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and
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Style is generally that of U.S. Geological Survey publications. (See USGS Suggestions to Authors, 7th ed., 1991, or recent issues of *Oregon Geology*.) Bibliography should be limited to references cited. Authors are responsible for the accuracy of the bibliographic references. Include names of reviewers in the acknowledgments.

Authors will receive 20 complimentary copies of the issue containing their contribution. Manuscripts, letters, notices, and meeting announcements should be sent to Klaus Neuendorf, Editor, at the Portland office (address above).

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Cover photo

The Tualatin Valley in Washington County, as seen on an old plastic relief map. Vertical exaggeration is 2:1. The article beginning on page 99 takes a new look at what is found under the surface of the valley and calls it the "Hillsboro Formation."

Reader survey results

Many thanks to everyone who took the time to reply to our survey in the March/April issue! Almost 150 people responded, and many suggested good ideas about how to improve the magazine.

About 90 percent of those who responded said they were "satisfied" or "very satisfied" with *Oregon Geology*. Almost half of all those who responded said they had been subscribers for 10 years or more. Since the magazine's inception as the *Ore Bin* in 1939, there have been different editors and contributors, but most readers still see it as a good place to find out about geology.

Readers have a wide variety of favorite topics. These include:

Number of responses	Topic
101	Geology of specific areas
89	Field trip guides
68	Plate tectonics
68	Volcanoes
67	Earthquakes
51	Mineral/gemstone localities
51	Announcements of new publications
42	Fossil localities
42	Hazards, such as landslides
38	Paleontology
32	Stratigraphy
31	Mining history

When asked about including new topics in *Oregon Geology*, about half the respondents thought it was a good idea, and about half didn't. However, even those who were interested in exploring other subjects want to make sure that it's still tied to geology. Among the leading suggestions were:

Number of responses	Topic
58	Archaeology
47	History
37	Geography
30	Climate
25	Hiking
24	Conservation issues
22	Wetlands

More than half the respondents were interested in articles about other states. Some wanted this restricted to states with geology that could be tied to Oregon's. Others were interested in finding out about areas of the country they grew up in or visited.

When asked whether we should add color photographs, only 49 people said yes. However, 80 people said they would be willing to pay more for a subscription if it included color.

We are always interested in why people subscribe to *Oregon Geology*. Knowing a little about our readers allows us to try to focus the magazine.

*(Continued on page 118, **Reader survey**)*

Post-middle Miocene geologic evolution of the Tualatin basin, Oregon[1]

by Doyle C. Wilson, Department of Geology, Portland State University, Portland, Oregon 97207

ABSTRACT

The geologic history of the Tualatin basin and its sedimentary fill after emplacement of the Columbia River Basalt Group (CRBG) are described in this paper. The core from the 334-m-deep hole HBD-1, drilled by the Oregon Department of Geology and Mineral Industry at the Portland-Hillsboro Airport, provides the primary information for the study, which is also supported by over 2,400 well logs and cores and by four seismic reflection lines.

The sedimentary section above the 26-m-thick paleosol at the top of the CRBG in drill hole HBD-1 is divided into two main groups: a 25-m-thick section of Missoula flood sediments called the Willamette Silt and an underlying, 263-m-thick, fine-grained sequence of fluvial and lacustrine Neogene sediments introduced here as the Hillsboro Formation.[2]

Pollen, diatom, and paleomagnetic data support dividing the Hillsboro Formation into a 230-m-thick Pleistocene package and an underlying, 75-m-thick Pliocene to upper Miocene unit. Heavy-mineral and INAA chemical analyses indicate that sediments of the Hillsboro Formation were primarily derived from local highlands surrounding the Tualatin Valley.

The structure at the top of the CRBG in the Tualatin basin shows a larger northern subbasin, with few faults cutting the Hillsboro Formation above the CRBG, and a smaller, more complexly faulted subbasin south and east of the Beaverton fault. Hillsboro Formation sedimentation rates increased tenfold from the late Miocene-Pliocene to the Pleistocene, concomitant with increased basin subsidence. Comparison of Neogene basin evolution among Willamette Valley depositional centers shows that they all began to form in the late Miocene. Studies of gravity anomalies and seismic reflection characters indicate that the Tualatin basin and the northern Willamette basin probably have similar depositional histories with accelerated subsidence in the Pleistocene. In contrast, the southern Willamette Valley, Stayton basin, and Portland basin experienced decrease or cessation of downwarping in late Pliocene to early Pleistocene time.

The Tualatin River knickpoint is unusually close to the river's mouth and has remained essentially unchanged since the Missoula floods filled the basin 12,700 years ago. The fact that the CRBG underlies the last stretch of the river's course has kept the river from cutting back into the valley, which has resulted in the low river gradient evident today in the Tualatin basin. Three identified geomorphic surfaces around the Tualatin River are related to ebbing Missoula Flood waters and more recent fluvial activity.

INTRODUCTION

The Tualatin basin, located in Washington County, is a northwest-southeast trending elliptical structure surrounded by the Portland Hills and Tualatin Mountains to the north and east, the Chehalem Mountains to the south, and the Coast Range to the west (Figure 1). Cooper and Bull Mountains lie within the southeastern part of the valley. Elevations range from approximately 335 m (1,100 ft) in the surrounding highlands to an average of 53 m (175 ft) on the valley floor. The elevation at the confluence of the Tualatin River, the major waterway that drains the Tualatin Valley, with the Willamette River is approximately 16.8 m (55 ft) above mean sea level.

The basin occurs as a partially isolated western extension of the Willamette Valley fore-arc regional low west of the Cascade Range volcanic arc complex. Approximately 4,300 m of Paleogene (Eocene to lower Miocene) marine and continental sediments overlie an Eocene oceanic basaltic basement in the Tualatin basin (Hart and Newcomb, 1965; Schlicker and Deacon, 1967). As much as 300 m of the middle Miocene Columbia River Basalt Group (CRBG) and up to 460 m of overlying Neogene continental sediments blanket the marine sediments. A thin capping of Late Pleistocene Missoula flood silt covers the Tualatin Valley to elevations of approximately 76 m (250 ft).

Excellent documentation exists on the hydrogeology and engineering geology of the CRBG and surficial features in the Tualatin Valley (Hart and Newcomb, 1965; Schlicker and Deacon, 1967) as well as the Paleogene history of the basin (Popowski, 1996). Detailed studies of the overlying sedimentary material in the basin are lacking. This report presents the post-CRBG Neogene (late Miocene to Holocene) history of the Tualatin basin and relates the sedimentary and structural conditions to the Willamette Valley–Coast Range region.

[1] This paper is a greatly reduced excerpt from the author's doctoral dissertation: **Post-Middle Miocene Geologic History of the Tualatin Basin, Oregon, with Hydrogeologic Implications**, completed 1997 at Portland State University (Wilson, 1997).

[2] As of this printing, the formation name is informal; steps to establish a formal geologic name have been initiated by the author.

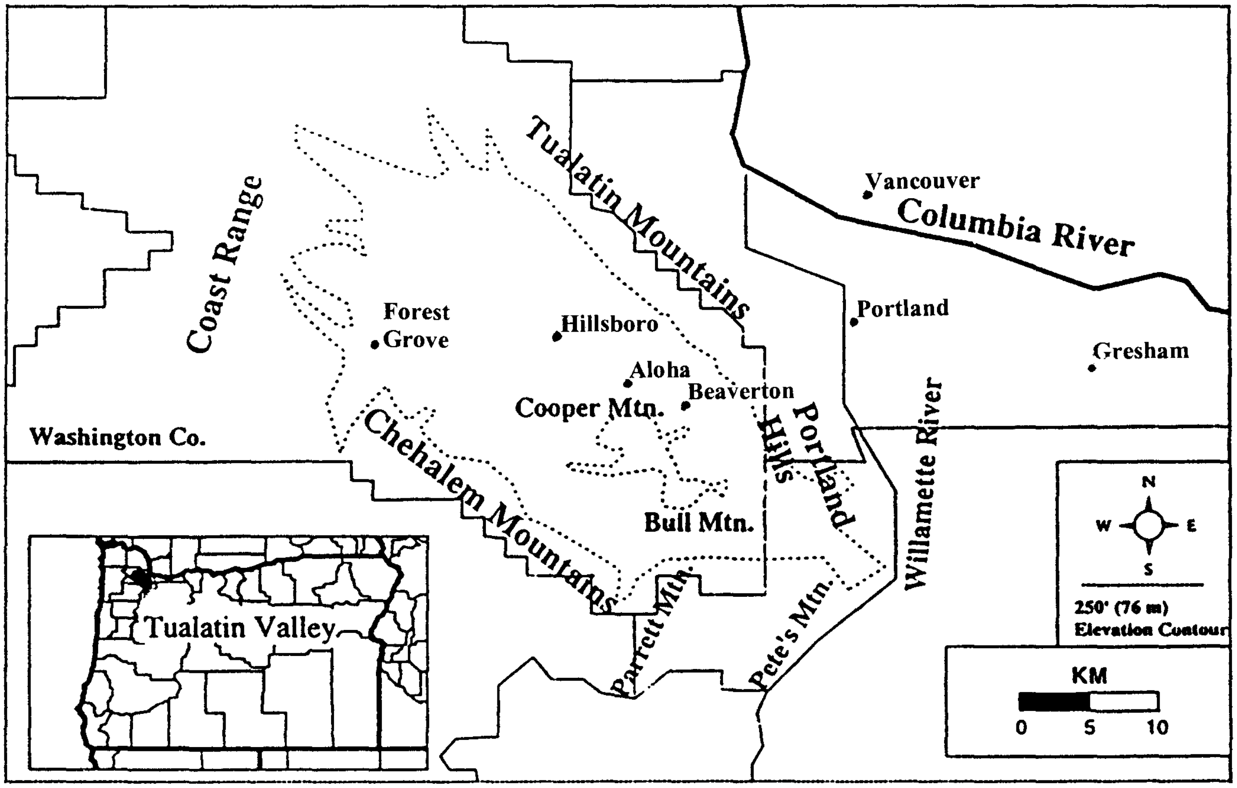


Figure 1. Location map of the Tualatin Valley and associated physiographic features. The northwest-southeast oriented valley is essentially surrounded by highlands. Dotted line marks 76-m (250-ft) elevation contour.

GENERAL GEOLOGIC SETTING

Many of the geologic studies around the Portland region have concentrated on the Portland basin, the Coast Range, and the Tualatin Mountains-Portland Hills area but have also included references to the Tualatin basin, leading to general stratigraphic relationships in the Tualatin and Portland basins (Figure 2).

Paleogene stratigraphy

Middle Eocene ocean-floor basalt, equivalent to the Siletz River Volcanics, is thought to form the basement rock of the Tualatin basin. These volcanic rocks are exposed in the Coast Range west of the valley, along with the overlying middle to upper Eocene Tillamook Volcanics and the upper part of the sedimentary Yamhill Formation (Hart and Newcomb, 1965; Schlicker and Deacon, 1967; Wells and others, 1994).

The middle to upper Eocene basalt of Waverly Heights is found around the southeast end of the Portland Hills and is believed to have been part of an oceanic island that docked on to western Oregon during the Eocene (Beeson and others, 1989a,b).

Eocene to lower Miocene marine sedimentary rocks overlie the Eocene volcanic rocks in the subsurface and in exposures along the western and southwestern edges of the valley (Popowski, 1996; Wells and others, 1994; Schlicker and Deacon, 1967). The units consist of tuffaceous mudstones, siltstones, and sandstones of the Eocene Yamhill, Cowlitz, Spencer, and Keasey Formations and the Oligocene Pittsburg Bluff and Scappoose Formations (Baldwin, 1981; Timmons, 1981; Van Atta and Kelty, 1985; Yeats and others, 1991; Van Atta and Thoms, 1993). Maximum thickness of the sediments is approximately 4,300 m.

