STATE OF OREGON
DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES
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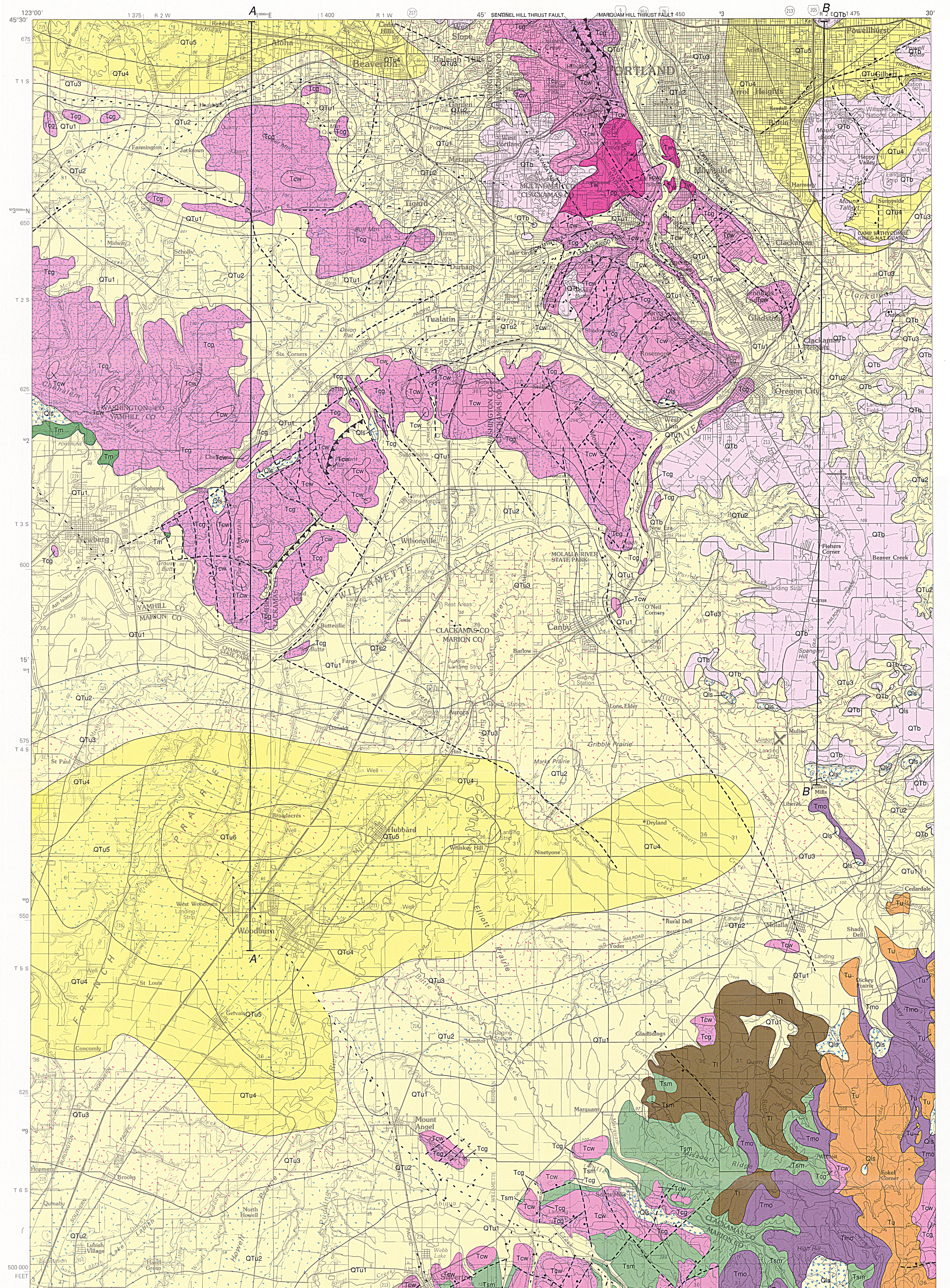
Map showing faults, bedrock geology, and sediment thickness of the western half of the Oregon City 1:100,000 quadrangle, Washington, Multnomah, Clackamas, and Marion Counties, Oregon

1997

IMS-4

Map showing faults, bedrock geology, and sediment thickness of the western half of the Oregon City 1:100,000 quadrangle, Washington, Multnomah, Clackamas, and Marion Counties, Oregon.

