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

By David Hebert

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.

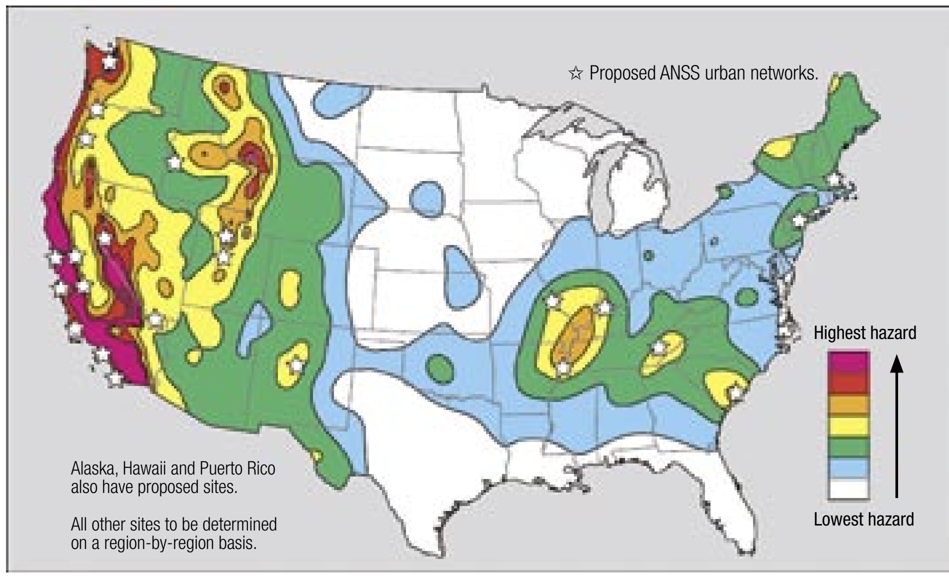
John Ebel, a professor of geophysics at Boston College and northeast coordinator for ANSS implementation, estimates that damaging earthquakes (magnitude 5 or greater) happen in New England every 50 to 60 years. In 1940, there was a magnitude-5.5 quake in New England, and the clock is ticking.

"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,

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.

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.

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 ultimate goal of the ANSS is to save lives, ensure public safety and reduce economic losses."

— Bill Leith

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

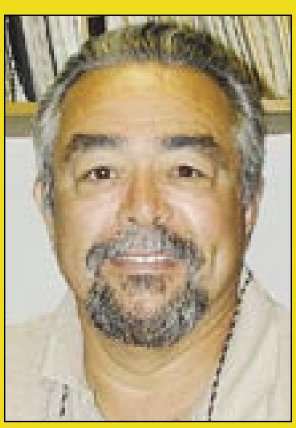
- **Recent Earthquakes** — Automatic maps and event information are available within minutes online at the USGS Earthquake Hazards Program Web site, which displays earthquake locations nationwide.
- **Did You Feel It?** – This is a citizen science Web page where shaking intensity maps are created by 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 — 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).

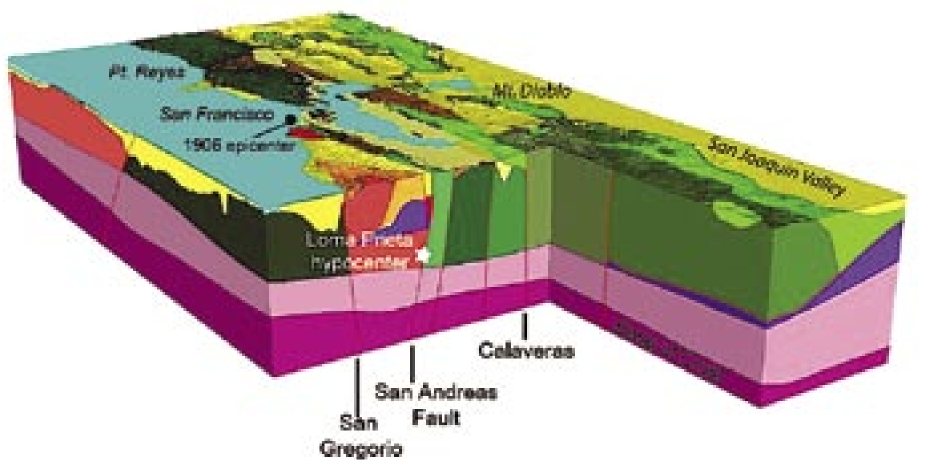
In Menlo Park, I also helped to prepare the sidewall and spot cores that came up from the hole, with the help of Sarah Draper (Utah State University), Sheryl Tembe (SUNY Stony Brook), Fred Chester (Texas A&M), Joe Svitek (USGS Menlo Park), Steve Hickman (USGS Menlo Park) and Dave Lockner (USGS Menlo 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.

Taking Seismic Science into the Third Dimension

3D Models Help Predict Shaking Vulnerability in Your Neighborhood

By Tania Larson



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.

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**

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.

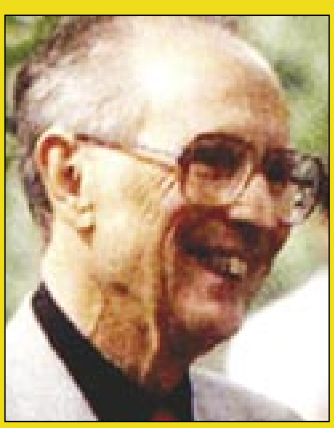
This information will help not only scientists, but residents, lawmakers and building designers. Chris Poland, president of Degenkolb Engineers, said, "The 3D velocity model will provide a much more detailed definition of the intensity of shaking."

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.