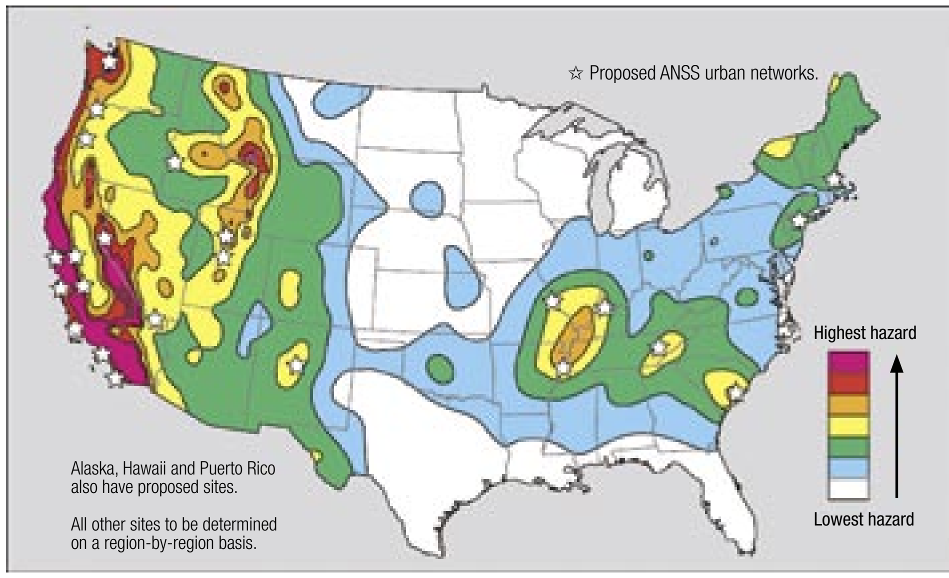
At the end of the day, however, it is scientific discovery that Stein enjoys most about being a USGS scientist. He says, "I'm not principally responsible for teaching, but for discovery. I am responsible for conducting research, and when we make discoveries, for making sure they are published. And I'm happy with that."

This is because, for Stein, discovery is the best part of the job. He says, "To discover something new — that's the intoxicating part, finding out something about how the Earth works. That's what drives all scientists."

The Advanced National Seismic System: A Sure Bet for a Shaky Nation

By David Hebert

Twenty-six U.S. urban areas, identified in the map at right, are at risk of significant seismic activity:



The earthquake hazards map of the conterminous United States shows the areas of highest seismic hazard in red and lowest seismic hazard in grey. The stars indicate urban areas where dense urban monitoring networks are proposed. The regional networks (not shown) will be concentrated in the areas of highest risk, and the national networks (not shown) will have sites evenly distributed throughout the country.

- Albuquerque, N.M.
- Anchorage, Alaska
- Boise, Idaho
- Boston, Mass.
- Charleston, S.C.
- Chattanooga-Knoxville, Tenn.
- Eugene-Springfield, Ore.
- Evansville, Ind.
- Fresno, Calif.
- Las Vegas, Nev.
- Los Angeles, Calif.
- Memphis, Tenn.
- New York, N.Y.
- Portland, Ore.
- Provo-Orem, Utah
- Reno, Nev.
- Sacramento, Calif.
- St. Louis, Mo.
- Salinas, Calif.
- Salt Lake City, Utah
- San Diego, Calif.
- San Francisco-Oakland, Calif.
- San Juan, P.R.
- Santa Barbara, Calif.
- Seattle, Wash.
- Stockton-Lodi, Calif.

If you were to learn that in 1886, a major U.S. city was ravaged by a magnitude-7.3 earthquake in which 60 people were killed and millions of dollars of damage done, where would you guess it had happened — Los Angeles? San Francisco? Anchorage?

Try Charleston, S.C.

In fact, damaging earthquakes have rocked several U.S. cities far from Alaska or California — Boston, Memphis and Salt Lake City, to name a few. Chances are, they will again, and those at risk need to be ready.

That's where the Advanced National Seismic System (ANSS) comes in.

The ANSS is a proposed nationwide earthquake-monitoring system designed to provide accurate and timely data and information products for seismic events, including their effects on buildings and structures.

"The ultimate goal of the ANSS is to save lives, ensure public safety and reduce economic losses," said Bill Leith, a USGS scientist and coordinator of the ANSS. "Rapid, accurate information about earthquake location and shaking, now available in parts of California, Washington and Utah, is generated by data from a dense network of seismic-monitoring instruments installed in high-risk urban areas. The information has revolutionized the response time of emergency managers to an earthquake in these areas, but its success depends on further deployment of instruments in other vulnerable cities across the United States."

Although the frequency of earthquakes on the West Coast is higher than other areas of the contiguous United States, the geologic characteristics nationwide mean that research and monitoring are necessary everywhere.

"When people think of faults and earthquakes, they tend to think of the San Andreas Fault, but earthquakes in the eastern United States might be different," said Eugene Schweig, a USGS geologist in Memphis, Tenn. "Assuming buildings will shake the same in the East as they do in California is probably not valid."

ANSS network instruments are already at work in many areas and are planned for other earthquake-prone regions nationwide, including Northern and Southern California, the Pacific Northwest, Alaska, Salt Lake City, the New Madrid Seismic Zone, and along the Atlantic Coast in South Carolina, New York and Massachusetts.

The ANSS, when fully implemented, will integrate all regional and national networks with 7,000 new seismic instruments, including 6,000 strong-motion sensors in 26 at-risk urban areas. (See map for a list of these areas.)

Boston is one of those urban areas — indeed, it has experienced damaging earthquakes before. In 1755, an earthquake centered near Cape Ann, Mass., caused building damage and chimney collapses in Boston. The buildup of the city since then would likely make matters much worse if such an earthquake were to happen there today.

John Ebel, a professor of geophysics at Boston College and northeast coordinator for ANSS implementation, estimates that damaging earthquakes (magnitude 5 or greater) happen in New England every 50 to 60 years. In 1940, there was a magnitude-5.5 quake in New England, and the clock is ticking.

"I talk to people all the time who ask, 'Earthquakes don't really happen here, do they?' " Ebel said. "And I answer, 'Yes, they do.' "

Although the frequency of earthquakes is much greater in the West, the damaging effects of a quake in the East travel farther.

"The 1994 magnitude-6.7 Northridge,

USGS Earthquake Scientists — A Nationwide Notion of Pride

By David Hebert

USGS scientists from across the country have been part of many incredible and memorable earthquake experiences. With that in mind, several of them were asked, **"What has been your proudest, most exciting or most noteworthy moment in USGS earthquake science?"**

The answers are as different as the scientists themselves.

Susan Hough

Title: Geophysicist/Seismologist

Location: Pasadena, Calif.

Length of service with the USGS: 14 years

In April of 1992, less than two months after joining the USGS office in Pasadena, Calif., I led the deployment of portable seismometers after the magnitude-6.1 "Joshua Tree" earthquake struck the Southern California desert near Palm Springs. My colleagues and I were able to keep these instruments running for the next few months, recording many thousands of aftershocks.

On the morning of June 28, 1992, the magnitude-7.3 Landers earthquake struck just to the north of where the Joshua Tree event had occurred. The portable seismometers — instruments developed by the USGS in Menlo Park — operated faithfully, recording invaluable close-in seismograms of the largest earthquake in California in 40 years.

Now, as in 1906, seismology remains a data-driven science: Our most important leaps in understanding have invariably come after large earthquakes not only strike but are recorded by increasingly sophisticated instrumentation. Earthquakes do not, however, record themselves. Long- and short-term monitoring requires ingenuity and commitment. The USGS has taken a leadership role with such efforts in the United States for nearly half a century. Looking back at my own career, I am proud of any number of accomplishments, but none more than the chance to contribute in a modest way to this tradition of excellence.

Calif., earthquake was not felt in San Francisco, less than 400 miles away," Ebel said. "If that same earthquake happened in Boston, it would be felt in Minneapolis-St. Paul, more than 1,000 miles away. There is potential for several metropolitan areas to be damaged by a single, large earthquake in the East."

In 1811 and 1812, a series of earthquakes, ranging in estimated magnitude from 7.5 to 8.0, started near New Madrid, Mo., and shook cities from St. Louis to Cincinnati. Although the probability for another 1811/1812-type sequence in the next 50 years is 7 to 10 percent, the probability for a magnitude-6 or greater during that same period is 25 to 40 percent.

"Based on paleoseismic work, we know that 1811- and 1812-like events have happened two or three times in the past," said Mitch Withers, seismic networks director at the Center for Earthquake Research and Information at the University of Memphis. "So we know it's not a fluke and that they tend to come in sequences, where there are several events clustered together in time. From a hazard and recovery point of view, it's much more difficult if we have several in a row like that."

Earthquake hazard concerns stretch to the Mountain States as well, where several earthquakes since 1935 have caused more than 30 deaths in Idaho, Montana and Wyoming. The threat of such a quake happening in a mountain urban area means preparation and monitoring are vital in at-risk locations such as Salt Lake City.

"We haven't had our 1906 earthquake in Utah yet, but our partnership with the USGS under the ANSS has made us feel much better prepared to deal with it when it happens," said Gary Christenson, a geologist and manager of the Geologic Hazards Program at the Utah Geological Survey. "The USGS has been a partner in earthquake monitoring in Utah from the beginning, and implementation of the ANSS has been a major achievement in improving preparedness, response and scientific/engineering data gathering."

The variety of earthquake hazard concerns that are both unique to and shared by urban areas nationwide illustrates the need for a consolidated, cooperative approach to information gathering and mitigation.

"The ANSS is working toward development and implementation of integrated software and human resources to more effectively use these with existing hardware resources to provide timely and valuable information to the public," Withers said.

Timely and valuable information is a key ingredient to effective mitigation. A possibility USGS scientists have been keenly aware of throughout the development of ANSS is that an early warning of even a few seconds would give schoolchildren enough time to get under their desks and would allow managers time to stop trains and subways, shut off pipelines and suspend medical procedures.

> **"The ultimate goal of the ANSS is to save lives, ensure public safety and reduce economic losses."**
>
> **— Bill Leith**

These sorts of warnings can only be accomplished through national cooperation, so a nationwide network of science and civic partners is working to make the ANSS a reality.

"The USGS and its regional partners combine resources to augment ANSS-funded stations to operate regional seismic networks," Withers said.

These partners include state geological surveys, university researchers, emergency managers, engineering organizations and more. The USGS works to unify perspectives and efforts to create a single, national force with which to address earthquake concerns and provide timely information.

"To have the USGS as overseer and coordinator of the ANSS makes sense," Ebel said. "The USGS is nationally involved in earthquake research and monitoring and it has expertise in house."

The USGS is the only agency in the United States responsible for the routine monitoring and notification of earthquakes. The USGS fulfills this role by operating the U.S. National Seismograph Network, the National Earthquake Information Center, the National Strong Motion Program and by supporting 14 regional networks in areas of moderate to high seismic activity. All of these efforts are being integrated into the ANSS.

"The ANSS contributes to the infrastructure that enables monitoring to be much more cooperative and integrated, allowing information to the public that combines data from all regional partners," Withers said.

The goal of USGS earthquake monitoring is to mitigate risk — using better instruments to understand the damage caused by shaking and to help engineers create stronger and sounder structures that ensure vital infrastructures, utility, water and communication networks can keep operating safely and efficiently.

The ANSS comprises several products that work to engage and inform the public, emergency managers and decision makers:

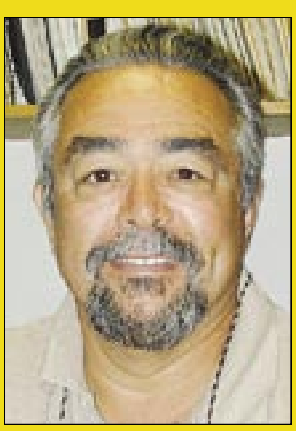
- **Recent Earthquakes** — Automatic maps and event information are available within minutes online at the USGS Earthquake Hazards Program Web site, which displays earthquake locations nationwide.
- **Did You Feel It?** – This is a citizen science Web page where shaking intensity maps are created by the people who felt the earthquake. [See page 33.]
- **ShakeMap** – A rapidly generated computer map that shows the location, severity and extent of strong ground shaking within minutes after an earthquake. Fast information on strong shaking in urban areas helps get emergency response to the right places.
- **Hazard Maps** – Hazard maps identify the areas of the country that are mostly likely to experience strong shaking in the future. ZIP code or latitude-longitude lookup is available. [See pages 26, 30, 31.]
- **Earthquake Notification** – Automated notifications of earthquakes are available through e-mail, pager or cell phone. This provides rapid information and updates to first responders and resources for media and local government.
- **Earthquake Catalog and Data** – Users can search an online catalog and download information and technical data.
- **Real-time Waveforms** – Real-time waveform displays from 60 stations, showing the movement of seismic waves, are available online 24 hours a day.
- **Regional Earthquake Info** – Information about earthquake hazards, historical seismicity, faults and more is available for different regions of the country and by state.
- **Movies of Structures Shaking** – These are Quicktime movies created from the recordings of fully instrumented structures during earthquakes.