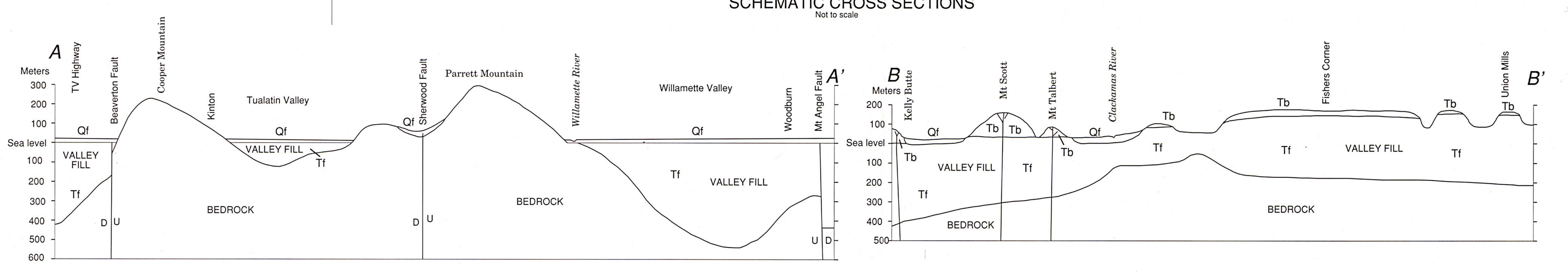
By S. Burns and others



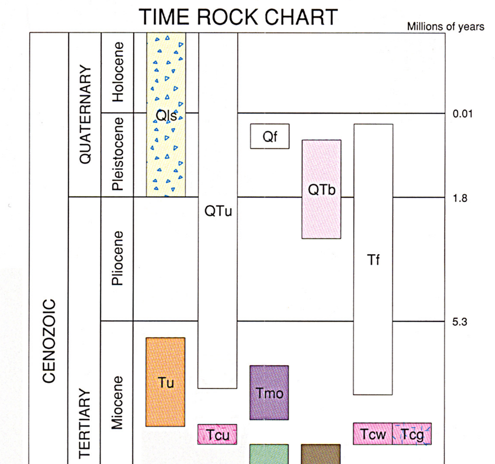
Base map by U.S. Geological Survey
Projection and 10,000-meter grid, zone 10 Universal Transverse Mercator
25,000-foot grid ticks based on Oregon coordinate system, north zone. 1927 North American Datum
1982 magnetic declination: 20 degrees east

Compiled by Scott Burns, Lawrence Growney, and Brett Brodersen, Department of Geology, Portland State University; and Robert S. Yeats, and Thomas A. Popowski, Department of Geosciences, Oregon State University

SCHEMATIC CROSS SECTIONS



TIME ROCK CHART



Time scale after Berggren and others, 1985

The purpose of this map is to show the geology of the northern Willamette Valley that is related to earthquake hazards. The map shows faults, bedrock geology of the uplands, and thickness of the sediments in the valleys, all factors that have some effect on how the area will respond to an earthquake. The map is designed for the nontechnical user and is a compilation of geologic information from other more detailed and more technical maps and reports listed elsewhere on the map.

