Historical earthquakes in and around Portland, Oregon

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ABSTRACT

A reevaluation of all known moderate-sized earthquakes in the Portland area has revealed that at least 17 events of Richter magnitude (M_L) 4 and larger have occurred in historic time; six events have been M_L 5 and greater. These observations indicate that the Portland region is the most seismically active area in Oregon. Based on the historical record, recurrence estimates suggest that a M_L 5.5 and larger earthquake will occur about every 100 to 150 years and a M_L 6 and larger earthquake every 300 to 350 years. A crustal earthquake of M_L 6 or greater could generate a greater level of ground shaking in the Portland metropolitan area than could a moment magnitude (M_W) 8+ event on the Cascadia subduction zone and thus needs to be considered in seismic hazard evaluations of the region.

INTRODUCTION

Fewpeople realize that the region centered on the city of Portland is possibly the most seismically active area within the state of Oregon. The Richter magnitude (M_L; see Table 1) 5.6 Scotts Mills earthquake of March 25, 1993 (Figure 1), which shook most of western Oregon and southwestern Washington, is the largest event known to have occurred in northwestern Oregon and attests to the earthquake potential of the region. The absence of larger events in the historical record, however, has led to the general belief that larger events cannot occur. Recent recognition of the potential for a great earthquake (moment magnitude [M_W] 8+) rupturing the Cascadia subduction zone has also accelerated research into investigating crustal faults, which are the sources of the earthquakes occurring in the Portland region. Seismic monitoring of earthquakes in northern Oregon since 1980 has led to an improved understanding of seismogenic sources and the rate of earthquake occurrence in the region.

In this study, we have reviewed the earthquake history of the Portland region and reevaluated all events of approximate M_L 4 and greater that have occurred since the first recorded earthquake in 1846. Specifically, estimates of the magnitudes of these moderate-sized earthquakes were based on the size of their felt areas (i.e., areas in which the earthquake was reported as having been felt by people)—particularly, of course, those earthquakes that occurred prior to adequate seismographic coverage and thus do not have instrumentally determined values. After these reevaluated events have been incorporated into the historical record, the earthquake recurrence for the Portland region can be estimated. Such information is critical for the estimation of average recurrence intervals of earthquakes larger than the largest ever observed, e.g., M_L 6 and greater, and hence for the assessment of seismic hazards.

EARTHQUAKE DETECTION

How do we learn about earthquake occurrences? Historical earthquake records can generally be divided into records of the pre-instrumental period and the instrumental period. In the absence of adequate seismographic coverage, the detection of earthquakes is generally based on direct observations and felt reports. The results are strongly dependent on population density and distribution, and the study region, typical of much of the western United States, was sparsely populated in the 1800s. Thus the detection of pre-instrumental earthquakes shows varying degrees of completeness.

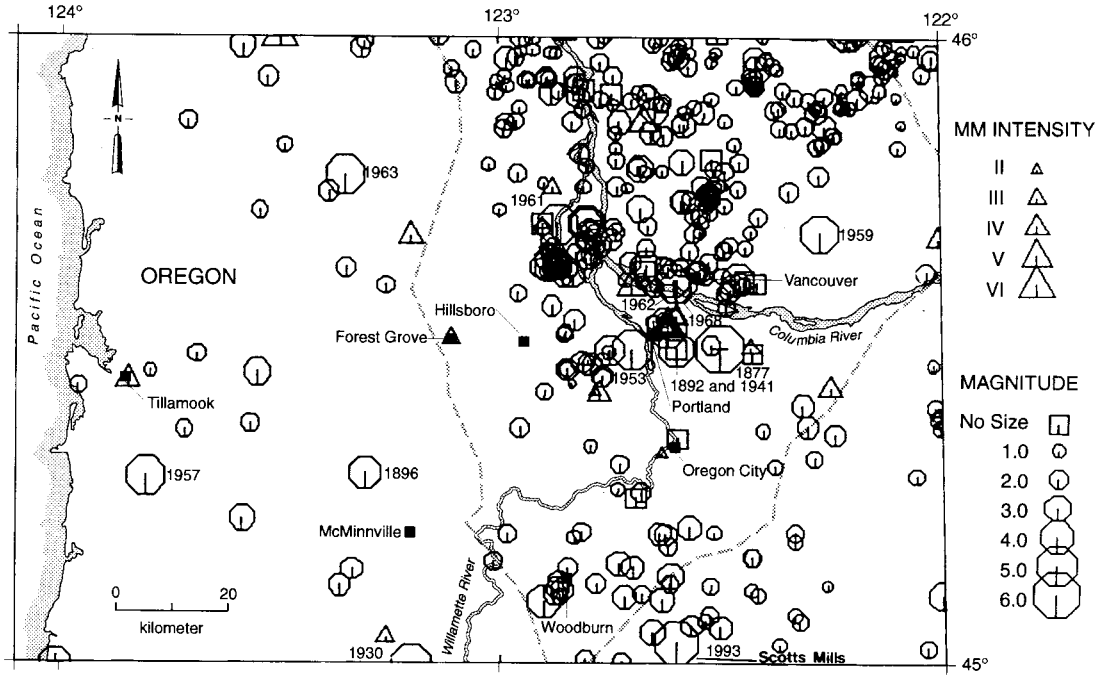


Figure 1. Historical seismicity of northwestern Oregon and portions of southwestern Washington during the period from 1846 to the present. In this study, the Portland region coincides with the Portland fold belt province as defined by Unruh and others (1993), and its boundaries are shown by the dashed line.

