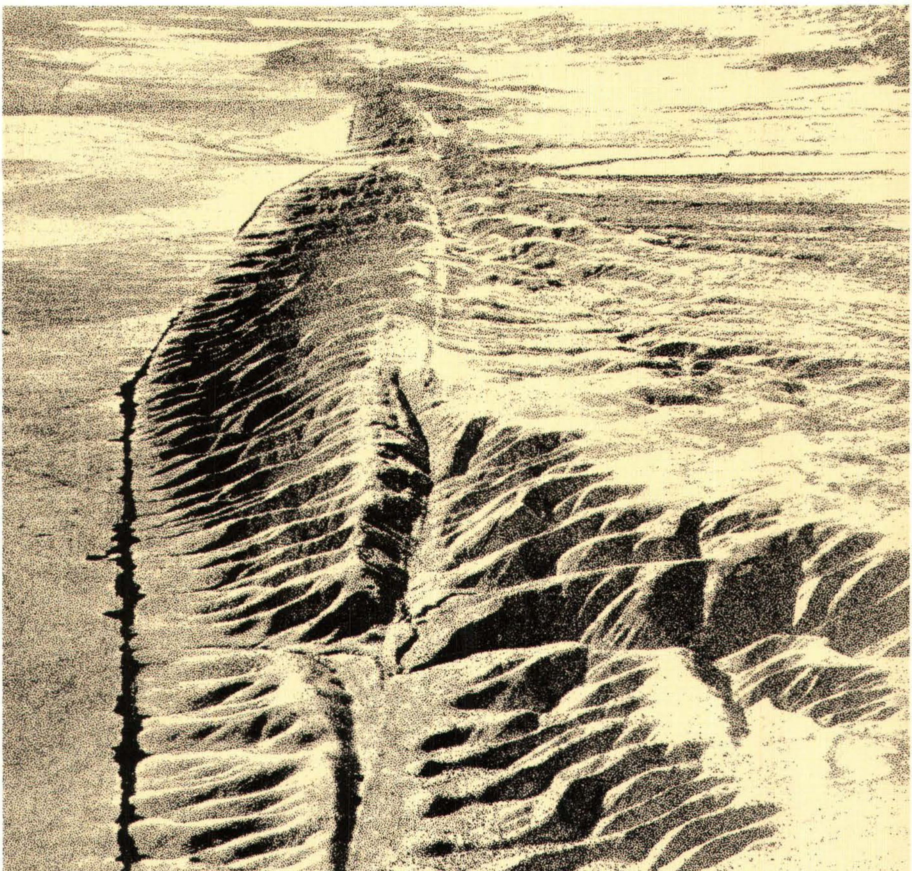
U.S. Department of the Interior / U.S. Geological Survey

