

**U.S. DEPARTMENT OF THE INTERIOR
U. S. GEOLOGICAL SURVEY**

**THE SCOTTS MILLS, OREGON, EARTHQUAKE OF
MARCH 25, 1993: INTENSITIES, STRONG-MOTION
DATA, AND TELESEISMIC DATA**

by

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This report has not been reviewed for conformity with U.S. Geological Survey editorial standards and stratigraphic nomenclature.

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This is the first of a series of reports on significant U.S. earthquakes to be produced jointly by the National Earthquake Information Center and the National Strong-Motion Program. We present basic observational data on the Scotts Mills, Oregon, earthquake of March 25, 1993: source parameters, prior seismicity from the epicentral region, damage reports, isoseismal maps, strong-motion data, and digital teleseismic data.

INTRODUCTION

On March 25, 1993, 5:35 A.M. Pacific Standard Time, western Oregon and Washington were shaken by a moderate earthquake centered near the community of Scotts Mills, Oregon. Property damage was estimated to be about \$28.4 million (Madin and others, 1993). Most economic loss resulted from damage to old unreinforced masonry structures. A reinforced-concrete and steel highway bridge also suffered damage and was closed for several days. There was economic loss due to fall of items from shelves and to closure of businesses in condemned buildings.

As part of a routine intensity-monitoring procedure, the Branch of Earthquake and Geomagnetic Information, U.S. Geological Survey, sent out 460 mail questionnaires to post-offices, police stations, and fire stations at towns in and near the region within which the Scotts Mills earthquake was felt. Two of us, B. G. Reagor and F. W. Baldwin, conducted a reconnaissance field trip in the region of strongest shaking. Damage in the region of maximum shaking corresponds to a Modified Mercalli Intensity of VII. The earthquake was felt over an area of approximately 97,000 square kilometers (37,500 square miles). Intensity observations and their interpretation are discussed in the section entitled "DESCRIPTION OF EARTHQUAKE EFFECTS."

The National Strong-Motion Program of the U. S. Geological Survey collected records from five strong-motion accelerographs that were triggered by the earthquake and that were situated at distances of 43 to 106 km from the earthquake's epicenter. The accelerograph in the upper gallery of the Detroit Dam (epicentral distance of 43 km) recorded a peak horizontal acceleration of .18g. The accelerograph immediately downstream of Detroit Dam recorded a peak horizontal acceleration of .06g. The strong-motion data are presented in the section entitled "STRONG-MOTION RECORDS".

Digital seismographs of institutions in the Federation of Digital Seismograph Networks obtained on-scale recordings of the Scotts Mills earthquake at epicentral distances ranging from 74 km to over 10,000 km. Data from these stations imply that the earthquake nucleated at a depth of approximately 16 km and involved a combination of strike-slip and reverse faulting. The focal mechanism and focal depth implied by the digital data are consistent with the earthquake occurring on the Mt. Angel fault, as had been suggested previously by other investigators. The digital data and

their interpretation are presented in the section entitled "FOCAL MECHANISM AND DEPTH DETERMINED FROM DIGITAL TELESEISMIC DATA."

SEISMOTECTONIC FRAMEWORK

The hypocenter and magnitudes of the Scotts Mills earthquake are as follows (U.S. Geological Survey, 1993; depth as determined in present study).

Origin time: 13:34:35.4 UTC
(05:34:35.4 PST)
Epicenter: 45.035°N., 122.607° W.
Depth: 16 km
Magnitude: 5.5 m_b (GS), 5.4 M_S (GS),
5.5 M_L (BRK), 5.7 M_L (SEA), 5.6 M_W (HRV)

The shock occurred in the Cascadia subduction zone, where the North American tectonic plate is being underthrust by the east-dipping Juan de Fuca tectonic plate. The hypocenter lies within the North American plate; the Juan de Fuca plate is several tens of kilometers deeper than the focus of the Scotts Mills earthquake (Michaelson and Weaver, 1989). Shocks lying within the North American plate, similarly situated well above the Juan de Fuca plate, have been observed elsewhere in northwest Oregon and western Washington (fig. 1, Ludwin and others, 1991; Yelin and Patton, 1991). These shocks are probably related to each other in a broad sense, perhaps corresponding to a region of high crustal strain resulting from the subduction of the Juan de Fuca plate beneath the North American plate. In detail, the earthquakes within the North American plate occur on many different geologic faults. One dense cluster of epicenters in figure 1 corresponds to shocks that accompanied eruptions of Mount St. Helens, but earthquakes at most other inland locations of the Pacific Northwest are not directly related to volcanic activity. There is no evidence that the Scotts Mills earthquake was related to volcanic processes.

Several previous earthquakes that have occurred since the mid-nineteenth century produced intensity VII effects within 100 km of the epicenter of the Scotts Mills earthquake (table 1). Intensities higher than VII have not been documented within 100 km of the Scotts Mills earthquake during the period since the mid-nineteenth century for which information is available.

Table 1. Earthquakes that produced intensities of VII and earthquakes that triggered strong-motion accelerographs within 100 km of the 1993 Scotts Mills earthquake.

Date	Origin Time (UTC)	Epicenter		Depth (km)	Magnitude			Source
		(°N)	(°W)		mb	MS	ML	
1877 Oct. 12	2153	45.750	122.500	..	...	...	...	1
<i>Intensity VII at Cascades and Portland, Oregon.</i>								
1949 Apr. 13	195542.0	47.167	122.617	70	...	...	6.9	1
<i>Intensity VII at Hillsboro, North Portland, Oregon City, Oswego, Portland, Pratum, Sandy, and Shedd, Oregon. Intensity VII at Camasa, Orchards, Stevenson, and Vancouver, Washington.</i>								
1961 Nov. 7	012908.4	45.700	122.400	33	...	...	4.5	1
<i>Maximum intensity VI. Triggered strong-motion accelerograph.</i>								
1962 Nov. 6	033643.6	45.642	122.588	16	...	...	5.2	1
<i>Intensity VII at Portland, Oregon. Triggered strong-motion accelerograph.</i>								
1965 Apr. 29	152843.7	47.400	122.300	59	6.5	6.5	6.6	1
<i>Maximum intensity VI at sites within 100 km of Scotts Mills, Oregon. Triggered strong-motion accelerograph.</i>								
1993 Mar. 25	133435.4	45.035	122.607	16	5.5	5.4	5.7	2
<i>Scotts Mills earthquake</i>								

[Sources (hypocenter and magnitude) : 1, Stover and Coffman, 1993; 2, U.S. Geological Survey, 1993, and this study]

MODIFIED MERCALLI INTENSITY SCALE OF 1931 (Abridged; Wood and Neumann, 1931)

- I. Not felt except by a very few under especially favorable circumstances.
- II. Felt only by a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing.
- III. Felt quite noticeably indoors, especially on upper floors of buildings, but many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibration like passing of truck. Duration estimated.
- IV. During the day felt indoors by many, outdoors by few. At night, some awakened. Dishes, windows, doors disturbed; walls made cracking sound. Sensation like heavy truck striking building. Standing motor cars rocked noticeably.
- V. Felt by nearly everyone; many awakened. Some dishes, windows, etc., broken; a few instances of cracked plaster; unstable objects overturned. Disturbance of trees, poles and other tall objects sometimes noticed. Pendulum clocks may stop.
- VI. Felt by all; many frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster or damaged chimneys. Damage slight.
- VII. Everybody runs outdoors. Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable in poorly built or badly designed structures; some chimneys broken. Noticed by persons driving motor cars.
- VIII. Damage slight in specially designed structures; considerable in ordinary substantial buildings with partial collapse; great in poorly built structures. Panel walls 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. Disturbed persons driving motor cars.
- 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.
- X. Some well-built wooden 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.
- XI. Few, if any (masonry), structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipe lines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly.
- XII. Damage total. Waves seen on ground surfaces. Lines of sight and level distorted. Objects thrown upward into the air.