Table 1. *Types of earthquake magnitudes*

Symbol	Description
M_L	Richter (local) magnitude
M_S	Magnitude derived from recorded surface waves
m_b	Magnitude derived from recorded body waves
M_D	Magnitude derived from recorded duration of earthquake
M_W	Moment magnitude, derived from seismic moment
M	Unspecified magnitude

An evaluation of the population growth in the Portland region shows gradual increase up to 1940 in all counties except Multnomah (Oregon) and Pierce (Washington). Despite this slow growth, however, many widely distributed towns were established in or near the Willamette Valley and along the Columbia River as early as the 1850s. For example, Portland was first settled in the mid-1840s. Similarly, Salem was established in 1844, Hillsboro in 1845, Forest Grove in 1850, Eugene in 1852, McMinnville in 1853, and Tillamook in 1866 (Figure 1). Newspapers in the region, which are a major source of documentation, began publishing soon after the establishment of the major towns. Based on this relatively early settlement in the region, we estimate that the pre-instrumental historical record is complete for earthquakes of M_L 5 and larger since about 1850.

Although seismograph stations were established as early as 1906 in Seattle and 1944 in Corvallis, adequate seismographic coverage of the Portland region did not begin until 1980, when the University of Washington expanded its regional network into northwestern Oregon. Prior to this time, few stations operated in Oregon. Two of the most important seismograph stations, although at considerable distance from Portland, were the Blue Mountains Observatory in northeastern Oregon and the Longmire station in southwestern Washington. The latter was operated as part of the Worldwide Standardized Seismographic Network in addition to the Corvallis station. Based on this evolution of seismographic coverage, the historical record is complete at small magnitude levels (M_L 2.5 and greater) only since 1980.

SIGNIFICANT EARTHQUAKES

Introduction

In historical times, 17 earthquakes of estimated M_L 4 and greater are known to have occurred within the Portland region (Figure 1). These events, their felt effects and felt areas are described in the following discussion. Available isoseismal maps including ones developed in this study for the earthquakes in 1941, 1961 (August 18, September 17, and November 6), and 1963 were evaluated.

On the basis of several empirical relationships between felt areas of various intensities and M_L developed by Toppozada (1975) for California and western Nevada, we have attempted to estimate the magnitudes of the significant historical earthquakes in the Portland region. We believe that these relationships are applicable to both western Oregon and Washington because the crustal attenuation in both regions appears to be comparable to California. For example, the attenuation factor, Q_0, is about 150 in much of California and approximately 200 in northwestern Oregon and southwestern Washington (Singh and Herrmann, 1983). When we use the well-constrained felt areas of the 1962 Portland and the 1981 Elk Lake earthquakes for calibration, the Toppozada (1975) relationships appear to estimate the actual magnitudes quite well.

1877 earthquake

The earliest known significant historical earthquake in the Portland region occurred on October 12, 1877 (Figure 1). Two events are actually reported for this day, one at about 9 a.m. PST and one at 1:53 p.m. PST (Berg and Baker, 1963). There appears to be some confusion in the various anecdotal sources as to which event had a maximum intensity of Modified Mercalli (MM) VII (see Table 2 for description of MM intensity scale). Research by Thenhaus (1978) uncovered the fact that a smaller event of maximum intensity MM III occurred at 9 a.m. and was probably located near Cascades, Washington, because it was not reported as felt elsewhere. The second earthquake, at 1:53 p.m., occurred near Portland, where it caused chimneys to break (MM VII). It was also felt in a number of towns around Portland (e.g., Marshfield) and as far north as Puget Sound (Figure 2). Based on the isoseismal map developed by Thenhaus (1978), the total felt area is estimated to be 41,250 km^2.