"USGS and ANSS support allows for much better monitoring than we would otherwise have," Withers said. "By making use of ANSS tools, we are able to provide rapid notification, recent earthquakes, ShakeMap, real-time data exchange, technical expertise exchange, etc."

Rapid and reliable information on the location, magnitude and effects of an earthquake is needed to guide emergency response, save lives, reduce economic losses and speed recovery. ANSS can offer these benefits if resources and efforts are continuously devoted to it.

"These things play out over decades to hundreds to thousands of years, so implementations and improvements have to be done year in and year out," Ebel said. "ANSS is a down-payment investment on future earthquake monitoring."

USGS Earthquake Scientists — A Nationwide Notion of Pride



Roberto J. Anima

Title: Geologist

Location: Menlo Park, Calif.

Length of service with the USGS: 33 years

For the past six or seven years, I have had the opportunity to report, both locally and internationally, to the Spanish-speaking public on both television and radio, about earthquakes, tsunamis and other natural disasters. I feel that this is important because much of the information reported in English was not being reported to the Spanish-speaking community. Because we live in an earthquake-prone area — the entire West Coast of North, Central and South America — these communities need to be made aware of the potential hazards that surround us and them. As part of these assumed duties, I have also helped in translating two fact sheets concerning earthquakes and tsunamis.

In 2001, I was asked to be part of the Tsunami Response Team that was invited to Peru in response to a series of tsunamis that occurred along the coast of Camana, Peru, as a result of a magnitude-8.4 earthquake off the coast of southern Peru. The study focused on tsunami deposits on the beaches between Ocoña and Mejia, Peru. I am currently working on mapping the rift valley of the San Andreas Fault, Tomales Bay. I am also mapping the continental shelf along the central California coast.

Ken Rukstales

Title: IT Specialist

Location: Golden, Colo.

Length of service with the USGS: 21 years

Along with Art Frankel and E.V. Leyendecker, we have produced seismic building-design maps that are the basis for the seismic design provisions of the International Building Code and the International Residential Code. These maps are the most significant product to ensure that buildings, bridges and other structures are designed to withstand expected levels of ground shaking caused by earthquakes. Properly designed, earthquake-resistant structures greatly reduce the loss of life and property from earthquakes.

Taking it all in Slide —
How the Trans-Alaska Pipeline Survived a Big One

Compiled by Heather Friesen

The Nov. 3, 2002, magnitude-7.9 central Alaska earthquake was one of the largest recorded earthquakes in our nation's history. The epicenter of the temblor was located near Denali National Park, approximately 75 miles south of Fairbanks and 176 miles north of Anchorage. It caused countless landslides and road closures, but minimal structural damage, and amazingly, few injuries and no deaths.

In contrast, the 1906 magnitude-7.9 earthquake and subsequent fires took 3,000 lives and caused $524 million in property losses. The remote location of the magnitude-7.9 Denali Fault earthquake played a role in ensuring that the earthquake was not more devastating. However, advanced seismic monitoring, long-term research and a commitment to hazard preparedness and mitigation also played a key role. The science done before the Denali Fault earthquake aided in the successful performance of the Alaska pipeline, and the science done after the Denali Fault earthquake revealed more about large quakes that will help save lives and property during future temblors, especially in populated areas.

Designed to withstand a magnitude-8 earthquake with up to 20 feet of movement, the Trans-Alaska Pipeline is supported by rails on which it can slide freely during an earthquake.

USGS seismologists and geologists serving on a federal task force were instrumental to ensuring that the Trans-Alaska Pipeline was designed and built to withstand the effects of a magnitude-8.0 earthquake with up to 20 feet of movement at the pipeline. The USGS design guidance proved to be on target. In 2002, the Denali Fault ruptured beneath the pipeline, resulting in an 18-foot horizontal offset. The resilience of the pipeline is a testament to the importance of science in hazard mitigation and decision making.

More than 30 years ago, Trans-Alaska Pipeline System (TAPS), formed by seven oil companies, confirmed the existence of a great deal of oil on the North Slope. In February 1969, TAPS announced plans to build a 4-foot diameter, 800-mile pipeline to carry crude oil from Prudhoe Bay to Valdez. Issues pertaining to the safety of the design emerged. Would the heat in the oil melt the pervasive, thick, permafrost layer and cause damaging spills? Would the pipeline be able to withstand a large earthquake in the nation's most seismically active state?

Walter Hickel, then U.S. Secretary of the Interior (1969-70), was alerted about the proposed pipeline and immediately appointed Bill Pecora, then USGS director (1965-71), to chair a technical advisory board. Pecora appointed the Menlo Park working group, made up mostly of USGS scientists, to advise the board.

USGS created several scientific documents to be used in planning the pipeline location and construction. Documents included an estimate of potential earthquake shaking levels and a report on thermal effects of a heated pipeline in permafrost that described how the pipe would float, twist and break.

In 1971, Pecora brought the Menlo Park group to Washington and thanked them for telling the oil companies "what they can't do," but now he wanted them to tell the companies "what they can do." Pecora locked the door of the conference room and told the group that he would not let them out until they had finished the analysis of the question "To bury or not to bury?" So the group put together the necessary stipulations on the pipeline construction. Among other things, the stipulations required that the pipeline system be designed to prevent oil leakage from the effects of a magnitude-8.0 earthquake on the Denali Fault.

In April 1974, construction of a 400-mile, all-weather road from the Yukon River to Prudhoe Bay was started. Pipeline and storage tank construction at Valdez began in 1975. Large segments of the Trans-Alaska Pipeline were elevated above ground to keep the permafrost from melting, and about half of the 800-mile pipeline was buried. A special fault design was adopted for crossing the Denali Fault Zone. Here the pipeline is supported by rails on which it can slide freely in the event of fault offset. In mid-1977, the first tanker shipped Alaska north slope oil from Valdez.

More than 14 billion barrels (nearly 550 billion gallons) have moved through the pipeline since startup in 1977. After the 2002 quake, the pipeline continued to carry 1 million barrels of oil each day, though it was temporarily shut down for inspection. With the pipeline intact, an important source of revenue for the state of Alaska was preserved. Moreover, as Alaskans know all too well, the consequences to the environment, should the pipeline have failed, would have been catastrophic.

"Good science made the difference between an emergency and a tragedy," said P. Patrick Leahy, USGS. "It's an example of how partnerships between the USGS, the Federal Emergency Management Agency, universities, state and local officials, and business leaders and the community enable us to apply our scientific knowledge. We know we can't stop the Earth from changing, but we can work together making public safety our primary goal."

The 2002 Denali earthquake is the largest seismic event ever recorded on the Denali Fault system — one of the longest continental faults in the world. The earthquake was similar to the magnitude-7.9 1906 earthquake, which ruptured the San Andreas Fault in Northern California. Both fault systems exhibit strike-slip movement, where blocks of continental crust slip horizontally past each other.

"Studying the 2002 Denali Fault earthquake is an opportunity to understand the consequences of a very large earthquake to better prepare for the time when one will occur in a much more densely populated area," said USGS scientist Peter Haeussler.

The Denali Fault earthquake was very directional. It ruptured rapidly over a long distance, focusing the earthquake energy in the direction of the earthquake

USGS Earthquake Scientists — A Nationwide Notion of Pride

David Oppenheimer

Title: Seismologist; Project Chief of the Northern California Seismic Network

Location: Menlo Park, Calif.

Length of service with the USGS: 28 years

The first memorable moment is scientific: In the mid-1980s, my colleague Paul Reasenberg and I developed software to compute the focal mechanism of an earthquake from first-motion polarities from seismograms. A focal mechanism indicates to seismologists the orientation and sense of relative motion of the fault on which the earthquake occurred. The ability to compute what was formerly done laboriously by hand opened up a new vista into the earthquake process.

When Paul, Bob Simpson and I began to look at the suite of focal mechanisms of aftershocks from the magnitude-6.2 Morgan Hill, Calif., earthquake in 1984, we were initially confounded. We discovered that the mechanisms for earthquakes adjacent to the Calaveras Fault were reflecting a state of stress in which the orientation of the maximum compressive stress was nearly perpendicular to the fault instead of being oriented approximately 30 degrees to the fault as predicted by classical mechanics.

This finding, together with borehole stress measurements, heat-flow measurements and geological observations, provided compelling evidence that the frictional strength of the Calaveras Fault was much lower than had been commonly thought. It was both exciting and gratifying to be making a new and fundamental observation that altered our understanding of fault mechanics and the process of how earthquakes are generated.

The second is operational: As the project chief of the USGS Northern California Seismic Network (NCSN), it has been my privilege to manage a complex project staffed by very creative and hard-working individuals who deploy and maintain seismic instrumentation and telecommunications, and who develop sophisticated, real-time data processing systems.

Perhaps the proudest moment was the occurrence of the September 28, 2004, magnitude-6 Parkfield earthquake. The Parkfield earthquake culminated in an effort that began more than 30 years earlier to instrument a section of the San Andreas Fault that repeatedly ruptures in similarly sized earthquakes every few decades. In an instant, the earthquake tested all phases of the NCSN and University of California-Berkeley monitoring system.

Not only did we successfully capture a rare data set for study by the seismological research community, but the results were automatically available on the Web. Within minutes after the earthquake, we were reliably and rapidly delivering earthquake information on the Web at a rate of 10,000 hits/sec. It was both exciting and gratifying to see that all of our instrumentation, telemetry and processing systems worked as designed.

rupture. As a result, said Haeussler, distant earthquake effects were most pronounced in one direction — southeast of the fault trace toward western Canada and the lower 48 states. Consequently, the Denali Fault earthquake was felt as far away as Louisiana. In the New Orleans area — more than 3,000 miles away — residents saw water in Lake Pontchartrain slosh about as a result of the earthquake's power. The earthquake also disturbed levels of water in Pennsylvania wells by up to two feet, damaged houseboats in Seattle from seismic sea waves, and triggered small earthquakes at many volcanic or geothermal areas in the direction of rupture. The most pronounced triggering was observed at Yellowstone, Wyo., with 130 small earthquakes recorded in the four hours following the 1,940-mile-away Alaskan rupture. By contrast, in the other direction, only one of the many active Alaskan volcanoes had triggered earthquakes.

"Research like this conducted by the USGS and collaborating institutions helps to anticipate the effects of future large earthquakes, such as the kind that will occur on the San Andreas Fault in the Los Angeles area," explained Lucy Jones, USGS scientist-in-charge for Southern California. "The effect of directivity may be important in hazard planning for future large Southern California earthquakes." The last time the San Andreas Fault ruptured in Southern California, in a magnitude-7.9 earthquake in 1857, the earthquake began in central California and ruptured southeastward toward the now highly urbanized Los Angeles region.

Thanks to George Gryc, Robert Page and Peter Haeussler.

Measuring Magnitude — What Do the Numbers Mean?

Compiled by Diane Noserale

Often two or more different magnitudes are reported for the same earthquake. Sometimes, years after an earthquake occurs, the magnitude is adjusted. Although this can cause some confusion in news reports, for the public and among scientists, there are good reasons for these adjustments.

Preliminary Magnitude

Following an earthquake, the first magnitudes that seismologists report are usually based on a subset of seismic-monitoring stations, especially in the case of a larger earthquake. This is done so that some information can be obtained immediately without waiting for all the data to be processed. As a result, the first magnitude reported is usually based on a small number of recordings. As additional data are processed and become available, the magnitude and location are refined and updated. Sometimes the assigned magnitude is "upgraded" or slightly increased, and sometimes it is "downgraded" or slightly decreased. It can take months before a magnitude is no longer "preliminary."

Sometimes the earthquake magnitude is reported by different networks of seismometers based on only their recordings. In that case, the different assigned magnitudes are a result of the slight differences in the instruments and their locations with respect to the earthquake epicenter. Depending on the specifics of the event, scientists might determine that the network closest to the event reports it most accurately. This is especially true where the instrumentation is denser. Other times, national networks, in which the instruments are often more state-of-the-art, produce the most reliable results.