Neogene stratigraphy

The middle Miocene Columbia River Basalt Group (CRBG) unconformably covers the Paleogene sediments and volcanics (Figure 3). This unit composes the majority of the surrounding highlands and Cooper, Bull, and Sexton Mountains within the Tualatin Valley. Flows of the Grande Ronde Basalt entered the Tualatin basin through the Sherwood trough (Beeson and others, 1989a). The Frenchman Springs Member (15.3 Ma) of the Wanapum Basalt has been mapped in the highlands bordering the southern margin of the basin (Beeson and Tolan, 1984; Beeson and others, 1985; Beeson and others, 1989b) and is present in the center of the basin (M.H. Beeson, oral communication, 1993). The CRBG is as much as 305 m thick under the Tualatin Valley, with separate flows as thin as 6 m (Schlicker and Deacon, 1967). The sequence has undergone structural deformation in the surrounding highlands and is faulted in the subsurface (Madin, 1990; Popowski, 1996).

Nonmarine clay, silt, sand, and a few gravel units of Neogene age unconformably overlie the CRBG and extend upward almost to the valley surface. The thickness of these deposits varies from feather edge at the basin margins to over 450 m in the central part of the basin under the city of Hillsboro (Hart and Newcomb, 1965; Schlicker and Deacon, 1967; Madin, 1990; Yeats and others, 1991). These sediments have been labeled in past work as age equivalent to the Pliocene Troutdale Formation and Sandy River Mudstone in the Portland basin. They are the primary focus in the following sections and are given formation status in this report.

Schlicker and Deacon (1967) distinguished a basal, laterized unit overlying the CRBG along most edges of the valley. They named it Helvetia Formation, assigned it to an early Pliocene age, and considered it equivalent to the earliest Troutdale Formation. In this paper, the Helvetia Formation is not separated out from the rest of the Neogene sediments.

The gray, pilotaxitic to diktytaxitic, olivine-bearing, Pliocene-Pleistocene Boring Lava is exposed around local volcanic centers in the Portland Hills (Trimble, 1963; Schlicker and Deacon, 1967). The Boring Lava stratigraphically lies within and on top of the Neogene sediments and the Portland Hills Silt and underlies Willamette Silt. Recent work indicates that the age of the Boring Lava flows of the Tualatin Mountains near Sylvan is between 0.26 Ma and 0.96 Ma, while the flows around Oregon City date back to to 2.4 Ma (Conrey and others, 1996).

The Willamette Silt is up to 37 m thick and occurs as an extensive surficial deposit of dominant medium-brown, micaceous, clayey to sandy silt, with sands throughout the valley plain and gravels in the east end of the valley near Lake Oswego (Schlicker and Deacon, 1967; Madin, 1990). The sediments unconformably overlie the Neogene sediments and are interpreted as catastrophic flood deposits from recurring jökulhlaups from glacial Lake Missoula in Montana during the late Pleistocene, between 12,700 and 15,300 years ago (Allison, 1978a; Waitt, 1985; Beeson and others, 1989b). Occasional ice-rafted erratics of metamorphic and plutonic rocks not originating in western Oregon are found in the sediments. Mullineaux and others (1978) document the age of the last flood cycle at 13,080 years ago.

Rhythmite sequences along the Columbia River in Washington and the Willamette River indicate that more than 90 flood cycles occurred during this time period, with at least 22 entering the southeastern part of the Tualatin Valley (Waitt, 1996). The floods were strong enough to scour the preexisting divide (presently 46 m in elevation) between the Tualatin and Willamette Valleys (Allison, 1978b) at the Tonquin scablands near Sherwood.

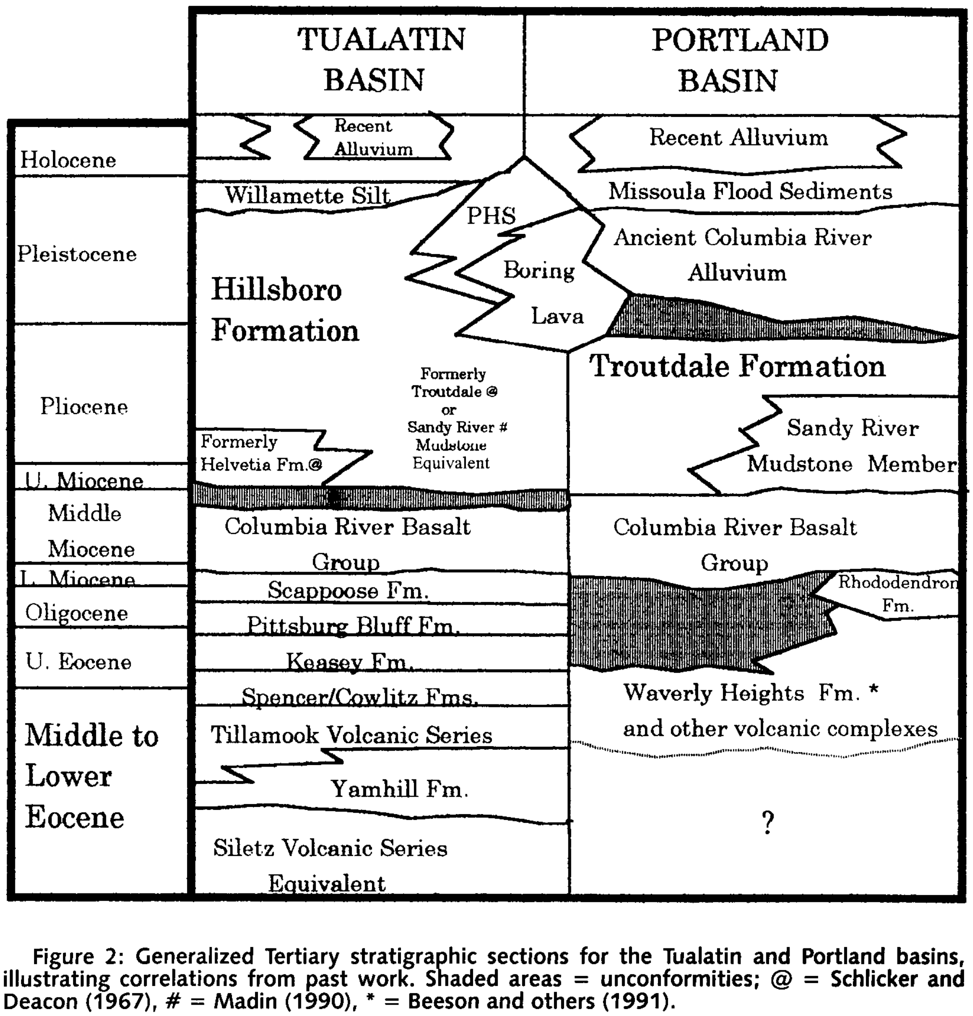


Figure 2: Generalized Tertiary stratigraphic sections for the Tualatin and Portland basins, illustrating correlations from past work. Shaded areas = unconformities; @ = Schlicker and Deacon (1967), # = Madin (1990), * = Beeson and others (1991).

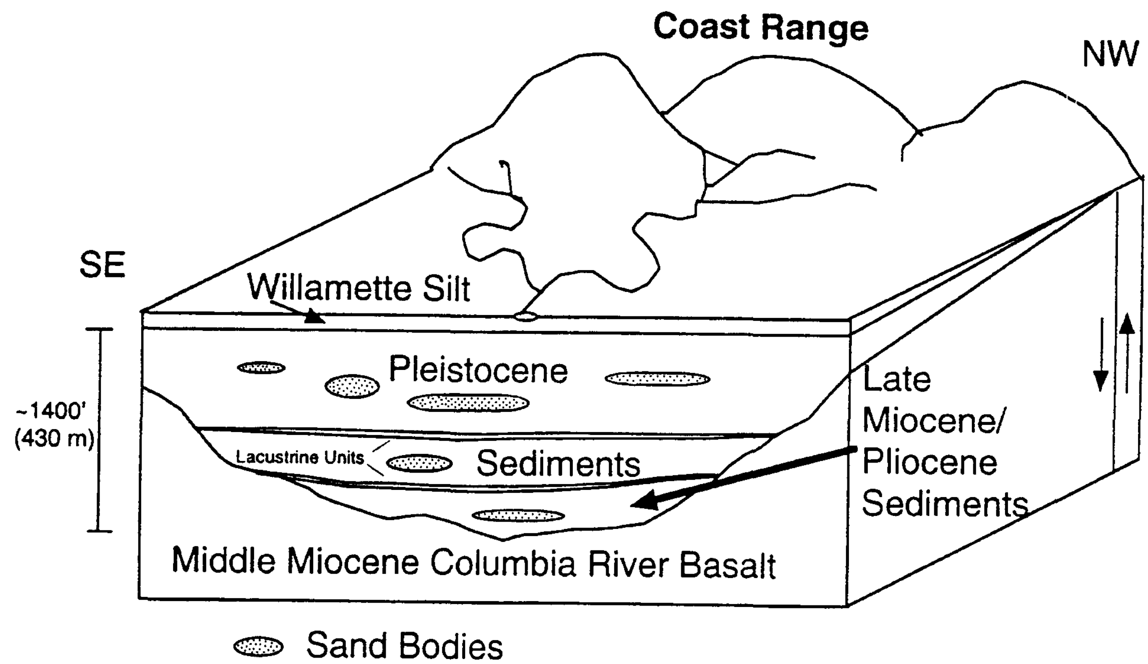


Figure 3. Schematic geologic model of Neogene sediment deposition overlying the Columbia River Basalt Group. The fluvial/lacustrine clastic rocks were primarily derived from the surrounding highlands, particularly the Coast Range.

Pleistocene loess deposits, the Portland Hills Silt, mantle the adjacent highlands and are thicker on the Portland Hills to the northeast than on the Chehalem Mountains to the southwest (Lentz, 1981). The micaceous unit has a uniform massive texture and may be as thick as 30 m on the Portland Hills. The eolian silt was arbitrarily mapped down to the 76-m (250-ft) elevation, below which are catastrophic flood deposits of the Willamette Silt (Schlicker and Deacon, 1967; Madin, 1990). The two units are almost impossible to distinguish in the field on a lithologic basis.

Regional structure of the Tualatin basin

The Tualatin basin is a fore-arc depression extending northwest from the Willamette Valley and is part of the Willamette-Puget Sound lowland and the fore-arc region related to the Cascade Range magmatic arc. It has been described as a broad syncline surrounded by sometimes faulted anticlines and monoclines (Figure 4; Trimble, 1963; Hart and Newcomb, 1965; Schlicker and Deacon, 1967; Frank and Collins, 1978; Al-Eisa, 1980; Brodersen, 1995). Within the valley, Cooper and Bull Mountains have also been described as faulted anticlines.

The Portland Hills fault zone, the boundary between the Tualatin Mountains-Portland Hills and the western margin of the Portland basin, consists of three named faults in the Tualatin Mountains-Portland Hills area: the Portland Hills fault, the Oatfield fault, and the East Bank fault on the northeast side of the Willamette River. Seismicity in the Portland area indicates that the Portland Hills fault and the Oatfield fault are still active (Yelin and Patton, 1991; Blakely and others, 1995). This fault zone is part of a major structural lineament across the Willamette Valley to the Clackamas River drainage (Balsillie and Benson, 1971; Perttu, 1981; Beeson and others, 1985, 1989a; Madin, 1990; Yeats and others, 1991; Yelin and Patton, 1991; Blakeley and others, 1995).