Explanation

(BP means years before the present; Ma means million years before the present)

- Qls — **Landslide deposits (Quaternary, last 1.8 million years)**
- QTu — **Valley unconsolidated sediments (Miocene through Quaternary, 14.5 Ma to today)**—Modern stream deposits, catastrophic flood deposits (unit Qf), and fluvial (river) and lacustrine (lake) deposits (unit Tf). Shown only on time-rock chart
- QTu1 — **Unconsolidated sediments with total thickness ranging from 0 to 99 m**
- QTu2 — **Unconsolidated sediments with total thickness ranging from 100 to 199 m**
- QTu3 — **Unconsolidated sediments with total thickness ranging from 200 to 299 m**
- QTu4 — **Unconsolidated sediments with total thickness ranging from 300 to 399 m**
- QTu5 — **Unconsolidated sediments with total thickness ranging from 400 to 499 m**
- QTu6 — **Unconsolidated sediments with total thickness of 500 m or greater**
- Qf — **Catastrophic flood deposits (late Quaternary, 15,300 to 12,700 years BP)**—Unconsolidated silt, sand, and gravel deposited by catastrophic floods in the Willamette Valley. These floods were caused by the repeated failure (possibly more than 90 times) of glacial dams along the Clark Fork River in western Montana that periodically impounded glacial meltwater in Glacial Lake Missoula near the present-day city of Missoula. Catastrophic flood deposits south of Oregon City are primarily silt with some sand. In Portland, the deposits are also mainly silt and sand, but gravel and sand are found locally where the silt has been washed away by outwash from the floods. This unit appears only on cross sections and the time-rock chart
- QTb — **Boring Lava (Pliocene to Pleistocene, 2.44 Ma to 260,000 years BP)**—Light-gray basalt and basaltic andesite flows with interstratified cinders and lava erupted from local vents in the Portland area. The flows are poorly exposed in many locations because of deep weathering and mantles of wind-deposited silt called loess (Portland Hills Silt)
- Tf — **Fluvial (river) and lacustrine (lake) sediments (Miocene to Pleistocene, 14.5 Ma to 20,000 years BP)**—Most of the sediments are of the Troutdale Formation, which is composed of friable (easily crumbled) to moderately well-cemented conglomerate with interbeds of sandstone, siltstone, and claystone. These ancestral Columbia River deposits contain abundant basalt from local sources as well as volcanic, metamorphic, and plutonic rocks from outside the study area. This unit also includes friable to moderately strong siltstone, sandstone, and claystone of Sandy River Mudstone. Some of the fine-grained sediment may be lake sediment. In the southern part of the map area, the units are unnamed. Some of these sediments may be only 20,000 years old, since deposition has probably been continuous throughout the Quaternary. Paleomagnetism of sediments from a drill hole near Sublimity shows that the sediments are largely Pleistocene in age (Crenna and others, 1994; Yeats and others, 1996). This unit appears only on cross sections and the time-rock chart
- Tu — **Undivided volcanic rocks (Miocene, 14.5 Ma to about 6 Ma)**—Andesite flows, basaltic andesite flows, mudflow breccia, water-laid tuff, and tuff of the Rhododendron Formation; tuffaceous siltstone and sandstone, pebble conglomerate, agglomerate, volcanic cobble conglomerate, and interbeds of air-fall tuff of the Sardine Formation
- Tmo — **Molalla Formation (Miocene, 13 to 10 Ma)**—Pumiceous volcanic conglomerate and tuff

Columbia River Basalt Group (Miocene, 16.5 to 15 Ma)—These basalts were erupted from linear fissures in northeastern Oregon, eastern Washington, and western Idaho. They entered the Willamette Valley through a wide gap in the Miocene Cascade Range to the northeast of the map area. Although the Columbia River Basalt Group is formally divided into five formations, only two of the formations are found in the map area. In some places the basalts are deeply weathered to thick, red lateritic soils. In the Portland Hills, these rocks are generally covered with wind-deposited silt called loess (Portland Hills Silt), which blew out of the flood plains onto the hills during the past two million years

