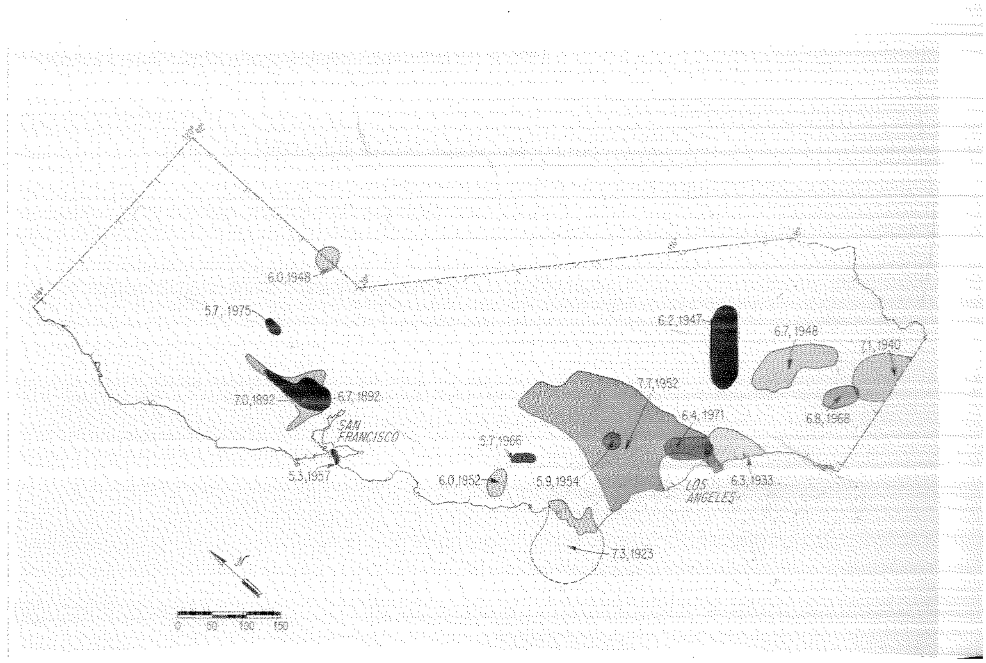
Engineering&Science
APRIL 1981

Is California "Overdue" for a Great Earthquake?

by KERRY SIEH

If a great earthquake is defined as one with a magnitude exceeding 8.0, the latest to rock California occurred in the central part of the state in 1906 — the San Francisco earthquake, whose magnitude is estimated to have been 8¼. Recent government estimates are that if that quake were to occur again, 11,000 lives could be lost and $38 billion of material damage could result. Forty-nine years prior to 1906, in 1857, southern California was racked by a similarly great earthquake. A repeat of this quake today could kill 13,000 or more people, leave 100,000 families homeless, and produce $15 billion worth of damage. The anticipated death toll is many times higher than that of any national calamity to date, and each of the latter two figures is about five times greater than the results of Hurricane Agnes in 1972, the greatest natural catastrophe so far in the history of the United States.

These kinds of facts and figures make Californians understandably sensitive to suggestions that the state is "overdue" for another great earthquake, and they react in various ways. When even a moderate-size jolt occurs somewhere in the state, scientists and laymen alike wonder if it is a forerunner or precursor of the big quake we have been anticipating for the last 70 years. Scientists are constantly scrambling over the state measuring bulges and gases and creakings of the earth's crust in the hope that they will be the predictors of the big event. The predictions of non-scientists that a great quake will devastate California on some January 4th or March 10th or November 30 have all-too-often commanded prominent positions in our newspapers and on our television broadcasts. Thrill-seekers seem to want to believe it will be soon, and they vicariously experience the seismic destruction of Los



One of the major differences between a great earthquake and a large-to-moderate earthquake is the size of the area over which destructive intensities may be felt. Each shaded patch on this map of California represents an area that has experienced destructive intensities during one of California's lesser earthquakes.

Angeles in their movie theater seats. Investors and home owners, on the other hand, hope and pray that it is at least 100 years in the offing.

Are we *really* overdue for a great earthquake? Can we actually expect a repeat of a 1906 or 1857 earthquake? If so, will it be in 1000 days or in 1000 years?

