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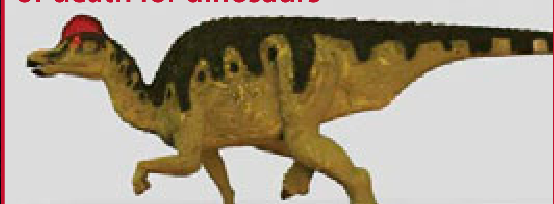

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FEATURE

THE THIRSTY DRAGON AND THE WEALTHY BEAR:
HOW CHINA, RUSSIA AND HIGH OIL PRICES INFLUENCE GLOBAL DYNAMICS

Russia and China are changing the terms of energy geopolitics, and in the process, changing everyone's place in the world. The first article in a two-part series examines the ways China asserts its influence in the global energy market and the implications for U.S. foreign policy and energy security.
Lindsey Bartlett and Michael E. Webber

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THE CAUSE OF CHINA'S DEVASTATION:
AFTER THE QUAKE

In the month following the May earthquake in China, two research teams traveled to the region to observe the devastation, with the hopes of lending their expertise to help rebuild. The teams provide firsthand accounts and sobering pictures of their experiences.
Sarah Bahan and Walter Mooney; Jian Guo Liu and Timothy Kusky

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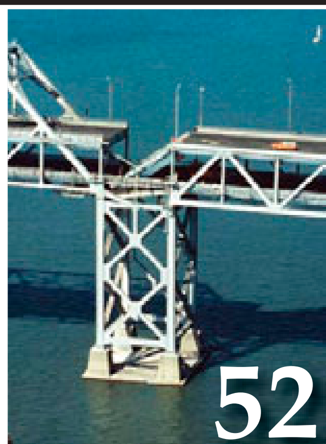
FEATURE

AT FIRST JOLT

Researchers cannot predict when and where the next earthquake will strike, but they can provide a few seconds to prepare before severe shaking starts. Such early warning systems can provide enough time to stop trains, close bridges and shut down utility plants.
Richard Allen



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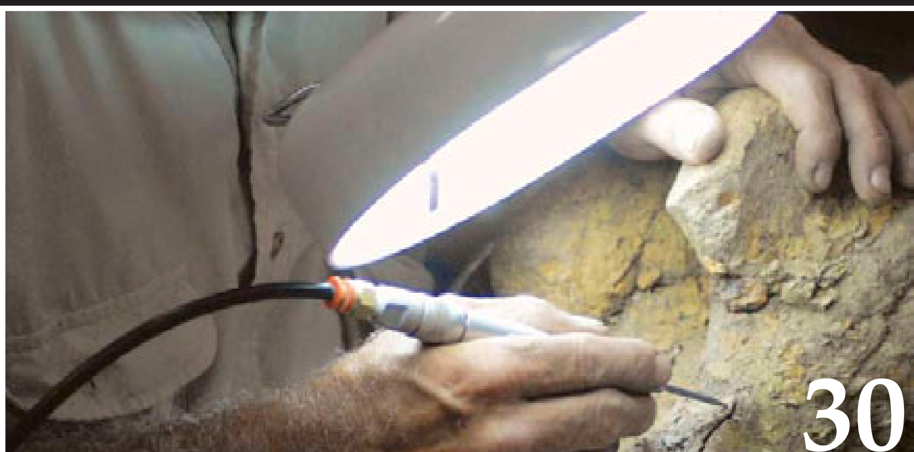
TRENDS AND INNOVATIONS

JURASSIC MED SCHOOL

You might be surprised to learn that many doctors teaching anatomy at medical schools are actually paleontologists, not physicians. But the growing trend of paleontologists and anthropologists staffing the faculties of med schools shouldn't be surprising: After all, one vertebrate isn't that different from another.
Mary Caperton Morton



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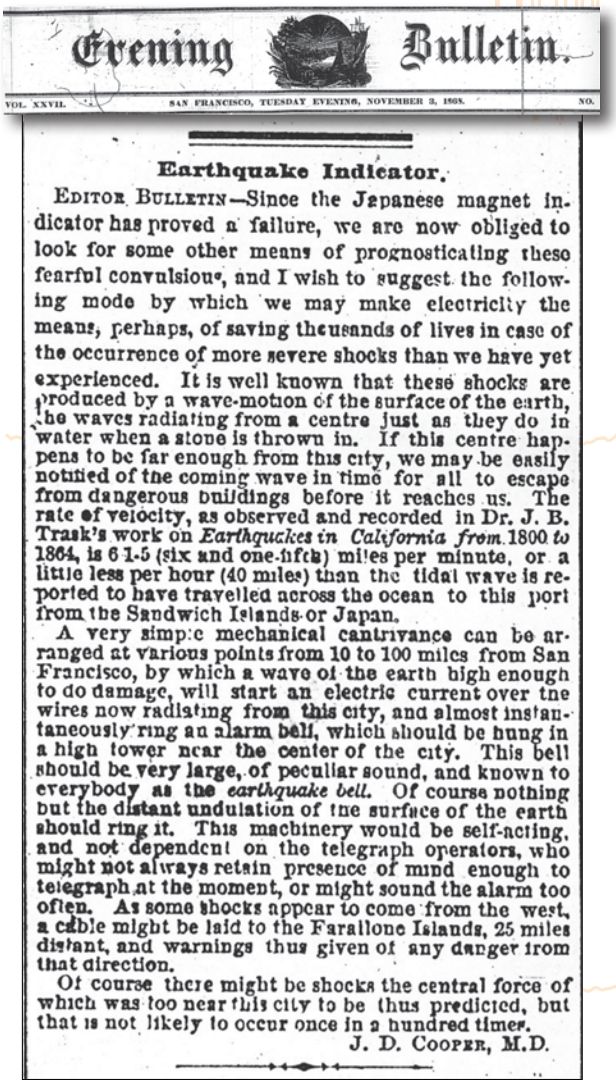
Bottom: Judd McCullum; middle left: Sarah Bahan; middle right: U.S. Geological Survey Photographic Library; Top: Nicolle Rager Fuller

