EARTHQUAKE-HAZARD GEOLOGIC MAPS OF THE PORTLAND, OREGON, METROPOLITAN AREA

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ABSTRACT

Earthquake-hazard geologic maps have been produced based on eight 1:24,000-scale quadrangle maps covering most of the Portland, Oregon, metropolitan area. The map data are derived from published and unpublished geologic mapping and interpretation of several thousand borehole logs. The maps depict the distribution and thickness of four units of poorly consolidated fine-grained Quaternary sedimentary materials that may amplify ground shaking or liquefy during earthquakes. The four units are Pleistocene catastrophic flood deposits, fine-grained facies; Holocene alluvium; Holocene artificial fill; and Pleistocene loess.

The maps also depict other Quaternary and bedrock geologic units, faults, and contoured depth-to-basement data. They show that the northwest-trending Portland and Tualatin basins are bordered by faults on their margins and separated by the folded and faulted basement rocks of the Tualatin Mountains (Portland Hills). Northwest-trending anticlines of the Portland Hills are cut by parallel and transverse high-angle faults and by southwest-dipping thrust faults. Although numerous northwest- and northeast-trending faults have been mapped in the area, none have yet been shown to cut Holocene deposits. However, some faults do cut Pleistocene rocks.

INTRODUCTION

In 1987, the Oregon Department of Geology and Mineral Industries (DOGAMI) began a 5-year program to assess earthquake hazards in the Portland, Oreg., metropolitan area with funding provided by the U.S. Geological Survey through the National Earthquake Hazards Reduction Program. In recognition of the importance of local geology in assessing earthquake hazards, a mapping program with two major goals has been carried out. The first goal of the mapping program was to identify faults that may cut young geologic deposits; the second goal was to map the distribution and thickness of fine-grained unconsolidated sedimentary deposits that may amplify ground shaking or liquefy during an earthquake. The final maps are based on compilation of existing maps, new surface mapping by the author, M.H. Beeson, and T.L. Tolan, and examination and interpretation of more than 5,000 borehole logs by the author. The maps (figs. 177–185, beginning on p. 362) are reductions of the U.S. Geological Survey's Beaverton, Gladstone, Hillsboro, Lake Oswego, Linnton, Mt. Tabor, Portland, and Scholls 1:24,000-scale topographic quadrangles (fig. 176).

The maps depict all major geologic units and identify Quaternary sedimentary units with high earthquake-hazard potential. Where there are sufficient data, the thickness of these sedimentary deposits is depicted with isopach lines. The maps also depict contoured depth-to-basement data and faults inferred from subsurface data.

All of the area covered in this study has been previously mapped at a variety of scales. The earliest small-scale work was a map by Treasher (1942) at a scale of 1:62,500. This was followed by a detailed map at the same scale by Trimble (1963). Several subsequent maps have involved compilation of existing surface data with water-well data (Mundorff, 1964; Hart and Newcomb, 1965; Hogenson and Foxworthy, 1965). The southwestern part of the area was first mapped in detail by Schlicker and Deacon (1967), and the Gladstone and Lake Oswego quadrangles (fig. 176) were compiled at 1:24,000 by Schlicker and Finlayson (1979). Parts of the area have been included in a 1:100,000-scale compilation by the Washington Department of Geology and Earth Resources (Phillips, 1987).

The mapping presented in this report differs from the previous mapping in varying degrees. On some quadrangles (Gladstone, fig. 185), there are significant changes in stratigraphy and structure. Other maps (Hillsboro and Scholls, figs. 178 and 182, respectively) differ little from the previous mapping. Significant departures from the previous mapping occur only where there is good field or subsurface evidence for the change.

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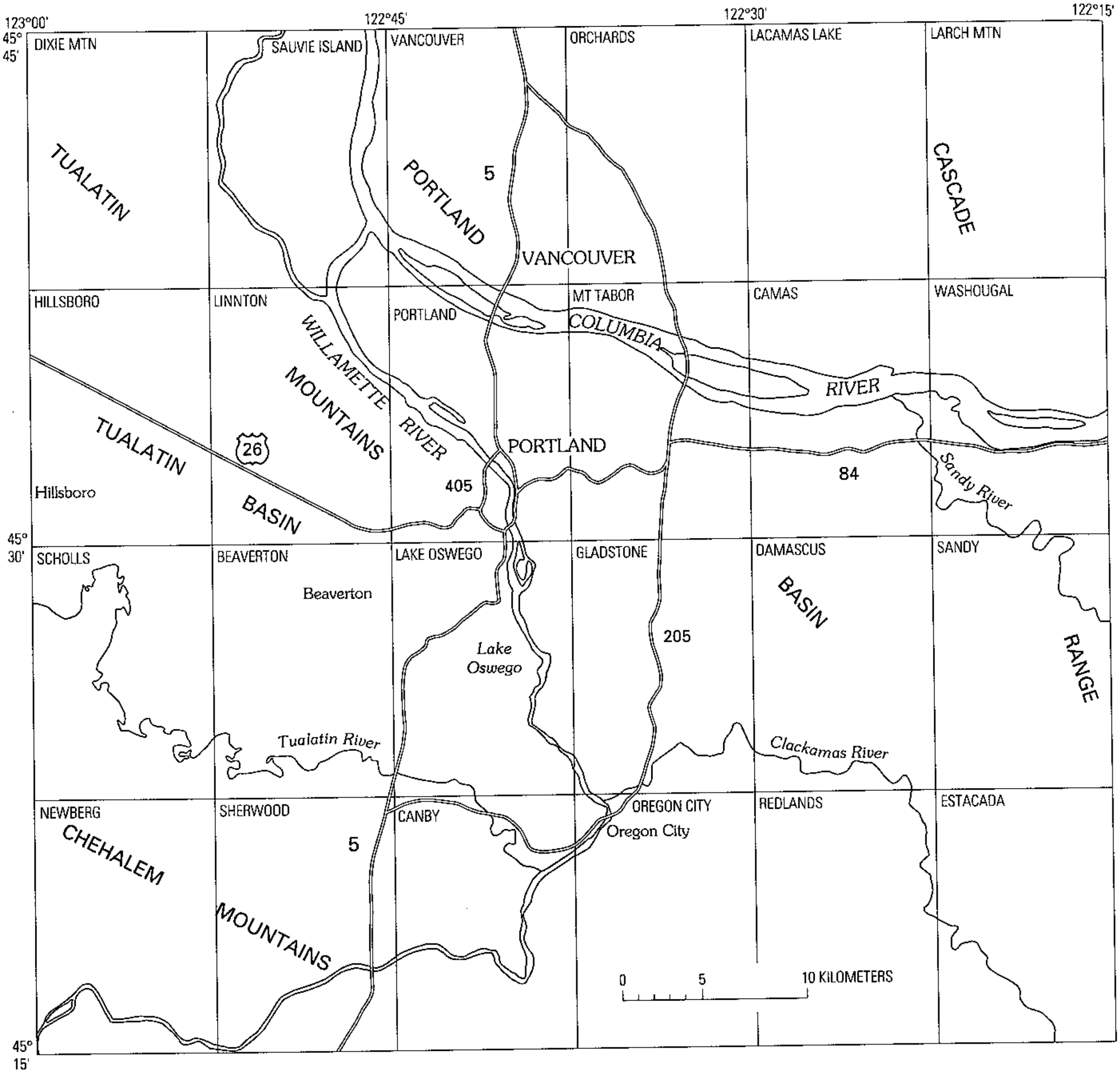

Figure 176. Index map of the Portland, Oreg., metropolitan area showing major cities, highways, and geographic features. The grid represents the U.S. Geological Survey's 1:24,000-scale topographic map coverage of the area. The quadrangle names are in the upper left-hand corner of each rectangle.

ACKNOWLEDGMENTS

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STRATIGRAPHY AND NOMENCLATURE

The stratigraphy of the Neogene sedimentary rocks that fill the Portland and Tualatin basins is still very poorly understood, and the nomenclature of these units is an unresolved issue. The nomenclature and stratigraphy used in this report are more completely discussed by Madin (1990). Nomenclature for the volcanic rocks of the region follows Beeson, Tolan, and Anderson (1989) except that the rocks of the Columbia River Basalt Group are not subdivided in this report.

