

SEISMICITY OF THE WESTERN UNITED STATES

By Perry Byerly*

The distribution of earthquakes throughout the world as based on historic records was studied thoroughly by Comte de Monessus de Ballore in the early part of this century. He accumulated a manuscript catalog of some 171,000 entries which is said to occupy 85 feet of bookshelves in the library of the Societe de Geographie in Paris. The historic record of earthquakes reported felt by people is obviously weighted in favor of those countries with the longest written history.

Montessus noticed that the greater number of shocks occurred in two approximately great circle zones about the earth. One of these passed through the East Indies, the Himalayas, the Caucasus, the Alps and the West Indies. The other zone encircled the Pacific Ocean. According to his record, about 54 percent of the earthquakes on record had occurred in the former zone and about 40 percent in the latter zone. This then was the record up to about 1906. It was Montessus who pointed out that the greater the gradient of the earth's crust the more earthquakes.

Writing in "Les Tremblements de Terre", published in 1906, Ballore mentions Milne's "ingenious" method of locating earthquake centers by the use of the records of seismographs. Ballore had considerable doubts about this new method. Unless it could be checked by someone feeling it he could not accept the earthquake.

But today it is not an earthquake if not recorded on instruments. Our pattern of thinking has changed. Although people in this area may feel what appears to be an earthquake, if we have no records we blame it on atmospheric disturbance.

Now our great catalog of earthquakes, "The Seismicity of the Earth" by Gutenberg and Richter, is based on instrumental data from about 1900 to date. The writers find that 80 percent of shallow shocks (depth of focus no more than 60 km.), 90 percent of intermediate depth shocks (depth of focus 70 to 300 km.), and all but one deep shock have occurred in the circum-Pacific zone. The Mediterranean and trans-Asiatic zone contain nearly all the others.

The Pacific coast of the United States shares in the activity of the circum-Pacific zone. One of the remarkable facts is that this area has no shocks of intermediate or deep types. This must be of utmost geologic significance but the explanation is not clear.

Although it is the Pacific region of this country which has the most earthquakes, it must not be forgotten that the greatest earthquakes known to have occurred in the United States centered in the Mississippi valley in southern Missouri. Here is no great gradient of the earth's crust--no high mountains bordering deep seas. These three earthquakes in 1811-12 were felt all along the Atlantic Seaboard, in Canada and along the Gulf

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coast. They were strong enough to shake down chimneys at a distance of 325 miles from the center. At this distance east of the San Andreas Fault the 1906 California earthquake was not even felt.

To a certain extent a region which has great shocks very occasionally is fortunate if it has frequent smaller shocks to remind the inhabitants to build safely. Dr. Tandon has told me that northern India lacks these smaller reminders which we have in California.

The Pacific Coastal States

California-Oregon-Washington

California: Although all parts of California experience occasional earthquakes, they occur most numerous along a fairly definite zone. This zone is off the coast at the extreme north of the state. Many of the shocks centering here are strong and are felt in the towns of Humboldt and Del Norte County. Occasionally there is a shock centering inland and these do the major damage. To the south of this region the San Andreas Fault runs through Mendocino, Sonoma and Marin counties. Since this portion of the fault experienced the largest displacements observed in 1906, we may trace our earthquake zone along it, although this territory has been comparatively free of earthquakes since 1906.

South of the Golden Gate the earthquake zone follows the Coast Ranges. There are no centers at any great distance to sea. Earthquakes are frequent, both small and moderate. In the San Francisco Bay area there have been large shocks in 1836, 1838, 1865, 1868 and 1906. The zone turns with the geologic structure and coast line near Santa Barbara county. Its width is approximately that of the mountain belt. The San Andreas Fault was the seat of the very large earthquake of 1857 in this region. The Tehachapi earthquake of 1952 was in the northern part of the zone and the Santa Barbara shock of 1925 in the southern part. In the vicinity of Los Angeles County the zone embraces the region from the coast to the Great Valley, the 1857 fault break to the north and the Long Beach earthquake of 1933 along the coast. To the southwest in southern Orange County we can cite the great destruction at San Juan Capistrano in 1812. However the main zone of recent activity swings inland to the Imperial Valley which has been the seat of many destructive shocks in this century.