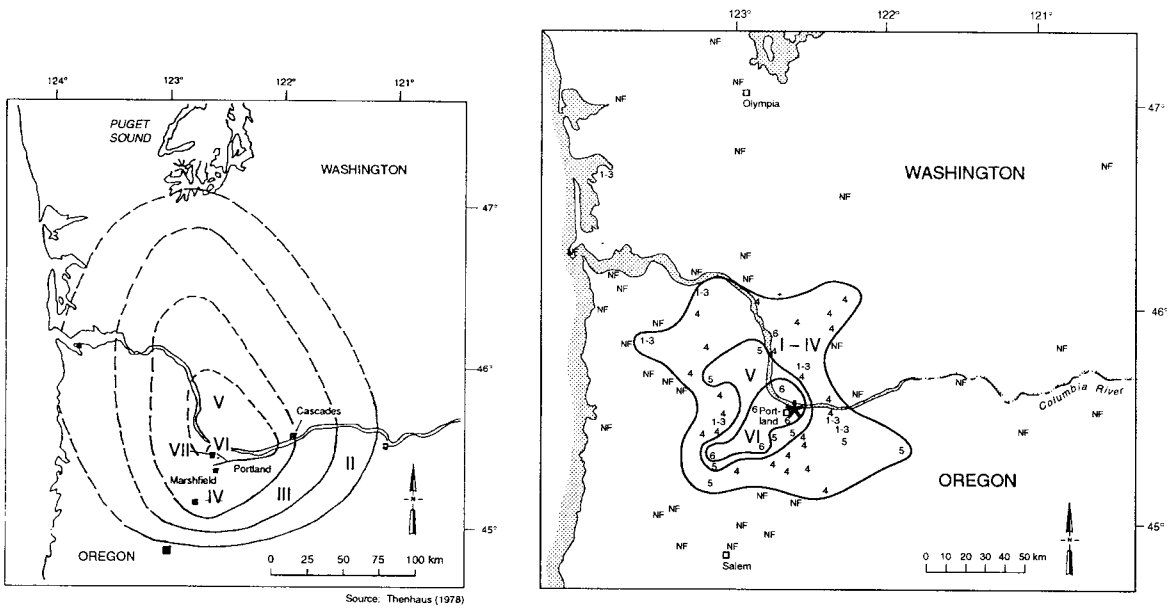


Figure 2. Isoseismal maps for the 1877 and 1941 earthquakes. Asterisk indicates instrumentally determined epicenter.

Table 2. *Abridged Modified Mercalli (MM) intensity scale. Equivalent Rossi-Forel (RF) intensities in parentheses.*

I	Not felt except by a few under especially favorable circumstances. (RF I).
II	Felt only by a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing. (RF I to II).
III	Felt quite noticeably indoors, especially on upper floor of buildings, but many people do not recognize it as an earthquake. Standing motorcars may rock slightly. Vibration like passing of truck. Duration estimated. (RF III).
IV	Felt indoors by many, outdoors by few during the day. Some awakened at night. Dishes, windows, door disturbed; walls make creaking sound. Sensation like heavy truck striking building. Standing motorcars rocked noticeably. (RF IV to V).
V	Felt by nearly everyone, many awakened. Some dishes, windows, and other fragile objects broken; cracked plaster in a few places; unstable objects overturned. Disturbances of trees, poles, and other tall objects sometimes noticed. Pendulum clocks may stop. (RF V to VI).
VI	Felt by all, many frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster and damaged chimneys. Damage slight. (RF VI to VII).
VII	Everybody runs outdoors. Damage negligible in buildings of good design and construction; slight to moderate in well-Ebuilt ordinary structures; considerable in poorly built or badly designed structures; some chimneys broken. Noticed by persons driving cars. (RF VIII).
VIII	Damage slight in specially designed structures; considerable in ordinary substantial buildings with partial collapse; great in poorly built structures. Panel wall thrown out of frame structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water levels. Persons driving cars disturbed. (RF VIII + to IX).
IX	Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb; great in substantial buildings; with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken. (RF IX +).
X	Some well-built structures destroyed; most masonry and frame structures destroyed with foundations; ground badly cracked. Rails bent. Landslides considerable from river banks and steep slopes. Shifted sand and mud. Water splashed, slopped over banks. (RF X).
XI	Few, if any, [masonry] structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipelines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly.
XII	Damage total. Waves seen on ground surface. Lines of sight and level distorted. Objects thrown into the air.

Averaging the estimated magnitudes from the various felt area relationships indicates that the 1877 earthquake probably was about a M_L 5¼ event (Table 3). For comparison, the M_L 5.5 Portland earthquake of 1962 was felt in Seattle with an intensity of MM IV, whereas the 1877 earthquake was felt only in the southern Puget Sound with an intensity of MM II. The less severe damage reported for the 1877 earthquake supports the conclusion that the 1877 earthquake had a smaller magnitude than the 1962 event.

1892 earthquake

At 8:30 p.m. PST on February 3, 1892, a "severe" earthquake (MM VI) (Townley and Allen, 1939) caused brick buildings to sway and windows to rattle in Portland, terrifying people inside (Holden, 1898) (Figure 1). The motion was reported as lasting 30 seconds and as being the most severe shock ever felt in Portland, although this is puzzling, given the observations of the 1877 event. As far as is known, no major damage occurred. In Astoria, the earthquake lasted 3 seconds, causing houses to shake. It was felt as a light shock as far west as the Yaquina Head lighthouse on the Oregon coast. The earthquake was felt over an area of more than 26,000 km^2 (Coffman and others, 1982), although no known isoseismal map has been developed. Based on this felt area, a poorly constrained value of a M_L 5 is estimated (Table 3).

1896 earthquake

The inhabitants of McMinnville were awakened at 3:17 a.m. PST on April 2, 1896, by an earthquake of maximum intensity MM VI, accompanied by a loud rumbling noise and followed by two or three distinct shocks in rapid succession (Townley and Allen, 1939). The earthquake was felt in Portland at about 3:20 a.m. PST as a single shock of brief duration and was also felt as far south as Salem. The earthquake was felt over an area of about 2,600 km^2 (Coffman and others, 1982) and is thought to have occurred close to McMinnville (Figure 1), which was the location of the greatest felt intensity (Berg and Baker, 1963). We estimate a M_L 4 for this earthquake, because we believe the felt area may be somewhat underestimated (Table 3).