Different Methods of Calculating Magnitude

The concept of using magnitude to describe earthquake size was first applied by Charles Richter in 1935. The magnitude scale is logarithmic so that a recording of 7.1, for example, indicates a disturbance with ground motion 10 times larger than a recording of 6.1. However, the difference in energy released is even bigger. In fact, an earthquake of magnitude 7.1 releases about 33 times the energy of a magnitude 6.1 or about 1,000 times the energy of a magnitude-5.1. Another way of thinking of this is that it takes about 1,000 magnitude-5.4 earthquakes to equal the energy released by just one magnitude-7.4 event. A earthquake of magnitude 2 is normally the smallest felt by people. Earthquakes with a magnitude of 7.0 or greater are commonly considered major; great earthquakes have a magnitude of 8.0 or greater.

Through the years, scientists have used a number of different magnitude scales, which are a mathematical formula, not a physical scale. Although news reports often call all magnitudes "Richter," scientists today rarely use Richter's original method. Unless further detail is warranted, USGS simply uses the terms magnitude or preliminary magnitude, noted with the symbol "M," in its news releases.

The Most Common Magnitude Scales in the United States

When earthquakes occur, energy is radiated from the origin in the form of different types of waves. Moment magnitude (M_W) is usually the most accurate measure of an earthquake's strength, particularly for larger earthquakes. Moment magnitude accounts for the full spectrum of energy radiated by the rupture and is generally computed for earthquakes of at least magnitude 5.5 when the additional data needed for this computation are available and the effort is warranted. Using some sophisticated regional networks in which noise is limited, seismologists can compute moment magnitudes for earthquakes down to less than magnitude 3.5.

Surface-wave magnitude (M_S) is computed only for shallow earthquakes, those with a depth of less than 30 miles. Body-wave magnitude (m_b) is computed for both shallow and deeper earthquakes, but with restrictions on the period of the wave. And local "Richter" magnitudes (ML) are computed for earthquakes recorded on a short-period seismometer local to (within 370 miles of) the focus of the earthquake.

Seismologists may measure an earthquake's magnitude with one scale. Then, once more data are available, reassign the magnitude using another scale deemed more accurate based on the additional data. For example, for the 1999 earthquake near Ismit, Turkey, the 7.8 magnitude first cited was a (M_S) surface-wave magnitude. The later figure of 7.4 is a (M_W) moment magnitude. Magnitudes assigned to a specific event for years can sometimes change.

Compiled with assistance from Steve Vandas.

USGS Earthquake Scientists — A Nationwide Notion of Pride

Brian Sherrod

Title: Research Geologist

Location: Seattle

Length of service with the USGS: 11 years

One of my most memorable times as a USGS scientist is when I found evidence of surface rupture along the Seattle Fault near Bellevue, Wash. I was looking for evidence of the Seattle Fault east of Seattle — using old aerial photographs taken from biplanes in the 1930s, more recent laser mapping data, geologic maps and lots of field work. I had a good idea where I thought a strand of the fault zone traversed the area I was working in, so I obtained permission to do some detailed work on an undeveloped parcel of land near the shoreline of Lake Sammamish.

After many hand-excavated test pits and soil auger holes, I thought I had found a trace of the fault that put weathered Miocene bedrock against young glacial deposits. The time had finally come to really test my ideas with a large excavation across what I thought was a fault. I remember being nervous when the backhoe arrived and we finally began excavating. Within a short time, though, we uncovered a thrust fault that placed weathered bedrock and old glacial deposits over a recent forest soil. The fault and buried soil were within a few meters of where I originally thought the fault was.

Want to know what was most satisfying about this discovery? I had many modern tools at my disposal, including LiDAR (laser) maps, geospatial information systems and a host of detailed geophysical studies, but it was getting down on my hands and knees in the dirt (oops, soil...) and doing the field geology that really made this study succeed.

Joan Gomberg

Title: Research Seismologist

Location: Memphis, Tenn.

Length of service with the USGS: 18 years

The most exciting thing for me was discovering the strong correlation between distant aftershocks and focusing of seismic waves (implying triggering by the waves) — a Eureka moment! Visiting Bhuj, India, was also memorable.

Building Safer:

How Decades of Earth Science is Helping to Reduce the Biggest Earthquake Vulnerability — Man-Made Structures

By Tania Larson

On October 17, 1989, occupants of the Transamerica Pyramid in San Francisco were unnerved as the building started to shake. Sixty miles away, in the forest of Nisene Marks State Park in the Santa Cruz Mountains, the Loma Prieta earthquake had struck with a magnitude of 6.9. The seismic waves were channelled — focused by the geological features of the area — toward San Francisco. USGS instruments installed in the building showed that it shook for more than a minute and that the top floor swayed more than a foot from side to side.

The earthquake caused more than $6 billion in damages and took 63 lives. Yet no lives were lost in the Transamerica Pyramid. Despite the intensity of the shaking, the 49-story building came through undamaged. Having been aware of the area's potential for even larger earthquakes, engineers had designed the Transamerica Pyramid to withstand greater stresses than those from the Loma Prieta earthquake.

The biggest danger during an earthquake is often the failure of man-made structures. Not only are lives lost to falling buildings, collapsed bridges and crumbling facades, but disruption of infrastructure and utilities can cause additional hazards and actually keep emergency crews from life-saving resources. Earth scientists have been working for more than 100 years to improve our understanding of earthquake hazards. One of their most important goals is to provide designers, lawmakers and residents with the information they need to build structures that are better able to withstand the forces of the earthquakes they are likely to face.

Unreinforced masonry buildings are especially vulnerable during strong earthquake shaking. Shaking-hazard maps are used to determine areas where these types of buildings need to be reinforced to make them safe during earthquakes. Photo: J. Dewey

Building Codes Help Protect Earthquake-Prone Communities

"The most common cause of damage to a structure (a building or bridge) during an earthquake is strong ground shaking," says E.V. Leyendecker, USGS scientist emeritus. "The first line of defense against such shaking is the design and construction of structures to resist it."

And as USGS scientist David Perkins points out, "Earthquake building codes are the primary means to prevent or limit damage to structures."

Building codes help protect us by requiring that new construction meet certain safety requirements. In many earthquake-prone areas, these codes specify the levels of earthquake forces that structures must be designed to withstand.

"To ensure that the code is adequate without being excessively expensive to implement, engineers have to know the likelihood that certain levels of ground shaking will be experienced during the lifetime of the structure," says Perkins.

But how do they know what conditions a building is likely to face? USGS has developed a number of products to show not only how probable it is that a structure will face small, moderate and large earthquakes, but also how much shaking buildings are likely to experience and how they tend to respond to these varying levels of shaking.

Hazard Maps to Reveal Nationwide Seismic Threats

Since 1948, scientists have been making national earthquake-shaking maps that show the variations in the seismic threat from one area to the next. These maps demonstrate the potential shaking hazard from future earthquakes across the country, and they are frequently updated as scientists learn more about earthquakes and the hazards they pose.

Looking to the Past to "Construct" Models of the Future

Coming up with these estimations can be very complicated. Basically, researchers do everything they can to learn about past events: where earthquakes have occurred, how frequently and at what size; how the vibrations have traveled through the ground; how those vibrations were affected by soil and bedrock; and how all of this affected both the land and the structures we have built. Researchers then combine this information to build models of future earthquakes.

As earth scientists look at historical earthquakes, they are particularly interested in the levels of shaking the earthquakes have caused. "Earth scientists can determine past shaking levels by studying the effects of past earthquakes on people, structures and the landscape," says Perkins. "For more recent earthquakes, instrumentation on the ground and in buildings gives a more direct measure of the shaking experienced."

Scientists have been putting instruments in buildings since the 1940s. From this data, scientists and engineers can directly estimate how earthquake shaking will affect similar buildings in the future. When the information is less direct, researchers use computer models of buildings to indirectly generate the estimated effects.

Digging Deeper

What they don't learn with instrumentation above the ground, researchers can sometimes learn from clues beneath the ground surface. The layers of the earth typically lie flat, but when an earthquake rumbles through these layers, they are disrupted, leaving breaks and folds and other clues scientists can use to learn more about an area's susceptibility to earthquakes.

"Historical seismicity alone does not tell us all we need to know about future earthquake locations and magnitudes," says Perkins. "Accordingly, earth scientists look for faults and signs of earthquake liquefaction or earthquake-induced landslides in the geological past in order to estimate the sizes and dates of these

USGS Earthquake Scientists — A Nationwide Notion of Pride

Heidi Stenner

Title: Geologist

Location: Menlo Park, Calif.

Length of service with the USGS: 7 years

In 1999, a large, magnitude-7.4 earthquake rocked northwestern Turkey. The fault that ruptured is similar in a lot of ways to the San Andreas Fault in California, so it was important to learn all we could about the quake and its effects. As part of a small team, I helped map where and how the fault ruptured the ground. In doing so, we saw multi-story apartment buildings reduced to a single story of rubble, people living in tents outside their homes in the rain and bridges and overpasses rendered useless. And we heard a lot of sad stories.

Seeing firsthand the effects of an earthquake really motivated me to do what I can to keep that from happening again. Understanding the science behind earthquakes is one aspect needed to better prepare and reduce the risk to people from such events. It is my time in Turkey that reminds me most why we need to keep advancing earthquake science.

Thomas Noce

Title: Geologist

Location: Menlo Park, Calif.

Length of service with the USGS: 20 years

I'm most proud to have been working to help quantify the hazards in the greater San Francisco Bay Area, particularly in the areas of man-made land that didn't exist in the 1906 earthquake. These areas are potentially the most vulnerable in a repeat scenario of the 1906 event, and the Loma Prieta earthquake of 1989 provided but a glimpse of their shortcomings. We have learned a great deal about liquefaction and hazard analysis since then, and we have developed methodologies to identify and quantify the liquefaction hazards that will serve us not only here in the Bay Area, but across the country in all seismically-at-risk regions.

Although much work remains to be done in the Bay Area to complete the hazard mapping, what we have begun and hope to finish will serve as an example of how hazard mapping should be done in the future in historically active liquefaction zones across the United States, such as the New Madrid seismic region, Charleston, S.C., the Pacific Northwest and Alaska.

It has been equally exciting to work with the best of the best in their fields, with people who care about their work and their contributions to make the world a safer place.

events. This allows them to extend the 'history' of large events back as much as 10,000 years or more. From this longer history, earth scientists can also determine the rate at which earthquakes of all sizes occur."

However, as Leyendecker points out, this does not tell the entire story. Designing a building requires knowledge not only of the earthquakes it will likely face, but also how those earthquakes will affect the building — the loads it will have to bear and how and to what capacity it will respond to those forces. "Research conducted since the 1906 San Francisco earthquake, particularly over the last 20 to 30 years under the National Earthquake Hazards Reduction Program, has contributed to these three areas of loads, response and capacity," says Leyendecker.

Science Advancements Help Refine and Improve Building Codes

Thanks to increased earth science focus, building codes have seen regular major changes since the 1960s, and according to Perkins, these advancements have paid off.

"Structures built using recent building codes have withstood remarkably large levels of ground motion in the earthquakes that have been experienced since the 1990s," says Perkins.

For example, in 1971, the magnitude-6.6 San Fernando earthquake left the Los Angeles dam badly damaged. This dam, so weakened that a strong aftershock could have caused a collapse, was all that stood between 80,000 people and 15 million tons of water. Residents in an 11-square-mile area were forced to evacuate their homes while the water behind the dam was lowered. With years of ground motion studies and advancements in earthquake studies to turn to, engineers built a new, safer dam. This new structure was tested in 1994 when the magnitude-6.7 Northridge earthquake hit the area. The new dam held, with very little damage.

"In 1996, a major revision of the ground-shaking-hazard maps, developed in collaboration with the earth-science community and design engineers, resulted in major improvement of building codes and design standards," says Leyendecker. The revisions incorporated new descriptions of the hazard, such as the specific soil and rock conditions and how buildings experience vibrations in response to the vibrations of the ground.

"This new way of describing the hazard enables structural engineers to better predict structural response to ground shaking for design purposes. Knowledge of the site condition of the maps also enables engineers to adjust the design to incorporate the actual site condition. In the end, these improvements result in better protection of lives and property," says Leyendecker.

By taking all of this information into account, scientists have created a powerful data set. "With all these forms of earth science information," says Perkins, "researchers can compute the likelihood of future earthquake ground shaking at all locations in the U.S. It is maps of these probabilistic ground motions that are used to determine building code requirements."

More than 20,000 cities, counties and local government agencies use building codes based on these maps, but shaking-hazard maps have many other applications. They are also used by insurance companies to set rates for properties in different areas, civil engineers to estimate the stability of hillsides, the Environmental Protection Agency to set construction standards for waste-disposal facilities, and the Federal Emergency Management Agency to allocate funds for earthquake education and preparedness.

To make sure users understand and get the best value out of the maps, the USGS offers workshops to familiarize users with the shaking-hazard maps and earthquake issues.

