EARTHQUAKES

Where they come from—why they occur —and what their effects are

by HUGO BENIOFF

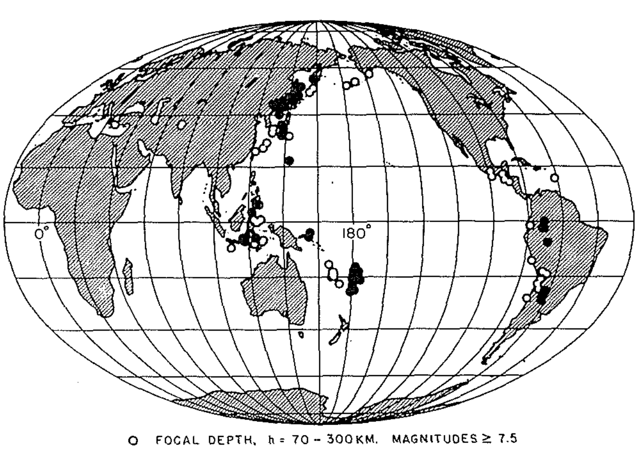
CALIFORNIA HAS HAD a long history of earthquakes going back for many hundreds of thousands of years—and since it is very likely that the state will continue to have earthquakes for a long time to come, we who live here must somehow learn to get along with them. To do this we must have some knowledge about them—where they come from, what produces them, and what their effects are.

Earthquakes do not occur throughout the whole body of the earth. They are absent in the core, which we believe to be composed of iron and nickel. They are also absent throughout most of the mantle surrounding the core. All the earthquakes which have been observed since seismographic instruments were developed have occurred within the outermost 400-mile layer of the earth.

Some of the earthquakes which occur at the maximum depth of 400 miles are quite large, but since they are at least 400 miles from the nearest man-made structure, they produce little or no damage. The most destructive shocks are shallow, originating within a thin surface layer, not more than 27 miles in thickness. California has only the shallow-type earthquakes.

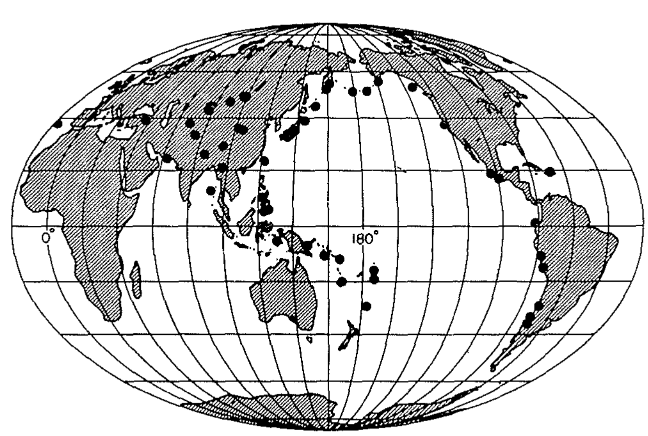
The deep earthquakes are not distributed uniformly over the globe but are confined to the circumpacific arc (left, below). Thus, in the western hemisphere, they occur along the coasts of South America, Mexico and Central America. There have been none on our California coast, and none along the Canadian coast. Beginning with the Aleutians, the active arc continues through Kamchatka, Japan, Manchuria, the East Indies and terminates in the southern end of the Tonga Islands near New Zealand. Earthquakes of intermediate depth (27-150 miles) occur along the circumpacific arc and, in addition, along a belt extending from Southern Asia through Asia Minor and the Mediterranean region.

The distribution of the shallow earthquakes is, in general, about the same as that of the deeper ones, but somewhat more widespread. A chart showing the positions of all the great shallow earthquakes which have occurred on the earth since 1904—when the seismograph was developed—(below) shows locations on the coast of South America, in Mexico, Central America, California (the San Francisco earthquake of 1906), the Queen Charlotte Islands off the coast of Canada, the Aleutians and along the eastern coast of Asia and the East Indies to New Zealand. Additional locations appear