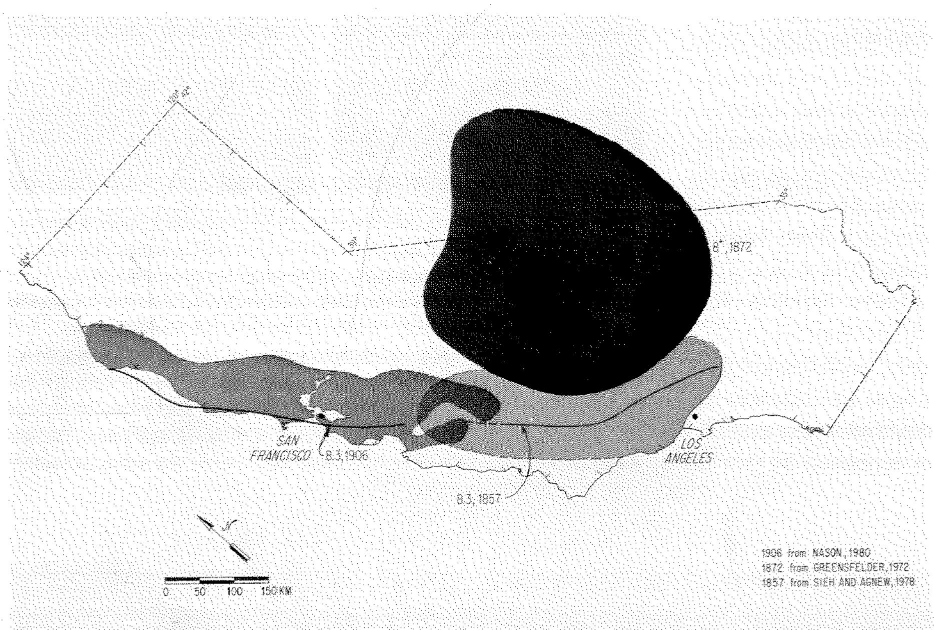
To come up with any sort of answer to those questions, we need first to sort out the great earthquakes from the lesser ones. A random sampling of moderate quakes would include the 1971 San Fernando quake, the Long Beach earthquake of 1933, and the 1952 Tehachapi earthquake. Many of us in southern California remember the shaking that February morning in 1971, which resulted in about 60 deaths and $500 million in property loss. Older Californians will recall that hundreds of lives were lost in the Long Beach event. If schools had been in session when it struck, thousands of children would have perished in the ruins of the numerous collapsed school buildings. The 1952 earthquake was widely felt, but it really produced severe damage only in the agricultural regions south of Bakersfield. We must expect that relatively local earthquakes like these will continue to occur frequently throughout California; and though each will affect a relatively small area, some of them will be far from inconsequential. A moderate event in a heavily populated area could actually produce damage and casualties comparable to a more remote great earthquake.

The three great California earthquakes about which we have eyewitness reports — those of 1906, 1872, and 1857 — were much more extensively felt than any moderate earthquake. Events of this size have the potential of severely affecting very large portions of the state, partly because they last longer than moderate quakes. Most of us who experienced the 1971 earthquake report between 10 and 30 seconds of shaking, but most Californians who felt and reported the 1857 earthquake estimated a duration of one to three minutes. The long duration and low frequencies associated with these events make them much more capable of seriously damaging large buildings than are moderate earthquakes.

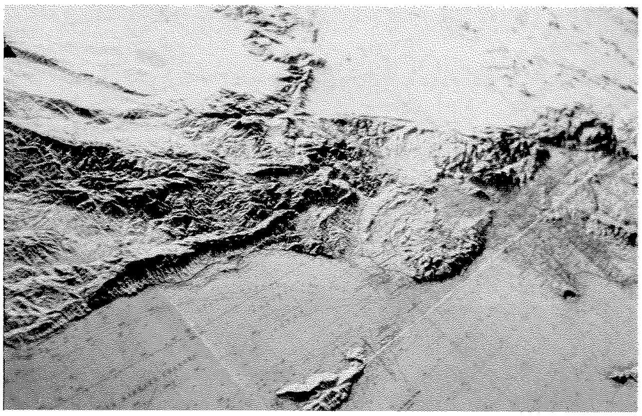
Many of us in the business of estimating how frequently earthquakes are likely to strike a given region talk about the average "recurrence interval" (R.I.). In south central Chile, for example, a 100-kilometer-long section of the coast has experienced four great earthquakes in the historical period — one each in 1575, 1737, 1837, and 1960. The repeat time, or recurrence interval, between quakes has varied from 100 to 162 years. The average of these values is 128 years, but the actual values have deviated by as much as 22 percent. Similarly, a 1300-year-long historical record for a 400-kilometer-long section of coastal Japan reveals repetition of great earthquakes every 90 to 260 years. The average R.I. is 180 years, but individual intervals have varied as much as 50 percent from this value.