1930 earthquake

On July 19, 1930, at 6:38 p.m. PST, an earthquake of intensity MM V–VI (Coffman and others, 1982) occurred near Perrydale, Oregon, a town about 20 km northwest of Salem (Figure 1). Plaster cracked and windows rattled at McCoy (Neumann and Bodle, 1932), and the roadbed was cracked 0.8 km west of Perrydale. A smaller foreshock occurred in the same area on July 8 at 12:30 p.m. PST but with a maximum intensity of only MM III. Although no felt area has been estimated for the larger earthquake, reports of localized damage indicate a magnitude of at least M_L 4 (Table 3).

1941 earthquake

A strong earthquake was felt by most residents of Portland on December 29, 1941, at 10:37 a.m. PST (Figure 2). Small objects were displaced, and some trees and bushes were shaken (Neumann, 1943). Display windows shattered, and plaster cracked in Hillsboro and Sherwood. The earthquake caused chimneys to crack, vases to overturn, trees to shake and a school bell to ring in Yamhill, frightening many people (Neumann, 1943). Intensity MM VI effects were also felt in Vancouver and Woodland, Washington, where plaster cracked, vases overturned, and small objects moved. The felt area is estimated to be about 9,000 km^2, although this value is not well constrained. The epicenter is assigned to the Portland area, the location of the maximum intensity (Figure 1). Based on the size of the felt area, the earthquake appears to be about M_L 4½ (Table 3).

1953 earthquake

Coffman and others (1982) report that an earthquake of intensity MM VI occurred in northwest Oregon on December 15, 1953, and was felt over an area of about 8,000 km^2 (Figures 1 and 3). Slight damage was sustained in Portland and Roy, Oregon, and in Vancouver, Washington. The earthquake occurred sometime just before 8:32 p.m. PST on December 15, the time the earthquake was instrumentally recorded in Corvallis. In Portland, it was generally felt, frightening many people, cracking plaster, and causing objects and dishes to fall (Murphy and Cloud, 1955). Murphy and Cloud (1955) report one cracked chimney, slight damage to a tile fireplace, and cracks at the juncture between a one-story building and the abutting apartments. The location of this event is well constrained by the isoseismal map (Figure 3), which shows the maximum intensity within a small zone between Vancouver and Portland. Calculations of magnitude from the felt area suggest this earthquake to be about M_L 4½ (Table 3).

1957 earthquake

On November 16, 1957, at 10:00 p.m. PST, an earthquake shook the area just northwest of Salem (Brazee and Cloud, 1959) (Figure 4). The instrumental (i.e., instrumentally determined) location reported in Coffman and others (1982) lies about 80 km northwest of Salem, 60 km further west than the felt epicenter would suggest (Figure 1). This large discrepancy may be due to a

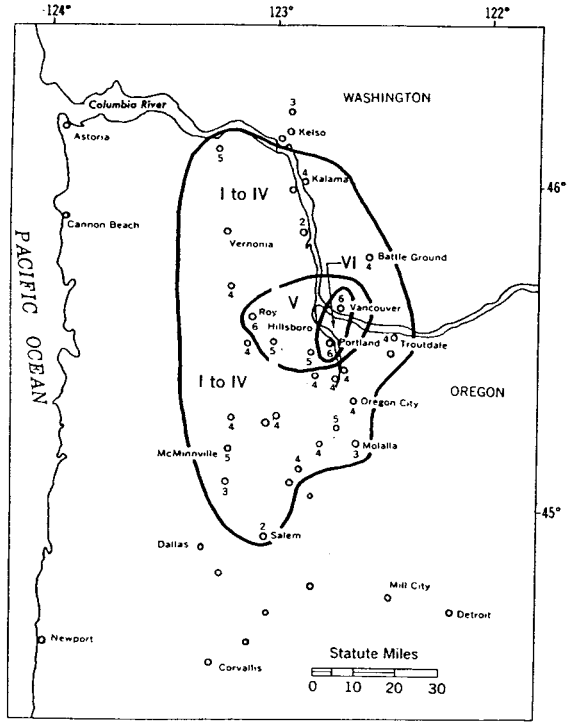


Figure 3. Isoseismal map for the 1953 earthquake.

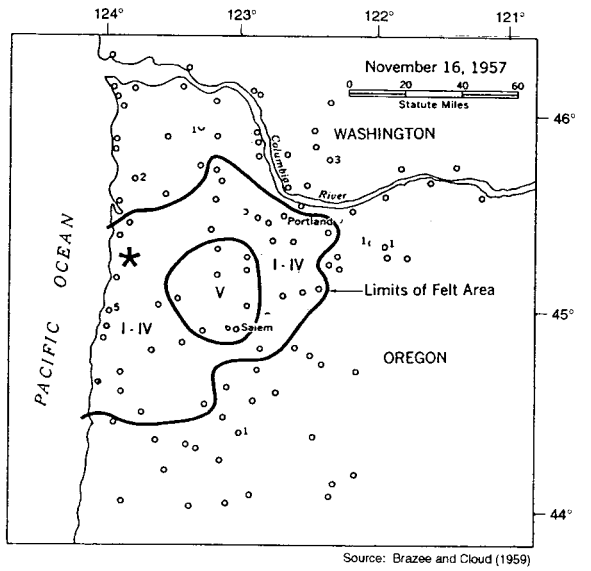


Figure 4. Isoseismal maps for the 1957 earthquake. Asterisk indicates instrumentally determined epicenter.