ON THE COVER: The bear (Russia), the dragon (China) and Uncle Sam (the United States) play poker with oil and coal. Illustration by Nicolle Rager Fuller, Sayo-Art Science Illustration. Inset: Drew Lee/Ohio University

AT FIRST JOLT

Will we have warnings for the next big EARTHQUAKE?

Part of the San Francisco-Oakland Bay Bridge collapsed during the Loma Prieta earthquake on Oct. 17, 1989.



Evening Bulletin.

VOL. XXVII. SAN FRANCISCO, TUESDAY EVENING, NOVEMBER 3, 1868. NO.

Earthquake Indicator.

EDITOR BULLETIN—Since the Japanese magnet indicator has proved a failure, we are now obliged to look for some other means of prognosticating these fearful convulsions, and I wish to suggest the following mode by which we may make electricity the means, perhaps, of saving thousands of lives in case of the occurrence of more severe shocks than we have yet experienced. It is well known that these shocks are produced by a wave-motion of the surface of the earth, the waves radiating from a centre just as they do in water when a stone is thrown in. If this centre happens to be far enough from this city, we may be easily notified of the coming wave in time for all to escape from dangerous buildings before it reaches us. The rate of velocity, as observed and recorded in Dr. J. B. Trask's work on *Earthquakes in California from* 1800 *to* 1864, is 6 1-5 (six and one-fifth) miles per minute, or a little less per hour (40 miles) than the tidal wave is reported to have travelled across the ocean to this port from the Sandwich Islands or Japan.

A very simple mechanical contrivance can be arranged at various points from 10 to 100 miles from San Francisco, by which a wave of the earth high enough to do damage, will start an electric current over the wires now radiating from this city, and almost instantaneously ring an alarm bell, which should be hung in a high tower near the center of the city. This bell should be very large, of peculiar sound, and known to everybody as the *earthquake bell*. Of course nothing but the distant undulation of the surface of the earth should ring it. This machinery would be self-acting, and not dependent on the telegraph operators, who might not always retain presence of mind enough to telegraph at the moment, or might sound the alarm too often. As some shocks appear to come from the west, a cable might be laid to the Farallone Islands, 25 miles distant, and warnings thus given of any danger from that direction.

Of course there might be shocks the central force of which was too near this city to be thus predicted, but that is not likely to occur once in a hundred times.

J. D. COOPER, M.D.

Following the 1868 Hayward earthquake in San Francisco, Calif., J.D. Cooper, a medical doctor, suggested erecting an earthquake early warning network.

Richard Allen

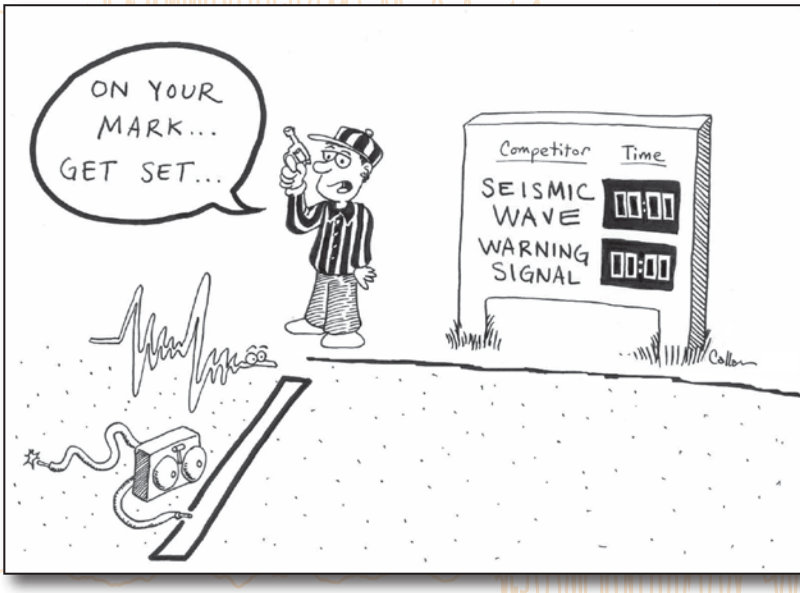
Before the next earthquake, you might get a warning. Maybe not much of a warning — perhaps a few seconds or tens of seconds at best. But it might be enough time to crawl under the kitchen table or move away from an office bookcase. A few seconds' warning could allow trains to slow and stop, and the stoplights on the roads could turn red, stopping traffic before a bridge or busy intersection. Nuclear power plants could halt operations while refineries isolate tanks and vulnerable pipelines. By combining modern digital seismic networks with modern communication systems, scientists are trying to create an earthquake early warning that comes before you are knocked off your feet and your world turns upside down.

Earthquake early warning is not earthquake prediction. The intent is not to predict when and where an earthquake will occur. In fact, earthquake prediction is not something that most earth scientists think will be possible in the foreseeable future. Rather, earthquake early warning involves rapid detection of the beginnings of an earthquake, assessment of the likely shaking and then subsequent warnings to those in harm's way.