DEPOSITS WITH HIGH EARTHQUAKE-HAZARD POTENTIAL

Poorly consolidated Quaternary deposits commonly amplify ground motions or fail due to liquefaction during major earthquakes. These phenomena enhanced the damage caused by many recent earthquakes such as those in Mexico City in 1985 (Seed and others, 1988), Armenia in 1988 (Borcherdt and others, 1989), and San Francisco in 1989 (Plafker and Galloway, 1989). Poorly consolidated deposits of sand, silt, or clay that overlie more competent materials are most likely to amplify ground shaking. Deposits of poorly consolidated saturated sand and silt are most likely to liquefy during strong ground shaking. Both types of deposits are widely distributed in the Portland area, as originally recognized by Schlicker and others (1964). The ground-shaking amplification at any site will depend on the thickness and seismic-velocity profile of the sedimentary column beneath the site. Earthquake-induced liquefaction of the sedimentary materials at any site will depend on the strength and duration of local ground shaking as well as hydrologic conditions at the site. The data in this report provide one essential element for the quantitative modeling of ground-shaking amplification or earthquake-induced liquefaction, but these data alone are not sufficient to make a reliable, quantitative estimate of potential earthquake hazards at any site.

Many of the deposits in the Portland area may be susceptible to earthquake-induced landsliding. However, the mapping of potentially unstable slopes or existing landslides that may reactivate during an earthquake is beyond the scope of this report.

The following four Quaternary geologic units in the Portland metropolitan area may have high amplification or liquefaction potential:

- Pleistocene loess
- Pleistocene catastrophic flood deposits, fine-grained facies
- Holocene alluvium
- Holocene artificial fill

Of the four units, only the fine-grained facies of the catastrophic flood deposits and the alluvium are sufficiently uniform in thickness to be mapped using isopachs. The remaining geologic units on the maps (Pleistocene gravels and older sedimentary and volcanic rocks) typically have relatively low potential for amplification of earthquake ground motion or liquefaction. The nature and distribution of the units with high earthquake-hazard potential are described below and in figure 177.

PLEISTOCENE LOESS (Ql)

This unit consists of loessal silt that mantles higher slopes in the Portland area. The loess is difficult to distinguish from the silts of the Pleistocene catastrophic flood deposits (Qff), and the lower boundary of the unit is mapped on the assumption that the loess is either buried by unit Qff or has been eroded by catastrophic flooding below an altitude of 90 m. Previous workers (Trimble, 1963; Schlicker and Deacon, 1967; Lentz, 1977) have generally depicted the loess as thicker on ridgecrests and thinner on valley walls and floors. Field work for this study indicates that the valley walls of minor drainages are typically covered with in-place or colluvial loess and that exposure of underlying bedrock units is rare except in stream channels. Limited subsurface data indicate that the loess is widely variable in thickness, reaching a maximum of 30 m along the crest of the Tualatin Mountains (Portland Hills). Loess 6–12 m thick is common along the slopes of the Tualatin Mountains and substantially thinner deposits are present on the Chehalem Mountains (fig. 182), Mt. Scott (fig. 185), and Cooper and Bull Mountains (figs. 182 and 183). As a result of the variable distribution and thickness of the loess, it has been mapped over the underlying bedrock units only in the areas in which significant (1.5 m or greater) loess can be expected to occur. The loess is notoriously landslide prone when saturated and represents a significant earthquake-induced landslide hazard.

PLEISTOCENE CATASTROPHIC FLOOD DEPOSITS, FINE-GRAINED FACIES (Qff)

This unit consists of crudely to complexly layered, poorly consolidated, coarse sand to silt deposited by one or more phases of catastrophic floods from late Pleistocene Glacial Lake Missoula. The catastrophic flood deposits occur along the Willamette and Columbia Rivers and throughout the Tualatin basin. The thickness of the catastrophic flood deposits is typically 9–18 m, with a maximum thickness of 55 m in the map area. The catastrophic flood sediments were deposited beneath regionally ponded floodwaters, the highest of which reached an elevation of approximately 122 m above sea level, based on the distribution of ice-rafted erratics (Allison, 1935). However, the catastrophic flood deposits are typically found no higher than 75–90 m above sea level. Ponding of floodwaters to 122 m above sea level may not have happened sufficiently often or for a sufficient length of time to allow significant sediment deposition at higher elevation. It is difficult to distinguish the catastrophic flood deposits from loess in most outcrops and well logs, so the contact between the two units is commonly drawn following the 90 m contour in the absence of site-specific data.

Evidence of liquefaction is commonly observed in good exposures of unit Qff in the form of silt and sand dikes. Some of the liquefaction dikes cut earlier dikes and bedding planes and paleosol layers in the catastrophic flood deposits. It is not clear whether liquefaction occurred during multiple catastrophic flood events, subsequent earthquakes, or both.

HOLOCENE ALLUVIUM (Qal)

Quaternary alluvium consists of poorly consolidated sand, silt, clay, and gravel deposited by the Columbia and Willamette Rivers and their tributaries. In the Willamette and Columbia Rivers, sand and silt predominate although organic material and clay are locally abundant, and gravel deposits are rare with the exception of Ross Island, a major gravel bar in the Willamette River (figs. 180 and 184), and scattered gravels at the base of deposits in the Columbia and Willamette Rivers. The channels of the Columbia and Willamette Rivers have been filled with as much as 55 m of fine-grained alluvium. The upper limit of the fine-grained alluvial deposits is apparently restricted to a maximum elevation of 10 m above modern sea level, an elevation that corresponds to the maximum level of historical floods. Alluvium deposited by the Clackamas River (fig. 185) is dominantly volcaniclastic gravel and sand. Alluvium deposited by the Tualatin River (figs. 182–184) is predominantly sand, silt, clay, and organic material. In both the Clackamas and Tualatin River drainages, alluvial deposits are largely restricted to channels incised into the catastrophic flood deposits. Limited subsurface data suggest that alluvium deposited by minor tributaries thins rapidly away from the stream channels and is generally less than 1–2 m thick on floodplains. The alluvium deposited by these tributaries has been omitted from the maps in this report for the sake of clarity.

HOLOCENE ARTIFICIAL FILL (Qaf)

Artificial fill is widespread in developed areas along the floodplains of the Columbia and Willamette Rivers and in gullies in the downtown and East Portland areas. Although the most common material is sand dredged from the river, older fills contain significant amounts of construction rubble, mill ends, and sawdust. Unit Qaf is mapped only where fill material has eliminated lakes, sloughs, or gullies delineated during the 1898 survey for the earliest topographic map of Portland (U.S. Geological Survey, 1905). This unit was mapped by comparing the 1:24,000-scale U.S. Geological Survey topographic maps with the 1:62,500-scale U.S. Geological Survey topographic map (U.S. Geological Survey, 1905) and is therefore only depicted on the Portland (fig. 180), Mt. Tabor (fig. 181), and Linnton (fig. 179) quadrangles. Artificial fill 1.5–5 m thick is common in the developed areas of the Columbia and Willamette River floodplains, but its thickness and distribution are highly variable and cannot be accurately depicted at the scale of these maps.

STRUCTURE

A primary goal of this program was to identify potentially active faults in the Portland area. Two general classes of faults have been mapped in this study. Faults designated on the maps by a long dash pattern are inferred from the offset of well-defined stratigraphic units, and these faults are largely confined to the Lake Oswego quadrangle (fig. 184) and the southwest quadrant of the Gladstone quadrangle (fig. 185) where the stratigraphy of the Columbia River Basalt Group has been mapped in detail (M.H. Beeson and T.L. Tolan, unpublished mapping, 1988; Beeson, Tolan, and Madin, 1989). Faults designated with dotted lines in these areas represent buried faults mapped by Beeson, Tolan, and Madin (1989). Faults designated by dotted lines on the other quadrangles are mapped along relatively abrupt changes in elevation of a single contact. There is clearly significant erosional relief on many of the major contact surfaces, particularly the top of the Columbia River Basalt Group that is incised by buried paleochannels up to 152 m deep. The interpretation of any particular change in contact elevation as a fault rather than buried paleotopography is based on examination of regional trends, neighboring structures, and geomorphology.

The sense of vertical offset on faults is generally obvious from the change in the elevation of the contact. The amounts of fault offset indicated by depth-to-bedrock contours on the maps are estimates based on limited borehole data. The vertical offset on many faults appears to die out or change sense along strike.