While both the Loma Prieta and Northridge earthquakes demonstrated that we can build safer structures that do withstand earthquakes, there were still considerable losses that revealed just how vulnerable major metropolitan areas can be when hit by an earthquake. Awareness of this vulnerability was reinforced by the 1995 Kobe, Japan, earthquake. With magnitudes of 6.7 and 6.9, respectively, both the Northridge and the Kobe events are considered moderate earthquakes, yet even in these areas known for their earthquake preparedness, the losses suffered by the densely populated urban areas were catastrophic.

Houses without adequate connections to foundations can easily shift during even moderate earthquake shaking, causing extensive damage. Pipes and wires may be broken by a slight cripple-wall shift, resulting in fires, water damage or other problems. Much damage of this type can be avoided by using inexpensive bracing techniques, such as those recommended in the seismic design provisions of building codes.

High-Resolution Maps to Help High-Risk Urban Areas

To address this vulnerability, engineers, officials and emergency-response teams needed better, more detailed information. In 1998, the USGS began high-resolution earthquake hazard mapping in three high-risk urban areas: the eastern San Francisco Bay region, Seattle and Memphis. Since then, projects in St. Louis, Mo., and Evansville, Ind., have also been started.

These projects will provide city officials with hazard maps that are more detailed and take local and regional geology into account. As the Loma Prieta earthquake demonstrated, geology can play a big role in how a city is impacted by an earthquake. The assessments are also addressing potential ground failure hazards, such as liquefaction and earthquake-triggered landslides.

This research is being used to create urban hazard maps, scenario earthquake maps and long-term forecasts of earthquake probabilities. These products will provide better details for updating building codes, reducing risks and planning for recovery in high-risk metropolitan areas.

Looking Long Term

The hazard maps that influence today's building codes incorporate more than a century of seismic monitoring and decades of research. In their quest to find ways to protect people from the effects of earthquakes, USGS researchers have come up with many creative ways to expand their understanding of the hazards. They have traveled the globe, comparing notes and historical records with researchers around the world. They have dug through mud and sand and clay. They have bored through layers of rock. They have even learned about earthquakes by examining long-drowned forests and other side effects earthquakes have had on the landscape.

By taking all of these efforts and turning them into products communities can use to protect themselves, USGS researchers have helped save many lives and millions of dollars. But they know their work is not done. In the next 100 years, they will continue to look for new ways to refine and enhance the maps and models that influence building codes, making all of our structures — from our homes, to our hospitals, to the infrastructures that support our resources — better able to withstand the earthquakes they will inevitably face.

Thanks to E.V. Leyendecker, Nicolas Luco, David Perkins and Robert Wesson for their help and expertise.

USGS Earthquake Scientists — A Nationwide Notion of Pride

Hal Macbeth

Title: Supervisor of seismic analysis for the Northern California Seismic Network

Location: Menlo Park, Calif.

Length of service with the USGS: 26 years

Public Education: The Earthquake Hazards Team has put a superior effort into providing Web-based information to the public not only about where recent or historical earthquakes have occurred, but also about how the public can use that information to protect themselves and others from earthquake hazards in the future. This effort has brought public awareness and access to disaster crisis information to a level where, in the end result, we hope some lives might be saved.

Through the efforts of public outreach, I have personally fielded calls and e-mails daily on questions about earthquakes, volcanoes, landslides and other hazard/earth science information. Many of these calls are from our nation's youth, who are eager to educate themselves and potentially will be our nation's next generation of scientists. That's much to be proud of.

Emergency Hazards Response: I have seen this as a continually evolving effort to better improve the access of real-time earthquake information for federal, state and local disaster-response teams. I serve as one of five USGS duty seismologists who are on call 24/7 for emergency response to earthquakes occurring in Northern California. ShakeMaps (one of our map products showing calculated ground-shaking intensities) are produced minutes after a moderate-to-large earthquake strikes, alerting rescue/repair crews to focus on the most damaged areas first.

Efforts are also being made to establish an early warning system for ground shaking in a large earthquake, potentially giving a few seconds warning ... more potential lives saved.

I don't think I could be any more proud than being a team member of an organization whose ultimate purpose is to protect lives and property not only here in the United States, but also helping to identify and possibly mitigate hazards in a global crisis, such as tsunamis and other earthquakes occurring around the world.

Working for a Safer Southern California
A Profile of Lucy Jones

An Interview with Lucy Jones

By Diane Noserale

What is your nightmare earthquake scenario?

Any magnitude-7 in the Los Angeles basin, and we have many faults — Santa Monica, Hollywood, Puente Hills, Palos Verdes, Sierra Madre — that are capable of producing an earthquake of that size. During a Santa Ana wind condition when fires cannot be controlled is the scenario for a true nightmare. "Multi-hazard" is not just popular jargon.

What was your most interesting experience while working in the field?

I generally don't do fieldwork. I use the permanent seismic network. But to bribe me to go to graduate school at MIT, Professor Peter Molnar (my eventual thesis advisor) offered to take me on fieldwork in Afghanistan for the two months before school started. I spent the time running portable seismographs in the Hindu Kush Mountains. In one of the villages, someone tried to buy me from Peter for two camels, double the going rate.

You talk to all kinds of groups. Do you see a difference between young and old people's perceptions about earthquakes?

No. There is a fundamental divide between people who are afraid of earthquakes and those who aren't, but I have not found a defining characteristic of what makes people afraid.

By Stephanie Hanna and Diane Noserale

Lucy Jones, chief scientist of the Earthquake Hazards Program in Southern California, is truly a household name and the face of the USGS in Southern California. Over the past 23 years, she has worked tirelessly to calm shattered nerves following earthquakes and to convince Southern Californians that they can take steps to make their lives safer during an earthquake.

Born in Santa Monica in 1955, Jones is a fourth-generation Southern Californian who has earned an undergraduate degree in Chinese language and literature from Brown University and a Ph.D. in geophysics from the Massachusetts Institute of Technology. This somewhat unusual combination tells the tale of her diverse interests and helped her (as a graduate student in 1979) to become the first American scientist to work in China following the normalization of relations.

In 1983, Jones joined the USGS as a seismologist. Her first interview as an employee of the USGS was on PBS's nationally televised "MacNeil/Lehrer Report" in 1985. During a spate of earthquakes that followed, she quickly became the go-to scientist for earthquake interviews, appearing on almost all the major network television news shows and making hundreds of appearances on local Los Angeles affiliates. An articulate spokeswoman, Jones has a knack for seeing through the question asked and responding to the concern or fear that prompted it.

Jones has appeared multiple times on many national programs, including "Dateline," "Nightline" and "The Today Show." She has worked with the staff of Universal Studios and even been to Disneyland to instruct the "Three Little Pigs" in earthquake safety and non-structural mitigation (They already had learned the construction lesson!) on Disney's "Toon-Town Kids."

For broadcasts across the nation, she must often appear awake, alert and articulate at 3 a.m., many times after live late-night newscasts. What little sleep afforded during these times is often interrupted by the shaking of local earthquakes or her beeper.

Jones' most enduring media persona is that of the calm working mom. During a post-earthquake news conference in 1992, she comforted her fussing 1-year-old. She was shown carrying a baby and advising people not to abandon their homes and potentially be caught near freeway overpasses during powerful aftershocks. She is still asked, "How's your baby?" and responds that he is a defensive tackle on his high school's JV football team.

Over the past 23 years, Lucy Jones has worked to calm shattered nerves following earthquakes and to convince Southern Californians that they can take steps to make their lives safer during an earthquake.

In her spare time — between earthquakes, media appearances, running the USGS office in Pasadena and family responsibilities with her two sons and husband, Egill Hauksson, a seismologist at Caltech — Jones has authored more than 80 scientific papers. Her research focuses primarily on earthquake-hazard assessment and forecasting earthquake aftershocks. Her theoretical geophysics work forms the basis for a Web service that provides 24-hour forecasts for strong shaking from aftershocks in California. [See page 30.]

She has also written several guest editorials printed in major daily newspapers and published several guidebooks for the general public and for classrooms. One of her more significant and lasting contributions was in writing and developing the publication "Putting Down Roots in Earthquake Country." [See page 34].

Her contributions to public safety also include briefing local and state officials on complex earthquake topics, helping to develop safety plans for several cities, including Los Angeles, and helping to train first responders in cities and counties throughout Southern California.

USGS Earthquake Scientists — A Nationwide Notion of Pride

Peter Haeussler

Title: Research Geologist

Location: Anchorage, Alaska

Length of service with the USGS: 14 years

No doubt, my most exciting experience was as the principal geologic investigator for the immediate post-earthquake geologic response to the Nov. 3, 2002, magnitude-7.9 Denali Fault quake in Alaska.

Right after the earthquake, we chartered a helicopter — we were looking for surface ruptures of the Denali Fault. It was really exciting to be able to follow surface ruptures on land and through glacier ice. It was the first time rupturing has been seen through glacier ice right after an earthquake.

I also remember following the Denali Fault rupture when it suddenly ended, and we couldn't find any more surface rupture. Our helicopter then flew over a mountain, and there we saw more surface rupture, this time on the little-known Totschunda Fault, which we followed out to the west where it terminated.

Also, in the two days of initial investigations, we discovered there were these humongous landslides that had covered glaciers. The clouds were down low on the deck, and as we flew over in the helicopter, we were asking, "What's all this rock here?" We then realized, "Oh — landslides!"

About 10 days after the earthquake, we were also continuing to try to map the fault trace, and we wanted to go east but couldn't because of weather. We decided to head west, and we started to find all the valleys full of clouds, so we couldn't get to the trace.

We were getting near the helicopter's fuel limit as we were flying over a glacier, and we saw surface rupture through the glacial ice — we realized we had found a previously unknown major thrust fault, which is now known as the Susitna Glacier Thrust Fault.

That was incredibly exciting to see on the ground, and satisfying because we had heard of Japanese seismologists who had a notion of there being thrusting at the beginning of the earthquake sequences. So when we saw this, we said, "Well, there it is!"

That first day we were on the Susitna Glacier Thrust Fault, we heard a sound like a deep Howitzer in the distance; then the bushes on the tundra would start shaking. It was very wild hearing and feeling an earthquake aftershock while standing on the fault plane.

In the end, it was the discovery and mapping out of the entire surface rupture and finding these other faults that was just really exciting.

Jones is, or has been, a member of a number of local, national and international decision-making commissions and professional associations. In 2002, then-Governor Gray Davis appointed her to the California Seismic Safety Commission, and she was reappointed by Governor Arnold Schwarzenegger in 2005. The work of the Commission has led to two bills now before the California Legislature. Jones has advised the California Office of Emergency Services on the state's earthquake-prediction and response plans and has briefed the U.S. Congress and other high-level officials.

Generous with her time, Jones estimates that since joining the USGS she has given more than 200 talks to civic groups, teachers associations and the public. From 2- and 3-year-olds at preschool to retirement home residents, Jones has provided science education with a focus on hands-on inquiry to a variety of audiences and age groups. She has worked to empower those who are frightened by repeated earthquakes with the message "you can keep yourself safe."

"The magnitude-5.0 Pasadena earthquake in 1988 was the most memorable [for me]. It was almost directly beneath my house during the night and literally threw us out of bed. Also, it was the first time my oldest child, Sven, then 2 years old, saw me on TV (in that case, a live interview) and told my husband, 'Mommy's in the TV!'"

— Lucy Jones

All these efforts have earned her many professional awards, not only in her specialty of seismology, but also from educators, civic groups, safety officials and from the media. In 2000, she was awarded the Alquist Medal for "significant contribution to earthquake safety in California." This year, she became the second non-journalist to win a Golden Mike Award from the Radio and TV News Association of Southern California for a radio-news special that drew lessons from Katrina for a future big earthquake in Los Angeles.

Top 10 Things Northern Californians Should Do to Prepare for the Next Big Earthquake

Excerpted from material by the 100th Anniversary Earthquake Conference Steering Committee

The people, businesses and government agencies in Northern California will risk suffering loss of life and structural and financial damage when major earthquakes strike. Scientists, engineers and emergency-management experts gathering for the 100th Anniversary Earthquake Conference call on the region's citizens, businesses and governments to take the following actions to increase safety, reduce losses and ensure a speedier recovery when the next major earthquake strikes.

✔ Develop a Culture of Preparedness at Home, Work and School

1. Know the seismic risks of the buildings you inhabit, the transportation systems you use and the utilities that serve them, and the actions you can take to protect yourself.

2. Be prepared to be self-sufficient for up to three days (72 hours) following a disaster.

3. Take steps to ensure adequate response care for all special-needs populations — seniors, the poor, the disabled and other vulnerable residents.

4. Get involved in preparing the region to respond to and recover from major earthquakes. This includes region-wide, multi-organizational plans, training, exercises and coordination assessments, as well as continuing improvements in our collective understanding of seismic risks.