In both of these regions, the period of dormancy since the latest great event is only a few decades, which is much less than the average or even the shortest recurrence interval. So we do not expect a repeat of great earthquakes in these areas for at least the next half century. We can expect that great earthquakes in southern California also occur with an average R.I., and much of my work has focused on determining what that interval is. We can also expect that actual, individual intervals will deviate several percent or tens of percent from that average, as they do elsewhere in the world.

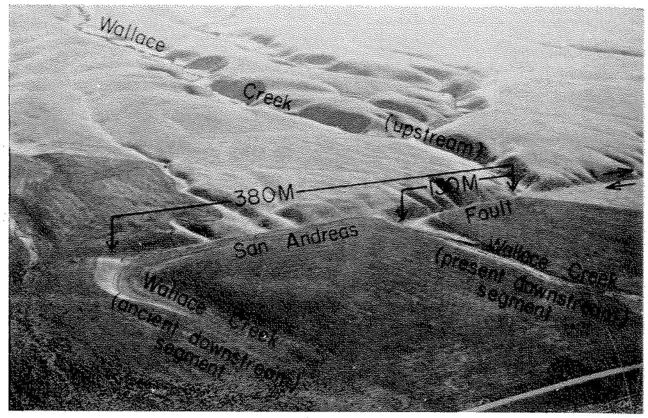
Our understanding of how and why earthquakes recur in California begins with the geological concept of plate tec-



In contrast to the map on the opposite page, this one shows the area of heavy shaking for the three great historic California earthquakes. On each map the date of the tremor and its magnitude appear next to the shaded patch, and (except for the 1872 earthquake) an arrow points to the epicenter.



A relief map of a section of southern California clearly delineates the San Andreas fault as a series of aligned linear valleys and escarpments stretching across the photo above between the arrows. The Garlock fault drops almost vertically to meet the San Andreas.



This aerial view of Wallace Creek (taken by Robert Wallace of the United States Geological Survey) is labeled to show the effects of repeated earthquakes on a piece of ground that straddles the San Andreas fault.

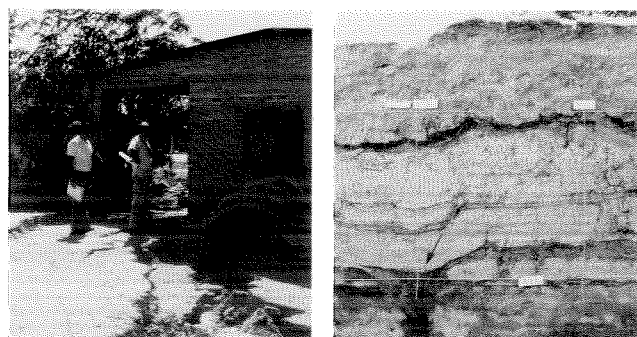
tonics — a model of the earth in which a number of rigid plates move independently over the surface, floating on a viscous layer of the earth's mantle. It is at the boundaries of those plates, where they interact with each other, that most seismic and volcanic events occur. Most of California is on the North American Plate, which is moving with respect to the Pacific Plate (on which much of southern California sits) at about 5.5 centimeters per year. The boundary between the two plates is marked by the San Andreas fault. This fault is the main actor in the plate tectonic drama in California, and it is the culprit that produced two of the three great historical earthquakes.

We can't, of course, know exactly what the San Andreas fault has in store for us, but geologists can make informed guesses about it because they believe that events and processes occurring in modern times are governed by the same laws that controlled them in the geological past. In short, the behavior of the San Andreas fault in the past is a clue to its future behavior. With this in mind, in the past five years I have become very well acquainted with two small pieces of ground that straddle the San Andreas fault — one at Wallace Creek west of Bakersfield, and one at Pallett Creek near Palmdale. In them resides the record of prehistoric earthquakes, their sizes, and their dates.