The northeast trending Sherwood fault bounds the southeast part of the basin (Yeats and others, 1991). The Gales Creek and Newberg faults just to the west and southwest of the basin are part of the Gales Creek-Newberg-Mount Angel fault zone that forms a parallel couple with the Portland Hills-Clackamas River fault zone (Al-Eisa, 1980; Yeats and others, 1991; Werner and others, 1992; Popowski, 1996). Recent field mapping suggests that the Gales Creek fault zone has played a major role in the deformation of this portion of the northern Coast Range (Wells and others, 1994; Popowski, 1996).

TUALATIN BASIN POST-CRBG STRATIGRAPHY

The Oregon Department of Geology and Minerals Industries (DOGAMI) cored the 334-m-deep Hillsboro Deep Test No. 1 (referred to in this report as HBD–1) at the Portland-Hillsboro Airport (NW¼ sec. 28, T. 1 N., R.

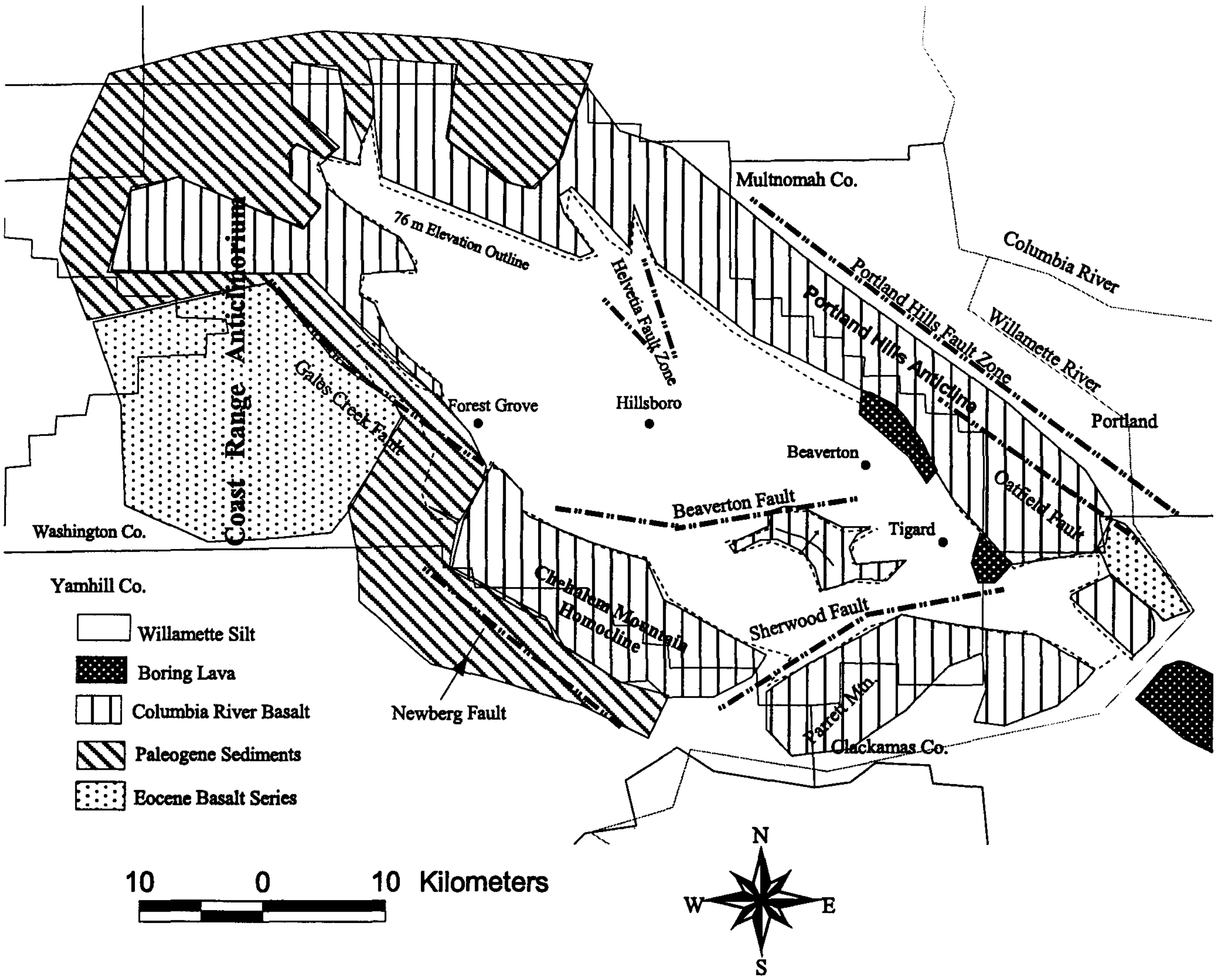
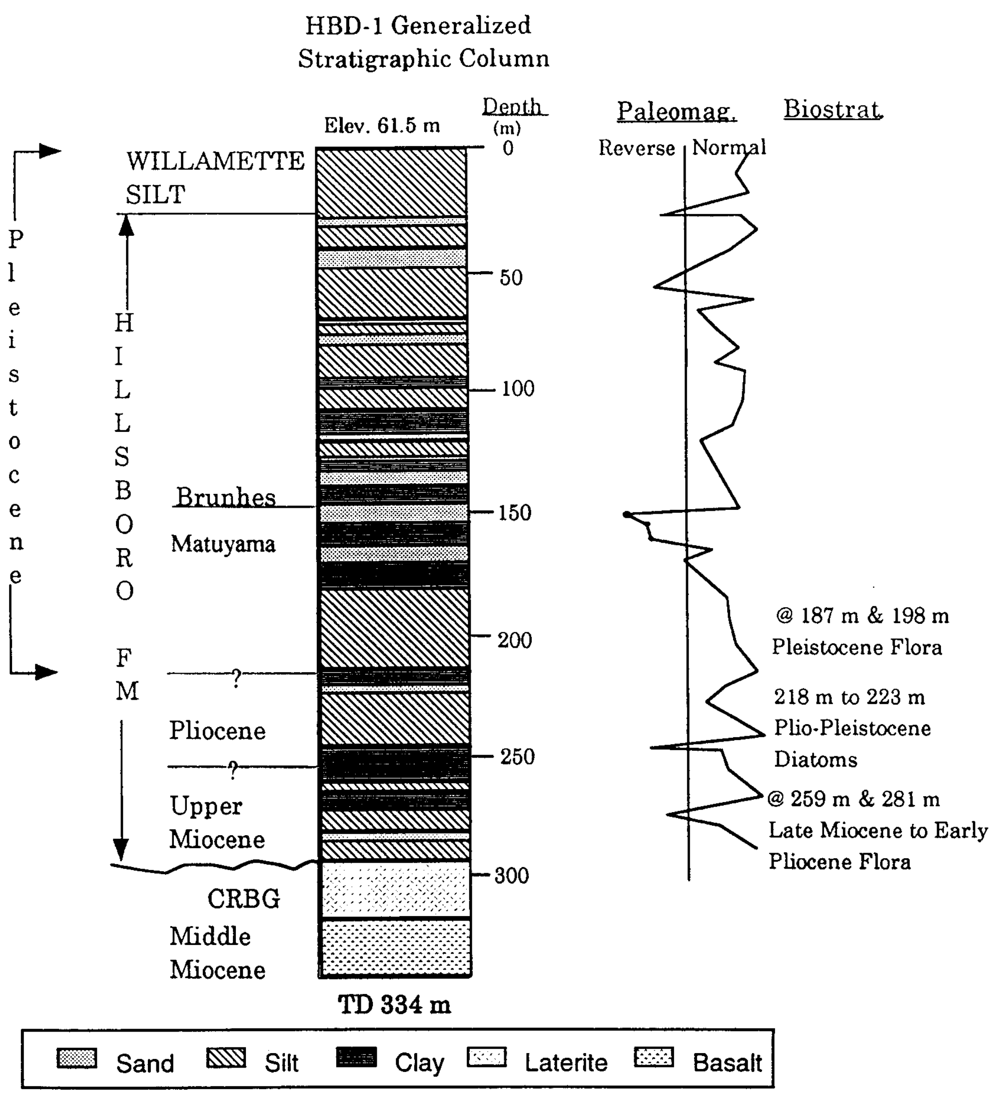


Figure 4. Generalized geologic map and major structural features related to the Tualatin basin. Modified from Schlicker and Deacon, 1967, and Beeson and others, 1991.

2 W.) in 1993 as part of a regional seismic hazards study (Figure 5). HBD-1 encountered 288 m of fluvial and lacustrine sediment overlying 30.5 m of lateritic soil and weathered basalt of the Columbia River Basalt Group (CRBG). Black, unweathered basalt underlies the weathered zone from 314 m to a drilled total depth of 334 m. In this report, the sedimentary section is divided into two units: (1) Missoula flood deposits known as the Willamette Silt (Schlicker and Deacon, 1967) at the top of the section and (2) the bulk of the section overlying the CRBG and introduced in this report as the Hillsboro Formation. The term Hillsboro Formation is used to disassociate these sediments, in contrast to past practice, from those of the Troutdale Formation or Sandy River Mudstone in the Portland basin. The HBD-1 core is the type section for the Hillsboro Formation. From it, correlations are made to other parts of the basin. Most of the author's analytical work on the Hillsboro Formation originates from this cored unit.

Depositional and stratigraphic relationships within the Hillsboro Formation and the Willamette Silt away from HBD-1 were developed using three exposures (two were created at construction sites and have since been covered); cores and drill samples from government, industry and private drill holes; gamma-ray profiles of 60 drill holes; approximately 2,400 water wells and private and government lithology logs of drill holes; and four regional seismic reflection data lines. The gamma logs were generated to locate the boundaries between the Willamette Silt and the Hillsboro Formation and the Hillsboro Formation and the top of the CRBG. Copies of the water well logs were obtained from the Watermaster of Washington County in Hillsboro and the Oregon Water Resources Department in Salem.

The Helvetia Formation of Schlicker and Deacon (1967) has not been separated from the rest of the Hillsboro Formation in this study. Available information does not warrant separation of these sediments. Several



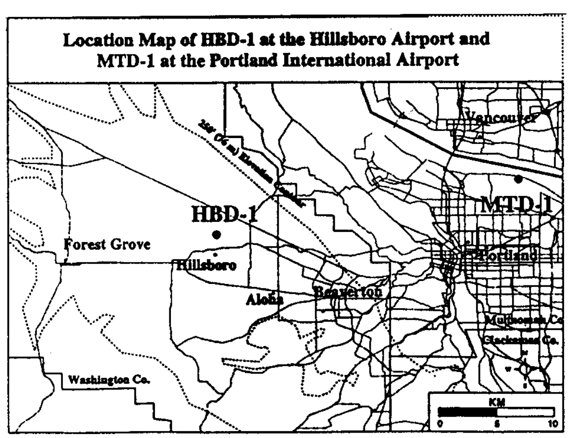


Figure 5. Stratigraphic section of HBD-1 core boring at the Portland-Hillsboro Airport and and location map of HBD-1 and drill hole MTD-1 at the Portland International Airport. Both core tests were drilled in 1993 by the Oregon Department of Geology and Mineral Industries as part of a seismic-hazard study. Pollen, diatom, and paleomagnetic data indicate that the bulk of the Hillsboro Formation is Pleistocene.

samples collected at the type locality just north of Helvetia, Oregon, contain the same materials and textures as the Hillsboro Formation.