bias in the population distribution or site-response effects in the Willamette Valley area around Salem. Similarly, strong ground shaking occurred in the Salem area in the recent Scotts Mills earthquake, as typified by the damage to the State Capitol building, although the epicenter lay about 32 km to the east. Most people in Salem were frightened by the 1957 earthquake, where the highest intensity is reported (MM VI) (Figure 4). However, only slight damage, consisting of cracked walls and plaster, was reported in the western part of Salem (Brazee and Cloud, 1959). Momentary power outages were reported, including a television blackout. Some people felt a single sharp, blast-like jolt, while others said the vibrations lasted for several seconds. The magnitude, based on the felt area of 13,600 km^2 assumed for this event (Figure 4), is estimated to be about M_L 4½ (Table 3).

August 18, 1961, earthquake

At 8:46 p.m. PST, on August 18, 1961, a maximum intensity MM VI earthquake was felt in and around the towns of Lebanon and Albany south of Salem (cover illustration). This earthquake was felt over an area of 18,300 km^2 from southwest Lane County in Oregon to Cowlitz County in Washington. The instrumental location is approximately 40 km northeast of the location of the maximum intensity (cover illustration), where chimneys toppled, windows broke, traffic lights and signs fell, and plaster cracked. The instrumental (i.e., instrumentally determined) magnitude assigned to this earthquake is M 4.5 (unspecified magnitude scale) by Cal Tech in Pasadena, California, and a coda duration magnitude (M_D) 3.9 as measured at the Longmire station (T. Yelin, U.S. Geological Survey, personal communication, 1993). The available data show a large felt area trending north-south, but the east-west extent is difficult to constrain. The magnitude of the event from limited felt information suggests a M_L 4½ (Table 3).

September 15/17, 1961, earthquakes

Two moderate earthquakes occurred on September 15 and 17, 1962, approximately in the same vicinity near Siouxon Peak in southwestern Washington. The maximum intensities and felt areas are MM VI and 22,000 km^2, and MM VI and 24,300 km^2, respectively (cover illustration and Table 3). The first event occurred at 7:25 p.m. PST near Cougar, Washington, in Gifford Pinchot National Forest. The event was felt by and frightened many people, and the shock lasted 20 seconds. Small objects were overturned, and hanging objects swung east-west (Lander and Cloud, 1963). Several aftershocks that were felt followed the first event.

The September 17 earthquake, the larger of the two events, occurred at 7:56 a.m. PST. Instrumental magnitudes for the two principal earthquakes on September 15 and 17 are M_L 4.8 and M_L 5.1, respectively, determined from the Wood-Anderson seismograph operated by the University of California at Berkeley (UCB) in Arcata, California (Grant and Weaver, 1986) (Table 3). The epicenter of the larger event was southeast of Cougar (cover illustration), where the shaking lasted 20 seconds, and most observers felt it and heard moderate earthquake noises. A house shifted 2.5 cm on its foundations in North Bonneville, Washington. In Stevenson, Washington, there was slight damage to chimneys, cement foundations cracked, a woodstove moved 15 cm, and plate glass "rippled like a flag" (Lander and Cloud, 1963). In Latourell, Oregon, some cracks were found in a heavy cement basement foundation. Booming noises were heard at Yale Dam and Washougal, Washington. Grant and Weaver (1986) suggest that this earthquake occurred within the Mount St. Helens seismic zone.

November 6, 1961, earthquake

At 5:29 p.m. PST on November 6, 1961, an earthquake was widely felt over an area of 23,000 km^2 in northwest Oregon and southwest Washington (cover illustration). There is some uncertainty in the instrumental location of this earthquake. However, an aftershock of maximum intensity MM V on November 7 at 1:30 p.m. was felt principally in the Portland area, where china clinked, pictures tilted, and a television set slid across the floor. The location of the aftershock suggests that the main shock may have occurred

closer to Portland than the instrumental locations would indicate (cover illustration and Figure 1).

During the main shock, minor cracking of plaster appeared to be the principal damage (Lander and Cloud, 1963). Some people reported that this event was the sharpest shock felt in Portland since the body-wave magnitude (m_b) 7.1 earthquake of April 13, 1949, that was centered around Olympia, caused $25 million in damage, and killed eight people. The 1961 earthquake caused a brick chimney to fall, plaster to crack, interior lights to break, door frames to jam, and a water fountain in Portland to spring a leak (Lander and Cloud, 1963). Groceries were thrown from shelves in a grocery store, and windows rippled. People reported noises from several directions. In nearby Glenwood, Washington County, the earthquake was felt by all in the community. Concrete foundation blocks broke, loud rumbling noises like a truck passing by were heard, and a porch roof under repair fell down (Lander and Cloud, 1963).