At Wallace Creek, the San Andreas fault has been offsetting small stream channels for millennia — 9 meters of offset occurred in 1857. Faint evidence for still older gully segments indicates that similar offsets were associated with earlier great earthquakes. The downstream and upstream segments of Wallace Creek now show a separation of 130 meters. If 9 meters is an average offset, 14 or 15 earthquakes might be represented in the 130-meter offset. An older channel is offset 380 meters, which by the same standards might represent about 42 earthquakes.

Studying the geology of these channels, with the aid of a tractor and a backhoe, revealed their ages and history. Several deposits of sediment were uncovered in excavated trenches — the oldest is an alluvial fan deposited by floodwaters flowing out of the mountains. A radiocarbon date indicated it was being laid down 19,000 years ago. The channel that is offset 380 meters was cut into the alluvial fan before new deposits were laid down in it between 4000 and 6000 years ago. Finally, radiocarbon analyses show that the gully offset 130 meters is less than 4000 years old. Since, according to our average of 9 meters per quake, 14 or 15 earthquakes have produced the 130-meter offset, which we now know is less than 4000 years old, the average R.I. is 285 years or less. Similarly, 42 earthquakes in 6000 years gives an average R.I. of 145 years or more. So the average R.I. at Wallace Creek seems to be between 1½ and 3 centuries.

At Pallett Creek, however, we can now see evidence for prehistoric earthquakes in much finer detail than at Wal-



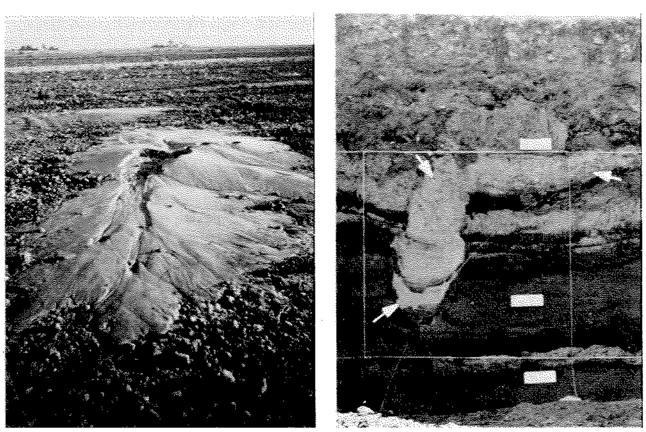
An earthquake in Baja California last June created the fissure running through the yard and beneath the house (left above). Excavation would show that layers of ground beneath it are also broken. Eventually, evidence of this earthquake will be buried beneath unbroken layers of sediments. If a geologist excavates the area after that happens, he will find something similar to the cut at Pallett Creek (right). A 16th-century earthquake caused the fissure (arrow) that cuts downward through various layers of peat. The fact that none of the overlying layers is broken by this fissure is evidence that the earthquake occurred after the lower sediments were deposited.

lace Creek. Until about 1910 Pallett Creek was a swamp in which black peats were formed and periodically buried by sand and gravel borne by the creek's floodwaters, leaving a layer cake of the peats, clays, sands, and gravels. Dissecting the cake layer by layer has led to unraveling the seismic history of the past 2000 years. About a dozen earthquakes have occurred in that period. Radiocarbon dating shows that the deepest layer was deposited about the year 0 A.D., and old planks and bottles in the uppermost layers indicate that the youngest deposits were laid down in the late 1800s or early 1900s.

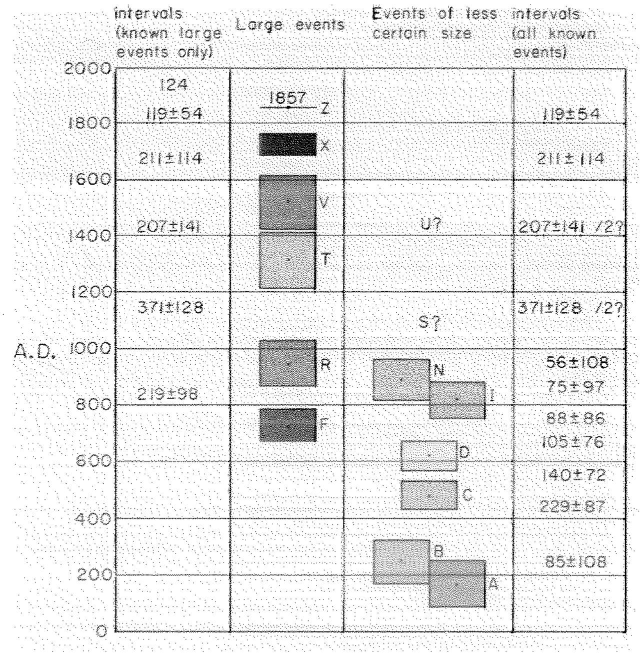
In the Pallett Creek excavations we have found several features similar to those formed during recent earthquakes elsewhere. There are fissures, for example, overlain by unbroken layers of sediment. The layers beneath these fissures (which were on the surface at the time of a given earthquake) are broken. This means that the earthquake that produced each fissure occurred after the lower layers were deposited, but before the unfissured layers above were laid down.