- Tcw — **Columbia River Basalt Group, Wanapum Basalt (Miocene, 15.5 to 15.0 Ma)**—Fresh exposures are dark-gray to black basalt. Flows are commonly blocky to columnar jointed, with one flow (Ginkgo flow) often displaying well-formed prismatic columns
- Tcg — **Columbia River Basalt Group, Grande Ronde Basalt (Miocene, 16.5 to 15.6 Ma)**—Fresh exposures are light- to dark-gray basalt. Flows typically display blocky to columnar jointing
- Tcu — **Columbia River Basalt Group, undifferentiated (Miocene, probably 16.5 to 15.0 Ma)**—Sometimes the basalt flows are buried beneath thick deposits of sediment on the uplands and cannot be identified as either Wanapum or Grande Ronde Basalt
- Tsm — **Scotts Mills Formation (Oligocene and Miocene, 30 to 16 Ma)**—Marine and nonmarine sedimentary rocks consisting of volcanic conglomerate, arkose, and mudstone, tuffaceous sandstone, burrowed claystone, limestone, and interbedded coal
- Tl — **Little Butte Volcanics (Oligocene and Miocene, 30 to 16 Ma)**—Basalt and basaltic andesite flows and flow breccias
- Tm — **Marine sedimentary rocks (Eocene and Oligocene, 40 to 30 Ma)**—Tuffaceous sandstone and marine siltstone formed in shallow seas bordered by shifting deltas and brackish water bays; mainly Pittsburg Bluff Formation. Some coal and ash are also present
- Tw — **Basalt of Waverly Heights (Eocene, about 40 Ma)**—Sequence of subaerial basaltic lava flows believed to represent a portion of a 40-million-year-old volcanic island formed on an ancient ocean floor that became part of western Oregon. Sediments associated with the basalt suggest a marine environment. Fresh flow surfaces are brownish gray to black. Open cavities (vesicles and vugs) within the flow tops and joints are commonly filled with secondary minerals

FAULTS AND OTHER MAP SYMBOLS

- **Contact between two geologic units**
- **Fault, well located within 30 m**
- **Fault**—Dashed where inferred, dotted where concealed, bar and ball on downthrown side
- **Thrust fault**—Teeth on overthrust side of line

Identification of faults: Faults or displacements along fracture zones in rocks and sediment are difficult to locate in this part of Oregon because of heavy vegetation and deep weathering of exposed rocks. There are very few rock outcrops to study, and most faults shown on the map are not visible in the field. One fault has been identified from offset of rock units in surface rock outcrops. This is the "well-located" fault. Other faults were located by finding offsets of different units in well logs (information from wells). Offsets of beds have also been noted in seismic line and aeromagnetic anomalies. Most of the faults on the map are inferred or concealed.

Activity of the faults: Faults are classified into three groups (Hart, 1992). **Active faults** have evidence of movement in the last 10,000 years (Holocene time). If there has been movement on a fault during the Quaternary (last 1.8 million years), the fault is classified as **potentially active**. If there has been no movement during the Quaternary, the fault is considered **inactive**.

In the portion of Oregon covered by this map, the Holocene rocks or sediments do not appear to have been offset by faulting. Therefore, according to the classification adopted here, there are no active faults in the map area. However, Geomatrix (1994) classified the Mount Angel fault in the area as being active based on seismic activity (earthquake foci on or near the fault in historic time) during the Scotts Mills earthquake of 1993 and a swarm of earthquakes near Woodburn in 1990 (Werner and others, 1992). Geomatrix has also considered that the Portland Hills fault zone might be active, based solely on records of seismic activity in historic time (Yelin and Patten, 1991). Geomatrix (1994) also classified four other faults in the area as being potentially active (exhibiting movement in the Quaternary): the Beaverton fault, Sherwood fault, Newberg fault, and Bolton-Marylhurst fault. The rest of the faults on the map have not been classified as to activity.