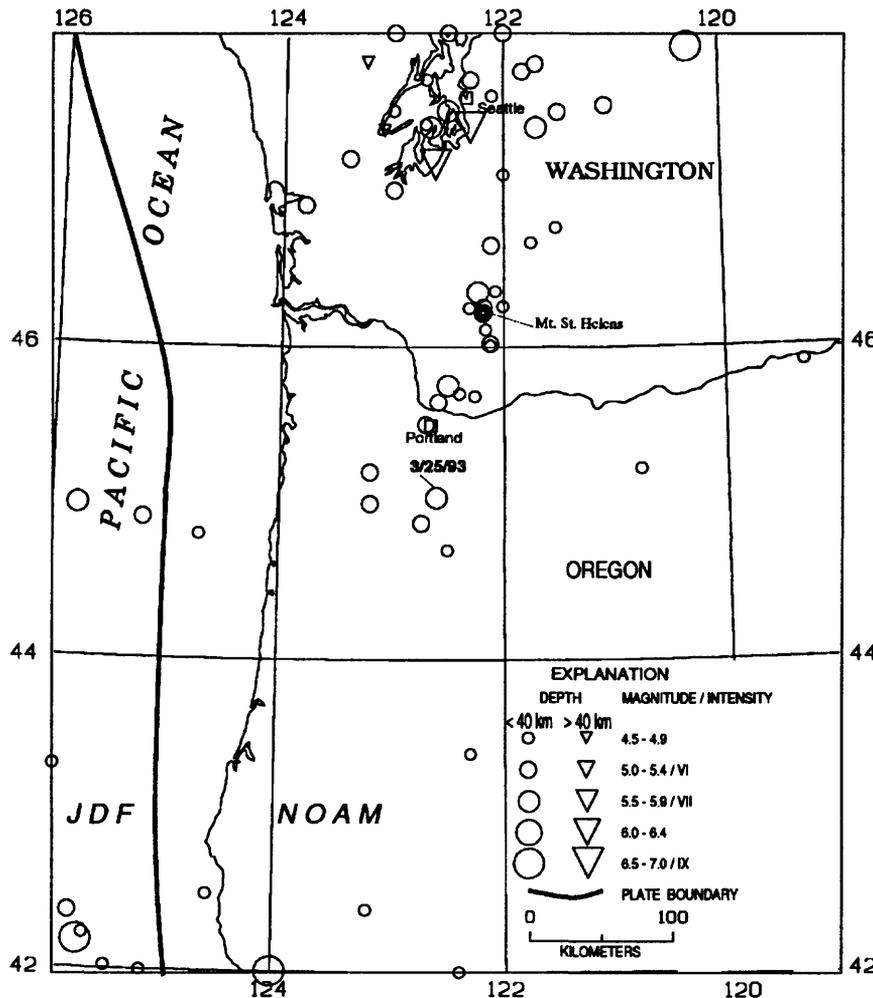


Figure 1. Seismicity of western Oregon and southwestern Washington, from 1872 through the occurrence of the 1993 Scotts Mills earthquake. Earthquakes plotted are those with magnitudes 4.5 and larger and earthquakes for which no magnitudes were computed but for which intensities of VI or greater were observed. Almost all shocks lying inland of the coastline and having depths less than 40 km occurred in the North American (NOAM) plate. Shocks with depths exceeding 40 km lay within the Juan de Fuca (JDF) plate, as did most shallow offshore earthquakes. The mapped plate boundary shows where the JDF plate underthrusts the NOAM plate near the surface; from this surficial boundary the subducted JDF plate dips to the east beneath the NOAM plate. Seismicity data are from Stover and Coffman (1993) and the *Preliminary Determination of Epicenters* of the National Earthquake Information Center.

DESCRIPTION OF EARTHQUAKE EFFECTS

Intensities assigned by the U. S. Geological Survey are based on the Modified Mercalli Intensity Scale of 1931 (Wood and Neumann, 1931). The abridged version of the scale is given on the adjacent page; the scale is reproduced in its entirety in the annual *U.S. Earthquakes* publication of the U.S. Geological Survey and in Stover and Coffman (1993). We follow Stover and Coffman (1993) and U.S. Geological Survey practice of the last decade and assign intensities of V and above principally on the basis of effects on human structures and contents of structures.

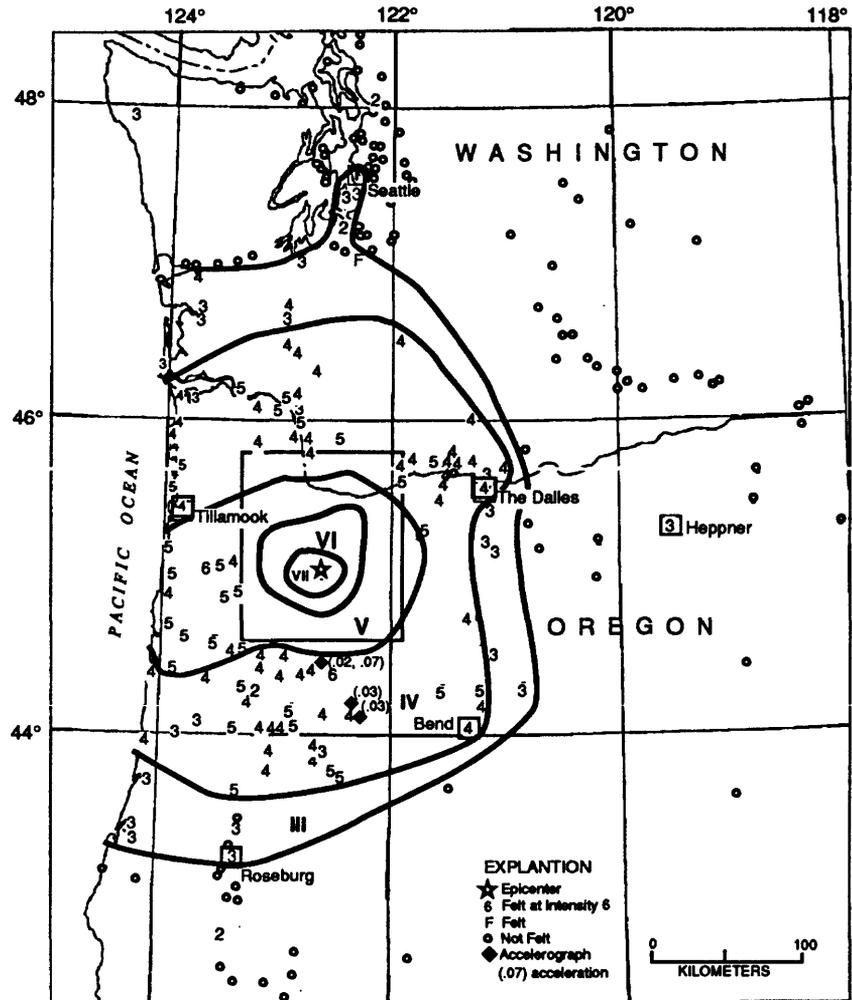
The distribution of intensities associated with the Scotts Mills earthquake is shown in figures 2 and 3.

The most severe damage from the Scotts Mills earthquake occurred to old (pre-1950), unreinforced masonry buildings. Bonneville and others (1993) state

that, in addition to being constructed of unreinforced masonry, most damaged buildings had other characteristics that made them vulnerable to earthquake shaking: "unanchored gable end walls, tall story heights, interaction with adjacent buildings of different height, and high parapets all were factors" (Bonneville and others, 1993, p. 5). Buildings constructed in recent decades, including those of unreinforced masonry, sustained only minor damage directly from the earthquake, although some were damaged by falling bricks from adjacent older buildings. In the residential parts of communities, the most characteristic type of damage was chimney damage.

Area newspapers noted four cases of people needing medical attention for minor injuries suffered in the earthquake and three cases of people needing attention for inhalation of noxious fumes (see entry below under Woodburn). People have been killed in other U.S. earthquakes from falls of masonry similar to those that occurred during the Scotts Mills earthquake; the absence

Figure 2. Isoseismal map for the Scotts Mills, Oregon, earthquake of March 25, 1993. Roman numerals represent average Modified Mercalli intensities for the regions between isoseismals; Arabic numerals represent intensities in individual towns or zip-code regions. Squares represent towns identified on the figure. Shown also are three sites at which the U.S. Geological Survey Cooperative Strong-Motion Network accelerographs were triggered in the Scotts Mills earthquake. Peak accelerations in units of g ($1g = \text{local acceleration of gravity, } \sim 980 \text{ cm/sec}^2$) are shown in parentheses next to the accelerograph sites. Multiple values are those recorded by different accelerographs triggered at that site (table 2). Near-source intensities and accelerograph sites are plotted in figure 3, which is an enlarged view of the area within the box.



of serious injuries or fatalities in the case of the Scotts Mills earthquake may be attributable in part to few people being in or near damaged buildings when the shock occurred.

The U.S.G.S. Earthquake Report questionnaire asks respondents about the presence and strength of earth noise that may have accompanied the earthquake. More than half of the questionnaires returned from within the intensity VI and VII isoseismals reported strong or moderate earth noise associated with the earthquake. For intensity V and all lower intensities, more than half the respondents either explicitly reported not hearing noise or did not answer the question about earth noise.

Descriptions of damage attributed to the press were taken from the *Canby Herald*, the *Molalla Pioneer*, the *Newberg Graphic*, the *Oregonian*, the *Outlook* (Gresham), the *Sandy Post*, the *Statesman Journal* (Salem), the *Wilsonville Spokesman*, and the *Woodburn Independent*.

Intensity VII Oregon—

Dayton (SH 18 bridge over Yamhill River)- One end of a span dropped, leaving a 6 to 8 inch (15 to 20 cm) vertical offset between that span and the adjacent span. The drop resulted from the toppling of a pedestal on which the span rested (Bonneville and others, 1993). A car encountering the offset from the downdropped side had blowouts in all tires, and the driver nearly lost control of the vehicle (press report). In addition to the damage due to the overturned pedestal, the asphalt approach to the bridge settled several inches due to soil compaction. The bridge was given a temporary repair after having been out of service for three days.

Molalla- The Molalla Union High School South Campus building, constructed in 1925, suffered structural damage to its brick and mortar walls. Bricks from the south and west gables were

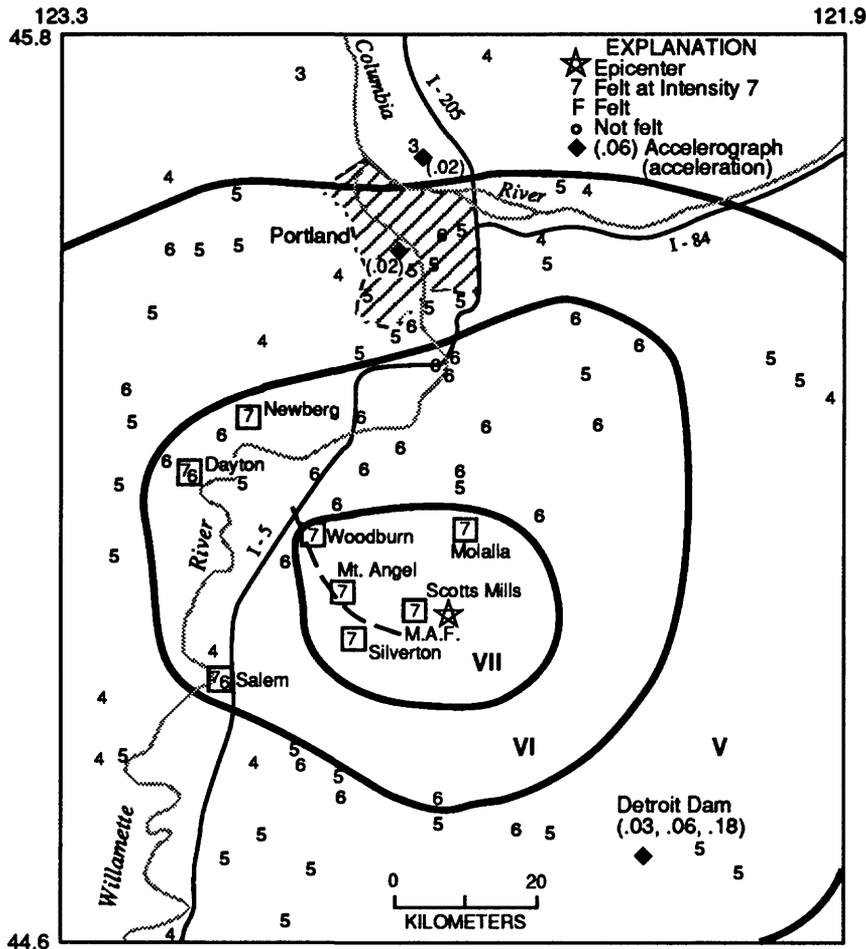


Figure 3. Near-source intensities and sites at which U.S. Geological Survey Cooperative Strong-Motion Network accelerographs were triggered in the Scotts Mills earthquake. Roman numerals represent average Modified Mercalli intensities for the regions between isoseismals; Arabic numerals represent intensities in individual towns or zip-code regions. Squares represent towns identified on the figure. Peak accelerations in units of g ($1g = \text{local acceleration of gravity, } \sim 980 \text{ cm/sec}^2$) are shown in parentheses next to the accelerograph sites. Multiple values shown for Detroit Dam are those recorded by three different accelerographs triggered at that site (table 2). MAF = Mount Angel fault.