Another familiar feature is the sandblow or sand volcano. The strong shaking of an earthquake results in the eruption of small fountains of sand and water from the earth, leaving a little cone of sand that will eventually be covered and preserved by further layers of sediment. This has happened repeatedly at Pallett Creek. Small scarps resulting from fault slip have also repeatedly been formed, buried, and preserved.

I don't know how large each of the earthquakes at Pallett Creek was, but I have made some progress in assessing the sizes of some of them. What I try to do is to reconstruct a deformation pattern associated with each event and compare them with each other. The 1857 earthquake evi-



. . . and before the unfissured layers were laid down. Sandblows or sand volcanoes like the one at the left above, which was found in the Imperial Valley after a recent earthquake, are features formed during many earthquakes. In the late 17th or early 18th century, a similar small fountain of sand (arrows on photo at the right) erupted during an earthquake on the San Andreas fault. Its profile was revealed nearly three centuries later in the course of Kerry Sieh's geological research at Pallett Creek near Palmdale. In each of the photos of the Pallett Creek cuts, the area that is enclosed by the string is a one-meter square.



dence is now buried by a half meter or so of sand and gravel, and the modern ground surface is fairly level. The ground surface in 1857 was also nearly flat — until the earthquake deformed it. The unit of sediment overlying the 1857 deformation is a mold of the topography produced by the earthquake, showing fissures, sandblows, and scarps. I try to make maps that indicate not only the style but the amount of deformation produced by each earthquake. A map of the 16th-century earthquake at Pallett Creek shows deformations similar in size to those produced by the 1857 earthquake — which I know was a great earthquake. Thus I can assume that the 16th-century event was probably as big as that of 1857.

Above is a summary of the evidence for earthquakes at Pallett Creek, together with their R.I. averages. Recognized earthquakes are represented by rectangles; the position of the rectangle on the vertical time scale indicates the date, the earliest being at the bottom and the latest at the top. The height of the rectangle represents the uncertainty in the date of the earthquake, the lower and upper lines indicating the earliest and latest limits. (It has nothing to do with the size of the event.) For example, the time of the 1857 event is known very precisely, so it is shown as a very narrow line. All the events in the left center column have deformations, offsets, and scarps at least as large as those of the 1857 event, so they can be categorized as large — probably great — earthquakes. The events in the right center column have not been *demonstrated* to be large events, though they may well have been. And the occurrence of events "U" and "S" is suspected but not yet proven.

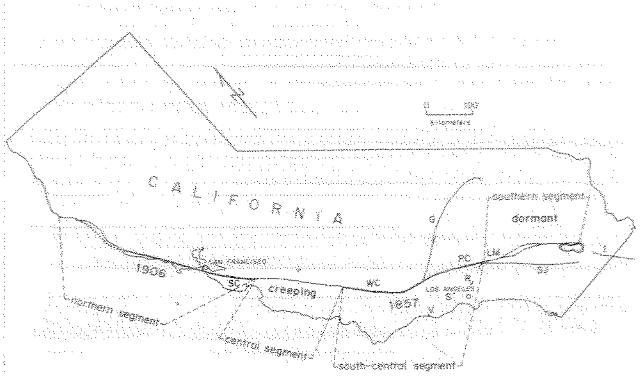
The R.I. between each event is shown in both the far left- and the far right-hand columns. Those on the left are calculated assuming that only the confirmed large events occurred. Those intervals, with one exception, are refreshingly long — 225 years, on the average. On the right are the intervals calculated assuming that all recognized events are large. Some of these intervals are frighteningly short. In fact, if events "U" and "S" did occur, the average recurrence intervals would be a mere 123 years.

