A Walk in Earthquake Country

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Right before the turn of the millennium, people worried about Y2K problems. Scared that the intricate technological system would go awry once that final digit turned from "9" to "0" as the clock chimed, they stored food and water and carried flashlights and radios. By releasing a series of movies about the destruction of our planet, Hollywood did not help alleviate the public's concerns. In 1998's *Deep Impact*, a mile-wide comet moves toward Earth. The same year, *Armageddon* promised that an asteroid the size of Texas would destroy the human race, perhaps much like the dinosaurs. Yet two unfriendly celestial bodies did not seem to be enough; the filmmakers had to throw in a Godzilla, a monster lizard that aimed to obliterate Manhattan and to produce more fiends like herself to take over the world. Even after the millennium anxiety passed, the fascination with the end of our world did not seem to subside. *The Core*, released last year, demonstrated the havoc that would take place if the Earth's core came to a stop.

Scary as these Hollywood productions might seem, none of the disasters depicted promise to make an appearance in the near future, if ever. After all, these thrillers are created to hold people at the edges of their seats and, if the filmmakers are talented, to create a hair-raising experience for the audience. For California residents, however, disaster is no backdrop for a box-office best seller; it is an imminent reality.

Southern California is best known for Hollywood, beaches, good weather, and earthquakes. There have been more than 200,000 earthquakes recorded in Southern California in the last decade. The name Earthquake Country is therefore fitting. Although most of the quakes were unnoticeable, the few that were the most destructive have changed many people's lives.[1] On January 17, 1994, the 6.7 magnitude Northridge earthquake caused by a fault movement in Los Angeles claimed 57 lives and caused more than $30 billion in damages, making it the costliest tremor in U.S. history.[2, 3]

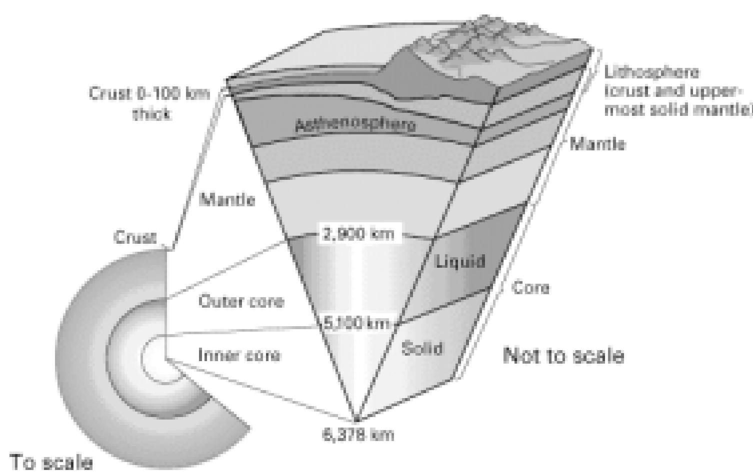

Figure 1. Layers of the Earth.

Situated at the boundary between the Pacific and North American plates which move past each other at the rate of 45 millimeters (1.75 inches) per year, Southern California is covered by over 200 faults of all sizes. Most notorious is the San Andreas Fault, particularly the southern portion, which has been known to wreak havoc in Southern California. Relatively dormant since the 7.9 magnitude Fort Tejon earthquake in 1857, the San Andreas Fault has not since been responsible for causing any more tremors in Southern California.[4] Scientists predict that the fault's almost 150 years' worth of tectonic strain will be released within the next 30 years, causing a 8.0 magnitude (or higher) earthquake.[5] More recently, experts forecast that a quake of at least 6.4 on the Richter scale will occur by September 5, 2004, along the southern portion of the fault.[6]