The San Andreas Fault




SAN ANDREAS FAULT

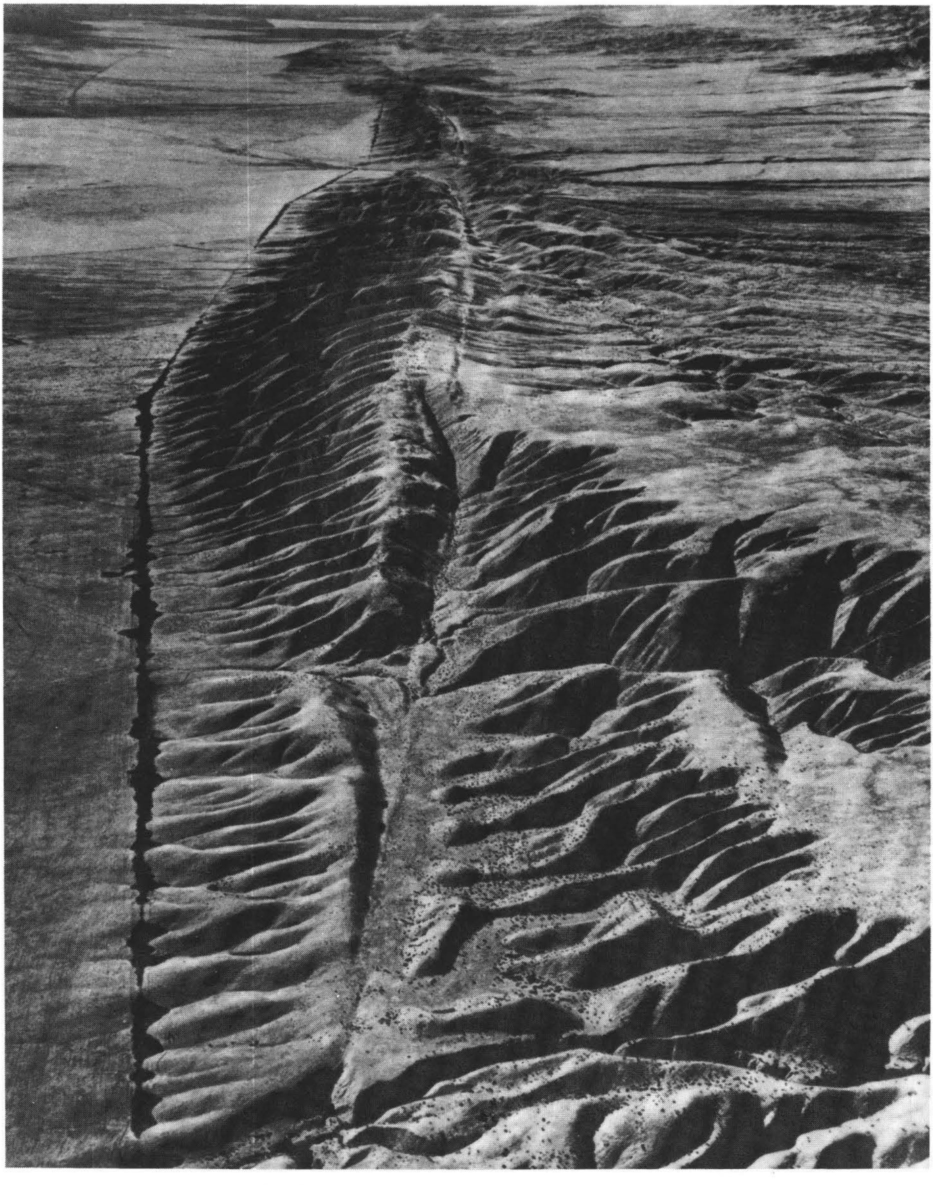
The San Andreas Fault

by

Sandra S. Schulz and
Robert E. Wallace

Housing development along the San Andreas fault near San Francisco, California *(photo by Robert E. Wallace)*.

The presence of the San Andreas fault was brought dramatically to world attention on April 18, 1906, when sudden displacement along the fault produced the great San Francisco earthquake and fire. This earthquake, however, was but one of many that have resulted from episodic displacement along the fault throughout its life of about 15-20 million years.

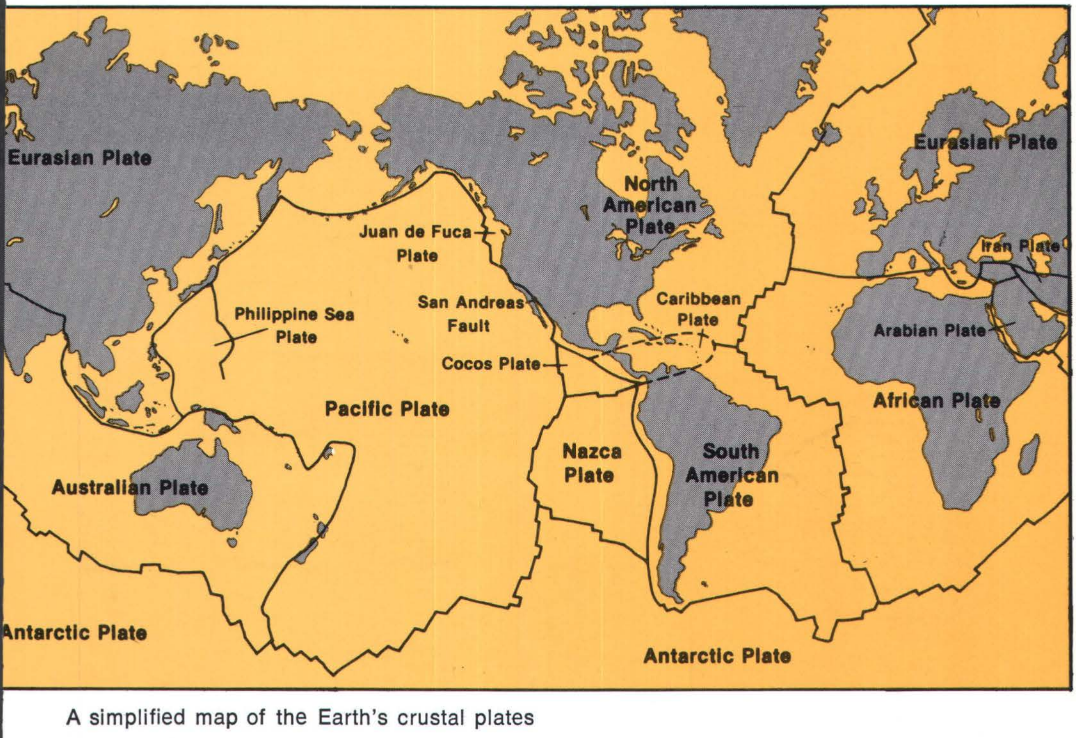


San Andreas fault in the Carrizo Plain, central California *(photo by Robert E. Wallace).*

What Is It?

Scientists have learned that the Earth's crust is fractured into a series of "plates" that have been moving very slowly over the Earth's surface for millions of years.

Two of these moving plates meet in western California; the boundary between them is the San Andreas fault. The Pacific Plate (on the west) moves northwestward relative to the North American Plate (on the east), causing earthquakes along the fault. The San Andreas is the "master" fault of an intricate fault network that cuts through rocks of the California coastal region. The entire San Andreas fault system is more than 800 miles long and extends to depths of at least 10 miles within the Earth. In detail, the fault is a complex zone of crushed and broken rock from a few hundred feet to a mile wide. Many smaller faults branch from and join the San Andreas fault zone. Almost any road cut in the zone shows a myriad of small fractures, fault gouge (pulverized rock), and a few solid pieces of rock.