Horizontal offset cannot be proved or disproved on any of the mapped faults. Exposed fault planes are rare, but subhorizontal slickensides have been found on fault planes in the Columbia River Basalt Group in the southeastern part of the Lake Oswego quadrangle (fig. 184) (M.H. Beeson, oral commun., 1989).

All of the faults mapped clearly cut the Columbia River Basalt Group and, therefore, have been active since middle to late Miocene time. Several faults cut the upper Miocene to Pliocene Sandy River Mudstone and Troutdale Formation. The youngest faulted rocks in the area are the upper Pliocene to Pleistocene basalt flows of the Boring Lavas. The exact age of faulted Boring Lavas flows in the map area is not yet known. Outside the map area, flows in the Damascus quadrangle (fig. 176) as young as 510±23 ka are faulted (Madin, 1994). Offsets of the Pleistocene loess, the fine-grained facies of the Pleistocene catastrophic flood deposits, or Holocene alluvium have not yet been determined.

The Tualatin Mountains are a narrow northwest-trending range that rises about 305 m above the adjacent basins. Mapping in the Lake Oswego quadrangle (fig. 184) (Beeson, Tolan, and Madin, 1989) has shown the range to be a folded and complexly faulted structural high composed of the Columbia River Basalt Group. Broad anticlinal folds are cut by numerous high-angle faults both transverse and parallel to the main northwest structural axis. The structural high is also cut by several southeast-dipping thrust faults. Schlicker and others (1964) and Balsillie and Benson (1971) suggested that the Tualatin Mountains were the result of uplift along a hypothetical Portland Hills Fault. The mapping of Beeson, Tolan, and Madin (1989) and Beeson, Tolan, and Madin (1991) indicates that the Tualatin Mountains may best be considered a major fault zone.

The large-scale structure of the Portland and Tualatin basins is fairly well understood, and this report only adds detail to the models previously proposed by Swanson and others (1993), Hammond and others (1974), and Hart and Newcomb (1965).

The Tualatin basin is a broad northwest-trending syncline that is faulted along the eastern margin where it meets the Tualatin Mountains (figs. 179 and 183). Intrabasin faulting occurs along the north and east edges of the Bull and Cooper Mountain anticlines (figs. 182 and 183).

The Portland basin is clearly fault bounded along its west edge from the Clackamas River as far north as downtown Portland (figs. 180, 184, and 185). A fairly abrupt step of about 100 m occurs in the top of the basement (units Tcr and Twh) as far north as downtown Portland (fig. 180). Northwest of downtown Portland, this abrupt step is poorly defined or absent. However, the unusually steep and straight front of the Tualatin Mountains and also gravity data by Beeson and others (1975) imply a continuation of a fault in this area, as suggested by Schlicker and others (1964) and Balsillie and Benson (1971). The east edge of the Portland basin is outside the area of this study, but it also appears to be fault bounded with an abrupt step in the top of the basement along much of its margin (Mundorff, 1964; Davis, 1986; Hartford and McFarland, 1989; Swanson and others, 1993). Data on the depth to bedrock are absent in the center of the basin, but limited gravity data (Perrtu, 1980) and proprietary seismic data suggest that the top of the basement is fairly flat through the center of the basin and about 487 m deep. A northwest-trending basement high (Hogenson and Foxworthy, 1965; Swanson and others, 1993; Madin, 1994) occurs south and east of the map area (Damascus quadrangle, fig. 176). Gravity data and limited subsurface data suggest that this high extends to the northwest beneath Mt. Scott, Kelly Butte, Mt. Tabor, and Rocky Butte. The amount of structural relief on this buried feature has been estimated at 91 m based on gravity data of Perrtu (1980). Faulting identified on the Mt. Tabor quadrangle near Rocky Butte and Mt. Tabor (fig. 181) is probably associated with this feature. No depth to basement data are available for the Mt. Tabor or Gladstone quadrangles (figs. 181 and 185, respectively) except along the westernmost edges of both. Depth to bedrock on the remainder of these two quadrangles is a matter of conjecture, and contours have not been drawn.

CONCLUSIONS

The earthquake-hazard geologic maps described in this report indicate that large portions of the Portland metropolitan area are covered by poorly consolidated Quaternary sand, silt, and clay deposits. These deposits may significantly amplify ground shaking or liquefy in future earthquakes, and the maps provide the basic geologic data necessary to estimate the potential for these damage-enhancing effects. Earthquake hazard maps based on these geologic maps have been published for the Portland (Mabey and others, 1993), Mt. Tabor (Mabey, Madin, Meier, and Palmer, 1995), Gladstone (Mabey, Madin, and Meier, 1995b), Lake Oswego (Mabey, Madin, and Meier, 1995c), and Beaverton (Mabey, Madin, and Meier, 1995a) quadrangles.

The earthquake-hazard geologic maps also demonstrate that there are numerous faults in the Portland metropolitan area, although none have been shown to be Holocene in age. The faults depicted by these maps should not necessarily be considered hazardous without further investigation.

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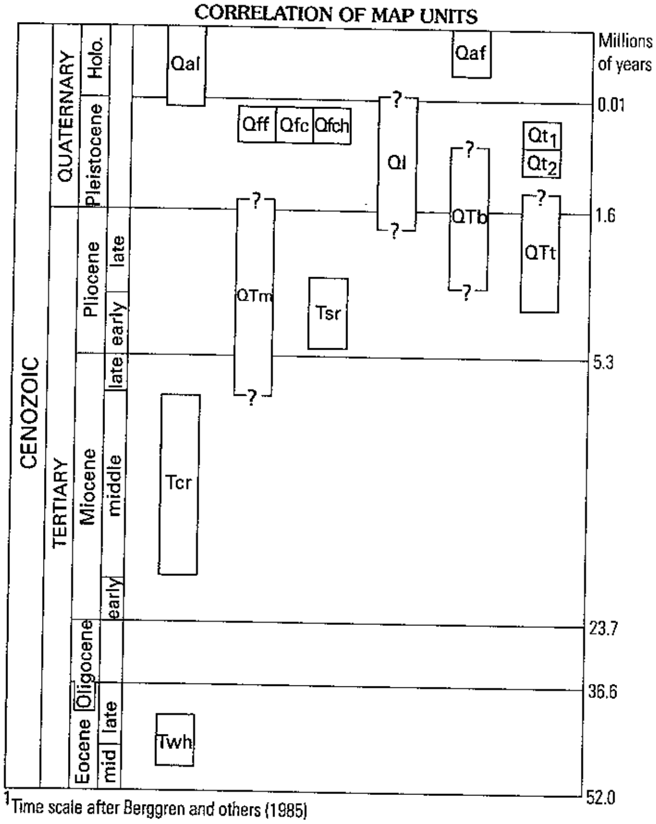
CORRELATION OF MAP UNITS



[1]Time scale after Berggren and others (1985)

DESCRIPTION OF MAP UNITS

(Condensed and revised from Madin, 1990)

Qaf **Artificial fill (Holocene)**—Sand and silt fill that locally includes rock, gravel, construction rubble, sawdust, and mill ends

Qal **Alluvium (Holocene)**—Poorly consolidated river and stream deposits of silt, sand, clay, and gravel confined to channels and floodplains of the major rivers and tributary streams

Catastrophic flood deposits (Pleistocene)—Boulders, gravels, sandy gravels, and sands containing high percentages of clasts derived from the Columbia River Basalt Group and representing high-energy, subfluvial deposition during catastrophic floods caused by repeated failure of the ice dam that impounded Glacial Lake Missoula (Bretz and others, 1956; Baker and Nummedal, 1978; Waitt, 1985; Allen and others, 1986). The age of the most recent catastrophic flood is estimated as 15,500–13,000 yr B.P. (Mullineaux and others, 1978; Waitt, 1987; Beeson, Tolan, and Madin, 1989). Within the study area, catastrophic flood sediments are subdivided into three facies:

Qfch **Channel facies**—Poorly consolidated, complexly interlayered and variable silts, sands, and gravels deposited in major floodways by catastrophic flood events.