shaken down; the gable walls were not attached to the wood frame of the gable roofs (Bonneville and others, 1993). The west gable bricks fell onto an entrance porch, in an area where students usually congregate before and after school. School hallways were littered with bits of acoustical tile and plaster, and there were cracks in the stairwells (press report). Cement-block maintenance buildings behind the school building were also cracked (press report).

Several unreinforced masonry commercial buildings sustained structural damage. Exterior walls of the 44-year-old Odd Fellows Hall became detached from the roof and tilted outward over adjacent buildings; authorities ordered the hall and two adjacent buildings closed. Bricks and mortar fell from the walls of a three-bay carwash. Eight businesses located in or adjacent to damaged buildings were ordered temporarily closed (press report).

There was chimney damage in residential districts, as well as minor cracking of interior walls and items shaken off shelves or walls. Most instances of chimney damage were associated with older, two-story, wood-frame houses. Damage included chimneys being separated from houses, chimneys sustaining cracks or having bricks fall from them, and chimneys shaken down to roof line. Some sidewalks and roads sustained large cracks or were buckled; some masonry fences or retaining walls were cracked or destroyed; some windows were broken out; heavy furniture was displaced; light furniture or small appliances overturned; many glassware items or dishes broke; many small objects overturned and fell; residents experienced difficulty walking or standing.

Mount Angel- Saint Mary's Catholic church sustained damages estimated at \$4 to \$6 million (press report). Exterior walls were cracked, as were buttresses; the 200-foot high bell tower

listed about 5 degrees from vertical (press report); a stained-glass window cracked. The church was built in 1912 and had been declared a national historic landmark.

Elsewhere in town, many chimneys were cracked or had bricks fallen from them; many items were shaken off store shelves; many glassware items or dishes broke; some windows were broken out; many small objects overturned and fell.

Newberg- Loss from earthquake damage was preliminarily estimated to be about \$700,000. Damage was heaviest in the old part of town along First Street; at least 14 buildings were appreciably damaged, among them the Francis Theatre building, the Bank of America building, the Newberg Fitness Center, and the Portland General Electric building. At George Fox College, Wood-Mar Hall had fallen plaster; three sets of library shelving collapsed. Residents of a four-unit apartment building were evacuated. (press reports)

Interior walls sustained large cracks; sidewalks and roads sustained large cracks; underground pipes were broken; masonry fences or retaining walls were cracked; some windows were broken out; many items were shaken off store shelves; furniture was displaced; many small objects overturned and fell.

Salem (State Capitol building)- There was significant damage to the old section of the capitol building, which was built in 1935. The 106 foot high rotunda cracked and bulged out by three feet; the dome over the rotunda was extensively cracked and fallen plaster littered the Rotunda floor; the ten-ton "Oregon Pioneer" statue on a pedestal atop the dome was slightly rotated, so that mortar between the pedestal and the dome proper was cracked (press reports).

Scotts Mills- Several chimneys were cracked, lost bricks, or were broken at the roof line; masonry exterior walls sustained large cracks; interior walls sustained large cracks; masonry fences and retaining walls were cracked or partially fallen; many items were shaken off store shelves; furniture was displaced; many small objects overturned and fell; some windows were broken out.

Silverton- Several chimneys were cracked, lost bricks, or were broken at the roof line; masonry exterior walls cracked or bulged outward; many items were thrown from store shelves; many glassware items or dishes were broken; many small objects overturned and fell; windows were broken out; a few people ran out of buildings.

Woodburn- Three people received medical attention as a consequence of exposure to noxious fumes at the Woodburn Wal-Mart; the fumes arose from spilling and mixing of garden chemicals, paint, and battery acid (press report). The tops of unreinforced brick exterior walls fell. Brick third-story walls of the Salud Medical Center collapsed and fell through the second story ceiling, forcing temporary closure of the center. Structural damage was heaviest along Front Street, where authorities closed seven buildings because of quake damage (press report).

Many chimneys were cracked, lost bricks, or fell; interior walls sustained large cracks; underground pipes cracked; masonry fences or retaining walls were cracked; some windows were broken out; many items were shaken off store shelves; many glassware items or dishes broke; many people ran out of buildings.

Intensity VI:

The following effects were commonly noted on returned questionnaires, and we do not list them for each location: trees and bushes shook moderately; standing vehicles rocked moderately; moving vehicles rocked moderately; vibration was described as moderate or strong; a few people ran out of buildings; felt by and awakened many or all.

Oregon—

Aumsville- A few chimneys were cracked; brick and concrete-block exterior walls sustained hairline cracks; plaster and drywall sustained a few large cracks; a few windows cracked; a few items were shaken off store shelves; a few glassware items or dishes broke; a few small objects overturned and fell.

Aurora- Interior walls split at seams; brick exterior walls sustained hairline cracks; chimneys were broken at the roof line; bricks that had fallen from a chimney damaged a car parked below (press

- report); many items were shaken off store shelves (press report); several glassware items or dishes broke; water splashed onto sides of swimming pools; a few tombstones were displaced.
- Beaver Creek-** Drywall sustained large cracks; masonry exterior walls sustained hairline cracks; a few small objects overturned and fell.
- Boring-** A few chimneys were cracked or had bricks fallen from them; plaster and drywall sustained hairline cracks; exterior brick walls sustained hairline cracks; masonry fences and retaining walls were cracked; a few windows cracked; a few items were shaken off store shelves; a few small objects overturned and fell; hanging pictures swung out of place; water splashed onto sides of swimming pools.
- Canby-** Some chimneys were cracked or had bricks fallen from them; plaster and drywall sustained hairline cracks; ceiling tiles fell in the city hall; some windows were broken out; many items were shaken off store shelves (press report); many glassware items or dishes broke; furniture was displaced; many small objects overturned and fell; hanging pictures swung out of place or fell; a clock fell to the floor (press report); trees and bushes shook strongly; moving vehicles rocked moderately; water splashed onto sides of swimming pools; masonry fences or retaining walls were cracked; people had difficulty walking or standing.
- Cascadia-** Interior walls sustained large cracks; exterior walls sustained hairline cracks; a few windows cracked; a few glassware items or dishes broke; several small objects overturned and fell; hanging pictures swung out of place.
- Colton-** At one residence a wall was detached from the ceiling; interior walls sustained cracks; the chimney pulled away from a house; masonry fences or retaining walls were cracked; many items were shaken off store shelves; small appliances were displaced; several dishes and knickknacks were broken; several small objects overturned and fell; hanging pictures fell; water splashed onto banks of ponds; small rock falls occurred; wells were muddied.
- Dayton-** Bricks fell from the tops of a few chimneys; a fireplace crumbled in one residence; hairline cracks occurred in exterior walls and in foundations; a few items were shaken off store shelves; a few glassware items or dishes broke; many small objects overturned and fell; hanging pictures fell.
- Donald-** A few chimneys were cracked or had bricks fallen from them; exterior walls sustained hairline cracks; a few large cracks occurred in drywall; masonry fences or retaining walls were cracked; several items were shaken off store shelves; a few glassware items or dishes broke; many small objects overturned and fell; hanging pictures fell; water splashed onto sides of swimming pools.
- Dundee-** A few chimneys were cracked or had bricks fallen from them; the top ten feet of a chimney at Dundee Elementary school was rotated (press report); ceiling tiles fell in the Dundee Elementary gymnasium (press report); plaster and drywall sustained hairline cracks and a few large cracks; masonry fences or retaining walls were cracked; a few windows cracked; many items were shaken off store shelves; furniture was displaced; many small objects overturned and fell; hanging pictures fell.
- Estacada-** A few chimneys were cracked; brick exterior walls sustained hairline cracks; plaster and drywall sustained hairline cracks and a few large cracks; masonry fences or retaining walls were cracked; a few windows cracked; a few items were shaken off store shelves; a few glassware items or dishes broke; a few small objects overturned and fell.
- Forest Grove-** The Forest Grove Fire Hall, in poor condition before the earthquake, sustained heavy damage and will have to be replaced (press report). Elsewhere exterior and interior walls sustained hairline cracks; several items were shaken off store shelves; several small objects overturned and fell; hanging pictures swung out of place; windows, doors, and dishes rattled loudly.
- Gervais-** A few chimneys fell; interior walls sustained hairline cracks; a few windows cracked or were broken out; several items were shaken off store shelves; small appliances were displaced; a few small objects overturned and fell.
- Gladstone-** A few chimneys were cracked; exterior walls sustained hairline cracks; interior walls sustained hairline cracks and a few large cracks;

masonry fences or retaining walls were cracked; a few windows cracked; many items were shaken off store shelves; many glassware items or dishes broke; many small objects overturned and fell; hanging pictures fell.