✔ Ensure Resiliency in Recovery

8. Collaboratively plan for the regional relocation and housing, both short- and long-term, of residents displaced by potential fires, uninhabitable buildings or widespread economic and infrastructure disruption following a major earthquake.

9. Assess and plan for financing your likely repair and recovery costs following a major earthquake.

10. Ensure adequate post-event funding to provide economic relief to individuals and communities after a major earthquake, when resources are scarce yet crucial for recovery and reconstruction.

In conclusion, the earthquake professionals of the 100th Anniversary Earthquake Conference believe that, based on our current understanding of the hazards, local planning, stronger building codes and ongoing mitigation have substantially reduced the potential loss of life and property that a major Northern California earthquake could cause. While many areas are better prepared than ever before, the region is not yet sufficiently ready for the next major earthquake, and the social and economic consequences could prove to be long-lasting and ruinous to communities. A renewed emphasis on preparedness and safety is needed to fully prepare Northern California for a major natural disaster.

✔ Invest in Reducing Losses

5. Target those buildings that pose the greatest risk of collapse for seismic mitigation through retrofit, reduced occupancy or reconstruction.

6. Retrofit or replace all facilities essential for emergency response to ensure that they function following earthquakes. These facilities include fire and police stations, emergency communications centers, medical facilities, schools, shelters and other community-serving facilities.

7. Set priorities, and retrofit or replace vulnerable emergency- and community-serving infrastructure — including cellular communications, airports, ports, roads and bridges, transportation, water, dams and levees, sewage, and energy supplies — to ensure that functions can be resumed rapidly after earthquakes.

1906 Earthquake Centennial Alliance

EERI Earthquake Engineering Research Institute

DRC Disaster Resistant California

SSA

O.E.S

USGS Earthquake Scientists — A Nationwide Notion of Pride

John Solum

Title: Mendenhall Fellow, Earthquake Hazards Team

Location: Menlo Park, Calif.

Length of service with the USGS: 1 year

My proudest moment has definitely been working with the team of scientists from a large number of academic institutions, as well as the USGS, on the San Andreas Fault Observatory at Depth (SAFOD), which is part of the EarthScope project funded by the National Science Foundation.

The SAFOD hole successfully crossed the active San Andreas Fault at a depth of several kilometers this past summer. I spent the summer of 2005 driving between Menlo Park and the SAFOD site near Parkfield, Calif., spending a few days here and there at the drill site to lend a hand, and then driving back to Menlo Park to analyze samples using a powder X-ray diffractometer (a lot of people were also kind enough to ferry samples up to me from the drill site).

In Menlo Park, I also helped to prepare the sidewall and spot cores that came up from the hole, with the help of Sarah Draper (Utah State University), Sheryl Tembe (SUNY Stony Brook), Fred Chester (Texas A&M), Joe Svitek (USGS Menlo Park), Steve Hickman (USGS Menlo Park) and Dave Lockner (USGS Menlo Park). We devoted a lot of long hours to extracting the cores from the pieces of drilling equipment they were collected with and then preserving them, making thin sections from them and making a first pass at describing their mineralogy.

There were three sessions on SAFOD at the annual meeting of the American Geophysical Union in San Francisco in December 2005 (Naomi Boness, a post-doctoral student at Stanford University, and I were the conveners of those sessions). It was very heartening for me to see all of the effort that people had put into analyzing results from SAFOD pay off with a lot of really nice presentations at that meeting. I'm a newcomer to the SAFOD project, and I feel very privileged to have been able to work with so many highly dedicated scientists.

Not Just a California Thing

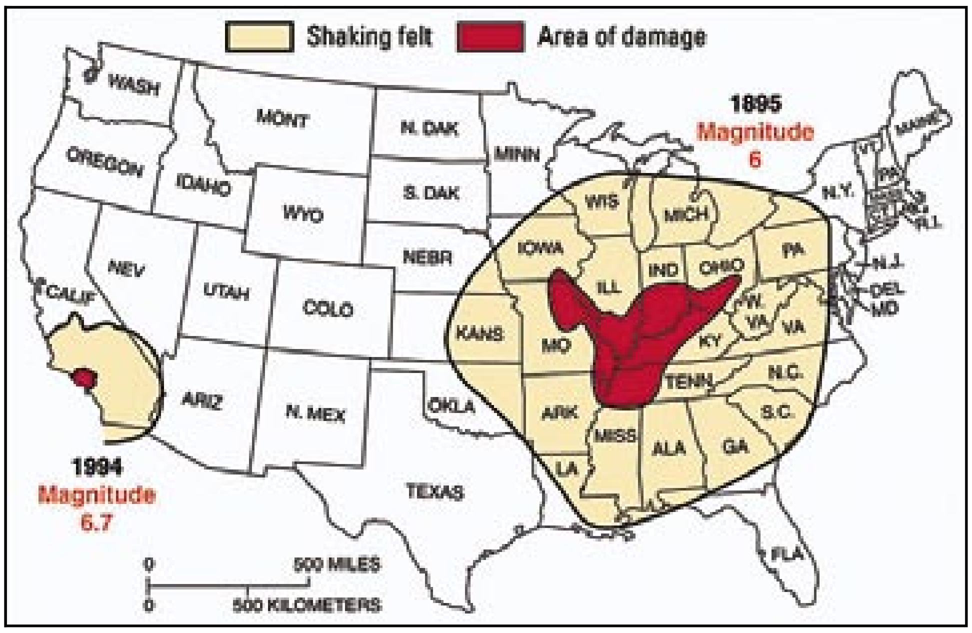
Why Earthquakes in the Eastern and Central United States could be a Bigger Problem than You Think

By Diane Noserale

Scientists estimate that Memphis has a 25 to 40 percent probability of a magnitude-6.0 or greater earthquake during the next 50 years. During the winter of 1811 to 1812, the central Mississippi River Valley was violently shaken by a series of earthquakes with magnitudes of 7.5 to 8.0. The area of strong shaking from these shocks was two to three times larger than that of the 1964 Alaska earthquake and 10 times larger than that of the 1906 San Francisco earthquake. And there's a 7 to 10 percent chance that an earthquake of this size will hit in the next 50 years.

The eastern United States is not generally regarded as "earthquake country." Yet, earthquakes do strike here. A look back shows that the eastern and central United States have a significant earthquake history, and there are factors that could make these areas of the country even more vulnerable than the West.

In November 1755, an earthquake with an estimated magnitude of 6.0, centered 25 miles off the coast of Cape Ann, Mass., heavily damaged Boston. In August 1886, a magnitude-7.3 earthquake hit Charleston, S.C., destroying most of the city. During the winter earthquakes of 1811 to 1812, observers reported that the ground rose and fell. Large waves were generated on the Mississippi River; high banks collapsed; and whole islands disappeared. Raised or sunken lands, fissures and large landslides



Earthquakes of similar size (1895 New Madrid Seismic Zone earthquake and 1994 Northridge earthquake) show how earthquakes in the central and eastern United States affect much larger areas than earthquakes in the West. Illustration by Eugene Schweig

covered an area of at least 30,000 square miles. Chimneys were toppled, and log cabins were thrown down as far away as Cincinnati, Ohio, and St. Louis, Mo. These earthquakes were felt throughout the eastern United States, rattling even the White House. President Madison and his wife were said to have thought a burglary was in progress.

Almost every state east of the Mississippi River has had at least one earthquake strong enough to cause damage, and a major earthquake seems to occur somewhere along the Eastern Seaboard about once every 100 years.

Earthquakes in the central and eastern United States are less frequent than in the western United States, but they affect much larger areas. For example, let's compare two earthquakes of similar strength: a magnitude-6.8 earthquake in the New Madrid Seismic Zone in 1895 and the magnitude-6.7 Northridge, Calif., earthquake in 1994. After the New Madrid earthquake, shaking was reported from Louisiana to Michigan and from Kansas to North Carolina. Shaking reports from the Northridge earthquake, however, were mostly limited to Southern California.

This strong contrast is caused by differences in geology east and west of the Rocky Mountains. Rocks in the eastern and central United States transmit earthquake waves more efficiently and for greater distances than those in the West.

This expansive shaking is a concern because of how shaking affects buildings and other structures. It has been said that earthquakes don't kill people, buildings do. A greater population density and an older stock of buildings and roads that have not been retrofitted for earthquake safety are a big concern. Building codes with strict provisions for earthquake-resistant construction of new buildings are less common in eastern and Middle America than in California and much of the West.

Another complication for earthquake science in the eastern United States is that faults here rarely break the ground surface. Although this is a good thing, it means that in many areas faults capable of hosting earthquakes have not been mapped or even identified. How frequently and how strongly earthquakes hit the area is, therefore, often unknown.

When it comes to earthquakes, one of the most important differences between the East and the West is the lack of awareness about earthquake hazards. Many people are unaware of the potential for a major earthquake to hit outside of California, and fewer still know what to do when one does hit. Whether in the East, the West or somewhere in between, all Americans should learn the earthquake risk for their area and incorporate earthquake preparedness into their overall disaster plan.

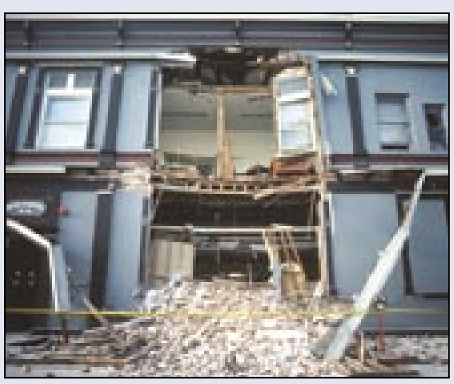
Written with assistance from Tania Larson

Forecast of Aftershock Hazard Maps Show Daily Shaking Probability

By Tania Larson

In the course of a day, the probability for moderate-to-strong earthquake shaking in California is between 1-in-10,000 and 1-in-100,000. That isn't very high when you consider that the average American has a one-in-2,500 chance of being in a car accident in the same period of time. However, there are times when the likelihood of experiencing earthquake shaking goes up considerably. The USGS 24-hour forecast of aftershock hazard maps show Californians when and where the risk is elevated.

Custom earthquake probability maps are available nationwide. Simply enter your ZIP code, the magnitude, and number of years you would like the probability to reflect; and the tool will return a map of your area. But the results are



Forecast of aftershock hazard maps show Californians the likelihood of strong aftershocks, which could destroy already damaged buildings. Photo: J.K. Nakata

based on a mean probability for random time periods.

The USGS and the Swiss Federal Institute of Technology, with additional funding from the Southern California Earthquake Center, have developed a way to quantify the current probability of shaking based on recent seismic activity — all the earthquakes recorded by the California Integrated Seismic Network, part of the USGS ANSS. [See page 22].

The aftershock forecast map, released in May 2005, shows the chance for strong shaking at any location in California within the next 24 hours.

"The only times probabilities become large enough to cause concern is after a significant earthquake that may have already caused damage," said Matt Gerstenberger, former USGS Mendenhall Fellow, when the maps were released. "Aftershocks are likely in this situation, and the new maps show where those aftershocks are most likely to be felt and how the hazard changes with time."

As a fault ruptures, it tends to stutter, like heavy furniture pushed along a hard floor. Sometimes, the first earthquake is a main event, followed by a series of aftershocks. At other times, it is a foreshock with a larger earthquake to follow. Either way, after the rumbles of one earthquake subside, there is a strong probability of more shaking to come. Within an hour of a damaging earthquake, there will likely be several aftershocks. The second day will often have half as many aftershocks as the first day.

Updated hourly, the forecast maps illustrate this change in the likelihood of experiencing shaking during earthquake sequences. Perhaps even more importantly, they take magnitude and distance into account and show where potentially damaging levels of shaking are likely to occur. Past sequences show that an increase in probability could be seen before about half of California's larger earthquakes.