A magnitude of M_D 4.5 has been estimated from the Longmire station (T. Yelin, U.S. Geological Survey, personal communication, 1993); however, Grant and Weaver (1986) note that Longmire magnitudes tend to overestimate the actual value by several tenths of a magnitude unit. Based on the felt area, we estimate a M_L 5 for the 1961 event (Table 3).

1962 earthquake

Until the recent Scotts Mills earthquake, the largest event in historical times in the Portland region occurred at 7:36 p.m. PST on November 5, 1962, with a maximum intensity of MM VII (Coffman and others, 1982) (Figure 1). Numerous chimneys cracked or fell down, windows broke, and plaster cracked in Portland (Dehlinger and Berg, 1962). Six light fixtures fell in a grocery store, and the newsroom located on the fourth floor of the *Journal* Building sustained cracks (Lander and Cloud, 1964). No damage to utilities occurred, but the upsurge of telephone use after the earthquake caused a temporary disruption of service in some areas. A crack 7 m long and 4 cm wide appeared on a road between Tillamook and Oceanside, Oregon (Lander and Cloud, 1964). In Vancouver, Washington, a large chandelier fell, and a jail elevator was put out of service. Numerous aftershocks occurred, but none were large enough to be felt in Portland.

The magnitude of this earthquake has been variously estimated as M 4¾ (UCB-Berkeley, probably M_L), M_L 5 (Dehlinger and others, 1963), M_L 5½ (UCB-Arcata), and more recently as M_D 4.9 and M_L 5.2 (Yelin, 1990) and M_W 5.2 (Yelin and Patton, 1991) (Table 3). It was felt over a wide area (estimated as 52,400 km^2 from Coffman and others [1982] and 70,000 km^2 in this study) (Figure 5). Our magnitude estimate based on the felt area is M_L 5½ (Table 3). Peak ground accelerations of 0.076 *g* (vertical) and 0.103 *g and 0.096 g (horizontal) were measured at a the U.S. Coast and Geodetic Survey strong motion seismograph in the former State Office Building in downtown Portland (Dehlinger and others, 1963). Dehlinger and others (1963) located this event at a depth of 15–20 km, although this value is not well constrained.*

In a more recent study of earthquakes in the Portland area, Yelin and Patton (1991) relocated this event to 15 km northeast of downtown Portland, just east of the original epicentral location of Dehlinger and others (1963), and to a depth of 16 km (Figure 5).

1963 earthquake

At 6:36 p.m. PST on December 26, 1963, an earthquake was felt with a maximum intensity of MM VI in northwestern Oregon (von Hake and Cloud, 1965). This earthquake was felt over an area of only 10,700 km^2 (Figure 6), and damage was slight. Plaster cracked in a few places, and books and pictures fell in North Plains and Timber, Oregon, and Toutle, Washington. In Tillamook, Oregon, a car swayed and went to the opposite side of the highway before being controlled. The isoseismal map for this earthquake (Figure 6) is not well constrained due to differing intensity reports in closely spaced

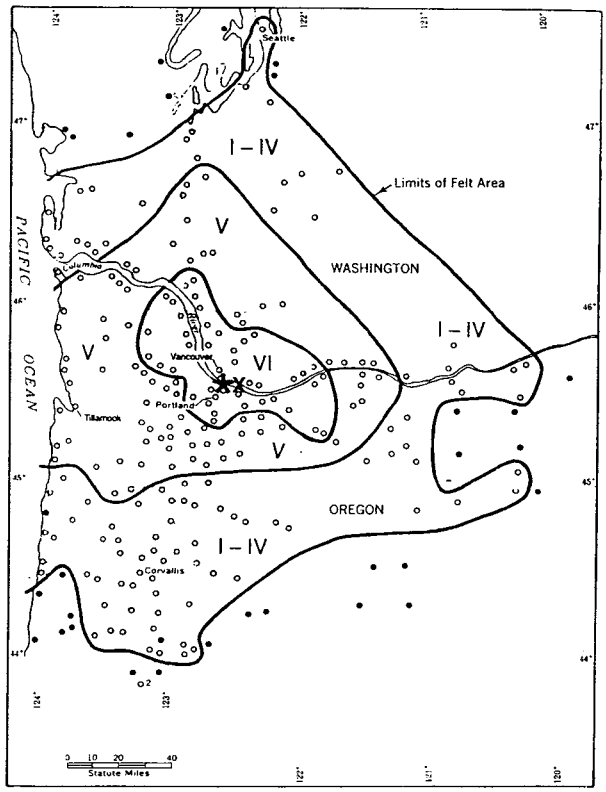
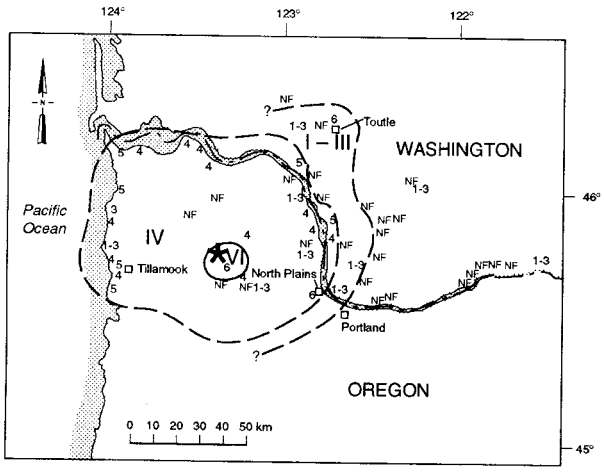


Figure 5. Isoseismal map for the 1962 earthquake. Asterisk indicates instrumentally determined epicenter.

locations—possibly an indication that varied site conditions played a major role in ground motions. The instrumental location, however, agrees well with the area of maximum intensities northwest of Portland (Figures 1 and 6). A magnitude of M_D 4.1 (Longmire) and m_b 4.5 (NOAA) have been instrumentally determined (Table 3). The calculated magnitude from the felt area is M_L 4½.