Grand Ronde- Bricks fell from a few chimneys; masonry exterior walls sustained large cracks; interior walls sustained hairline cracks and some separated from ceilings or floors; a few items were shaken off store shelves; a few glassware items or dishes broke; a few small objects overturned and fell; water splashed onto sides of swimming pools.

Gresham- A clay-brick wall of the Flav-R-Pac building, a warehouse built in 1920 and vacant at the time of the earthquake, was cracked and pulled away from the perpendicular wall at a corner (press report). Elsewhere, exterior and interior walls sustained hairline cracks; a few windows cracked; a few items were shaken off store shelves; a few glassware items or dishes broke; a few small objects overturned and fell; hanging pictures swung out of place.

Hubbard- A few chimneys were cracked; brick exterior walls sustained hairline cracks; plaster walls sustained hairline cracks and a few large cracks; a few windows cracked; many items were shaken off store shelves; small appliances were displaced; a few glassware items or dishes broke; many small objects overturned and fell; hanging pictures fell.

Lafayette- Bricks were shaken from the tops of chimneys.

Lake Oswego- Several chimneys were cracked; exterior and interior walls sustained hairline cracks; masonry fences or retaining walls were cracked; a few windows cracked; a few items were shaken off store shelves; a few small objects overturned and fell.

Mehama- Underground pipes cracked; some windows were broken out; a few items were shaken off store shelves; a few glassware items or dishes broke; several small objects overturned and fell.

Mill City- A few chimneys were cracked; exterior and interior walls sustained hairline cracks; masonry fences or retaining walls were cracked; a

few windows cracked; streets and highways were cracked; many items were shaken off store shelves; small appliances were displaced; a few glassware items or dishes broke; many small objects overturned and fell; hanging pictures fell.

Mulino- Exterior and interior walls sustained hairline cracks; several items were shaken off store shelves; furniture was displaced; several glassware items or dishes were broken; many small objects overturned and fell.

Oregon City- Several chimneys were cracked; exterior walls sustained hairline cracks; interior walls sustained hairline cracks and a few large cracks; masonry fences or retaining walls were cracked; sidewalks and streets sustained a few cracks; a few windows cracked; a few items were shaken off store shelves; furniture was displaced; a few glassware items or dishes broke; a few small objects overturned and fell; many small objects overturned and fell.

Portland (Rose City Park)- Bricks fell from several chimneys; a few interior and exterior walls sustained large cracks; a few windows cracked; a few items were shaken off store shelves; light furniture was displaced; several small objects overturned and fell; small landslides and rockfalls occurred.

Saint Paul- Interior walls of the 147-year-old Saint Paul Catholic church sustained cracks, and a few items fell off walls. Elsewhere there were isolated instances of the top bricks being knocked off chimneys.

Salem- With the exception of the intensity VII damage at the state capitol building, listed separately above, effects in Salem are those associated with intensities of VI or lower. Several acoustical ceiling tiles fell with fluorescent light fixtures in a public library and in city hall. A few chimneys were cracked; exterior and interior walls sustained hairline cracks; a few windows cracked; several items were shaken off store shelves; several small objects overturned and fell; hanging pictures fell.

Sandy- A few chimneys were cracked; exterior walls sustained hairline cracks; interior walls sustained hairline cracks and a few large cracks; a few small objects overturned and fell; hanging pictures swung out of place.

Stayton- A few chimneys were cracked or had bricks fallen from them; exterior and interior walls sustained hairline cracks; several items were thrown from store shelves; a few windows cracked; several small objects overturned and fell; hanging pictures fell.

West Linn- A few chimneys were cracked or fallen; brick exterior walls sustained hairline cracks; masonry fences or retaining walls were cracked; a few windows cracked; a few items were shaken off store shelves; a few glassware items or dishes broke; a few small objects overturned and fell; hanging pictures swung out of place.

Wilsonville- An exterior wall of the Wilsonville Bowling Lanes sustained a large crack; acoustical ceiling tile fell in the bowling alley; pins were down in every lane (press report). In the Mentor Graphics Building, a security guard was trapped for an hour inside a damaged elevator (press report). Exterior brick walls sustained hairline cracks; drywall sustained hairline cracks; a few small objects overturned and fell; hanging pictures swung out of place; moving vehicles rocked slightly.

Yamhill- A few chimneys were cracked, twisted, or had bricks fallen from them; a few bricks were loosened in the wall of the Yamhill Video store but did not fall; several items were thrown from store shelves; several knickknacks were broken; several items overturned and fell.

Intensity V

The following effects were commonly noted on returned questionnaires, but we do not list them for each location: trees and bushes shook slightly; vibration was described as moderate or strong; felt by and awakened many or all.

Oregon—

Amity- Intensity assigned from field evidence. Mail questionnaire reported that a few chimneys were cracked; exterior brick walls sustained hairline cracks; plaster walls sustained large cracks; highways sustained large cracks; underground pipes were broken; a few windows cracked; a few items were shaken off store shelves; several small objects overturned and fell; hanging pictures fell; water splashed onto sides of swimming pools and ponds.

Blodgett- A few small objects overturned and fell.

Brightwood- A few items were shaken off store shelves; water splashed onto sides of swimming pools; a few people ran out of buildings.

Carlton- A few items fell from walls; some pictures were tilted.

Cascade Locks- A few items were shaken off store shelves; a few small objects overturned and fell; hanging pictures swung out of place.

Cornelius- Light furniture or small appliances were displaced; a few glassware items or dishes broke; a few small objects overturned and fell; hanging pictures swung out of place; windows, doors, and dishes rattled loudly; standing vehicles rocked moderately.

Corvallis- A few windows cracked; a few glassware items or dishes broke; several small objects overturned and fell; hanging pictures fell; buildings shook strongly; walls creaked loudly; windows, doors, and dishes rattled loudly.

Crabtree- A few windows cracked; hanging objects or doors swung violently; small appliances were displaced; a few small objects overturned and fell; hanging pictures swung out of place; buildings shook strongly; walls creaked loudly; windows, doors, and dishes rattled loudly; water splashed onto sides of swimming pools.

Dallas- A brick exterior wall sustained large cracks; moving vehicles rocked slightly.

Detroit- A few items were shaken off store shelves; a few glassware items or dishes broke; several small objects overturned and fell, hanging pictures swung out of place; windows, doors, and dishes rattled loudly; a few people ran out of buildings; trees and bushes shook moderately.

Drain- A few small objects overturned and fell.

Eagle Creek- A few windows cracked; a few items were shaken off store shelves; a few glassware items or dishes broke; a few small objects overturned and fell; hanging pictures fell; moving vehicles rocked slightly.

Eddyville- A few small objects overturned and fell.

Elmira- A few items were shaken off store shelves; a few glassware items or dishes broke; a few small objects overturned and fell.

Falls City- Exterior and interior walls sustained hairline cracks; a few windows cracked; several small objects overturned and a few fell; hanging pictures swung out of place; a few people ran out of buildings.

Gaston- A few items fell from walls.

Gates- Several items were shaken off store shelves; several small objects overturned and fell; hanging pictures swung out of place; a few people ran out of buildings.

Government Camp- A few small objects overturned and fell; windows, doors, and dishes rattled loudly.

Hillsboro- A few items were shaken off store shelves; a few glassware items or dishes broke; several small objects overturned and fell; hanging pictures fell; moving vehicles rocked slightly; a few people ran out of buildings.

Idanha- A few items were shaken off store shelves; several small objects overturned and a few fell; hanging pictures swung out of place or fell; a few people ran out of buildings.

Independence- A few glassware items or dishes broke; a few small objects overturned and fell; hanging pictures swung out of place or fell; windows, doors, and dishes rattled loudly.

Jefferson- A few small objects overturned and fell; hanging pictures swung out of place.

Liberal (5 km [3 miles] north of Molalla)- Items fell from store shelves and a few knick-knacks overturned and fell.

Lyons- A few windows cracked; a few items were shaken off store shelves; light furniture and small appliances were displaced; several small objects overturned and fell; hanging pictures swung out of place; windows, doors, and dishes rattled loudly.

Marcola- A few items were shaken off store shelves; a few small objects overturned and fell; hanging pictures swung out of place.

Marion- A few windows cracked; several knickknacks were broken; several small objects overturned and fell; hanging pictures swung out of place or fell; windows, doors, and dishes rattled loudly.

Marylhurst- A few glassware items or dishes broke; a few small objects overturned and fell; hanging pictures swung out of place; windows, doors, and dishes rattled loudly.

McMinnville- A few small objects overturned; items were thrown from store shelves; a few people ran out of buildings.

Milwaukie- A few items were shaken off store shelves; a few small objects overturned and fell; standing vehicles rocked moderately.

Monroe- Bricks fell from a few chimneys; drywall sustained hairline cracks; a few small objects overturned and fell.

Nehalem- A few items were shaken off store shelves; a few glassware items or dishes broke; a few small objects overturned and fell.

North Plains- Drywall sustained hairline cracks; a few windows cracked; a few small objects overturned and fell.

Oakridge- Interior walls sustained a few large cracks.

Otis- A few small objects overturned and fell.

Pacific City- A few items were shaken off store shelves; a few small objects overturned and fell.

Portland (Brooklyn)- Drywall sustained hairline cracks; a few windows were cracked; several items were shaken off store shelves; a few glassware items or dishes broke; a few small objects fell.

Portland (Multnomah)- Drywall split at seams; a few items were shaken off store shelves; a few glassware items or dishes broke; a few small objects overturned and fell; hanging pictures were swung out of place.

Portland (Parkrose)- A few glassware items or dishes broke; a few small objects overturned and fell; hanging pictures swung out of place.

Portland (Southgate)- A few small objects overturned and fell.

Rainier- A few small objects overturned and fell.

Rockaway- Interior walls sustained hairline cracks; a few items were shaken off store shelves; a few glassware items or dishes broke; a few small objects overturned and fell; hanging pictures fell; moving vehicles rocked slightly; a few people ran out of buildings.