HBD-1 stratigraphy and sedimentology

Willamette Silt

The Willamette Silt at the HBD-1 site primarily consists of massive, micaceous, clayey, very fine sandy silt with scattered layers of silty clay, and some dispersed organic woody material near the base from 23 m to 24 m. The formation color changes at 6 m from an oxidizing medium yellow-brown to a reducing blue-gray. The color becomes mottled with blue-gray and light-brown in the basal 1.5 m of the unit. Crude laminations occur in thin sandy stringers at 20 m and gravel up to 4–5 mm is scattered about in the basal silt at 24 m.

Hillsboro Formation

The underlying Hillsboro Formation extends from 25 m to 288 m and consists, by thickness, of 20 percent sand units, 48 percent silt units and 32 percent clay units (Table 1). The sediments are generally poorly sorted and range from silty sands to muds, as classified by Folk (1968). Silt and clay are present in all samples, while very fine sand may be present in silt and clay units.

Sand units occur as thin beds ranging from millimeter-thick stringers to 3.7-m-thick layers. The sands are generally loose to slightly compacted, subangular to rounded, poorly to moderately poorly sorted, clayey, silty, and very fine to fine grained, although scattered layers of medium-grained to gravelly sands are present. The sand constituents include lithic fragments (mostly weathered basaltic grains), plagioclase and potassium feldspars, quartz, micas, and a variety of heavy minerals.

The clay and silt layers also contain micas and are generally massive in character. The clay colors vary (light-brown, blue-gray, gray-green, gray-brown, olive-brown, greenish-black), depending on the amount and oxidation level of iron in the material. The clay layers also exhibit various levels of competency; many clay layers are stiff to dense with plastic consistencies, while others crumble easily and are slightly or not plastic. Highly weathered basalt nodules ranging from very fine sand to gravel-sized are commonly included in the clays and silts.

Sedimentary structures are found sporadically in all three lithologies and include parallel and wavy micro-laminations, low angle cross-laminations, and possible burrow or root structures. Wood debris is present in small to moderate amounts throughout the Hillsboro Formation. Nearby water wells have penetrated woody zones up to 4 m thick. The section from approximately 152 m down to 271 m is peppered with the iron phosphate mineral, vivianite. The mineral dominantly occurs as a microcrystalline powder in small nodules. At two depth intervals, 152 m and 201.5 m, crystals up to 1 mm in length line fracture surfaces.

Table 1. Sand-silt-clay content of selected sediments from DOGAMI drill hole HBD-1

Depth (m)	Lithology	Total sand %	Total silt %	Total clay %
10.4	Silt	0.7	60.2	39.1
22.3	Silt	1.5	59.0	39.5
27.4	Silt	14.1	62.5	23.4
43.0	Sand	43.7	38.3	18.0
49.4	Silt	8.9	57.8	33.2
50.6	Clay	4.3	32.8	63.0
68.9	Sand	40.5	43.7	15.8
75.9	Clay	0.2	42.0	57.8
91.4	Sand	41.0	40.0	19.0
117.3	Sand	61.7	13.3	25.0
128.0	Sand	26.1	33.5	40.4
136.6	Sand	43.8	32.3	24.0
147.5	Sand	76.0	21.0	3.0
152.1	Clay	7.5	37.4	55.2
163.7	Sand	59.0	31.9	9.1
172.2	Silt	17.7	57.8	24.6
176.5	Silt	0.3	62.1	37.6
185.8	Sand	53.9	40.9	5.2
192.6	Silt	0.3	85.4	14.4
195.1	Sand	25.9	61.7	12.4
206.3	Clay	4.3	45.3	50.4
208.2	Silt	18.7	44.3	37.0
211.1	Sand	50.4	28.2	21.3
217.6	Sand	61.1	25.0	13.9
223.7	Sand	63.5	25.3	11.2
234.4	Clay	0.0	31.2	68.8
236.8	Clay	2.5	38.9	58.7
253.9	Silt	0.1	54.3	45.6
254.8	Silt	9.4	55.8	34.9
257.9	Silt	20.2	63.3	16.6
267.3	Sand	49.3	36.1	14.6
273.7	Silt	24.1	43.6	32.3
282.2	Clay	1.0	49.2	49.7
283.2	Silt	32.3	51.5	16.2
284.1	Sand	35.9	42.4	21.7
286.2	Clay	0.4	32.1	67.5

A diatomaceous zone from 218 m to 224 m consists mostly of a blue-gray, micaceous, silty clay with minor sand units and contains vivianite (Wilson, 1997). A low-density claystone of alternating brown and green-gray laminations is present between 221 and 221.5 m. *Aulacosira canadensis* is the predominant species present in the section (Edward Theriot, written communication, 1995).

No other units in the entire section have been recognized as containing diatoms. The interval between 218 and 222.5 m is interpreted as a lacustrine deposit bounded above and below by fluvial sediments.

A green-gray, well-indurated, silicified, 15-cm-thick mudstone, encountered at 231.5 m, is underlain by 2.5 m of somewhat less indurated, friable siltstone, and very fine sandstone. The mudstone and underlying siltstone contain highly contorted laminae, rippled claystone lenses, cross-bedding, and organic debris, which is indicative of active stream conditions.

The section underlying the silicified zone down to the lateritic soil of the CRBG is essentially similar to most of the Hillsboro Formation above the silicified zone, but with fewer sand units. A unique 30.5-cm-thick conglomerate at 283.5 m consists of rounded, highly weathered, red-brown basalt gravel in a white, siliceous cement. Red-brown, clayey, silty, very fine sand extends almost 1.8 m below the conglomerate. Below the sand are found 1 m of medium-brown, cross-laminated, clayey silt at 285–286 m and 1.7 m of brown-gray, silty clay with red-brown clay clasts and 1-mm-diameter weathered basalt nodules at 286–288 m. This zone has a sharp lower boundary at 288 m with the lateritic weathered zone of the CRBG.

The Hillsboro Formation can roughly be divided into upper and lower sections based on the percentage of sand present. Almost 62 percent of the cumulative sand unit thicknesses in HBD-1 is in the top 149 m of the Hillsboro Formation, with 24 percent of the total thickness of sand units occurring from 28 m to 58 m. Seven to ten fining-upward sand sequences beginning with poorly-sorted, medium-sized sands are recognized in the upper section. Some of the basal sands have associated gravel, mostly in the form of weathered, basaltic rock fragments. More units may be interpreted as fining upward when one considers an upward trending sand-silt-clay sequence. Thin clay drapes are present on top of some fining upward sand units.

Only 14.6 m of cumulative sand units (26 percent of the total sand) exist below 183 m with beds up to 1.8 m thick, averaging 1m thick. Four sand-to-clay fining-upward sequences 1–6 m thick are widely spaced apart in this interval. The sequences are identified by noting the following observations: either the sand components fine upward or the sequence trends upwards from sand to silt to clay. More fining-upward sequences may be counted if direct sand to clay relationships are allowed.

Columbia River Basalt Group

Lateritic weathered zone. The underlying weathered zone of the CRBG is 26 m thick and consists of red-brown lateritic soil from 288 m to 308 m composed of rounded, highly weathered, pisolitic basalt nodules and more irregularly shaped, gravel-sized weathered basalt in a clay matrix. The color of the clay matrix becomes highly variegated (red, ochre, light blue gray, yellow, and gray brown) at 291 m and shifts to medium gray, ochre, and red brown at 293 m. Highly weathered basalt zones gradually become more common with depth. The weathered basaltic material contains white plagioclase crystals and a greenish-yellow silicate mineral which is probably an alteration product. Streaks of weathered basalt gradually thicken and increase in number with depth. Moderate brown to black, finely crystalline, weathered basalt with streaks of fresher, hard, black basalt begins at 308 m and continues to 314 m.

Basalt. Black, hard, fine-grained basalt underlies the weathered basalt at 314 m and continues downward to total depth of the test hole. Elemental signatures from XRF data on samples of this basalt suggest that the unit is part of the Frenchman Springs Member of the Wanapum Basalt, which is the first recognition of this unit this far west, under the floor of the Tualatin Valley (Marvin Beeson, personal communication, 1993). The estimated age of the Frenchman Springs Member is approximately 15 Ma (Beeson and others, 1989a).

Sediment characterization

Sand classification and composition. Fourteen sand and silt unit samples from HBD-1 and three sand unit samples from other borings in the Tualatin Valley were examined to determine their sand classification. Almost all the samples consist primarily of lithic fragments, particularly weathered basalt grains. Sedimentary rock fragments in the form of polyquartz grains were the only other lithic type noted in the samples. The lithic composition averages 49 percent of the total sand.

The Hillsboro Formation sands plot in the feldspathic litharenite to litharenite regions, according to Folk's classification (Folk, 1968). The quartz to total feldspar ratios are consistent with other fore-arc sand compositions of the circum-Pacific region (Dickinson, 1982).

Hillsboro Formation sands are texturally immature, as they contain more than 5 percent clay matrix, exhibit poor to very poor sorting, and include angular grain shapes (Folk, 1968). The sands in the Hillsboro Formation have a mean maturity index of 0.21; thus are are very immature sands as prescribed by Pettijohn (1975). The immature nature of the sands suggests they accumulated in a low-energy environment free from turbulent current action that could have caused winnowing and sorting of the sands (Folk, 1968). Flood-plains or small, low-gradient streams are suitable depositional environments in the case of the HBD-1 sands.

Clay mineralogy. Hillsboro Formation clay and silt samples from HBD-1 contain variable amounts of smectite, kaolinite, and illite clay. Smectite is the dominant clay mineral in most samples analyzed, ranging up to 90 percent relative abundance of the clay minerals. The preponderance of smectite is indicative of a volcanic influence; however, Cunderla (1986) and Caldwell (1993) noted that the Yamhill and Spencer Formation sedimentary rocks in the northern Coast Range also contain a large percentage of smectite in the clay-size fraction, as do the Cowlitz, Pittsburg Bluff, and Keasey

Formations (Van Atta, 1971). This becomes important in considering the provenance of the sediments.

Kaolinite dominated the clay fraction in 27 percent of the samples tested and may reach significant percentages, composing 90 percent of the clay minerals in the clayey silt at 287 m in HBD-1, just above the weathered CRBG lateritic soil. Weathered feldspars such as found in the CRBG could provide a source for the kaolinite and illite (Mason and Berry, 1968). Illite composes less than 20 percent relative abundance in most samples.

The HBD-1 clay mineral samples were extracted from clay and silt units that exhibit different textural properties concerning their density and plasticity. Some of the units are characterized as dense and mildly to highly plastic, while others are classified as incompetent and nonplastic to slightly plastic in nature. Smectite percentages are high among both populations.

BASIN STRATIGRAPHY AND SEDIMENTOLOGY

Sediment exposures

Two Willamette Silt exposures were investigated during this study: a short series of cutbank exposures along the Tualatin River in sec. 21, T. 1 S., R. 2 W., approximately 3.2 km south of Hillsboro, and a temporary construction exposure on the south side of U.S. Highway 99W, just east of State Highway 217, in sec. 36, T. 1 S., R. 1 W., in the city of Tigard. The Tualatin River exposures consist of 2- to 3-m-tall cutbanks composed of uniform moderate yellow-brown, micaceous, very fine sandy, clayey silt. One contains a 0.8-m-thick and 5-m-wide debris channel consisting of basalt cobbles in a muddy matrix (Figure 6). The existence of the scour-and-fill sequence suggests a time break in silt deposition and supports the notion that multiple late Pleistocene catastrophic flood events extended into the Tualatin Valley (Waitt, 1985).