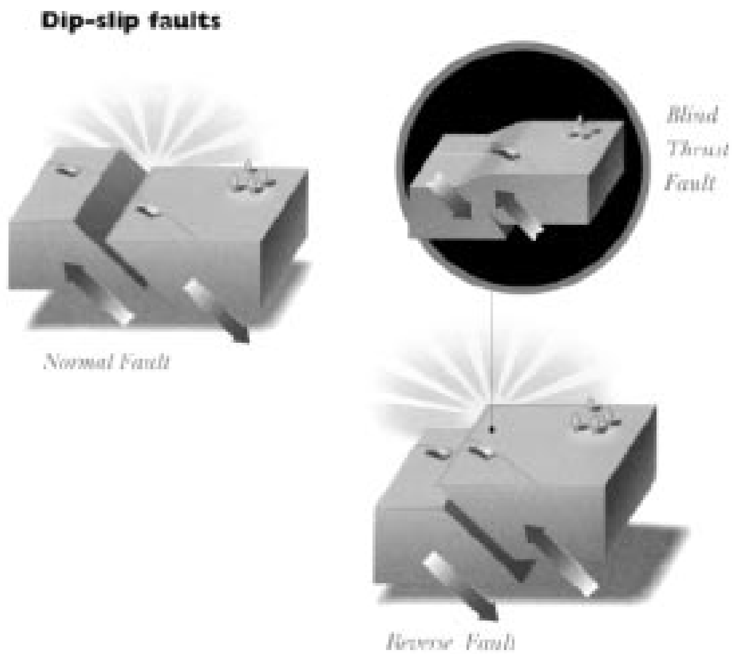

Figure 2. Types of Faults

A Bull That Lives Underground

When science and technology were still in their nascent stages, the Chinese spoke of earthquakes as the turning and tossing of a large bull that lives underground. Although we still have not unveiled all of the secrets of earthquakes, we have come to understand that an earthquake can be much more violent and capricious than the bull.

Our planet is much more than the green and blue ball often illustrated. Serene and beautiful as it may seem from outer space photographs, inside the 12,750 km diameter sphere dwells a restless spirit. Composed of three main layers, the earth holds much more than what meets the eye (Figure 1). The thin outermost layer, appropriately termed the *crust*, is rigid and brittle. Divided into the liquid outer and solid inner parts, the core is the innermost and densest of the three layers.[8] The denser and hotter middle layer, called the *mantle*, consists of semi-solid rocks rich in minerals.

The crust and the cooler upper part of the mantle make up the *lithosphere*, a layering of rigid rocks. Below the lithosphere is the *asthenosphere*, a narrower and hotter layer made up of semi-solid material. If you think we stand on solid, fixed ground, think again. The asthenosphere slowly flows while the lithosphere floats on top of it. The lithosphere does not seamlessly cover the earth. Instead, it is composed of giant and irregularly-shaped slabs called the *tectonic plates*. Along the boundaries of these plates, many of Earth's wonders and mischief occur.[8]

Variations of temperature and pressure across the layers cause the plates to move. Friction, however, hinders the movement. As a result, tectonic forces are built up within the Earth. Over a long period of time, strain accumulates until it overcomes friction and is released as energy. This strain relief usually happens as sudden shifts occur along *faults*, broken or crushed places on the plates, giving birth to earthquakes.[9]

In any battle, it helps to know your enemy's language. Wrestling with the underground bull is no exception. Because the mysteries surrounding earthquakes put them at an advantage, understanding earthquake jargon is a must to prepare for the struggle with Earth's might (Figure 3). It all begins with the *hypocenter*, or the focus, of the rupture of the earthquake. From this point, body waves are generated, which are used to determine the magnitude of the tremor as well as the corresponding surface location, or *epicenter*, of the earthquake. Body waves are further broken down into two categories: the smaller Primary (or P) waves and the lagging Secondary (or S) waves. Arriving after the body waves are the surface waves. Passing through Earth closest to the surface, these waves are like Sherman's March to the Sea, leaving behind a trail of destruction and damage.[1, 9]

The severity of earthquakes can be measured in intensity or magnitude. Intensity assesses the observed damages caused by the earthquakes and is calibrated in the United States by the Modified Mercalli Intensity Scale. Divided into 12 incremented levels ranging from "imperceptible shaking to catastrophic destruction", the scale is based purely on observations and surveys (Figure 4).

Magnitude, on the other hand, gauges the amount of energy released from the focus of the earthquake and is mathematically calibrated from the amplitude of the P-waves using the Richter Magnitude Scale.