Saint Paul- Plaster walls sustained a few large cracks; a few items were shaken off store shelves; a few glassware items or dishes broke; a few small objects overturned and fell; hanging pictures fell; moving vehicles rocked slightly.

Scio- A few chimneys were cracked; interior walls sustained hairline cracks or separated from ceiling or floors; a few tombstones were cracked; a few glassware items or dishes broke; several small objects overturned and a few fell; hanging pictures swung out of place; windows, doors, and dishes rattled loudly; a few people ran out of buildings; trees and bushes shook moderately; moving vehicles rocked moderately.

Shaw (3 km [2 miles] north of Aumsville)- Light damage to chimneys; possible thin cracks in foundations.

Siletz- Exterior and interior walls sustained hairline cracks; a few items were shaken off store shelves; a few glassware items or dishes broke; a few small objects overturned and fell; hanging pictures swung out of place; windows, doors, and dishes rattled loudly.

Sisters- A few windows cracked; several objects overturned.

Sublimity- Masonry fences or retaining walls were cracked; a few windows cracked; a few items were shaken off store shelves; a few glassware items or dishes broke; a few small objects overturned and fell; hanging pictures swung out of place; windows, doors, and dishes rattled loudly; moving vehicles rocked moderately.

Terrebonne- A few items were shaken off store shelves; a few glassware items or dishes broke; a few small objects fell.

Tidewater- A few items were shaken off store shelves; a few glassware items or dishes broke; a

few small objects overturned and fell.

Tualatin- Drywall sustained hairline cracks; a few small objects overturned and fell; hanging pictures swung out of place; windows, doors, and dishes rattled loudly.

Walterville- A few chimneys were cracked; drywall sustained hairline cracks; masonry fences or retaining walls were cracked; a few items were shaken off store shelves; a few glassware items or dishes broke; a few small objects overturned and fell; trees and bushes shook moderately; water splashed onto sides of swimming pools.

Welches- A few glassware items or dishes broke; several small objects overturned and fell; hanging pictures swung out of place.

Westfir- Ceiling tile loosened and sagged; small appliances were displaced; a few small objects overturned and fell; hanging pictures swung out of place; windows, doors, and dishes rattled loudly.

Willamina- A few windows cracked; a few items were shaken off store shelves; a few small objects overturned and fell; hanging pictures swung out of place.

Washington—

Amboy- Underground pipes were broken at one location; a few items were shaken off store shelves; hanging pictures swung out of place.

Camas- A few items were shaken off store shelves; a few small objects fell; hanging pictures swung out of place.

Cathlamet- A few items were shaken off store shelves; a few small objects overturned and fell.

Kalama- A few small objects overturned and fell; hanging pictures swung out of place; windows, doors, and dishes rattled loudly.

Longview- Many items were shaken off store shelves; hanging pictures fell; standing vehicles rocked moderately; moving vehicles rocked moderately.

Underwood- A few windows cracked; a few small objects overturned and fell.

Intensity IV

Oregon— Albany, Alsea, Arch Cape, Banks,

Beaverton, Bend, Blue River, Brownsville, Cannon Beach, Clatskanie, Columbia City, Cottage Grove, Creswell, Dexter, Eugene, Fairview, Fall Creek, Florence, Foster, Hood River, Junction City, Keizer, Lebanon, Lincoln City, Manzanita, Monmouth, Mount Hood, Oakridge, Odell, Philomath, Redmond, Rhododendron, Rickreall, Scholls, Seaside, Shedd, Sheridan, Springfield, Sweet Home, Tangent, The Dalles, Thurston, Tillamook, Tolovana Park, Turner, Vernonia, Vida, Waldport, Warm Springs, Warrenton.

Washington— Battle Ground, Bingen, Carson, Centralia, Cosmopolis, Glenwood, Husum, Kelso, Lyle, Randle, Ridgefield, Stevenson, Toledo, Toutle, Washougal, White Salmon, Winlock, Wishram, Woodland.

Intensity III

Oregon— Astoria, Coos Bay, Culver, Dufur, Gardiner, Greenleaf, Heppner, Lowell, Mapleton, Maupin, North Bend, Prineville, Roseburg, Scappoose, Sutherlin, Tygh Valley.

Washington— Carrolls, Chehalis, Dallesport, Forks, Lacey, Long Beach, Raymond, Seahurst, South Bend, Vancouver, Vashon.

Intensity II

Oregon— Glendale, Harrisburg.

Washington— Marysville, Tacoma.

Felt

Washington— Graham.

STRONG MOTION RECORDS

Strong-motion accelerographs operated by the National Strong-Motion Program (NSMP) were triggered at the following stations (table 2; fig. 4):

- Detroit Dam (3 records)
- Portland State University ((1 record)
- Green Peter Dam (2 records)
- Vancouver VA Hospital (1 record)
- Blue River Dam (1 record)
- Cougar Dam (1 record)

Maximum recorded accelerations occurred at Detroit Dam. An accelerograph located immediately downstream of the dam recorded a peak acceleration of .06 g; an accelerograph in the upper gallery of the dam

recorded a peak acceleration of .18 g. At other Corps of Engineers facilities, Green Peter, Blue River, and Cougar Dams, only 4 of the existing 14 accelerographs were triggered by the earthquake. Ground accelerations were low in the Portland-Vancouver area, reaching .02 g (table 2), barely sufficient to trigger the instrumentation.

Previous strong-motion records were obtained in Oregon at the Portland State Office building for earthquakes in 1961, 1962, and 1965 (table 1). Among these shocks, only the 1962 event produced a significant record, with a peak horizontal acceleration of .10g (fig. 5). The epicenter of the 1962 earthquake (Yelin and Patton, 1991) was located at a distance of approximately 15 km from the accelerograph.

FOCAL MECHANISM AND DEPTH DETERMINED FROM DIGITAL DATA

Figures 6 and 7 show broadband P-wave displacements recorded at stations of the Federation of Digital Seismograph Networks; the plotted seismograms are from stations with the best signal-to-noise ratio.

The shape of the P waveform is strongly influenced by the focal depth of the earthquake, by the orientation of the causative fault that produced the earthquake, and by the slip-direction that the crustal block on one side of the fault has moved with respect to the crustal block on the other side of the fault during the earthquake. Thus one may determine the depth, orientation, and slip direction of the causative fault by analysis of the waveform.

We have performed a preliminary analysis of the waveforms and obtained a depth of 16 km. The data imply two P-wave nodal-planes, one of which is the fault plane and one of which is the conjugate plane. Plane 1 has strike 316° (N44°W); dip 63° (NE); slip 152° (right-lateral oblique-reverse slip); plane 2 has strike 60°(N60°E); dip 65°(SE); slip 30° (left-lateral oblique-reverse slip). The focal mechanism implies that the shock was caused by compressional tectonic stress directed approximately north-south. Figure 8 shows how the data used in the analysis are distributed on the lower-hemisphere of the focal sphere. Dashed lines superimposed on the seismograms of figure 7 are synthetics, showing how well the inferred focal depth and source orientation account for the shape of those seismograms.

The depth and focal-mechanism orientation inferred for the Scotts Mills earthquake are consistent with a

Table 2. USGS strong-motion data for the Scotts Mills, Oregon, earthquake of March 25, 1993, 13:34:35.4 UTC

EPICENTRAL DISTANCE * (km)	STATION LOCATION (OWNER)	ACCELERATION	
		COMPONENT DIRECTION	MAXIMUM (g)
43	Detroit Dam, Oregon Downstream (ACOE)	198°	0.06
		Up	0.05
		108°	0.06
43	Detroit Dam, Oregon Gallery, Gallery Level #7 (ACOE)	198°	0.15
		Up	0.07
		108°	0.18
43	Detroit Dam, Oregon Gallery, Gallery Level #1 (ACOE)	198°	0.03
		Up	0.02
		108°	0.02
53	Portland State Univ., Oregon Cramer Hall, Basement (USGS)	291°	0.02
		Up	0.01
		201°	0.02
64	Green Peter Dam, Oregon Lower Gallery (ACOE)	042°	0.01
		Up	0.01
		312°	0.02
64	Green Peter Dam, Oregon Upper Gallery (ACOE)	042°	undamped
		Up	0.03
		312°	0.07
65	Vancouver, Washington VA Hospital (VA)	018°	0.02
		Up	0.02
		288°	0.02
100	Blue River Dam, Oregon Toe (ACOE)	329°	0.03
		Up	0.02
		239°	0.03
106	Cougar Dam, Oregon Center Crest (ACOE)	076°	0.03
		Up	0.02
		346°	0.02

* Epicentral distances in this table and in figure 4 are measured with respect to a preliminary epicenter at 45.06°N., 122.52°W. Distances with respect to the current preferred epicenter differ by up to 2 km.

ACOE=Army Corps of Engineers,

VA=Veterans Administration

suggestion that the shock involved slip at depth on the northwest-trending Mt. Angel fault (Madin and others, 1993). The Mt. Angel fault had been previously mapped as a right-lateral oblique-reverse fault and identified as possibly being seismogenic (Werner and others, 1992). The seismologically determined fault orientation and sense of slip are consistent with the geologically determined orientation and sense of slip. A plane having the orientation of our northwest-striking nodal plane (plane 1) and passing through the hypocenter of the earthquake would intersect the ground surface within several kilometers of the surface trace of the geologically mapped Mt. Angel fault. Even with the focal mechanism, however, presently available evidence linking the Mt. Angel fault with the Scotts Mills earthquake is not as strong as evidence linking specific faults with earthquakes in some other parts of the western U.S. Rather than occurring on the Mt. Angel fault, the Scotts Mills earthquake may have occurred on a mid-crustal fault that does not extend as a continuous dislocation up into the shallow crust (Madin and others, 1993).