EXPLANATION OF THICKNESS OF SEDIMENTS

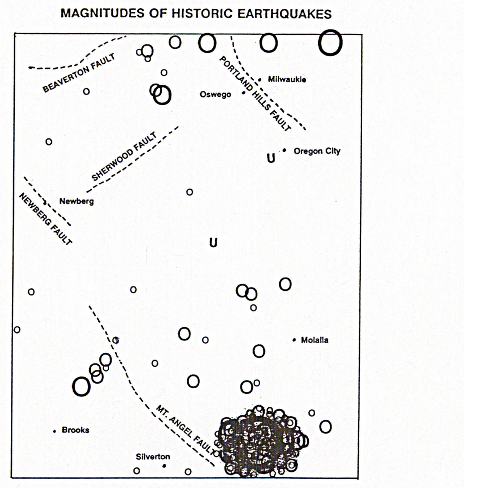
Thickness of the unconsolidated sediments is important in determining the potential for ground amplification of earthquake waves. Catastrophic flood deposits (unit Qf) and fluvial and lacustrine sediments (unit Tf) have been combined into the unit designated in the map explanation and time-rock chart as unit QTu. Thousands of well logs from water wells and foundation investigations were used to compile the thickness of the sediments (Werner, 1990; Madin, 1990; Gannett, 1992). In a few cases, seismic reflection profiles were used to supplement the well data to determine thicknesses (Werner, 1990).

EXPLANATION OF MAGNITUDES OF HISTORIC EARTHQUAKES

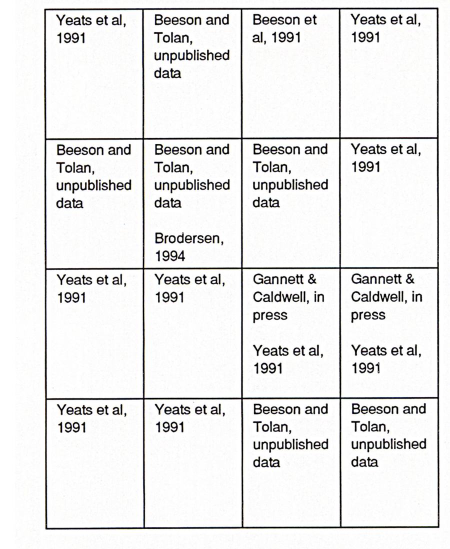
Epicenters of past earthquakes are plotted on the map below. Circles represent the magnitude of the earthquakes recorded during this century. The bigger the circle, the bigger the Richter scale magnitude. The major known faults of the map region have been drawn in for reference. The large concentration of epicenters in the southeast corner is from the Scotts Mills earthquake activity of 1993. Events below magnitude 1.0 are not recorded on the map. Data are based on a compilation by Unruh and others (1994).

- Magnitude from 1.0 to 1.9
- Magnitude from 2.0 to 2.9
- Magnitude from 3.0 to 3.9
- Magnitude from 4.0 to 4.9
- Magnitude from 5.0 to 5.9
- u Unknown magnitude

MAGNITUDES OF HISTORIC EARTHQUAKES



Sources of map data



Yeats et al, 1991	Beeson and Tolan, unpublished data	Beeson et al, 1991	Yeats et al, 1991
Beeson and Tolan, unpublished data	Beeson and Tolan, unpublished data	Beeson and Tolan, unpublished data; Brodersen, 1994	Yeats et al, 1991
Yeats et al, 1991	Yeats et al, 1991	Gannett & Caldwell, in press; Yeats et al, 1991	Gannett & Caldwell, in press; Yeats et al, 1991
Yeats et al, 1991	Yeats et al, 1991	Beeson and Tolan, unpublished data	Beeson and Tolan, unpublished data

GEOLOGIC HISTORY OF THE AREA

This portion of the Willamette Valley can be divided into three provinces. On the east side of the map is the Cascade Range, which is mostly volcanic in origin and which records the history of volcanic eruptions for the past 40 million years. In the middle of the map, trending from north to south, is the topographic basin of the Willamette Valley. This large trough has volcanic bedrock at its base and is filled mainly with unconsolidated or poorly consolidated sediments. The Tualatin Basin is on the northwest part of the map. It is rimmed by the Tualatin Mountains on the east, the Chehalem Mountains on the south, and the Coast Range on the west. In general, the mountains are mainly volcanic rocks, and between them are sediment-filled basins.