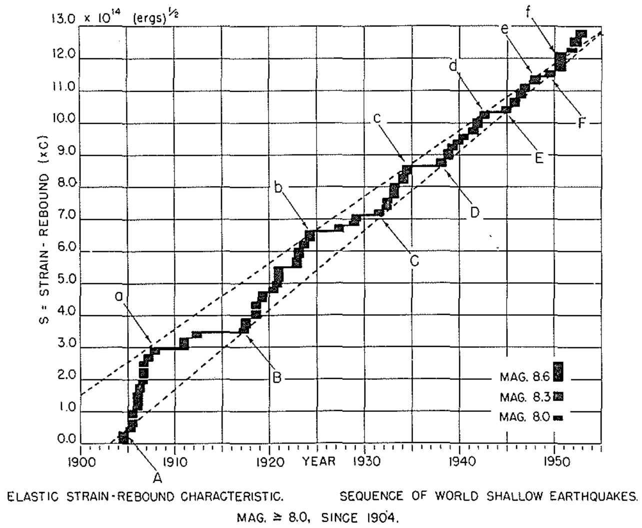


○ FOCAL DEPTH, h = 70 - 300 KM. MAGNITUDES ≥ 7.5
● FOCAL DEPTH, h = 300 - 650 KM. MAGNITUDES ≥ 7.0

LARGE INTERMEDIATE AND DEEP FOCUS EARTHQUAKES SINCE 1904.



SHALLOY EARTHQUAKES. MAGNITUDES ≥ 8.0 SINCE 1904.



Distribution of great shallow earthquakes shows they occur in alternate periods of activity and quiescence.

along the southern part of Asia and continue westward through Asia Minor to the Atlantic Ocean in the vicinity of Portugal and Spain.

These great earthquakes do not occur uniformly in time but rather in alternate periods of activity and quiesence (above). Beginning before 1904 there was a period of great activity which lasted until 1908. This was followed by a rest period of 10 years with only two earthquakes. Following this rest period an active period began, and so on up to the present date.

Peculiarly, these alternate periods of activity have decreased regularly in amplitude and duration with time. We do not know the full meaning of this behavior. It does indicate, however, that the great earthquakes of the earth are related in a single global stress-strain system.

The chart shows that at the present time the active periods have become so short that the great earthquakes are occurring about as fast as the strain builds up—one great earthquake per year.

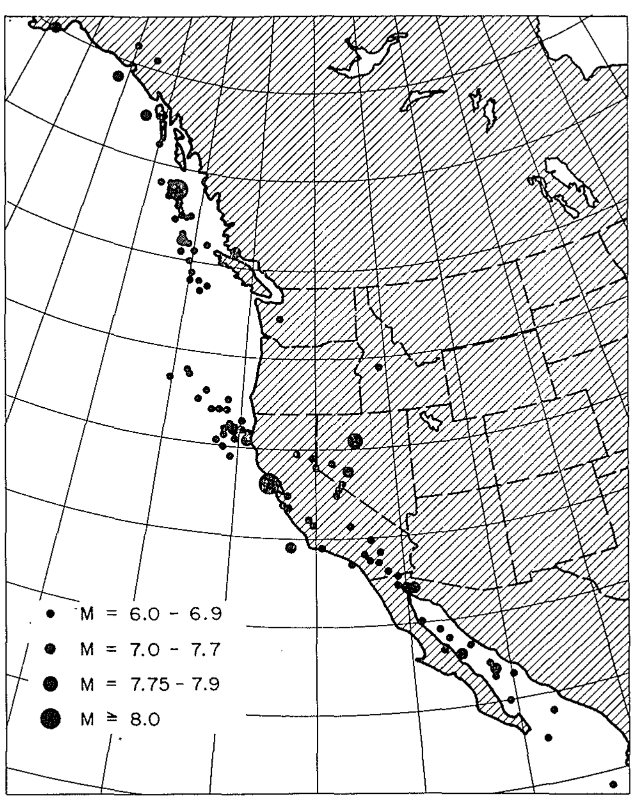
A map of all western North American earthquakes of magnitude 6 (the size of the Long Beach earthquake of 1933 and the Santa Barbara earthquake of 1925) or larger which have been instrumentally located is at the left below. It will be noted that the epicenters are concentrated along the Pacific coast. Actually, California and Nevada account for 95 percent of all the earthquakes in the United States.