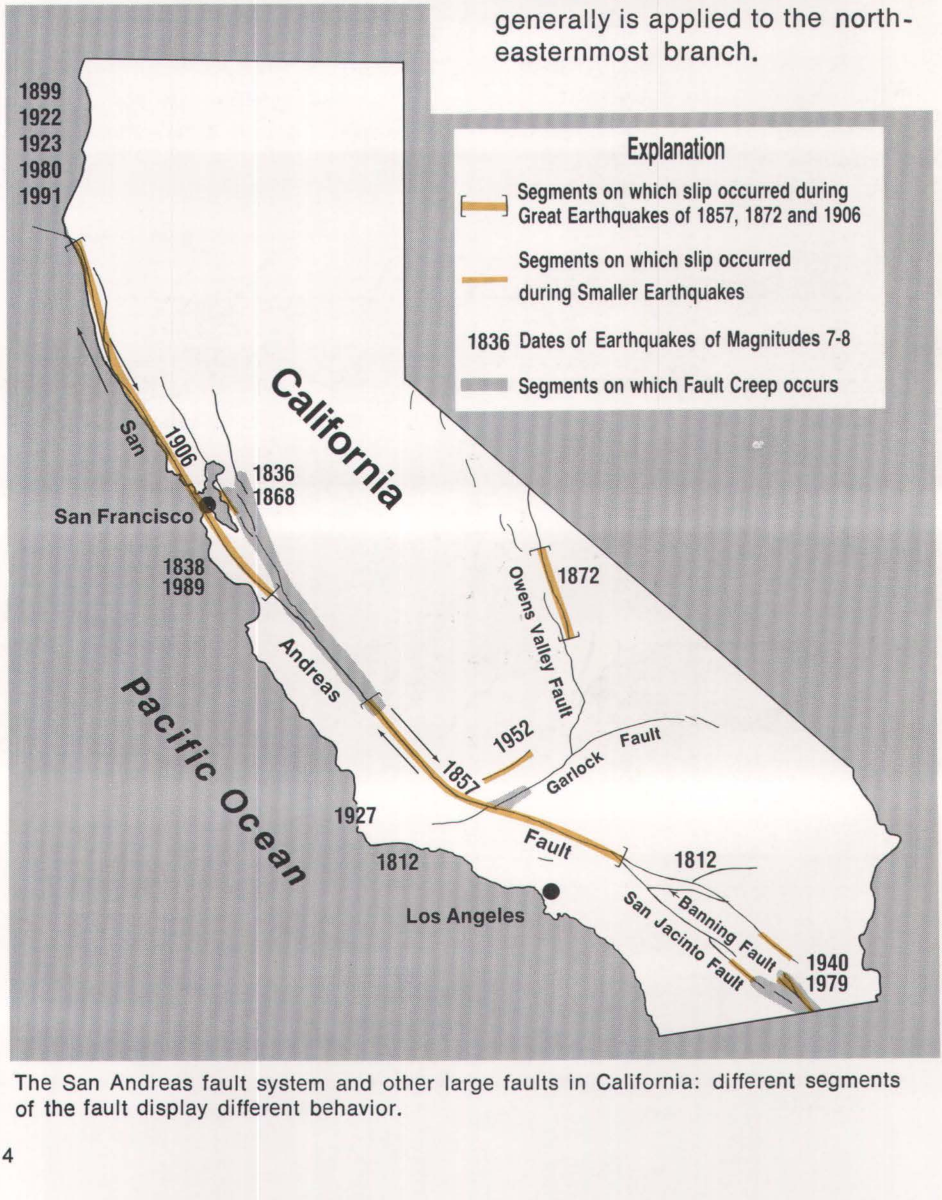


A simplified map of the Earth's crustal plates

Where Is It?

The figure below shows the general location of the San Andreas fault and several other major faults in California. The complex network of faults that make up the San Andreas fault system in central California is shown in the next figure.

The San Andreas fault forms a continuous narrow break in the Earth's crust that extends from northern California southward to Cajon Pass near San Bernardino. Southeastward from Cajon Pass several branching faults, including the San Jacinto and Banning faults, share the movement of the crustal plates. In this stretch of the fault zone, the name "San Andreas" generally is applied to the northeasternmost branch.



The San Andreas fault system and other large faults in California: different segments of the fault display different behavior.

The branches of the San Andreas fault system in central California *(from a map by Darrell G. Herd, USGS)*

What Surface Features Characterize It?

Over much of its length, a linear trough reveals the presence of the San Andreas fault; from the air, the linear arrangement of lakes, bays, and valleys in this trough is striking. Viewed from the ground, however, the features are more subtle. For example, many people driving near Crystal Springs Reservoir near San Francisco, or along Tomales Bay, or through Cajon or Tejon Passes may not realize that they are within the San Andreas fault zone. On the ground, the fault can be recognized by carefully inspecting the landscape. The fault zone is marked by distinctive landforms that include long straight escarpments, narrow ridges, and small undrained ponds formed by the settling of small blocks within the zone. Many stream channels characteristically jog sharply to the right where they cross the fault.