The central valley of California is almost free of epicenters. However the fringing effects of earthquakes in the Coast Ranges sometimes produce damage there.

The eastern borders of the southern Sierra Nevada have their shocks, particularly the great earthquake of 1872 on the Owens Valley Fault. Fair sized shocks occur north of this region along the eastern flank of the Sierra, sometimes over the boundary in Nevada. However as far north as Modoc County, in the northeast corner of the state, they are rare. There are no parts of the state where shocks are never felt.

The historic record of shocks in California begins in 1769.

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Oregon: Oregon presents an anomaly in the distribution of earthquakes along our Pacific Coast. Our seismic history of Oregon goes back less than a hundred years. In this period I find only four shocks on record which were strong enough to damage chimneys and for only two or three was other damage to masonry reported. The main California coastal zone passes to sea above Cape Mendocino and is a hundred or more miles at sea off Oregon. The zone on the eastern flank of the Sierra Nevada dies out before it reaches Oregon and the one coming down from the north in the Puget Sound area also dies out. Small shocks are felt in the state, but altogether only about 125 shocks have been reported felt in the state from 1866 to 1950.

Washington: Washington is the fourth most seismic state of the western United States. The earthquake history of that state begins in 1833 with the report of a slight shock at Fort Nisqually. Although many small shocks have been felt, there appear to have been only eight earthquakes strong enough to throw down chimneys. Most of these have been near Puget Sound. This is the southern extension of the very active zone coming down from Queen Charlotte and Vancouver Islands.

The Inland States

Nevada, Arizona, Utah, Idaho, Montana, New Mexico, Wyoming, Colorado

Nevada: Nevada is second to California in seismicity. The record begins in 1360 with a shock which was "very violent" in Carson City and was felt also in Utah and California. The population of Nevada is small--great areas are almost uninhabited. This has had its effect on the number of shocks reported. Of some 568 earthquakes reported between 1860 and 1952, only about 13 are stated to have damaged chimneys or walls. The larger shocks have occurred in the western half of the state. If one feels it necessary to speak of zones, he might think of a western zone as that near the eastern flank of the Sierra Nevada extending north from Owens Valley in California and another north-south zone running from the Excelsior Mountains in the south to Pleasant Valley in the north. In 1915 Pleasant Valley was the locale of a large earthquake accompanied by great surface faulting. In December 1954 even more spectacular faulting occurred in the Dixie Valley-Fairview Peak neighborhood. Minor faulting occurred to the south in two shocks: Cedar Mountains in 1932 and Excelsior Mountains in 1934. Minor faulting also accompanied the Fallon earthquakes of the summer of 1954.

Arizona: There are only about 35 earthquakes on record as having been felt in Arizona and having their centers in Arizona from 1850 to 1952. There have been also a number of California shocks which were felt in western Arizona. And the Sonora (Mexico) earthquake of 1887 was sharp in the south-eastern part of the state. Only four shocks centering in Arizona seem to have been of intensity VII or more although the Sonora shock was that great in parts of Cochise County. If one seeks to find an earthquake zone, he may see one running from north-central Arizona, north through central Utah, along the Idaho-Wyoming border and into central Montana.

Utah: The third most seismic state in the western United States is Utah. As in the case of the other states, excepting California, the history is very short. Also the population of the state is not large and there are vast desert regions. The record begins with 1853. The record discloses

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about 13 shocks which were strong enough to damage chimneys or crack walls. The total number on record to the end of 1952 is almost 250.

Idaho: Idaho has been fairly free of earthquakes since 1879 when the first shock was reported. There have been only about three shocks for which damage to masonry or chimneys has been reported. The total number of shocks is about 33. As throughout this survey, an effort has been made to exclude fringing effects of shocks centering in other states.

Montana: The state of Montana stands fifth in our seismicity list. The first report is from Helena in 1869. There have been perhaps eight shocks strong enough to damage chimneys and walls. The major seismicity has been in the western half of the state.