Therefore, a high magnitude earthquake in a sparsely populated region can rank relatively low on the intensity scale, and a low magnitude shake in a densely populated city can receive a high intensity mark. Based on a logarithm, each whole number magnitude on the scale is 10 times greater in P-wave amplitude and 31 times stronger in seismic energy than the whole number magnitude immediately preceding it.[10, 9] Negative magnitudes are also possible because the calculation of the Richter scale is purely mathematical. A .5 magnitude earthquake generates the same amount of energy "as dropping a quarter from waist height."[10] The condition of soil also affects the degree of damage a given earthquake can cause.[1]

The Role of Faults

Contrary to public belief, faults are planes instead of lines. The lines we see on the surface are merely the 2-D intersections of the two planes of rocks, which can be at any angle to the exterior of the Earth.[11] During an earthquake, the rocks on one side of the fault move relative to the rocks on the other side. The direction of the movement also varies and is used to classify the two different types of faults: strike-slip and dip-slip[1] (Figure 2).

A strike-slip fault consists of a vertical fault plane that moves horizontally past another plane. Left and right lateral faults make up the two subtypes of the strike-slip fault system.

The dip-slip fault system has three subcategories: normal, reverse and thrust. All consist of an angled fault plane that slides either up or down relative to another plane. In both normal and reverse faults, the planes simply slide away or toward each other, respectively.[1] In thrust fault, one plane slides over the other. The strike-slip fault is the most common type that plagues Earthquake Country.[11]

Longer faults correspond to bigger earthquakes. For a fault as long as the San Andreas, whose 1,200 kilometers traverse the Golden State, to reach a 8.0 magnitude earthquake is not terribly difficult[12] (Figure 5). The infamous San Andreas Fault extends from Los Angeles to the Northern California coast and into the Pacific.[13] It is part of the greater San Andreas Fault System that includes three other different faults: the San Jacinto Fault, the Whittier-Elsinore Fault, and the Imperial Fault, all of which run parallel to the San Andreas Fault. Together the four faults have been extensively investigated in Southern California, not only because as the fastest-slipping faults, they present the greatest threat to the region, but also because their positions are easily identifiable, making them easy to study.[1]

Each of these faults stretches over a long distance, and scientists believe that, at any given time, only parts of each fault are responsible for an earthquake. The southern portion of the San Andreas Fault measured at 550 kilometers, for example, was relatively dormant while its conjoined sibling caused distress in San Francisco.[1, 14]

The 2002 Denali earthquake in Alaska, the only state more earthquake-prone than California, however, proved that simultaneity of different earthquakes on different faults is possible.[14] The Alaska fault system is similar to the faults traversing Southern California. Studies of the Denali earthquake found that the 7.9 magnitude tremor was composed of three smaller earthquakes on three different faults. In fact, experts found the Denali earthquake to be strikingly analogous to the 1857 Fort Tejon and 1906 San Francisco earthquakes along the San Andreas Fault. All three started the tremor at a single point and spread along the fault with amazing speed. The Denali earthquake, however, originated on a previously unknown fault. Most of the faults in California have been carefully mapped out; therefore an earthquake that starts along an unidentified fault is unlikely in the Golden State.[14]

For a long time, it was thought that the south portion of the San Andreas Fault posed the greatest hazard to the Los Angeles area. Recently, however, it was discovered that the fault can trigger other faults within the Los Angeles region, creating a greater menace to the densely populated areas near downtown.

The job of terrorizing Southern California residents is also shared with six other faults in addition to the San Andreas Fault, including (Figure 5) the Garlock Fault, the Oakridge Fault, and the Sierra Madre Fault. These faults