A stream channel offset by the San Andreas fault, Carrizo Plain, central California *(photo by Robert E. Wallace).*

What Kind of Movement Has Occurred Along the Fault?

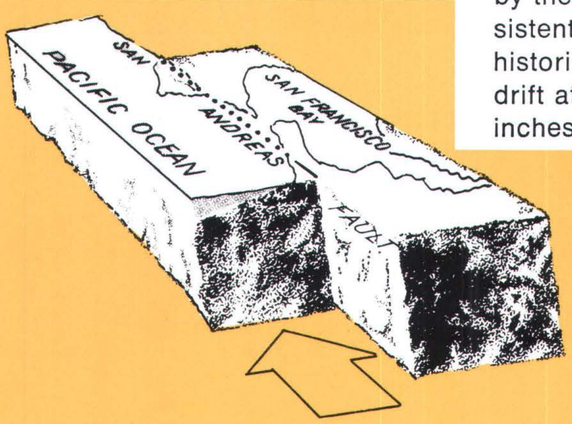
Blocks on opposite sides of the San Andreas fault move horizontally. If a person stood on one side of the fault and looked across it, the block on the opposite side would appear to have moved to the right. Geologists refer to this type of fault displacement as right-lateral strike-slip.

During the 1906 earthquake in the San Francisco region, roads, fences, and rows of trees and bushes that crossed the fault were offset several yards, and the road across the head of Tomales Bay was offset almost 21 feet, the maximum offset recorded. In each case, the ground west of the fault moved relatively northward.

Sudden offset that initiates a great earthquake occurs on only one section of the fault at a time. Total offset accumulates through time in an uneven fashion, primarily by movement on first one and then another section of the fault. The sections that produce great earthquakes remain "locked" and quiet over a hundred or more years while strain builds up; then, in great lurches, the strain is released, producing great earthquakes. Other stretches of the fault, however, apparently accommodate movement more by constant creep than by sudden offsets that generate great earthquakes (see the illustration on page 4). In historical times, these creeping sections have not generated earthquakes of the magnitude seen on the "locked" sections.

Geologists believe that the total accumulated displacement from earthquakes and creep is at least 350 miles along the San Andreas fault since it came into being about 15-20 million years ago. Studies of a segment of the fault between Tejon Pass and the Salton Sea revealed geologically similar terranes on opposite sides of the fault now separated by 150 miles, and some crustal blocks may have moved through more than 20° of latitude.

Although it is difficult to imagine this great amount of shifting of the Earth's crust, the rate represented by these ancient offsets is consistent with the rate measured in historical time. Surveying shows a drift at the rate of as much as 2 inches per year.

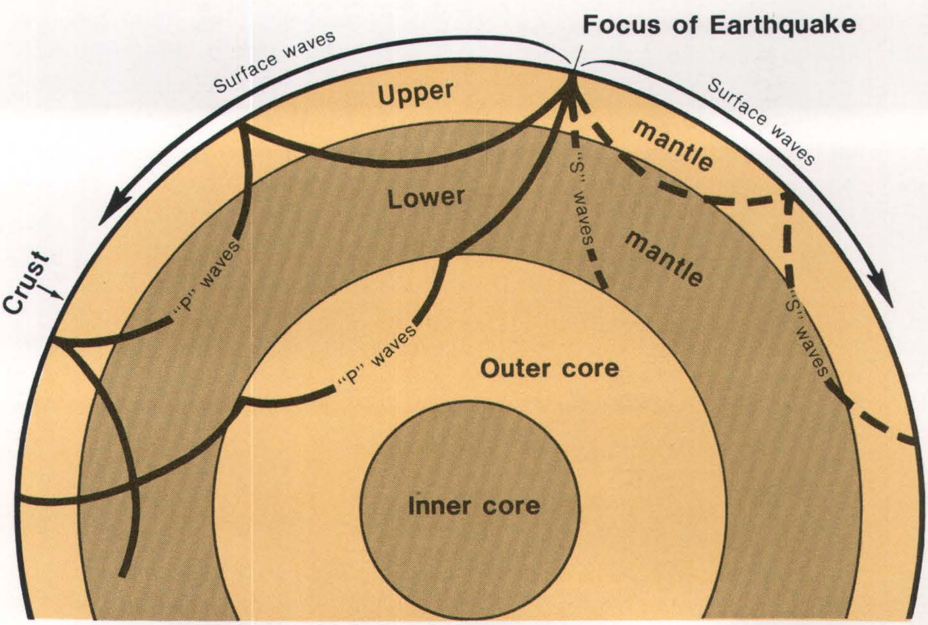


Movement of blocks along the San Andreas fault.

What Is an Earthquake?

The crustal plates of the Earth are being deformed by stresses from deep within the Earth. The ground first bends, then, upon reaching a certain limit, breaks and "snaps" to a new position. In the process of breaking or "faulting," vibrations are set up that are the earthquakes. Some of the vibrations are of very low frequency, with many seconds between waves, whereas other vibrations are of high enough frequency to be in the audible range.

The vibrations are of two basic types, compression waves and transverse or shear waves. Since the compression waves travel faster through the Earth, they arrive first at a distant point; they are known as primary or "P" waves. The transverse waves arriving later are referred to as shear or "S" waves. In an earthquake, people may note first a sharp thud, or blastlike shock, that marks the arrival of the P wave. A few seconds later, they may feel a swaying or rolling motion that marks the arrival of the S wave.