Qff **Fine-grained facies**—Coarse sand to silt deposited by catastrophic floods. Finer sedimentary materials are predominantly quartz and feldspar and also contain white mica. Coarser sedimentary materials are mostly fragments derived from the Columbia River Basalt Group

Qfc **Coarse-grained facies**—Poorly consolidated pebble to boulder gravel with silt and coarse sand matrix. Coarse sedimentary materials are poorly sorted and moderately to well rounded. Coarse deposits range from openwork gravel to gravel with considerable fine-grained matrix

Qt_1 Qt_2 **Clackamas River terrace surfaces (Pleistocene)**—Erosional terrace surfaces cut by the Clackamas River across semiconsolidated Pleistocene conglomerates of unit QTt. The surfaces are differentiated by their height relative to the modern Clackamas River. Unit Qt_2 surfaces are higher than unit Qt_1 surfaces. Includes the Estacada Formation of Trimble (1963)

Ql **Loess (Pleistocene)**—Poorly to moderately consolidated, massive, brown to red-brown or gray, quartzomicaceous silt. The exact age is uncertain; Lenz (1977) considered its age as between 700 and 34 ka based on relations with the Boring Lavas and catastrophic flood deposits. Includes the upland silt of Schlicker and Deacon (1967) and undifferentiated sediments of Beeson, Tolan, and Madin (1989)

QTt **Troutdale Formation (Pleistocene? and Pliocene)**—Moderately to well-lithified conglomerates with minor interbeds of sandstone, siltstone, and claystone and volcanic ash and debris flows. The conglomerates typically consist of well-rounded pebbles and cobbles derived from the Columbia River Basalt Group, high-alumina basalt from the High Cascades and Boring Lavas, andesite, dacite, and exotic metamorphic and plutonic rocks. The sand and silt conglomerate matrix and interbeds contain varying amounts of feldspathic, quartzomicaceous, and volcanic lithic and vitric sedimentary materials. Includes the Gresham and Walters Hill Formations of Trimble (1963) and unnamed conglomerate of Beeson, Tolan, and Madin (1989)

QTb **Boring Lavas (Pleistocene to Pliocene)**—Light-gray to gray, diktytaxitic, olivine-(less commonly, plagioclase-)phyric basalt and basaltic andesite flows erupted from a series of local vents. Swanson (1986) reports K/Ar age dates for Boring Lavas of 1.33 Ma (fig. 181, Rocky Butte, Mt. Tabor quadrangle) and 2.6 Ma (fig. 176, Oregon City area). Madin (1994) reports an age for Boring Lavas from the Damascus and Gladstone quadrangles (figs. 176 and 185) of 3,146±62 to 510±8 ka

QTm **Mudstone and sandstone (Pleistocene? to middle Miocene?)**—Moderately to poorly lithified mudstone and sandstone that fills the Tualatin basin; lithologically equivalent to the Sandy River Mudstone. The unit is poorly exposed, but cuttings from a few deep wells consist of blue-gray and brown quartzomicaceous silt and very fine sand. Well logs typically describe blue-gray and brown or red-brown sand and clay and, rarely, gravel. Includes the Troutdale Formation and Sandy River Mudstone of Trimble (1963), Helvetia Formation of Schlicker and Deacon (1967), and undifferentiated sediments of Beeson, Tolan, and Madin (1989)

Tsr **Sandy River Mudstone (Pliocene)**—Moderately to poorly lithified quartzomicaceous mudstone and sandstone in the Portland basin. Organic material is common, including branches and logs. Volcanic ash layers and pumice sands occur locally. Rocks are commonly finely laminated and locally ripple laminated and cross bedded

Tcr **Columbia River Basalt Group (middle Miocene)**—Tholeiitic flood-basalt flows that were erupted from long linear fissure systems in northeastern Oregon, eastern Washington, and western Idaho from about 17 to 6 Ma (Swanson and others, 1979; Hooper, 1982). Members and units belonging to the Wanapum and Grande Ronde Basalts, two of the five formations of the Columbia River Basalt Group, are present within the mapped area

Twh **Basalt of Waverly Heights and associated undifferentiated sedimentary rocks (Eocene)**—Subaerial basaltic lava flows and associated sediments that uncomformably underlie flows of the Columbia River Basalt Group. Two flows have yielded K/Ar dates of about 40 Ma (Beeson, Tolan, and Anderson, 1989)

——— **Contact**—Approximately located

— ┸ — **Fault**—Inferred from offset of well-defined stratigraphy; bar and ball on downthrown side

·--┸--· **Fault**—Inferred from offset of a single contact (on the Lake Oswego quadrangle and southwest corner of the Gladstone quadrangle, buried fault inferred from offset of well-defined stratigraphy); bar and ball on downthrown side

▲ — ▲ **Thrust fault**—Inferred from offset of well-defined stratigraphy; dotted where concealed; sawteeth on upper plate

- - 30 - - **Isopach of Qff or Qal**—Measurement in feet

·····300····· **Depth to basement contour**—Measurement in feet

▨ **Area overlain by more than 1.5 m of Ql**

←┼— **Anticline**—Arrowhead on axis indicates direction of local plunge

┴5 **Strike and dip of beds**

Subsurface data points

△ **Borehole bottoms in units Qal, Qff, or Ql**

\+ **Borehole bottoms in units Qfc, Qfch, QTt, QTm, QTb, or Tsr**

☐ **Borehole bottoms in units Tcr or Twh**

Figure 177. Explanation for earthquake-hazard geologic quadrangle maps in figures 178–185.

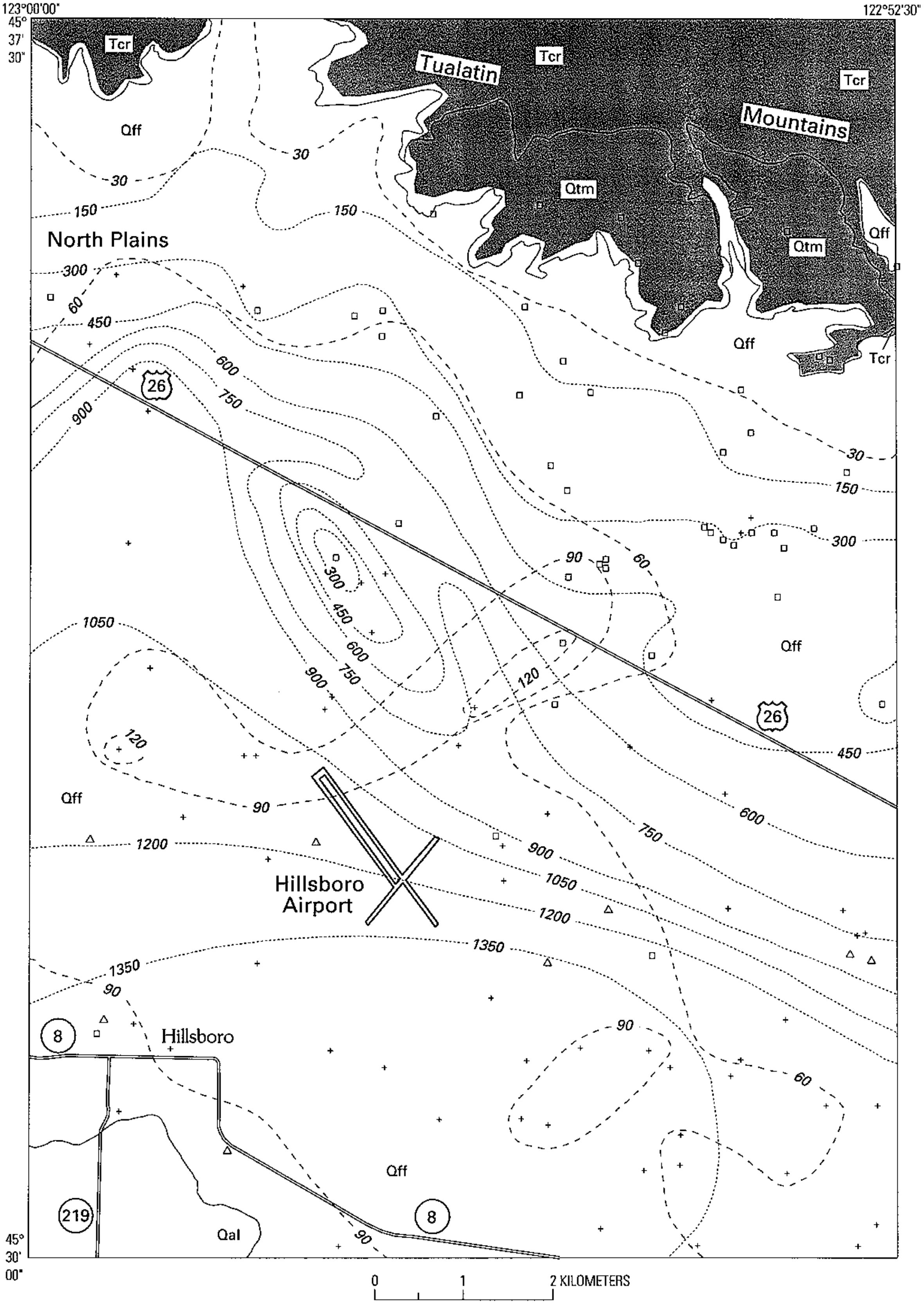


Figure 178. Geologic map of the U.S. Geological Survey's 1:24,000-series topographic Hillsboro quadrangle. From Madin (1990).