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NATIONAL STRONG-MOTION PROGRAM DIRECTION CONSTANTS MAX. ACCELERATION

Station No. 2133 44.72N, 122.25W 198° Sens. = 4.00 cm/g
 Max. = 0.06 g

Detroit Dam, Oregon

 Freq. = 17.2 Hz
 Damp. = 0.59 crit

SMA No. 950 (ACOE) Downstream Up 0.05

Earthquake of

 Sens. = 4.00 cm/g
 Freq. = 17.9 Hz
 Damp. = 0.59 crit

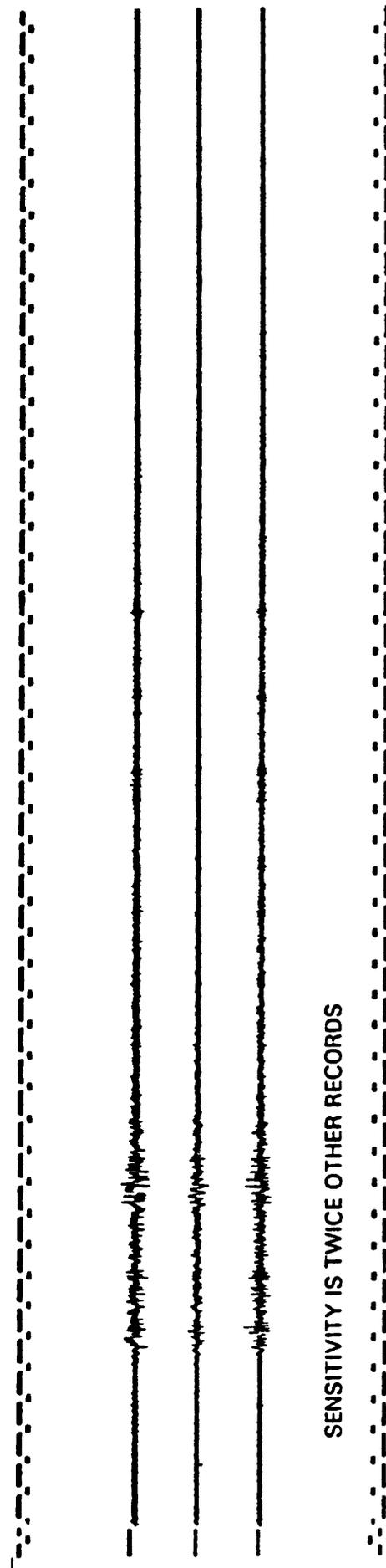
25 March 1993, 1334:36.5 G.m.t.

 108° Sens. = 4.00 cm/g
 Max. = 0.06 g

 Freq. = 16.7 Hz
 Damp. = 0.59 crit

Epicentral distance = 43 km

Film speed = 1 cm/sec



SENSITIVITY IS TWICE OTHER RECORDS

Figure 4. Accelerograms from the Scotts Mills earthquake recorded by the USGS Cooperative Strong-Motion Network.

<u>NATIONAL STRONG-MOTION PROGRAM</u>	<u>DIRECTION</u>	<u>CONSTANTS</u>	<u>MAX. ACCELERATION</u>
Station No. 2133 44.72N, 122.25W Detroit Dam, Oregon	198°	Sens. = 1.85 cm/g Freq. = 25.7 Hz Damp. = 0.59 crit	0.15 g
SMA No. 954 (ACOE) Gallery Level #7 Earthquake of 25 March 1993, 1334:36.5 G.m.t.	Up 108°	Sens. = 1.95 cm/g Freq. = 25.2 Hz Damp. = 0.59 crit Sens. = 2.00 cm/g Freq. = 26.2 Hz Damp. = 0.59 crit	0.07 0.18
Epicentral distance = 43 km		Film speed = 1 cm/sec	

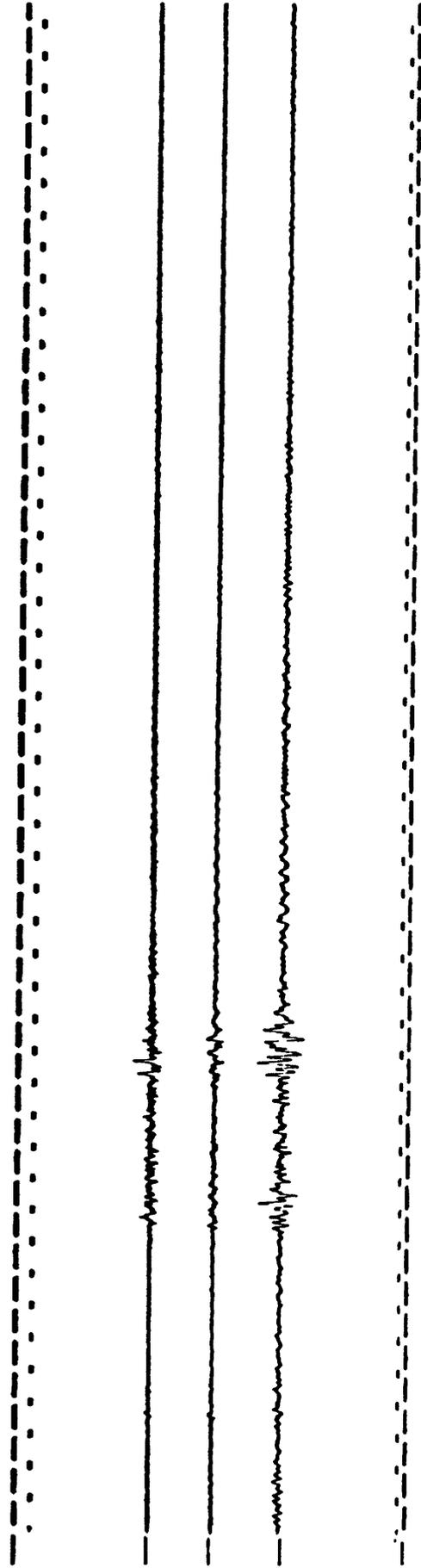


Figure 4 (Continued).

<u>NATIONAL STRONG-MOTION PROGRAM</u>	<u>DIRECTION</u>	<u>CONSTANTS</u>	<u>MAX. ACCELERATION</u>
Station No. 2133 44.72N, 122.25W Detroit Dam, Oregon	198°	Sens. = 1.82 cm/g Freq. = 25.7 Hz Damp. = 0.59 crit	0.03 g
SMA No. 955 (ACOE) Gallery Level #1 Earthquake of	Up	Sens. = 2.01 cm/g Freq. = 28.2 Hz Damp. = 0.59 crit	0.02
25 March 1993, 1334:36.5 G.m.t.	108°	Sens. = 1.81 cm/g Freq. = 25.9 Hz Damp. = 0.59 crit	0.02
Epicentral distance = 43 km Film speed = 1 cm/sec			

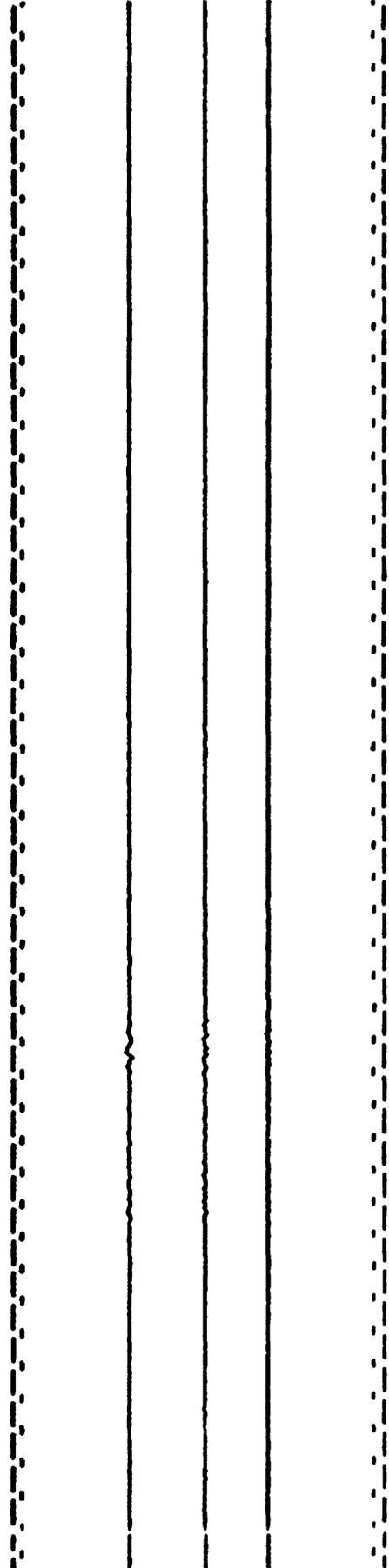


Figure 4 (Continued).

<u>NATIONAL STRONG-MOTION PROGRAM</u>	<u>DIRECTION</u>	<u>CONSTANTS</u>	<u>MAX. ACCELERATION</u>
Station No.2172 45.513N, 122.683 Portland State University, Oregon Cramer Hall	291°	Sens. = 1.79 cm/g Freq. = 26.0 Hz Damp. = 0.59 crit	0.02 g
SMA-1 No. 2718 (USGS) Basement Earthquake of	Up	Sens. = 1.76 cm/g Freq. = 26.0 Hz Damp. = 0.60 crit	0.01
25 March 1993, 1334:36.5 G.m.t.	201°	Sens. = 1.73 cm/g Freq. = 26.0 Hz Damp. = 0.65 crit	0.02
Epical distance = 53 km			
Film speed = 1 cm/sec			

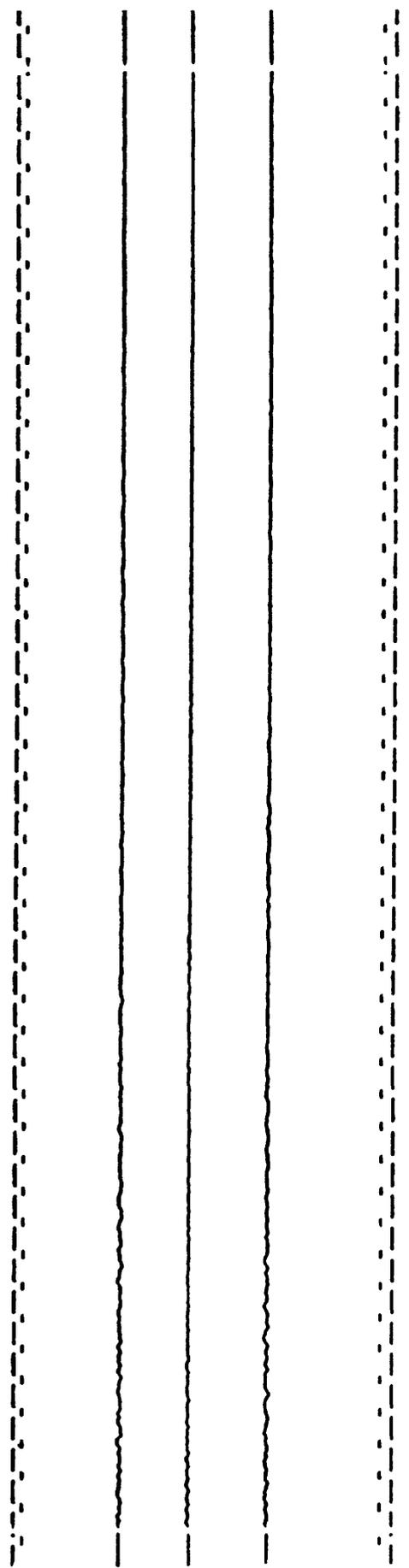


Figure 4 (Continued).