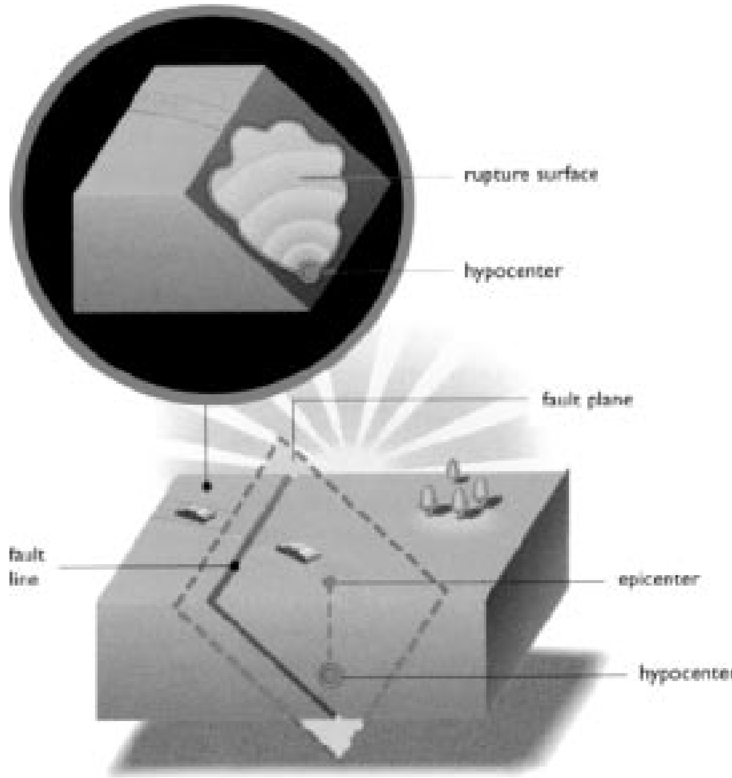

Figure 3. Earthquake terms.

were responsible for the 6.6 magnitude Sylmar earthquake and they are being watched as likely candidates for a major earthquake in the distant future. Like the faults in the San Andreas Fault System, the Santa Susana Fault, the San Cayetano Fault and the Cucamonga Fault are move, though at a slower rate of at least four millimeters each year.[1, 4]

Doomsday Near?

Homo sapiens are the smartest organisms on planet Earth, but even the wisest of our kind cannot tame nature. Unfortunately, the real world does not have a Pecos Bill who would catch a tornado as if it were an unwieldy bull. Humans simply cannot fight nature in a head-on collision. Instead, we cope with nature's austerity by using our ingenuity. When it rains, humans open their umbrellas. When it snows, humans put on a parka. When lightening strikes, humans install a lightening rod to divert the electricity. But with earthquakes, which affect large areas in a short amount of time without warning, humans are clearly at a disadvantage.

Unlike storms that announce their arrival with ominous cloud fronts, earthquakes bust through the doors without knocking. Until recently, the closest scientists came to forecasting earthquakes was estimating the occurrence of aftershocks.

Large earthquakes are usually accompanied by smaller earthquakes either before or after the main quake. A group of earthquakes occurring in neighboring regions within a short period of time are categorized into mainshock, aftershock, and foreshock. The tremor with the greatest magnitude is the *mainshock*. All other earthquakes either before or after the mainshock are called *foreshocks* and *aftershocks*, respectively. Aftershocks usually occur along faults near the mainshock and are triggered by a large earthquake's release of the tectonic stress. An aftershock bigger than the earthquake preceding it will be renamed the mainshock. The original mainshock thereby becomes a foreshock. Aftershocks usually take place within one hour and almost never more than 72 hours after the mainshock.[11, 15]

The ability to predict and approximate the position of aftershocks has helped greatly with the issuing of earthquake advisory warnings and reminders to the public to maintain safety measures immediately following a significant earthquake. But what the scientists really hope to achieve is an accurate prediction of the earthquake months before it happens. Such ability would allow ample time for preparation and significant reduction of lives lost and properties damaged. For a long time, experts considered earthquake forecasting an impossibility, but recent accurate predictions by UCLA seismologist and mathematical geophysicist Vladimir Keilis-Borok have proven otherwise.

After 20 years of study and collaborations with interdisciplinary and international scientists, Keilis-Borok's team accurately predicted in June 2003 the magnitude 8.1 Hokkaido, Japan, earthquake that happened on September 25 and the 6.5 magnitude San Simeon earthquake that took place on December 22, 2003.

By studying microquakes generally smaller than 3.5 in magnitude and by using algorithm to identify patterns in previous tremors, the team now forecasts a 6.4 (or greater) magnitude earthquake to occur along the San Andreas Fault by the first week of September this year. The predicted tremor has the potential to trigger ruptures on nearby faults, leading to a possible 7.5 magnitude earthquake. Located near the greater Los Angeles area, the disturbance will cause devastating damage.[6]

Since the release of a 1998 report that proposed a 40 percent chance of a "Big One," an 8.0 magnitude earthquake, within 30 years along the southern portion of the San Andreas Fault, apocalyptic speculations by Southern Californians have been on the rise. Yet no one seems particularly bothered by it. However, now that a more imminent prophecy has been proposed by a credible scientist, people are beginning to worry. Other experts, such as director of the Southern California Earthquake Center at USC, Thomas H. Jordan, are still skeptical about the validity of Keilis-Borok's prediction. Jordan argues that researchers still have much to learn about the formation and occurrence of earthquakes. The information at hand is simply not enough to provide a definite prediction.[6, 16]

Prior to Keilis-Borok's predictions, scientists at the University of California, Berkeley's Seismographic Laboratory already had found evidence suggesting a three-year cycle of earthquakes along the San Andreas Fault. This possible pattern may aid the researchers in predicting the next big hit on the Big Bend. Geophysicist Robert Nadeau, one of the project leaders, however, does not promise any formal predictions. Further study is still needed to confirm the cycle.