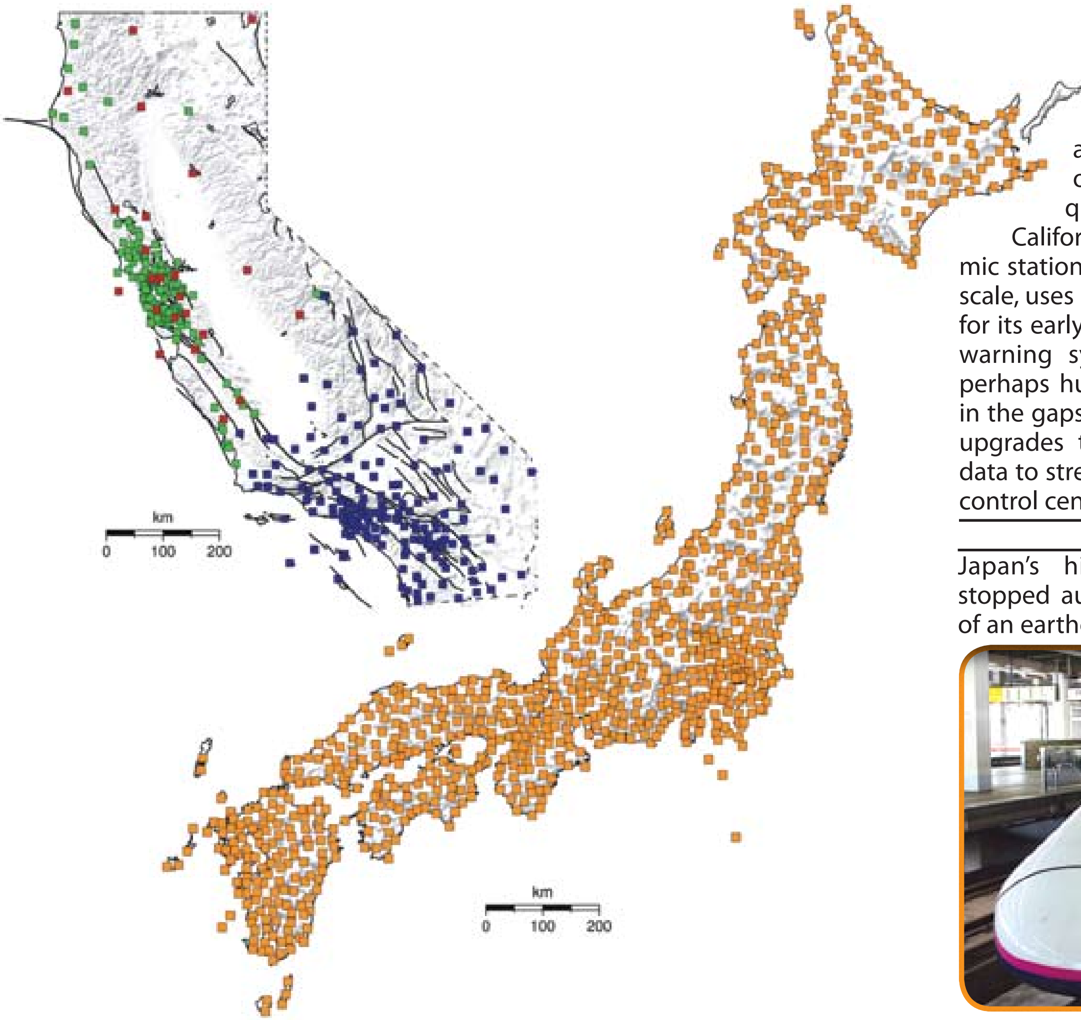
Bottom: State Historical Society, Madison, Wis.; top: U.S. Geological Survey Photographic Library

AN EARLY START

The concept of earthquake warning has been around for more than a century. On Oct. 21, 1868, a magnitude-7 earthquake shook the San Francisco Bay Area, rupturing the Hayward Fault that runs along the Oakland and Berkeley Hills. It served as a wake-up call for a city that had been expanding exponentially thanks to the California Gold Rush that began in earnest in 1849. Two weeks later, with the chaos still fresh in people's minds, J.D. Cooper, a medical doctor, proposed that an earthquake warning system be built. His plan was published in the San Francisco Evening Bulletin. Cooper envisioned sensors deployed at distances of 16 to 160 kilometers from the city, and telegraph cables that would transmit warnings to an earthquake bell that would ring out high above the city center whenever shaking was on the way. Unfortunately, as life returned to normal, the earthquake, its impact and Cooper's early warning system were forgotten.



Cooper was ahead of his time. It took 20 years for the first seismometers to be deployed in North America: In 1887 researchers at the University of California at Berkeley, installed seismometers close to the Hayward Fault at Berkeley. These instruments, developed in Japan following the destructive 1880 Yokohama earthquake, quickly spread around



This map shows the instruments in California (left) and Japan that are capable of being used in an earthquake early warning network. California has about 300 such seismic stations. Japan, shown at the same scale, uses more than 1,000 instruments for its early warning system. California's warning system would benefit from perhaps hundreds more stations to fill in the gaps in the current network, and upgrades to the equipment to allow data to stream more rapidly to network control centers.

Japan's high-speed trains can be stopped automatically at the first sign of an earthquake.

Bottom right: Jeff Falvo; bottom left: Richard Allen; top: Callan Bentley the world. Universities set up observatories to monitor earthquake activity just as they had set up observatories to monitor the sky. Such observatories could detect earthquakes all around the planet, including the 1906 Great San Francisco earthquake and the 1923 Great Kantō earthquake that destroyed much of Tokyo, killing more than 100,000 people.