The temporary construction exposure just off Highway 99W in Tigard consisted of a 4.6- to 6.1-m-thick section of light yellow-brown, massive, Willamette Silt unconformably overlying approximately 6–7.6 m of variegated red-brown, tan, and yellow-brown interbedded clay, silt, and very fine sand of the uppermost Hillsboro Formation. The unit lies horizontal to subhorizontal, although a pebble zone in the middle of the exposure demonstrates an apparent slight dip to the northeast. This area of the exposure may contain a low-angle reverse fault (Ian Madin, personal communication, 1996). The Willamette Silt exhibits little structure within the unit, although occasional shallow channel-like scours are apparent the base of the unit. The Hillsboro Formation displays a complex depositional style of discontinuous layers typical of fluvial environments and a postdepositional feature of interest: vertical silt dikes.

The vertical to steeply dipping sandy silt dikes in the Hillsboro Formation are 5 cm in width, extend to the bottom of the Willamette Silt (Figure 7), and probably resulted from liquefaction of an underlying sandy silt unit during earthquake activity in this part of the Tualatin Valley 12,000 to 15,000 years ago, some time after deposition of the catastrophic flood silts.

Figure 6: Willamette Silt exposure with a 0.8-m-thick, 5-m-wide channel of clayey silt and cobble-sized basalt clasts between flood silt layers. The existence of this channel supports the contention of multiple Missoula flood events into the Tualatin Valley.

Figure 7: A 5-cm-wide dike of silt to very fine sand in the Hillsboro Formation and into the overlying Willamette Silt (approximately separated by dashed line) in Tigard.

Neogene sediments probably related to the Hillsboro Formation were exposed during the construction phase of the Tri-Met West Side Light Rail Tunnel system through Sylvan Hill in the Tualatin Mountains-Portland Hills region. These sediments occur west of the summit at elevations from approximately 122–182 m and overlie lava flows of the Frenchman Springs Member of the Wanapum Basalt. The sediments were exposed in both tunnels and consist of two distinctive facies, a stratified unit of clayey silts with subordinate clayey, silty, sand and gravelly sand layers that unconformably overlies massive clayey silts that represent loess deposits. The gravel in the sands is weathered basalt from the CRBG. The boundary between the two units follows an irregular concave geometry suggesting that the overlying stratified sediments were produced by local reworking of the massive unit and underlying CRBG and final deposition downslope as channel cut-and-fill deposit.

Seismic-reflection data interpretation

Geometries and textures of four proprietary seismic reflection data lines were used to interpret depositional styles and to suggest modes of structural development. Three of the lines run north-south, and the fourth line extends east-west across the valley, intersecting the other three lines (Figure 8).

Three seismic reflection horizons were correlated throughout the line coverage in the Tualatin Valley. Horizon R at the top of the Columbia River Basalt Group is stratigraphically the lowest continuous horizon mapped. This horizon actually approximates the top of the hard basalt rock at the base of the lateritic weathering zone, as indicated in a synthetic seismogram generated from velocity data shot by DOGAMI in the HBD-1 boring (Wilson, 1997). Most of the velocities of the lateritic soil zone above the hard basalt in HBD-1 are not significantly higher than the overlying sediments.

A prominent pair of continuous reflectors were noted near the middle of the Hillsboro Formation, one labeled

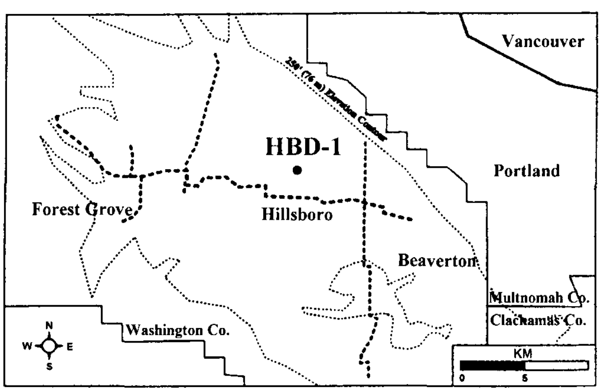


Figure 8. Location map of proprietary seismic reflection data in the Tualatin Valley. Data courtesy of Geophysical Pursuit, Inc., Houston, Texas.

"G" and the underlying labeled "O" on the seismic lines (Figure 9). The lithology at horizon G in the HBD-1 boring is silty clay (178–182 m below the surface) that displays a noticeable radioactive low response on the HBD-1 gamma log. Horizon O at the HBD-1 boring corresponds to silt and clay units that lie between a high-velocity, hard, siliceous layer at a depth of 231.6 m and a low-velocity clay layer at the 250-m depth. The lacustrine diatomaceous unit in HBD-1 consists of laminated clay and lies just above the stratigraphic level of horizon O which covers a large portion of the Tualatin basin. Interpretations made from the identification of the diatom species supports the notion of a widespread lake environment in this interval. Another lacustrine unit consisting of clay probably exists at level G; however, no diatoms have been identified in this clay in the HBD-1 boring.

Horizons G and O mark contrasting seismic characters in the Hillsboro Formation. The section above horizon G is noisy and discontinuous, suggestive of mixed fluvial lithologies that have different velocities (Sangree and Widmier, 1977). The section between horizons O and R is relatively quiet reflecting more continuity in lithologies. (These sections have been labeled PMf and PPlf by Popowski, 1996.)

The section between horizons G and R thins toward the edges of the northern and western valley boundaries. The three known lateral limits of horizons O and G occur approximately at the 122–152-m isopach lines of the Hillsboro Formation isopach map (Wilson, 1997, Figure 69), indicating uniform depositional limits of the main basin to the north and west edges. The overall geometry of the Hillsboro Formation observed on the seismic reflection data is indicative of a syndepositional sequence with continued basin subsidence.

Sediments older than horizon O pinch out progressively farther from the basin center with decreasing age. This trend leads to the conclusion that the main depositional basin has become larger with time.

AGE OF THE HILLSBORO FORMATION

Available pollen, diatom, and paleomagnetic data from Hillsboro Formation in the HBD-1 boring allow development of a time-stratigraphic relationship that is correlatable via seismic reflection data.

The age of the Hillsboro Formation from the base of the unit overlying the CBRG laterite to at least the 259-m depth in HBD-1 is upper Miocene to lower Pliocene. Sediment samples from 259 and 281 m below the surface contain abundant *Cupressaceae* (cypress, 44.6 percent of the assemblage at the 259-m level), while *Pinus* (pine), *Alnus* (alder), *Salix* (willow), and *Abies* (fir) make up most of the rest of the samples (Cathy Whitlock, written communication, 1994, Table 2). The important families present in these samples are *Carya* (hickory), *Cupressaceae*, *Fagus* (beech), *Ilex*

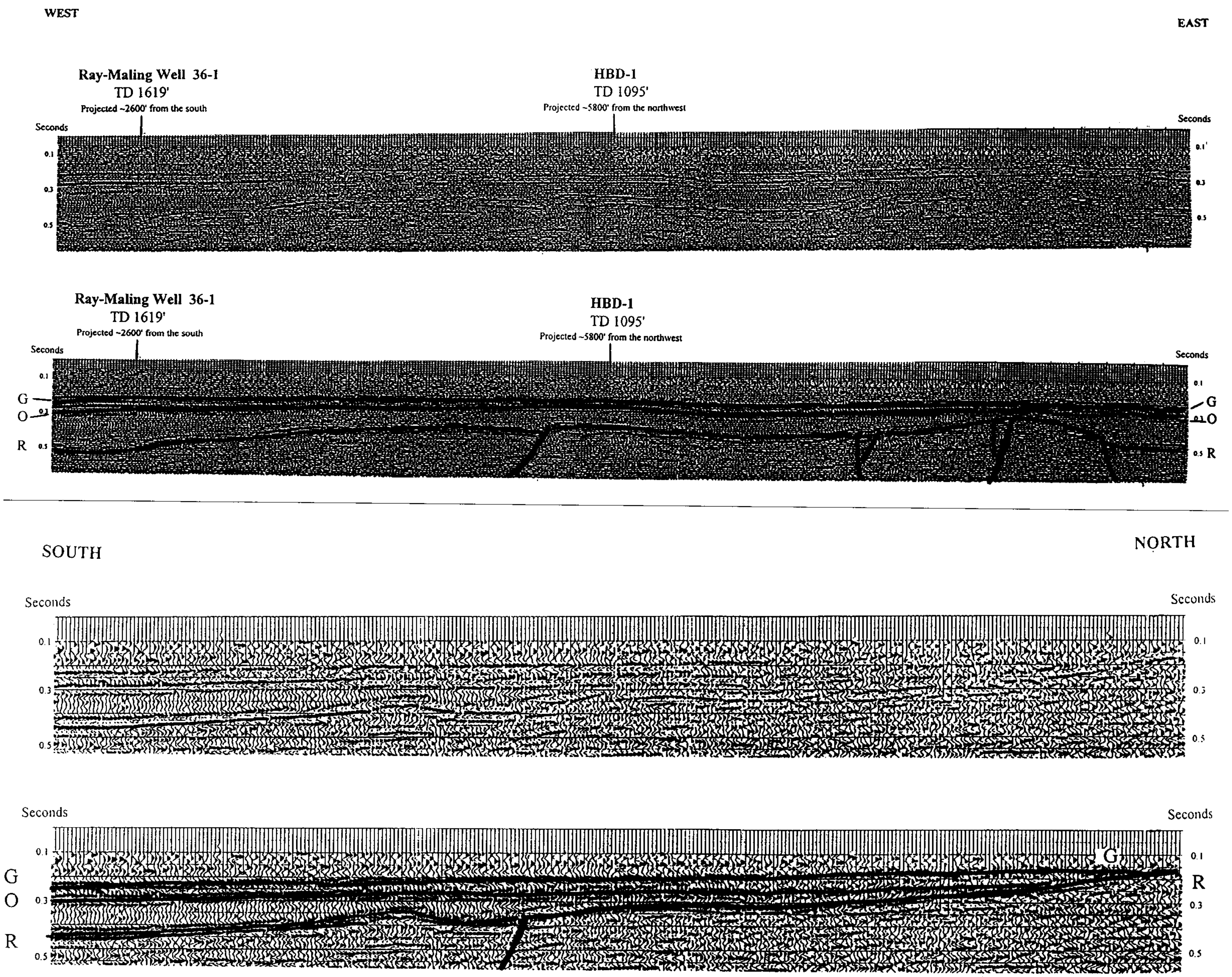


Figure 9. Seismic reflection profiles (interpreted version below the original) of the Tualatin basin, east-west (top pair) and north-south in the western part of the valley (bottom pair), showing three reflection horizons: the top of the Columbia River Basalt Group (horizon R) and indicators of lacustrine deposits within the Hillsboro Formation (horizons G and O). Profiles courtesy of Geophysical Pursuit, Inc., Houston, Texas.

(holly), *Juglans* (walnut), *Liquidamber* (sweetgum), *Nyssa*-type (tupelo), *Pterocarya* (wingnut), and *Tilia* (basswood). These specimens are not native to the modern Pacific Northwest but to eastern North American hardwood forests or to Asia. All except *Cupressaceae* occur in minor amounts.