The project, since 1984 led by Nadeau and the late Thomas McEvilly, examined 67 earthquakes with magnitudes between 3.5 and 4.7 around the central-upper region of the San Andreas Fault. The researchers found that most movements happened in one year and were followed by two relatively quiet years of microquakes. The same sequence repeatedly emerges in the study, forming the three-year cycle pattern.[17]

In order to collect information on the microquakes, generally overlooked in seismic studies, Nadeau's team drilled holes several hundred meters into the soil of Parkfield.[13] The region is the hotspot to study the San Andreas Fault because it is halfway between San Francisco and Los Angeles.[18] The fault segments north and south of Parkfield also differ significantly. The northern portion of the fault often slips and produces numerous tremors small in magnitude, while the southern portion of the fault accumulates tectonic strains in a locked position.[19] What Nadeau's team found in the boreholes was quite surprising. About half of the microquakes occur in the same place every few months or years. These places could represent locations where the planes of

The following is an abbreviated description of the 12 levels of Modified Mercalli intensity.

I.	Not felt except by a very few under especially favorable conditions.
II.	Felt only by a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing.
III.	Felt quite noticeably by persons indoors, especially on upper floors of buildings. Many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibration similar to the passing of a truck. Duration estimated.
IV.	Felt indoors by many, outdoors by few during the day. At night, some awakened. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building. Standing motor cars rocked noticeably.
V.	Felt by nearly everyone; many awakened. some dishes, windows broken. Unstable objects overturned. Pendulum clocks may stop.
VI.	Felt by all, many frightened. Some heavy furniture moved; a few instances of fallen plaster. Damage slight.
VII.	Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable damase in poorly built or badly designed structures; some chimneys broken.
VIII.	Damage slight in specially designed structures; considerable damage in ordinary substantial buildings with partial collapse. Damage great in poorly built structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned.
IX.	Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb. Damage great in substantial buildings, with partial collapse. Buildings shifted off foundations.
X.	Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations. Rail bent.
XI.	Few, if any (masonry) structures remain standing. Bridges destroyed. Rails bent greatly.
XII.	Damage total. Lines of sight and level are distorted. Objects thrown into the air.

Figure 4. Mercalli Scale.

the fault have trouble sliding past each other and therefore continuously rupture.[13]

Furthermore, the team found that the four biggest quakes—the 4.7 magnitude quake near San Juan Bautista in 1986, the 7.1 magnitude Loma Prieta earthquake in 1989, the 5.4 magnitude tremor in 1990, and again in San Juan Bautista in 1998—all happened during the first years of each of the three-year cycle, leading the scientists to believe that activities along the fault come in bursts of large quakes followed by relatively dormant periods.[14, 17]

Although there are enough cycles to suggest that the pattern is not merely a coincidence, the cycle was interrupted in the early to mid-90s. The gap led the researchers to reconsider the validity of the "alleged cycle" and doubt whether patterns even exist in seismic activities. After all, geologically speaking, 16 years is not a very long time. Even the researchers are still unsure if the 1906 San Francisco earthquake was part of the cycle. Nevertheless, the data is considered highly valuable, as no previous pattern with five complete cycles such as this one has ever been discovered along the fault. If the pattern continues, the next cycle of microquakes should happen this year. The pattern may change completely in the next decade. In the meantime, however, the project provides a starting point for future research.[14, 17]

Digging to China

Like a zoologists who captures the specimen to better study it, a geologist needs to catch a "live earthquake" to better examine it. This is exactly what many scientists have done to study the San Andreas Fault.