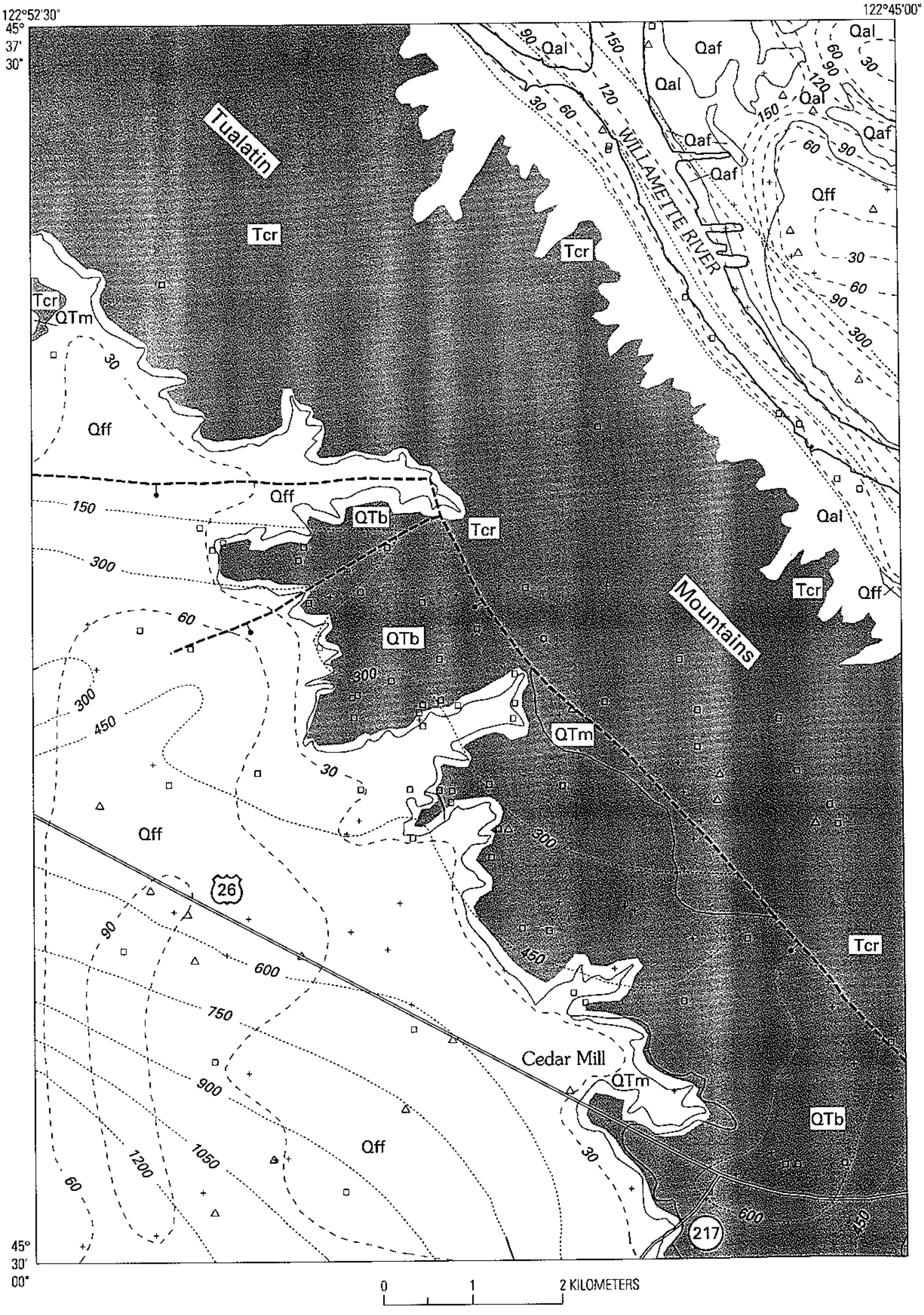


Figure 179. Geologic map of the U.S. Geological Survey's 1:24,000-series topographic Linnton quadrangle. From Madin (1990).

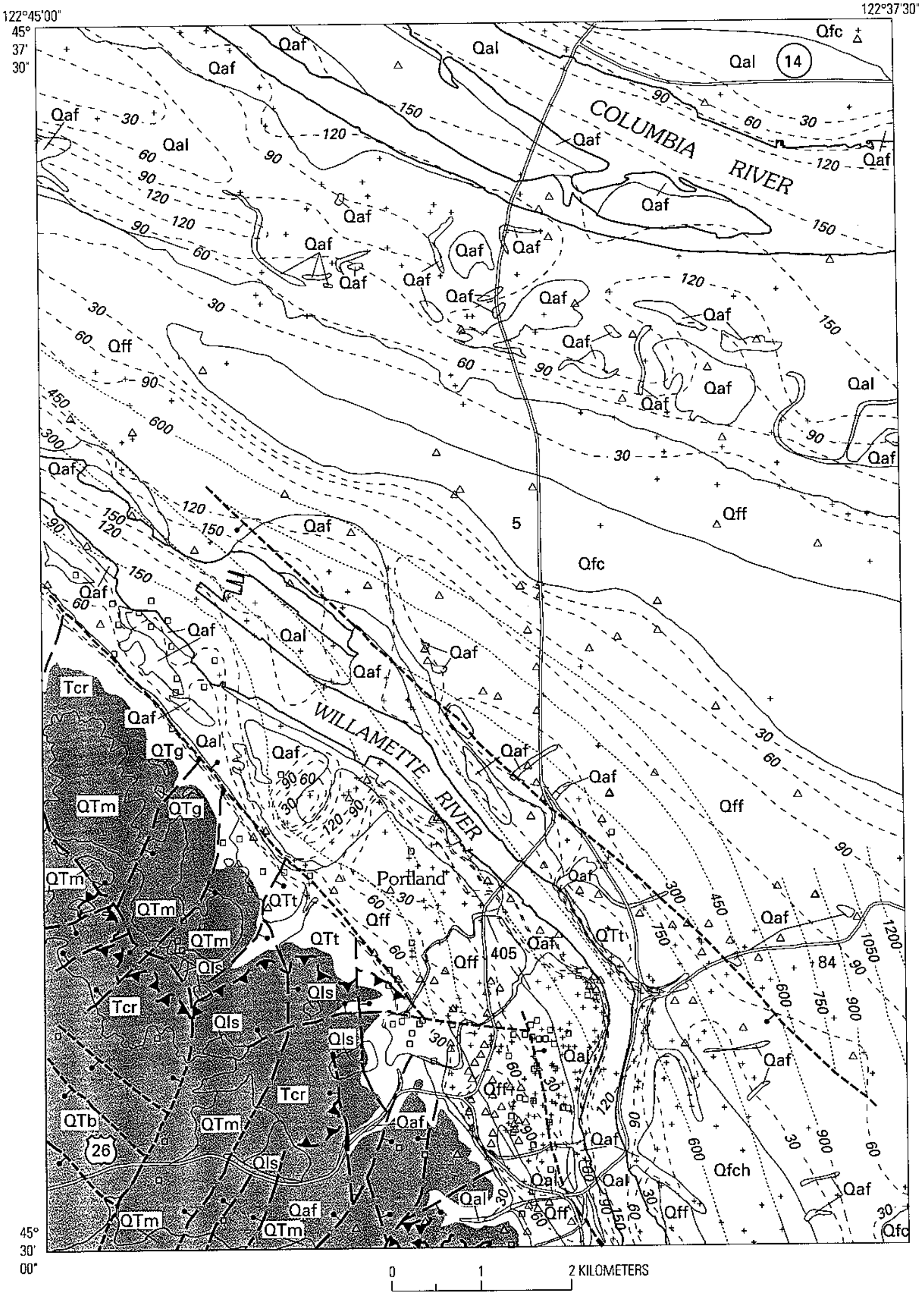


Figure 180. Geologic map of the U.S. Geological Survey's 1:24,000-series topographic Portland quadrangle. From Madin (1990).