By the late 1960s, Japan, which sits at the intersection of three tectonic plates, developed the world's first earthquake early warning system. It was simple: It used single seismometers that triggered after big ground motions. The seismometers were placed along the high-speed train tracks, and a signal from these seismometers could bring trains to a stop. But because the detectors were placed next to the tracks, the tracks were already shaking by the time the brakes were automatically applied. So seismologists moved the detectors away from the tracks and closer to the source of big quakes, just off the coast of Japan. The seismometers were positioned along the coast, like a line of centurions, guarding against ground shaking. When seismometers detected an earthquake, they transmitted a warning at the speed of light. This gave the trains more time to slow and stop before the tracks bent and buckled.

MODERN SEISMIC NETWORKS

Today, we have larger, more complex networks of seismometers than ever before. Hundreds of networks have been rolled out around the world — often after damaging earthquakes in an effort to prevent such destruction from happening again. For example, after the Jan. 17, 1994, magnitude-6.7 Northridge earthquake beneath Los Angeles, the U.S. Geological Survey and Caltech University deployed 130 seismometers. A year later, Japan installed more than 1,800 seismometers across the country in the wake of a magnitude-7.2 quake that shook Kobe and killed more than 6,000 people. Strong motion instruments, weak motion instruments and seismometers deep underground in boreholes all link back to a command center at the National Research Institute for Earth Science and Disaster Prevention and at the Japan Meteorological Agency.

These instruments were not intended for early warning. But the basic scientific research that has resulted has led to the development of modern earthquake early warning methodologies, which are based on P- and S-waves.

The ground shaking of an earthquake occurs in two phases. The P-wave, a sharp sudden jolt, comes first, followed later by the S-wave, a slow rolling shake that can go on for minutes and does most of the damage. So by detecting the P-wave, seismometers and signals can warn of the dangerous S-wave that knocks houses off their foundations. Thanks to our networks of seismometers, we can now predict large amplitude S-waves

Built in 1923, the University of California at Berkeley's football stadium straddles the Hayward Fault, which runs goalpost to goalpost. Continuous creep on the fault has caused the building to deform over time.

All: Richard Allen

seconds before they reach a given location. These predictions are not perfect, and there is always a margin of error that could lead to a false alarm. But by beating the S-wave, we increase the warning, giving people a few extra seconds to get under that table.

This concept was first put to the test one year ago this month, when Japan turned on its modern early warning system. Japan's National Research Institute for Earth Science and Disaster Prevention and the Japan Meteorological Agency combined their resources, and warnings are now available across the whole country, with more than 1,000 instruments feeding their data into the warning system. The seismic stations are spaced about 20 kilometers apart. The moment that an earthquake starts and seismometers pick up P-wave motion, several stations trigger an alarm, rushing their data to the central command. These instruments triangulate the epicenter location, estimate the magnitude and predict the location and severity of the shaking — all before the S-waves, and the real shaking, strike. If an earthquake is strong enough that the central command predicts severe shaking, the computers issue an immediate warning to the public via various communications systems, including radio and TV stations, personal computers and cell phones. Separate warnings go out to utility companies, the government and rescue teams. The warnings trigger the trains to stop and other utilities to halt operations as well. This is the first modern national earthquake warning system in the world — established in a country that has experienced great earthquake losses in the past.

The Japan Meteorological Agency runs the earthquake early warning center in Tokyo.

CALIFORNIA CHALLENGES

With Japan's system now working, California is trying to erect its own early warning system. But warning of quakes in California is more difficult because they happen right beneath cities, as opposed to Japan and other locations, such as Mexico (see sidebar), where the majority of the strongest quakes occur offshore, giving systems a bit more time to respond. San Francisco and Los Angeles are riddled with faults, some of which are massive and stretch the length of the state. The San Andreas Fault System, for example, divides two tectonic plates: The Pacific and North American plates grind past one another at the rate fingernails grow. But the faults' power is immense and it is building every day. The next big earthquake is coming: USGS estimates that there is a 99.7 percent chance that the state will experience a magnitude-6.7 quake or larger by 2038. So an early warning system is badly needed.

The California Integrated Seismic Network — a state and federally funded cooperation between the institutions running seismic networks across California — is now testing three early warning