Doug Yule of Cal State Northridge and his team of scientists are among the researchers who decided that the best way to understand the San Andreas Fault was to get up close and personal with its underground. The team dug trenches in the southern region of the fault and carbon-dated the fissures there. They found that the southern region of the San Andreas Fault is "pregnant" with high amounts of stress and will be "ready for delivery" any day now.[12]

A few years prior saw the completion of a pilot observatory hole by the San Andreas Fault Observatory project (SAFOD). SAFOD is a collaboration between the U.S Geological Survey (USGS) and Stanford University. Described as "the geo-scientific equivalent of the moon landing", the project was made possible by advanced drilling technology.[20] The project proposed to drill a borehole 4 km down into the heart of the fault near Parkfield, where various sensors could be installed to closely monitor the conditions and activities along the fault. The team started and completed a pilot hole in the summer of 2002. Located about 1.8 km southwest of the fault, the pilot hole was only 2.2 km deep but was at the same surface site where the actual 4 km hole will be drilled. The observatory is scheduled to be completed in 2007.[21]

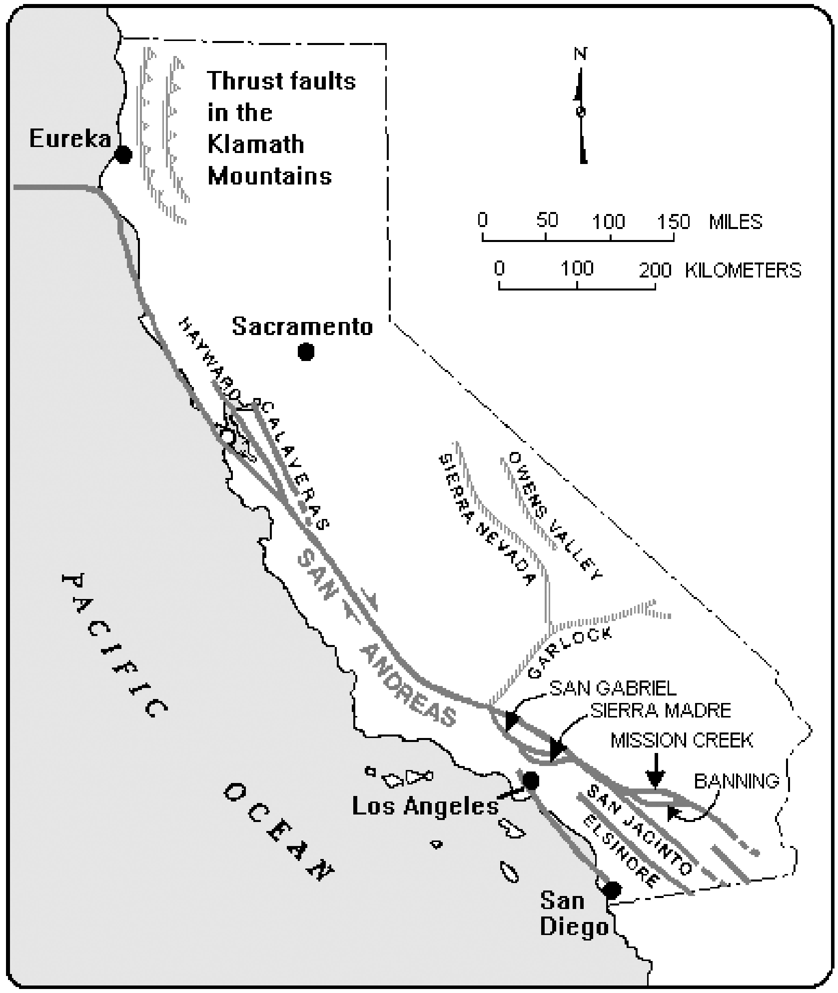

Figure 5. Faults in California.

SAFOD, part of a $25 million dollar project, intends to collect data on "the composition, strength, and frictional properties of rocks" at the San Andreas Fault. Scientists hope that the observatory will give them more accurate information that may one day be useful in earthquake predictions.[22] More importantly, SAFOD will allow scientists to assess whether it is even possible to make such predictions. A highly ambitious project, it is not expected that the hole will reach the full depth of 4 km below the surface. There is still a lot of information unknown inside the Earth; scientists cannot predict the difficulties they may run into. There has also been speculation as to whether direct drilling will affect the fault activity. While they hope for the best, one legitimate question persists: If scientists accurately predict earthquakes, how would the predictions be used and how would the public react to the forecast?[20, 22, 23]

Once Upon a Time

Our ancestors liked to make up stories about natural phenomena they did not understand and could not explain. Modern humans, however, despite much scientific knowledge available right at their fingertips, continue to invent their own stories of the world around them. Many outrageous myths about earthquakes originate in this way.