In California approximately one earthquake of magnitude 6 or larger occurs every year. The reason why we don't hear more about these frequent occurrences is that the state is large and most shocks thus occur in areas of low population density.

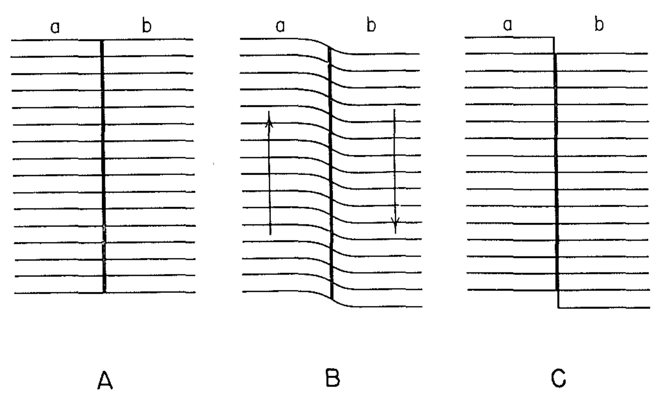
Earthquakes can be produced by volcanic activity, by blasts, even by the fall of meteorites, but the large destructive quakes are believed to be produced by slipping on faults. A fault is a fracture in the crust of the earth. The forces which presumably produce this fracture originally, may continue to operate for long periods of time afterward and so produce many additional slips along the original break.

The manner in which the fault mechanism operates is shown directly below. Following an earthquake such as that of San Francisco, in 1906, a series of parallel lines drawn across the fault (as at A) will be distorted at some later date, as shown at B of the figure, indicating that the block on one side of the fault has moved relative to the one on the other side. As a result of the high pressures which exist within the earth's crust the friction of the fault surfaces prevents slippage until the adjacent region is severely distorted.

There comes a time, however, when the stress at some point along the fault becomes greater than the friction holding the blocks together and they slip. Slip at one point increases the stress at neighboring points and consequently the slip is propagated along the fault up to



Western North American earthquakes—M6 and larger



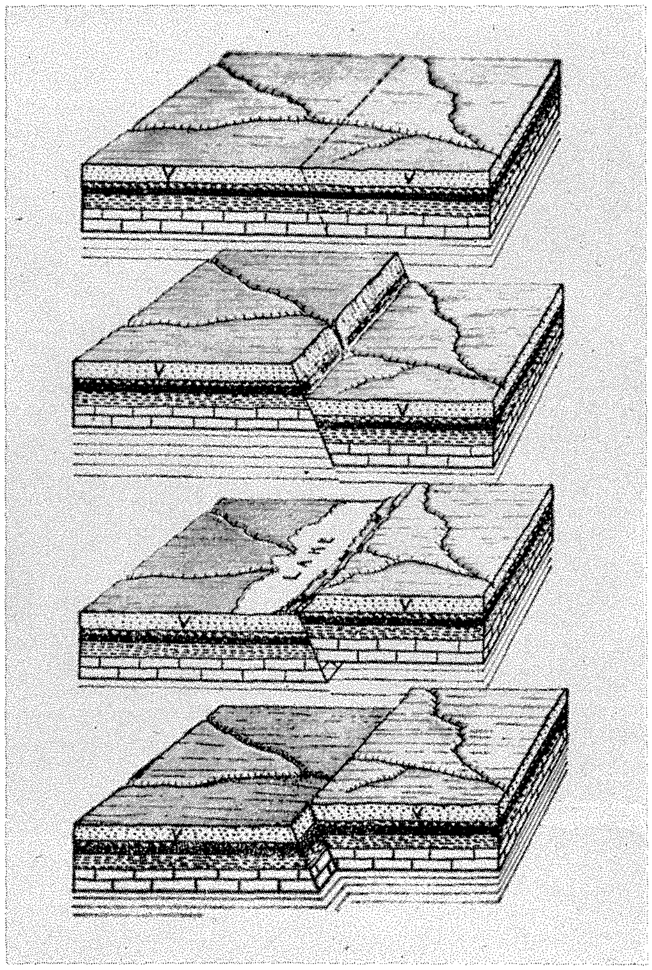
How the fault mechanism operates

distances of several hundred miles in great earthquakes. In the San Francisco 1906 earthquake the segment of the fault along which the slip occurred was approximately 180 miles in length, extending from some position off Point Arena in the north to San Juan Bautista in the south. The amount of slip at any point may vary from a few inches in a small earthquake to some 47 feet—the maximum which has been observed, in a large Alaskan earthquake. In the San Francisco 1906 shock the displacement was 21 feet. After the earthquake the parallel lines would appear as in C in the drawing. The blocks continue their relative movement after the shock and the earthquake generation process is thus repeated.