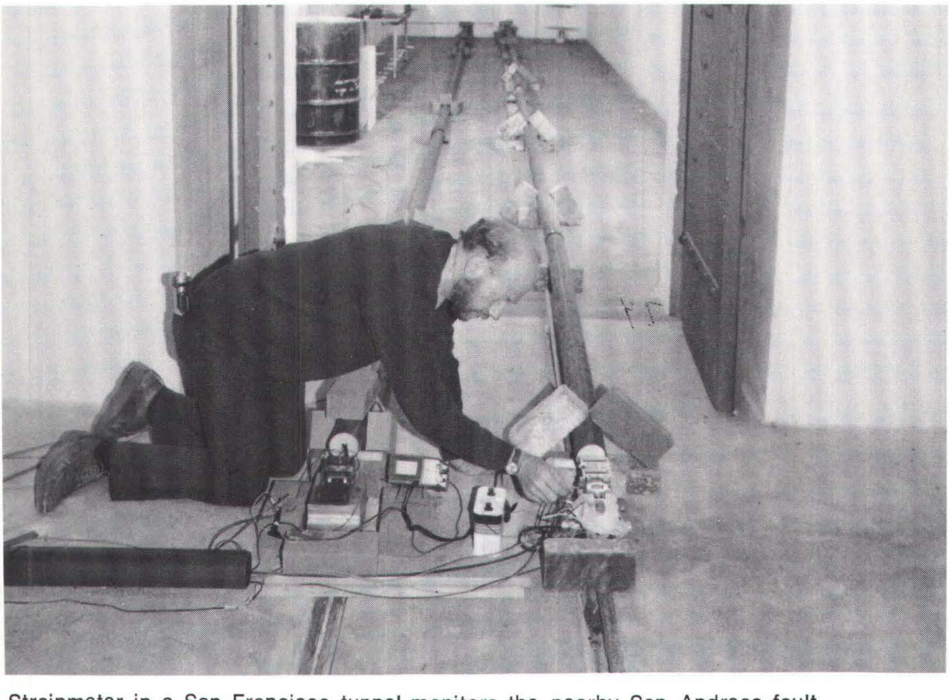


Cross section of the Earth showing the paths of some compression ("P," or primary) and transverse ("S," or shear) waves generated by earthquakes.

What Do Earthquake "Magnitude" and "Intensity" Mean?

Magnitude is a measure of the size of an earthquake. The Richter Scale, named after Charles F. Richter of the California Institute of Technology, is the best known scale for measuring the magnitude (M) of earthquakes. The scale is logarithmic; a recording of 7, for example, signifies a disturbance with ground motion 10 times as large as a recording of 6. The *energy* released by an earthquake of M 7, however, is approximately 30 times that released by an earthquake of M 6; an earthquake of M 8 releases 900 times (30 x 30) the energy of an earthquake of M 6. An earthquake of magnitude 2 is the smallest earthquake normally felt by humans. Earthquakes with a Richter value of 5 or higher are potentially damaging. Some of the world's largest recorded earthquakes—on January 31, 1906, off the coast of Colombia and Ecuador, and on March 2, 1933, off the east coast of Honshu, Japan—had magnitudes of 8.9 on this scale, which is open ended.

As the Richter scale does not adequately differentiate between the largest earthquakes, a new "moment magnitude" scale is being used by seismologists to provide a better measure. On the moment magnitude scale, the San Francisco earthquake is estimated at magnitude 7.7 compared to an estimated Richter magnitude of 8.3.



Strainmeter in a San Francisco tunnel monitors the nearby San Andreas fault.

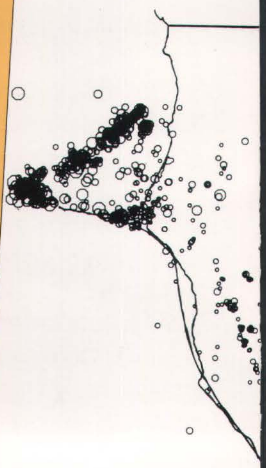
Intensity is a measure of the strength of shaking experienced in an earthquake. The Modified Mercalli Scale represents the local effect or damage caused by an earthquake; the "intensity" reported at different points generally decreases away from the earthquake epicenter. The intensity range, from I to XII, is expressed in Roman numerals. For example, an earthquake of intensity II barely would be felt by people favorably situated, while intensity X would produce heavy damage, especially to unreinforced masonry. Local geologic conditions strongly influence the intensity of an earthquake. Commonly, sites on soft ground or alluvium have intensities 2 to 3 units higher than sites on bedrock.