Many people believe that large earthquakes always occur at the break of dawn or in hot and dry weather. In fact, the occurrence of earthquakes, regardless of magnitude, has nothing to do with time of day or weather conditions. Several big earthquakes, such as the 6.4 magnitude quake in Long Beach, happened in the afternoon. The origin or focus of the earthquake, usually several kilometers underground, is also too deep into the earth to be affected by surface conditions.[1]

One of the most famous myths about earthquakes is that beachfront property will soon be available to Arizona and Nevada residents. Ever since experts announced the possibility of a major earthquake along the San Andreas Fault in the next 30 years, people have imagined that Southern California will one day break off the North American continent and fall into the ocean. The fact that the planes move horizontally along the fault denies any possibility of the region sinking into the Pacific Ocean.[1, 6]

Another false popular belief is that during a major earthquake "the earth opens". Such a scenario is only possible as a *deus ex machina* in fairy tales. In reality, the ground planes move along each other and never open. An open fault would suggest that the planes move independently of each other with no friction between them. By this logic, they would not even produce earthquake in the first place.

Deep Impact

An earthquake comes fast and goes fast. Within seconds or minutes, it can cause injuries that will take years or even decades to heal. This January marks the tenth anniversary of the earthquake that devastated Northridge. While the public mourns those who died, and the survivors look back on how their lives have changed since the shake, the government is evaluating its implementations of earthquake emergency preparations. Emergency preparedness simulations are now well underway and exercised annually. Maps of fault zones and preparedness handbooks are also distributed to help the public understand the Earthquake Country they live in and the importance of precautions.[16] But more importantly, Southern California cities, such as Los Angeles, have improved their Emergency Operation Centers (EOC). Ten years ago, Los Angeles' EOC was no more modern than a log cabin in the woods. Today, the center is equipped with advanced technology that will allow efficient communications between rescue sites.[24]

The effectiveness and comprehensiveness of other precautions are also put to the test when disasters strike. The Northridge earthquake revealed many shortcomings in public building codes and regulations in construction and emergency responsive protocols. Since then, billions of dollars have been spent to enhance many buildings' ability to withstand major earthquakes. Monitors were also installed to follow the buildings' safety status after a quake has occurred. Furthermore, many health-related buildings, particularly hospitals, are under scrutiny and development to ensure the structures can resist significant shaking. Experts are also continuing to work on novel construction technologies that will prevent old buildings from collapsing.[25]

Humans' vulnerability is often denied until a collision with forces of nature draws them out. Being aware of the danger of living in Earthquake Country is simply not enough. Extra precautions need to be taken in order to make the living and working environments safer. People who dismissed emergency preparedness advice as the worrywart's mantra now have emergency kits in their houses. They refresh perishable supplies on a regular basis and keep one gallon of water per day for each member of the family stocked in a safe and easily accessible place. Many residents also anchor their furniture and rearrange household objects to minimize the hazards of dropping or falling if a large earthquake were to happen. It is also recommended to keep a pair of slip-on shoes by the bedside in case of emergency evacuations.[26, 27]

Insurance policies that cover earthquake damages are now secured by more than 85 percent of homeowners, compared to 30 percent in 1995. Insurance means more protection for the residents, but it also means more risk for the companies. The Northridge earthquake damages still haunt many companies to this day. 21st Century Insurance Company, for example, has already paid more than $1.1 billion in claims and litigations related to the 1994 disaster. This and similar events prompted many insurance companies to reexamine and restructure their policies. Legislation has also been proposed to avoid system abuse and to protect both victim and company rights.[26, 28]

Overall, today's people, not just the experts, are more aware of the volatility of the land they live on and have taken proper precautions to make their environments a safer place.

Our planet is beautiful. Though its environment nurtures us, it still constantly assesses our staying power with many of its tests. From antiquity to present, humankind has and continues to face the trials of natural disasters. With the advancement of modern technology and scientific knowledge, we become more and more equipped to endure nature's trials. Like rain and snow, we cannot avoid earthquakes, a natural phenomenon, but we can minimize the damage from disasters. We cannot change what is going to happen, but we can prepare ourselves. Experts around the globe are working hard to achieve this goal. With sufficient understanding of the natural phenomena and ample preparation for the disasters to come, we will be able to bravely take on any challenges that nature has planned for us.

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