Taking Seismic Science into the Third Dimension

3D Models Help Predict Shaking Vulnerability in Your Neighborhood

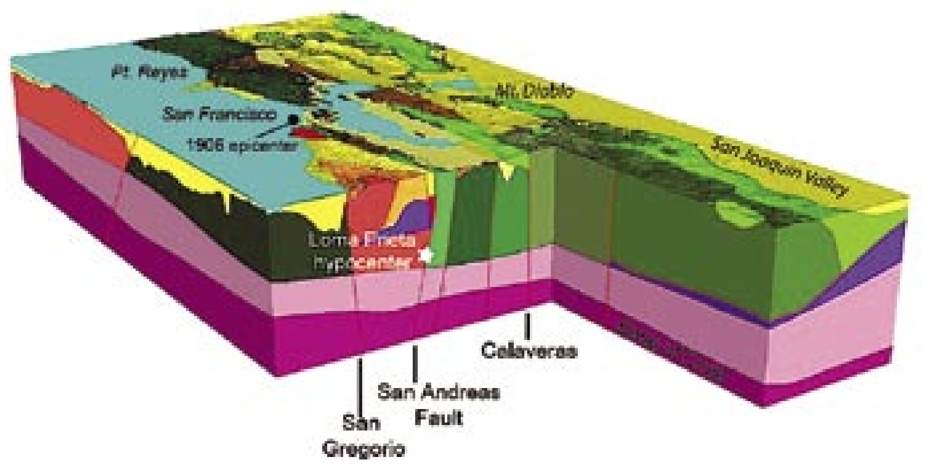
By Tania Larson

During the Loma Prieta earthquake in 1989, 42 people were killed when the Cypress Structure, the freeway approach to the Bay Bridge from Oakland, Calif., collapsed. But it wasn't just the strength of the earthquake that contributed to its fall. There were factors beneath the Earth's surface that made this location particularly vulnerable to earthquake shaking.

Remember the parable of the wise man who built his house upon the rock and the foolish man who built his house upon the sand? Well, the principle is still true today, and a new tool from the USGS is taking it to a whole new level. The USGS has created a 3D geologic map and seismic-velocity model of the upper 30 miles of the Earth's crust in the greater San Francisco Bay Area and much of Northern California.

"The new 3D model is a result of the long and productive collaboration between the California Geological Survey and USGS," said California state geologist John Parrish. "Its usefulness will be to test and predict the intensity and effects of shaking in future earthquakes and to build safer structures. This will be cost saving and life saving for residents of the Bay Area, now and in the future."

> **"For the first time, we have a tool that allows us to forecast the strong shaking likely to be produced by large Bay Area earthquakes on a neighborhood-by-neighborhood basis."**
>
> **— Tom Brocher**



Oblique view, looking from the southwest toward San Francisco Bay: The corner of the 3D Geologic Model has been cut away to show faults (red lines), basins (yellow) and other geologic rock units (various colors). By incorporating geologic features, scientists have created a powerful new tool to help protect people and their investments by showing where earthquake shaking is likely to be more intense.

Most loss of life and property damage during earthquakes stems from the effects of strong ground shaking, and scientists have shown that how long and how strongly a building will shake is directly influenced by the properties of the Earth beneath it. The Loma Prieta earthquake provided the first set of recordings of the levels of shaking on a wide variety of geologic materials, including soft, unconsolidated sand and clay.

These records clearly documented that ground shaking is much more violent on the soft sediments around the Bay margins than on bedrock. They also showed that differences in the Earth's crust can affect how seismic waves move through the ground. For example, at least two properties of the Earth's crust worked together to cause the collapse of the Cypress Structure. First, the structure was built on loose soils that shook much more strongly than surrounding regions on stronger ground. And second, there were variations in the thickness of the Earth's crust between the hypocenter and Oakland that actually focused energy toward Oakland and downtown San Francisco.

The 3D model is an important scientific advancement that combines 100 years of surface geologic mapping with decades of research into the seismic properties of rocks. It also incorporates information from boreholes and variations in the Earth's gravity and magnetic fields. In creating the model, scientists broke the upper 15 to 30 miles of the Earth's crust into irregular shaped blocks bounded by faults, making it a "fault and block" model. Since seismic waves can bounce off faults, bend and be focused as they cross faults, and be trapped and amplified in buried basins, the inclusion of subsurface faults and basins provides important information.

By pulling all of this information together, the model developers have created a powerful new tool for earthquake science. "We expect this new 3D model to revolutionize our ability to forecast the location of 'hotspots' — where shaking occurs most intensely — throughout the Bay Area," said Tom Brocher, USGS seismologist and co-developer of the model. "For the first time, we have a tool that allows us to forecast the strong shaking likely to be produced by large Bay Area earthquakes on a neighborhood-by-neighborhood basis."

In addition to helping researchers forecast strong ground motions that may damage buildings, essential infrastructure and levees, the 3D model will help locate earthquakes more accurately; predict where destructive liquefaction of the ground may occur; and model permanent ground deformation that may be produced by earthquakes, including ground subsidence that could cause flooding. The 3D geologic map was also built with the flexibility to serve other needs in the future. Researchers are already using it to study what happens when the crustal plates that meet in California move slowly past each other, and future refinements will help scientists study groundwater movement and toxic contaminant dispersion.

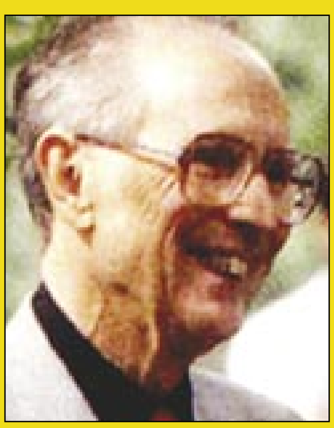
This information will help not only scientists, but residents, lawmakers and building designers. Chris Poland, president of Degenkolb Engineers, said, "The 3D velocity model will provide a much more detailed definition of the intensity of shaking."

With more detailed information, builders will have a better idea of how to tailor construction to fit the location, protecting people and their investments.

"There are hundreds of billions of dollars of new construction each year in high seismic regions," said Poland. "The more we can design for the proper amount of strength and durability, the more we can achieve cost efficiencies, perhaps in the billions, while giving people greater safety during a large, damaging earthquake."

USGS developers of the model include Thomas Brocher, Robert Jachens, Russell Graymer, Carl Wentworth, Bradley Aagaard and Robert Simpson.

USGS Earthquake Scientists — A Nationwide Notion of Pride



Jack Townshend

Title: Special Projects Coordinator, USGS Geomagnetism Group

Location: Fairbanks, Alaska

Length of service with the USGS: 33 years

I remember the magnitude-9.2 Good Friday earthquake in Alaska on March 27, 1964. I was chief of the U.S. Coast and Geodetic Survey's Geomagnetic and Seismological Observatory at the University of Alaska, Fairbanks (The Observatory was transferred to the USGS in 1973.)

The house my family and I lived in was on the observatory grounds. We were 300 miles from the earthquake's epicenter, but I remember feeling the shaking and hearing the observatory's earthquake warning alarms. I rushed to the instrument room and saw red ink splashed all over the place. Visual seismographs used at the time had inkwells, and the instruments had been shaken off their piers. The magnetic instruments were also askew. I called in the staff, and a few hours later, we had most of the instruments back up and working.

Later that night, I made a decision to do a preliminary intensity assessment in the Anchorage area. I managed to get on a flight chartered to fly doctors from Fairbanks to Anchorage to assist with medical care. We couldn't land until daylight because the airport tower was down and much of the runway was damaged. When we finally landed, I flagged down a car and driver and asked for a ride into town. The driver was a chief flight engineer with a major airline whose commercial jet had been grounded because of damaged runways. He volunteered to drive me around Anchorage and outlying areas to assess the damage and take photos.

After assessing the damage from the ground, we stopped at a useable airstrip, and I asked for a piloted plane to survey the landscape even further out and from the air. I was told that if I could find a pilot, they would lend me an airplane. Fortunately, I had a pilot with me! We flew around for a few hours taking photos and assessing the damage until the FAA restricted the airspace we were flying and instructed us to land.

The results of this and subsequent assessment trips were published by the Alaska Division of the American Association for the Advancement of Science, 1964 Proceedings of the Alaskan Science Conference held at The University of Alaska in Fairbanks, titled, Preliminary Intensity Evaluations of the Prince William Sound Earthquake of March 28, 1964, U.T.

A Guidebook to the San Andreas

Geology Fieldtrips on the World's Most Famous Fault

By Clarice Nassif Ransom

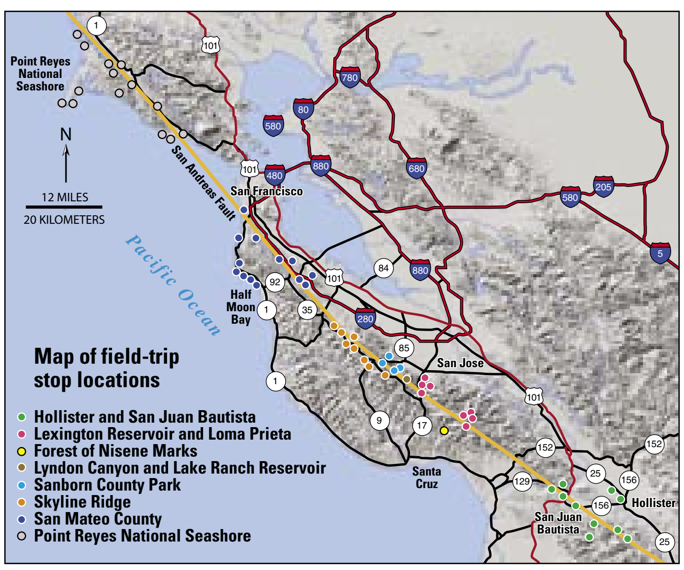
USGS scientist Philip W. Stoffer leads a public field trip in Sanborn Park on the San Andreas Fault. (Photo by Leslie Gordon)

When Philip W. Stoffer, geologist for the USGS in Menlo Park, Calif., learned he had lymphoma, or cancer of the lymph system, in 2004, he was not sure if he was going to live. The statistics for surviving were grim. He knew he had to do whatever he could to try to survive.

For four months during the summer of 2004, Stoffer underwent rounds of chemotherapy and a stem cell implant while in isolation at the Seattle Cancer Care Association. At the same time, he authored a first draft of *Where's the San Andreas Fault? A Guidebook to Tracing the Fault on Public Lands In the San Francisco Bay Region*, which was unveiled in April by USGS and the National Park Service (NPS).

The book features more than 50 destinations along the 800-mile fault, including 20 different hiking trips in national and local parks. Stoffer wrote the field guide as part of cancer survival therapy and to encourage people to live life, not just through maps, books, television or the Internet, but in person.

"Phil was hospitalized for weeks during the transplant," said Stoffer's good friend and colleague John Vogel, a USGS scientist in Tucson, Ariz., who spent many weeks with Stoffer during his recovery. "He worked every day, except for the a few days when he was most sick from the chemotherapy. I don't mean eight hours a day. If he was awake, he was working. It was amazing. He wasn't watching TV. He wasn't reading books or magazines. He was working. I would say that having something productive to do, to focus on, was therapeutic — make that incredibly therapeutic."



"I love to hike and explore," said Stoffer. "The whole experience of having cancer changed my outlook on life. I am someone who was not just treated for cancer, but cured from cancer. I had to give something back. You never know how much time you have left, and I had all of these pictures of different places along the San Andreas Fault that I had compiled over the years and a project I was going to get to, 'one day.' When I was in the hospital, I was motivated to write the book and get it done. I had a field trip to go on when I got out of the hospital."

Stoffer encourages everyone to see an aspect of the San Andreas Fault in person. The field guide provides detailed information about the geologic diversity of the landscape and also describes the cultural and historical aspects of the area. Loaded with colorful photographs and detailed road maps, the guide describes the natural setting in which Bay Area residents live. The guide should interest a wide spectrum of the public, from serious hikers and geology students, to casual strollers and earth science novices.

"The National Park Service relies on the organizations like the U.S. Geological Survey to provide scientific information to help make informed decisions and to help educate the public," writes Don Neubacher, park superintendent, Point Reyes National Seashore, in the preface to the guidebook. "This field guide is an example of collaboration between the two federal agencies. Our hope is that this guidebook will help enrich public understanding and encourage exploration of our natural and cultural heritage."

"The [guidebook] is the best thing since the invention of ice cream!" said David Boore, a docent with the Midpeninsula Regional Open Space District. "This publication is a fantastic resource for those interested in the geology of the San Francisco Bay Area. It's well-written, detailed, up-to-date, includes useful background information about earthquakes and faults, contains lots of color photos and maps, and the price is right."

Tom Brocher, a seismologist with the USGS, added, "This guidebook is a great educational resource for learning about the geology and natural environment along the coast in the Bay Area. What I love about the guidebook is that it offers several different tours of the San Andreas Fault that cater to diverse educational interests and hiking abilities. Everyone can find something of interest in it."

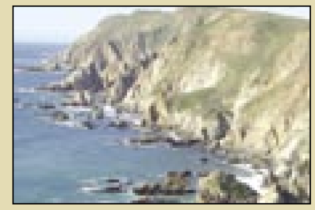
The release of the guidebook also coincides with the 100th anniversary of the Great San Francisco Earthquake. On April 18, 1906, the earth ruptured for about 300 miles along the San Andreas Fault through Northern California, both on land and where the fault extends offshore. The earthquake and fires that followed caused catastrophic damage to cities and towns throughout the region and had a dramatic impact on the culture and history of California. The event also initiated national interest in the study of earthquakes and disaster prevention. The field guide can be accessed online at http://pubs.usgs.gov/gip/2006/16/.