New Mexico: The state of New Mexico has had at least seven shocks on record since 1868 in which chimneys or walls were damaged. The total number on record is about 60. There were hundreds of shocks felt in Socorro and environs in 1906 and 1907 of which only three were counted for the seismicity rating. The order of these many shocks was not strictly that of main and aftershocks. In 1904 there was another month-long swarm of earthquakes at Socorro.

Wyoming and Colorado: Wyoming and Colorado are the least seismic of our western states. Although most earthquake regions have mountains, it does not follow that mountainous regions always have earthquakes. If one wishes mountains without real earthquake hazard, he should try Colorado. We find only one earthquake on record in Colorado of our class 3, strong enough to damage chimneys. Wyoming has none.

Seismicity

The map, figure one, rates the "seismicity" of the various states. Under the name of the state appears three numbers. The first of these gives the number of earthquakes on record of which the intensity was 4 or less. The second number represents those shocks of intensity 5 and 6, while the last number represents shocks of intensity above 6. The intensities were in the main those given by the Earthquake Catalog and by the U.S. Coast and Geodetic Survey. An effort was made to eliminate aftershocks, which follow in vast numbers a large shock. Also earthquakes were assigned to a state only if the epicenter appeared to have been in the state. To rate seismicity, each of the smaller shocks was weighted one, each of the intermediate shocks weighted five, and each of the larger shocks weighted twenty-five. These weighted values were summed for each state and the sum was divided by the area of the state. Then California was arbitrarily given the seismicity of 10 and the other states values in ratio of the above quotients.

California is clearly the banner state. It is true that its history is longer. The first entry in the Earthquake Catalog is for 1769, where that for Nevada, its nearest rival, is for 1860. However we could double the seismicity for all the other states and still leave California seismically preeminent.

Notable Earthquakes

An earthquake may be notable for any of three reasons: (1) If it is accompanied by a large surface fault break, which is rare and geologically most significant; (2) if it has a great magnitude, i.e. produces very

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large seismograms all over the earth and contains very great energy; such are also highly significant in relation to the geophysics of strain release and "energy budget" of the earth; (3) if it is so centered as to cause great damage to the works of man; then it is a matter of great significance to engineers, to relief agencies, and to those who lose lives and property.

So when we discuss notable shocks of the area they may be brought under these headings:

1. Faulting

Here we discuss only cases of very conspicuous faulting.

California

California, 1857, Fort Tejon earthquake: This earthquake was evidently a very great one for it was severe in both San Francisco and Los Angeles. The San Andreas Fault broke along its southern part for 200 or more miles. There was both horizontal and vertical displacement in unrecorded amounts.

California, 1872, Owens Valley earthquake: This was another very great earthquake felt throughout the state. The center was in the Owens Valley, on the Owens Valley Fault which lies on the eastern flank of the Sierra Nevada. The main fault break was for at least forty miles with vertical displacement as great as 23 feet and horizontal displacement as great as 18 feet. As in the 1857 quake, the population near the center was small. However 27 people were killed in the hamlet of Lone Pine.

California, 1906, San Francisco earthquake: This earthquake would be entered as notable in any of the above three categories. But it is supreme in class 1. In this shock the San Andreas Fault broke for a length of 270 miles, from Humboldt County in the north to San Benito County in the south. The displacement was almost purely horizontal and at the maximum amounted to 21 feet at the head of Tomales Bay. The west-erly side moved north relative to the easterly side. It is not clear whether the horizontal motion in the earthquake of 1872 (Owens Valley) was of the same nature.

California, 1940, Imperial Valley earthquake: Another conspicuous fault break occurred in 1940 in Imperial Valley. This was another case of horizontal movement, amounting to some 14 feet to 15 feet maximum. The west side moved north relative to the east side. The break extended at least 40 miles, crossing the border into Mexico where it was not followed to its end.

Nevada

There have been two cases of conspicuous faulting in Nevada and several others of cracking with very small displacement along lines or linear zones.

Nevada, 1915, Pleasant Valley earthquake: Pleasant Valley lies in north-central Nevada. "The fault appeared as a fresh vertical scarp from

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five to fifteen feet in height, running for over 22 miles along the junction of the alluvial apron and the base of the Sonoma Range." The Sonoma Range lies on the eastern border of Pleasant Valley.