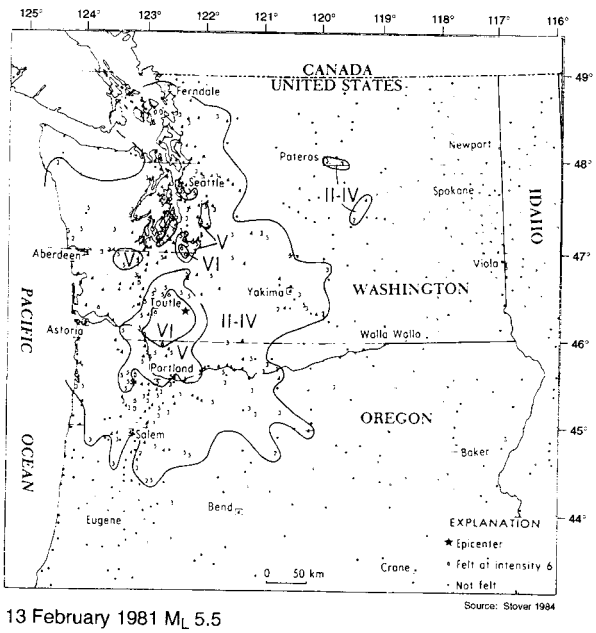
1981 earthquake

The 1981 Elk Lake, Washington, earthquake, the largest known earthquake associated with the St. Helens seismic zone, occurred at 10:09 p.m. PST on February 13, 1981. The earthquake, with magnitudes m_b 5.1, M_S (surface-wave magnitude) 4.8, M_L 5.5, and M_D 5.2 (Stover, 1984), was felt over an area of 104,000 km^2 (Figure 7 and Table 3). Maximum intensities of MM VI were felt around the epicentral region. Damage was reported as foundation and plaster cracks, overturned furniture, broken glasses and dishes, and a few cracked windows. In Ariel, the sidewalk cracked and in Graham, seiches (earthquake-generated waves) occurred in lakes and swimming pools, and chimneys were cracked (Stover, 1984). In Kidd Valley, pottery was broken and 300 maps fell to the floor in the Antique Shed store (Stover, 1984). The main shock was preceded nine months earlier by a swarm of earthquakes that occurred over a two-month period (Grant and others, 1984). The locations of about 1,000 aftershocks delineate a north-northwest-trending, right-lateral, strike-slip fault zone, 6 km long, 3 km wide, and extending from 5 to 12 km in depth (Grant and others, 1984). At least six aftershocks of M_L 2.9 to 3.6 were felt in Kidd Valley, 13 km east of Toutle, that night and the following day. The largest aftershock was felt as far south as Vancouver.



27 December 1963 M_D 5.0

Figure 6. Isoseismal map for the 1963 earthquake. Asterisk indicates instrumentally determined epicenter.



13 February 1981 M_L 5.5

Figure 7. Isoseismal map for the 1981 earthquake.

Other significant earthquakes

Portland has been the site of several smaller earthquakes of interest. One earthquake occurred on January 27, 1968, at 12:28 a.m. PST, in the Portland area. This was the first large event since the damaging November 5, 1962, earthquake (Heinrichs and Pietrafesa, 1968). Heinrichs and Pietrafesa (1968) estimate the magnitude to be M_L 3.7 and the depth of focus to be at 20 to 24 km. Their epicenter places this earthquake south of the Columbia River in the eastern Portland area (Figure 1).

Another earthquake occurred on May 13, 1968, at 10:52 a.m. PST, and its epicenter is located between northeast Portland and the Columbia River. The instrumentally determined value of M_L 3.8 for the event is from the Blue Mountains Observatory. The focal depth is thought to be around 4–12 km (Couch and others, 1968), although it is not well constrained due to lack of adequate seismographic coverage. A maximum intensity of MM IV was felt in Portland. The earthquake caused windows to rattle and hanging objects to swing, but no damage was reported. This earthquake occurred in the vicinity of the November 5, 1962, and the January 27, 1968, events (Figure 1).