Story written with contributions from Tom Brocher.

Stoffer's Favorite Bay Region Places to Visit:

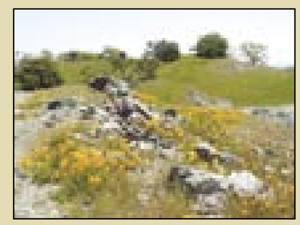
The High Peaks area within Pinnacles National Park.

■ **Pinnacles National Monument** (San Benito and Monterey Counties) — This monument features high, rugged mountain scenery (an ancient volcano), boulder-covered slot canyons and many miles of well-maintained hiking trails.



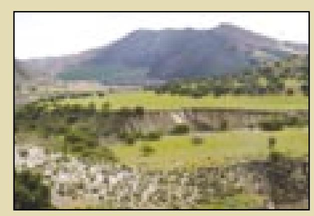
Point Reyes Headlands in Point Reyes National Seashore.

■ **Point Reyes National Seashore** (Sonoma County) — This national park features unrivaled coastal sea cliffs and coastal prairie scenery.



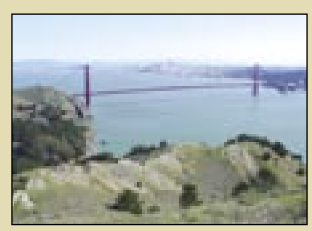
California poppies growing near the top of Mount Wilson in Henry Coe State Park.

■ **Henry Coe State Park** (Santa Clara County) — This is the second largest state park in California and has hundreds of miles of trails throughout the central Diablo Range.



The valley of the Arroyo Seco Canyon in the Ventana Wilderness.

■ **Arroyo Seco Canyon** (Ventana Wilderness, Monterey County) — This wilderness area features a perennial stream that cuts through gorges in the Santa Lucia Range. The lower valley usually has unrivaled spring wildflowers.



The Marin Headlands portion of Golden Gate National Recreation Area.

■ **Marin Headlands, Golden Gate National Recreation Area** (Marin County) — This park provides spectacular views of the San Francisco Bay and has many miles of excellent hiking and riding trails.

Elkhorn Slough harbors the largest tract of tidal salt marsh in California.

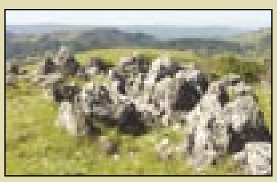
■ **Elkhorn Slough** (Santa Cruz and Monterey County) — This is a kayaking, wildlife-viewing wonderland.

The seacliffs at Cove Beach in Año Nuevo State Park.

■ **Año Nuevo State Park** (San Mateo County) — Año Nuevo is host to large seasonal population of elephant seals and other marine mammals, and also has scenic beaches and access to coastal mountain hiking.

The rugged sea cliffs along the coast trail in Wilder Ranch State Park.

■ **Wilder Ranch State Park** (Santa Cruz County) — This park has many miles of hiking and riding trails, including trails along an undeveloped 4-mile stretch of sea cliffs.

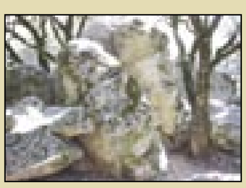


The outcrops of limestone on the top of Black Mountain.

■ **Black Mountain** (Mid Peninsula Open Space Preserve, San Mateo County) — This is an exceptional hiking area within the central Santa Cruz Mountains.

Two large, fire-scorched Coastal Redwoods in Big Basin State Park.

■ **Big Basin State Park** (Santa Cruz County) — This has a relatively untouched stand of great coastal redwoods, but the park also has many miles of hiking trails that extend from the crest of the Santa Cruz Mountains, near Castle Rock State Park, to the coast at Año Nuevo.

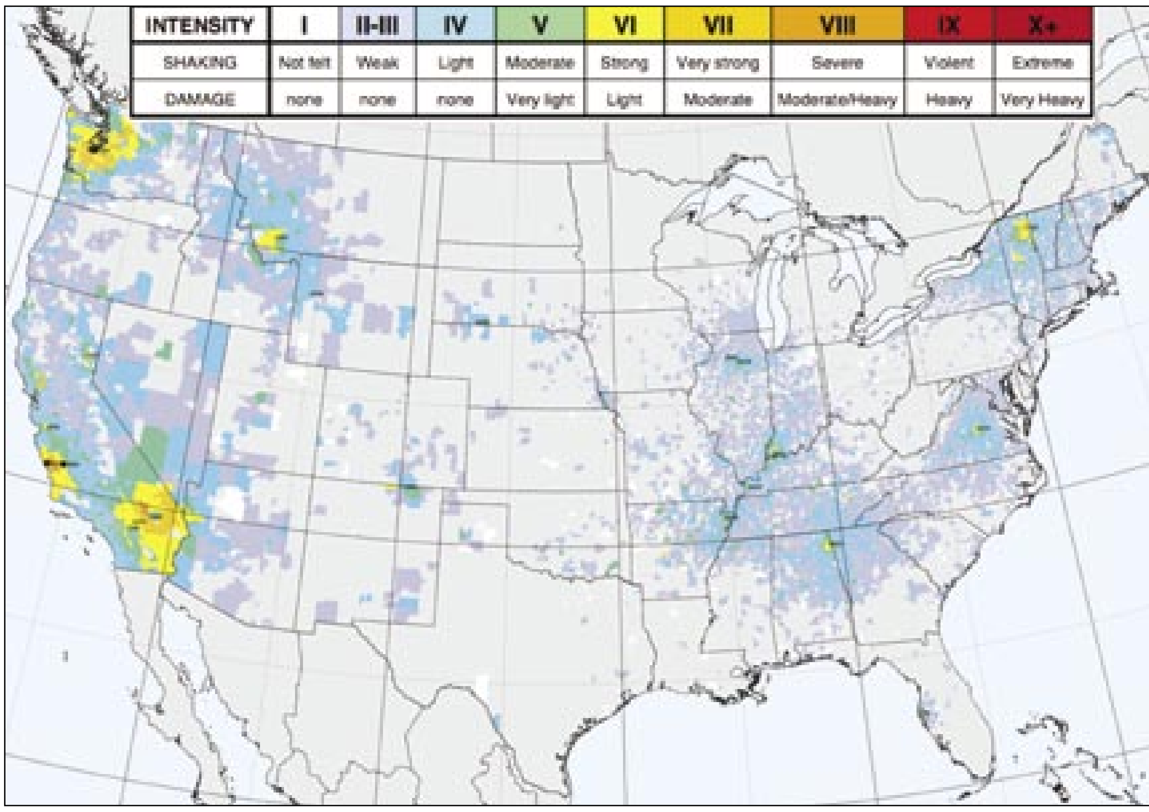


One of the unusual rock formations along the trail system at Castle Rock State Park.

■ **Castle Rock State Park** (Santa Clara and Santa Cruz Counties) — This park straddles the crest of Castle Rock Ridge in the central Santa Cruz Mountains and provides exceptional hiking and rock-climbing opportunities.

Did You Feel It?

Citizen Science Goes Seismic



This map shows responses for ZIP codes in the conterminous United States since Did You Feel It? started. More than 500,000 individual responses have been measured. Earthquakes have been felt in all 50 states and in the U.S. territories.

By Heidi Koontz and David Wald

Have you ever been through an earthquake? Did you know that reporting your experience during an earthquake can help save lives and property during future quakes?

As a result of work by USGS with the cooperation of various regional seismic networks, the world can log in on the Internet and tell USGS scientists what they felt during an earthquake.

By logging on to the USGS Earthquake Hazards Program Web site (http://earthquake.usgs.gov) and clicking on the "Did You Feel It?" link, the public can help provide information about the extent of shaking and damage during earthquakes. These "citizen scientists" may also provide specific details about how their area may respond to future earthquakes.

Did You Feel It? and ShakeMaps have revolutionized the way earthquakes are reported and how emergency responders take action.

USGS scientist David Wald knew these tools could help communicate post-earthquake information. But when he wrote a computer program on a whim in the late '90s, he had no idea how pivotal these instruments would become to citizens, a.k.a. Net-izens, and emergency responders.

"We wanted to make the science tangible and allow the users to tell us in simple terms how the quake impacted them, so we could in turn create something user-friendly for emergency personnel to rely upon," said Wald, who created the software along with Vincent Quitoriano and James Dewey.

As a result of work by USGS with the cooperation of various regional seismic networks, the world can log in on the Internet and tell USGS scientists what they felt during an earthquake.

Not too long ago, the first thing that most people did after feeling an earthquake was to turn on their television or radio for information. Recently, more and more people turn to the Internet instead, not only to obtain information, but also to share their experience of the earthquake.

Users enter their ZIP code and answer a list of questions, such as, "Did the earthquake wake you up?" and "Did objects fall off shelves?" These responses are compiled into a database, and within minutes, a map to take shape on the Internet. In a couple of hours, with several thousand responses at times, a Community Internet Intensity Map shows where and how strongly the earthquake was felt and where damage has been reported.

The maps are then continuously updated as additional data are received. Did You Feel It? Summarizes the responses, and an intensity value is assigned to each ZIP code received. The intensity may change as more questionnaires are submitted, and the map reflects these modifications. ZIP code areas are color-coded according to the intensity scale that accompanies the map. From the user's perspective, Did You Feel It? is interactive, providing instantaneous feedback on the individual's intensity along with a link back to the maps.

During the past five years, more than 500,000 reports for earthquakes ranging from magnitude 2.0 (New Jersey, April 2004) to magnitude 7.9 (Alaska, December 2001) have been logged via the Did You Feel It? Web site. Events have been felt in every state in the nation, as well as in Puerto Rico, Guam, the Virgin Islands and other U.S. territories. What's more, other phenomena, often initially perceived as earthquakes, have been widely reported with Did You Feel It?, including sonic booms from the space shuttle, other supersonic aircraft and even meteors! Recently, the system went worldwide; and numerous responses for earthquakes felt around the globe, including reports within thousands of miles of the magnitude-9.1 2004 great Sumatra tsunami earthquake, were documented.

Putting Down Roots in Earthquake Country

Are You Prepared for "The Big One"?

By Tania Larson

Earthquakes are scary because they are largely unpredictable. We don't know exactly when, where or with how much force they are going to strike, but we do know they will strike again. It's easy to feel powerless in the face of such information, but there are several things you can do to protect yourself and your loved ones. In fact, preparedness is key to survival.

"Putting Down Roots in Earthquake Country," developed by the USGS and numerous partners, contains a wealth of earthquake information. There are two versions of the handbook, one for Northern California and one for Southern. Both provide information to help you prepare for, survive and recover from future earthquakes.

"All Californians need to be made aware of earthquake hazards and how to survive them," said California state geologist John Parish. "This handbook is a valuable primer for preparedness."