Earthquakes Along the Fault

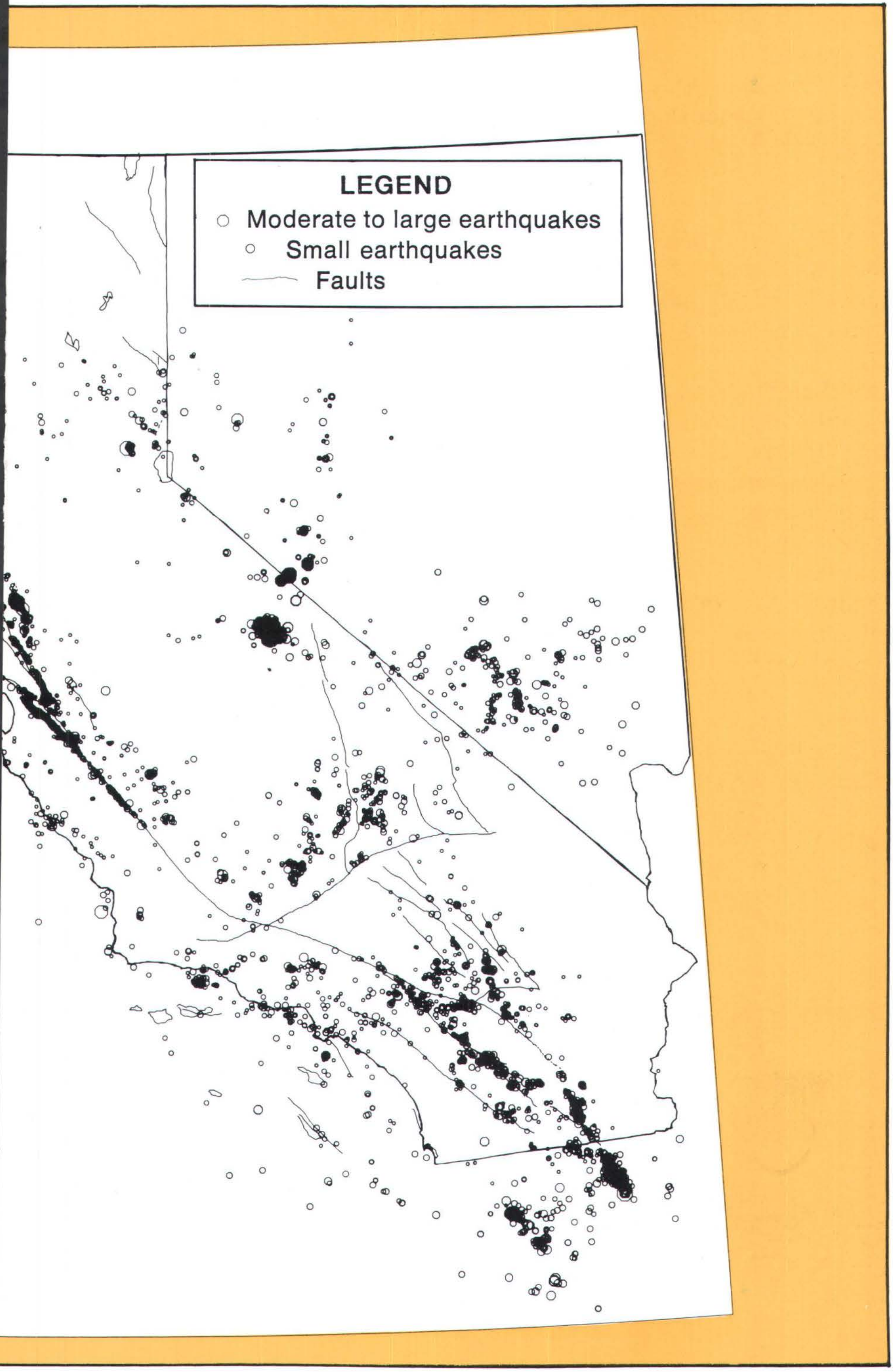
The map shows the location of all earthquakes of magnitude 1.5 and larger in the California-Nevada region during 1980. Literally thousands of small earthquakes occur in California each year, providing scientists with clear indications of places where faults cut the Earth's crust.

The largest historical earthquakes that occurred along the San Andreas fault were those in 1857 and 1906 (see the map on page 4).

The earthquake of January 9, 1857, in southern California apparently was about the same magnitude as the San Francisco earthquake of 1906. According to



Earthquakes of magnitude 1.5 and larger recorded in 1980 on the San Andreas and other large faults in California and Nevada *(data compiled by Jerry P. Eaton, USGS, and others)*