The Mexican Connection

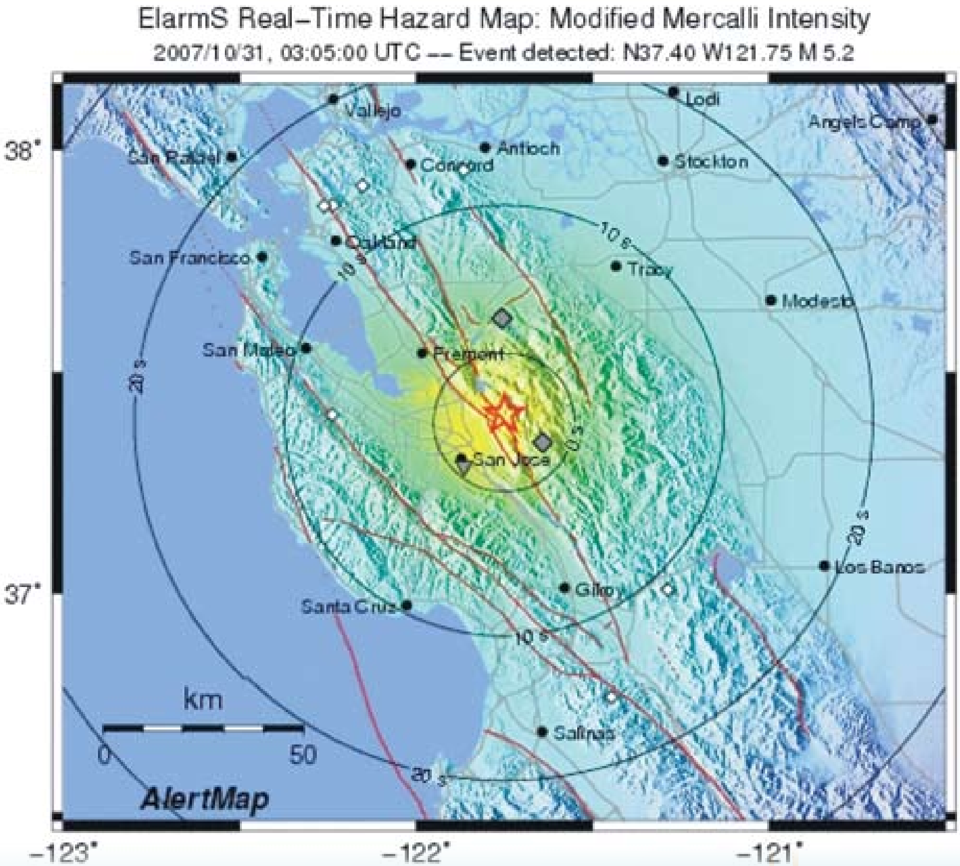
On Sept. 19, 1985, Mexico City shook. The thick lake sediments upon which the city stands quivered and convulsed for three or four minutes. By the time it was done, 9,000 people were dead and another 100,000 people homeless. In the aftermath, the city swore it would be prepared next time.

The government redoubled efforts to reduce the impact of earthquakes. As in Japan (see main story), the biggest quakes hit Mexico City from offshore faults. As the city is more than 300 kilometers from the epicenters of these quakes, it takes more than a minute for the ground in Mexico City to start rolling. A line of seismometers deployed along the coastline can signal the city in real time, giving the city a minute to prepare — enough time to stop traffic, shut down utilities and allow people to take cover.

RA

Wreckage of a 21-story steel-constructed building in the Pina Suarez Apartment Complex in Mexico City, Mexico, following the magnitude-7.8 earthquake on Sept. 19, 1985.

Bottom: Richard Allen; top: U.S. Geological Survey Photographic Library



On Oct. 30, 2007, a magnitude-5.4 earthquake rippled across the San Francisco Bay Area in California. The largest earthquake in the region since the 1989 Loma Prieta earthquake, it was felt by most people but caused little damage. One of the California Integrated Seismic Network's early warning test systems, called ElarmS, caught the earthquake. This map shows the distribution of ground intensity predicted using the first few seconds of data recorded by seismometers near the epicenter in San Jose, marked by a star. The warmer colors show stronger shaking near the epicenter and the cooler colors show weaker shaking at greater distances. The predicted ground shaking ended up being very accurate. The data used to generate this map were available a few seconds before the shaking was felt in San Francisco.

PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18–34	34–65	65–124	>124
PEAK VEL.(cm/s)	<0.1	0.1–1.1	1.1–3.4	3.4–8.1	8.1-16	16-31	31-60	60-116	>116
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

California Integrated Seismic Network

methodologies. Using the seismic networks of Caltech, Berkeley and USGS, the California Integrated Seismic Network is working with the Southern California Earthquake Center to build an analysis center at the University of Southern California that will gather the test warnings and let researchers know how well the test systems perform.

Two of the California test methods, called "ElarmS" and "Virtual Seismologist," rely on the network of seismometers across the state and estimate earthquake locations as seismic stations detect P-wave arrivals, then predict the magnitude and the shaking intensity, nearly exactly the way the Japanese system works. As each second passes, more data become available, and earthquake locations, magnitudes and shaking estimates can be improved. If the predicted shaking is severe, the systems issue a warning. The warning estimates the intensity of shaking at a given location and the number of seconds until it starts. This approach is probably the most accurate, although network methods can't provide warnings at the epicenter because the waves arrive too quickly — sort of like the tsunami warnings that are helpful farther away from a quake's epicenter but not so helpful in the immediate vicinity. Under our current system, even if an earthquake is just 15 or 20 kilometers away, however, there is enough time to gather the data, generate and transmit enough of a warning to potentially save some lives.

Because major quakes — the ones that are remembered for generations — rupture on long faults radiating destruction, early warning systems that rely on network detections could provide millions of people with 10 seconds or more of warning, if the fault starts rupturing some distance from cities. For example, in the 1989 Loma Prieta earthquake, the Nimitz Freeway in Oakland collapsed. Masonry bricks rained down in the streets of San Francisco. The Marina District quivered, collapsed and then burned. All of this took place almost a hundred kilometers from the epicenter. More than 80 percent of the fatalities occurred where there could have been more than 10 seconds of warning. The same is true in Los Angeles. The 1994 Northridge earthquake caused widespread damage, with buildings as far as 65 kilometers away red-tagged, or marked for demolition.

The third system the California Integrated Seismic Network is testing should help provide some warning to those people who are directly above the epicenter of a quake. The "onsite" approach uses a single seismic station, as opposed to multiple stations like the other warnings. Three seconds after detection of a P-wave, instruments analyze the wave, predict the S-wave, and allow a warning to be issued. The systems save a few seconds, which might make all the difference. The catch is that there may be more false or missed alarms, but depending on the warning issued, the trade-off might be a good one. Getting under a desk for a few false alarms is not that costly — in fact, it is a good drill, part of a necessary user education.