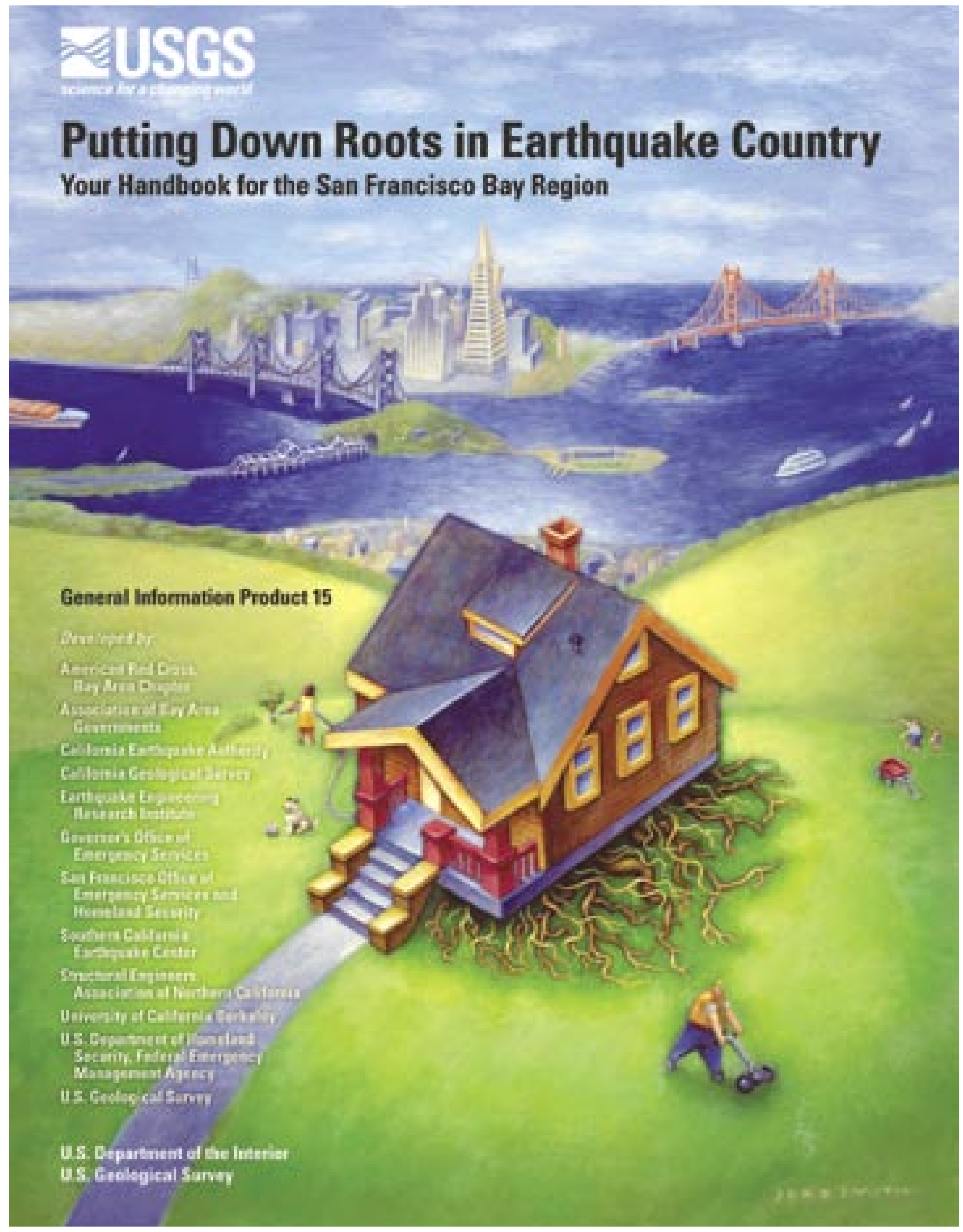
Because earthquakes can strike previously unknown faults, even those who don't believe they are in an earthquake-prone area could benefit from the handbook's clear explanations and practical advice.

The handbook contains seven steps to earthquake safety and is filled with recommendations you can start on today. One tip is to make sure areas where people sit or sleep are clear of dangerous items — bookcases, glass picture frames and other heavy objects — that could fall during an earthquake. Other tidbits of wisdom are to prepare your loved ones for earthquakes by making disaster kits, practicing earthquake safety with children, and making sure you don't forget Fido and Fluffy in your disaster-preparedness plan.

So, what do you do when the earth actually starts shaking? — "Drop, Cover and Hold On."

About the Handbooks

These practical guides to earthquake survival are the result of many groups coming together to meet a public need. When a magnitude-6.9 earthquake struck Loma Prieta, Calif., on October 17, 1989, it caused extensive damages and took many lives. Many people, having seen the destructive power of earthquakes but still having little understanding of how to protect themselves, came out of the event with an overly heightened sense of fear; others thought they had survived "the big one" and came out with an overly heightened sense of safety. However, this earthquake, though strong and damaging, had only released 3 percent of the energy of the "Great 1906 Quake" and was not "the big one" that scientists believe is likely to occur in the area. Something needed to be done to give residents both a realistic understanding of the dangers and knowledge of the things they should do to protect themselves.



"Putting Down Roots" cover art by Jere Smith.

Peter Ward, now retired, was a USGS seismologist at the time of the Loma Prieta earthquake. He said, "While we in the geosciences were studying the scientific causes and effects of Loma Prieta, those in the social sciences asked us how we could help them educate the public to be better prepared for future earthquakes that we told them would surely happen." In response, Ward contacted Red Cross officials and offered to write a booklet explaining why and how frequently earthquakes occur in the San Francisco Bay area and what people could do to prepare to survive future earthquakes.

The Red Cross and other disaster-relief agencies pitched in the funds to produce the booklet, and three months later, "The Next Big Earthquake In the Bay Area May Come Sooner Than You Think — Are You Prepared?" was published. With a pressrun of ultimately more than 3 million copies, this helpful, easy-to-read booklet became the most widely distributed publication ever prepared by the USGS.

The magnitude-6.7 Northridge earthquake in 1994, created the need for a book targeting the southern part of the state, and "Putting Down Roots in Earthquake Country — Your Handbook for Living in Southern California" was produced. The handbook was first written in 1995 by Lucy Jones, USGS scientist-in-charge for Southern California. She said, "It took a year of my life but was extremely satisfying. I was able to bring my understanding of earthquakes to many people and reduce fear and empower change."

Two million copies were printed and distributed between 1995 and 2003. For the 10th anniversary of the Northridge earthquake, Jones teamed up with Mark Benthien, of the Southern California Earthquake Center, to update the handbook.

Shortly after the Southern California edition was updated, a version for Northern California was underway, and "Putting Down Roots in Earthquake Country — Your Handbook for the San Francisco Bay Region" was published in 2005.

The creation and distribution of these booklets has been a phenomenal collaborative effort, bringing federal and state agencies, private companies, nonprofit organizations and the media together to

"Putting Down Roots" is full of helpful hints to protect you, your loved ones and your property from earthquake hazards. This cutaway diagram shows how weak cripple walls can be strengthened with properly attached plywood sheets.

identify and meet the needs of local communities.

Zoback said, “The amazing thing about ‘Roots’s’ Northern California version was the coming together of all the groups and agencies in the greater Bay Area with ‘ownership’ of the earthquake problem — science, engineering and emergency response. The best thing about the effort was that it was a true team collaboration, all 12 groups listed on the cover as authors actually contributed to the writing in a significant way.”

This edition of the handbook is part of the 1906 Earthquake Centennial Alliance effort, and thanks to the Pacific Gas & Electric (PG&E) Foundation, plans for the handbook now include translation into Spanish and several Asian languages.

When the new version was released, Harold Brooks, CEO of the Red Cross Bay Area Chapter, said, “The American Red Cross will be working over the next three years to get more than 1 million additional families in the Bay Area prepared for a large earthquake. This handbook will play an important role in our training efforts.”

On September 18, 2005, booklets were distributed to more than 500,000 readers in the Sunday edition of the *San Francisco Chronicle*. On April 9, 2006, the handbook was sent to more than 1 million readers with the Sunday *Los Angeles Times*, and upon completion, the forthcoming Spanish version will be included in *Oy*, the *LA Times*’ Spanish language daily.

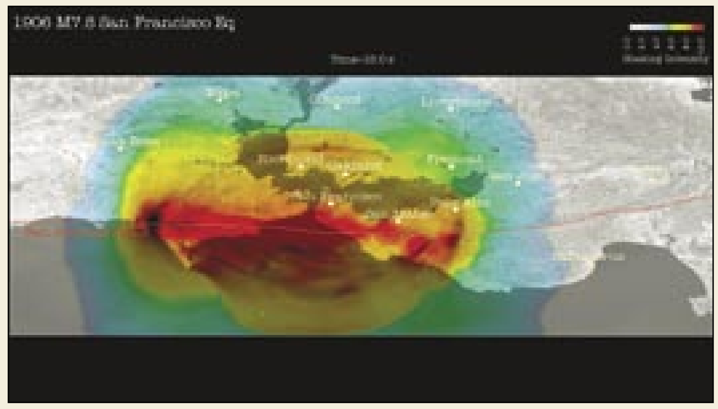
“The real story of the success,” Zoback said, “is the amazing continued demand for the booklet.” The San Francisco General Hospital requested 5,000 copies for their employees. The Solano County Jail requested 200 for concerned inmates. But Zoback thinks the best compliment came from former ambassador and *Sunset Magazine* publisher William (Bill) Lane. She said, “Bill called and said he loved ‘Roots’ and wanted to give a copy to every household in his town, Portola Valley. He drove his station wagon to our office, and we loaded up 21 boxes (2,100 copies!) in the back. He then took them to the Menlo Park post office where he paid to have the postmaster deliver one to every household in Portola Valley.”

A Web site was created that allows people to order up to 10 copies of the handbook, and Zoback is happy to report that many people are ordering multiple copies. She said, “We were sending them to auto body shops, beauty shops, etc. — absolutely the best type of grass roots distribution, folks giving them to folks they care about.”

If you would like copies for yourself and loved ones, visit http://pubs.usgs.gov/gip/2005/15 or call the Red Cross at (510) 595-4459 for the Northern California Handbook. For the Southern, go to http://www.earthquakecountry.info/.

A Profusion of Products and Events for the 1906 Earthquake Centennial

In addition to those already mentioned in this publication, the U.S. Geological Survey is involved with a number of products and several events commemorating the 1906 centennial, many of which are listed below. Please continue to visit http://earthquake.usgs.gov/regional/nca/1906/ for more information.



A 1906 ground-shaking simulation shows how the earthquake spread from its epicenter, about two miles west of the San Francisco Zoo, and grew to cause strong shaking and damage along more than 300 miles of the San Andreas Fault.

PRODUCTS

The USGS Gives Tours of the 1906 San Francisco Earthquake — This USGS tour offers a variety of information, from ground-shaking maps and fault locations to historic photographs and quotes from those who were actually there. This tour uses Google Earth™, a computer program that combines satellite imagery with geospatial information to allow users to view and interact with actual images of the Earth’s surface in three dimensions.

The USGS Gives a Virtual Tour of the Hayward Fault — This is a Web-based strip map. This tour offers a virtual helicopter tour of the Hayward Fault with parcel scale resolution so that property owners can locate their land.

Two New USGS Maps Identify San Francisco Bay Area Liquefaction Risk — The first of these products is a new map of the young geologic deposits in the low-lying sections of the Bay Area. Some of these areas can undergo liquefaction, the phenomenon in which saturated soils lose their stiffness and strength during shaking, and some can greatly increase the severity of shaking that is transmitted through the deposits.

The second of the map products, derived from the first map, shows the likelihood that these young deposits will liquefy due to the strong shaking a big earthquake will produce.

Two New USGS Maps Show the Bay Area’s Active Faults and Geologic Materials — The first of these products is a new map of the known Quaternary-active faults in the Bay Area that have pushed up mountains and generated earthquakes over the past 2 million years.

The second product is a new map of the geologic materials and structures of the Bay Area.

USGS Partnership Puts Curriculum Into the Classroom — The USGS has created two new educational resources to help teachers explain earthquake science.

“Earthquake Science Explained” highlights how scientists study earthquakes, what evidence they collect and what they have learned since the 1906 Earthquake.

“Living in Earthquake Country: A Teaching Box,” a newly released online earthquake hazard resource, provides teachers with lessons including fully developed hands-on earthquake curriculum, teaching points and easy-to-reproduce handouts.

The USGS Unveils New Digital Map to Show Active Portions of the San Andreas Fault near San Francisco to Help the Public Be Better Prepared for Earthquakes — This is the first-ever comprehensive digital strip map of the San Andreas Fault on the San Francisco peninsula. The map features new, more accurate mapping of the 1906 fault rupture and also includes digital versions of previous paper-only maps along with earthquake reports from the 1906 earthquake, designated fault hazard zones, trenches and historical photos.

EVENTS

April 18

“Shock Waves: 100 Years After the 1906 Earthquake” — The USGS’ Steve Wessels hosts this one-hour documentary, scheduled for prime time on San Francisco Bay Area CBS affiliate KPIX Channel 5.

April 18-22

The International Earthquake Conference — The conference will focus on the 1906 earthquake, a century of progress in earthquake science and engineering and the likely impact of future earthquakes in the Bay Area. Organized by Disaster Resistant California, the Seismological Society of America and the Earthquake Engineering Research Institute.

April or May

Meet the Hayward Fault Face to Face — The USGS will host “The Hayward Fault — An Interpretive Viewing and Educational Exhibit” along the Hayward Fault, near Sailway Drive at Central Park in Fremont, Calif.

The exhibit will feature a 12-to-15-foot-deep trench across the Hayward Fault in Fremont. The fault is easily visible within the sediments at this location, and visitors will be encouraged to descend a staircase to meet the Hayward face to face. For safety reasons, the trench walls will not be vertical, and the space will not feel too confining.

Recreation of the Famous 1906 Kite Photograph of San Francisco After the Earthquake and Fire — The Drachen Foundation and the USGS’ Scott Haefner recreate photographer George Lawrence’s famous aerial image of San Francisco, taken from a kite three weeks after the earthquake and fire of 1906.

Late May/Early June

USGS Open House in Menlo Park — This is an opportunity for the public and partners to see displays of USGS research and talk to scientists about their work in a variety of fields. A special earthquake tent will focus on 1906 and other topics. There will also be interactive displays and activities for adults and children.

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