Similar floral collections are reported from two other localities in the Willamette Valley, northwest of Monroe (Roberts and Whitehead, 1984) and just east of Corvallis (Scott Billings, written communication, 1996). The age interpretations from these two sites are late Miocene to early Pliocene. These species also have been reported from upper Miocene sediments in the foothills around the Willamette-Puget Sound lowland region (Wolfe, 1969). Pliocene flora has been described from the Troutdale Formation in the eastern Portland basin area (Wolfe, 1969). The broadleaf species *Pterocarya*, *Ulmus* (elm), *Platanus* (sycamore), and *Aesculus* (buckeye) are represented in the Pliocene sediments but are not found in nearby early Pleistocene strata.

Diatoms present in a laminated mudstone and an underlying fine-grained sand from 218 m to 224 m in the HBD-1 drill core suggest that lower to upper Pliocene deposits continue farther uphole to at least 218 m (Edward Theriot, written communication, 1995). The prominent diatom species in two examined samples, *Aulacosira canadensis*, is a common planktonic Neogene diatom that has been identified in several other Pacific Northwest sites, including Harper, Oregon (Hustedt, 1952), and the Yakima region in Washington (Van Landingham, 1991). The species ranges from early Miocene to Recent. Rare specimens of the centric genus *Pliocaenicus* indicates that the sediments are Pliocene to lower Pleistocene in age (Edward Theriot, written communication, 1994). This genus is global in its Pliocene range. Rare fragments of the benthic genera *Rhopalodia* and *Melosira* and the generally poor preservation of most specimens suggest that the environmental conditions were alkaline, eutrophic lacustrine. The lack of abundant benthic forms suggests either deep-water conditions or a turbid, shallow water environment.

Pleistocene-aged Hillsboro Formation sediments occur above the diatomaceous zone in HBD-1 up to the Willamette Silt boundary at 25 m. Pollen samples at 186.5 m and 198 m are dominated by the tree families *Picea* (spruce), *Abies*, and *Pinus* with subordinate amounts of *Cupressaceae*, *Alnus*, *Quercus* (oak), *Salix*, *Tsuga heterophylla* (western hemlock), *Pterocarya*, *Rhus* (sumac), *Ulmus*, and *Fagus* (Table 2). A small amount of *Pterocarya* present may be from older material, as the species is currently restricted to Asia (Cathy Whitlock, written communication, 1994). The preponderance of spruce, pine, and fir indicates a closed coniferous forest with cooler than present conditions. This assemblage type indicates that the sediment of this interval is of late Pliocene to middle Pleistocene age.

Table 2. HBD-1 pollen species abundancies with comparison to pollen identified by Roberts and Whitehead (1984) at the Monroe, Oregon, locality, in percent

Tree and shrub species	HBD-1 depths (m) 186.5	197.8	259.1	281	Monroe, Oreg. pollen ranges
Abies	8.8	12.0	2.1	6.5	10-15
Acer macropyllum	0.0	0.0	0.5	0.0	n/a
Alnus	1.0	1.3	7.4	3.4	10-20
Betula	0.0	0.0	0.0	0.3	0.9-3.3
*Carya**	0.0	0.0	0.3	0.0	< 1
Cuppressacae	1.3	1.3	44.6	0.3	10.0
Ericaceae	0.0	0.0	0.0	0.6	0.3-3.2
Fagus	0.0	0.3	1.1	0.0	0.3-2.6
Fraxinus	0.0	0.5	0.3	0.0	1.8-3,3
*Ilex**	0.0	0.0	0.0	0.1	0.3-5.6
*Juglans**	0.0	0.0	1.1	0.0	0.3
*Liquidambar**	0.0	0.0	0.3	0.3	0.8-2.4
Nyssa	0.0	0.0	0.3	0.0	0.5
Picea	27.0	42.3	1.1	10.1	4-20
Pinus	37.3	22.9	19.0	38.6	1.2-22
Pseudotsuga	0.3	0.3	0.3	0.6	0.8-2.4
*Pterocarya**	0.0	0.5	0.3	0.3	1.0
Quercus	0.0	1.1	1.1	0.0	2.8-26
Rhus	0.0	0.3	0.3	0.0	n/a
Rosacae	0.0	0.0	0.5	0.0	0.5
Salix	0.7	0.8	5.0	0.0	0.6
Taxodiaceae-Taxaceae	0.0	0.0	0.3	0.0	n/a
*Tilia**	0.0	0.0	0.0	1.7	0.5-1.0
Triporate	0.0	0.0	0.0	1.1	n/a
Tsuga heterophylla	0.0	0.5	0.8	3.1	0.3-2.8
Tsuga mertensiana	0.3	0.0	0.0	0.0	n/a
Ulmus/Zelkova	0.0	0.3	0.5	0.3	0.8-1.6

* = Genus is no longer extant in the Pacific Northwest

Identified specimens of herbs and pteridophytes include *Artemisia*, *Asteraceae*, *Cyperaceae*, *Dryopteris*, *Monolete* spores, *Poaceae*, *Pteridium*-type, *Tubuliflorae*, and *Urtica*-type. Aquatic and algal species of *Potamogeton* and *Sagittaria* were also recognized in the samples.

Forty thermally demagnetized (250°C and 350°C) paleomagnetic inclinations recorded for the Hillsboro Formation in HBD-1 exhibit a downhole switch from normal to reverse inclinations at a depth of 150.3 m (Figure 5). This probably marks the 0.78-Ma boundary between the Brunhes and Matuyama magnetic epochs (Izett and Obradovich, 1991). Three successive samples at 150.3, 155.8, and 164 m, half-way down in the Hillsboro Formation, comprise a zone of reverse magnetism in the boring. A fourth sample at 181.7 m has a zero inclination at 350°C. This interval is the only succession of reversals noted in the Hillsboro Formation, although more inclinations around this zone are needed to confirm this interpretation. Placement of the Brunhes-Matuyama boundary at 150.3 m fits within the confines of the pollen data.

Results from the HBD-1 synthetic seismogram, together with HBD-1 pollen and diatom ages, indicate that the seismic reflection horizon G occurs within lower Pleistocene sediments and the seismic reflection horizon O correlates with Pliocene to late Miocene deposits. Seismic reflection data in the region display successive pinchouts of older to younger event layers away from the basin center, including horizons O and G. The Hillsboro Formation is all Pleistocene in the Tualatin basin north and west of the pinchout of seismic horizon G, where the sediment section is 122 m thick or less.

The age of Hillsboro Formation deposition may be further defined in the northeastern part of the Tualatin basin using the 0.26- to 0.96-Ma Boring Lava flows that partially intertongue and mostly overlie the sediments. Layered sediments in the Tri-Met Westside Light Rail Tunnel underlie the 0.96-Ma Boring Lava flow and sit on top of the 15-Ma weathered Wanapum Basalt of the CRBG. The eolian and water-laid sediments are loess and reworked loess that were originally derived from Pleistocene glaciation.

Pieces of wood from the Gillenwater No. 1 water well on River Road south of Hillsboro (NE¼ sec. 21, T. 1 S., R. 2 W.) were recovered from 29 m below the surface. The contact between the Willamette Silt and the underlying Hillsboro Formation in this well is approximately at a depth of 21.3 m. This wood sample was ^{14}C-dated to determine a minimum age of the Hillsboro Formation below the Willamette Silt. The sample was found to be older than the 43.7-ka dating limit for ^{14}C analysis. At this locality, the uppermost Hillsboro Formation below the Willamette Silt is older than 43.7 ka, in contrast to the 12.7–15.3 ka of overlying Willamette Silt deposits (Waitt, 1985).

The >43.7-ka ^{14}C date of wood at the top of the Hillsboro Formation south of Hillsboro indicates slow sedimentation in the upper Pleistocene, until the Missoula flood events of 15.3–12.7 ka (Waitt, 1985) entered the Tualatin Valley. Stream-terrace and valley-floor development postdate the catastrophic flood sediments.

PROVENANCE OF THE HILLSBORO FORMATION

In past studies (Trimble, 1963; Schlicker and Deacon, 1967; Madin, 1990), most of the Tualatin basin sediments have been associated with the Troutdale Formation or the Sandy River Mudstone of the Portland basin. Determining the provenance of the Hillsboro Formation sediments was attempted in this study to define the relationship of the sediment packages.

The Portland basin and the northern Willamette Valley directly receive sediments from streams draining the Cascade Range. The Portland basin has also directly received sediments from the northern Rocky Mountain area. Barnes (1995) noted that the geochemical signatures from the lower Troutdale Formation sediments fit with Columbia River source sediments.

Analysis of heavy-mineral and INAA geochemistry data from Hillsboro Formation samples collected in the Tualatin Valley indicate that most of the sediments entered the basin from the surrounding highlands, and some of the finer fractions were airborne from outside the region.

Fifty-eight mounted slides of sand grains from Hillsboro Formation in DOGAMI drill hole HBD-1 and water wells around the Tualatin Valley were used to determine the augite-hypersthene-hornblende (AHH) relative percentage in each sample. Recent stream sediments in the Tualatin Valley and on the Columbia River and ancient sediment samples from the Troutdale Formation were also analyzed for their AHH relative percentages to compare with the Hillsboro Formation.

Instrumental Neutron Activation Analysis performed by Barnes (1995) and this author (Wilson, 1997) on 56 sediment samples from drill hole HBD-1 and other DOGAMI core borings of the Tualatin Valley confirms that there is a general consistency in the Hillsboro Formation provenance over time in the central part of the Tualatin Valley.

The Tualatin Mountains-Portland Hills along the north and east boundaries of the valley apparently have had enough relief since the middle Miocene to keep most of the Columbia River sediments from entering the Tualatin Valley. Quartzite pebbles found in Hillsboro Formation in the Tri-Met westside light-rail tunnel may be clues to local flood events of the Columbia River through canyons in the Portland Hills into the valley. Upper Hillsboro Formation sands in the Lake Oswego-Tigard area were delivered by the proto-Willamette River during the Pleistocene.

NEOGENE STRUCTURE OF THE TUALATIN BASIN

The geometry of the Tualatin basin at the top of the CRBG consists of a large west-northwest-oriented synclinal downwarp north of Chehalem and Cooper Mountains. The CRBG surface in the basin around the Hillsboro area is as much as 460 m below the Tualatin Valley surface. The Beaverton fault, which bounds this downwarp on the south side, extends from the north side of Cooper Mountain westward almost to the Fern Hill area of the northern Chehalem Mountains.

The CRBG rises to the surface at David Hill, north of Forest Grove, and other smaller hills to the north. The Gales Creek fault zone in the Gales Creek Valley west of David Hill separates Paleogene sedimentary rocks to the east from Tillamook Volcanics to the west and extends southeast into Forest Grove. The Gales Creek fault zone probably has played a part in the uplift of the Paleogene sedimentary rocks and CRBG at the southwestern margin of the Tualatin basin (Popowski, 1996).

The Tualatin basin at the top of the CRBG south of the Beaverton fault is structurally more complex than north of the fault (Figure 10). Cooper and Bull Mountains break up the structural low, and faulting is more prevalent in the area, especially on the east side of these two uplifts. An eastern horst extension of Cooper Mountain in secs. 25–28, T. 1 S., R. 1 W., is buried under Willamette Silt. South of the horst is a complex graben structure bounded on the south side by the northeast-southwest-trending Sherwood fault. This narrow subbasin has a maximum width of only 3 km. The structural low wraps around the southern end of Bull and Cooper Mountains to join a subbasin west of Cooper Mountain. Two east-west-trending, fault-controlled CRBG structural highs extending west from Cooper Mountain discontinuously reach the surface and divide the west-side subbasin into two separate depressions. South of the Sherwood fault there is at least one narrow subbasin that follows the topographic low of the Tualatin River floodplain to the mouth of the current river.