Other moderate-sized earthquakes in the Portland region include the following:

- A MM V on August 4, 1959, 21 km northeast of Portland (Figure 1), which was felt over an area of 1,570 km^2. In Portland, the event caused swaying motion, and a few objects were displaced (Eppley and Cloud, 1961). Based on the felt area, the magnitude for this earthquake, estimated to be M_L 4.7 by the Canadian seismographic network, appears to be significantly overestimated.
- A m_b 4.6 event on March 7, 1963, which occurred west of Salem but was felt from Portland to Eugene (von Hake and Cloud, 1965). Damage was limited to slightly cracked plaster and broken dishes in Salem.
- A M_D 3.5 (Longmire) earthquake on January 26, 1964, near Merrill Lake, Washington (von Hake and Cloud, 1966). The event was felt over an area of 5,000 km^2 but only made windows and dishes rattle.
- A M_D 4.1 (Longmire) (MM V) event on October 1, 1964, 9 km east of Cougar (von Hake and Cloud, 1966). Many people were awakened in Portland, and windows and doors rattled.
- A m_b 4.3 (MM V) event on November 30, 1968, in Lewis County, Washington, that was felt over an area of 2,600 km^2 (Coffman and Cloud, 1970).

EARTHQUAKE RECURRENCE

The recurrence or frequency of occurrence for earthquakes in a given magnitude range in a specific region can be estimated on the basis of the Gutenberg-Richter relationship developed for that region. We have estimated this relationship for the Portland region, using our revised historical earthquake record and following the maximum-likelihood procedure developed by Weichert (1980). The earthquake record was corrected for incompleteness, and dependent events (foreshocks and aftershocks) were deleted. All event magnitudes were converted to equivalent M_L values.

Assuming the usual form of the Gutenberg-Richter relationship of $\log N = a - bM$, the recurrence parameters of b and a of 0.84±0.07 and 2.55, respectively, were estimated for the Portland region. This recurrence results in a return period for earthquakes of M_L 6 and greater of about 325 years, with the uncertainty in this value being at least several decades. For M_L 5.5 and greater, the return period of 100 to 150 years is consistent with the occurrence of the 1962 Portland and 1993 Scotts Mills earthquakes in the 150-year historical period. For M_L 6.5 and greater earthquakes, the return period is estimated to be approximately 800–900 years.

CONCLUSIONS

In the relatively brief historical record for northwestern Oregon and southwestern Washington, a large number of moderate-sized earthquakes up to M_L 5.6 have shaken the Portland region and sometimes caused damage. In view of the tectonic and geologic setting of the Portland region astride the Cascadia subduction zone, however, the occurrence of earthquakes as large as M_L 6½ or larger, which have not been experienced in historic times, also seems quite possible. The historical record suggests that such events may occur in the Portland region every few hundred years. It would seem prudent that residents as well as the engineering community and government agencies take the proper steps to mitigate the hazards that will be posed by such probably damaging earthquakes.

Table 3. *Significant historical earthquakes in the Portland region, showing areas for three MM intensity zones ($A_{I\text{-}V\text{-}VI}$), magnitudes calculated from each area (M_{A_I}, etc.), average (M_{ave}), and best estimate (M_{FA}) magnitudes. Recording source abbreviations: UCB = University of California-Berkeley; UW = University of Washington; NOAA = National Oceanic and Atmospheric Administration*

Earthquake	Maximum intensity	A_I (km²)	A_V (km²)	A_{VI} (km²)	M_{A_I}	M_{A_V}	$M_{A_{VI}}$	M_{ave}	M_{FA}	Instrumental magnitude (recording station or source)
October 12, 1877	VII	41,250	2,875	125	5.2	4.6	4.3	4.7	5¼	—
February 3, 1892	V-VI	26,000	—	—	4.9	—	—	—	5	—
April 2, 1896	V	2,600	—	—	3.3	—	—	—	4	—
July 19, 1930	V-VI	—	—	—	—	—	—	—	4	—
December 29, 1941	VI	9,300*	2,143	803	4.2	4.5	5.0	4.6	4½	—
December 15, 1953	VI	10,000	1,782	341	4.3	4.4	4.7	4.5	4½	—
November 16, 1957	VI	13,600	2,476	—	4.5	4.6	—	4.55	4½	—
August 18, 1961	VI	18,300	—	—	4.6	—	—	4.6	4½	M 4.5 (Pasadena); M_D 3.9 (Longmire).
September 15, 1961	VI	22,000	3,213	—	4.8	4.7	—	4.75	4¾	M_L 4.8 (UCB-Arcata).
September 17, 1961	VI	24,300	5,125	—	4.8	4.9	—	4.85	5	M_L 5.1 (UCB-Arcata).
November 6, 1961	VI	23,000	5,656	919	4.8	5.0	5.1	5.0	5	M_D 4.5 (Longmire).
November 5, 1962	VII	70,000	29,403	6,790	5.4	5.7	5.8	5.6	5½	M_W 5.2 (Yelin and Patton, 1991); M_L 5.0 (Dehlinger and others, 1963); M_L 5.5 (UCB-Arcata).
December 26, 1963	VI	10,700	—	—	4.3	—	—	4.65	4½	M_D 4.1 (Longmire); m_b 4.5 (NOAA).
February 14, 1981	VI	104,000	15,800	1,900	5.8	5.4	5.3	5.5	5½	M_L 5.5, M_D 5.2 (UW); M_S 4.8 , m_b 5.1 (Stover, 1984).

*Felt area estimate not well constrained

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To our readers

Because of the length of the articles, this issue has been expanded from the usual 24 pages to 28 pages. As a result, we shall publish one of our later issues with 20 pages. —*ed.*