So far, the California tests are encouraging. Data from about 300 seismic stations stream into command centers at Caltech, Berkeley and USGS. Test algorithms process the data and try to detect any earthquakes much faster than has ever been possible before. The results are archived for analysis in a massive database at the Southern California Earthquake Center. We even had occasion to test the system last year. On Oct. 30, 2007, the Alum Rock earthquake rumbled across the San Francisco Bay Area. It was only a magnitude-5.4 quake and it did little damage, but it was the biggest quake since Loma Prieta, and the Bay Area woke up. Triggered by the P-waves, the test warning system detected the earthquake, locating it beneath San Jose. The computers were aware before the shaking reached San Francisco. No warning would have been possible in the South Bay, around San Jose, but before the shaking reached the North Bay, the calculations were complete. No warning was issued, because the system was still being tested. But the test provides a good indication of how the system might be used in the future.

Strawberry Canyon, in the hills above the University of California at Berkeley campus, houses a seismic station that is part of California's earthquake early warning network.

IMPLEMENTING THE SYSTEM

The next challenge is to implement California's warning system. The first step is to determine how big the seismic network needs to be to provide warning to major cities; this is a goal of the California Integrated Seismic Network study. More seismometers will certainly be needed, perhaps hundreds, to fill in the gaps across the entire state and to build upon the foundation of modern instruments installed in the 1980s and 1990s. Japan, for example, is using more than a thousand seismometers distributed across about the same area where California currently has 300. Next, we need to upgrade the communications system, which will give us a few additional seconds and make sure the signals reach the computers. Then, we must develop a method of getting the warning out.

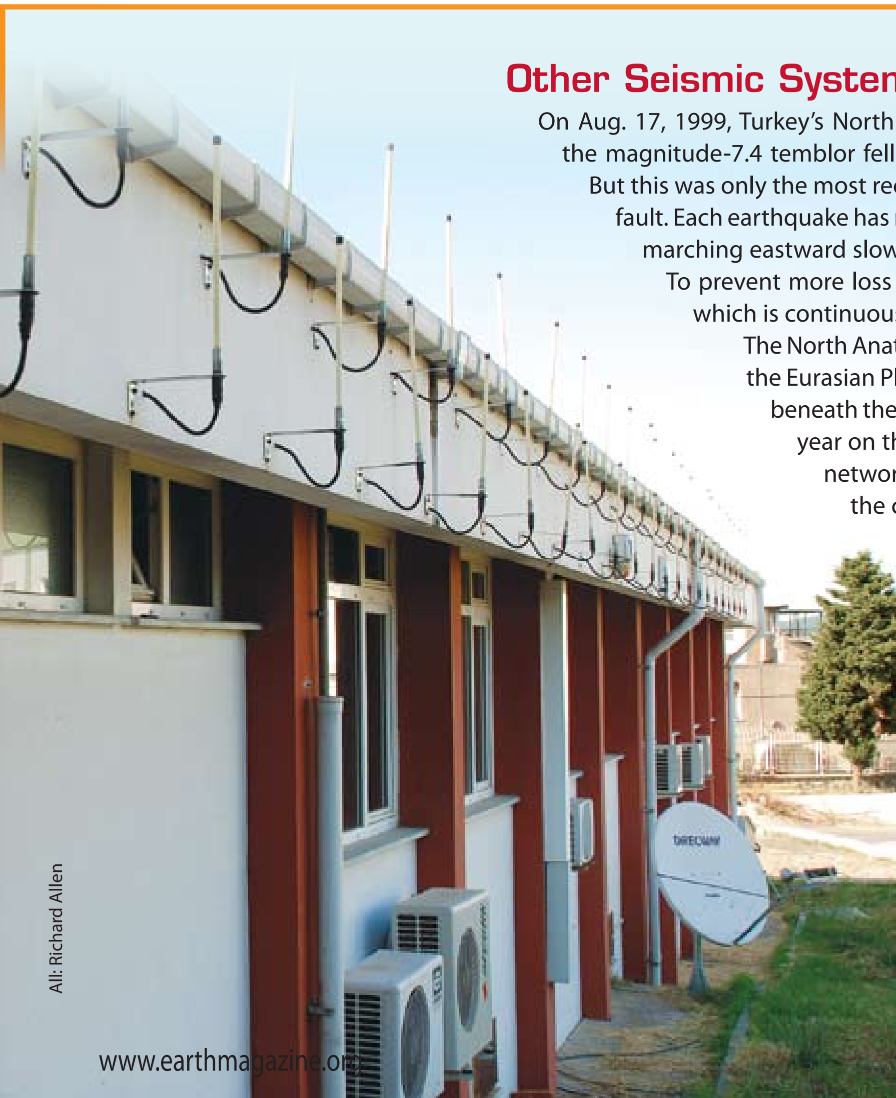
Other Seismic Systems

On Aug. 17, 1999, Turkey's North Anatolian Fault violently ruptured. The shuddering of the magnitude-7.4 temblor felled much of the city of Izmit and killed 20,000 people. But this was only the most recent event in a long sequence of earthquakes along the fault. Each earthquake has ruptured an adjacent segment of the fault, with ruptures marching eastward slowly. By that logic, Istanbul is likely the fault's next target. To prevent more loss of life, in 2007 Turkey started its own warning system, which is continuously being improved.