Nevada, 1954, Dixie Valley-Fairview Peak earthquake: A remarkable series of en echelon faults accompanied two shocks about four minutes apart in December 1954. The region of this faulting was south of the Pleasant Valley area. The 1954 faulting extended in a north-south zone for some 50 miles. Scarps as great as 23 feet were formed, although these were in soil on hillsides so that they probably should not be thought of as equal to displacements in the basement rock.

The above represent what the writer would call conspicuous faulting in the western United States--faulting of a type that makes one feel justified in saying that the break was the direct cause of the shaking. Some dozen cases of minor cracking in linear zones could be cited.

2. Magnitude

Certainly the early earthquakes of 1857 (Fort Tejon) and 1872 (Owens Valley) were shocks of great energy, although seismographic recording was unknown in those early years. It is possible that the earthquake of 1838 in the San Francisco Bay region deserves to be rated high. The reports are meager but they suggest a surface break of the San Andreas Fault and great intensity.

Since seismograms have been available we can judge the earthquakes by the Richter magnitude. The 1906 earthquake (San Francisco) was the largest, magnitude $8\frac{1}{4}$. The 1915 (Pleasant Valley) with magnitude $7\frac{3}{4}$, and the 1952 (Tehachapi) with magnitude 7.6 follow, although not at all in the same class as the 1906. As for others of magnitude 7 or greater, we find the 1954 (Fairview Peak) shock at 7.2 and the 1949 (Seattle) earthquake at 7.0.

There have been some shocks centering well off the coast of Humboldt County, California with magnitude of 7, but I have excluded these as well as those over the boundary in Mexico and British Columbia.

3. Damage

Once again the 1906 earthquake heads the list. The earlier large California shocks visited a state too sparsely populated to do great damage to the works of man. The 1906 shock did great damage to cities for a length of some 150 miles adjacent to the fault. The next earthquake to rouse California thoroughly was the Santa Barbara shock of 1925. Its magnitude was only $6\frac{1}{4}$ but it centered very near the city and the damage was great. Then came the Long Beach earthquake of 1933, again a shock of magnitude $6\frac{1}{4}$ but centering in a heavily populated region. The Imperial Valley has had a number of shocks locally destructive but I think the one of 1940 is the only one which should be included here.

In the state of Washington the Seattle or Olympic earthquake of 1949 deserves mention in this category.

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The Helena, Montana shocks of October 1935 (the effects of the three large ones cannot be separated) also deserves inclusion under this category.

We shall now rate those shocks included in this section on a multiple scale of five numbers. The first number will represent the intensity, the second, R, the maximum distance to which the shock was felt, the third, N, the number of people killed, the fourth, D, the property damage in dollars, and the fifth number the magnitude.

For shortness let us define various ranges of R, H and D in a scale 1 to 9.

	R miles	N	D
1	< 10	< 10	$< 10^4$
2	10-50	10-50	10^4-10^5
3	50-100	50-100	10^5-10^6
4	100-200	100-500	10^6-10^7
5	200-350	500-1,000	10^7-10^8
6	350-500	1,000-5,000	$10^8-5 \times 10^8$
7	500-750	5,000-20,000	$5 \times 10^8-10^9$
8	750-1,000	20,000-100,000	$10^9-2.5 \times 10^9$
9	> 1,000	> 100,000	$> 2.5 \times 10^9$

Then for nine of the above shocks:

<u>Earthquake</u>	<u>Date</u>	<u>I</u>	<u>R</u>	<u>N</u>	<u>D</u>	<u>M</u>
San Francisco	1906	9	6	4	6	$8\frac{1}{4}$
Santa Barbara	1925	8	5	2	4	$6\frac{1}{4}$
Long Beach	1933	8	5	4	5	$6\frac{1}{4}$
Helena	1935	8	5	1	4	$6\frac{1}{4}$
Imperial Valley	1940	8(9)	6	1	4	6.7
Seattle	1949	8	6	2	4	7.0
Kern County (Tehachapi and Bakersfield)	1952	9	6	2	5	7.7
Dixie Valley-Fairview Peak	1954	8(9)	6	1	2	7.1
Eureka	1954	7	5	1	3	6.6

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It should be noted that the effects of the two Kern County shocks are not separated.