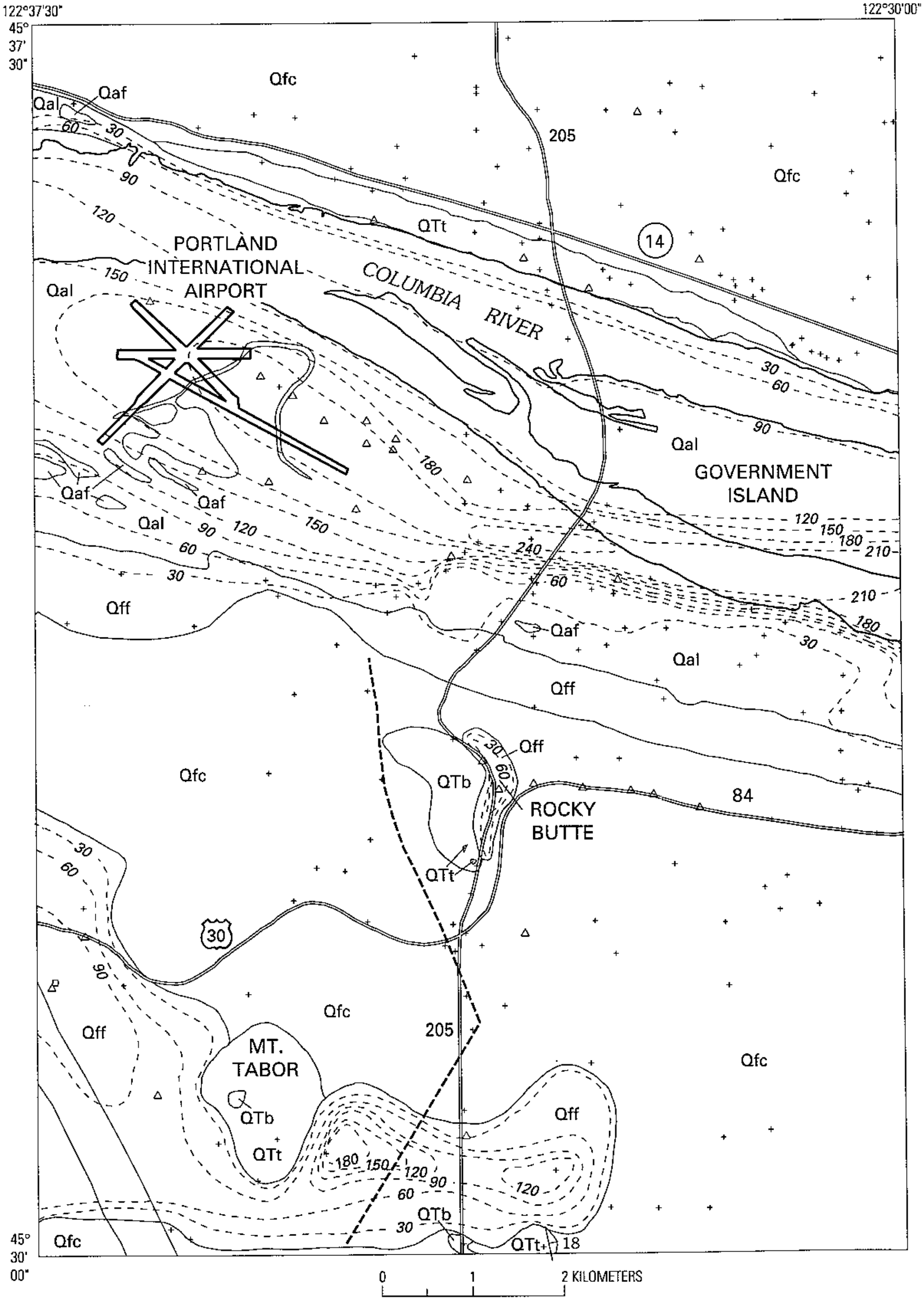


Figure 181. Geologic map of the U.S. Geological Survey's 1:24,000-series topographic Mt. Tabor quadrangle. From Madin (1990).

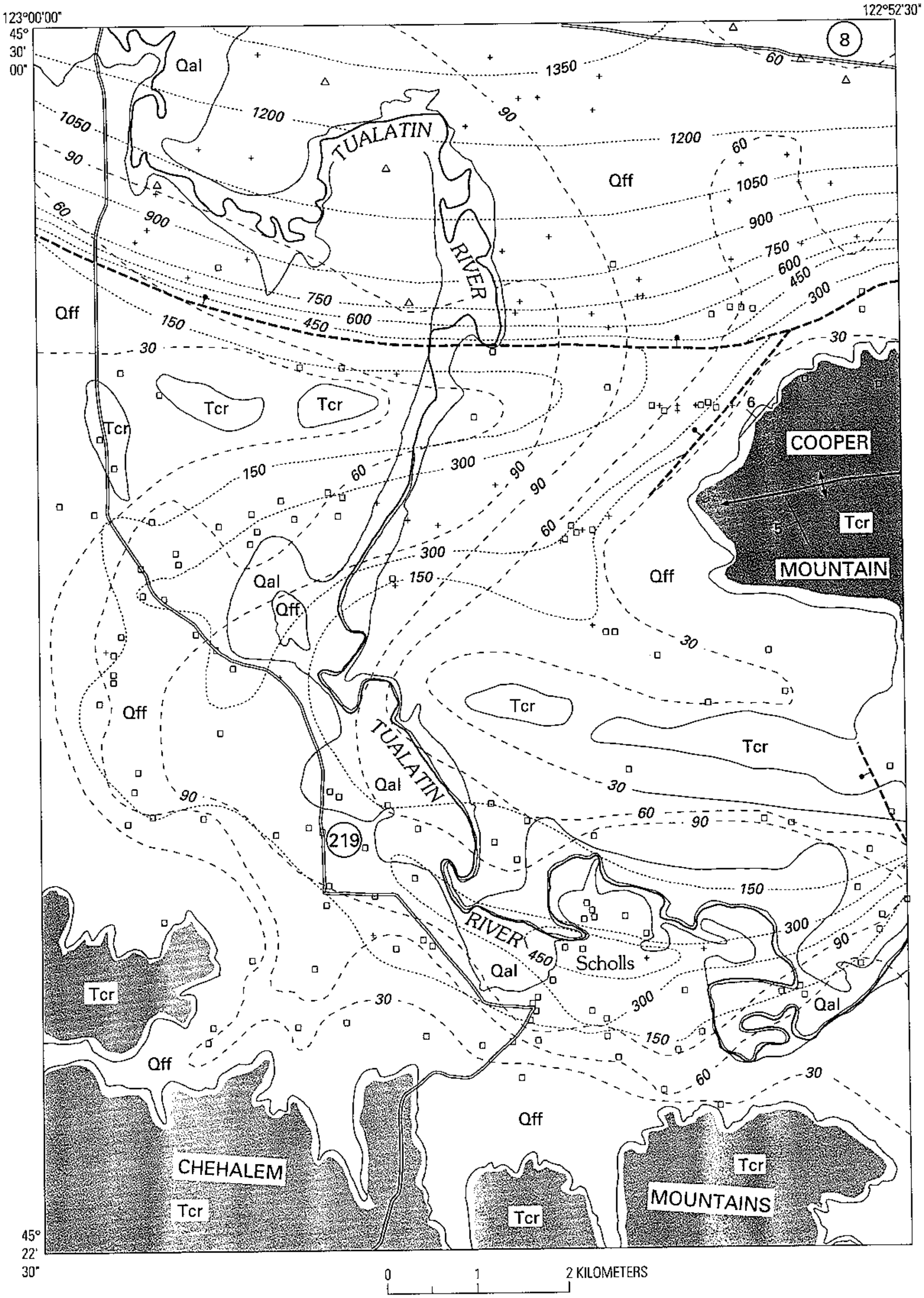


Figure 182. Geologic map of the U.S. Geological Survey's 1:24,000-series topographic Scholls quadrangle. From Madin (1990).