The North Anatolian Fault, which marks the tectonic boundary between the Eurasian Plate and the Anatolian Plate, lies to the south of Istanbul, beneath the Marmara Sea. More seismometers will be deployed next year on the floor of the Marmara, next to the fault. These seismic networks will relay their warning along undersea cables back to the city, hopefully giving a few more seconds of warning.

One month after Izmit, it was Taiwan's turn. On Sept. 21, 1999, a powerful slip along the Chelungpu Fault along the western part of the island produced the magnitude-7.6 Chi-Chi earthquake, which tore through the island, killing about 2,500 people. Following that disaster, Taiwan began testing a warning system too; they hope to have it in place before the next big earthquake.

RA



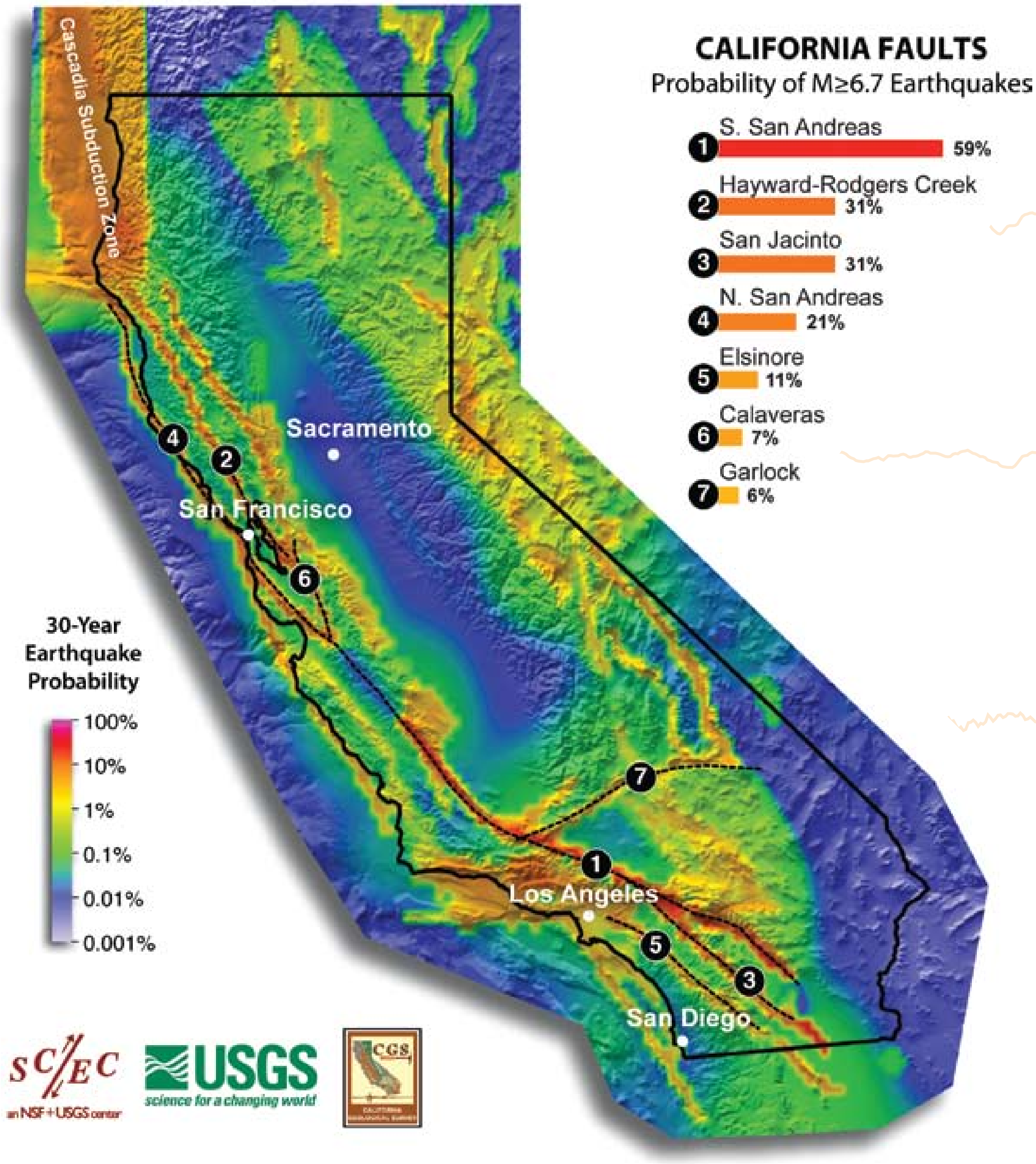
All: Richard Allen

Antennas line the roof of the Kandilli Observatory at the Earthquake Research Institute of Bogazici University in Istanbul, Turkey, receiving data from Turkey's earthquake early warning network.

The best approach to warn people is to use as many communications systems as possible, on both an institutional level and a personal level. Like in Japan, direct connections to train systems, airports, utility companies, refineries and power stations could initiate an automated response. Sensitive operations like computer chip manufacturing and eye surgery could pause. Radio and TV stations could broadcast a warning. A warning could be sent to a person's computer, which could then calculate how long they have and how strong the shaking will be. Cell phone communication towers could send a message to all cell phones in range. In Japan, the private sector is making this happen. Wireless communication companies provide the service to their subscribers. And people can buy a tissue-box-sized device for their homes or offices that counts down the warning.