The problem is that the Pallett Creek data are frustratingly ambiguous at exactly the level of most significance. On the one hand, the average R.I. may be 225 years. Alternatively, it may be less than 150 years, and only a few very long R.I.s are more than the current 124-year-long period of dormancy. And there is certainly the possibility that the average R.I. is only 123 years, with the current 124-year period of dormancy being greater than all but one of the past 9 recurrence intervals.

Now, how does all this fit into a regional picture of the San Andreas fault? First, we can break the fault down into four segments according to what we know about its activity — northern, central, south central, and southern. The 1857 earthquake may be characteristic of all great earthquakes along the south central segment if the average R.I. at Wallace Creek is identical to that at Pallett Creek. This is most likely if the average R.I. is between 150 and 225 years, since this is the range of overlap in the R.I. determined at the two sites. If the average R.I. at Pallett Creek is about 125 years, earthquakes must be more frequent there than at Wallace Creek, where the shortest average R.I. appears to be about 150 years.

Two large earthquakes have been produced historically along the northern segment — one in 1838 and the other in 1906. We suspect that the recurrence intervals are similar to those along the south central segment of the fault, but geologic studies like those I have described have only just begun there.

The 170-kilometer-long central stretch of the fault has historically slipped at rates as high as 30 millimeters per year. Some geologists have speculated that this stretch will not be involved in a future great earthquake because the strain accumulation is being relieved by this annual fault slip, or creep. Others have suggested that, since this creeping section separates the two segments that have produced great earthquakes, it is unlikely that a "superquake" that



The San Andreas fault can be broken down into four segments in terms of its historic activity. Studies at Wallace Creek (WC), Pallett Creek (PC), and at a site near Indio (LM) are revealing much of the record of its behavior. Three other major southern California faults are also shown — the Garlock (G), the San Jacinto (SJ), and the Imperial (I).

ruptured all three sections could occur at one time. I would like to point out, however, that the 30 mm/yr of slip in the creeping zone is only a fraction of the long-term slip rate, which at Wallace Creek is between 33 and 64 mm/yr. Thus it is quite plausible that a great event could rupture the south central section, propagate through the creeping central segment with a few meters of offset, and rupture the northern segment too. Our civil preparedness programs should allow for the possibility that both San Francisco and Los Angeles could be severely damaged simultaneously by such a superquake.

The southern segment of the San Andreas fault has historically been dormant — it has not produced a great event in the 210-year-long historical period. I have been working at a site just east of Indio in an attempt to determine its potential. Studies there are far from complete, but the preliminary findings indicate that the latest great earthquake in this area may have been over 350 to 600 years ago. Two or three great earthquakes have occurred within this same period of time at Pallett Creek.

It is possible to argue that such a long period of dormancy means either that this segment is the next to go or that it is less of a risk than the segment that broke in 1857. My opinion is that no one (including myself) has enough information at this time to make a meaningful statement about its possibilities.

What conclusions can we draw for the south central section of the fault if the data at Wallace Creek suggest that great earthquakes recur every 1½ to 3 centuries on the average, and the data at Pallett Creek yield evidence that the average recurrence interval is somewhere between 125 and 225 years? If the interpretations at Wallace Creek can be believed, the current dormant period will not equal the average R.I. until at least the beginning of the 21st century. Before we let this reassure us, however, let me remind you that great earthquakes don't tend to adhere rigorously to their average R.I. when making individual appointments. Just recall the 20 to 50 percent variations for Chile and Japan.

The Pallett Creek data allow that we could just be reaching the average R.I., which means that the next great earthquake in southern California would not break millennial tradition if it occurred within the next decade. Neither would the prehistoric record be contradicted if that event failed to occur within the lifetime of most readers of this article.

We are almost certainly not "overdue" for a repeat of the great 1857 earthquake, but we are clearly well along in the process. We are much too far along, in fact, to neglect serious preparations for the eventuality. Geologists will continue to work toward more precise forecasts and predictions of great earthquakes, but the data we have already assembled should press upon all of us the immediate need for civic action toward preparedness. The economic and human risks are just too great to gamble with the odds. The future of all of us depends on such preparedness. □