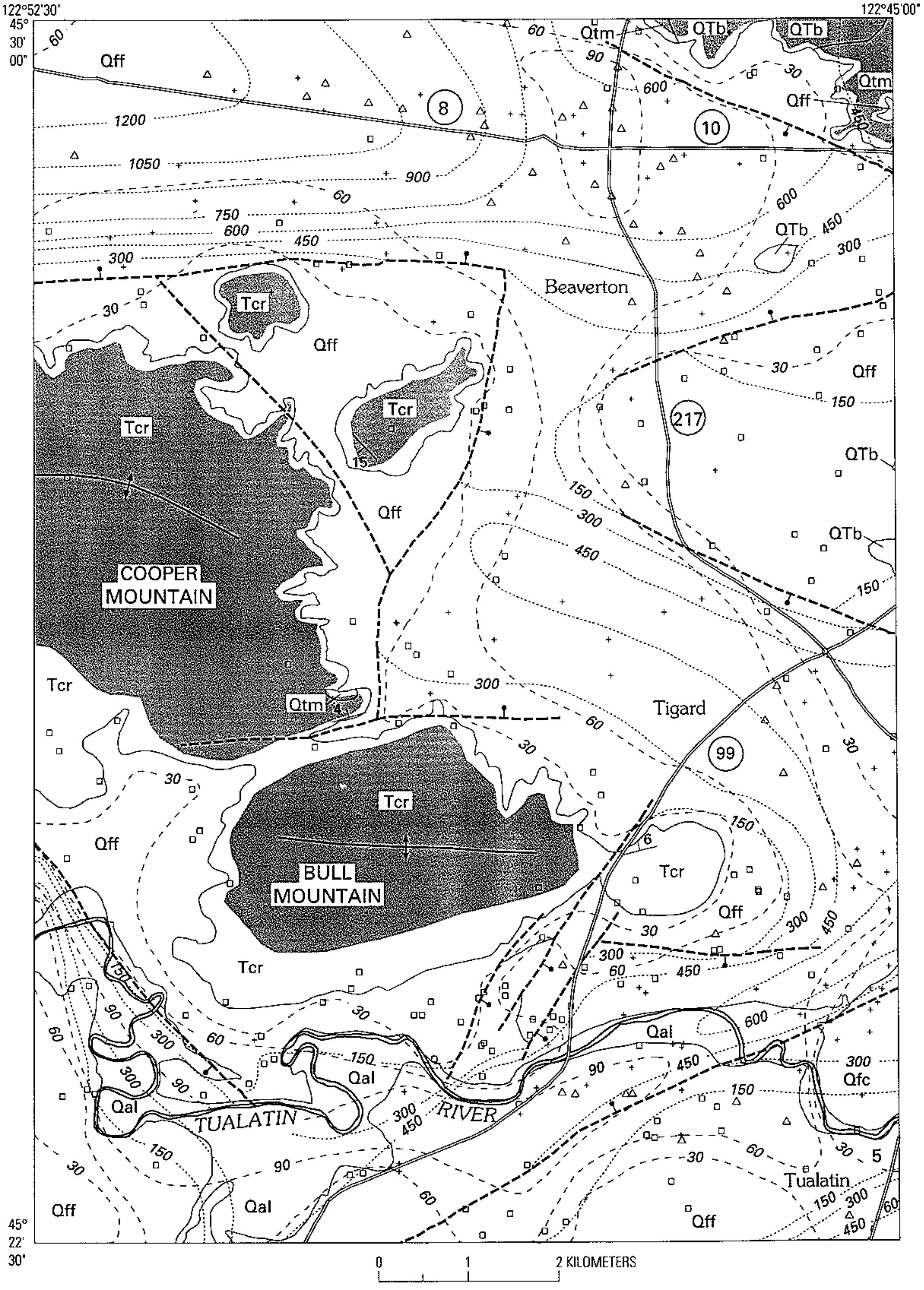


Figure 183. Geologic map of the U.S. Geological Survey's 1:24,000-series topographic Beaverton quadrangle. From Madin (1990).

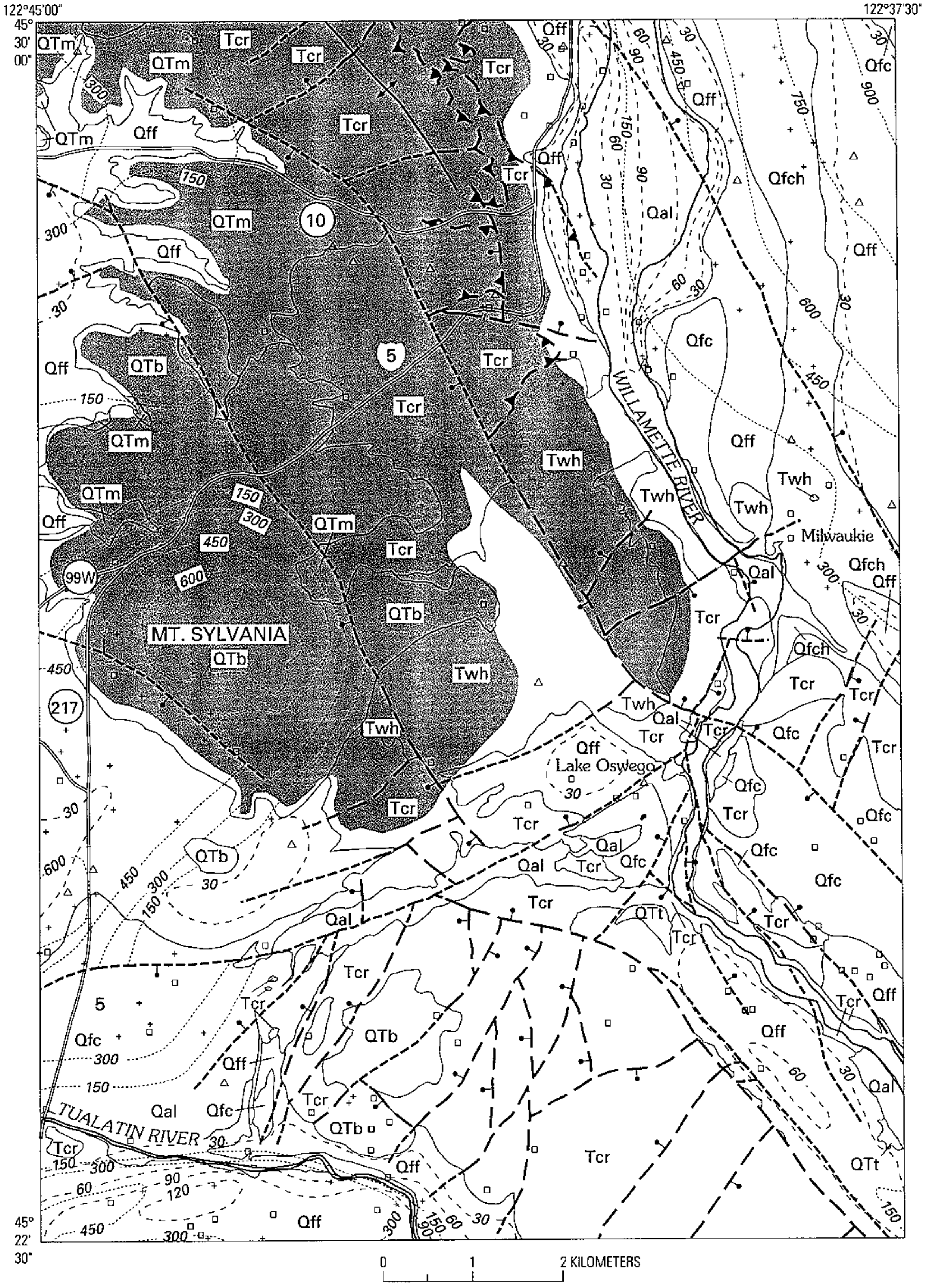


Figure 184. Geologic map of the U.S. Geological Survey's 1:24,000-series topographic Lake Oswego quadrangle. From Madin (1990).