Most of the geologic history found in the rocks of this area occurred during the last 50 million years. Much of the area was under water 40 to 50 million years ago, and rocks of unit Tm are formed from sediments deposited in seas that covered most of the area. Only a small section of unit Tm crops out in the west, because most of these rocks have been covered with younger volcanic rocks. The basalt of Waverly Heights (unit Tw), found in south-central Portland, represents a 40-million-year-old volcanic island that was accreted (joined) to western Oregon. Farther to the east, the volcanoes of the ancient Western Cascades began to erupt about 40 million years ago. This volcanism continued intermittently until about 9 million years ago, when volcanic activity began to shift more to the early High Cascades to the east. Some of the products of the earlier Western Cascade volcanism (Little Butte Volcanics [unit Tl], Molalla Formation [unit Tmo], and undivided volcanic rocks [unit Tu]) are interbedded with rocks of the Scotts Mills Formation (unit Tsm) in the southeast part of the map. Most of the rocks produced by volcanism in the ancient Western Cascades are buried by younger volcanic rocks.

Most of the map area was covered between 16.5 to 15 million years ago by lava flows of Columbia River basalt which flowed into the area from fissure eruptions in eastern Oregon and Washington. First, the Grande Ronde flows (unit Tcg) covered the area, followed by the Wanapum flows (unit Tcw). After the basalt flows were emplaced, andesitic volcanism started again in the Cascades, producing the rocks of the Molalla Formation (unit Tmo) and other volcanic rocks of the Rhododendron and Sardine Formations (unit Tu). As the Willamette Valley and Portland Basin gradually developed, they began to fill with sediments carried into the area by the ancestral Columbia River and mountain streams that flowed from the Cascade Range. In the Portland area, these deposits are called the Troutdale Formation and Sandy River Mudstone. Localized volcanic vents in the Portland area produced the Boring Lavas (unit QTb) from 2.44 million years ago to 260,000 years ago. Glaciation of the Cascade Range during the past two million years has produced large fans of sediments in the Willamette Valley.

During the last couple of million years, large landslides have occurred in the area. These are shown on the map as unit Qls.

The last major event to occur was a series of perhaps more than 90 catastrophic floods that occurred from 15,300 to 12,700 years ago. These floods resulted from the breaking of ice dams that periodically built up Glacial Lake Missoula in western Montana. The floods did some scouring in the northern part of the mapping area but generally deposited sediments in the main portion of the Willamette Valley. Rivers have cut down into these flood deposits during the last 13,000 years.

Earthquakes have always been part of the history of this region of Oregon. Wherever mountains are found, earthquakes have likely been part of the mountain development. Today, some faults are active, while others have not shown activity for many tens of thousands of years.

EARTHQUAKE HISTORY OF THE NORTHERN WILLAMETTE VALLEY

Oregon lies on a plate boundary where the North American plate is moving in a westerly direction and colliding with and overriding the Juan de Fuca oceanic plate, which is moving in an easterly direction from its origin off the coast of Oregon. The Juan de Fuca plate is being subducted under the North American plate along a great fault called the Cascadia Subduction Zone. At a depth of 100 to 120 km along the subduction zone, rocks and sediments begin to melt, forming magma. The magma rises to the earth's surface to form the volcanoes of the Cascade Range. Similar plate boundaries are found in Alaska and Chile, where earthquakes often occur. Because the potential magnitude of an earthquake is often estimated by determining the maximum length of breakage that can occur along a fault, scientists believe the long Cascadia Subduction Zone has potential for causing large-magnitude earthquakes.