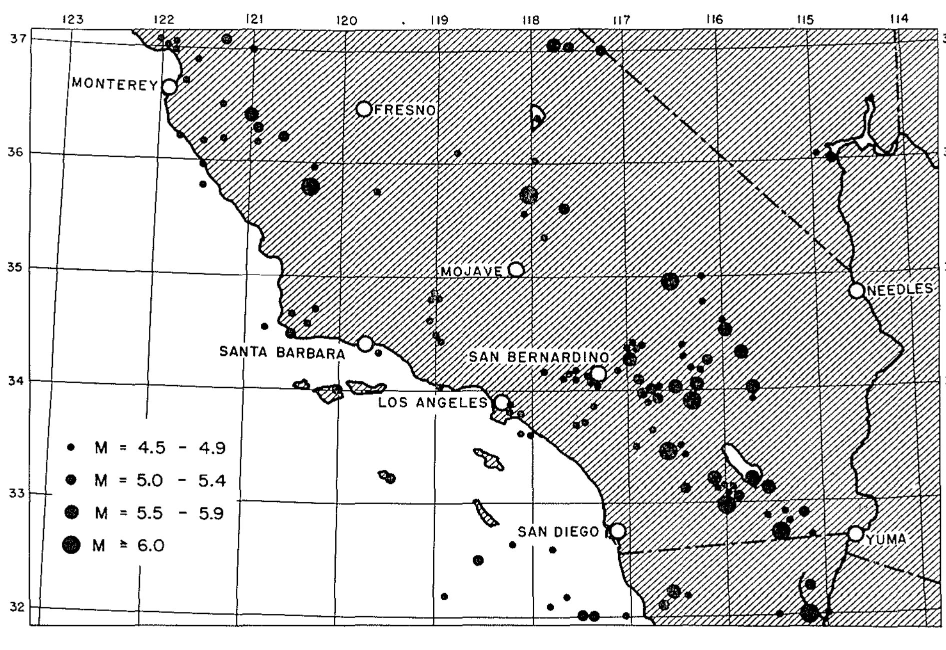
In the type of fault shown in the upper diagram at the right, known as a normal fault, the fault plane is inclined to the vertical and the upper block moves downward while the lower block moves upward. Generally faults of this type produce small earthquakes. No large shocks have occurred in California on this type of fault.

In a reverse fault, represented by the middle diagram, the upper side moves up and the lower side moves down. This is the type of fault which generated the 1952 earthquake in Kern County.

In the third type of fault, shown in the lower diagram, the blocks move horizontally. This movement is characteristic of California's San Andreas fault, which produced the great San Francisco earthquake of 1906, and a similar one in the southern part of the state in 1857. The San Andreas is the principal fault of California. It extends from a point off the coast of Oregon (page 18) through the California coast in the region of Point Arena, passing very near the city of San Francisco, and continues on through Gorman, Palmdale, Cajon Pass, San Gorgonio Pass and the eastern edge of the Coachella Valley. It ends in the Gulf of California.



Three types of faults. Top diagram shows a fault before the earth has slipped. Second diagram down shows a normal fault. Third: a reverse fault. Fourth: a fault in which the blocks move horizontally—a movement characteristic of California's San Andreas fault.



SOUTHERN CALIFORNIA EARTHQUAKES, 1934 - 1950. MAGS. ≥ 4.5

Map of southern California earthquakes from 1934 to 1950 shows eight quakes of magnitude 6 and larger. California and Nevada account for 95 percent of all earthquakes in the United States.

Air view of the San Andreas fault, looking approximately north from the vicinity of Indio. Though the structure at the lower left looks like part of that at the right, it is not. The motion of the fault is such that the oceanic (left) side is moving north relative to the continental side—at the rate of about two inches a year.