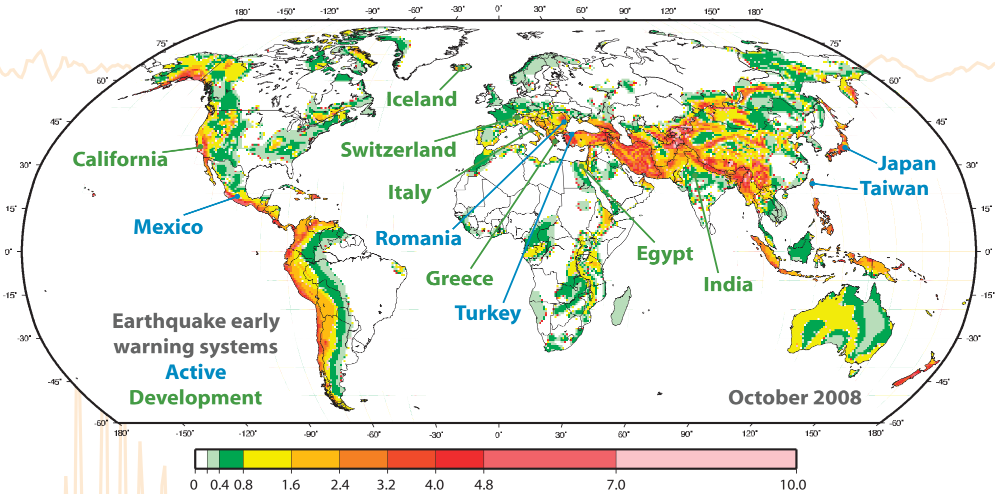
WILL IT WORK?

Is all of this research and work worth the effort? In the year since Japan's warning system went online, two sizable earthquakes have hit the country. Both were caught and a warning sent out. A magnitude-6.9 quake, similar in size to the Loma Prieta earthquake, rattled the city of Sendai on June 14, 2008. A hundred kilometers from the epicenter, the subway system got a five-second warning — enough time to stop all the trains. In Yamagata, 120 kilometers from the quake, hospital personnel saw the warning on TV and rushed to check patient respirators. But there was no warning at the epicenter, and though none could have been issued, the public was disappointed. In the magnitude-6.8 earthquake that hit on July 24, 2008, the warning took a little longer, coming only three seconds prior to shaking 130 kilometers



USGS/SCEC/CGS

The bar graph compares the 30-year probabilities of magnitude-6.7 or greater quakes for seven of California's faults (numbered on the map). The fault with the highest probability is the Southern San Andreas (59 percent in the next 30 years). For Northern California, the most likely source of such earthquakes is the Hayward-Rodgers Creek Fault (31 percent in the next 30 years).



Earthquake Hazard: Peak ground acceleration (ms^{-2}) with 10% probability of exceedance in 50 years

from the event. There has also been one false alarm. On June 14, 2008, in Ibaraki Prefecture, a single seismic station triggered an alert. The trains came to a stop before anyone realized that a mistake had been made. A faulty seismometer was the culprit, but there was no public warning because that required two stations to trigger.

These are encouraging results for a brand new, highly complex system that can reach across the country in an instant. Scientific challenges remain, because earthquakes still provide us with surprises. Seismologists have much more work ahead of them. But as the Japanese system is fine-tuned, the warning times will likely increase and the chance of false alarms will diminish. The big test — an earthquake capable of causing mass fatalities — has yet to occur.

To build such a system in California, we need political will and financial investment. We can only hope that the clear danger will be such a catalyst. According to USGS, the Southern San Andreas Fault, the one that wraps around Los Angeles, has the greatest risk of rupture; that is followed by the Hayward Fault, which runs along San Francisco's East Bay, beneath San Jose, Oakland and Berkeley. The Northern San Andreas Fault, which runs through the peninsula on the west side of San Francisco Bay, is also at risk. Really, though, nowhere in California is immune.

Almost exactly 140 years after an earthquake on the Hayward-Rodgers Creek Fault inspired J.D. Cooper to propose an earthquake warning system, the region is due for another one. The average recurrence interval of the last five Hayward Fault earthquakes is 138 years. The repeat interval is variable, ranging from 95 to 160 years, so the earthquake may not be tomorrow, but it is coming. History shows that we respond to yesterday's earthquake. But now we have an opportunity to act before the next big one strikes.

Allen is a seismologist at the Seismological Laboratory and in the Department of Earth and Planetary Science at the University of California at Berkeley. E-mail: rallen@berkeley.edu.

Much of San Francisco, Calif., was destroyed by the Great San Francisco Earthquake and the ensuing fire on April 18, 2006.

Bottom: U.S. Geological Survey Photographic Library; top: Richard Allen

Internet Resources for Earthquake Early Warning Systems

- The California Integrated Seismic Network is a cooperation between institutions running real-time seismic networks in the state. They provide rapid post-earthquake information. http://cisn.org
- One of the early warning methodologies being tested in California is "ElarmS." The ElarmS Web site describes the approach and shows results of system tests in various countries around the world. www.ElarmS.org
- The 1868 Hayward Earthquake Alliance is commemorating the 140th anniversary of J.D. Cooper's earthquake. This site contains information about the 1868 earthquake and guidelines on how to prepare your family and workplace for the next big earthquake. http://1868alliance.org
- Japan Meteorological Agency is now providing earthquake warnings. These pages summarize how they do it and what actions they recommend. www.jma.go.jp/jma/en/Activities/eew.html
- U.S. Geological Survey Earthquake Hazards Program's Web site includes maps of recent earthquakes in the United States and around the world. http://earthquake.usgs.gov/
- The U.S. National Earthquakes Hazards Reduction Program is a multi-agency effort to mitigate future earthquake effects. http://www.nehrp.gov/