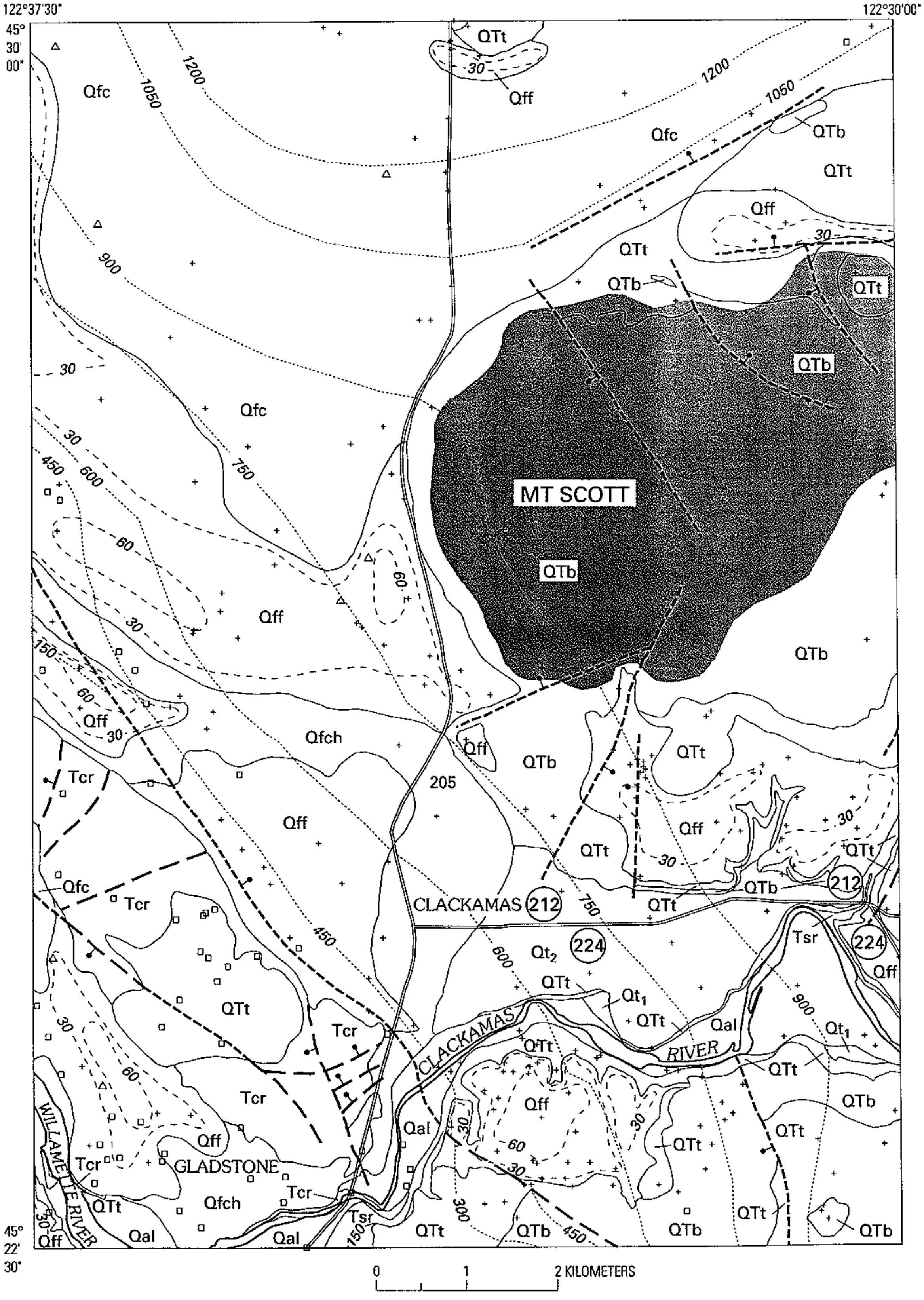
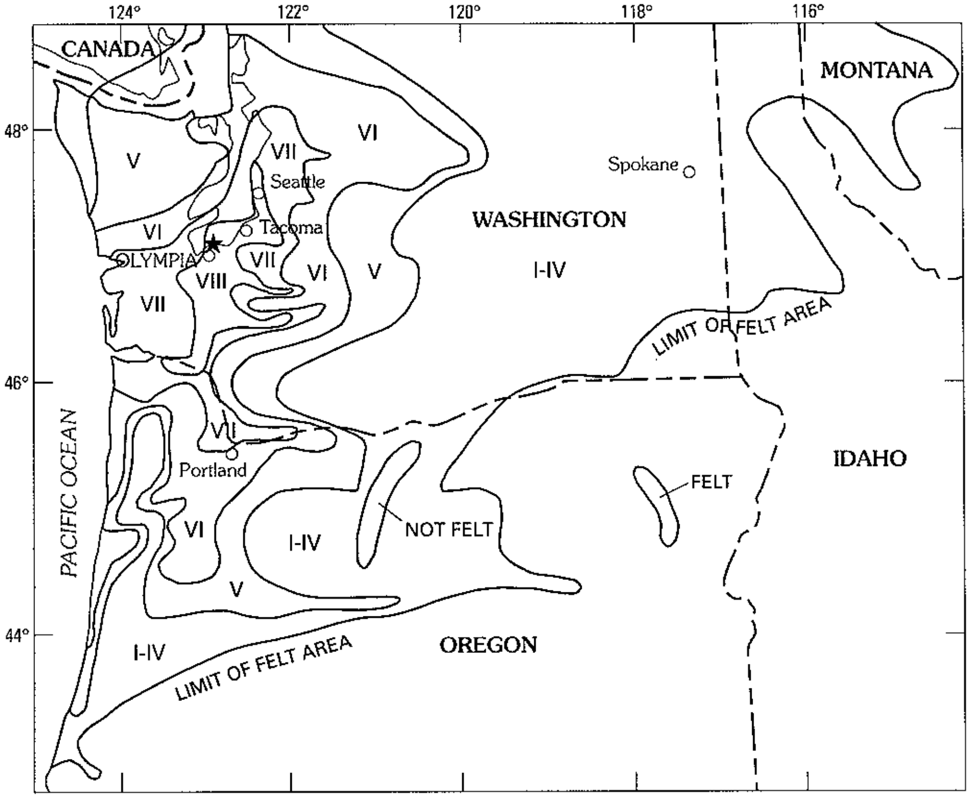
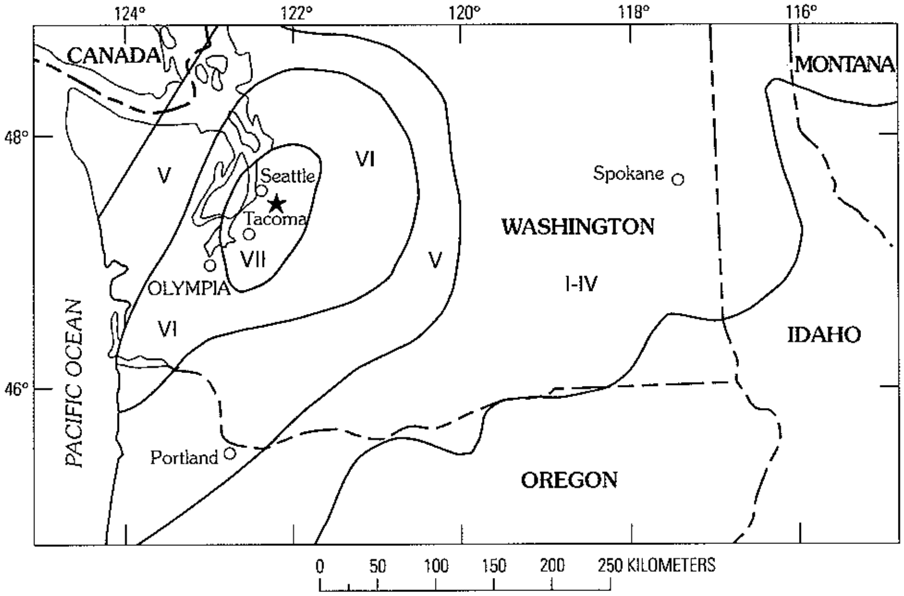


Figure 185. Geologic map of the U.S. Geological Survey's 1:24,000-series topographic Gladstone quadrangle. From Madin (1990).



EARTHQUAKE OF APRIL 13, 1949



EARTHQUAKE OF APRIL 29, 1965

Figure 186. Modified Mercalli intensity maps for the Puget Sound earthquakes of April 13, 1949 (modified from Ulrich, 1949), and April 29, 1965 (modified from Algermissen and Harding, 1965). Stars indicate the earthquake epicenters.