Another great fault, the Owens Valley fault, is connected with the rise of the Sierra block. In this fault the slip is both vertical and horizontal. There is another fault north of Los Angeles, known as the Garlock fault, which takes off from the San Andreas fault in the vicinity of Tejon Pass and extends at least 150 miles eastward. This fault has not been active in recent years, but the geological evidence indicates that it is very much alive. The San Jacinto fault, which is actually a branch of the San Andreas, has produced destructive earthquakes in the last 50 years. The small Inglewood fault was responsible for the 1933 earthquake in Long Beach. The White Wolf fault produced the earthquake of July, 1952.

The first great earthquake in California since white man has lived here occurred in 1857 on the southern section of the San Andreas fault. The active segment extended from a point north of Gorman to some point near the Mexican border. In 1857 this region was thinly populated and the evidence we have for the size of the earthquake is not very extensive. However, in the vicinity of Gorman a rancher reported that his circular corral

THE SAN FRANCISCO EARTHQUAKE OF 1906

These pictures of the great earthquake which struck San Francisco at 5:13 a.m. on April 18, 1906 were taken by Thomas F. Bullock, an Oakland photographer. Filed away for years, they were brought in to the San Francisco Chronicle *this spring—on the 47th anniversary of the quake—by Mr. Bullock's daughter, Mrs. Mildred Lindquist. Though these are only a few samples of almost 100 pictures taken by Mr. Bullock, they gave an indelible impression of this historic earthquake.*

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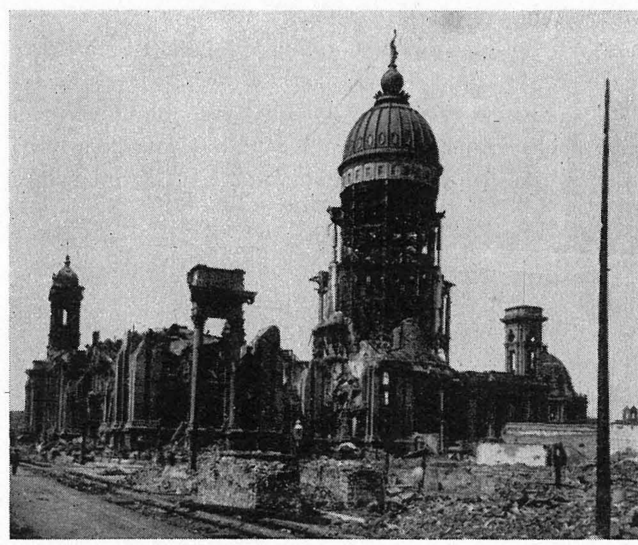
Right: Some homes were spared the fire which followed the quake—but many, like these, dropped into their basements when the quake struck.

Below: The one building left standing in this scene is the Hotel Hamilton—and it is nothing but a fire-scorched shell.



Above: The dome of the old City Hall was the only part of that building which came through the quake intact.

Left: The amusement center in Golden Gate Park. The structure was rebuilt, and is still in use.

became S-shaped after the earthquake. This indicates that the slip was of the same order of magnitude as that which produced the San Francisco earthquake of 1906. In fact, we feel rather confident from this and other evidence, that the 1857 shock produced violent shaking throughout the whole southern section of the state.

In 1872 there was a great earthquake on the Owens Valley fault in the vicinity of Lone Pine and Bishop. This earthquake shook down nearly all of the buildings at Lone Pine and killed a number of people.