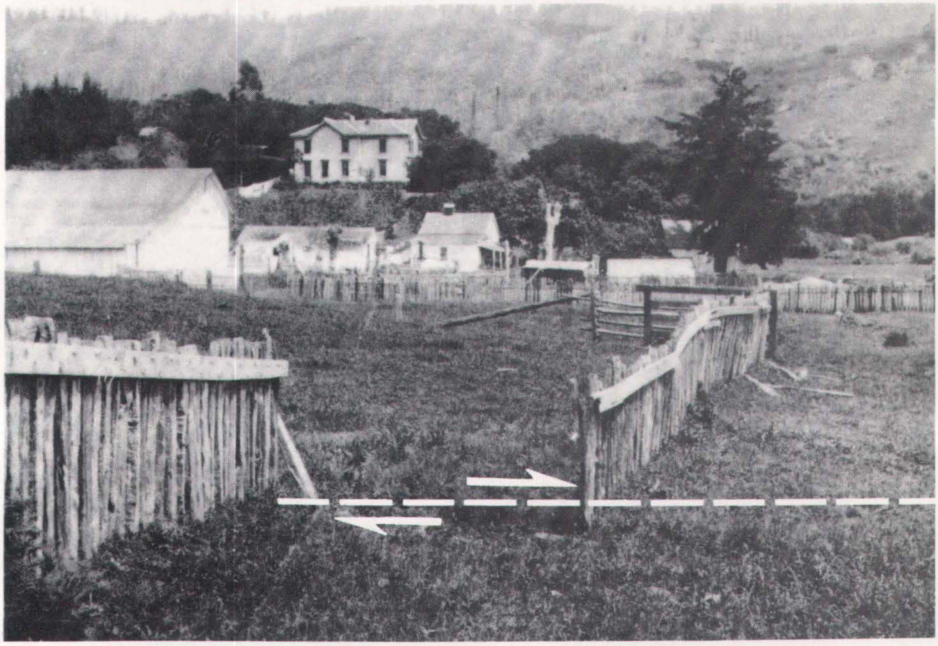

LEGEND
Moderate to large earthquakes
Small earthquakes
Faults

newspaper accounts, ground movement in both cases was roughly the same type. An account of the 1857 earthquake describes a sheep corral cut by the fault that was changed from a circle to an "S"-shape—movement clearly representative of right-lateral strike-slip. Studies of offset stream channels indicate that as much as 29 feet of movement occurred in 1857.

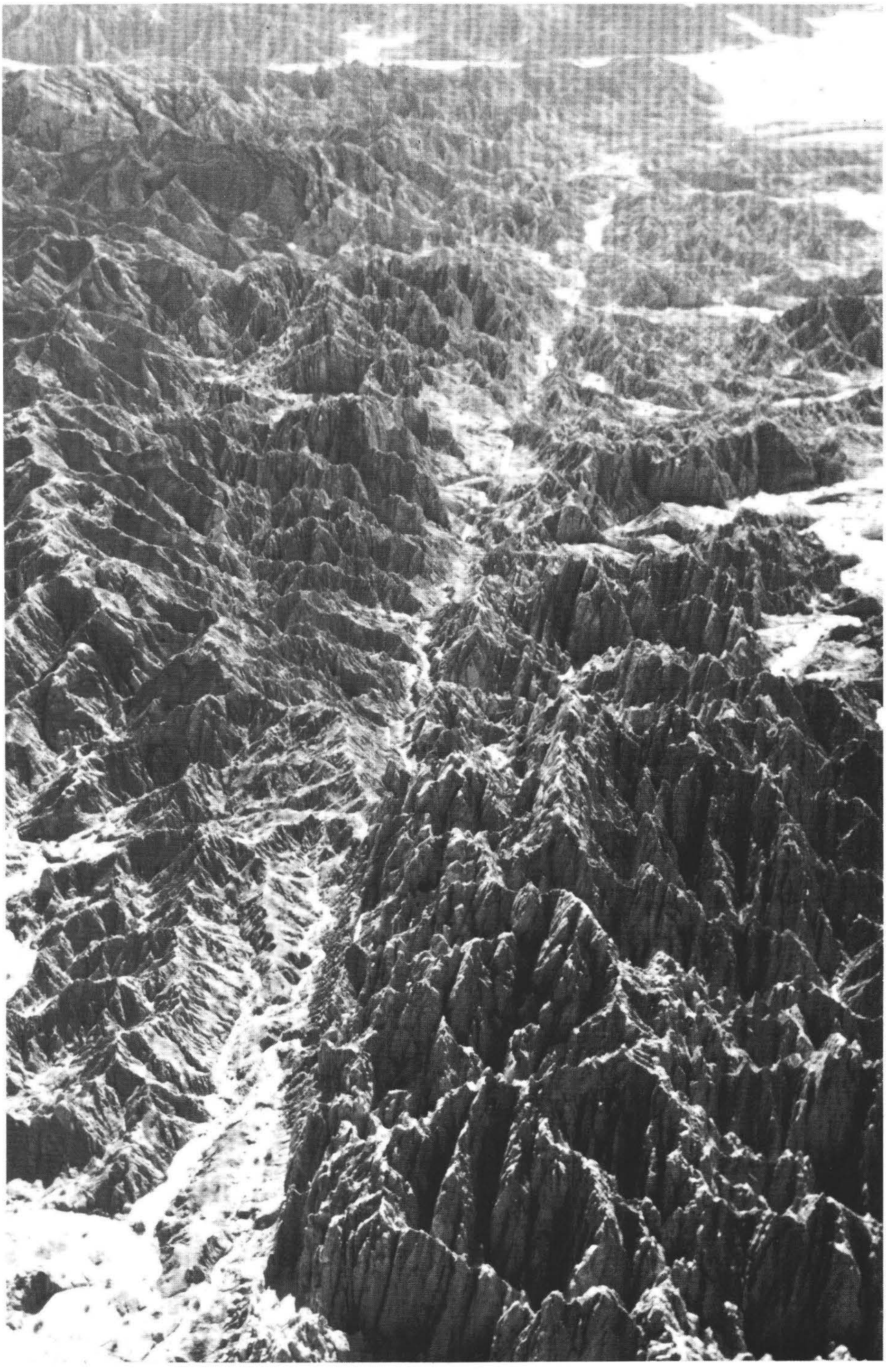
The San Francisco earthquake and fire of April 18, 1906, took about 700 lives and caused millions of dollars worth of damage in California from Eureka southward to Salinas and beyond. The earthquake was felt as far away as Oregon and central Nevada. The 1906 earthquake, which has been estimated at a magnitude 8.3 on the Richter Scale, caused intensities as high as XI on the Modified Mercalli Scale. Surface offsets occurred along a 250-mile length of the fault from San Juan Bautista north past Point Arena and offshore to Cape Mendocino.