The Hillsboro Formation fills a depression that wraps around the west, south, and east sides of Cooper and Bull Mountains developed during the Pleistocene as a result of the associated uplifting.

The axis of the Hillsboro Formation parallels the CRBG west-northwest orientation, and the sediment unit obtains a thickness of >451 m just west of downtown Hillsboro.

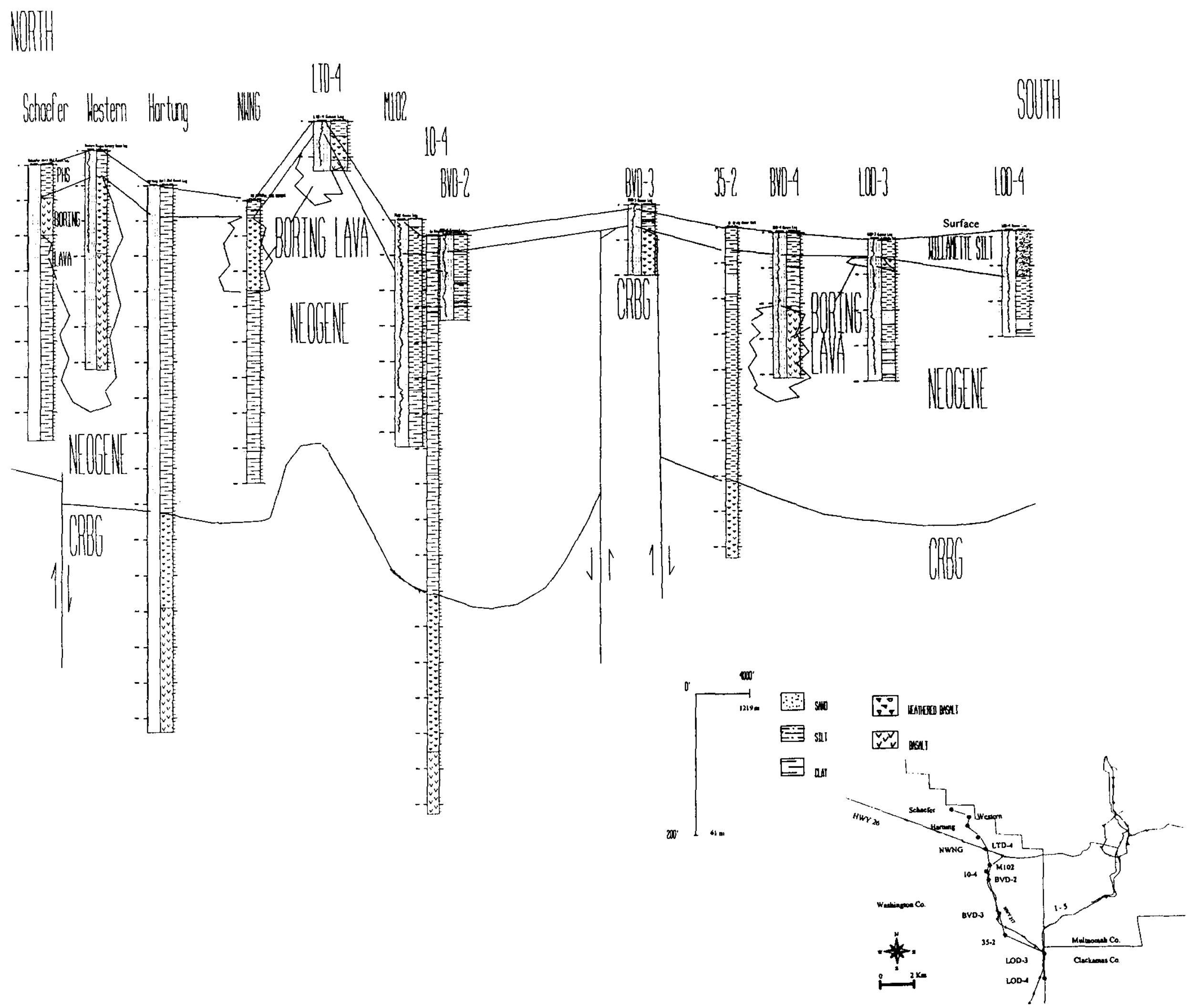


Figure 10. North-south section across the eastern margin of the Tualatin Basin, demonstrating the faulted nature of this portion of the basin. The Neogene sediments, consisting almost wholly of silts and clays, are faulted out in the region of BVD-3. Boring Lava flows are interlayered with the younger Neogene sediments.

The top Hillsboro Formation surface displays a gentle downwarp from 55–67 m above mean sea level at the basin edges to 18 m above sea level near the basin center at Hillsboro. Uplifted Hillsboro Formation is present in the Tri-Met light-rail tunnel at an elevation of 183 m. The gross pattern of the top Hillsboro Formation contours within the basin may represent paleostream flood plains prior to burial by the catastrophic floods that produced the Willamette Silt deposits. The present Dairy Creek and McKay Creek drainages overlie the low troughs of the top Hillsboro Formation as does the Tualatin River flood plain throughout most of the valley. Beaverton Creek, Cedar Mill Creek, Willow Creek, Holcomb Creek, Fanno Creek, and most of Rock Creek also follow Hillsboro Fomation troughs. These drainages were evidently able to reestablish themselves after each Missoula flood event, probably because the floodplain depressions were never completely buried.

Few faults break into the upper Hillsboro Formation package in the central basin; although one seismically identified fault north of Cornelius cuts into the upper part of the Hillsboro Formation This fault may extend into the Chehalem Mountains between Fern and Spring Hills. The entire group of Hillsboro Formation reflection horizons abruptly stop at the Beaverton fault, indicating that the fault was actively uplifting Cooper Mountain at least during the late stages of sedimentation.

OTHER DEPOSITIONAL BASINS IN THE REGION

The Tualatin, Portland, and northern Willamette basins all contain Neogene sediments (with initial deposition during the late Miocene) that reach comparable thicknesses in the basin centers and are influenced to some degree by the same dextral fault shear couple (Portland Hills-Clackamas River fault zone and Gales Creek-Newberg-Mount. Angel fault zone).

South of Salem, Neogene sediment deposition occurs in two main subbasins, the Stayton basin and the southern Willamette Valley (Yeats and others, 1991). These basins initiated subsidence independently from the northern Willamette basin in the late Miocene (Crenna and others, 1994). The Stayton basin stopped sinking by Pliocene to middle Pleistocene time, accumulating more than 400 m of Neogene sediments.

The Tualatin and northern Willamette basins appear to have had similar depositional histories since the post-middle Miocene. Subsidence of the northern Willamette basin from late Miocene to at least late Pleistocene and into the Holocene is evidenced by warping of the Pliocene-Pleistocene fan gravel base and by the broad convexity of the modern Willamette River profile (Crenna and others, 1994). The thickening of fan gravel deposits in the southwest portion of the northern Willamette basin reflects greater rates of subsidence during the Pliocene-Pleistocene interval in this part of the basin, possibly due to accelerated uplift in the northern Coast Range.

In the Portland basin, the presence of <100 m of probable Columbia River alluvium directly overlying the Troutdale Formation in the MTD-1 boring suggests that insignificant Pleistocene deposition took place within the basin as the eastern side uplifted. Any Pleistocene sediments deposited prior to the Missoula flood events were stripped away during the glacial flood episodes. Troutdale Formation sediments exposed in the Bridal Veil channel of the Columbia River Gorge illustrate basin uplift during Pliocene-Pleistocene time.

The Tualatin basin, by contrast, contains up to 213 m of Pleistocene sediments at the HBD-1 boring (and more in the center of the basin), demonstrating a marked difference in the timing and rate of basin subsidence from the Portland basin (Table 3).

Table 3. HBD-1 and MTD-1 estimated sediment thickness based on age and corresponding sedimentation rates

Boring no.	Thickness	For 1.6 Ma	For 2.4 Ma
	Pleistocene sedimentation rate		
HBD-1	~213.4 m	0.13 mm/yr	0.09 mm/yr
MTD-1	<85 m??	<0.05 mm/yr??	<0.03 mm/yr??
	Pliocene/upper Miocene sedimentation rate		
HBD-1	74.7 m	0.011 mm/yr	0.007 mm/yr
MTD-1	335.3 m	0.053 mm/yr	0.03 mm/yr

An explanation for the basin subsidence timing difference between the two basins may rely on the proximity of the subsiding Tualatin basin to the uplifting Coast Range, while the Portland basin is farther away with an intervening structure, the Tualatin Mountains-Portland Hills, between the two basins.

Early subsidence and cessation of the Portland, Stayton, and southern Willamette basins at the Pliocene-Pleistocene boundary contrast with continued subsidence of the Tualatin and northern Willamette basins into the latest Pleistocene or Holocene. The result is an interesting pattern of relative Pleistocene uplift at the northern and southern ends of the Willamette Valley region with relative downwarping between.

GEOMORPHOLOGY OF THE TUALATIN RIVER

Parsons (1969) described the Tualatin River flood plain as part of a hanging valley above the Willamette Valley. Most of the Tualatin River channel downstream from Forest Grove is approximately 18.3 to 21.3 m above the Willamette River confluence. The flat profile in the valley indicates that the river has not yet had a chance to fully recover and erode the catastrophic flood sediments of the Willamette Silt (Waitt, 1985) that cap the valley surface. The Tualatin River knick point, the first change from steeper to gentler river gradient upstream, is located 2.8 km from its mouth near West Linn. This is unique in comparison to other Willamette River tributaries. The closest knick point to a river mouth is 16 km in the Clackamas River. CRBG underlying the last 3 km of the Tualatin River has been more resistant to erosion than the Willamette Silt or other sediments that underlie the lower stretches of most of the other major tributaries to the Willamette River.

Two primary terrace surfaces are present along the Tualatin River main stem and at the downstream end of Dairy Creek, Gales Creek and McKay Creek in the western part of the Tualatin Valley. The surfaces consist of the present-day floodplain and a terrace surface that represents the main Tualatin Valley floor. An intermediate bench between the flood plain and the valley floor is intermittently present in the lower stretches of the river, south of Hillsboro 6–10 m below the floodplain surface. The flood plain is most likely more than 300 years old, yet the river has evidently not abandoned the surface during flood events. The inability of the Tualatin River to cut through the knickpoint near West Linn may have contributed to this unique situation.

Lithostratigraphic and geomorphic evidence suggests that the Tualatin River experienced erosive periods of incision soon after the Missoula flood events. Lowering of the Tualatin River's base level due to erosion of the river's knick point downstream or climatic factors that intermittently alter the magnitude of the river's discharge could influence terrace development (Shelby, 1985). The geographic pattern of the mapped terraces is reminiscent of paired, polycyclic terrace development (Chorley and others, 1984).

CONCLUSION

The post-middle Miocene Tualatin basin is characterized by a subsiding structural low and is filled with fluvial and lacustrine clastic sediments. The HBD-1 core at the Portland-Hillsboro Airport consists of 288 m of sediment overlying a lateritic paleosol belonging to the Frenchman Springs Member of the CRBG. The top 25 m of the sediment package is assigned to the Willamette Silt, which is the depositional result of the late Pleistocene Missoula catastrophic glacial flood episodes. Sediments between the Willamette Silt and the top CRBG laterite are named the Hillsboro Formation in this report.

Study of Hillsboro Formation sand, silt, and clay unit percentages indicates that most of the Hillsboro Formation was deposited in a fluvial environment, that stream activity increased with time in the area of HBD-1, and that most sand deposition occurred close to the basin center in broad, linear trends.