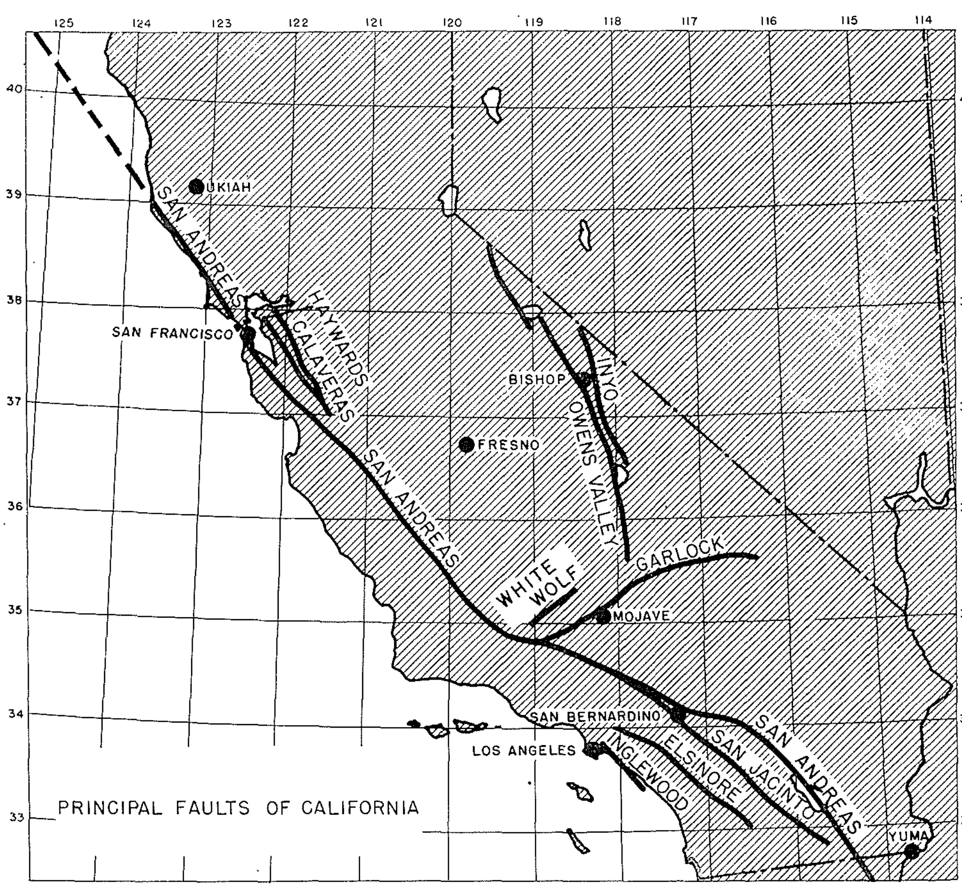
The motion of the San Andreas fault is such that the oceanic side is moving north relative to the continental side. Measurements by the U. S. Coast and Geodetic Survey indicate that the rate of this movement is roughly two inches a year. If this movement continues long enough, the day will come when Los Angeles will be opposite San Francisco. If the two inches a year is approximately correct, we may expect the stress in this fault to build up at such a rate as to repeat the slip about once per century and a quarter. A slip of the southern segment similar to that which produced the 1857 shock may thus be expected to occur any time within the next 25 or 50 years.

The San Francisco earthquake of 1906 liberated a thousand times as much energy as the Long Beach earthquake in 1933, but it was liberated over a much larger area, so that the intensity at any given point was not very much greater. We do not definitely know the total off-set on the San Andreas fault which has occurred since it started moving, but a recent paper by Hill and Dibblee indicates that it may be as much as 350 miles.

In the 1952 earthquakes in Kern County faulting began at a point near Wheeler Ridge at a depth of about 12 miles. The slipping reached the surface in something like three seconds, and moved northeastward along the fault for a distance of approximately 36 miles to the vicinity of Caliente in a matter of about 16 seconds.

Every earthquake of any size is followed by a number of after-shocks, which we believe are produced by elastic after-working in the rock. If a straight piece of wood or metal is bent and held fast for an instant and then released, it will fling back most of the way quickly, but there will be a small part of the recovery which takes place slowly. Rocks behave in this same manner. The principal shock is thus produced by the quick elastic recovery and the after-shocks represent the remaining slow creep recovery. Aftershocks may be distributed over a wide area as they have been in Kern County. It was one of these aftershocks, with a magnitude of only 5½, which occurred close enough to Bakersfield to cause greater damage than that produced by the principal shock.

There have been some instances where aftershock activity ceased in a matter of two or three days, and others where it ran as long as three years. Unless a new segment of the White Wolf fault should slip, the present tapering off of aftershock activity in Kern County indicates that the sequence is nearly at an end.



The San Andreas, which produced the 1906 San Francisco earthquake, is the principal fault of California. However, the Owens Valley, San Jacinto, Inglewood and White Wolf faults have also produced destructive quakes.