On May 18, 1940, an earthquake of magnitude 7.1 occurred along a previously unrecognized fault in the Imperial Valley. Similar movement on the Imperial fault occurred during an earthquake in November 1979. The greatest surface displacement was 17 feet of right-lateral strike-slip in the 1940 earthquake. Clearly, this fault is part of the San Andreas system.

Other earthquakes of probable magnitudes of 7 or larger occurred on the Hayward fault in 1836 and 1868 and on the San Andreas fault in 1838.



A fence, near Point Reyes, California, offset 8.5 feet by displacement on the fault during the 1906 earthquake *(photo by G. K. Gilbert)*



The San Andreas fault in the Mecca Hills, southern California *(photo by Robert E. Wallace).*

When Could the Next Large Earthquake Occur Along the San Andreas Fault?

Along the Earth's plate boundaries, such as the San Andreas fault, segments exist where no large earthquakes have occurred for long intervals of time. Scientists term these segments "seismic gaps" and, in general, have been successful in forecasting the time when some of the seismic gaps will produce large earthquakes. Geologic studies show that over the past 1,400 to 1,500 years large earthquakes have occurred at about 150-year intervals on the southern San Andreas fault. As the last large earthquake on the southern San Andreas occurred in 1857, that section of the fault is considered a likely location for an earthquake within the next few decades. The San Francisco Bay area has a slightly lower potential for a great earthquake, as less than 100 years have passed since the great 1906 earthquake; however, moderate-sized, potentially damaging earthquakes could occur in this area at any time.

A great earthquake very possibly will not occur unannounced. Such an earthquake may be preceded by an increase in seismicity for several years, possibly including several foreshocks of about magnitude 5 along the fault. Before the next large earthquake, seismologists also expect to record changes in the Earth's surface, such as a shortening of survey lines across the fault, changes in elevation, and

A devastating fire followed the 1906 earthquake in San Francisco (*photo from the P. E. Hotz Collection, USGS Library, Menlo Park, Calif.*)

effects on strainmeters in wells. A key area for research on methods of earthquake prediction is the section of the San Andreas fault near Parkfield in central California, where a moderate-size earthquake has occurred on the average of every 20-22 years for about the last 100 years. Since the last sizeable earthquake occurred in 1966, Parkfield has a high probability for a magnitude 5-6 earthquake before the end of this century and possibly one may occur within a few years of 1988. The U.S. Geological Survey has placed an array of instruments in the Parkfield area and is carefully studying the data being collected, attempting to learn what changes might precede an earthquake of about that size.

The San Fernando earthquake of 1971 collapsed freeway overpasses in southern California *(photo by Robert E. Wallace).*

What Can Be Done About the Faults and Earthquakes?

Even though people cannot stop earthquakes from happening, they can learn to live with the problems caused by earthquakes. Three major lines of defense against earthquake hazards are being developed. Buildings in earthquake-prone areas should be designed and constructed to resist earthquake shaking. Building codes that require attention to earthquake shaking have been improving in recent decades and constitute a first line of defense. In some cities, programs are underway to strengthen or tear down older buildings most likely to collapse during earthquakes. A second line of defense involves the selective use of land to minimize the effects of hazardous ground. High-occupancy or critical structures, for example, should not be placed astride the San Andreas fault or on landslide-prone areas. The third line of defense will be the accurate prediction of earthquakes. When such prediction becomes possible, it will permit timely evacuation of the most hazardous buildings.

A major program aimed at learning how to predict earthquakes and to assess and minimize their hazards was initiated following the Earthquake Hazards Reduction Act of 1977 and is being carried out by the U.S. Geological Survey, other Federal Agencies, universities, and private groups.

This publication is one of a series of general interest publications prepared by the U.S. Geological Survey to provide information about the earth sciences, natural resources, and the environment. To obtain a catalog of additional titles in the series "General Interest Publications of the U.S. Geological Survey," write:

Books and Open-File Reports Section
U.S. Geological Survey
Federal Center, Box 25425
Denver, CO 80255

☆U.S. GOVERNMENT PRINTING OFFICE: 1992—306-523

USGS survey team using a laser beam geodolite to monitor motion between fixed points on either side of the San Andreas fault. Aircraft gathers information on atmospheric conditions between geodolite and target several kilometers away.

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural and cultural resources. This includes fostering wise use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interests of all our people. The Department also promotes the goals of the Take Pride in America campaign by encouraging stewardship and citizen responsibility for the public lands and promoting citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and for people who live in Island Territories under U.S. Administration.