<u>NATIONAL STRONG-MOTION PROGRAM</u>	<u>DIRECTION</u>	<u>CONSTANTS</u>	<u>MAX. ACCELERATION</u>
Station No. 7000 45.64N, 122.66W Vancouver VA Hospital, Washington	018°	Sens. = 1.88 cm/g Freq. = 25.9 Hz Damp. = 0.59 crit	0.02 g
SMA-1 No. 771 (VA) Earthquake of	Up	Sens. = 1.73 cm/g Freq. = 25.9 Hz Damp. = 0.59 crit	0.02
25 March 1993, 1334:36.5 G.m.t.	288°	Sens. = 1.84 cm/g Freq. = 25.6 Hz Damp. = 0.59 crit	0.02

Epicentral distance = 65 km Film speed = 1 cm/sec

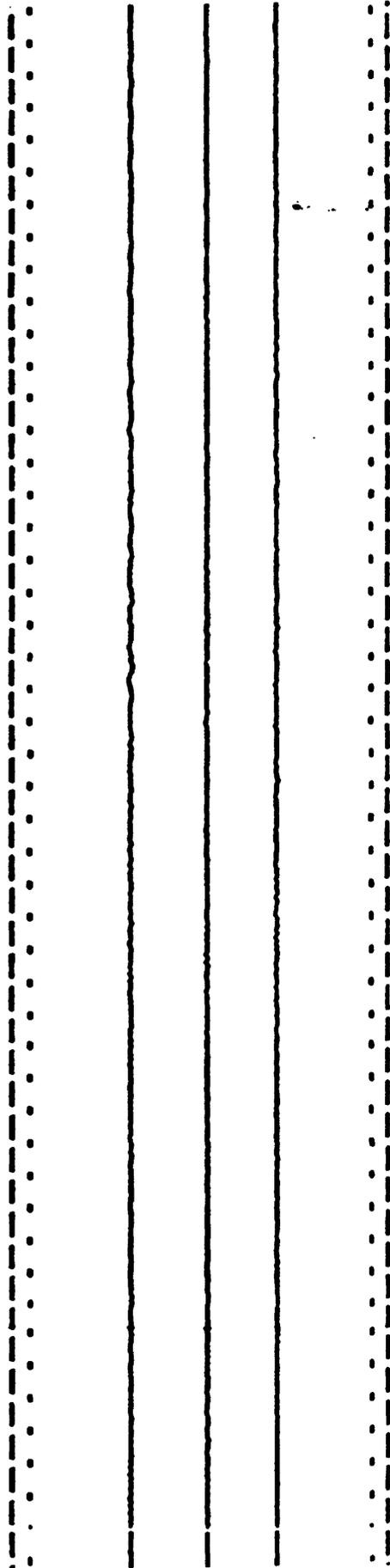


Figure 4 (Continued).

NATIONAL STRONG-MOTION PROGRAM DIRECTION CONSTANTS MAX. ACCELERATION

Station No. 2146	44.17N, 122.33W	329°	Sens. = 3.84 cm/g Freq. = 18.4 Hz Damp. = 0.59 crit	0.03 g
Blue River Dam, Oregon - Toe				
SMA-1 No. 940 (1/2 G) (ACOE)		Up	Sens. = 3.98 cm/g Freq. = 17.1 Hz Damp. = 0.59 crit	0.02
Earthquake				
25 March 1993, 1334:36.5 G.m.t.		239°	Sens. = 4.00 cm/g Freq. = 17.7 Hz Damp. = 0.59 crit	0.03

Epicentral distance = 100 km Film speed = 1 cm/sec

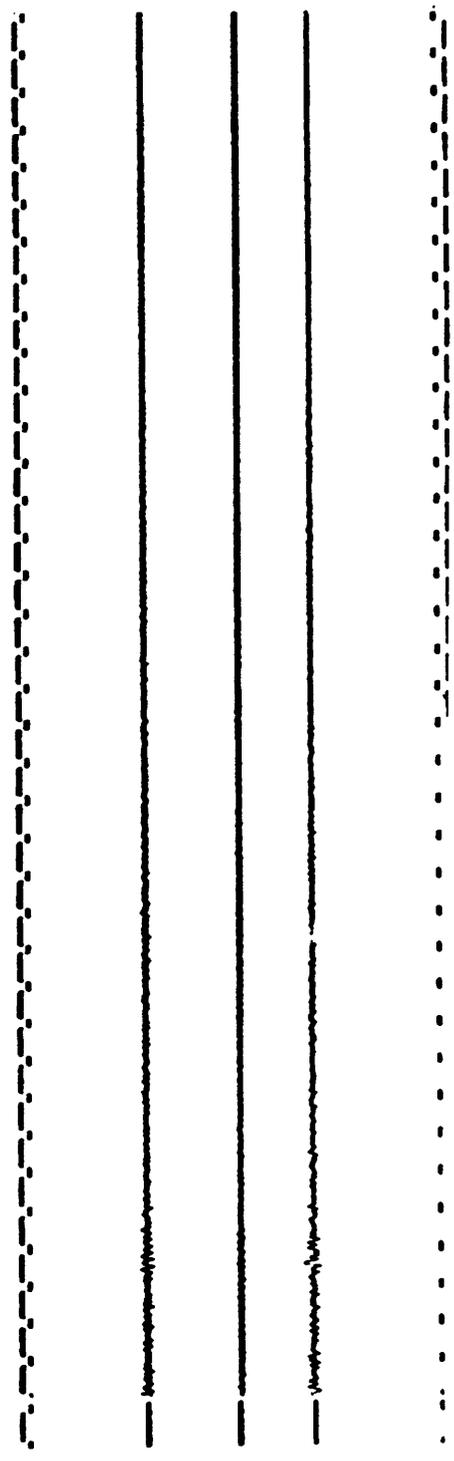


Figure 4 (Continued).

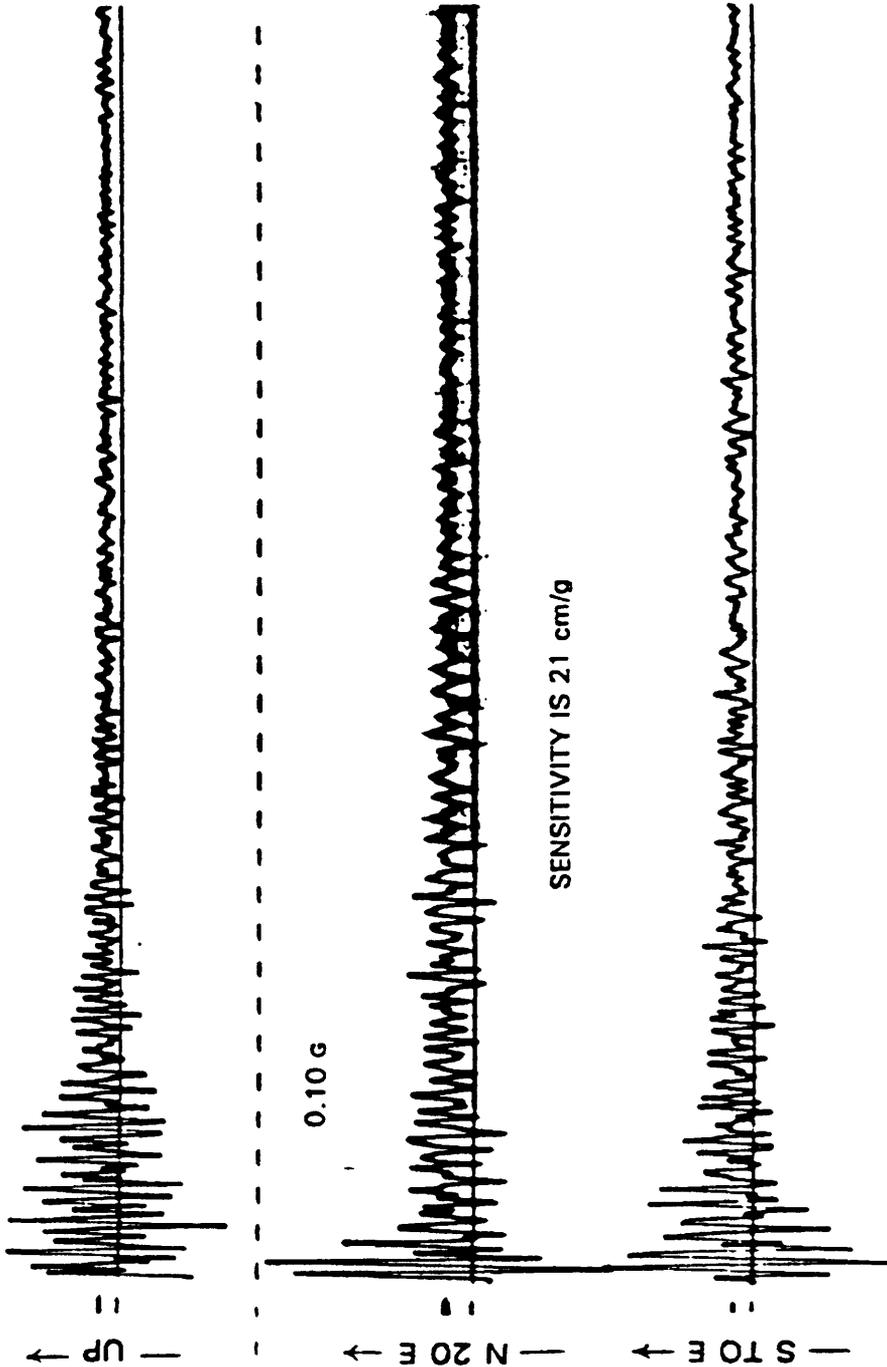


Figure 5. Strong-motion record obtained from the earthquake of November 6, 1962, 03:36 UTC, at Portland, Oregon, in the basement of the Oregon State Office Building. Station coordinates are 45.52°N., 122.68°W. Epicentral distance = 15 km. One cm = 1 sec.