Two probable lacustrine sections are recognized in the Hillsboro Formation of HBD-1. The upper section occurs from about 178 m to 184.7 m in depth and correlates to the prominent, basin-wide seismic-reflection horizon G. The reflector either signifies an extensive lacustrine environment or a disconformity. A more certain interpretation of a lacustrine environment is found in a unique diatomaceous unit between 217.9 m and 222.5 m in depth. The diatomaceous interval closely correlates to the relatively continuous seismic reflection horizon O, which supports the extensive nature of the lake environment.

Hillsboro Formation sands are immature with moderate to poor sorting, medium to very fine grained textures and containing significant levels of silt and clay. The sand unit compositions are classified as either litharenites or feldspathic litharenites.

Smectite is the most abundant clay mineral in most of the Hillsboro Formation silts and clays analyzed, yet kaolinite dominates in some units. Illite typically occurs in minor amounts, but may comprise up to 40 percent of the clay minerals.

The age of the Hillsboro Formation in HBD-1 is derived from pollen, diatom, and paleomagnetic data. The pollen assemblage at 186.5 m and 197.8 m in HBD-1 characterizes the Pleistocene interval with open spruce, fir, and pine forests. Paleomagnetic inclinations from silts and clays in HBD-1 switch from normal to reversed at 149.4 m, signifying the 0.78 Ma Brunhes-Matuyama paleomagnetic epoch boundary. Pliocene to upper Miocene sediments underlie the Pleistocene sequence to the top laterite soil of the CRBG. The diatomaceous zone contains probable late Pliocene forms; therefore the top 213 m is considered Pleistocene. Pollen extracted from 259 m and 281 m in HBD-1 belong to a partially exotic assemblage dated in other parts of the Willamette Valley as late Miocene.

Radiometric ages from wood and Boring Lava samples in other parts of the Tualatin Valley are used to determine stratigraphic relationships away from HBD-1. A radiocarbon date from wood at the top of the Hillsboro Formation south of Hillsboro is older than 43,700 years. This suggests that the central Tualatin Valley surface prior to the Missoula flood events is at least this age. Available ages from Boring Lava flows near Sylvan Hill in the eastern part of the valley imply that the underlying Hillsboro Formation in this part of the valley is one million years or older.

Heavy-mineral-suite and INAA geochemistry analyses from HBD-1 and other penetrations in the Tualatin and Portland basins indicate that the Hillsboro Formation was primarily derived from the Coast Range and surrounding highlands. Augite-hornblende-hypersthene (AHH) relative percentages from the Hillsboro Formation in the Tualatin basin are deficient in hypersthene and contain dominant levels of augite or hornblende, which supports local sources for fluvial sediment deposition. In contrast, sediments from the Portland basin and northern Willamette Valley have highly variable AHH relative percentages, including a large percentage of hypersthene, a mineral primarily derived from the Cascade Range. Unusually low scandium and chromium levels from a siliceous mudstone at 231.6 m suggest that volcanic ash from Cascade Range air-fall events at least once covered the Tualatin Valley.

The Hillsboro Formation geometries from seismic reflection data demonstrate that sedimentation first took place near the basin center and progressively filled the basin as subsidence continued. Reflection characteristics mark a relatively quiet interval of more consistent lithologies below horizon G and a noisier section of more varied clastic sediments above horizon G, agreeing with observations of more sand deposition in the upper 152 m found in HBD-1.

The faulted CRGB basement of the Tualatin basin segregates a large, northern subbasin, with few faults cutting into the sediments from the CRBG, and a smaller, more complexly faulted southern subbasin south and east of the Beaverton fault. Most faulting in this area is restricted to the CRBG and below; however, there are exceptions, denoting structural activity in the basin during the Pleistocene. Most faults at the top of the CRBG south of the Beaverton fault are roughly oriented east-west and cut into the Hillsboro Formation. This area was active in the Pleistocene, since all of the Hillsboro Formation has been removed south of the Beaverton fault on Cooper and Bull Mountains and on a buried horst to the east in the Beaverton-Tigard area.

Hillsboro Formation sedimentation rates in the Tualatin basin calculated from age relationships in HBD-1 increase one order of magnitude from the late Miocene-Pliocene to the Pleistocene. Increased sediment supply to the basin implies an increase in basin subsidence and/or relative uplift of surrounding highlands, particularly the Coast Range. The 335-m-thick Troutdale Formation at the MTD-1 Portland International Airport boring of the Portland basin, in contrast, is all pre-Pleistocene, indicating a temporal difference in subsidence between the two basins.

The temporal development of the Tualatin basin compares well with the northern Willamette basin. Both basins have thick sequences of fine-grained, Neogene clastic material. Seismic-reflection line data exhibit similar reflection characters and trends in both basins. They have subsided during the Pleistocene, share a common major structural lineament in the Gales Creek-Mount. Angel fault zone, and are adjacent to the northern Coast Range. The south Willamette Valley, including the Stayton basin, was downwarped, received thick sequences of late Miocene and Pliocene sediments, and stopped subsiding at the beginning of the Pleistocene. In the Portland basin, Cascadian uplift during the Pleistocene may have slowed or stopped subsidence.

The Missoula floods entered the Tualatin Valley at least 22 times through the Lake Oswego gap. One or more flood events transported ice-rafted sediments to elevations of 122 m.

The Tualatin River knickpoint is within 3.2 km of its confluence with the Willamette River, in contrast to other Willamette River tributaries whose knickpoints are tens of miles upstream from their mouths. Boring information at the Tualatin River mouth reveals that the river is riding on top of CRBG which is slowing the erosion process of the river and leading to the flat longitudinal profile upstream.

Three post-Missoula flood geomorphic surfaces are present along the Tualatin River and two persist into the adjoining major tributaries. The main valley floor is equivalent to the Senecal surface (12,700 years old) of the Willamette Valley. A middle, discontinuous level is the upper Winkle surface (10,000–12,700 years old). The age of the modern Tualatin River flood plain is between that of the Horseshoe (300 years old) and Winkle surfaces.

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Oregon joins AGI, other states in proclaiming Earth Science Week

The countdown to the first Earth Science Week has begun. Mark your calendars now for the October 11–17 celebration. This year, Earth Science Week is one of the most ambitious 50th anniversary initiatives for the American Geological Institute (AGI), and it offers the geoscience community new opportunities to demonstrate the importance of the earth sciences. Geoscience organizations have responded enthusiastically to the idea, and AGI member societies and state geological surveys are planning Earth Science Week activities and events. "The goal for Earth Science Week," says AGI President Susan Landon, "is to have all geoscientists in the country do something in their communities to promote the earth sciences." AGI's role in sponsoring an annual Earth Science Week is to provide a clearinghouse for ideas, activities, and special events and to provide support materials that make it easy for geoscientists participate. Information about Earth Science Week is available from the American Geological Institute and on the World Wide Web at **www.earthsciweek.org**.

Oregon Senator Ron Wyden demonstrated his support for the earth sciences by reading the AGI-adopted resolution on Earth Science Week into the Congressional Record. The governors of seventeen states, Alabama, Arizona, Colorado, Connecticut, Florida, Illinois, Kansas, Kentucky, Maine, Nevada, North Carolina, North Dakota, Ohio, Oregon, South Dakota, Tennessee, and Vermont, have already issued Earth Science Week proclamations and resolutions, and more are expected to follow.

A common thread in the proclamations is recognition that the role of geology and the earth sciences are fundamental to society and to our quality of life. An understanding of geology and the earth sciences can help citizens make wise decisions for land management and use, is crucial to addressing environmental and ecological issues, and provides the basis for preparing for and mitigating natural hazards.

Earth Science Week has enormous potential for increasing public awareness and understanding of the importance of the earth sciences in our lives. The celebration, which will be held annually during the second full week of October, will give geoscientists and organizations repeated opportunities:

To give students new opportunities to discover the earth sciences

To highlight the contributions that the earth sciences make to society

To publicize the message that earth science is all around us

To encourage stewardship of the Earth, and

To develop a mechanism for geoscientists to share their knowledge and enthusiasm about the Earth and how it works

Many Earth Science Week activities will focus on education. AGI has recently published a colorful 18"x24" poster on Geoscience Careers and will produce a second poster in time for Earth Science Week. The first module of EarthWorks, a set of middle-school student and teacher activities on soils, will be available in time for Earth Science Week, as will a general-interest booklet on soils that is part of AGI's Environmental Awareness series. *—AGI news release*

MLR welcomes hydrogeologist Bob Brinkmann to its staff

Bob Brinkmann joined the Department of Geology and Mineral Industries on August 12, 1998. Bob will serve as the staff hydrogeologist for the Mined Land Reclamation program. He was selected from a very competitive field of 24 candidates. The six-person interview team that recommended hiring him, was made up of people from DOGAMI, the Water Resources Department, and the mining industry. The final three candidates were subjected to a three-hour interview, which included a visit to an operating mine site.

Staff hydrogeologist is a new position at MLR, established during the last legislative session. Bob will provide needed expertise in the field of hydrogeology and will allow the program to make better decisions in this complex and controversial area. In addition, he will conduct approximately 150 statewide site inspections per year to support the program's field presence. The foundation of the MLR program is working directly with mine operators.

Bob has a Bachelor of Science degree in Geology from Colorado State University and 12 years of experience working as a hydrogeologist in the mining industry and as a private consultant. After graduation, Bob went to work for Chevron Resources, Inc., for 6 years and most recently was with Olympus Environmental Consulting, Inc. He has worked all around the West, including the Northwest. While with Chevron, he gained experience dealing with mine dewatering in fracture-flow volcanic environments; and he has experience working with water-supply and contaminant hydrogeology issues. □

In the next *Oregon Geology*: Special focus on earthquake damage-and-loss estimates

DOGAMI earthquake scientists have developed a statewide, county-by-county estimate of earthquake damage and losses for two of the possible cases of earthquake events in Oregon.

The November/December issue will focus on this special subject. □

*(**Reader survey**, continued from page 98)*

People indicated several different reasons why they subscribe:

Number of responses	Reason
97	General interest in geology
76	Latest scientific papers on Oregon geology
69	Keep up with geology activities in Oregon
62	For professional reasons
49	Geologic hazards information
47	Earthquake information
36	Mining information

More than two thirds of those responding said they share the magazine with others in the office or family.

People from many occupations read our magazine. Responses to this question yielded a significant number (28) under "other," including, for example, registered nurse, mobile park manager, real estate professional, retailer, physician, and photographer.

Number of responses	Occupation
49	Retired
48	Professional geologist
29	Educator
22	Scientist other than geologist
20	Government worker
14	Prospector or explorationist
12	Engineer
10	Work in energy industry

Almost 85 percent of those responding are male, 63 percent are over 50, and 63 percent have done graduate work in college.

The breakdown in demographics includes:

Number of responses	Age
6	18–34
44	35–50
41	51–64
51	65+

Number of responses	Education
17	High School
44	College
92	Graduate work

In short, our readers come from a variety of backgrounds and have a variety of interests. We often get comments that *Oregon Geology* has too many technical articles. It's sometimes difficult to balance the needs of professional geologists with those of other professionals or the interested public.

Since the department began publishing a magazine in 1939, we have been constantly adjusting the content and format to keep up with the changing needs of our readers. For example, the first *Ore Bin* had three articles: the value of Oregon's mineral production, a description of the area around Newberry Crater, and a new metallurgical process. We will continue to try to publish a magazine that is useful to our readers.

We appreciate your interest in geology and hope you will always feel free to contact us about what you like and suggestions to make our magazine better. ☐

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