Earthquakes can be generated from three different sources in Oregon (Mabey and others, 1993). Earthquakes can occur on faults in the overriding North American plate. These **crustal earthquakes** are the most common earthquakes and occur at depths of 10 to 16 km below the surface. The earthquakes are a response to a buildup of stress in which the maximum horizontal compressive stress is oriented north-south (Werner, 1990; Werner and others, 1991). The earthquakes recorded in the area covered by this map are of this type. The maximum size of such earthquakes is estimated as approximately 6.5 on the Richter scale, although the largest recorded magnitude is 5.6 at Scotts Mills in 1993. **Slab earthquakes** are the second type of earthquake. They occur along faults in the subducting Juan de Fuca plate that is being shoved under the North American plate. The two Washington earthquakes that occurred in 1949 in Olympia (magnitude 7.1) and in 1965 in Tacoma (magnitude 6.5) were both slab earthquakes and were also felt in the northern Willamette Valley. The maximum magnitude expected for this type of earthquakes is 7.5. The third type of earthquake is the **subduction zone earthquake** that is created as the two plates that are locked against each other periodically break free to move. No subduction zone earthquakes have occurred in Oregon during the 200-year modern historical record, but recent research from buried soils in the coastal marshes (Atwater, 1987; Darienzo and Peterson, 1990) indicates that the last major event was 300 years ago and that subduction zone earthquakes have recurred on the average every 400 to 600 years. Their maximum magnitude has been predicted to be about 8.5, with a duration of shaking of three minutes and an epicenter probably offshore (Geomatrix, 1994). These large earthquakes are a major point of concern for the Willamette Valley.

Very few earthquakes have been recorded in the area covered by this map. Records were poorly kept before 1950, and since that time, only one major event has occurred in this region. On March 25, 1993, the Scotts Mills earthquake with a magnitude of 5.6 occurred on or near the Mount Angel fault near Molalla. This earthquake did over $20 million damage. Other smaller events are recorded with circles on the inset map.

EARTHQUAKE HAZARDS

An earthquake can cause damage through ground shaking, liquefaction, landslides, fault rupture, tsunamis (seismic sea waves) and seiches (waves in lakes) (Mabey and others, 1993). The effects of earthquakes can range from people being alarmed by feeling the earthquake, items falling off shelves, chimneys collapsing, pipelines bursting, to buildings collapsing and people being killed. In the part of Oregon covered by this map, ground shaking, liquefaction, and landslides are considered to be the major concerns during an earthquake. Tsunamis, or seismic sea waves, are primarily a problem along the Oregon coast and not inland in the Willamette Valley. A seiche is a harmonic wave set up on a lake or large body of water by sloshing from an earthquake, and because there are few large bodies of water in the map area, seiches are of limited concern. Fault rupture of the ground surface occurs mainly from earthquakes with a minimum magnitude of about 6.0 to 6.5, and since 6.5 is the maximum size expected for any crustal earthquake in this portion of the Willamette Valley, fault ruptures are expected be rare in the area (Mabey and others, 1993).

The most severe damage from an earthquake is concentrated in areas affected by the following factors: (1) ground shaking from proximity to the fault, (2) amplified ground shaking from unconsolidated sediments under a site, (3) liquefaction of water-saturated sand and silts, and (4) landslides triggered by the shaking. The last three factors listed above are considered factors of site geology, and damage resulting from those factors is relatively independent of how close the site is to the fault. By locating existing faults and focusing on the three factors of site geology listed above, one can begin to understand earthquake hazards of the area (Mabey and others, 1993).

(1) **Location of local faults:** Local faults are shown on this map because they are probably responsible for most local crustal earthquakes. The closer one lives to an active fault, the greater the chance of damage from movement during an earthquake on that fault. The amount of activity of most of the faults shown on the map is unknown. Several faults in the map area have potential for rupture, even though there is no geologic evidence for rupture in the last 10,000 years or longer. The expected time interval between earthquakes on individual faults is very long, probably tens of thousands of years. For this reason, the hazard is considered an area source, which means that some fault in the area may produce an earthquake on the average of every few decades—but which exact fault will produce the earthquake is not known. These earthquakes are called source quakes and cannot be predicted by fault maps (Geomatrix, 1994).

(2) **Ground shaking amplification:** Ground shaking from an earthquake can be modified by the nature of unconsolidated (uncemented) sediments under the site and by the degree of water saturation. As the thickness and firmness of the sediments change, the amplification of the earthquake waves and the strength of shaking can also change. Subduction zone earthquakes along the coast could generate large seismic waves that could be greatly increased in amplitude when they encounter the sediments of the Willamette Valley. The thicknesses of the unconsolidated sediments have been mapped to give a relative indication of areas with differing local amplification of earthquake waves, especially from subduction zone earthquakes. A generalization is that the thicker the unconsolidated sediments, the greater the potential for amplification.