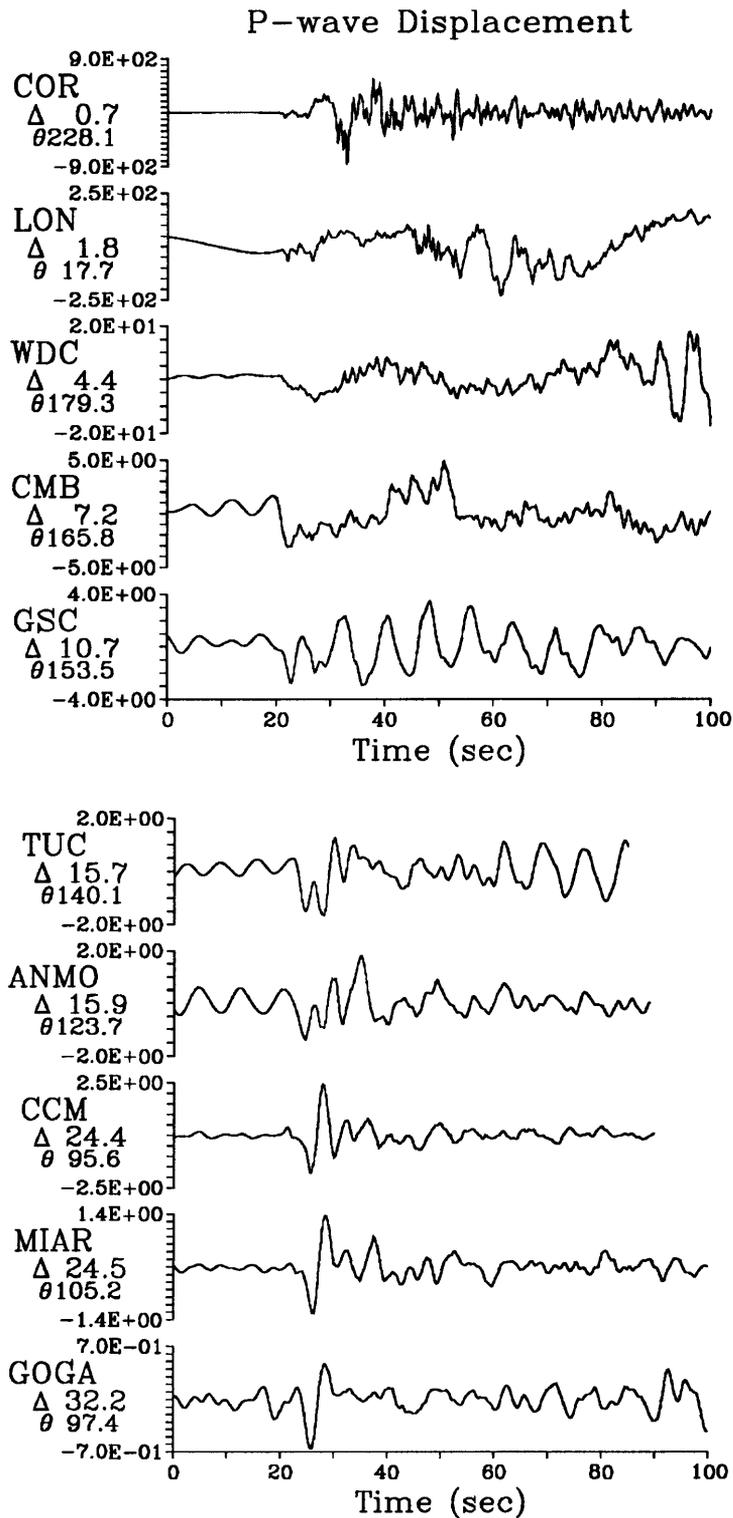


Figure 6 . P-wave displacements recorded at stations of the Federation of Digital Seismograph Networks. Stations are ordered by increasing distance (Δ , given in degrees). The azimuth of each station from the source is given by θ . Amplitudes of displacements are given in microns. Stations are identified by standard abbreviations used by the National Earthquake Information Center.

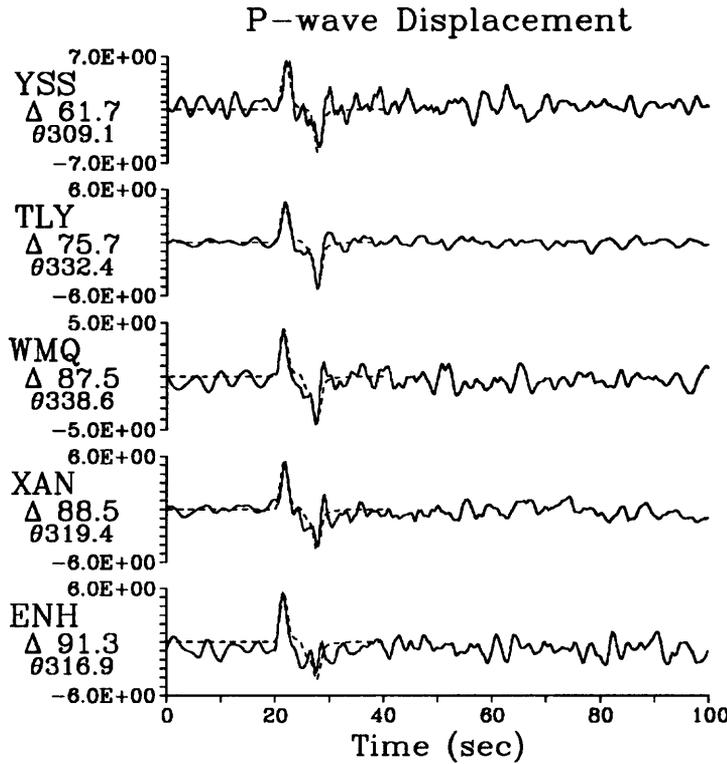


Figure 7. Observed P-wave displacements recorded at stations of the Federation of Digital Seismograph Networks, together with synthetic displacements (dashed lines) computed for the preferred focal mechanism. Otherwise, representation of the data is as in Figure 6.

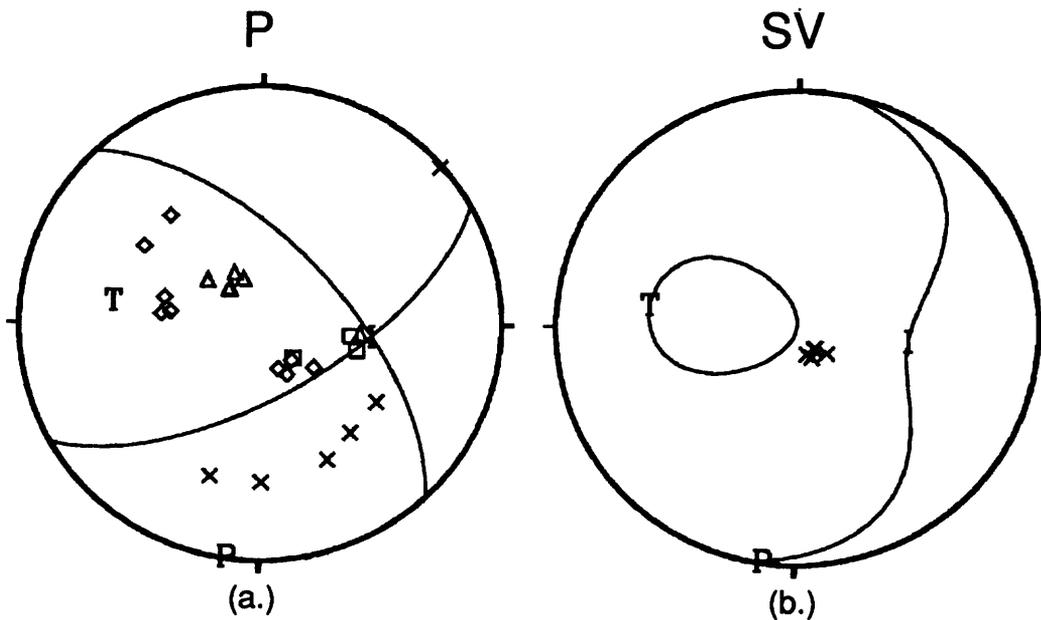


Figure 8. Focal mechanism of the Scotts Mills earthquake, showing the distribution of data used to construct the focal mechanism. Lower hemispheres of the focal sphere are represented in equal-area projection. (a.) P-wave data: triangle - P-wave compression; diamond - pP wave that left the source as a compression; square - nodal P-wave or pP-wave; diagonal cross - P-wave dilatation; curved lines - projections of P-wave nodal-planes, one of which corresponds to the earthquake fault-plane. (b.) sP first motions: diagonal cross - dilatational sP first-motion; curved lines - nodal lines for SV radiation pattern.