The intensity rating expresses my judgment. I feel that intensity 9 is as high as we should go in any of the shocks even if faults did break in some of them and even if incipient landslides were set off and loose earth was disturbed by them. Others may well disagree.

Conclusion

The western part of the United States is only moderately seismic except for California. The aseismicity of Oregon is the great anomaly. The Pacific ring of epicenters is far enough at sea off Oregon to render that state quiet. But in neighboring California and Washington the seismic zone is on land.

However our history is short. Perhaps one hundred years from now the picture may have altered.

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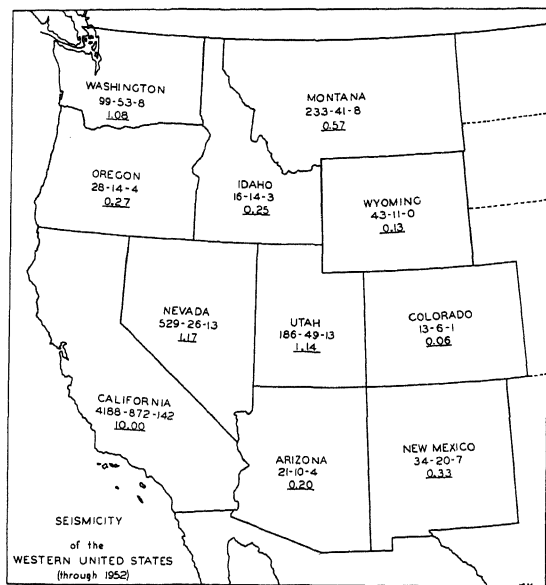


Fig. 1

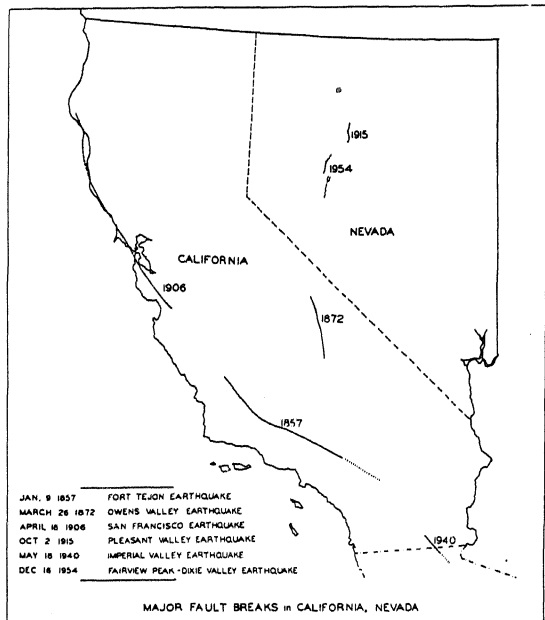


Fig. 2

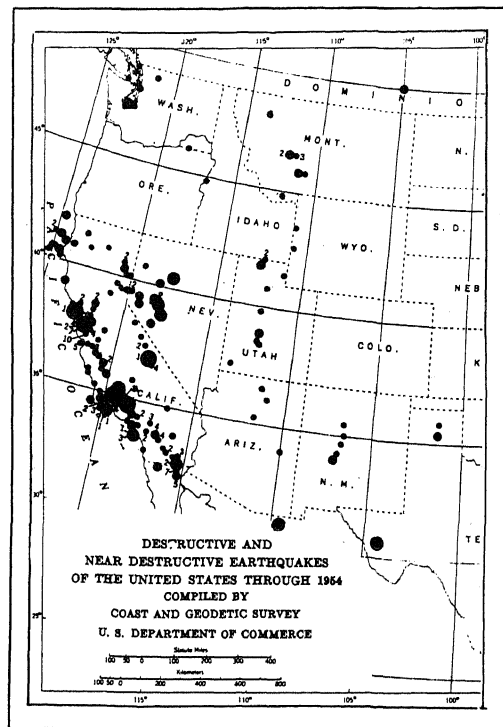


Fig. 3