(3) **Soil liquefaction:** The process called liquefaction occurs when an earthquake causes soil to lose its solid properties, behave like a liquid, and flow. Soils that have a tendency to liquefy are mainly loose sands and silts that are saturated with water. Liquefied soils can oscillate back and forth and rupture pipelines, move downhill or laterally, move bridge abutments, rupture buried utility lines, or pull buildings apart (Mabey and others, 1993). Light objects such as underground storage tanks can float to the surface, and heavy objects like buildings can sink. Movements may be only a few inches but can cause great destruction. In this portion of the Willamette Valley, most sites susceptible to liquefaction are on the flood plains of the large rivers.

(4) **Landslides triggered by ground shaking:** Known landslides are shown on the map because earthquakes can trigger existing landslides to move again, especially at their edges. It is possible that many of the large landslides of the Willamette Valley were generated by earthquakes in the past. Earthquake waves can also create new landslides on steep slopes and on slopes with thick soils. The locations of new landslides are difficult to predict unless areas of steep terrain are believed to have greater potential for landsliding during an earthquake. Steep slopes can be identified on the topographic map used as the base for this map. More than 20 percent of the Portland Hills are covered by old landslides, many which could have been caused by earthquakes (J.E. Allen, personal communication, 1994).

EARTHQUAKE POTENTIAL IN THE AREA

Research in the last ten years has significantly advanced our understanding of the earthquake potential and corresponding hazards in the northern Willamette Valley. It is now accepted that damaging earthquakes much larger than any in the historical record are possible (Mabey and others, 1993). Maps that provide the location of faults and the important site geology characteristics like thickness of sediments and old landslides help evaluate the potential for earthquake damage. Some parts of the Willamette Valley are more prone to damage from earthquakes than others, so these factors should be taken into consideration in planning and development decision making.

The site geology of the region also exhibits some areas of possible concern. Ground amplification will vary with unconsolidated sediment thickness and firmness. The hazard can generally be thought of as greater with thicker sediments. The greatest landslide potential is on old landslides and also on the steepest slopes. The greatest liquefaction is most likely along the largest rivers.

Even though mapping techniques have improved for the area, it is still not possible to gauge the earthquake potential for local faults (Mabey and others, 1993). The Mount Angel fault is the only known active fault in the area (based on known seismicity and offset of stream deposits based on seismic reflection), so proximity to it may suggest larger chances of damage (Werner and others, 1992). None of the other faults have been clearly demonstrated to be active, though some may be potentially active. A few researchers have suggested that, based on regional seismic activity, the Portland Hills fault may be active (Yelin and Patton, 1991). If it is, it could cause a large earthquake with a magnitude over 6 (Geomatrix, 1994). The distribution of faults in the map area is such that most people live within a distance of 20 km of a fault, especially in the northern part of the map area. In the south, there are fewer known faults, but the Mount Angel fault seems to be active.

The northern Willamette Valley is threatened by all three types of earthquakes: crustal, slab, and subduction. There is uncertainty about the frequency, magnitude, and location of these future events. Oregon's seismicity rate is not as great as that of California, but it is clear Oregon's earthquake potential has been underestimated in the past.

While this map depicts scientists' understanding of the geology of the region at this time, much more work needs to be done to determine not only the activity of each of the faults but also the existence of other faults. Relative earthquake hazard maps based on studies of ground response are needed for some of the highly populated areas of this map to provide a more quantitative and detailed approach to earthquake hazards. This map is only a first step in the process of reducing the risk to life and property from earthquakes.

This map should not be used to determine the hazard potential of a particular site but instead to help determine which areas need specific detailed studies of earthquake hazard potential. Site-specific studies are always needed to determine the risk at any site.

ACKNOWLEDGMENTS

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